Quilcene-Snow Watershed Planning Area

Prediction of Gaged Streamflows by Modeling

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Cover photos: Department of Ecology flow measurement stations in the
Quilcene-Snow Watershed Planning Area

Quilcene-Snow Watershed Planning Area

Prediction of Gaged Streamflows by Modeling

by

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Water Resource Inventory Area (WRIA) 17

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Abstract

This study evaluates flow gaging stations in the Quilcene-Snow watershed planning area, which is located in Water Resource Inventory Area (WRIA) 17 excluding the Sequim Bay watershed. The study addresses five telemetry flow stations that the Washington State Department of Ecology (Ecology) currently operates, and three Ecology gages no longer in operation.

This study developed regression-based models for Ecology study gages based on other reference gages 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 10%) for summer flows at three stations and good (10-15%) at four stations.

Recommendations were made based on study results:

- *Big Quilcene River near Mouth*: Based on the quality of models, consider decommissioning or transferring this station to a third party. Also explore improved modeling using diversion data.
- *Tarboo Creek near Mouth*: Review flow data needs to determine if direct measurements are needed at this station or if the regression-based model suffices to meet those needs and if decommissioning, cooperative funding, or transfer is appropriate.
- *Little Quilcene River near Mouth*, *Snow Creek at WDFW*, and *Salmon Creek at West Uncas Road* (now *Salmon Creek at WDFW*): These three stations appear to be redundant to each other. Review data needs for these stations to determine if one or more of these stations could be decommissioned, operated with cooperative funding, or transferred.
- *Chimacum Creek near Mouth*: Continue funding of this station.

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.

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Introduction

Overview of the Watershed

The project study area is the Quilcene-Snow watershed planning area, which consists of WRIA 17 not including the Sequim Bay watershed (Figure 1 – see "Figures" section following "References").[1] The descriptions of the basin in this Introduction are summarized from the WRIA 17 Stage 1 Technical Assessment (Parametrix, et al., 2000) and from the Watershed Management Plan for the Quilcene-Snow Water Resource Inventory Area (Cascadia Consulting Group, 2003).

Geography

The Quilcene-Snow watershed planning area includes about 625 square miles (1620 square kilometers) in the northeast Olympic Peninsula in Washington State (Figure 1). WRIA 17 includes many rivers and creeks that drain into the Strait of Juan de Fuca, Admiralty Inlet, Hood Canal and associated bays and harbors. The most significant of these streams are the subject of this study and are discussed below.

Elevations range from sea level to 7,756 feet (2364 meters) at Mount Constance. Higher elevation areas are forested, while low elevation valley bottoms are pasture. About 27,000 people live in the planning area, with the center of population in Port Townsend.

Climate

WRIA 17 experiences the Pacific Northwest maritime climate, with cool, wet winters and mild, dry summers. The Olympic Mountains affect the precipitation regime strongly. The rain shadow area in the northern basin receives rainfall of 15 to 20 inches annually (380 to 510 millimeters). Rainfall increases with elevation, with Olympic Mountain foothills to the west receiving 70 to 80 inches annually (1800 to 2000 millimeters).

Hydrology and Water Use

The highest elevation areas, which feed the Big and Little Quilcene Rivers, experience significant snowpack in the winter. Snow and Salmon Creeks drain areas of moderate elevation that experience transient snowpack. The rest of the streams in the study area drain areas of lower elevation which are rainfall-dominated.

The largest diversions of surface water are from the Big and Little Quilcene Rivers for the City of Port Townsend and the Quilcene National Fish Hatchery. Average annual water use by the City was reported to be 17.9 cubic feet per second (cfs) from the Big Quilcene River and 4.1 cfs from the Little Quilcene River, which represent about 7 to 8 percent of the annual flow. The

[1] The portion of WRIA 17 in the Sequim Bay watershed is included in the Elwha-Dungeness watershed planning area.

hatchery is entitled to a water right of 15 cfs from the Big Quilcene River at all times and can withdraw up to 40 cfs, provided flows are maintained in the bypass reach. Another 20 to 40 cfs is allocated to other users. Allocations in the Big Quilcene River total about twice the summer low flow. Actual water use and the percent of use during summer low flows are uncertain. An analysis of the streamflow characteristics of the Big and Little Quilcene Rivers was prepared for the City of Port Townsend by Orsborn and Orsborn (2000).

Groundwater resources are concentrated in areas with alluvial deposits. Many areas have shallow bedrock and therefore limited aquifer storage. The Watershed Plan estimated an annual groundwater recharge of 140,659 acre-feet and an estimated consumptive use of groundwater at 9,940 acre-feet (less than 10 percent of recharge).

Land Ownership, Land Use, and Water Use

The study area lies entirely in Jefferson County. Port Townsend is the only incorporated city in the study area. Other communities include Port Hadlock, Chimacum, Port Ludlow, and Quilcene.

About 70 percent of the study area is privately owned, with 20 percent federal and 10 percent state lands. Forestry is the predominant land use in about 40 percent of the basin. Rural residential is the second largest land use. Commercial and industrial use is concentrated around Port Townsend, and the Navy has an installation on Indian Island.

Watershed Planning and Instream Flow Rules

Watershed planning first started in the Quilcene-Snow watershed in 1991, with the development of the Dungeness-Quilcene Plan. The plan was in place by 1994 and addressed water conservation, public education, fisheries, instream flows, water quality, and water for growth.

In 1998 the Washington legislature passed RCW 90.82 which created a statewide watershed planning program. The Quilcene Snow (WRIA 17) planning unit began working together in 1999, building on previous watershed planning under the Chelan Agreement pilot program in 1991. Jefferson County is Lead Agency for Watershed Planning under RCW 90.82 in WRIA 17. The Watershed Management Plan was adopted by the Quilcene Snow Planning Unit in 2003.

The WRIA 17 Quilcene-Snow Watershed Plan made recommendations for the management of future water supplies and stream flow for many of the rivers and streams in the planning area. In November 2009, Ecology adopted Chapter 173-517 WAC, the instream flow rule for the Jefferson County portion of the Quilcene Snow, WRIA 17.

Regulatory instream flows were set at specific *control stations* throughout the basin, with seniority set by the date of rule adoption. When water flow at a control station decreases to the rule’s flow levels, water users with more junior (newer) appropriations cannot diminish or negatively affect the regulated flow and may have to stop diverting or provide mitigation. The gages addressed by this study designated as regulatory control stations are identified in Table 1.

Implementation of the instream flow rule is now proceeding. Details about the rule and its implementation can be found at www.ecy.wa.gov/programs/wr/instream-flows/quilsnowbasin.html.

In 2010 the Planning Unit changed its name to the East Jefferson Watershed Council (EJWC, www.ejwc.org/) to better reflect its scope, focus, and geography. In addition to the EJWC, the Hood Canal Coordinating Council (HCCC, http://hccc.wa.gov/) has been active in issues related to streamflows and fish habitat in the Quilcene-Snow watershed planning area. The HCCC serves as the salmon recovery organization for the Hood Canal Salmon Recovery Region (www.rco.wa.gov/salmon_recovery/regions/hood_canal.shtml). The EJWC and HCCC coordinate their work on salmon recovery.

Flow Monitoring

Ecology has historically operated 8 flow monitoring stations in the study area (Figure 1, Table 1 and www.ecy.wa.gov/programs/eap/flow/shu_main.html). These stations consist of:

- Six active *telemetry* gages where real-time data is provided.
- One historical staff gage where *manual stage-height* readings were collected infrequently (at least once per month) from a staff gage and converted to instantaneous flow values.
- Two historical gages where multiple years of *continuous* data were collected.

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 analyzed in this study are shown in Table 1. All active and historical stream gages have sufficient data and were included in this study, except for the newly installed station on Salmon Creek. This new station is a short distance downstream from the decommissioned Salmon Creek station, and flows at the new location are likely very similar to those at the upstream station.

One current and one historical flow gaging station located on Jimmycomelately Creek were not included in this study. Although Jimmycomelately Creek is in WRIA 17, it is managed as part of the Elwha-Dungeness watershed planning area and was analyzed in a previous study of that area (Pickett, 2012).

The United States Geological Survey (USGS) has measured streamflow in WRIA 17 and in neighboring basins at a variety of sites historically and currently (USGS, 2012). Three active USGS stations were used in this study (Table 2), one in WRIA 17 and two in neighboring basins:

- Big Quilcene station: "non-real time" (non-telemetry continuous data which usually lags by several months from collection to posting).
- Duckabush station: telemetry non-real time (data which is sent by telemetry but not posted in real time).

- Dungeness station: real-time (telemetry station with preliminary data available within hours).

Five historical USGS stations in WRIA 17 have no data after 1994 and were not used for this analysis.

Table 1. Ecology flow monitoring stations in the Quilcene-Snow watershed planning area (WRIA 17).

ID	Station Name	Code	Status	Type[1]	Proposed Control Station?	Start	End	No. Days[2]	Comment
17A060	Big Quilcene R. near Mouth	BigQ-ECY	Active	T	Yes	10/26/1999	1/23/2013	3712	MSH only 10/26/1999 - 9/25/2001
17D060	Little Quilcene near Mouth	LilQ	Active	T	Yes	8/21/2002	1/23/2013	3729	
17G060	Tarboo Creek near Mouth	Tarboo	Active	T	Yes	4/10/2003	1/23/2013	3271	
17B050	Chimacum Creek near Mouth	Chim	Active	T	Yes	4/10/2003	1/23/2013	3359	
17E060	Snow Creek at WDFW[3]	Snow	Active	T	Yes	8/21/2002	1/23/2013	3448	
17F050	Salmon Creek at WDFW[3]		Active	T	Yes	2/21/2013	-	0	Newly installed
17F060	Salmon Ck. at West Uncas Rd.	Salmon	Historical	C	Yes	10/31/2002	9/30/2011	3145	Former telemetry station
17H060	Thorndyke Creek near Mouth	Thorn	Historical	C	Yes	10/1/2003	9/30/2010	2277	Former telemetry station
17J050	Pheasant Creek at Mouth	Pheas	Historical	MSH	-	4/29/2003	4/22/2008	205	

[1] T: Telemetry; C: Continuous; MSH: Manual Stage Height
[2] Number of daily average flow values used in this study
[3] Washington Department of Fish and Wildlife

Table 2. USGS flow monitoring stations in and adjacent to the Quilcene-Snow watershed planning area (WRIA 17).

ID	Station Name	Code	Status	Type[1]	Proposed Control Station?	Start	End	No. Days[2]
12052210	Big Quilcene River below Diversion near Quilcene	BigQ-GS	Active	NRT	-	10/1/1999	1/15/2013	4856
12054000	Duckabush River near Brinnon	Ducka	Active	TNRT	-	10/1/1999	1/23/2013	4861
12048000	Dungeness River near Sequim	Dung	Active	RT	-	10/1/1999	1/23/2013	3596

[1] NRT: Non-real time (Continuous); TNRT: Telemetry non-real time; RT: Real time
[2] Number of daily average flow values used in this study

Study Goals and Objectives

This project has the following goals:

1. Develop computer modeling tools that can estimate streamflows in the Quilcene-Snow watershed planning area for each Ecology flow monitoring station.
2. Assess the ability of computer modeling tools to support Ecology and other agencies as well as members of the watershed planning unit and other 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 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, 2013). The implementation of that plan is described in this section.

Data Sources and Characteristics

Flow Data

Daily average flow data were compiled for seven Ecology stations and three USGS stations with continuous data, and instantaneous flows were compiled for the Ecology station with manual staff gage readings (Tables 1 and 2). Flows at all stations were analyzed from August 21, 2002 through January 23, 2013. Flow data were withheld from the analysis when derived using interpolations or correlations, or where data review indicated unacceptably poor quality data. Tables 1 and 2 show the timeframes of data and the total number of data values used in the study.

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* because 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 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 January 2013. However, provisional data were not used if they showed extreme deviations from neighboring values in space and time, and if Ecology monitoring staff confirmed the likelihood of technical problems.

Figures 2 through 9 show the streamflows for the stations analyzed in this study, with flows from other selected reference gaging stations shown for comparison. 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.

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.

Five stations were selected to compare meteorological conditions in the basin to areal flows:

1. Mount Crag SNOTEL (Station Code "MTCW1")
   www.wcc.nrcs.usda.gov/nwcc/site?sitenum=943&state=wa
2. Dungeness SNOTEL (Station Code "DGSW1")
   www.wcc.nrcs.usda.gov/nwcc/site?sitenum=648&state=wa
3. RAWS Cougar Mountain (Station Code "COUGA")
   www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?waWCOU
4. RAWS Quilcene (Station Code "WQUIE")
   www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?waWQUC
5. COOP Chimacum (Station Code "WACHIM")
   www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wachim

Areal flows from the Ecology telemetry and stand-alone stations are shown in Figures 10 through 17. Also shown are (1) precipitation data from one of the RAWS stations listed above, and (2) non-snow precipitation, snowmelt, and average daily air temperatures from one of the SNOTEL stations listed above.

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 10 through 17 are of interest:

- Streams with a mixed snowmelt and rainfall-based hydrology include the Big Quilcene and Little Quilcene Rivers and Snow and Salmon Creeks (Figures 10, 11, 14, and 15).
- Tarboo, Chimacum, Thorndyke, and Pheasant Creeks are lower elevation streams dominated by rainfall responses (Figures 12, 13, 16 and 17).

Regressions and Other Analysis Methods

Flow data were first evaluated by comparing daily average flows from each study station for the entire record (October 26, 1999 through January 23, 2013) 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.

To select reference stations from existing real-time or telemetry stations, correlations between the stations were evaluated (Table 3). 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.
4. 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.
5. 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.)
6. 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.

Table 3. 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.

	BigQ-ECY	*Chim*	*LilQ*	*Snow*	*Tarboo*	*Salmon**	*Thorn**	*Pheas**	*Dung*	*Ducka^*	*BigQ-ECY*
Chim	0.63										
LilQ	***0.87***	*0.79*									
Snow	***0.82***	***0.81***	**0.93**								
Tarboo	*0.75*	***0.81***	***0.86***	***0.81***							
Salmon*	0.70	*0.80*	*0.79*	***0.89***	*0.73*						
Thorn*	*0.71*	0.54	*0.76*	*0.76*	***0.85***	0.59					
Pheas*	0.41	0.44	0.52	0.49	0.50	0.41	0.04				
Dung	*0.75*	0.25	0.51	0.45	0.30	0.39	0.43	0.26			
Ducka^	***0.86***	0.35	0.61	0.54	0.49	0.44	0.52	0.34	***0.85***		
BigQ-GS+	**0.97**	0.50	*0.79*	*0.73*	0.62	0.61	0.64	0.38	***0.84***	**0.91**	

ECY-Telemetry
ECY-Continuous Historic
ECY-Continuous Current
ECY-Manual Staff
USGS
Regulatory Control Station

- ***** **Historical gage**
- **+** **Non-real time**
- **^** **Telemetry non-real time**

7. 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:
      - *Baseflows* – less than the baseflow threshold occurring all year.
      - *Non-baseflows (Freshet and storm flows)* – greater than the baseflow threshold occurring all year.
   b. Four categories:
      - *Summer baseflows* – less than the baseflow threshold occurring from mid-summer through early autumn.
      - *Winter baseflows* – less than the baseflow threshold occurring from late autumn through early summer.
      - *Winter non-baseflows* – greater than the baseflow threshold occurring from late autumn through early summer.
      - *Summer non-baseflows* – greater than the baseflow threshold occurring from mid-summer through early autumn.
   c. Three categories, either:
      - *Summer baseflows* – less than the baseflow threshold occurring from mid-summer through early autumn.
      - *Summer non-baseflows* – greater than the baseflow threshold occurring from mid-summer through early autumn.
      - *Winter flows* – flows occurring from November through June.

      or:
      - *Summer baseflows* – less than the baseflow threshold occurring from mid-summer through early autumn.
      - *Winter baseflows* – less than the baseflow threshold occurring from late autumn through early summer.
      - *Non-baseflows (Freshet and storm flows)* – greater than the baseflow threshold occurring all year.

   Quality metrics (described in the next section) were evaluated for all combinations.

Quality Analysis

As described in the project plan (Pickett, 2013), 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.

$RPD_i = [100 * (P_i – O_i)] / [(O_i + P_i) / 2]$, where
$P_i = i^{th}$ prediction
$O_i = i^{th}$ observation
RPD_i = relative percent difference of the i^{th} 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.

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

Median %RSD for annual streamflow or summer baseflow	Characterization
Less than 10%	Very good
Greater than 10% and less than 15%	Good
Greater than 15% 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 4 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 of 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 5 shows the quality of each regression. Goodness-of-fit is indicated by the median %RSD values for all flows and for the summer baseflows.

- The primary regression-based model had a **very good** fit (%RSD values less than 10%) for both summer baseflows and all flows at *Big Quilcene River near Mouth.*
- Two stations had primary regression-based models with a **very good** fit for summer baseflow and a **good** fit for all flows (%RSD values between 10% and 15%):
    - *Tarboo Creek near Mouth*
    - *Thorndyke Creek near Mouth*
- Primary regression-based models had a **good** fit for both summer baseflow and all flows at *Little Quilcene River near Mouth.*
- Three stations had primary regression-based models with a **good** fit for summer baseflow and a **fair** fit for all flows (%RSD values between 15% and 20%):
    - *Chimacum Creek near Mouth*
    - *Snow Creek at WDFW*

- *Salmon Creek at West Uncas Road*

- The primary regression-based model had a **poor** fit for all flows (%RSD values greater than 20%) at the staff gage station *Pheasant Creek at Mouth.*

Figures 18 through 25 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. Note that the right-hand scale on the graph varies between figures so that the temporal patterns can be seen clearly. A few patterns can be observed:

- Small differences in very low flows can produce RPD values of high magnitude[2]. 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 -1.8% to 4.1% for all stations.
- For baseflows, the RPD values were biased high, with median values ranging from 3.1% to 17.5%. This is consistent with the tendency of RPD at low flows to produce high values.
- The range of RPD values varied among the stations:
  - The narrowest range of -91% to 76% was found at the *Big Quilcene River near Mouth* station
  - The widest ranges occurred at the *Tarboo Creek near Mouth* station (-161% to 148%) and at the *Pheasant Creek at Mouth* station (-143% to 197%).

  A narrow RPD range indicates that the quality regression-based model is relatively good, while a wide range suggests a poorer quality model.

[2] 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 4. Regressions for study gages using the hydrograph separation method.

Station ID	Station Name	Reference Station Code	Baseflow Threshold (cfs)	Hydrograph Separation		Linear or Power?	Coefficient	Intercept or Exponent	r^2	n
				Season	Flow level					
Ecology Telemetry Gages										
17A060	Big Quilcene River near Mouth	BigQ-GS (Primary)	34.9	Aug-Oct	base	Linear	0.667	18.6	0.053	509
				Aug-Oct	nonbase	Linear	1.08	0.655	0.93	417
				Nov-Jul	base	Power	1.23	1.07	0.15	106
				Nov-Jul	nonbase	Linear	1.28	9.16	0.94	2673
17A060	Big Quilcene River near Mouth	LilQ (Secondary)	13.3	Aug-Oct	base	Power	18.1	0.322	0.10	470
				Aug-Oct	nonbase	Linear	5.87	-39.7	0.78	408
				Nov-Jul	base	Power	8.68	0.793	0.17	122
				Nov-Jul	nonbase	Linear	2.39	54.5	0.72	2607
17D060	Little Quilcene River near Mouth	Snow (Primary)	4.9	Sep-Nov	base	Linear	0.841	8.41	0.060	342
				Sep-Nov	nonbase	Linear	1.84	-0.210	0.91	541
				Dec-Aug	base	Power	4.63	0.926	0.47	231
				Dec-Aug	nonbase	Linear	1.71	6.64	0.84	2272
17D060	Little Quilcene River near Mouth	BigQ-ECY (Secondary)	60.2	Sep-Oct	base	Power	0.585	0.809	0.26	499
				Sep-Oct	nonbase	Linear	0.140	6.04	0.79	95
				Nov-Aug	base	Linear	0.223	4.05	0.20	388
				Nov-Aug	nonbase	Linear	0.304	3.19	0.72	2624
17G060	Tarboo Creek near Mouth	Chim (Primary)	6.5	Jun-Sep	base	Linear	0.0476	1.69	0.010	661
				Jun-Sep	nonbase	Linear	0.297	0.0850	0.62	457
				Oct-May	All flows	Power	0.440	0.941	0.75	1963
17G060	Tarboo Creek near Mouth	Snow (Secondary)	7.5	Aug-Sep	base	Linear	0.266	1.08	0.31	373
				Oct-Jul	base	Linear	0.167	2.08	0.051	363
				All year	nonbase	Linear	0.254	0.376	0.62	2235
17B050	Chimacum Creek near Mouth	LilQ (Primary)	17.2	Jun-Sep	base	Linear	0.150	3.13	0.092	552
				Jun-Sep	nonbase	Power	0.576	0.752	0.71	581
				Oct-May	base	Power	1.47	0.716	0.32	317
				Oct-May	nonbase	Power	0.773	0.821	0.59	1835
17B050	Chimacum Creek near Mouth	Salmon (Secondary)	3.8	Jun-Sep	base	Linear	0.608	3.56	0.09	493
				Jun-Sep	nonbase	Power	1.65	0.744	0.53	530
				Oct-May	base	Power	7.70	0.211	0.040	249
				Oct-May	nonbase	Linear	1.13	7.19	0.60	1537

Table 4, continued. Regressions for study gages using the hydrograph separation method.

Station ID	Station Name	Reference Station Code	Baseflow Threshold (cfs)	Hydrograph Separation		Linear or Power?	Coefficient	Intercept or Exponent	r^2	n
				Season	Flow level					
Ecology Telemetry Gages										
17E060	Snow Creek at WDFW	Salmon (Primary)	3.0	Jul-Oct Jul-Oct Nov-Jun	base nonbase All flows	Power Power Power	2.86 1.59 3.36	0.413 1.07 0.859	0.089 0.57 0.76	391 515 1937
17E060	Snow Creek at WDFW	LilQ (Secondary)	14.4	Aug-Oct Aug-Oct Nov-Jul	base nonbase All flows	Power Linear Linear	2.38 0.371 0.493	0.228 0.518 2.48	0.0070 0.68 0.84	478 337 2571
Ecology Historical Continuous Gages										
17F060	Salmon Creek at West Uncas Road	Snow (Primary)	5.5	Jul-Oct Jul-Oct Nov-Jun	base nonbase All flows	Linear Linear Power	0.475 0.275 0.610	0.609 2.46 0.889	0.19 0.47 0.76	430 476 1937
17F060	Salmon Creek at West Uncas Road	LilQ (Secondary)	13.8	Jul-Dec Jul-Dec Jan-Jun	base nonbase All flows	Power Power Power	2.11 0.270 0.301	0.102 0.905 0.928	0.0016 0.71 0.65	547 951 1591
17H060	Thorndyke Creek near Mouth	Tarboo (Primary)	-	All year	All flows	Linear	0.965	3.76	0.72	2030
17H060	Thorndyke Creek near Mouth	LilQ (Secondary)	14.8	Jun-Aug Jun-Aug Sep-May Sep-May	base nonbase base nonbase	Linear Linear Linear Linear	0.160 0.0153 0.185 0.202	3.99 6.25 5.56 0.844	0.14 0.14 0.076 0.61	113 414 318 1376
Ecology Manual Staff Gages										
17J050	Pheasant Creek near Mouth	Chim Snow	(Primary) (Secondary)	All year All year	All year All year	Power Power	0.374 0.417	0.565 0.446	0.16 0.11	184 170

Table 5. 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 5-10%	10 - 15%	15 - 20%	>20%
Ecology Telemetry Gages				**Very Good**	**Good**	**Fair**	**Poor**
17A060	Big Quilcene River near Mouth	BigQ-GS	Summer baseflow All flows	X X			
17A060	Big Quilcene River near Mouth	LilQ	Summer baseflow All flows	X 		 X	
17D060	Little Quilcene River near Mouth	Snow	Summer baseflow All flows		X X		
17D060	Little Quilcene River near Mouth	BigQ-ECY	Summer baseflow All flows		X 	 X	
17G060	Tarboo Creek near Mouth	Chim	Summer baseflow All flows	X 	 X		
17G060	Tarboo Creek near Mouth	Snow	Summer baseflow All flows	X 			 X
17B050	Chimacum Creek near Mouth	LilQ	Summer baseflow All flows		X 	 X	
17B050	Chimacum Creek near Mouth	Salmon	Summer baseflow All flows		X 	 X	
17E060	Snow Creek at WDFW	Salmon	Summer baseflow All flows		X 	 X	
17E060	Snow Creek at WDFW	LilQ	Summer baseflow All flows			 X	X
Ecology Historical Continuous Gages				**Very Good**	**Good**	**Fair**	**Poor**
17F060	Salmon Creek at West Uncas Road	Snow	Summer baseflow All flows		X 	 X	
17F060	Salmon Creek at West Uncas Road	LilQ	Summer baseflow All flows				X X
17H060	Thorndyke Creek near Mouth	Tarboo	Summer baseflow All flows	X 	 X		
17H060	Thorndyke Creek near Mouth	LilQ	Summer baseflow All flows	X 	 X		
Ecology Manual Staff Gages				**Very Good**	**Good**	**Fair**	**Poor**
17J050	Pheasant Creek near Mouth	Chim Snow	All flows All flows				X X

Table 6 summarizes the reference stations analyzed for the Ecology study stations. The numbers in the grid indicate whether the active station is the primary (1^o) or secondary (2^o) preference. Totals for each station are shown at the bottom. Table 6 gives some sense of which gages were most useful as reference stations.

Table 6. Summary of study and reference flow monitoring stations.

Reference stations → / Study Stations ↓	BigQ-ECY	LilQ	Tarboo	Chim	Snow	Salmon	BigQ-GS
BigQ-ECY		2^o					1^o
LilQ	2^o				1^o		
Tarboo				1^o	2^o		
Chim		1^o				2^o	
Snow		2^o				1^o	
Salmon		2^o			1^o		
Thorn		2^o	1^o				
Pheas				1^o	2^o		
No. Primary	-	1	1	2	2	1	1
No. Secondary	1	4	-	-	2	1	-
TOTAL	1	5	1	2	4	2	1

Preferences:
1^o Primary
2^o Secondary

Discussion

Ecology has developed procedures to evaluate its flow gaging network (Ecology, 2011). The selection and support of gages are based on a variety of agency priorities. For the gages discussed in this report, a detailed review of gaging needs is beyond the scope of this study and will be conducted separately. However, technical information resulting from this study about these gages – whether they are relatively unique or redundant and the ability to predict flows at a station from a neighboring gage – is valuable input to that decision-making process.

Based on this study's technical analysis, stations can be categorized for future action:

- The best quality model results were on the Big Quilcene River, where there are two gages. This suggests redundancy for these streams, and the Ecology gage *Big Quilcene River near Mouth* could be a candidate for decommissioning. In addition, there should be an opportunity to improve the estimate of downstream flows at the Ecology gage near the mouth if flow data for the City of Port Townsend diversion could be obtained and subtracted from flows from the USGS gage upstream of the City diversion.

- The model for Ecology's gaging station *Tarboo Creek near Mouth* had a very good fit for summer baseflows and a good fit for all flows. This station should be reviewed to see if modeling could possibly replace direct measurement of flows. The water management needs that depend on this data should be reviewed to determine whether the regression-based model would meet those needs or if continued operation of the gage is justified.

- The models for the three Ecology stations *Little Quilcene River near Mouth*, *Snow Creek at WDFW*, and *Salmon Creek at West Uncas Road* had good to fair quality. These three streams are neighboring and similar in their watershed characteristics, and regressed well to each other. The redundancy between these three stations suggests an opportunity to reduce the direct monitoring effort. These gages should be reviewed to see if modeling could possibly replace direct measurement of flows at one or two of these stations. The water management needs that depend on the data from these stations should be reviewed to determine whether a regression-based model would meet those needs at any of these stations, or whether continued operation of these gages is justified.

- The Ecology station *Chimacum Creek near Mouth* has a regression-based model that shows a good fit for summer baseflows and a fair fit for all flows. Based on the modeling analysis and the unique characteristics of this stream, this station should be the highest priority for continued funding and operation.

- Regression-based models were developed for a historical staff gage station and a historical continuous station, and these models are available for use should the need arise.

All of the continuous flow gages evaluated in this study are identified as regulatory control stations as part of the Quilcene-Snow instream flow rule. Stations considered for decommissioning as a result of this study could be kept active with cooperative funding, transferred to another agency for operation, or restored in the future if real-time data is needed for water management.

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 Quilcene-Snow watershed planning area (WRIA 17).
- The quality of the streamflow estimates from these regression-based models was evaluated. Based on the results of that evaluation, recommendations are provided for Ecology's support of flow gaging stations:
    - *Big Quilcene River near Mouth*: Based on the quality of models, consider decommissioning or transferring this station to a third party. Also explore improved modeling using diversion data.
    - *Tarboo Creek near Mouth*: Review flow data needs to determine if direct measurements are needed at this station or if the regression-based model suffices to meet those needs. Based on that review, consider decommissioning this station, operating it with cooperative funding, or transfer to a third party.
    - *Little Quilcene River near Mouth*, *Snow Creek at WDFW*, and *Salmon Creek at West Uncas Road* (now *Salmon Creek at WDFW*): These three stations appear to be redundant to each other. Review data needs for these stations to determine if one or more of these stations could be decommissioned, operated with cooperative funding, or transferred.
    - *Chimacum Creek near Mouth*: Continue funding of this station.
- Regressions are available to predict flows for staff and continuous gage stations that have been decommissioned.
- 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 can be provided as needed to staff from Ecology, local partners, or other agencies.
- Where real-time access to flow estimates using the regression-based model is needed for a particular gage, the model should be programmed into an internet platform so that the public can access predicted flows from real-time reference station flow data.
- If a regression-based model is in active use, a flow study should be done at regular intervals to check and update the model.

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Figures

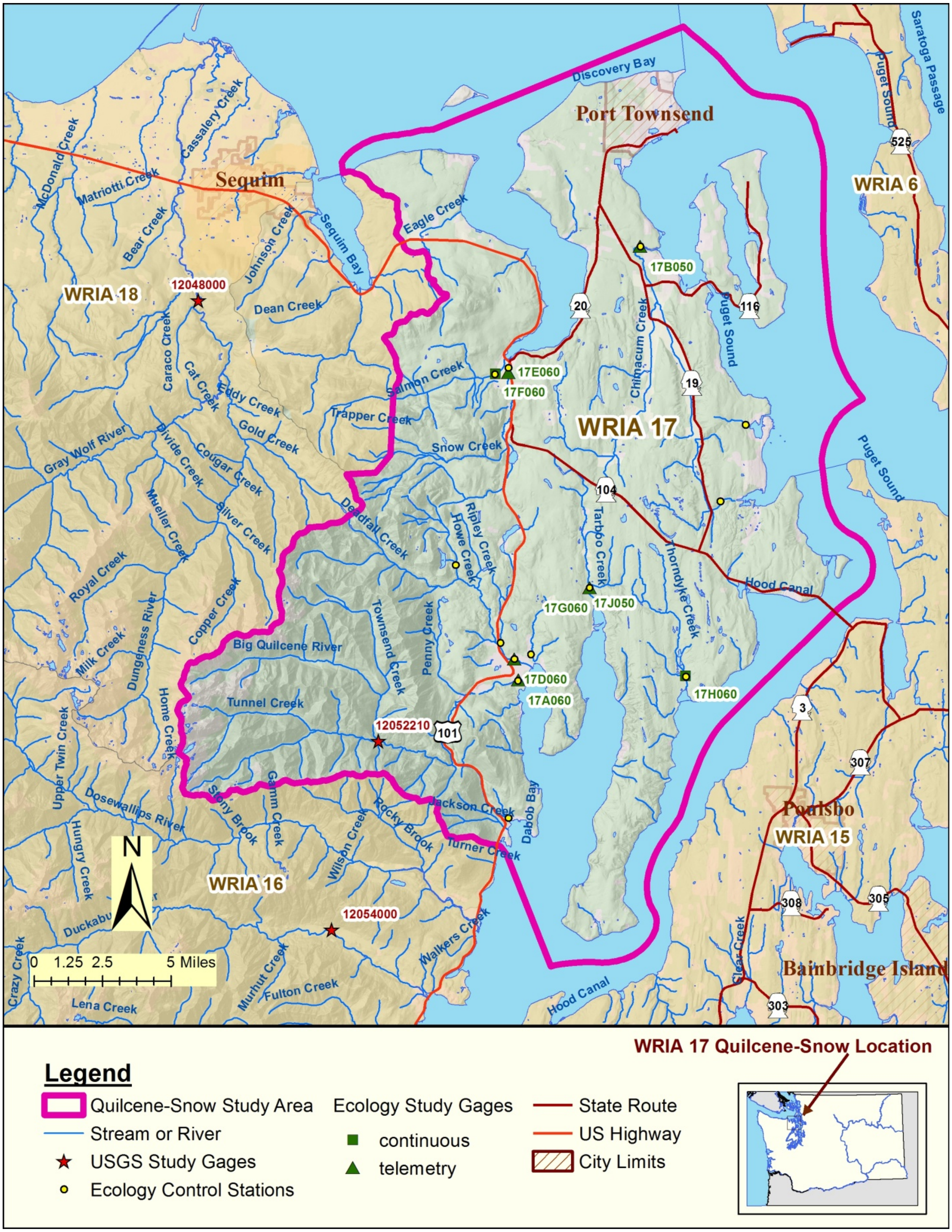

Figure 1. Quilcene-Snow watershed study area.

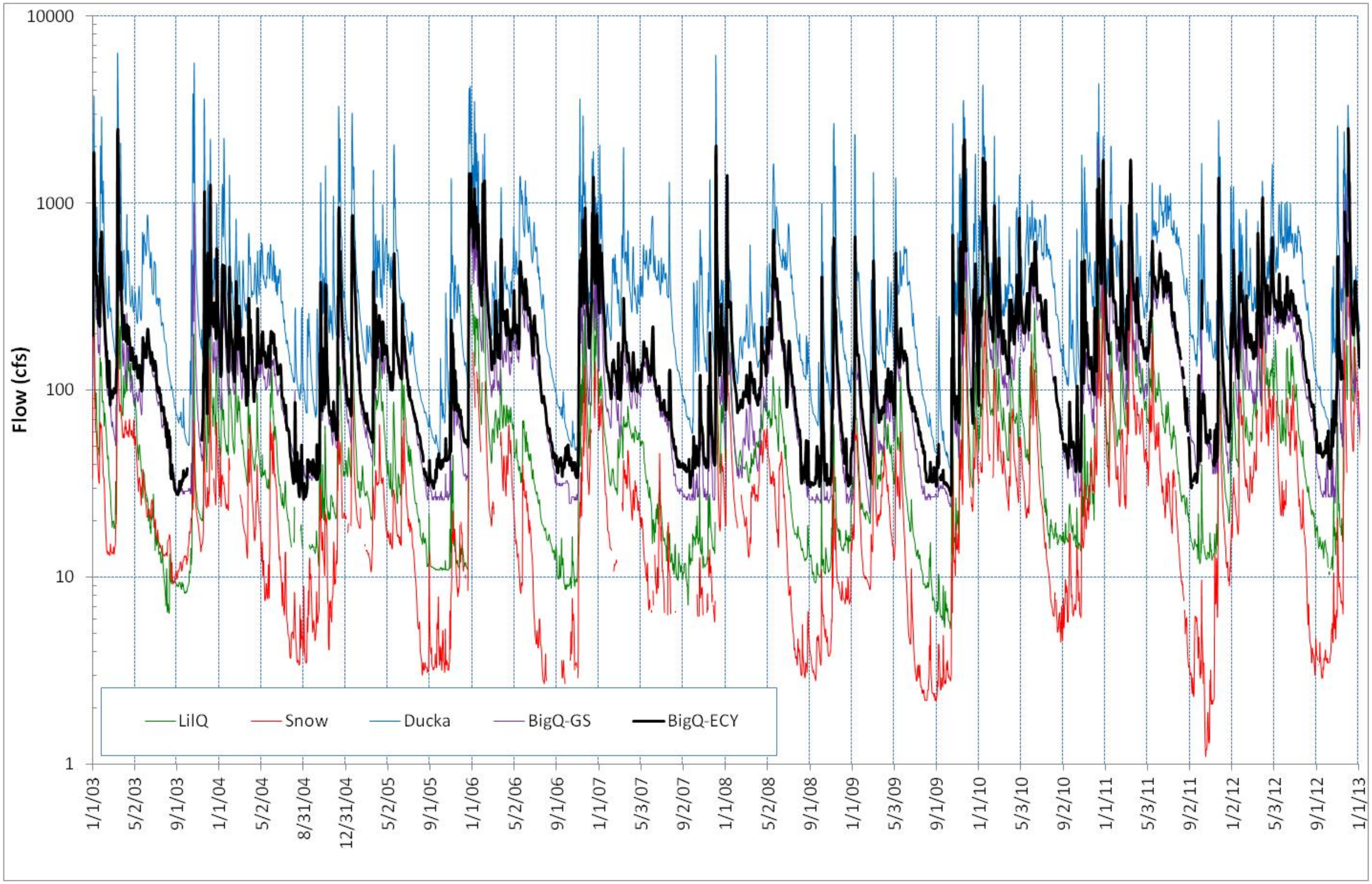

Figure 2. Measured flows at the Ecology "Big Quilcene River near Mouth" gaging station, with flows from other selected gages.

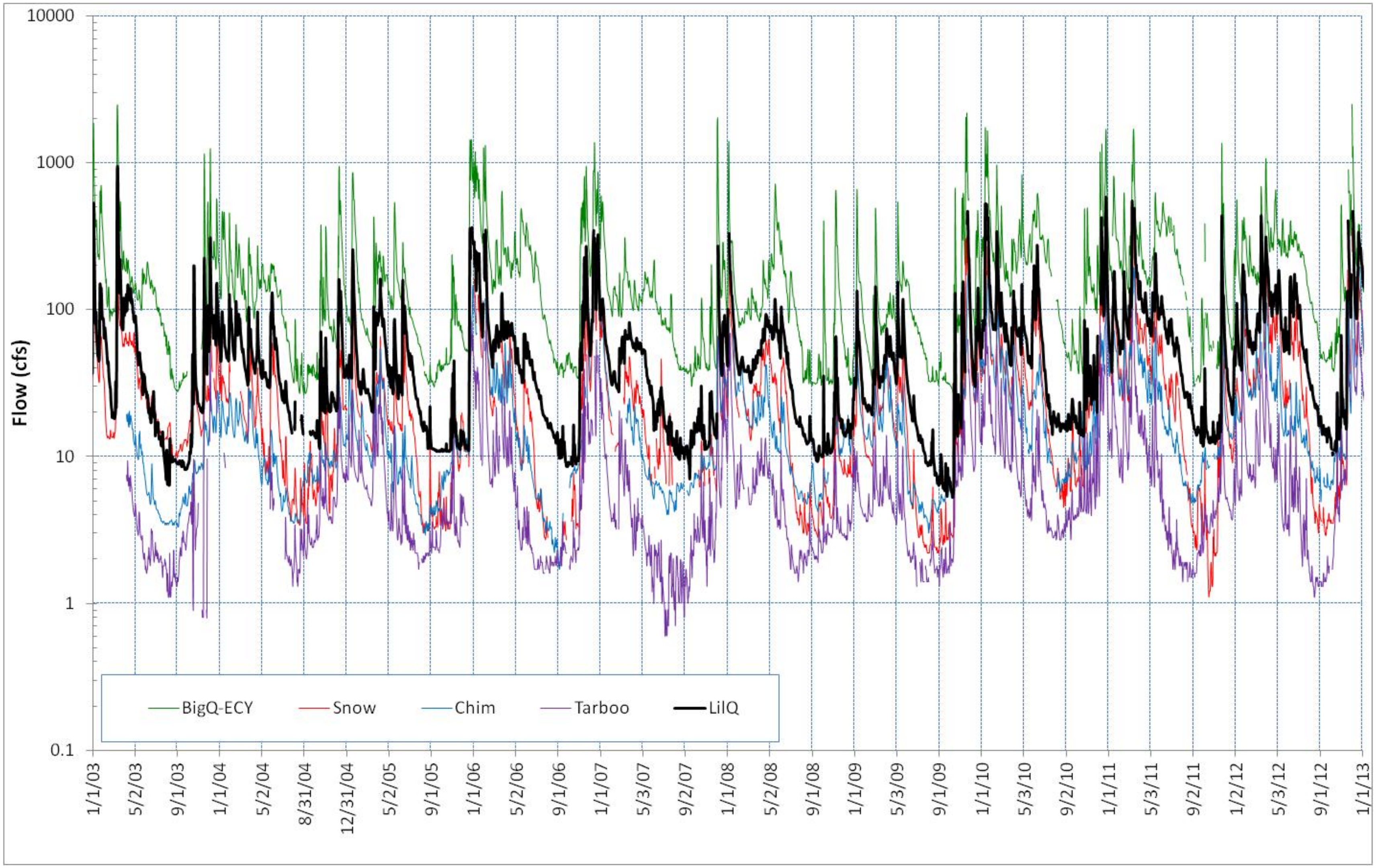

Figure 3. Measured flows at the Ecology "Little Quilcene River near Mouth" gaging station, with flows from other selected gages.

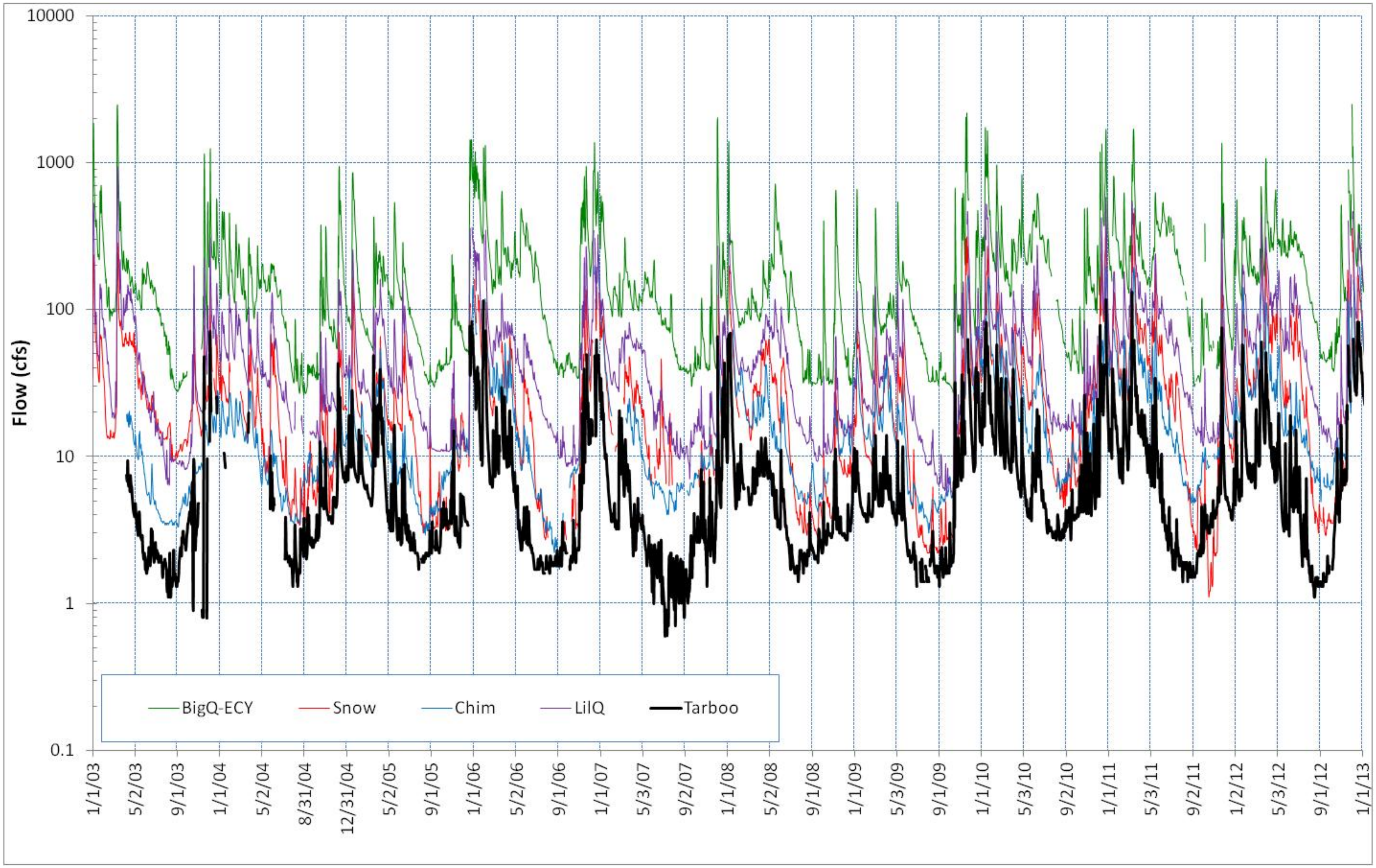

Figure 4. Measured flows at the Ecology "Tarboo Creek near Mouth" gaging station, with flows from other selected gages.

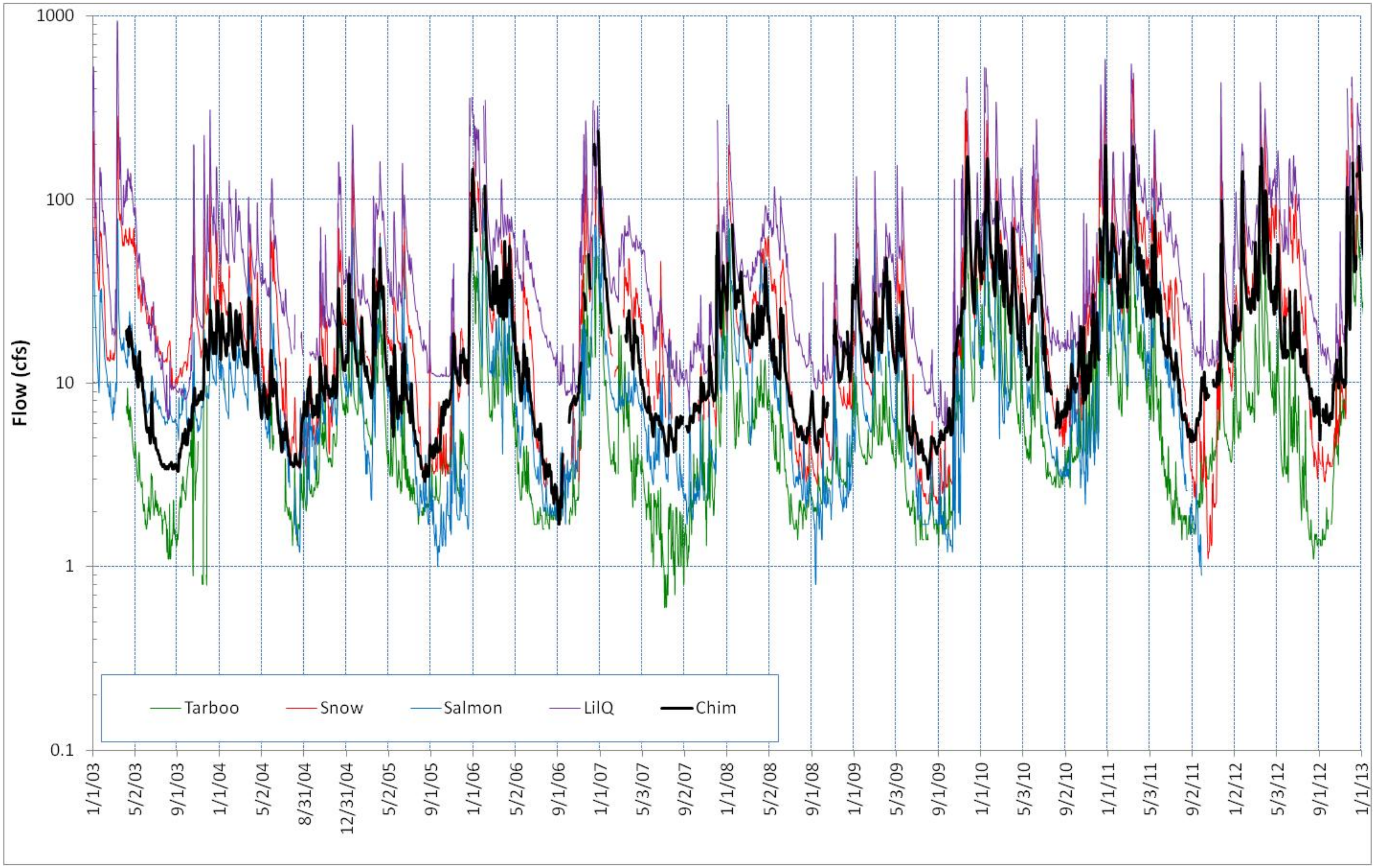

Figure 5. Measured flows at the Ecology "Chimacum Creek near Mouth" gaging station, with flows from other selected gages.

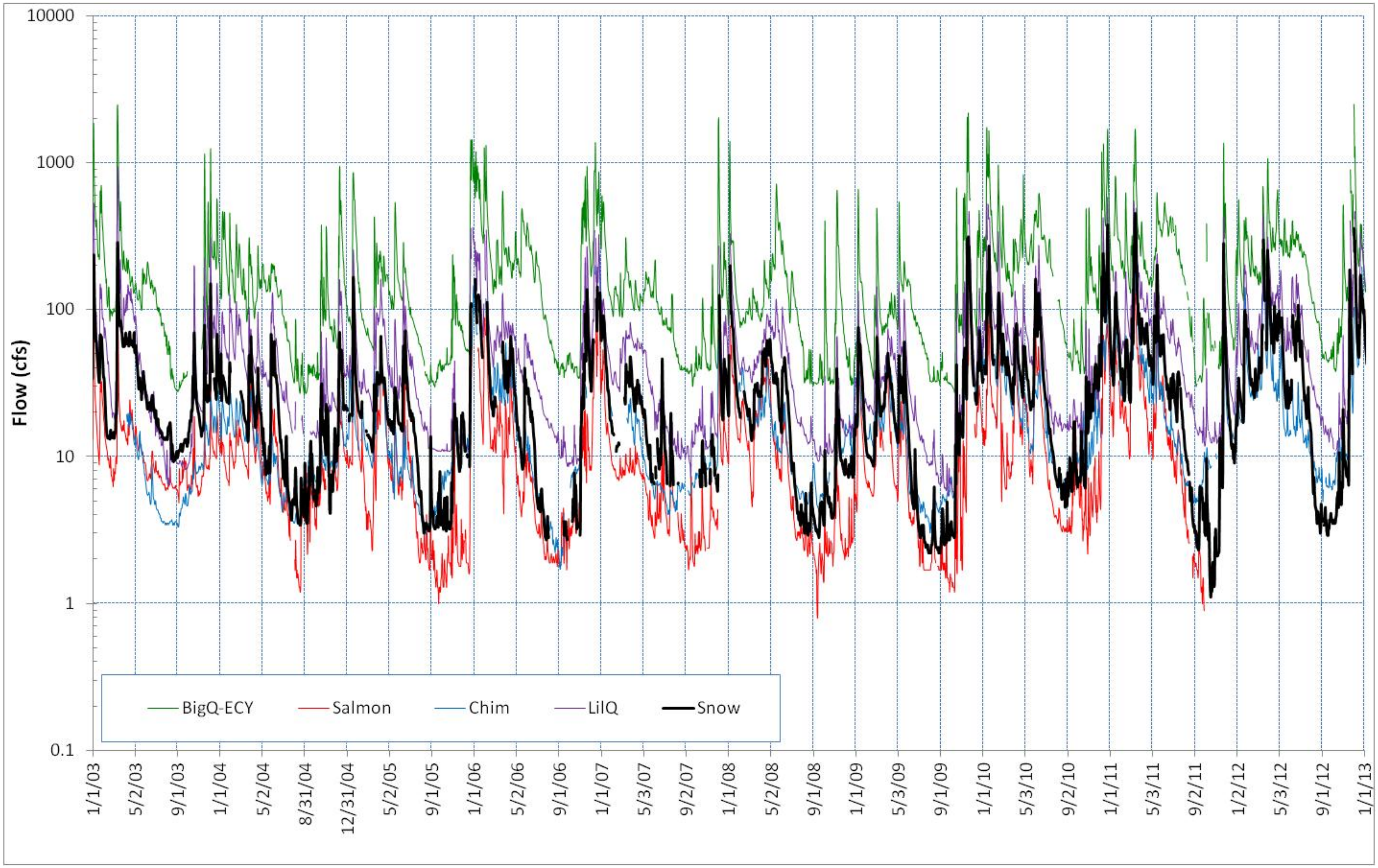

Figure 6. Measured flows at the Ecology “Snow Creek at WDFW” gaging station, with flows from other selected gages.

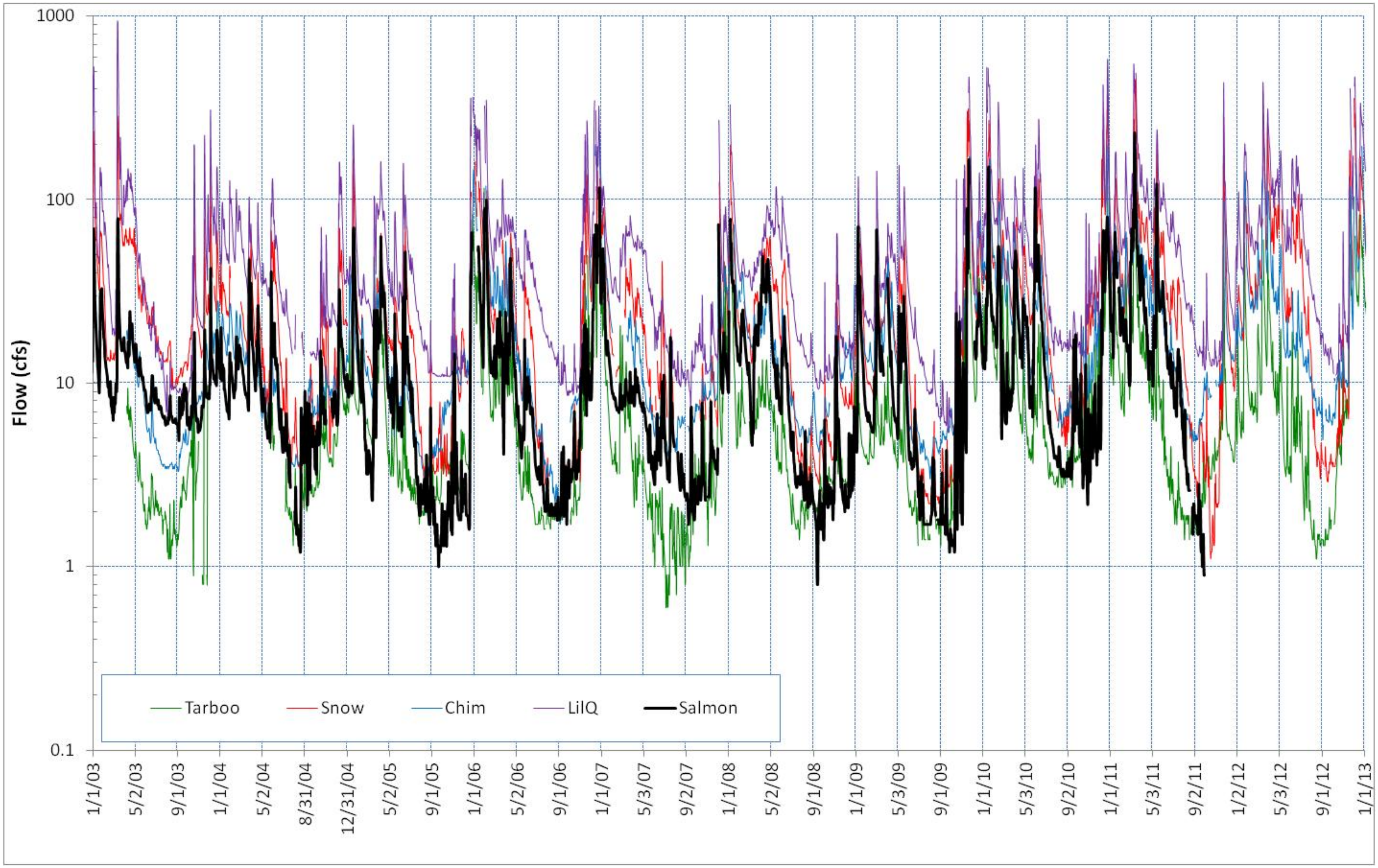

Figure 7. Measured flows at the Ecology "Salmon Creek at West Uncas Road" gaging station, with flows from other selected gages.

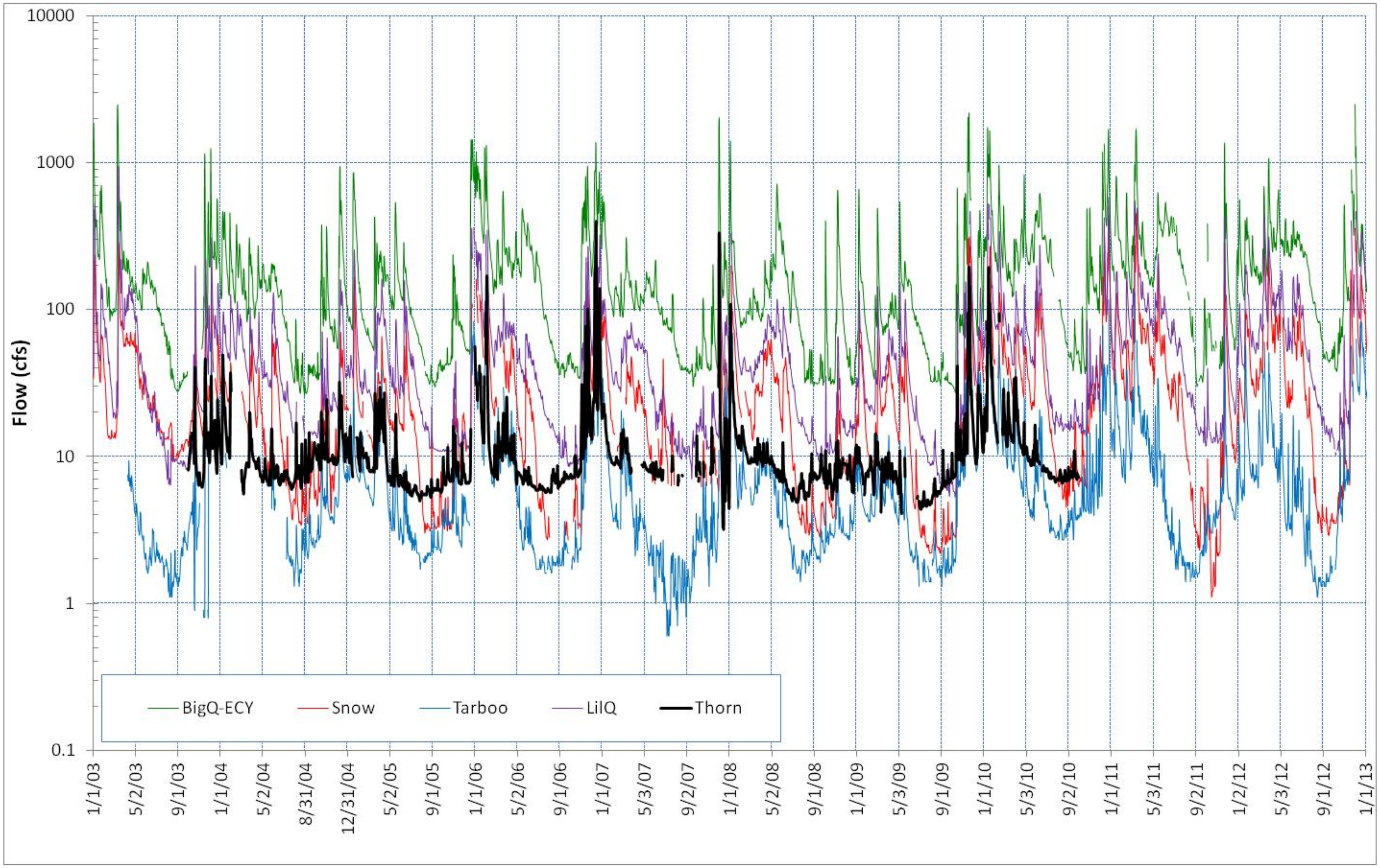

Figure 8. Measured flows at the Ecology "Thorndyke Creek near Mouth" gaging station, with flows from other selected gages.

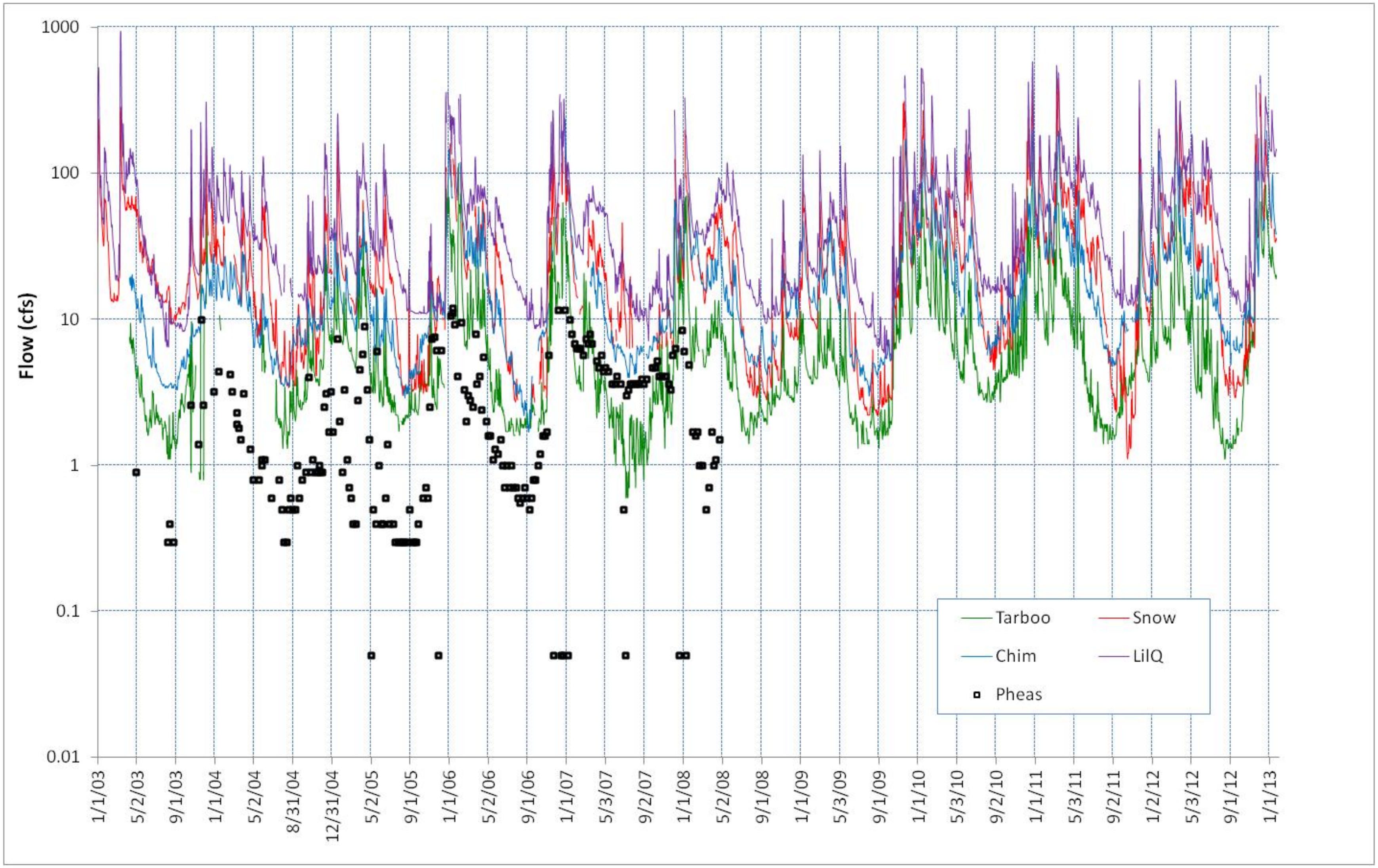

Figure 9. Measured flows at the Ecology “Pheasant Creek at Mouth” gaging station, with flows from other selected gages.

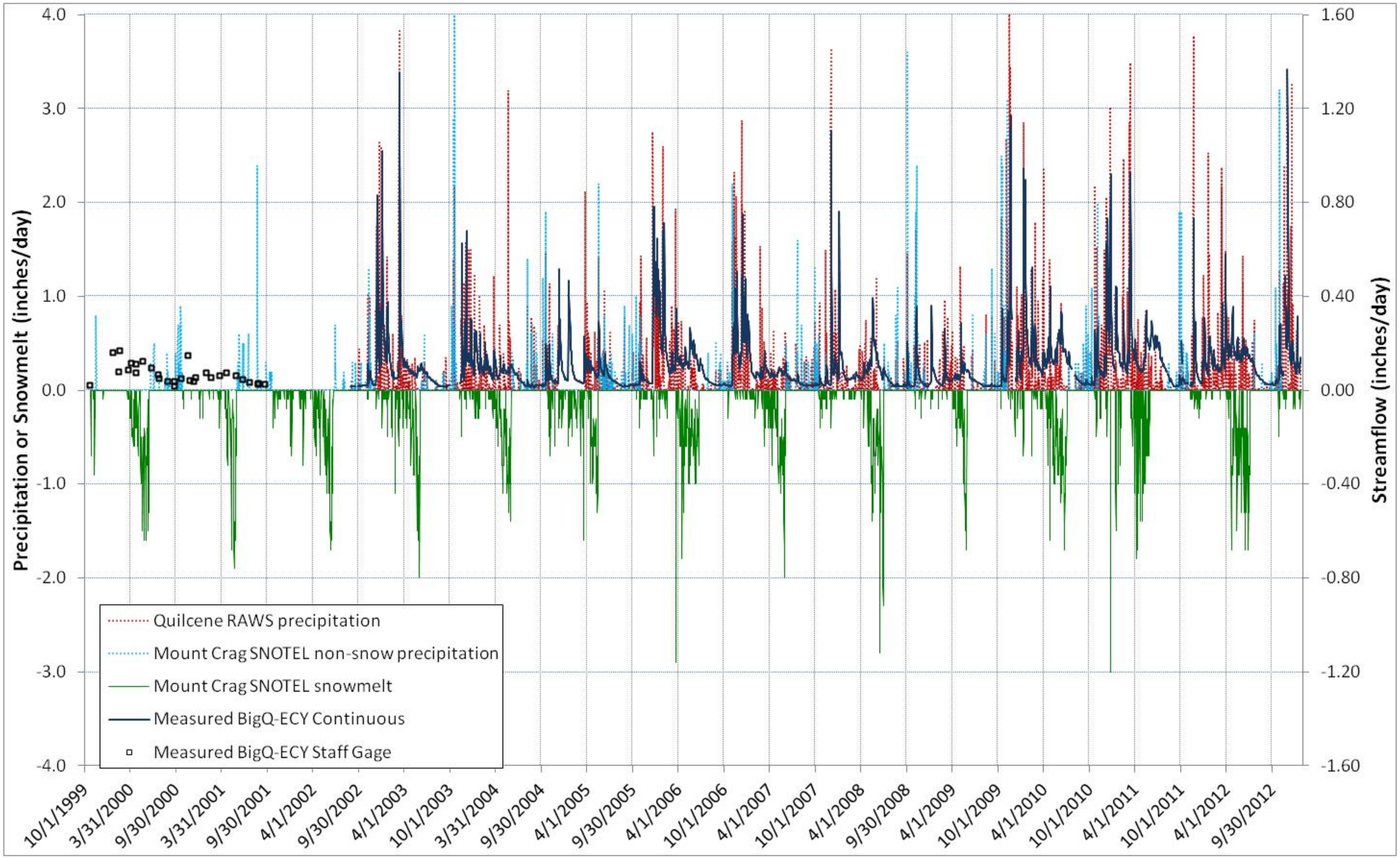

Figure 10. Measured areal flows at the Ecology “Big Quilcene River near Mouth” gaging station, with precipitation and snowmelt data.

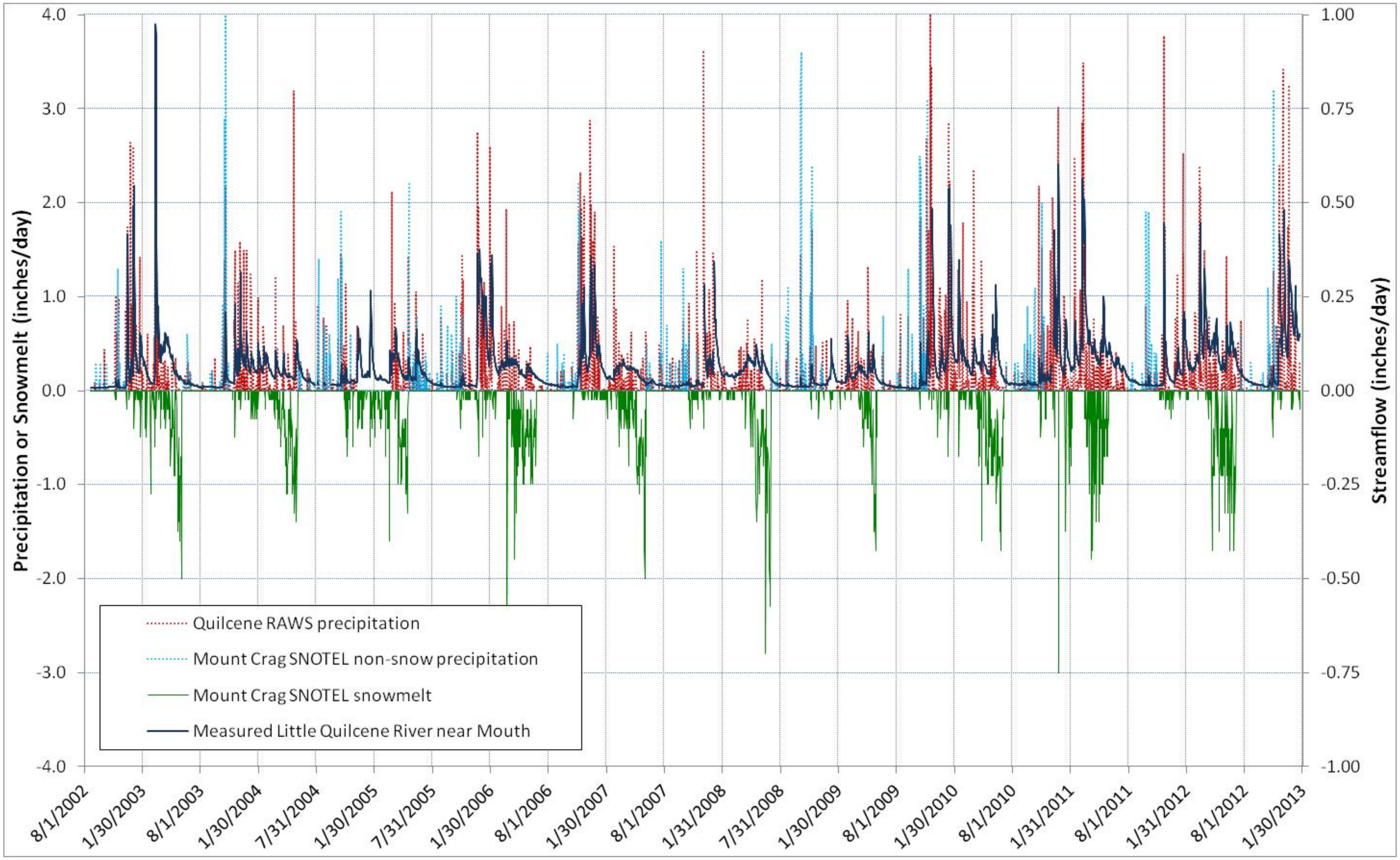

Figure 11. Measured areal flows at the Ecology "Little Quilcene River near Mouth" gaging station, with precipitation and snowmelt data.

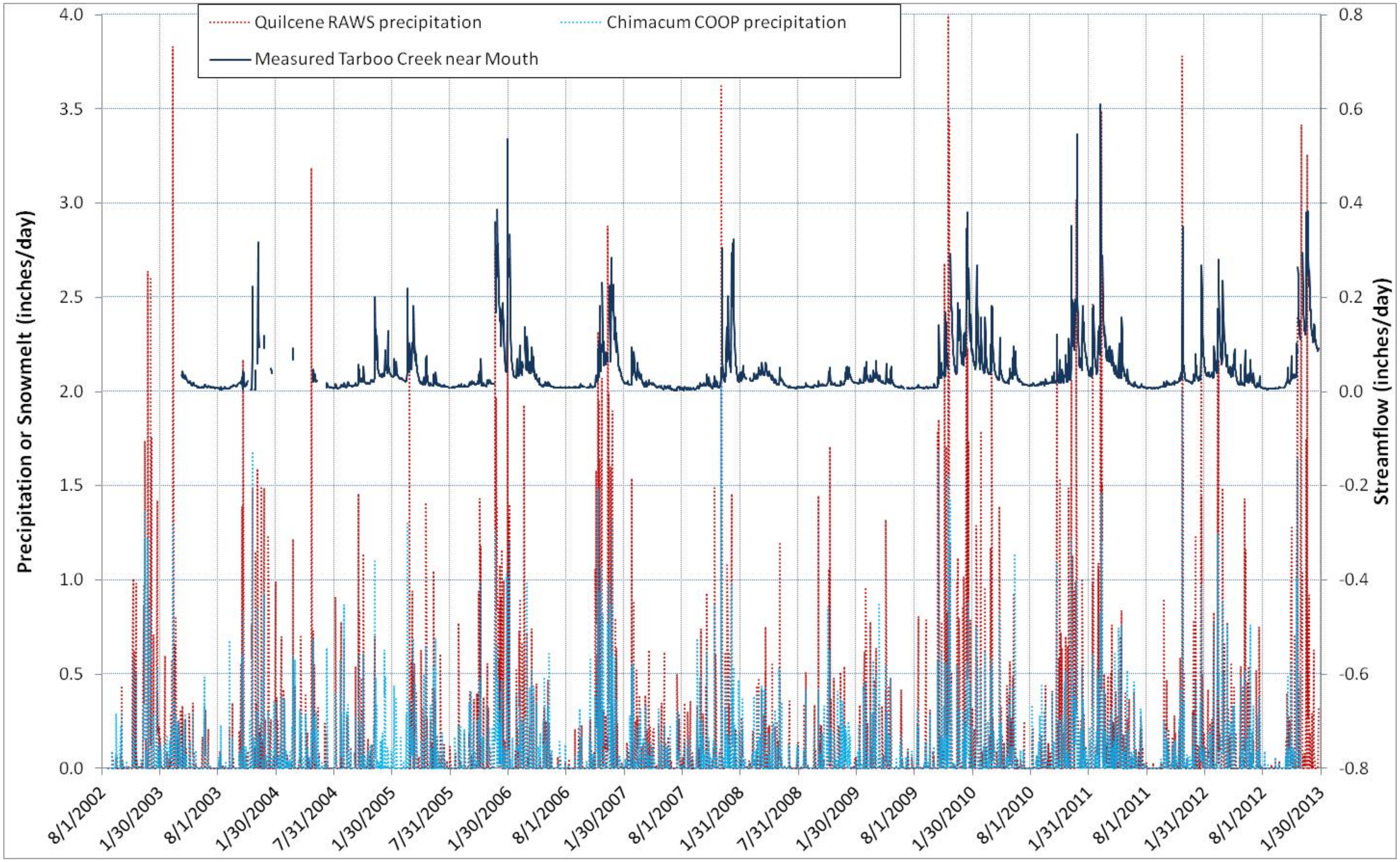

Figure 12. Measured areal flows at the Ecology "Tarboo Creek near Mouth" gaging station, with precipitation data.

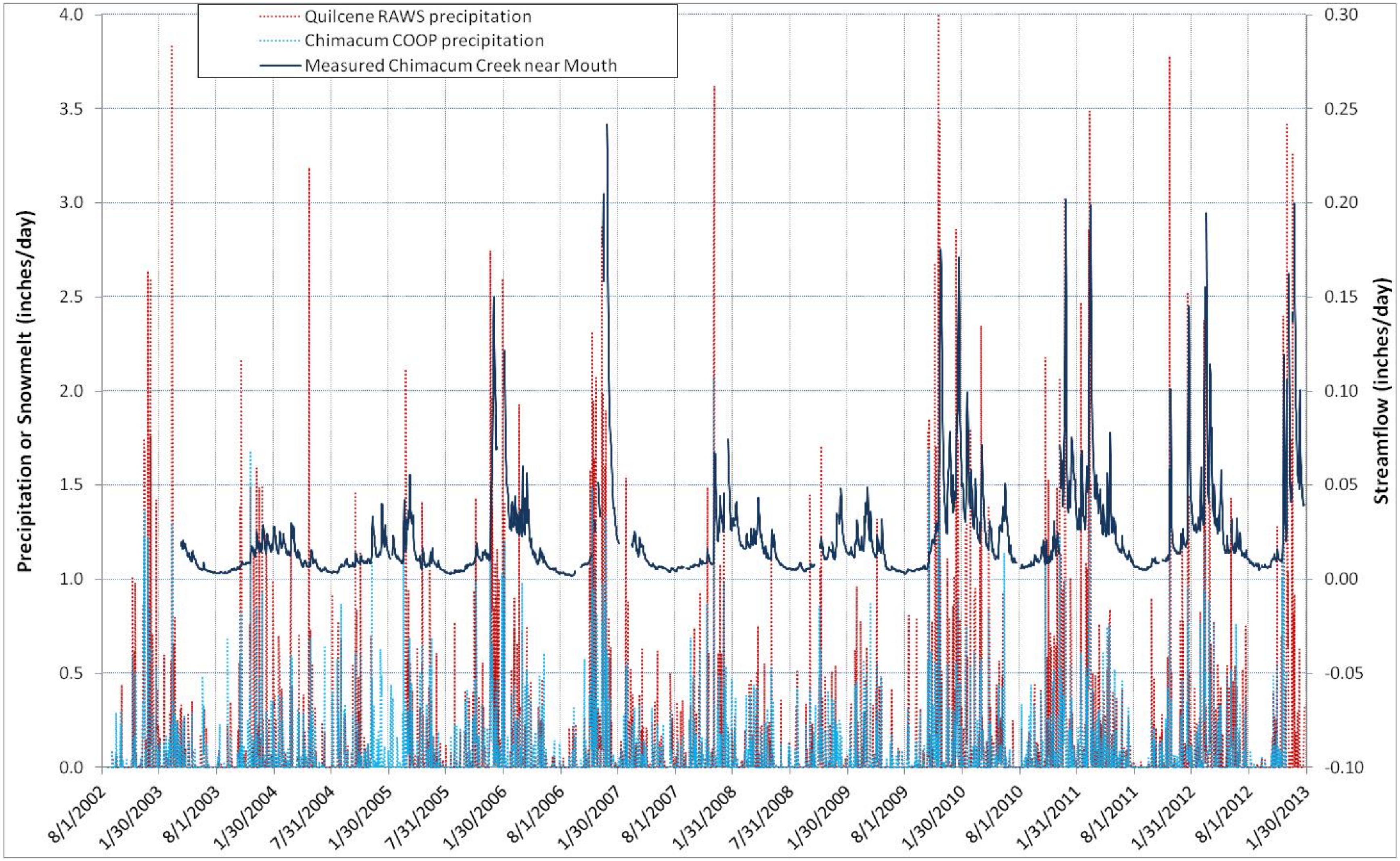

Figure 13. Measured areal flows at the Ecology "Chimacum Creek near Mouth" gaging station, with precipitation data.

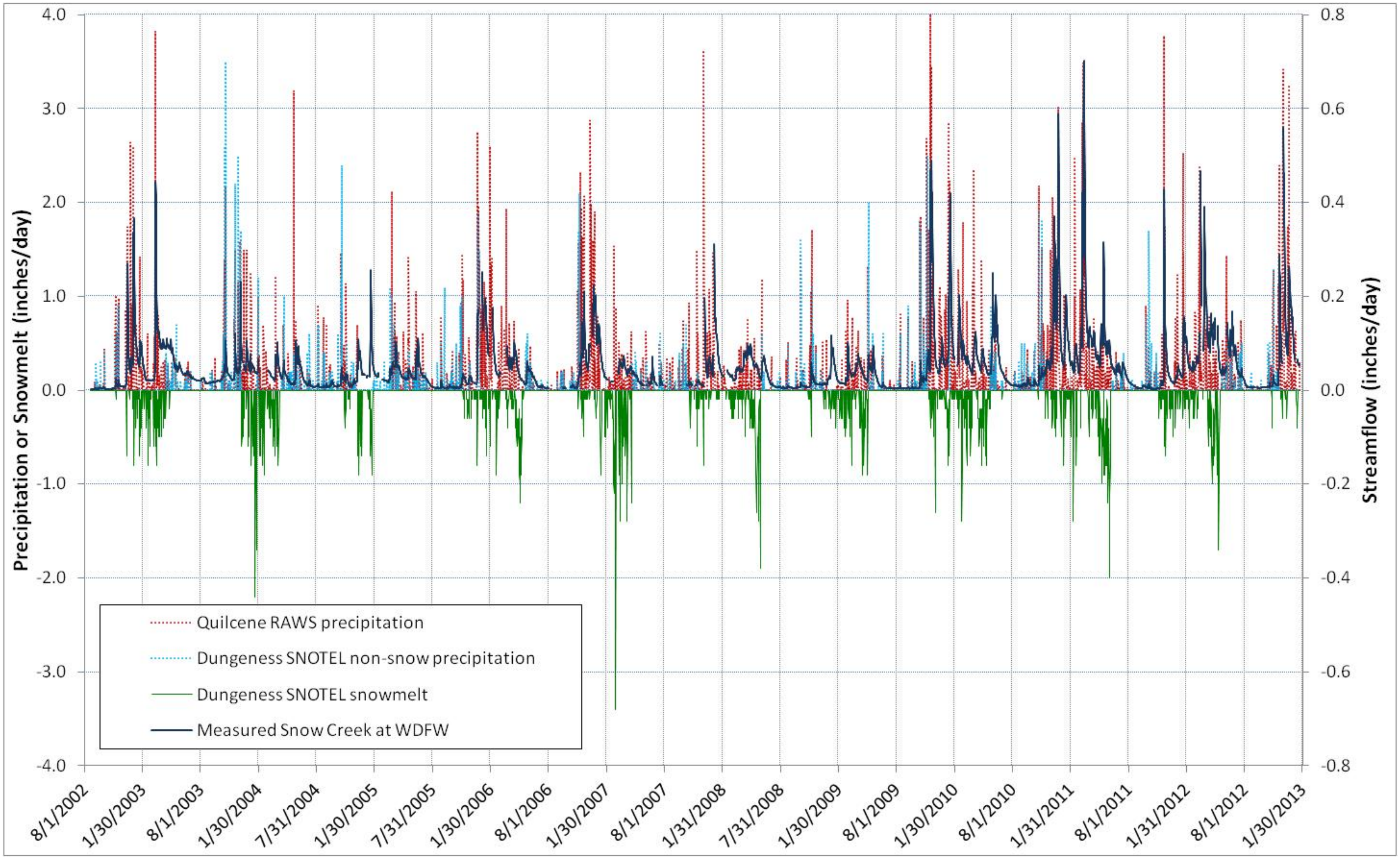

Figure 14. Measured areal flows at the Ecology “Snow Creek at WDFW” gaging station, with precipitation and snowmelt data.

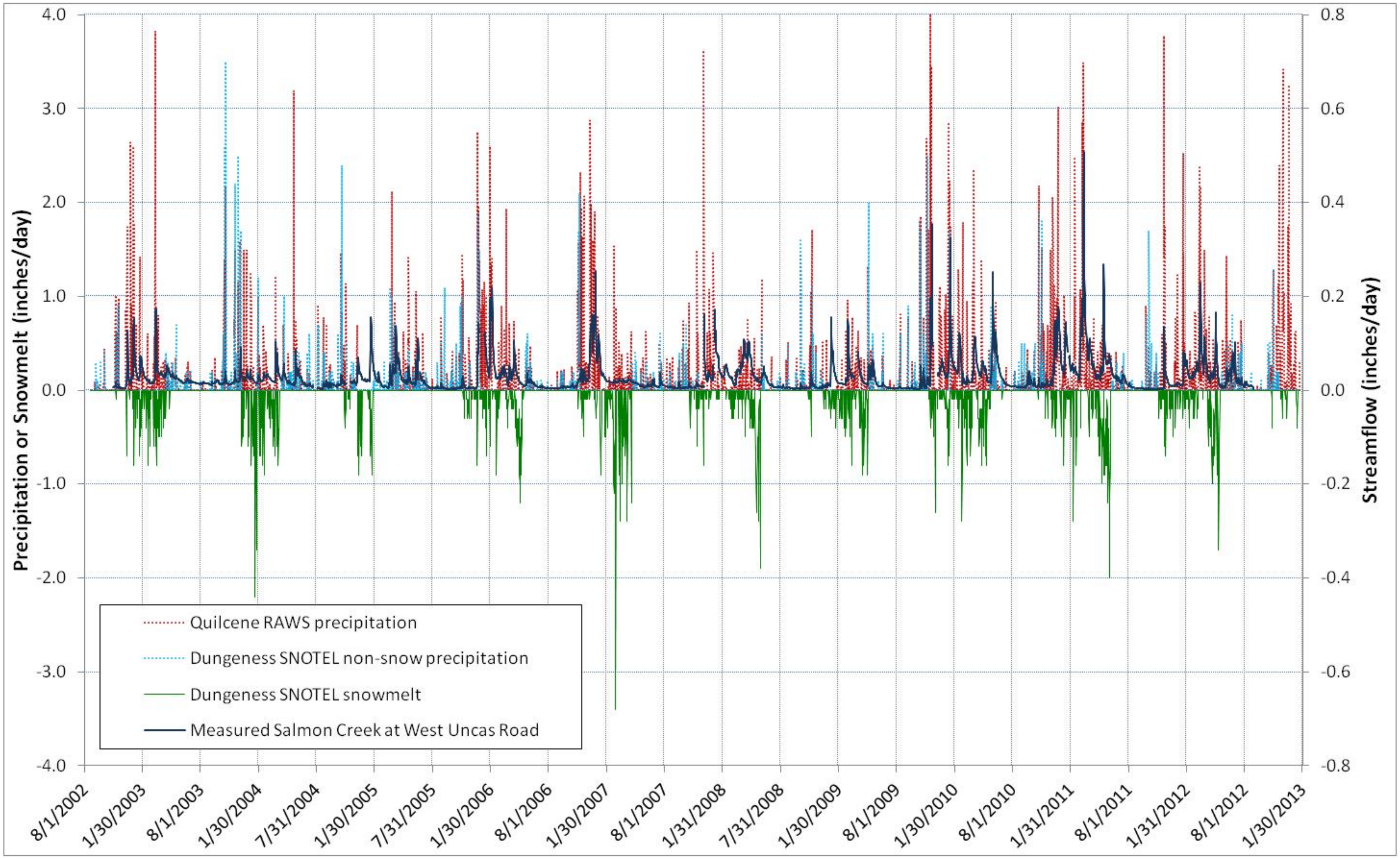

Figure 15. Measured areal flows at the Ecology “Salmon Creek at West Uncas Road” gaging station, with precipitation and snowmelt data.

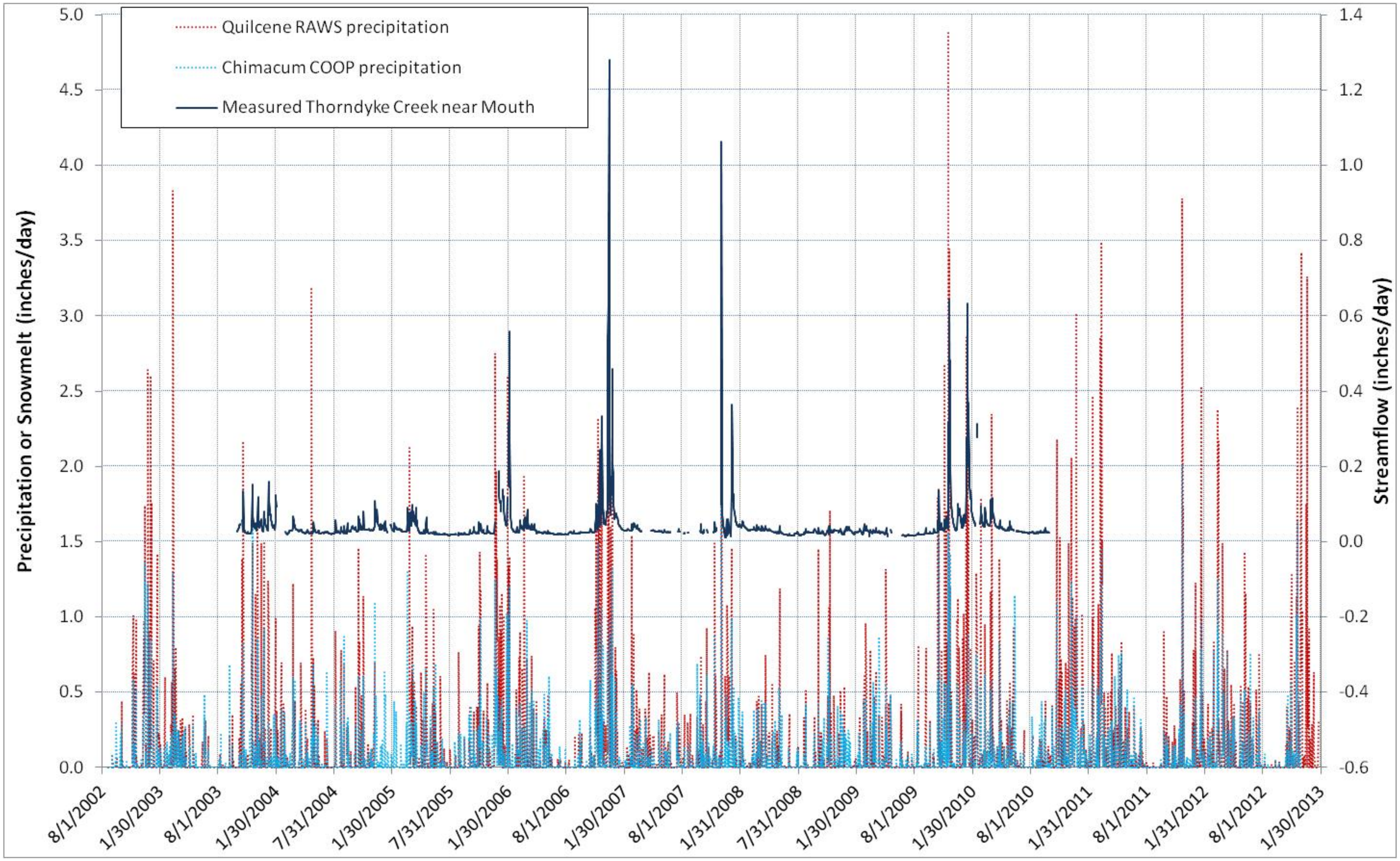

Figure 16. Measured areal flows at the Ecology “Thorndyke Creek near Mouth” gaging station, with precipitation data.

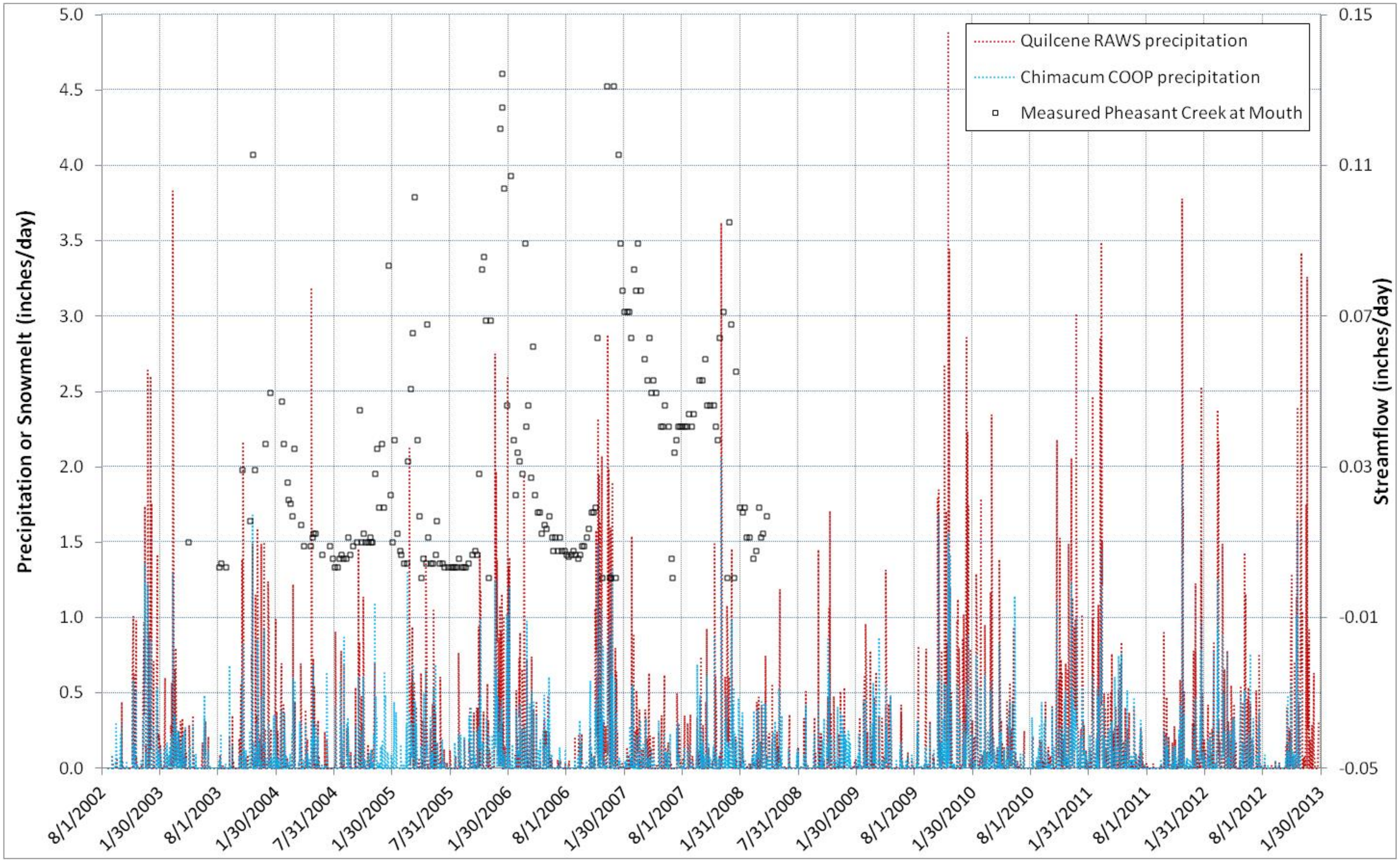

Figure 17. Measured areal flows at the Ecology “Pheasant Creek at Mouth” gaging station, with precipitation data.

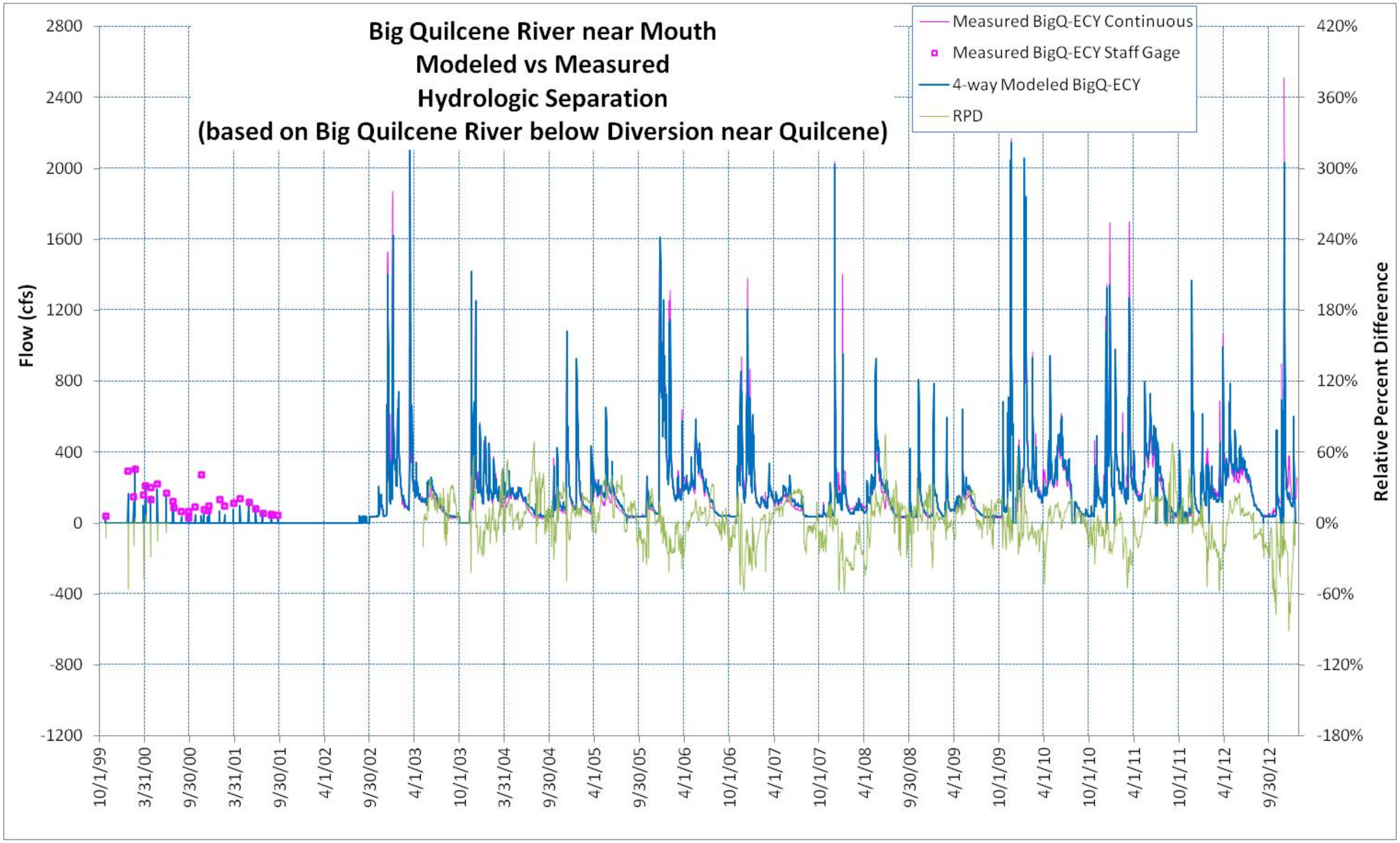

Figure 18. Measured flows at the Ecology “Big Quilcene River near Mouth” gaging station, and modeled flows based on the USGS “Big Quilcene River below Diversion near Quilcene” station, with relative percent difference of paired values.

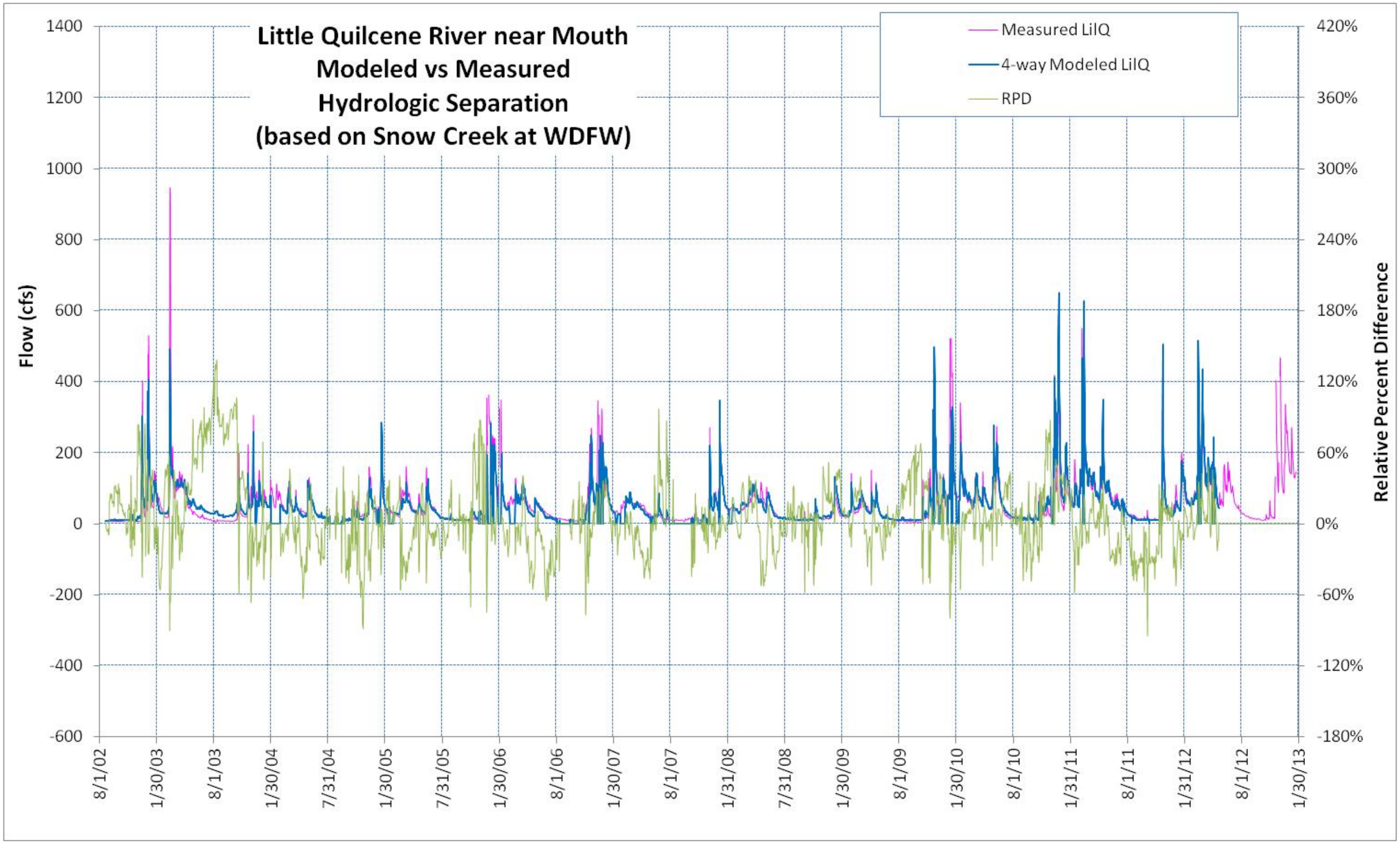

Figure 19. Measured flows at the Ecology “Little Quilcene River near Mouth” gaging station, and modeled flows based on the Ecology “Snow Creek at WDFW” station, with relative percent difference of paired values.

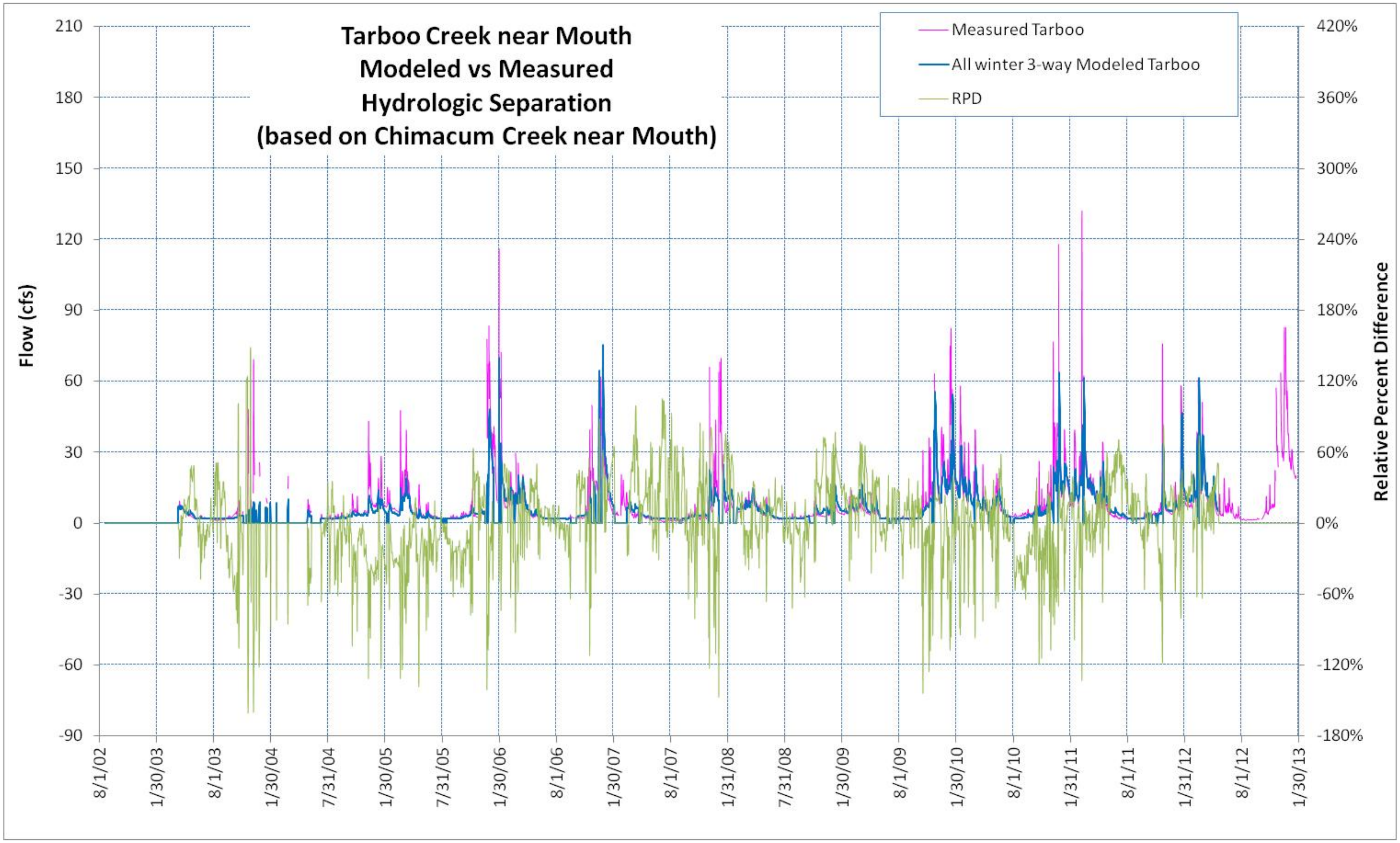

Figure 20. Measured flows at the Ecology "Tarboo Creek near Mouth" gaging station, and modeled flows based on the USGS "Chimacum Creek near Mouth" station, with relative percent difference of paired values.

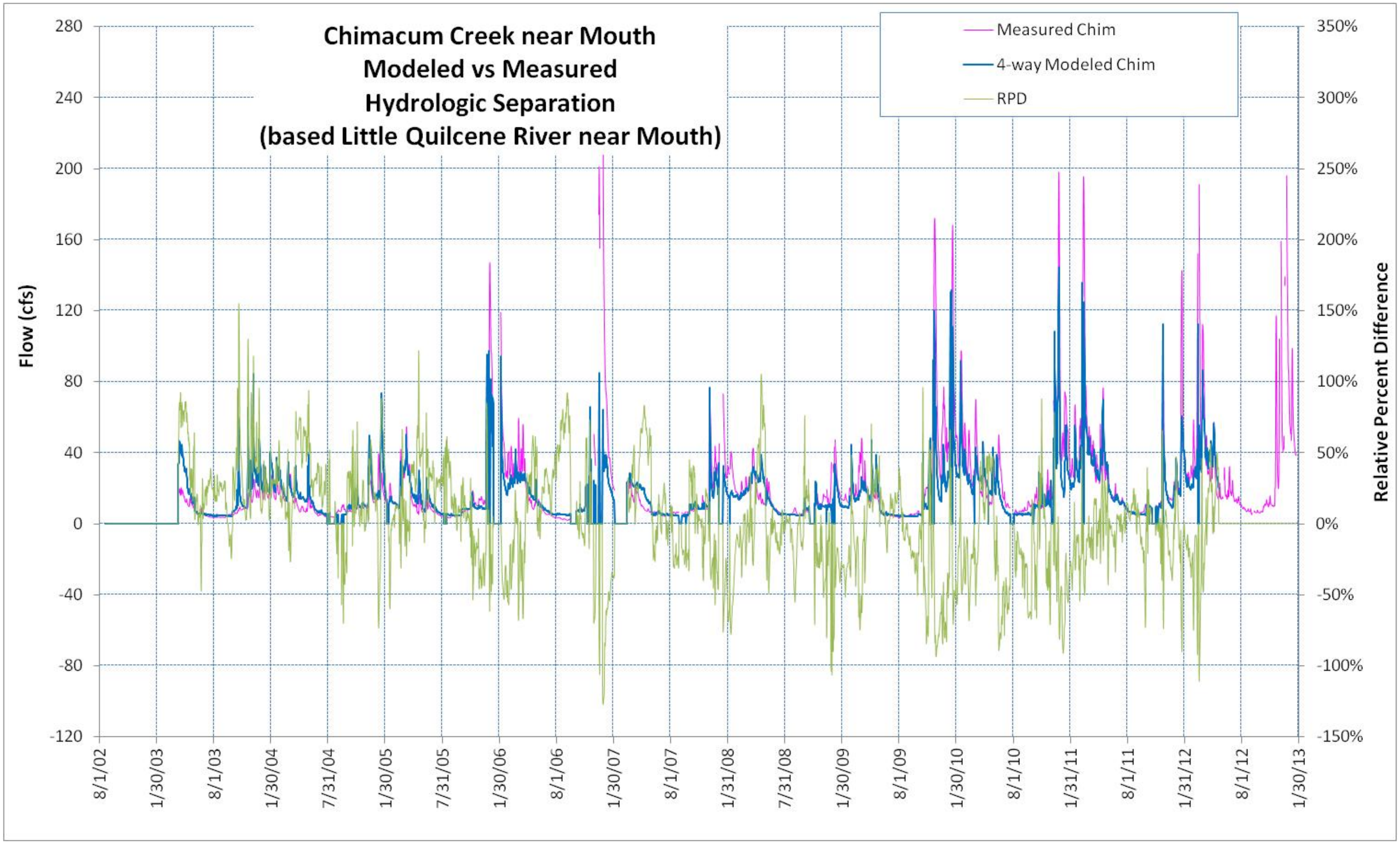

Figure 21. Measured flows at the Ecology "Chimacum Creek near Mouth" gaging station, and modeled flows based on the Ecology "Little Quilcene River near Mouth" station, with relative percent difference of paired values.

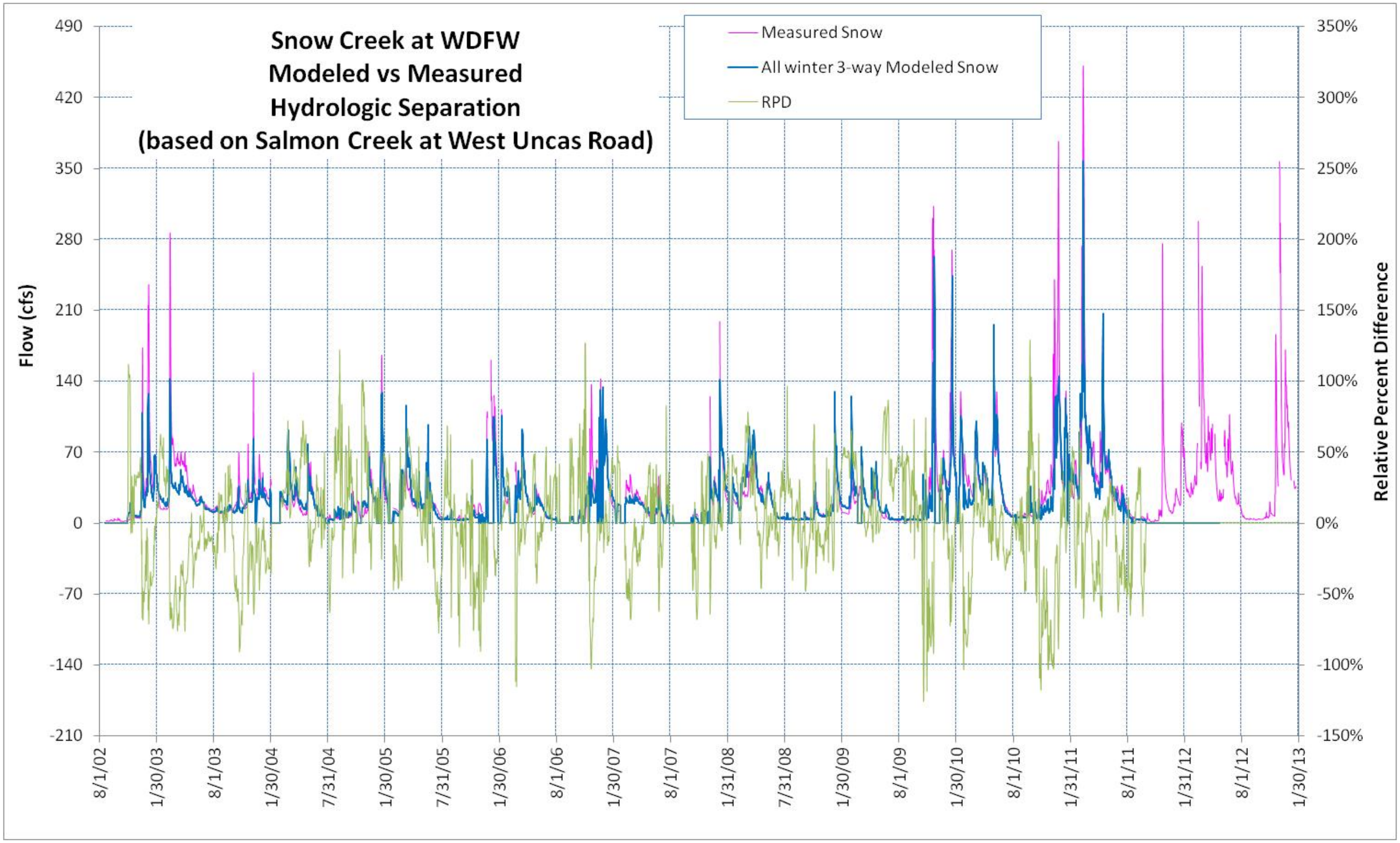

Figure 22. Measured flows at the Ecology "Snow Creek at WDFW" gaging station, and modeled flows based on the Ecology "Salmon Creek at West Uncas Road" station, with relative percent difference of paired values.

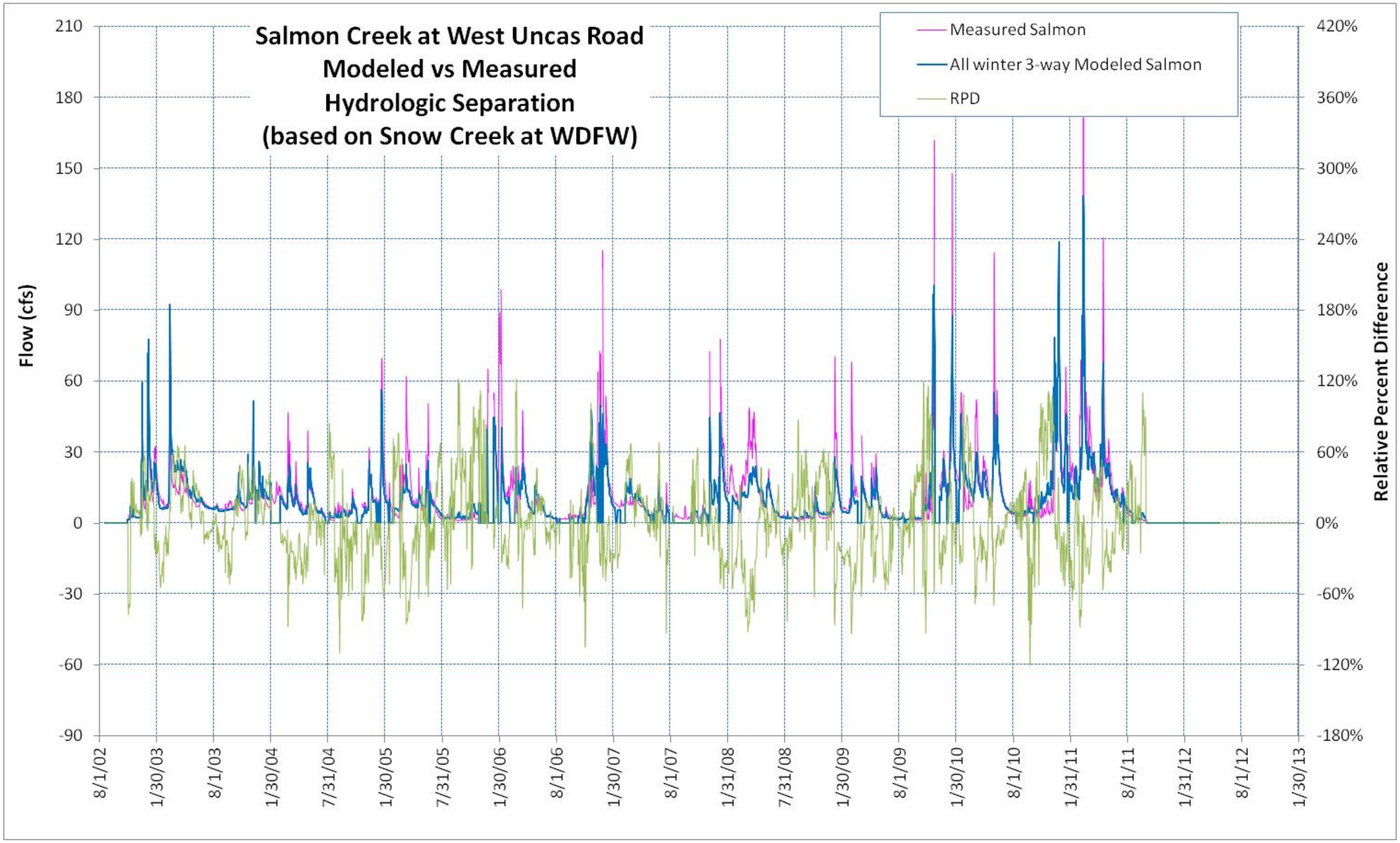

Figure 23. Measured flows at the Ecology "Salmon Creek at West Uncas Road" gaging station, and modeled flows based on the Ecology "Snow Creek at WDFW" station, with relative percent difference of paired values.

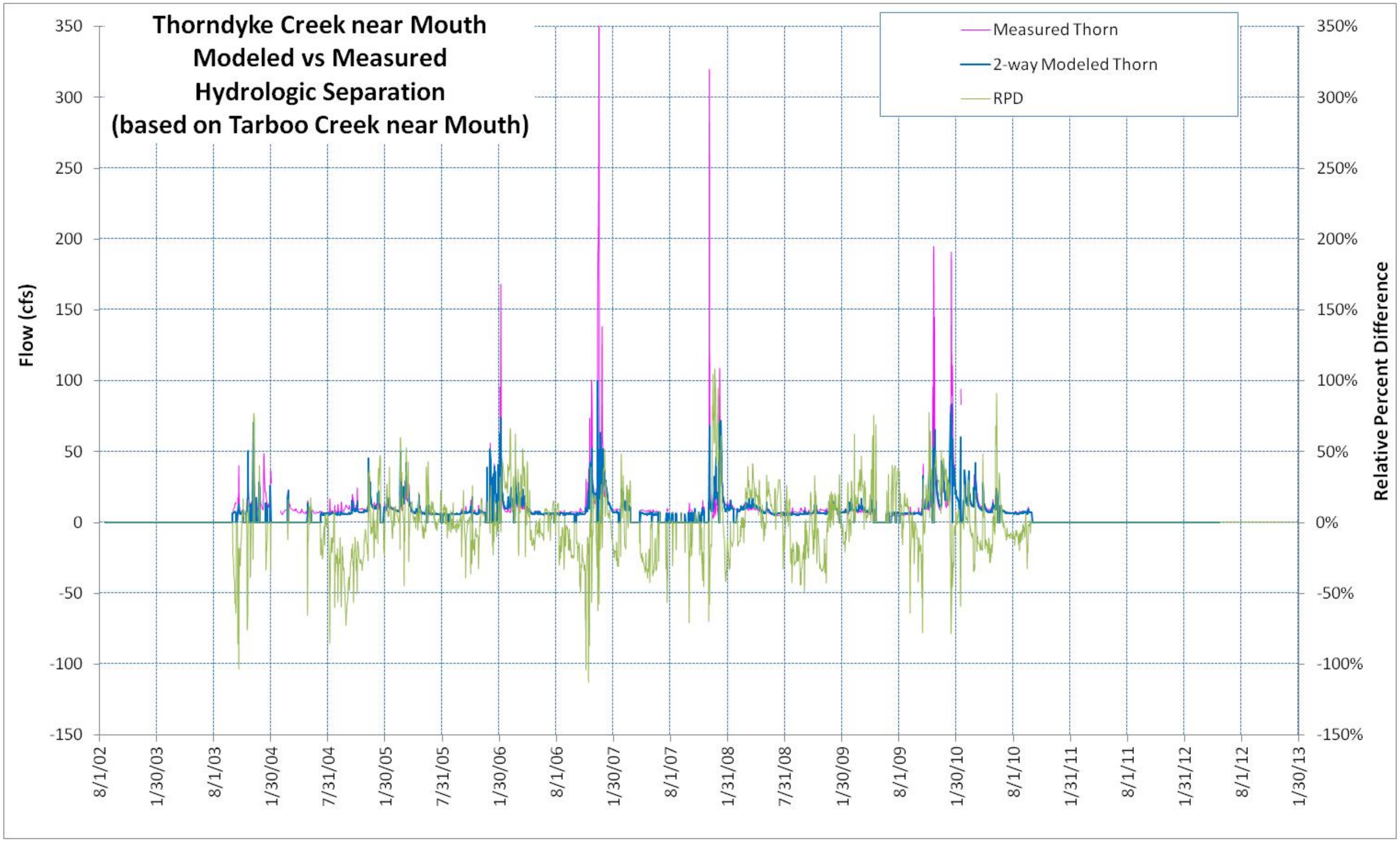

Figure 24. Measured flows at the Ecology "Thorndyke Creek near Mouth" gaging station, and modeled flows based on the Ecology "Tarboo Creek near Mouth" station, with relative percent difference of paired values.

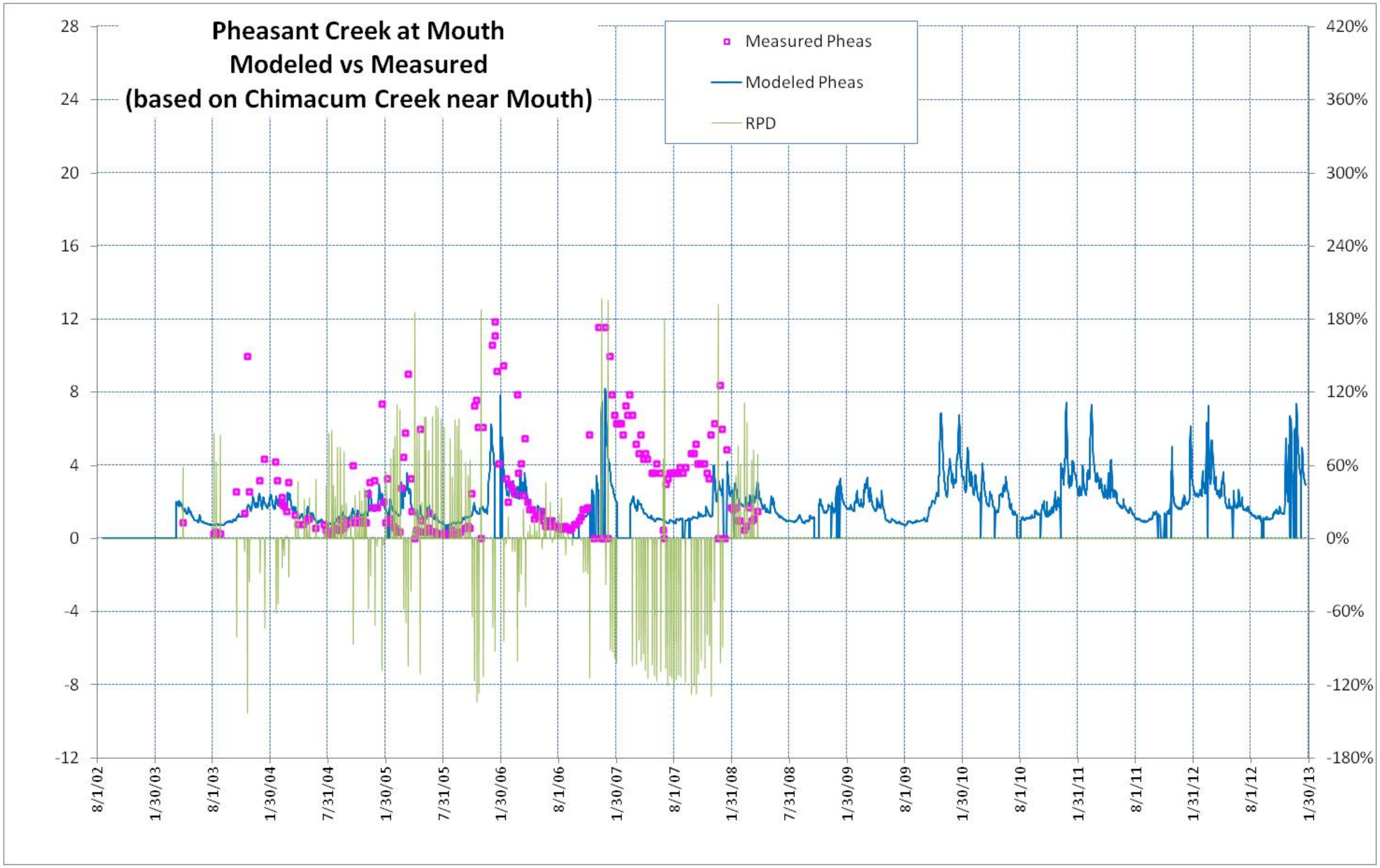

Figure 25. Measured flows at the Ecology "Pheasant Creek at Mouth" gaging station, and modeled flows based on the Ecology "Chimacum Creek near Mouth" station, with relative percent difference of paired values.

Appendix. Glossary, Acronyms, and Abbreviations

Glossary

Acre-foot: A volume of water equivalent to one horizontal acre in width and length and one foot of depth.

Areal flow: Surface water discharge per unit of watershed area, in units of length per time (for example, inches per day). Sometimes also called *unit flow* in hydrologic literature.

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.

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.

Quilcene-Snow watershed planning area: Contiguous with Water Resource Inventory Area (WRIA) 17, except for the Sequim Bay watershed.

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, also called the “Quilcene-Snow”, which includes the watersheds in the northeast Olympic Peninsula from the Big Quilcene River to the southeast to the Sequim Bay watershed to the northwest.

WY: Water Year, defined in this report as October 1 through September 30.

Acronyms and Abbreviations

%RSD	Percent relative standard deviation
AP	Airport
cfs	Cubic feet per second
Deg	Degrees
Ecology	Washington State Department of Ecology
EJWC	East Jefferson Watershed Council
F	Fahrenheit, a unit of temperature
HCCC	Hood Canal Coordinating Council
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
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Area
WY	(See Glossary above)