Nooksack Watershed Planning Area (WRIA 1)

Prediction of Gaged Streamflows by Modeling

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Cover photo: Department of Ecology Flow Measurement Stations in the Nooksack Basin.

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Prediction of Gaged Streamflows by Modeling

by

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Abstract

The Washington State Department of Ecology (Ecology) has operated 14 streamflow gaging stations in Water Resource Inventory Area (WRIA) 1. WRIA 1 includes the Nooksack River watershed and other neighboring watersheds that drain to Puget Sound and the Fraser River.

This study developed regression tools for the Ecology gages for the period of record ending in September 2009. These regressions were based on other Ecology and United States Geological Survey (USGS) gages using power relationships and a hydrograph separation method. Regressions were also developed for two USGS gages on the mainstem Nooksack River. The quality of these regressions was assessed using statistical tools. Regression quality was better for the gages on the Nooksack River mainstem and forks and poorer for tributary gages.

Flows were evaluated at regulatory flow control stations in WRIA 1. Recommendations were made for how to measure or estimate flows at control stations using direct measurements, regressions, or watershed ratios. The quality of those methods was also assessed.

The TOPNET hydrologic model of WRIA 1 was evaluated and ways to apply the model to flows at WRIA gaging and control stations were explored. The TOPNET model results were compared to measured or estimated flows using statistical tools. The calibrated TOPNET model did not perform as well as the regressions, but is still useful for stations in the Nooksack River mainstem and forks and for tributaries with little or no flow data. More development work is needed to improve model predictions and allow them to be used to predict “real-time” flows.

Recommendations were made regarding the discontinuation or retention of the gages based on study results. Useful regressions were found between Ecology and USGS gages in the Nooksack River mainstem and forks, in lowland Nooksack tributaries, and in coastal tributaries. This suggests that some of these stations are redundant for many purposes.

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Introduction

Overview of the Watershed

The focus of this study is Water Resource Inventory Area No. 1 (WRIA 1), which is also referred to as the Nooksack watershed planning area. This area is bordered on the north by the international border with Canada, on the east by the Cascade crest (the divide between the Puget Sound and Columbia basins), on the south by the Skagit River basin, and on the west by Puget Sound (Figure 1). Detailed information on the WRIA can be found at the website for the WRIA 1 Watershed Management Project (http://wria1project.whatcomcounty.org/About-The-Watershed/10.aspx).

Hydrologically, WRIA 1 is a complex region. The range of landscape elevations extend from Mount Baker at 10,778 feet (3,285 meters) to the Puget Sound shoreline. Upper elevation watershed areas are dominated by glacier and snowmelt, while lower elevations are rainfall-dominated. Total land area is about 1,628 square miles (4,217 square kilometers).

WRIA 1 can be divided into three basin categories:

- **The Nooksack River basin.** The watershed for the Nooksack River and all its tributaries lies in WRIA 1, except for the portions in British Columbia.
- **Coastal basins.** Several small watersheds in WRIA 1 drain directly into Drayton Harbor, Birch Bay, Lummi Bay, Bellingham Bay (including Lake Whatcom), and the northeastern side of Samish Bay.
- **Fraser River tributaries.** The upstream portion of the Sumas River and Saar Creek drains north into Canada from WRIA 1; and several headwater tributaries of the Fraser River lie in the northeast corner of WRIA 1, including the Chilliwack River and Silesia Creek.

Mean annual rainfall in WRIA 1 varies from 40 inches around Bellingham, generally increasing with elevation to over 100 inches in the highest elevations. Evapotranspiration rates in low-lying areas are approximately 30 inches per year, mostly occurring in May through August at rates of 4 and 5 inches per month.

Groundwater levels are relatively shallow in the river valleys and low-lying areas of northwestern Whatcom County, suggesting that connectivity between surface water and groundwater in these areas is high.

Snowpack is a significant source of seasonally stored water, with April 1 (seasonal maximum) snow depths on Mount Baker averaging about 170 inches and within the range of 70 to 310 inches over the last 80 years. Seasonal maximum snow water equivalents (SWEs) over the last 13 years at SNOTEL stations in the basin ranged from 9 to 74 inches.

Streamflows can vary widely in WRIA 1 streams. Those draining the higher elevations typically show a spring peak-flow pattern from snowmelt, or a summer peak-flow pattern from glacial melt. The low elevation streams tend to be rain-dominated with peak flows following soon after periods of heavy rainfall. Intermediate elevations are characterized by a mixed snow-rain regime, and the mainstem and forks of the Nooksack River can show characteristics of all these regimes. All watercourses show a period of gradually diminishing summer low flow associated with dry weather and receding groundwater inflows.

Water use in Whatcom County in 1995 was estimated by The United States Geological Survey (USGS) at 87 million gallons per day (MGD) of groundwater, and 74 MGD of surface water. About 49% of groundwater use was for public supply and about 43% for irrigation. Surface water use was about 67% for public supply, 21% for irrigation, and 9% for industrial use.

Political jurisdictions in WRIA 1 include Whatcom County, Lummi Nation, Nooksack Tribe, City of Bellingham, and several other smaller cities and towns: Ferndale, Blaine, Lynden, Everson, Nooksack, and Sumas. Whatcom Public Utility District also plays a key role in water management.

Whatcom County has experienced rapid population growth, doubling from 82,606 to 166,814 persons between 1970 and 2000. This has resulted in growth in rural residential and urban land uses, especially around Bellingham and in the Drayton Harbor watershed. The economy has traditionally been dependent on timber, farming, and fishing, and many industries related to those sectors were established in Whatcom County, such as food processors and lumber and paper mills. Whatcom County is also home to large oil refining and aluminum smelting plants.

About 20% of WRIA 1 is zoned for forestry, 11% for rural development, 8% for agriculture, and 7% for urban and commercial/industrial development. The eastern one-third of WRIA 1 is mostly forested lands managed by the U.S. Forest Service and Park Service. Of the western two-thirds, about 60% is either undeveloped, timber lands, or managed as open space. Agriculture dominates the low-lying areas around Lynden, the Sumas River, the Lower Nooksack, Barrett Lake, and Drayton Harbor. Agricultural water use includes irrigation, stock watering, and facility washdown.

WRIA Planning Process

Over the past 11 years, the WRIA 1 Planning Group has been developing and implementing the WRIA 1 Watershed Management Project (WMP) under the RCW 90.82 planning process. Participants in the WRIA 1 Planning Group include representatives of:

- City of Bellingham
- Whatcom County
- Whatcom Public Utility District
- Lummi Nation
- Nooksack Indian Tribe
- Ecology (representing state agencies)
- Other local governments and water interests.

The history of the WMP is described on the WRIA 1 WMP website (http://wria1project.whatcomcounty.org/About-The-Project/History/15.aspx) and in the Quality Assurance (QA) Project Plan for this study (Pickett, 2009). The WRIA 1 Planning Group has been a key organization for local stakeholder involvement in this study.

Several efforts related to the WRIA 1 WMP are relevant to this study:

- The USGS conducted a hydrologic assessment for WRIA 1, which compiled and assessed hydrologic data (USGS, 2001).
- Utah State University (USU), as part of its technical support for the WRIA 1 WMP:
    - Reviewed existing models.
    - Made recommendations for hydrologic modeling.
    - Conducted surveys of the basin in support of modeling.
    - Developed a hydrologic model of streams in WRIA 1 (called "TOPNET"), and
    - Developed a Decision Support System for watershed planning in WRIA 1.

Flow Monitoring

Department of Ecology Stations

The Washington State Department of Ecology (Ecology) has 14 current and historical flow monitoring stations (www.ecy.wa.gov/programs/eap/flow/shu_main.html, Table 1 and Figure 2):

- Five of the stations are telemetry stations that provide real-time continuous gage height measurements, which are converted to real-time flow values.
- Two stations are historical stations with continuous data. Bar Creek was discontinued in the spring of its first year of operation due to damage from a landslide. Maple Creek was discontinued in 2008 due to excessive beaver activity near the gage.
- Two stations are *stand-alone* stations that collect continuous gage height measurements for periodic download and conversion to discharge measurements. These stations were *manual stage* stations until 2007, but were upgraded for the Drayton Harbor Total Maximum Daily Load study (Mathieu and Sargeant, 2008).
- Five were stations where *manual stage* readings were collected infrequently (at least once per month). These stations were discontinued in October 2009. The Middle Fork Nooksack River station was historically stand-alone, but vandalism forced a downgrade to manual stage.

For all stations, flow discharge is (or was) measured directly on a regular basis, and rating curves are developed and updated for determining flow from gage height data.

USGS Stations

The USGS has gaged flow throughout WRIA 1 at a variety of sites historically and currently (USGS, 2001):

- Continuous streamflow data have been collected at 56 stations, of which 12 are currently active. The stations active through 2009 are listed in Table 2 and shown in Figure 2. Of the stations active in 2009:
    - 6 are *real-time* telemetry stations. Ecology provides partial funding for the 2 mainstem Nooksack River stations at North Cedarville and at Ferndale through the USGS Cooperative Stream Gaging Program.
    - 7 are *non-real-time* stand-alone stations. Of the stand-alone stations active in 2009, 1 has been discontinued, 3 are still operated through funding from the Lummi Tribe with Ecology 90.82 watershed planning grant funds and other funds, and 2 are now funded by the Nooksack Tribe. Future funding for these stations may change due to ongoing state budget problems.
- A total of 2,537 miscellaneous flow measurements have been collected at 134 sites in the Nooksack basin over the last 100 years.

Typical flows at the Ecology and USGS gages in the Nooksack basin vary widely. For example, comparing the annual mean flows for Water Year 2006 (October 2005-September 2006):

- The coastal streams and most of the Nooksack tributaries averaged less than 100 cubic feet per second (cfs).
- The larger Nooksack tributaries and forks averaged from 100 to just over 1000 cfs.
- The mainstem Nooksack River averaged from 1,700 up to almost 4,000 cfs.

Flows can also vary widely between years. Between Water Years 1967 and 2008, annual mean flows in the Nooksack River at Ferndale ranged from 2,536 cfs (2001) to 5,152 cfs (1991). The maximum flow on record is 57,000 cfs (November 10, 1990), while the minimum flow on record is 463 cfs (October 26, November 9, 10, 1987).

Other Stations

Three other flow data sets were used in this study:

- Terrell Creek at Helwig Road near Birch Bay State Park (collected by the Nooksack Salmon Enhancement Association). Twenty-seven spot measurements were made from February 2003 through February 2005. Flows were measured in four other locations in Terrell Creek during this time frame. The station chosen for this analysis is the farthest downstream. The abbreviated station code is “NSEA-Ter”.
- Squalicum Creek at West Street (collected by the City of Bellingham). This is an active continuous monitoring station that began collecting data in February 2006. Note that the station name is the same as Ecology’s station; they are located less than 50 feet apart. The City measures flows in other locations that are not pertinent to this study. The abbreviated station code is “COB-Squal”.

- Spot flow measurements were collected by Ecology as part of the Drayton Harbor TMDL study (Mathieu and Sargeant, 2008). Flow measurements from Dakota and California Creeks were selected for analysis from locations corresponding to regulatory control stations (see below).

These stations provide additional data to meet the study objectives.

Table 1. Ecology flow monitoring stations in WRIA 1.

Station ID	Station Name	Station Code	Start Date	End Date	Type
01N060	Bertrand Creek near mouth	ECY-Bert	13-Jun-2003	Current	Real-time
01C070	Hutchinson Creek near Acme	ECY-Hutch	13-Jun-2003	Current	Real-time
01P080	Tenmile Creek above Barrett Lake	ECY-Ten	12-Jun-2003	Current	Real-time
01A140	Nooksack River above the Middle Fork	ECY-NFN	14-Jun-2003	Current	Real-time
01F070	South Fork Nooksack River at Potter Road	ECY-SFN	14-Jun-2003	Current	Real-time
01J060	Bar Creek at mouth	ECY-Bar	3-Jul-2003	19-Oct-2003	Historical Continuous
01K050	Maple Creek at mouth	ECY-Maple	15-Oct-2003	3-Nov-2008	Historical Continuous
01R090	California Creek at Valley View Road	ECY-Calif	7-Apr-2005 8-Nov-2007	23-Oct-2007 30-Sep-2009	Historical Manual Stage Stand-alone
01Q070	Dakota Creek at Giles Road	ECY-Dak	1-May-2003 7-Nov-2007	1-Nov-2007 30-Sep-2009	Historical Manual Stage Stand-alone
01G100	Middle Fork Nooksack River above Clearwater Creek	ECY-MFN	13-Jun-2003 10-Oct-2006	9-Oct-2006 30-Sep-2009	Historical Stand-alone Historical Manual Stage
01L050	Anderson Creek at mouth	ECY-And	15-May-2003	30-Sep-2009	Historical Manual Stage
01M090	Kamm Slough at Northwood Road	ECY-Kamm	1-May-2003	30-Sep-2009	Historical Manual Stage
01S070	Squalicum Creek at West Street	ECY-Squa	23-Apr-2003	30-Sep-2009	Historical Manual Stage
01D100	Sumas River at Telegraph Road	ECY-Sumas	24-Apr-2003	30-Sep-2009	Historical Manual Stage

Table 2. USGS active flow monitoring stations in WRIA 1.

Site Number	Site Name	Site Code	Start Date	Type
12205000	North Fork Nooksack River below Cascade Creek near Glacier	USGS-NFN	1-Oct-1937	Real-time
12206900	Racehorse Creek at North Fork Road near Kendall	USGS-Race	1-Oct-1998	Stand-alone[1]
12207750	Warm Creek near Welcome	USGS-Warm	1-Oct-1998	Stand-alone[2]
12207850	Clearwater Creek near Welcome	USGS-Clear	1-Oct-1998	Stand-alone[1]
12208000	Middle Fork Nooksack River near Deming	USGS-MFN	28-Aug-1920	Real-time
12209490	Skookum Creek above diversion near Wickersham	USGS-Skook	1-Oct-1998	Stand-alone[3]
12210000	South Fork Nooksack River at Saxon Bridge	USGS-Skook	1-Oct-2008	Real-time
12210700	Nooksack River at North Cedarville	USGS-NNCV	15-Oct-2004	Real-time
12210900	Anderson Creek at Smith Road near Goshen	USGS-And	1-Oct-1998	Stand-alone[3]
12212050	Fishtrap Creek at Front Street at Lynden	USGS-Fish	1-Oct-1998	Stand-alone[3]
12212390	Bertrand Creek at International Boundary	USGS-Bert	5-May-2007	Stand-alone
12212430	Unnamed tributary to Bertrand Creek near H Street near Lynden (Jackman Ditch)	USGS-Jack	6-Jan-2007	Real-time
12213100	Nooksack River at Ferndale	USGS-NFern	1-Oct-1966	Real-time

[1]Funded by Nooksack Tribe.
[2]Discontinued in 2009.
[3]Funded by Lummi Tribe.

Flow Modeling

TOPNET Model

As described above, USU developed and calibrated a hydrologic model for WRIA 1. USU (Tarboton, 2007) describes the TOPNET model as follows:

TOPNET is a distributed hydrologic model with basic model elements being topographically delineated drainages that discharge into the stream network that is then used to route flow to the outlet. Within each drainage, an enhanced version of the TOPMODEL rainfall runoff model is used to compute runoff from precipitation and other weather inputs. The enhanced TOPNET includes additional processes such as irrigation, artificial drainage, and impervious areas, as well as enhanced snowmelt and evaporation calculations, and provides a means for integrated simulation of water management, including demand estimation, in-stream flow requirements, and users with differing rights to take water when it is scarce.

The TOPNET model has 337 nodes where flows are simulated. Many of these nodes were designed to correspond to gaging stations and regulatory control stations. A total of 177 subdrainages were included in the model. The model was calibrated to 4 multi-year periods from 1947 through 2001. Model validation looked at 3 other one-year time periods.

Calibration was most successful for the gages on the mainstem and North Fork. Calibration results for several of the tributaries (Fishtrap, Tenmile, and Dakota Creeks) were reported as satisfactory, while the model had difficulty reproducing hydrologic characteristics for other tributaries (Sumas River; Skookum, Smith, and Olsen Creeks). The model performed poorly for Kendall, Coal, and Racehorse Creeks.

For the analysis in this study, Christina Bandaragoda of Silver Tip Solutions provided Ecology with a version of the TOPNET model that had been extended to simulate daily flows from October 1959 through December 2005 (Bandaragoda, 2009).

USGS Station Analysis

The Lummi Nation requested that USGS conduct an analysis of the 6 flow measurement stations they were supporting. The resulting study (Curran and Olsen, 2009) analyzed the low-flow statistics for the 6 stations to “determine if any of the gaging stations could be removed from the network without significant loss of information.” Methods used included “hydrograph comparison, daily-value correlation, variable space, and flow-duration ratios, and other factors relating to individual subbasins”.

The study also “considered the value of individual stream gages to future regional regression models, which benefit from variability in basin characteristics. Regional regressions are used to estimate streamflow at ungaged sites based on basin characteristics and don’t consider streamflow correlation.” (Curran, 2010)

Based on this analysis, the 6 stations were prioritized from most to least important:

1. Skookum Creek (12209490)
2. Anderson Creek (12210900)
3. Warm Creek (12207750)
4. Fishtrap Creek (12212050)
5. Racehorse Creek (12206900)
6. Clearwater Creek (12207850)

The USGS determined that the optimum network would include the first 5 stations, while the minimum network would consist of the first 2.

Regulatory Control Stations

In December 1985, Ecology set minimum instream flows under the Nooksack Instream Resources Protection Program (IRPP) for WRIA 1 (Ecology, 1985). Flows at specified *control stations* in each designated stream are senior in right to any water rights established after the date of the rule implementing the IRPP (Chapter 173-501 WAC). Therefore, the rule requires the users of rights junior to the instream flows to reduce or cease withdrawals if streamflow fell below the minimum instream flow at a control station. For that reason, the ability to measure or predict flows at control stations has an important regulatory purpose.

Regulatory flow control stations established by the IRPP rule are shown in Table 3. The USGS ID numbers refer to historical flow monitoring stations, but the Ecology ID numbers are informational only. The periods of record for the USGS gages are shown in Table 3.

Review of the control station locations specified in the rule revealed that the locations of several of the stations are ambiguous or contradictory. After research into the history of the rule-making and discussions among staff, uncertainty about control station locations was resolved. A memo describing that analysis and its conclusions can be found in Appendix B, and the locations are shown in Figure 3.

Table 3. Ecology control stations from WAC 173-501-030.

Stream Management Unit Name	Agency	ID	River Mile	Town-ship	Range	Section	Stream Management Reach
Anderson Creek	Ecology	2109-00	1.4	39 N.	4 E.	19	From confluence with Nooksack River to headwaters, including all tributaries.
Bells Creek	Ecology	2073-00	0.5	39 N.	5 E.	21	From confluence with Nooksack River to headwaters, including all tributaries.
Bertrand Creek	Ecology	2124-00	1	40 N.	2 E.	26	From U.S./Canada border to confluence with Nooksack River, including all tributaries.
California Creek	Ecology	2134-00	3	40 N.	1 E.	21	From influence of mean annual high tide at low instream flow levels to headwaters, including all tributaries.
Canyon Creek	Ecology	2045-00	0.2	40 N.	6 E.	35	From confluence with North Fork Nooksack River to headwaters, including all tributaries.
Cornell Creek	Ecology	2057-00	0.6	39 N.	6 E.	1	From the confluence with North Fork Nooksack River to headwaters, including all tributaries.
Deer Creek	Ecology	2130-50	0.2	39 N.	2 E.	28	From the confluence with Tenmile Creek to headwaters, including all tributaries.
Gallop Creek	Ecology	2056-00	0.3	39 N.	7 E.	6	From the confluence with North Fork Nooksack River to headwaters, including all tributaries.
Hutchinson Creek	Ecology	2101-00	1.8	38 N.	5 E.	36	From confluence with South Fork Nooksack River to headwaters, including all tributaries.
Johnson Creek	Ecology	2149-00	0.5	41 N.	4 E.	35	From U.S./Canada border to headwaters including all tributaries.
Maple Creek	Ecology	2059-00	0.8	40 N.	6 E.	30	From confluence with North Fork Nooksack River to headwaters, including all tributaries.
Porter Creek	Ecology	2084-00	0.7	38 N.	5 E.	11	From the confluence with Middle Fork Nooksack R. to headwaters, including all tributaries.
Racehorse Creek	Ecology	2071-00	1.5	39 N.	5 E.	11	From confluence with North Fork Nooksack River to headwaters, including all tributaries.
Silver Creek	Ecology	2132-00	2	38 N.	2 E.	4	From confluence with Nooksack River to headwaters, including all tributaries.
Smith Creek	Ecology	2111-00	0.8	39 N.	4 E.	22	From confluence with Nooksack River to headwaters, including all tributaries.
Terrell Creek	Ecology	2133-00	2.2	40 N.	1 E.	31	From influence of mean annual high tide at low instream flow levels to headwaters, including all tributaries.
Wiser Lake Creek	Ecology	2126-00	0.7	39 N.	2 E.	3	From confluence with Nooksack River to headwaters, including all tributaries.

Table 3, continued. Ecology control stations from WAC 173-501-030.

Stream Management Unit Name	Agency	ID	Period of Record	River Mile	Town-ship	Range	Section	Stream Management Reach
Canyon Creek at Kulshan	USGS	12-2085-00	7-1948 to 9-1954	0.2	39 N.	5 E.	27	From confluence with North Fork Nooksack River to headwaters, including all tributaries.
Dakota Creek near Blaine	USGS	12-2140-00	7-1948 to 10-1954	3.5	40 N.	1 E.	9	From influence of mean annual high tide at low instream flow levels to headwaters, including all tributaries.
Fishtrap Creek at Lynden	USGS	12-2120-00	7-1948 to 10-1971	6.9	40 N.	3 E.	16	From U.S./Canada border to confluence with Nooksack River, including all tributaries.
Kendall Creek	USGS	12-2065-00	8-1955 to 8-1981 (n=15)	0.1	39 N.	5 E.	3	From the confluence with North Fork Nooksack River to headwaters, including all tributaries.
Nooksack River (at Deming)	USGS	12-2105-00	7-1935 to 9-2005	36.6	39 N.	5 E.	31	From confluence with Smith Creek to confluence of North Fork and Middle Fork Nooksack Rivers.
Nooksack River (at Ferndale)	USGS	12-2131-00	10-1966 to present	5.8	39 N.	2 E.	29	From influence of mean annual high tide at low instream flow levels to confluence with, and including, Smith Creek.
Nooksack River (Middle Fork)	USGS	12-2080-00	8-1920 to present	5	38 N.	5 E.	13	From confluence with North Fork to headwaters.
Nooksack River (North Fork)	USGS	12-2072-00	9-1964 to 12-1975	44.1	39 N.	5 E.	15	From confluence with Middle Fork to head-waters.
Nooksack River (South Fork)	USGS	12-2090-00	5-1934 to 9/2008	5	38 N.	5 E.	19	From confluence with Nooksack River (mainstem) to headwaters.
Saar Creek	USGS	12-2155-00	11-1954 to 8-1959 (n=8)	0.2	41 N.	5 E.	31	From U.S./Canada border to headwaters, including all tributaries.
Skookum Creek near Wickersham	USGS	12-2095-00	7-1948 to 9-1969	0.1	37 N.	5 E.	27	From confluence with South Fork Nooksack River to headwaters, including all tributaries.
Sumas River near Sumas	USGS	12-2145-00	7-1948 to 9-1955	2.1	41 N.	4 E.	2	From U.S./Canada border to headwaters including all tributaries.
Tenmile Creek at Laurel	USGS	12-2129-00	5-1968 to 9-1972	4.4	39 N.	2 E.	13	From confluence with Nooksack River to headwaters, including all tributaries.

Study Goals and Objectives

The study Quality Assurance Project Plan (Pickett, 2009) defined the goals and objectives of this study.

The goals of this project are to:

1. Develop modeling tools that can determine flows in WRIA 1 for Ecology flow monitoring sites and regulatory control stations.
2. Determine the quality of the modeling tools.
3. Assess their ability to support Ecology and the WRIA 1 Planning Group in their water management activities in the basin.
4. Identify data gaps in flow measurement or modeling.
5. Support Ecology in making decisions about use of its flow gaging resources statewide.

To meet this goal, this project has the following objectives:

1. Develop statistical and simple hydrologic models that can predict flows at Ecology flow monitoring stations in WRIA 1 based on relationships with long-term USGS flow stations or other Ecology flow stations.
2. Evaluate whether sufficient flow information is available to develop simple modeling tools that predict flows at regulatory control stations and develop models for those stations.
3. Evaluate the USU TOPNET hydrologic model for WRIA 1 and determine whether it can be applied to predict flows at Ecology flow monitoring stations and regulatory control stations at a level of effort within the schedule designated for this project, and if so, develop those applications.
4. Assess the quality of the results of the modeling tools developed for Objectives 1 through 3.
5. Provide support in determining a long-term approach to flow discharge assessment that combines direct monitoring of gage height with modeling approaches, thus reducing the total number of flow monitoring stations using continuous stream gage measurements.
6. 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.
7. Recommend any flow measurement needs to allow flows to be estimated or measured for regulatory control points.
8. Provide training and technology transfer of project products to Ecology staff and local partners.

The study scope was changed slightly after publication of the QA Project Plan. The objectives above also apply to the two USGS flow monitoring stations on the mainstem Nooksack River at North Cedarville and at Ferndale. These two stations were added to the analysis because Ecology contributes to the funding of these stations.

Methods

Data Sources and Characteristics

Flow Data

Daily average flow data were compiled for 13 Ecology stations. (Bar Creek was not included because of its short record.) Flows at Ecology stations available in December 2009 were analyzed from the beginning of the data set through September 2009. Flow data were withheld from the analysis when derived using interpolations or correlations, or where the continuous record followed a straight line interpolation that did not correlate to other stations[1].

Daily average flow data for 11 active and 12 historical USGS flow stations were used in the analysis. Data for these stations was obtained from the USGS National Water Information System website (http://waterdata.usgs.gov/wa/nwis/sw).

The 12 historical stations used are:

- 12211000 Anderson Creek near Goshen.
- 12213500 California Creek near Custer.
- 12208500 Canyon Creek at Kulshan.
- 12212000 Fishtrap Creek at Lynden.
- 12215000 Johnson Creek at Sumas.
- 12206500 Kendall Creek at mouth, at Kendall.
- 12207200 North Fork Nooksack River near Deming.
- 12210500 Nooksack River at Deming, WA.
- 12215500 Saar Creek near Sumas.
- 12209500 Skookum Creek near Wickersham.
- 12209000 South Fork Nooksack River near Wickersham.
- 12212900 Tenmile Creek near Laurel.

Two stations from Table 2 were *not* used because they did not generate useful regressions to the stations of interest:

- 12212430 Unnamed tributary to Bertrand Creek near H Street near Lynden.
- 12207750 Warm Creek near Welcome (discontinued in 2009).

Some of the Ecology and USGS flow data have been labeled as *provisional*, meaning that final data quality checks had not been completed. Both 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

[1] Bertrand Creek near mouth (01N060): 8/28/2004 to 9/10/2004 and 4/28/2008 to 6/8/2008; Maple Creek @ mouth (01K050) from 7/21/2004 to 8/20/2004.

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 September 2009.

Figures 4 through 16 show the streamflows for each of the Ecology stations as compared to flows from other selected gaging stations. Figure 17 shows flows at the two mainstem Nooksack River USGS 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 elevations. Notable characteristics of the flow patterns are:

- Low-lying tributaries are dominated by rainfall events, with peak flows in late fall and winter.
- Spring freshet (snowmelt) flows cause high flows during late spring and early summer in the Nooksack River mainstem and forks and in the higher elevation tributaries.
- Dry-season baseflow conditions (low flows absent a stormwater runoff component) typically occur in August and September but can extend well into the fall (sometimes as late as mid-November).
    - Low-elevation tributaries show variability in flow during the summer (including zero flows) that is likely the result of agricultural withdrawals.
    - The Nooksack Middle and North Forks show increases in flow during the summer associated with periods of high air temperatures caused by glacial melt on Mount Baker.
- Winter baseflow can also occur in the higher elevation tributaries and are associated with periods of cold air temperatures.

Meteorological Data

Precipitation and air temperature data were reviewed to support the hydrologic analyses in these studies. This included both the determination of baseflow conditions and application of the TOPNET model.

Table 4 shows the meteorological stations used for this study. For each station a note is provided to show if it was used for the input data set to the WRIA 1 TOPNET model. The “End Date” column indicates whether data are available in real time from the web, if data are historical only, or if data are available with a lag time of several months between collection and posting (with an end date of “2009-06-30” in this table).

Areal Flows

To get a better understanding of the hydrologic response of the system to precipitation and snowmelt, flows were standardized to *areal flows* 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.

Table 4. Meteorological stations used in this study.

Station ID	Latitude	Longitude	Elevation (meters)	Station Name (as published)	Short ID	Source[1]	Used in TOPNET?	Start Date	End Date
2131	48.85	-121.78	1280	Wells Creek	WelST	SNOTEL	yes	1995-10-01	present
2132	48.68	-121.9	976	Elbow Lake	ElbST	SNOTEL	yes	1995-10-01	present
2101	48.87	-121.25	1106.4	Beaver Pass	BeavST	SNOTEL	no	2001-10-05	present
2136	48.82	-121.92	1514.9	MF Nooksack	MFNST	SNOTEL	no	2002-10-10	present
71108	49.03	-122.37	58	Abbotsford Airport (CYXX)	AbbAP	CANADA	yes	1944-10-01	present
330024	48.88	-122.32	45.1	Lawrence	LawAWS	AWN	no	2008-04-28	present
330025	48.86	-122.47	21.6	Ten Mile	TenAWS	AWN	no	2008-04-04	present
340061	48.97	-122.31	25.0	Nooksack	NooAWS	AWN	no	2002-05-14	present
340063	48.94	-122.51	20.7	Lynden	LynAWS	AWN	no	2002-05-15	present
330101	48.44	-122.39	7.0	WSU Mt Vernon	MtVAWS	AWN	no	1993-11-01	present
330159	48.50	-122.38	8.5	Sakuma	SakAWS	AWN	no	2006-06-29	present
450574	48.8	-122.53	45.4	Bellingham Airport (KBLI)	BelAP	NWS	yes	1949-01-01	present
450176	48.52	-122.62	6	Anacortes	Anaco	NCDC	yes	1931-01-01	2009-06-30
450564	48.78	-122.48	43	Bellingham 2 N	Bel2N	NCDC	yes	1931-01-01	1985-04-30
450566	48.73	-122.47	91.4	Bellingham KVOS	KVOS	NCDC	yes	1998-04-01	2006-12-31
450587	48.72	-122.52	4.6	Bellingham 3 SSW	Bel3S	NCDC	yes	1985-08-01	2009-06-30
450729	49	-122.75	18.3	Blaine	Blaine	NCDC	yes	1931-01-01	2009-06-30
451484	48.97	-122.33	19.5	Clearbrook	Clrbk	NCDC	yes	1931-01-02	2009-06-30
451679	48.53	-121.75	59.4	Concrete PPL Fish Stn	Concr	NCDC	yes	1931-01-01	2009-06-30
452157	48.72	-121.13	271.6	Diablo Dam	DiabDm	NCDC	yes	1931-01-01	2009-06-30
453160	48.88	-121.93	285	Glacier RS	GlacRS	NCDC	yes	1934-07-01	1983-07-31
455663	48.87	-121.67	1266.1	Mount Baker Lodge	MtBL	NCDC	yes	1931-01-01	1952-12-31
455678	48.43	-122.38	4.3	Mount Vernon 3 WNW	MtV3N	NCDC	yes	1956-01-01	2005-01-31
455840	48.68	-121.25	160	Newhalem	Newha	NCDC	yes	1959-01-01	2009-06-30
457185	48.73	-121.07	376.7	Ross Dam	RosDm	NCDC	yes	1960-09-01	2009-06-30
457507	48.5	-122.23	18.3	Sedro Woolley	SedWo	NCDC	yes	1931-01-02	2009-06-30
458715	48.65	-121.7	210	Upper Baker Dam	UpBDm	NCDC	yes	1965-10-01	2009-06-30

[1] SNOTEL = Snowpack Telemetry system, U.S. Department of Agriculture.
CANADA = Meteorological Service of Canada.
AWN = Washington Agricultural Weather Network.
NWS = National Weather Service.
NCDC = National Climatic Data Center (Cooperative station).

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

1. Wells Creek SNOTEL station (www.wcc.nrcs.usda.gov/snotel/snotel.pl?sitenum=909&state=wa).
2. Bellingham Airport National Weather Service (www.wunderground.com/history/airport/KBLI/2009/9/24/CustomHistory.html)

Areal flows from the Ecology telemetry and stand-alone stations are shown in Figures 18 through 26, and for the mainstem Nooksack River USGS stations in Figures 27 and 28. Precipitation data from Bellingham Airport are shown for low-elevation stations. For high-elevation tributaries, non-snow precipitation, snowmelt data, and average daily air temperature are shown from the Wells Creek 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 in Figures 18 through 28 are of interest:

- Areal flow values vary widely between the stations, with peak flow values in the lower elevation tributaries less than 1 inch per day, while maximum values in the Nooksack River forks reach almost 4 inches per day. These differences likely reflect:
  - The increase in precipitation at higher elevations.
  - The influence of glacial and snowmelt from the higher elevations.
  - Groundwater infiltration in the lower elevations.
- Hutchinson Creek (Figure 22) shows hydrologic characteristics that are a mixture of a lowland rainfall-dominated stream and a higher elevation stream with a spring freshet. The period of flows produced by snowmelt is short in duration and ends early in the spring, which is typical of a watershed of moderate elevation.
- Maple Creek (Figure 23), although it is located in the Cascade foothills and is topographically similar to Hutchinson Creek, is hydrologically more like a low-elevation creek. This may be because of the local geology and effect of Silver Lake.
- Short-term spikes in flow can be seen from some significant rain events. However, the relationship in flow to precipitation varies widely, reflecting the relative differences in the locations of the precipitation event itself and of the meteorological and flow stations, as well as differences in local surficial geology and antecedent soil saturation.

Regressions and Other Analysis Methods

Flow Regressions for Flow Monitoring Stations

Flow data were first evaluated by comparing daily average flows from each station of interest (13 Ecology gages and 2 USGS mainstem gages) with flows from several USGS and Ecology reference stations using power regressions. A power regression takes the form of $y=cx^b$, where the coefficient c and the exponent b are determined by the regression between paired values of x and y. A power regression is arithmetically identical to the linear regression of two log-transformed data sets.

Reference stations were selected to be analyzed that were most similar geographically, topographically, and hydrologically. In general this resulted in the grouping of stations into:

- Nooksack River mainstem and forks.
- Lowland tributaries (tributaries of the mainstem Nooksack River and Sumas River).
- Higher elevation tributaries (tributaries to the Nooksack River forks).

As reference stations for most Ecology gaging stations, the two USGS stations with the best fit and the Ecology station with the best fit were selected for further analysis. In a few cases, only USGS gages were selected for regressions.

In two cases, a synthetic hydrograph was developed by combining multiple stations:

- An estimate for flow at the USGS station “Nooksack River at North Cedarville” was obtained by adding data from the USGS stations on the three forks.
- An estimate for flow at the Ecology station “Nooksack River above the Middle Fork” was obtained by subtracting data from USGS stations on the Middle and South Forks from data from the USGS “Nooksack River near North Cedarville” station.

Two USGS stations were moved recently so stations in two different locations were combined to obtain a longer time series for regressions:

- In October 2008, USGS moved its South Fork Nooksack station from “Nooksack River near Wickersham” to “South Fork Nooksack River at Saxon Bridge”. Since the old station had data for almost 70 years, but the new station only had about a year of data, data from the two stations were combined. Data from the Wickersham station was added to flows from the USGS Skookum Creek station before being combined with the other data set. This adjustment was found to improve regressions using combined data from this station.
- Data from the USGS station “Nooksack River at North Cedarville” was combined with data from the historical USGS station “Nooksack River at Deming, WA”. There is a difference in watershed areas between these stations of less than 1%, so data were combined without adjustment.

Where the times 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 1 or 2 days. For all pairs of stations evaluated, peak flows occurred most often on the same date. This result is consistent with Parker (1974) who found travel times of 16 hours or less in the Nooksack River between Everson and the mouth (a distance of about 24 river miles). Based on this analysis, time-lagging of data was not used in this study.

Flow data were then evaluated to determine whether a hydrograph separation technique would improve the relationship. Hydrologic baseflows are the groundwater inflow component of a stream hydrograph. In reality, baseflows vary 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.

The baseflow threshold at each study gage (the station being modeled) 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.

For the 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.) This threshold value was then used to stratify the reference gage flows into baseflows and non-baseflows. Regressions then were developed separately for the stratified data sets.

Flows were also stratified seasonally and regressions developed for each stratified data set. If regressions based on seasonal stratification improved the quality of the overall regression model, then they were used in the final model. Otherwise only the annual baseflow and non-baseflow stratified data sets were used.

As a result of this approach, for most of the continuous gages and for staff gages (10 stations), flows were divided into two categories for this analysis.

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

Data from four stations were segregated into four categories. These were the two mainstem stations and the North and Middle Fork Nooksack River stations.

- **Summer baseflows –** less than the baseflow threshold occurring from July through October.
- **Winter baseflows –** less than the baseflow threshold occurring from November through June.
- **Winter non-baseflows –** greater than the baseflow threshold occurring from November through June.

- **Summer non-baseflows –** greater than the baseflow threshold occurring from July through October.

For one station (Hutchinson Creek) data were segregated into three categories:

- **Baseflows –** less than the baseflow threshold occurring from July through October.
- **Winter flows –** flows occurring from November through June.
- **Summer non-baseflows –** greater than the baseflow threshold occurring from July through October.

TOPNET Model Analysis for Flow Monitoring Stations

The WRIA 1 TOPNET model was run to generate daily flows from October 1959 through December 2005. The results were compared to measured and estimated flow data from Ecology and USGS flow gaging stations and regulatory control stations, and the relative quality of the TOPNET model results were determined.

The WRIA 1 TOPNET model was evaluated to determine whether it could be adapted for real-time flow estimates. The calibrated model was run and then two modifications of the model were explored:

- Shortening the run time by running a shorter time series. The model starting date was moved to 1989 and to 1994, and the final four years of the simulation were compared to the calibrated model. The goal was to find the shortest version of the model that would produce equivalent results for the most recent dates.
- Running the model with meteorological data available in real-time. The calibrated model uses meteorological data that are not available in real-time. A real-time simulation would need to obtain real-time meteorological data, so methods were explored to replace data from one station with data from other stations. The most promising are:
  - Multivariate linear regressions.
  - The method developed by Thornton et al. (1997) and used for DAYMET simulations (www.daymet.org/).

The TOPNET model was designed to have nodes at control stations and most historical and active flow monitoring stations. Therefore model flow results can be obtained for those locations.

Analysis of Regulatory Control Stations

A multi-tiered approach was employed to evaluate potential tools to determine flows at control stations.

- Some control stations are the site of an active flow gage. If the ratio between watershed areas of the control station and a flow gaging station are between 0.95 and 1.05, the stations are considered to be equivalent.

- If a control station is on the same stream as an active flow gage but not in the same location, flow at the control station was estimated from the flow gate using the ratio between the watershed areas above the control and flow gaging stations.

  This simple approach assumes that flow increases in the downstream direction in proportion to the watershed area, and does not take any other gains or losses into account.

- Where control stations have on-site historical gage flow data that overlap data from a nearby active flow gaging station, regressions were developed between the two stations.

- Flow for control stations with no measured flows were estimated from the ratio of watershed areas between the control station and an active flow gaging station from the watershed most geographically and topographically similar.

  This is a crude method that likely provides results with high variability. However, in the absence of direct flow measurements or other data to support a more complex analysis, this is the best method available.

The measured or estimated flows from the control stations using these methods were then compared to the TOPNET model results for the control station locations.

Quality Analysis

As described in the project plan (Pickett, 2009), 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 predicted and observed pairs individually and using the median of RPD values for all pairs of results.

$$RPD = (|P_i - O_i| * 2) / (O_i + P_i), \text{ where}$$
$$P_i = i^{th} \text{ prediction}$$
$$O_i = i^{th} \text{ observation}$$

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.

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

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	Median RPD	Description
Less than 5%	Between ± 5%	Very Good
Between 5% and 15%	Between ± 10% for all flows; Between ± 20% for baseflows	Good
	Does not meet criteria above	Poor

The relative quality of the TOPNET model results was assessed using the %RSD between paired daily average model output flows and measured or estimated flows at gaging or control stations.

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Results

Flow Gaging Stations

Table 5 presents the results of the regression modeling analysis. For each study gage, a regression from a primary reference station is presented, and for most study gages, another regression based on a secondary reference station is also offered. Several regression options are presented because of the possibility that some of the gages could be discontinued.

For each regression, 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 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.

Table 6 shows the quality of each regression. Goodness of fit is indicated by the median %RSD values for all flows and for the baseflows (or summer baseflows for 3- or 4-way separation).

Overall the primary regressions had good fits for the USGS mainstem stations and for the Ecology stations on the three forks, with %RSD values below 15% for both baseflows and all flows.

- Several Ecology stations had good fits (15% or less) for all flows but poor fits (greater than 15%) for baseflows: Bertrand Creek and Sumas River.
- Several Ecology stations had good fits for baseflows but poor fits for all flows: Hutchinson, Dakota, and Squalicum Creeks; and Kamm Slough.
- The other Ecology stations had poor fits for both baseflows and all flows: Tenmile, Maple, California, and Anderson Creeks.
- California and Dakota Creeks have good fits to each other.

Figures 29 through 43 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:

- A small difference in very low flows can produce an RPD 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.

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[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 5. Regressions for study gages using hydrograph separation method.

Station ID	Station Name	Reference Station Code	Baseflow Threshold (cfs)	Hydrograph Separation Unit	Coefficient	Exponent	r^2	n
Ecology Real-time Gages								
01N060	Bertrand Creek near mouth	USGS-Bert (Primary)	1.8	Baseflow[1] Non-baseflow[2]	6.602 6.106	0.395 0.737	0.08 0.89	190 680
		USGS-Fish (Secondary)	14.6	Baseflow Non-baseflow	0.844 0.476	0.878 1.143	0.29 0.83	563 1669
01C070	Hutchinson Creek near Acme	USGS-Skook (Primary)	45.0	Summer baseflow[3] Winter flows[4] Summer non-baseflow[5]	0.700 2.311 0.575	0.665 0.616 0.753	0.54 0.35 0.65	463 1442 367
		USGS-Race (Secondary)	9.0	Baseflow Non-baseflow	5.149 3.517	0.209 0.617	0.08 0.44	488 1784
01C070	Tenmile Creek above Barrett Lake	USGS-Fish (Primary)	16.0	Baseflow Non-baseflow	1.224 0.677	0.677 0.886	0.34 0.74	611 1681
		ECY-Bert (Secondary)	8.3	Baseflow Non-baseflow	2.221 1.299	0.500 0.750	0.34 0.79	477 1759
01A140	Nooksack River above the Middle Fork	USGS-NFN (Primary)	732	Summer baseflow Winter baseflow[6] Winter non-baseflow[7] Summer non-baseflow	1.915 11.578 27.824 8.779	0.992 0.782 0.638 0.775	0.77 0.55 0.62 0.78	444 368 873 564
		USGS-NNCV (Primary)	2410	Summer baseflow Winter baseflow Winter non-baseflow Summer non-baseflow	0.575 94.112 2.609 9.507	1.018 0.307 0.792 0.660	0.71 0.02 0.60 0.67	547 265 349 1088
01F070	South Fork Nooksack River at Potter Road	USGS-SFN (Primary)	256	Baseflow Non-baseflow	0.756 1.280	1.064 0.987	0.91 0.93	466 1825
01K050	Maple Creek at mouth	USGS-Fish (Primary)	11.4	Baseflow Non-baseflow	0.123 1.103	1.473 0.770	0.19 0.53	306 1497
		ECY-Hutch (Secondary)	12.0	Baseflow Non-baseflow	0.019 0.886	2.636 0.922	0.43 0.55	422 1371
Mixed Stand-alone and Manual Staff Gages								
01R090	California Creek at Valley View Road	USGS-And (Primary)	1.0	Baseflow Non-baseflow	2.454 2.223	0.262 0.738	0.19 0.74	165 558
		ECY-Dak (Secondary)	4.7	Baseflow Non-baseflow	0.685 0.428	0.650 1.032	0.12 0.88	175 494

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

Station ID	Station Name	Reference Station Code	Baseflow Threshold (cfs)	Hydrograph Separation Unit	Coefficient	Exponent	r^2	n
01Q070	Dakota Creek at Giles Road	USGS-Bert (Primary)	2.2	Baseflow Non-baseflow	3.198 1.952	0.560 0.837	0.24 0.80	152 427
		ECY-Calif (Secondary)	2.2	Baseflow Non-baseflow	3.529 1.767	0.352 1.027	0.25 0.88	160 509
01G100	Middle Fork Nooksack River above Clearwater Creek	USGS-MFN (Primary)	370	Summer baseflow Winter baseflow Winter non-baseflow Summer non-baseflow	1.901 4.215 1.741 3.386	0.857 0.679 0.839 0.762	0.30 0.34 0.79 0.75	63 349 98 247
Manual Staff Gages								
01L050	Anderson Creek at mouth	USGS-And ECY-Bert	(Primary) (Secondary)	All flows All flows	1.791 0.130	0.902 1.179	0.86 0.76	215 192
01M090	Kamm Slough at Northwood Road	USGS-Bert ECY-Bert	(Primary) (Secondary)	All flows All flows	1.023 1.512	0.488 0.411	0.61 0.63	60 138
01S070	Squalicum Creek at West Street	COB-Squal USGS-Bert	(Primary) (Secondary)	All flows All flows	0.659 0.738	1.081 1.054	0.94 0.89	105 56
01D100	Sumas River @ Telegraph Road	USGS-Fish ECY-Ten	(Primary) (Secondary)	All flows All flows	2.447 3.667	0.753 0.815	0.79 0.79	210 216
USGS Real-time Gages								
12210700	Nooksack River at North Cedarville	USGS-NFern (Primary)	2100	Summer baseflow Winter baseflow Winter non-baseflow Summer non-baseflow	0.960 2.460 1.005 1.158	1.002 0.865 0.982 0.976	0.82 0.69 0.90 0.89	2787 2410 1143 9235
12213100	Nooksack River at Ferndale	USGS-NNCV (Primary)	2050	Summer baseflow Winter baseflow Winter non-baseflow Summer non-baseflow	1.984 0.796 1.800 1.306	0.911 1.056 0.945 0.970	0.83 0.73 0.89 0.87	2869 2420 1847 8560

[1] Below threshold; year-round.
[2] Above threshold; year-round.
[3] Below threshold; July through October.
[4] All flows November through June.
[5] Above threshold; July through October.
[6] Below threshold; November through June.
[7] Above threshold; November through June.

Table 6. Model quality results (regression and TOPNET) as median %RSD for study gaging stations.

Station ID	Station Name	Reference Station Code	Hydrograph Separation Unit	Precision: median %RSD						Bias: median RPD	Descrip-tion
				5 - 10%	10 - 15%	15 - 20%	20 - 30%	30 - 40%	>40%		
Ecology Real-time Gages											
01N060	Bertrand Creek near mouth	USGS-Bert	Summer baseflow All flows		 X	X 				10-20% ±10%	Poor Good
01N060	Bertrand Creek near mouth	USGS-Fish	Summer baseflow All flows			 X	X 			>20% ±10%	Poor Poor
01N060	Bertrand Creek near mouth	TOPNET	All flows					X			
01C070	Hutchinson Creek near Acme	USGS-Skook	Summer baseflow All flows	X 			 X			±10% ±10%	Good Poor
01C070	Hutchinson Creek near Acme	USGS-Race	Summer baseflow All flows		X 		 X			10-20% ±10%	Good Poor
01C070	Hutchinson Creek near Acme	TOPNET	All flows					X			Poor
01C070	Tenmile Creek above Barrett Lake	USGS-Fish	Summer baseflow All flows			 X	X 			10-20% ±10%	Poor Poor
01C070	Tenmile Creek above Barrett Lake	ECY-Bert	Summer baseflow All flows			X X				10-20% ±10%	Poor Poor
01C070	Tenmile Creek above Barrett Lake	TOPNET	All flows					X			Poor
01A140	Nooksack River above the Middle Fork	USGS-NFN	Summer baseflow All flows		X X					±10% ±10%	Good Good
01A140	Nooksack River above the Middle Fork	USGS-NNCV	Summer baseflow All flows		X X					±10% ±10%	Good Good
01A140	Nooksack River above the Middle Fork	TOPNET	All flows			X					Poor
01F070	South Fork Nooksack River at Potter Road	USGS-SFN	Summer baseflow All flows	X X						±10% ±10%	Good Good
01F070	South Fork Nooksack River at Potter Road	TOPNET	All flows		X						Good
01K050	Maple Creek at mouth	USGS-Fish	Summer baseflow All flows				 X		X 	>20% ±10%	Poor Poor
01K050	Maple Creek at mouth	ECY-Hutch	Summer baseflow All flows				 X	X 		>20% ±10%	Poor Poor
01K050	Maple Creek at mouth	TOPNET	All flows						X		Poor
Mixed Stand-alone and Manual Staff Gages											
01R090	California Creek at Valley View Road	USGS-And	Summer baseflow All flows				X X			>20% ±10%	Poor Poor

Table 6, continued. Model quality results (regression and TOPNET) as median %RSD for study gaging stations.

Station ID	Station Name	Reference Station Code	Hydrograph Separation Unit	Precision (%RSD) 5 - 10%	10 - 15%	15 - 20%	20 - 30%	30 - 40%	>40%	Bias - median RPD	Descrip-tion
01R090	California Creek at Valley View Road	ECY-Dak	Summer baseflow All flows		X X					10-20% ±10%	Good Good
01R090	California Creek at Valley View Road	TOPNET	All flows						X		Poor
01Q070	Dakota Creek at Giles Road	USGS-Bert	Summer baseflow All flows		X	 X				±10% ±10%	Good
01Q070	Dakota Creek at Giles Road	ECY-Calif	Summer baseflow All flows		X X					±10% ±10%	Good Good
01Q070	Dakota Creek at Giles Road	TOPNET	All flows					X			Poor
01G100	Middle Fork Nooksack River above Clearwater Creek	USGS-MFN	Summer baseflow All flows	X	 X					±10% ±10%	Good Good
01G100	Middle Fork Nooksack River above Clearwater Creek	TOPNET	All flows		X						Good
Manual Staff Gages											
01L050	Anderson Creek at mouth	USGS-And ECY-Bert	All flows All flows			X	 X			±10% ±10%	Poor Poor
01L050	Anderson Creek at mouth	TOPNET	All flows						X		
01M090	Kamm Slough at Northwood Road	USGS-Bert ECY-Bert	All flows All flows	X		 X				±10% ±10%	Good Poor
01M090	Kamm Slough at Northwood Road	TOPNET	All flows						X		
01S070	Squalicum Creek at West Street	COB-Squal USGS-Bert	All flows All flows		X	 X				±10% ±10%	Good Poor
01S070	Squalicum Creek at West Street	TOPNET	All flows						X		
01D100	Sumas River at Telegraph Road	USGS-Fish ECY-Ten	All flows All flows		 X	X				±10% ±10%	Poor Good
01D100	Sumas River at Telegraph Road	TOPNET	All flows						X		
USGS Real-time Gages											
12210700	Nooksack River at North Cedarville	USGS-NFern	Summer baseflow All flows	X X						±10% ±10%	Good Good
12210700	Nooksack River at North Cedarville	TOPNET	All flows		X						Good
12213100	Nooksack River at Ferndale	USGS-NNCV	Summer baseflow All flows	X X						±10% ±10%	Good Good
12213100	Nooksack River at Ferndale	TOPNET	All flows		X						Good

- The range of RPD values vary widely between stations. The right-hand scale on the graph varies between figures so that the temporal patterns are clear.

Over all flows, the median RPD was good, with a range of +/- 10% for all stations. However, for baseflows, the RPD values tended to be poor and biased high. This is consistent with the tendency of RPD at low flows to produce high values.

Table 6 also shows the accuracy of the TOPNET model. Predictions on the South Fork, Middle Fork, and the two USGS mainstem stations were of good quality (less than 15% RSD). However, compared to the regression results for all flows, the model's predictions are consistently poorer.

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^o) or secondary (2^o) preference. Totals for each station and the USGS priorities are shown at the bottom.

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

Station Code	USGS-Bert	USGS-And	USGS-Fish	USGS-Race	USGS-Skook	USGS-NFN	USGS-MFN	USGS SFN	USGS-NNCV	USGS-NFern	COB-Squal	ECY-Bert	ECY-Ten	ECY-Hutch	ECY-Dak	ECY-Calif
ECY-Bert	1^o		2^o													
ECY-Hutch				2^o	1^o											
ECY-Ten			1^o									2^o				
ECY-NFN						1^o			2^o							
ECY-SFN								1^o								
ECY-Maple			1^o											2^o		
ECY-Calif		1^o													2^o	
ECY-Dak	1^o															2^o
ECY-MFN							1^o									
ECY-And		1^o										2^o				
ECY-Kamm	1^o											2^o				
ECY-Squal	2^o										1^o					
ECY-Sumas			1^o										2^o			
USGS-NNCV										1^o						
USGS-Nfern									1^o							
Primary	3	2	3	-	1	1	1	1	1	1	1	-	-	-	-	-
Secondary	2	-	1	1	-	-	-	-	1	-	-	2	1	1	1	1
TOTAL	5	2	4	1	1	1	1	1	2	1	1	2	1	1	1	1
USGS Priority		2	4	5	1											

Preferences: 1^o = Primary; 2^o = Secondary; 3^o = Tertiary.

Regulatory Control Stations

A summary of suggested methods to determine flows at regulatory control stations is provided in Table 8. The number of stations with high uncertainty indicates that many control stations have no direct flow measurements from which to determine compliance with the instream flow rule.

Table 8. Summary of methods to determine flows at control stations.

Stream Management Unit Name (Control Station)	Nearest Active Continuous Gage	Method to determine flow from active gage	Uncertainty
Bertrand Creek	ECY-Bert	Use gage directly	low
Nooksack River (at Ferndale)	USGS-NFern	Use gage directly	low
Nooksack River (Middle Fork)	USGS-MFN	Use gage directly	low
Racehorse Creek	USGS-Race	Use gage directly	low
Skookum Creek near Wickersham	USGS-Skook	Use gage directly	low
Nooksack River (North Fork)	ECY-NFN	Use gage directly	low
Nooksack River (at Deming)	USGS-NNCV	Use gage directly	low
Dakota Creek near Blaine	ECY-Dak	Use 1-part regression to: 1) ECY-Bert; or 2) USGS-Fish; or 3) ECY-Dak	moderate
California Creek	ECY-Calif	Use 1-part regression to: 1) ECY-Calif; or 2) ECY-Bert; or 3) USGS-Fish	moderate
Terrell Creek	ECY-Bert	Use 1-part regression to: 1) USGS-Fish; or 2) ECY-Bert; or 3) ECY-Ten	moderate
Anderson Creek	USGS-And	Use 2-part regression for ECY-And[1]	moderate
Sumas River near Sumas	USGS-Fish	Use 2-part regression for ECY-Sumas[1]	moderate
Maple Creek	ECY-Hutch	Use 2-part regression for ECY-Maple[1]	moderate
Hutchinson Creek	ECY-Hutch	Multiply gage flows by 1.15	moderate
Nooksack River (South Fork)	USGS-SFN	Multiply gage flows by 0.80	moderate
Tenmile Creek at Laurel	ECY-Ten	Multiply gage flows by 0.91	moderate
Fishtrap Creek at Lynden	USGS-Fish	Multiply gage flows by 0.60	moderate
Deer Creek	ECY-Ten	Multiply gage flows by 0.27	high
Johnson Creek	USGS-Fish	Multiply gage flows by 0.62	high
Kendall Creek	USGS-Race	Multiply gage flows by 2.79	high
Wiser Lake Creek	ECY-Bert	Multiply gage flows by 0.14	high
Saar Creek	USGS-Fish	Multiply gage flows by 0.26	high
Smith Creek	USGS-And	Multiply gage flows by 0.87	high
Bells Creek	USGS-Race	Multiply gage flows by 0.40	high
Silver Creek	ECY-Ten	Multiply gage flows by 0.38	high
Canyon Creek at Kulshan (MFN)	USGS-Race	Multiply gage flows by 0.83	high
Porter Creek	USGS-Clear	Multiply gage flows by 0.24	high
Canyon Creek near Warnick (NFN)	USGS-Race	Multiply gage flows by 2.94	high
Cornell Creek	USGS-Clear	Multiply gage flows by 0.28	high
Gallop Creek	USGS-Clear	Multiply gage flows by 0.13	high

[1]See Table 5.

A qualitative description of the uncertainty of those flows is also shown:

- Control stations located at or near active flow gaging stations have low uncertainty (data quality of the gage itself).
- Control stations with a regression to an active station or with an active station on the same creek are expected to have moderate uncertainty (data quality good or poor).
- Control stations that are estimated with a ratio to a neighboring watershed are considered to have high uncertainty (probably only a rough estimate).

Three control stations – Dakota, California, and Terrell Creeks – have small data sets of recent flow measurements. Regressions were developed for these three creeks, and the results are shown in Table 9.

Table 9. Regressions for control stations with recent flow data.

Station Name	Reference Station Code	Reference Station Priority	Coefficient	Exponent	r^2	n	%RSD
Dakota Creek near Blaine	ECY-Bert	1	0.167	1.139	0.958	28	5-10%
	USGS-Fish	2	0.049	1.431	0.931	32	10-15%
	ECY-Dak	3	0.234	1.301	0.90	19	15-20%
California Creek	ECY-Calif	1	0.902	1.114	0.933	20	10-15%
	ECY-Bert	2	0.233	1.022	0.936	19	10-15%
	USGS-Fish	3	0.059	1.349	0.90	23	15-20%
Terrell Creek	USGS-Fish	1	0.048	1.368	0.656	27	20-30%
	ECY-Bert	2	0.024	1.433	0.564	18	20-30%
	ECY-Ten	3	0.096	1.350	0.44	18	20-30%

Three control stations – Anderson and Maple Creeks and Sumas River – are close to the location of gages that were recently discontinued. The regression for the Ecology flow measurement station at this location (Table 5) can be used for the control station.

Table 10 shows a summary of the control stations and which active flow stations can be used for measuring and estimating flow at those control stations. The numbers in the grid indicate whether the active station is the primary, secondary, or tertiary preference (1^{st}, 2^{nd}, or 3^{rd}). Totals for each station and the USGS priorities are shown at the bottom.

TOPNET model results were compared to measurements and estimates of flow at control stations. The results of this analysis are shown in Table 11. Each control station is shown paired with a reference gage where:

1. Direct measurements were available at the same location.
2. Flow estimates were available from regressions to direct measurements.
3. Flow estimates were derived from watershed-area ratios without confirmation by direct measurement.

Table 10. Summary of control stations with relevant active flow gaging stations.

Stream Management Unit Name (Control Station)	USGS-And	USGS-Fish	USGS-Race	USGS-Skook	USGS-NFN	USGS-MFN	USGS SFN	USGS-NNCV	USGS-NFern	ECY-Bert	ECY-Ten	ECY-Hutch	ECY-Dak	ECY-Cal	USGS-Clear
Bertrand Creek										1^o					
Nooksack River (at Ferndale)									1^o						
Nooksack River (Middle Fork)						1^o									
Racehorse Creek			1^o												
Skookum Creek near Wickersham				1^o											
Nooksack River (North Fork)					1^o										
Nooksack River (at Deming)								1^o							
Dakota Creek near Blaine		2^o								1^o			3^o		
California Creek										2^o	3^o			1^o	
Terrell Creek		1^o								2^o	3^o				
Anderson Creek	1^o														
Sumas River near Sumas		1^o													
Maple Creek												1^o			
Hutchinson Creek												1^o			
Nooksack River (South Fork)							1^o								
Tenmile Creek at Laurel											1^o				
Fishtrap Creek at Lynden		1^o													
Deer Creek											1^o				
Johnson Creek		1^o													
Kendall Creek			1^o												
Wiser Lake Creek										1^o					
Saar Creek		1^o													
Smith Creek	1^o														
Bells Creek			1^o												
Silver Creek											1^o				
Canyon Creek at Kulshan (MFN)			1^o												
Porter Creek															1^o
Canyon Creek near Warnick (NFN)			1^o												
Cornell Creek															1^o
Gallop Creek															1^o
Number of Primary gages	2	5	5	1	1	1	1	1	1	3	3	2	-	1	3
Number of Secondary gages	-	1	-	-	-	-	-	-	-	2	-	-	-	-	-
Number of Tertiary gages	-	-	-	-	-	-	-	-	-	-	2	-	1	-	-
TOTAL	2	6	5	1	1	1	1	1	1	5	5	2	1	1	3
USGS Priority	2	4	5	1											6

Preferences: 1^o = Primary; 2^o = Secondary; 3^o = Tertiary

Table 11. Comparison of TOPNET results at control stations to flow measurements and estimates.

Stream Management Unit Name (Control Station)	Method to determine flow from reference gage for comparison to TOPNET		TOPNET relative accuracy	
	Reference Gage	Method*	median %RSD	n
Bertrand Creek	ECY-Bert	1. Direct	30-40%	933
Nooksack River (at Ferndale)	USGS-NFern	1. Direct	**10-15%**	14337
Nooksack River (Middle Fork)	USGS-MFN	1. Direct	**0-5%**	7032
Racehorse Creek	USGS-Race	1. Direct	30-40%	2649
Skookum Creek near Wickersham	USGS-Skook	1. Direct	40-50%	6302
Nooksack River (North Fork)	ECY-NFN	1. Direct	**10-15%**	4107
Nooksack River (at Deming)	USGS-NNCV	1. Direct	**10-15%**	15712
Hutchinson Creek	ECY-Hutch	3. Multiply by 1.15	30-40%	933
Dakota Creek near Blaine	USGS-Fish	2. 1-part regression	40-50%	1065
California Creek	ECY-Calif	2. 1-part regression	70-100%	124
Nooksack River (South Fork)	USGS-SFN	1. Direct	**0-5%**	13244
Tenmile Creek at Laurel	USGS 12212900 (Tenmile Creek)	1. Direct	50-60%	1614
	ECY-Ten	3. Multiply by 0.91	40-50%	934
Fishtrap Creek at Lynden	USGS-Fish	1. Direct	30-40%	4389
Anderson Creek	ECY-And & USGS 12211000 (Anderson Ck)	1. Direct	60-70%	127
	USGS-And	2. 2-part regression	40-50%	2649
Sumas River near Sumas	ECY-Sumas	1. Direct	50-60%	111
	USGS-Fish	2. 2-part regression	50-60%	1065
Maple Creek	ECY-Maple	1. Direct	40-50%	809
	ECY-Hutch	2. 2-part regression	50-60%	933
Terrell Creek	NSEA-Ter	1. Direct	40-50%	27
	USGS-Fish	2. 1-part regression	60-70%	1045
Deer Creek	ECY-Ten	3. Multiply by 0.27	70-100%	934
Johnson Creek	USGS 12215000 (Johnson Creek)	1. Direct	70-100%	7
	USGS-Fish	3. Multiply by 0.62	40-50%	1065
Kendall Creek	USGS 12212000 (Fishtrap Ck)	1. Direct	70-100%	7
	USGS 12209500 (Skookum Ck)	2. 1-part regression	70-100%	4389
	USGS-Race	3. Multiply by 2.79	50-60%	2649
Wiser Lake Creek	ECY-Bert	3. Multiply by 0.14	50-60%	932
Saar Creek	USGS 12212000 (Fishtrap Ck)	2. 1-part regression	30-40%	4389
	USGS-Fish	3. Multiply by 0.26	20-30%	1065
Smith Creek	ECY-And & USGS 12211000 (Anderson Ck)	3. Multiply by 0.87	60-70%	127
	USGS-And	3. Multiply by 1.23	60-70%	2649
Bells Creek	USGS-Race	3. Multiply by 0.40	40-50%	2649
Silver Creek	ECY-Ten	3. Multiply by 0.38	60-70%	934

Table 11, continued. Comparison of TOPNET results at control stations to flow measurements and estimates.

Stream Management Unit Name (Control Station)	Method to determine flow from reference gage for comparison to TOPNET		TOPNET relative accuracy	
	Reference Gage	Method*	median %RSD	n
Canyon Creek at Kulshan	USGS 12212000 (Fishtrap Ck)	2. 1-part regression	40-50%	4389
	USGS-Race	3. Multiply by 0.83	30-40%	2649
Porter Creek	USGS-Clear	3. Multiply by 0.24	30-40%	2734
Canyon Creek (NFN)	USGS-Race	3. Multiply by 2.94	50-60%	2649
	ECY-Maple	3. Multiply by 2.66	70-100%	809
Cornell Creek	USGS-Clear	3. Multiply by 0.28	60-70%	2734
Gallop Creek	USGS-Clear	3. Multiply by 0.13	30-40%	2734

(*) 1 = Compared to measured data.
2 = Compared to regression.
3 = Compared to watershed ratio estimate.

Most of the regressions shown are those described in Tables 5 and 9. In three cases – Kendall Creek, Saar Creek, and Canyon Creek at Kulshan – regressions were developed between historical flow measurements at the control station to the historical gage "Fishtrap Creek at Lynden' (USGS 12212000). This allowed the development of a longer time series of flows during time periods overlapping the period with TOPNET output.

In general, good matches between the TOPNET model results and measured or estimated flows (15% RSD or less) could only be found for the stations on the Nooksack River mainstem or forks (shown in bold). Most of the other showed %RSD levels of 30% or more. For most of these sites this error also includes a large error in the flow estimate. However, the comparisons to measured flows on the tributaries also showed a broad range of %RSD values.

Evaluation of TOPNET Model

The TOPNET model was designed to be part of a Decision Support System for the WRIA 1 Planning Group. The model was evaluated to see whether it could be adapted to supply real-time flow estimates for critical flow monitoring and control stations.

To achieve this purpose, TOPNET would need to be modified to be updated quickly with real-time meteorological data. The original model used several cooperative (NCDC) stations whose data are not available in real time (Table 4). At the same time, there are several Agricultural Weather Network stations available with real-time meteorological data that were not used in the model.

TOPNET is programmed to use complete time series, so a method to fill data gaps is needed. The methods used in calibrating the model are not described in the model documentation and remain unknown. Therefore methodologies were explored to meet this purpose.

A preliminary analysis of daily average temperatures using multiple regression and the DAYMET method indicated that strong relationships exist that can be used (r^2 values greater than 90% for all regressions). The root mean square error for paired measured values and regression estimates were between 0.7 and 2.5 ^oC and were comparable between the two methods. The DAYMET method appears to be preferable since it has a physical basis and would be more robust for extrapolation of values.

The results of applying the TOPNET model to flow measurement and control stations suggest that the model performs well for the Nooksack River mainstem and forks, but poorly for most tributaries. The calibrated version of TOPNET used appears to be outperformed by the regression method where adequate flow time series are available. The model may still be the best method available for streams that are ungaged or only have old or limited flow data available.

However, the TOPNET model is highly complex and would require dedicated expertise to update. The cost of updating the model should be weighed against the cost of additional flow gaging.

Discussion

Analysis of Regressions

WRIA 1 is a highly complex region hydrologically, and this is demonstrated by the results of this study. The strongest regression relationships were found among the Nooksack River mainstem and forks. This is likely due to the large watersheds drained by these rivers, which would tend to "average out" local effects and the varying effects of rainfall, snowmelt, and glacial melt.

The tributaries of the Nooksack River mainstem and forks have highly varied hydrology, which reflects a variety of factors that include:

- The effect of the geology of subbasins on surface runoff and groundwater inflows.
- The effect of topography on the rain-snow balance and local weather effects.
- Land uses in the subbasins, and in particular the effect of agricultural water use on summer low flows.

In an ideal world, many more flow gages would be installed in order to better understand the variability of hydrology in WRIA 1. However, limited resources force water management agencies to focus on key monitoring locations and find relationships that help management in ungaged streams. For this reason, a holistic approach to flow monitoring is needed.

The results of the regression analysis provide a tool that could allow the replacement of some gages with regressions that meet a level of quality sufficient to serve most purposes in WRIA 1.

Flow monitoring stations on the mainstem and forks appear to be redundant in terms of the ability of the regressions to predict flow.

- Regression relationships between Ecology and USGS stations on each fork are good, so some discussions are needed to determine the best site for monitoring in each fork.
- The regression relationship between the North Cedarville and Ferndale gages is good. The uses of the gages should be reviewed to determine if both are needed. The relationship is poorest for flood flows, which could be due to higher variability in rating curves at high flows. Consideration should be given to whether high flow monitoring is needed at both locations, or if measurement of stage height only would suffice for evaluation of flood stage at one of the gages.

Tributaries are highly varied, and good relationships were rarely found.

- Maple and Hutchinson Creeks are quite unique hydrologically and may be representative geographically and topographically of other watersheds in their region of the WRIA. Maple Creek had poor quality regressions with other gages. Hutchinson had regressions to USGS gages whose quality were good at low flows but poor at higher flows. Creeks draining from the north side of the North Fork are underrepresented in monitoring, and Maple was one of the only recent gages in this area. Consideration might be given to restoring flow measurements on this creek at a new location, or on a neighboring creek such as Kendall or Canyon Creeks.

- Low-lying tributaries of the mainstem Nooksack show some similarities, but relationships between gages were for the most part of poor quality.
- Flows in tributaries that had staff gages until last year appear to be well reproduced by the regressions.
- Coastal tributaries are well represented by California and Dakota Creeks, and each regresses to the other with a good fit. Both of these gages may not be needed in the long run. However, if both returned to staff gages or were discontinued, there would be no continuous monitoring of coastal tributaries.

The ability of these regressions to meet water management needs depends on the accuracy needed. The timing and magnitude of the error of flow estimates will need to be compared to the management needs to determine their usefulness.

Comparison of Ecology and USGS Gages

The USGS study of the six Lummi-funded gages (Curran and Olsen, 2009) recommended priorities for stations should funding reductions force the discontinuation of some.

Table 12 shows which active gages were the basis of the primary and secondary regression (1 or 2 in the table) for each of the study gages. The number of times each active station was used as a primary or secondary basis of regression is shown, along with the priority set by USGS for Lummi-funded gages.

Some patterns help understand the tradeoffs between gages.

- Four gages – the USGS Bertrand and Fishtrap gages, and the Ecology Bertrand and Tenmile gages – are closely related. Two of these four gages should be retained: one of the two Bertrand gages, and either the Tenmile or Fishtrap gage.
    - The USGS Fishtrap gage was used the most times for regressions, but funding is uncertain. If the Fishtrap gage were discontinued, then one of the two Bertrand gages and the Tenmile gage should be continued.
    - The USGS Bertrand gage is not prioritized, but was used the second most times in regressions. If it were discontinued, then the either the Ecology Bertrand or the USGS Fishtrap should be continued.
    - If Ecology's Bertrand gage were discontinued, then the USGS Bertrand gage and either the Tenmile or Fishtrap gage should be continued.
    - If Ecology's Tenmile gage were discontinued, then the USGS Fishtrap gage should be continued.
- The Racehorse Creek and Hutchinson Creek gages could be considered for discontinuation if the Skookum Creek gage were retained.

- The California Creek and Dakota Creek gages could be considered for discontinuation if the USGS Anderson Creek gage and one of the Bertrand Creek gages were retained.

Ecology, USGS, and the WRIA Planning Group should work closely to determine the highest priority gages from both agencies' stations.

Table 12. Summary of regression relationships between flow stations.

Station Code	USGS-Bert	USGS-And	USGS-Fish	USGS-Race	USGS-Skook	USGS-NFN	USGS-MFN	USGS SFN	USGS-NNCV	USGS-Nfern	COB-Squal	ECY-Bert	ECY-Ten	ECY-Hutch	ECY-Dak	ECY-Calif
ECY-Bert	1		2													
ECY-Hutch				2	1											
ECY-Ten			1									2				
ECY-NFN						1			2							
ECY-SFN								1								
ECY-Maple			1											2		
ECY-Calif		1											3		2	
ECY-Dak	1											3				2
ECY-MFN							1									
ECY-And		1	2													
ECY-Kamm	1		2													
ECY-Squal	2										1					
ECY-Sumas			1										2			
USGS-NNCV										1						
USGS-NFern									1							
Number of Primary	3	2	3	-	1	1	1	1	1	1	1	-	-	-	-	-
Number of Secondary	1	-	3	1	-	-	-	-	1	-	-	1	1	1	1	1
Number of Tertiary	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-
TOTAL NUMBER	4	2	6	1	1	1	1	1	2	1	1	2	2	1	1	1
USGS Priority		2	4	5	1											

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Conclusions and Recommendations

This study draws the following conclusions and recommendations:

- The hydrograph separation method can be used to develop regression-based models to estimate streamflow at Ecology gaging stations in the WRIA 1 Nooksack River basin.
- The quality of the streamflow estimates from these regressions varies between stations. The best results were found on the Nooksack River mainstem and forks. Results from Ecology tributary stations were of poorer quality.
- The regression tool could provide an adequate replacement for Ecology's gages on the North, Middle, and South Forks, based on relationships with the USGS gages on the same forks.
- The regressions appear to be adequate to replace Ecology's staff gages.
- Ecology's Bertrand Creek and Tenmile Creek gages should be reviewed in conjunction with the USGS Bertrand Creek and Fishtrap Creek gages. Only two of these four gages should be discontinued. One of the two Bertrand Creek gages should be retained, and either the Fishtrap Creek or Tenmile Creek should be retained.
- If the USGS Anderson Creek gage and one of the Bertrand Creek gages are retained, then the California Creek and Dakota Creek gages could be considered for discontinuation. However, it might be desirable to retain one of these two gages to be representative of coastal streams in WRIA 1.
- If the USGS gage at Skookum Creek is retained, Ecology's Hutchinson Creek gage might be discontinued. However, this watershed has unique hydrologic characteristics that may merit retaining this gage.
- Flows at the discontinued Maple Creek gage can be estimated by regression. However, the relationship is poor, and there are currently no gages that represent creeks on the north side of the North Fork Nooksack River (such as Kendall, Maple, or Canyon Creeks). Consideration should be given to establishing a gage on one of these creeks, if warranted by sufficient need for flow data of this quality. Possible good sites include the fish hatchery on Kendall Creek and Maple Creek just north of Maple Falls in the community park area.
- The two USGS gages on the mainstem Nooksack River are somewhat redundant, because regressions could predict one from the other. The degree of redundancy depends on data needs from these stations. These two stations should be reviewed, and Ecology should consider supporting only the higher priority gage.
- The locations of regulatory flow control stations have been clearly identified, and suggestions are provided regarding available flow measurements or methods to estimate flow at the control stations. If active flow monitoring stations are discontinued, these methods will need to be revised.

- The accuracy of the regression tools should be evaluated against flow monitoring needs for Ecology and the local community to determine whether the tools provide an acceptable substitute for flow gaging. All regression-based modeling tools 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 still 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 where a rough estimate is acceptable.

- Regressions from provisional data should be of sufficient quality to be applied to identified uses. Updating of regression models with quality-checked data could slightly improve the quality of the regressions. Regression tools should be updated when additional measured flow data are available and when flow data quality reviews are completed.

- The TOPNET model appears to provide poorer quality estimates of flow than regressions. However the model may be useful to (1) estimate flows for streams were little or no flow data are available, or (2) provide screening estimates simultaneously at all control stations.

- Continued improvements in the TOPNET model could be considered, including:
    - Reprogram and recalibrate to recent flows using only real-time meteorological stations.
    - Try to improve the calibration on tributaries.
    - Develop a method to update and run the model automatically with real-time meteorological data.

  However, the cost of improvements to the TOPNET model should be weighed against the cost of additional flow gaging.

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Figures

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Figure 1. Water Resource Inventory Area 1 sub-basin boundaries.

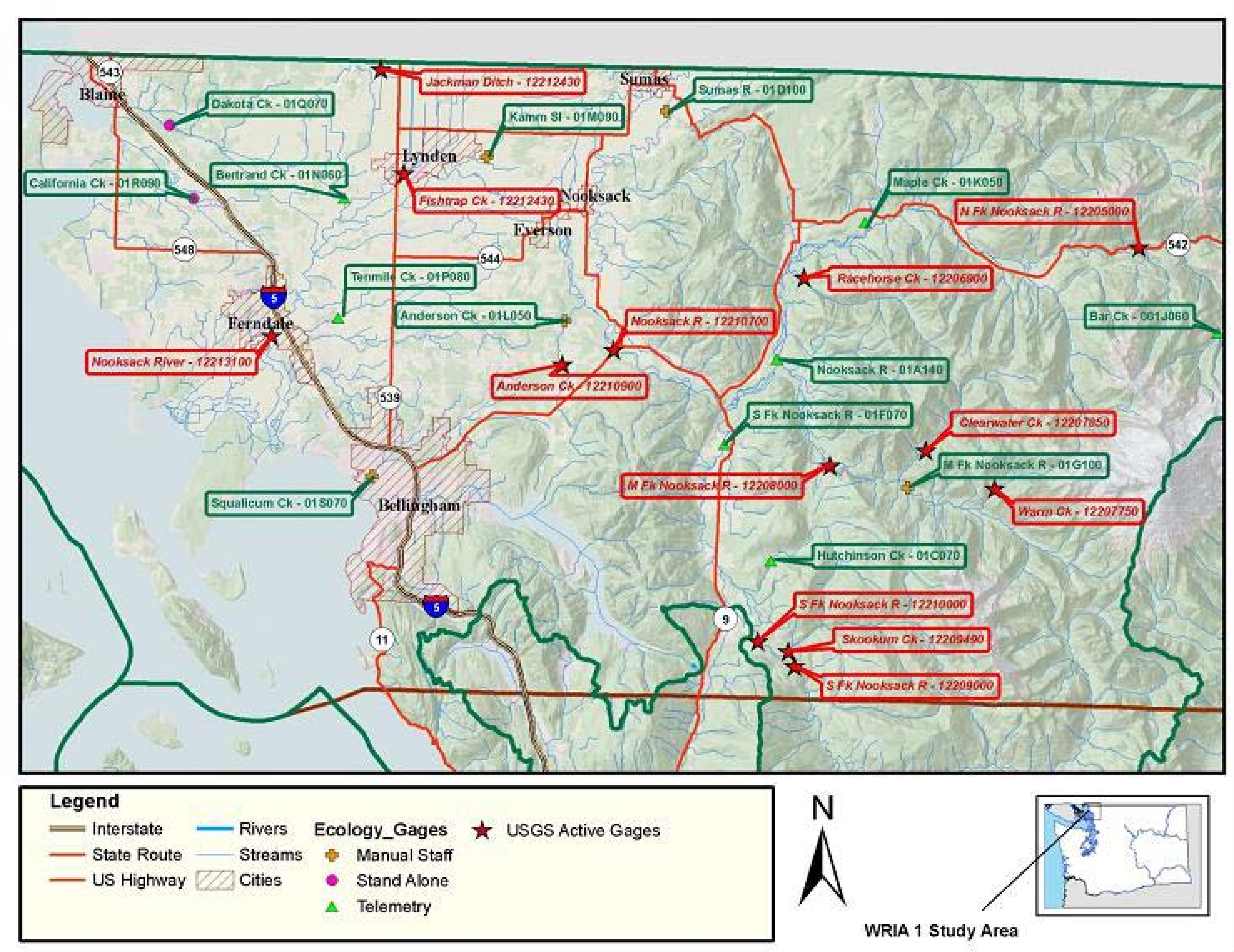

Figure 2. WRIA 1 flow monitoring: active and historical Ecology stations and active USGS stations.

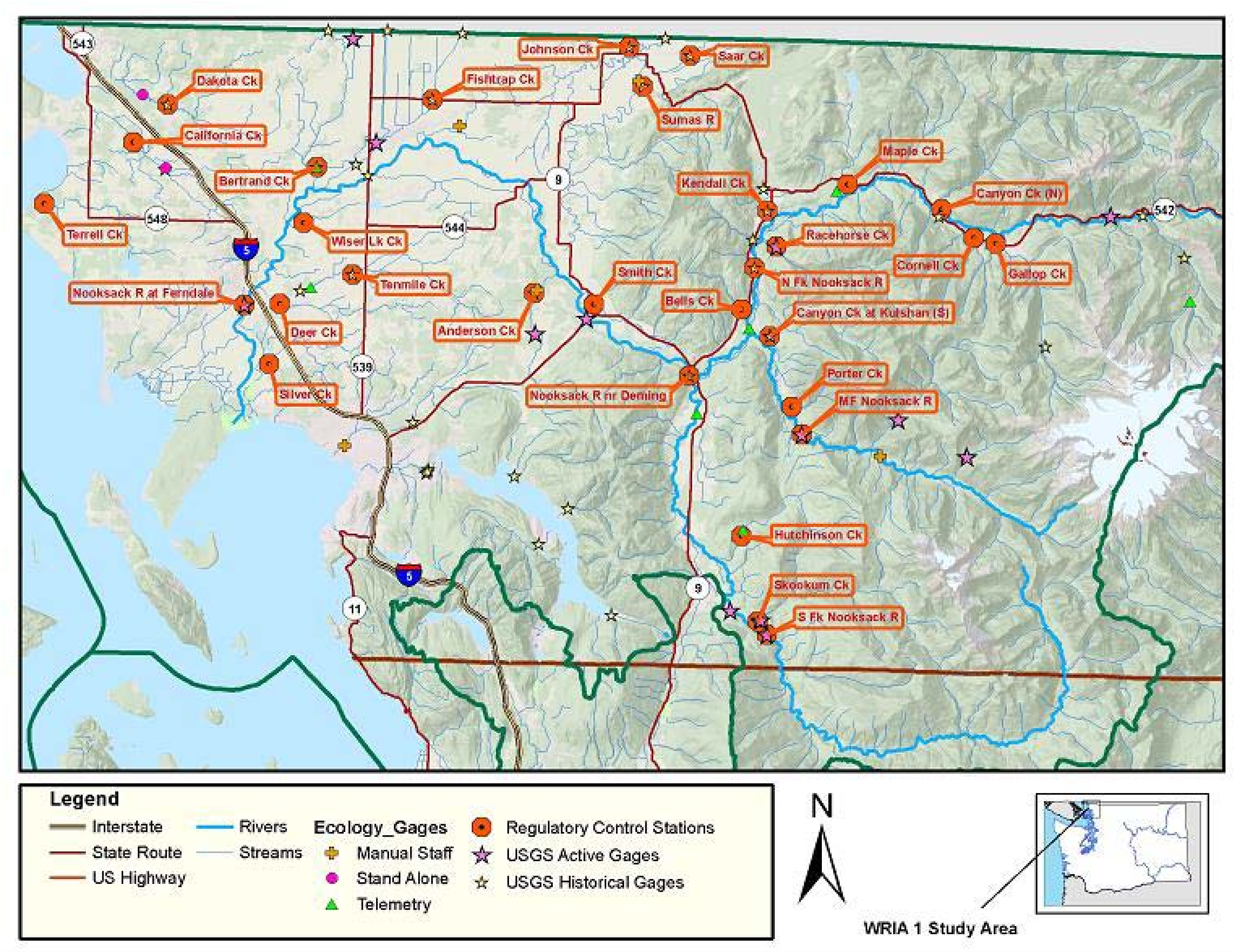

Figure 3. Location of WRIA 1 regulatory control stations.

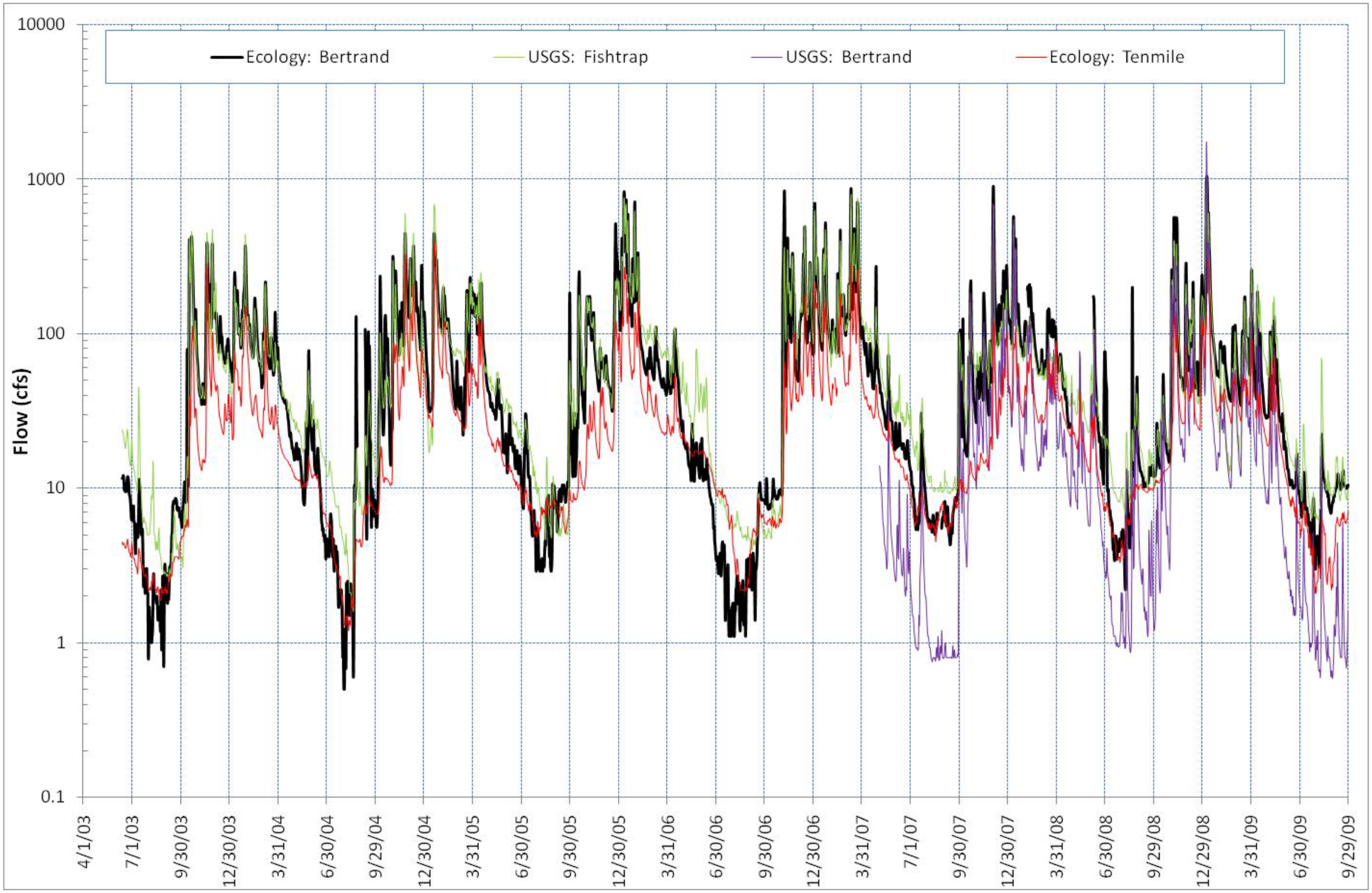

Figure 4. Measured flows at the “Bertrand Creek near mouth” gaging station, with flows from other selected gages.

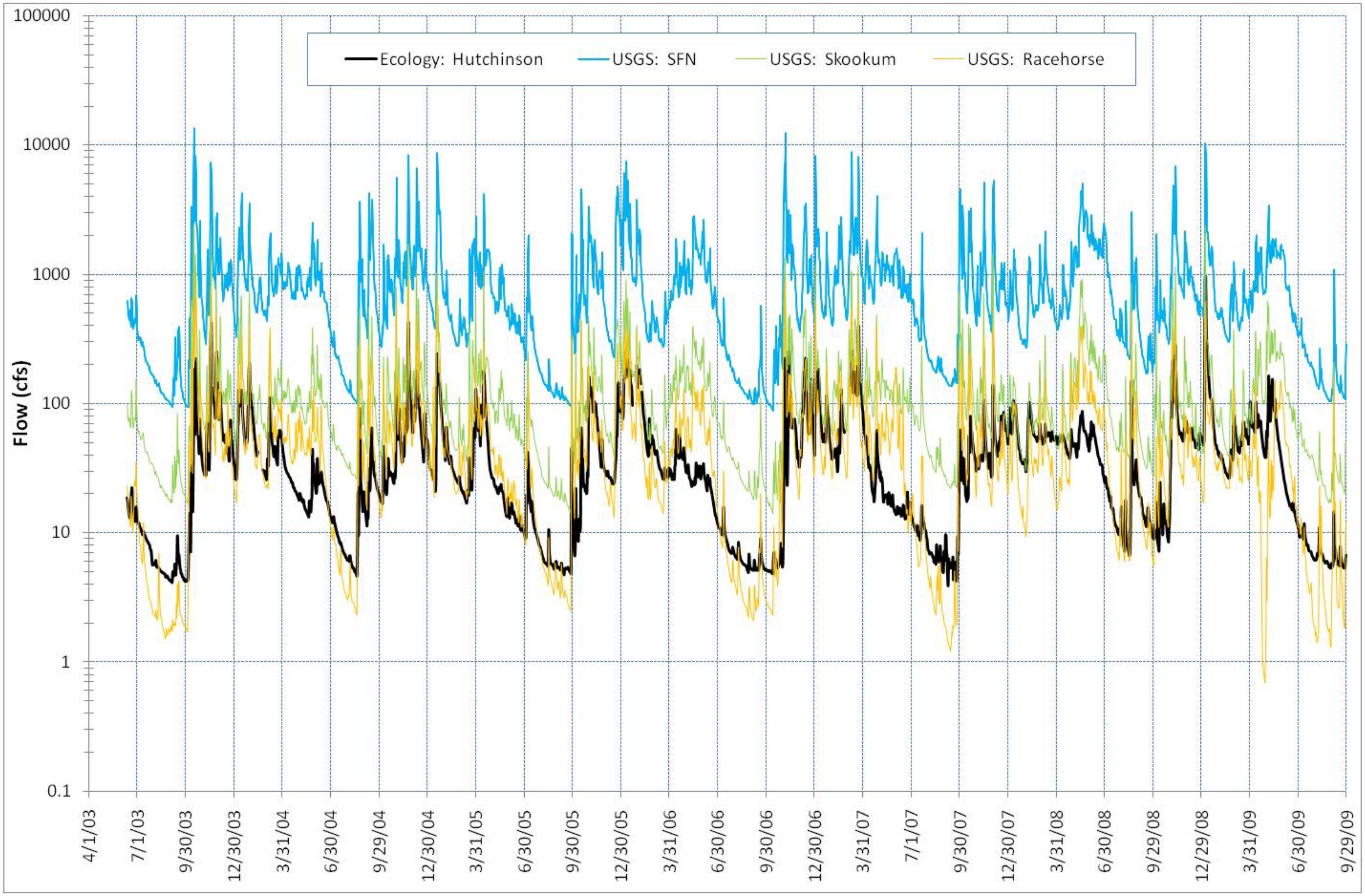

Figure 5. Measured flows at the “Hutchinson Creek near Acme” gaging station, with flows from other selected gages.

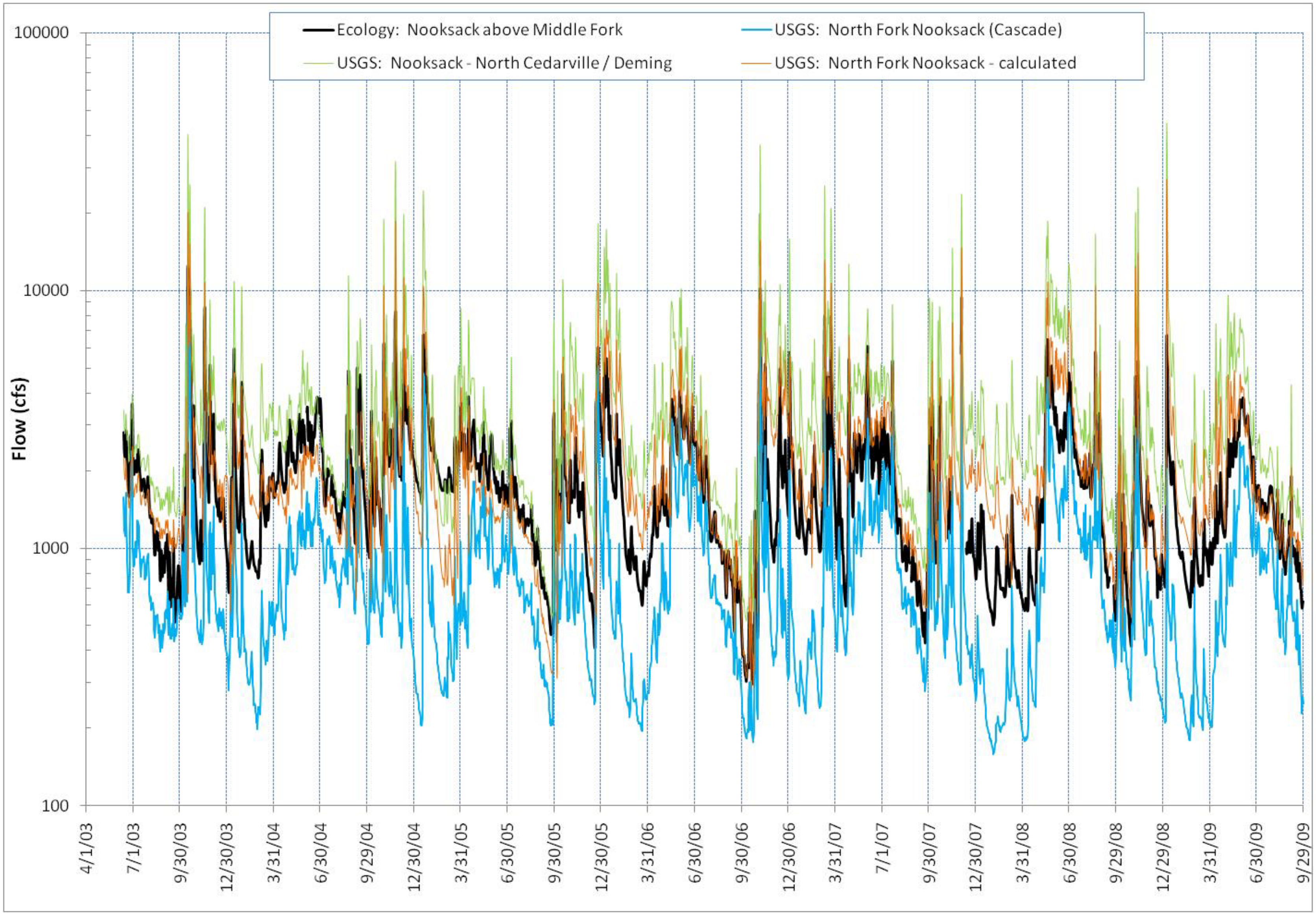

Figure 6. Measured flows at the "Nooksack River above the Middle Fork" gaging station, with flows from other selected gages.

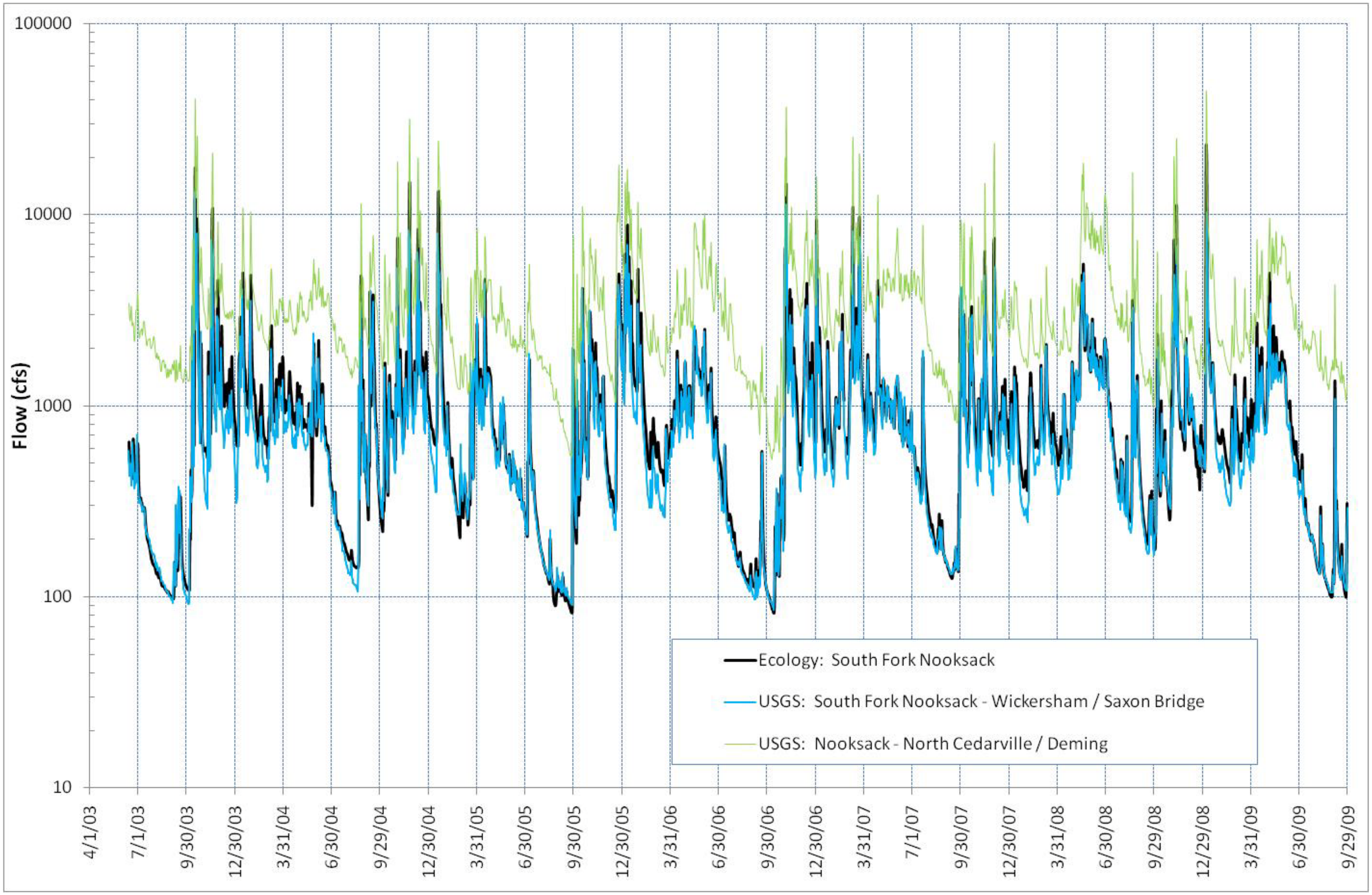

Figure 7. Measured flows at the “South Fork Nooksack River at Potter Road” gaging station, with flows from other selected gages.

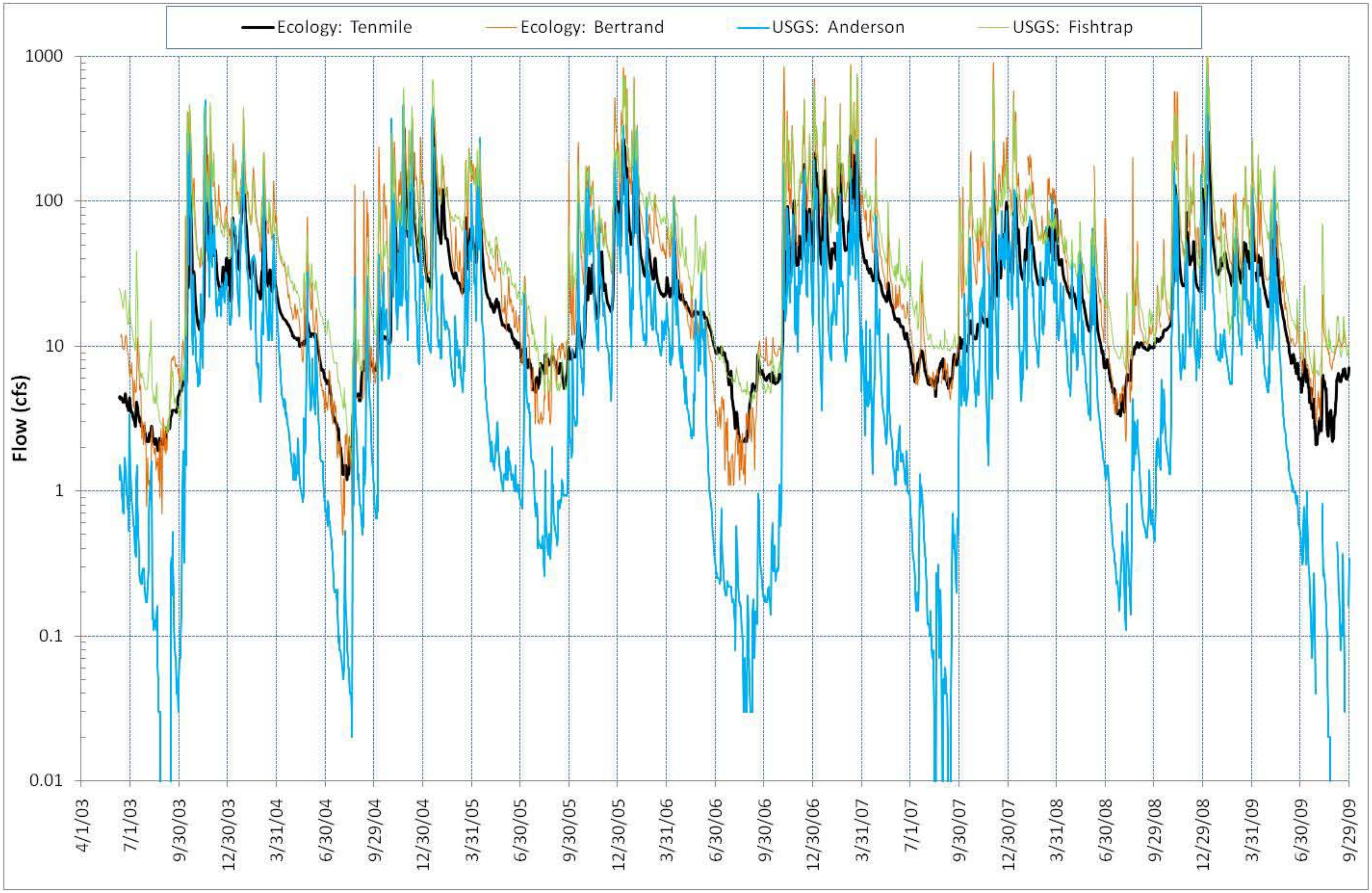

Figure 8. Measured flows at the “Tenmile Creek above Barrett Lake” gaging station, with flows from other selected gages.

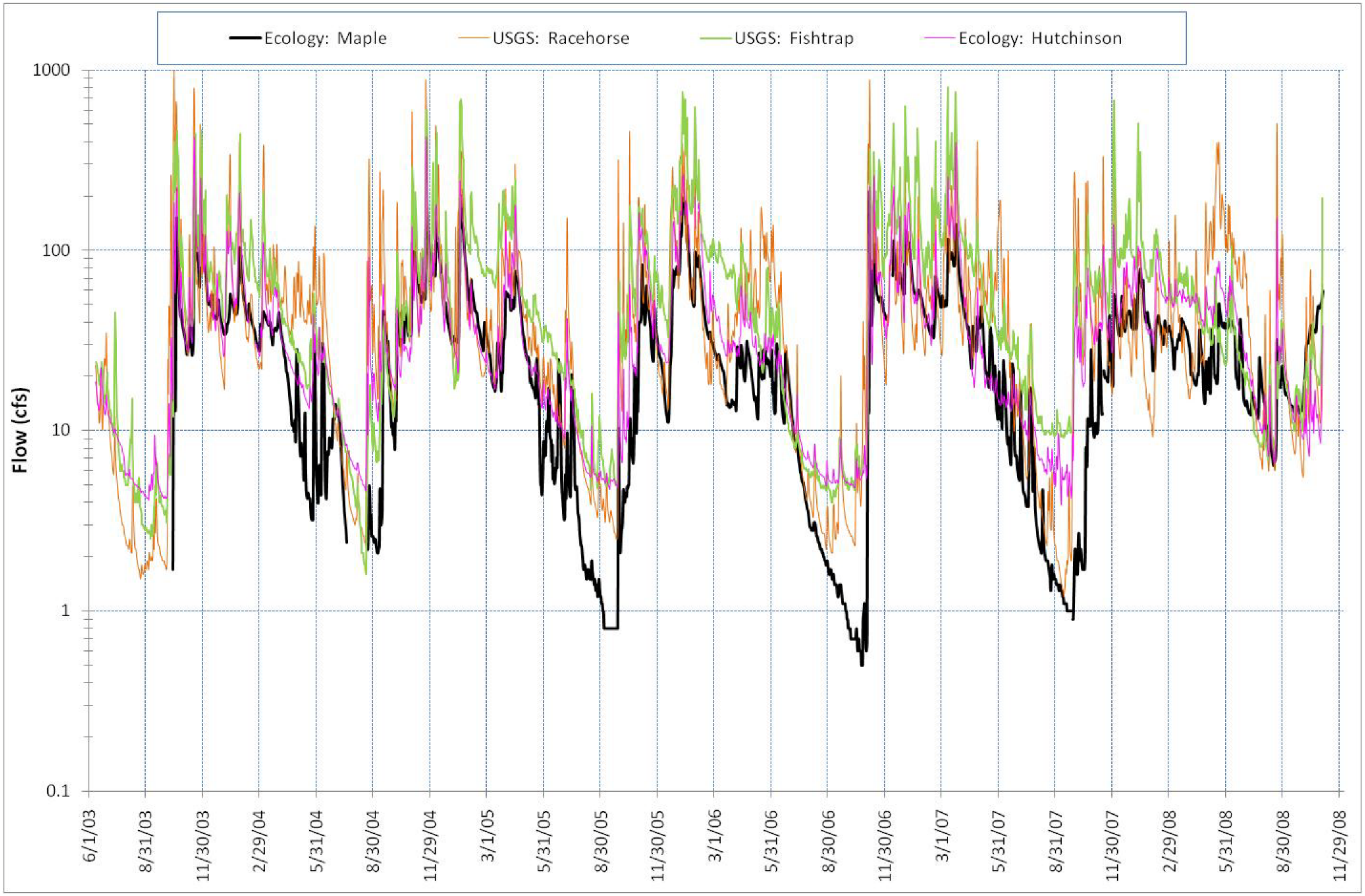

Figure 9. Measured flows at the “Maple Creek at mouth” gaging station, with flows from other selected gages.

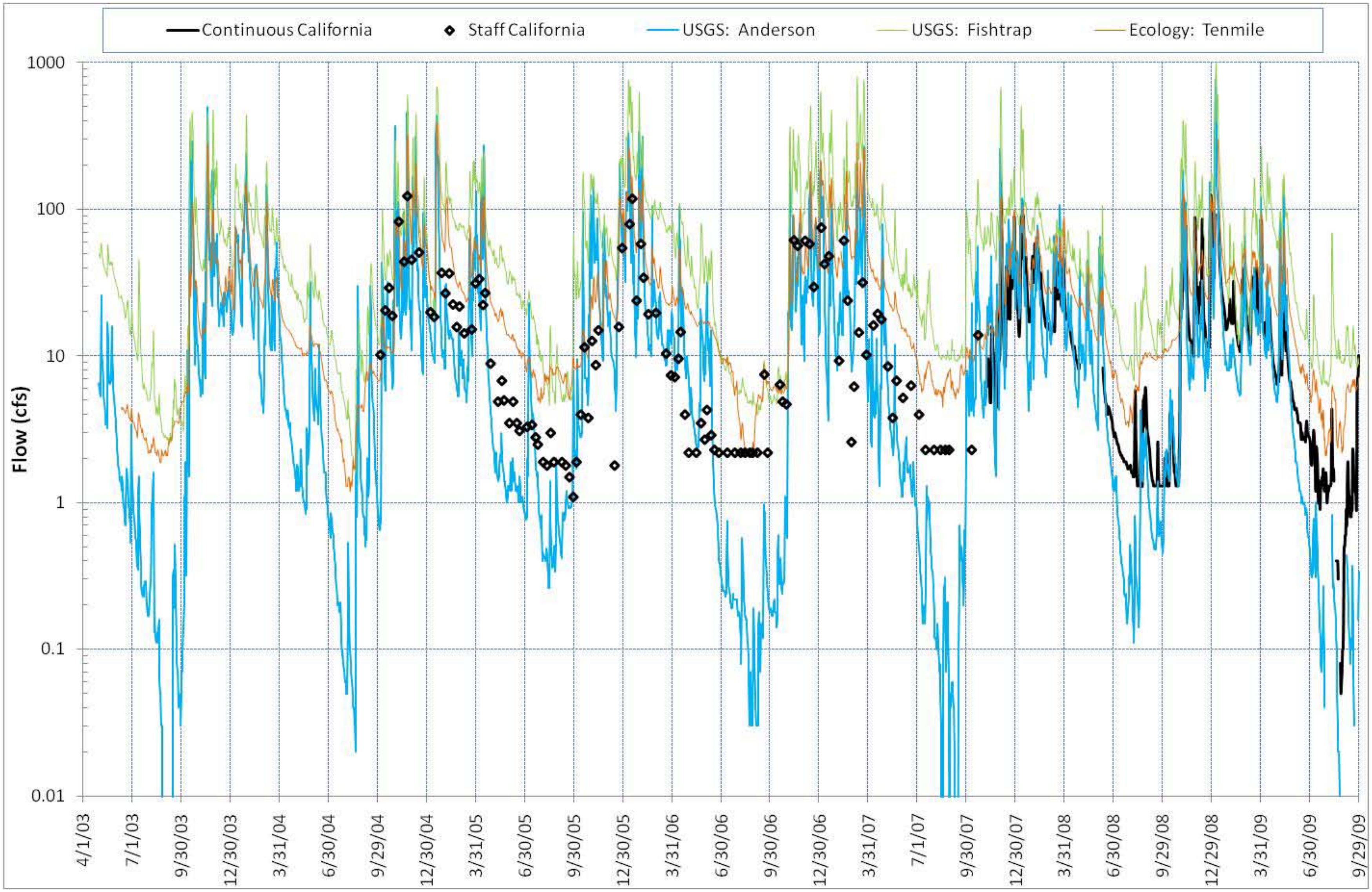

Figure 10. Measured flows at the "California Creek at Valley View Road" gaging station, with flows from other selected gages.

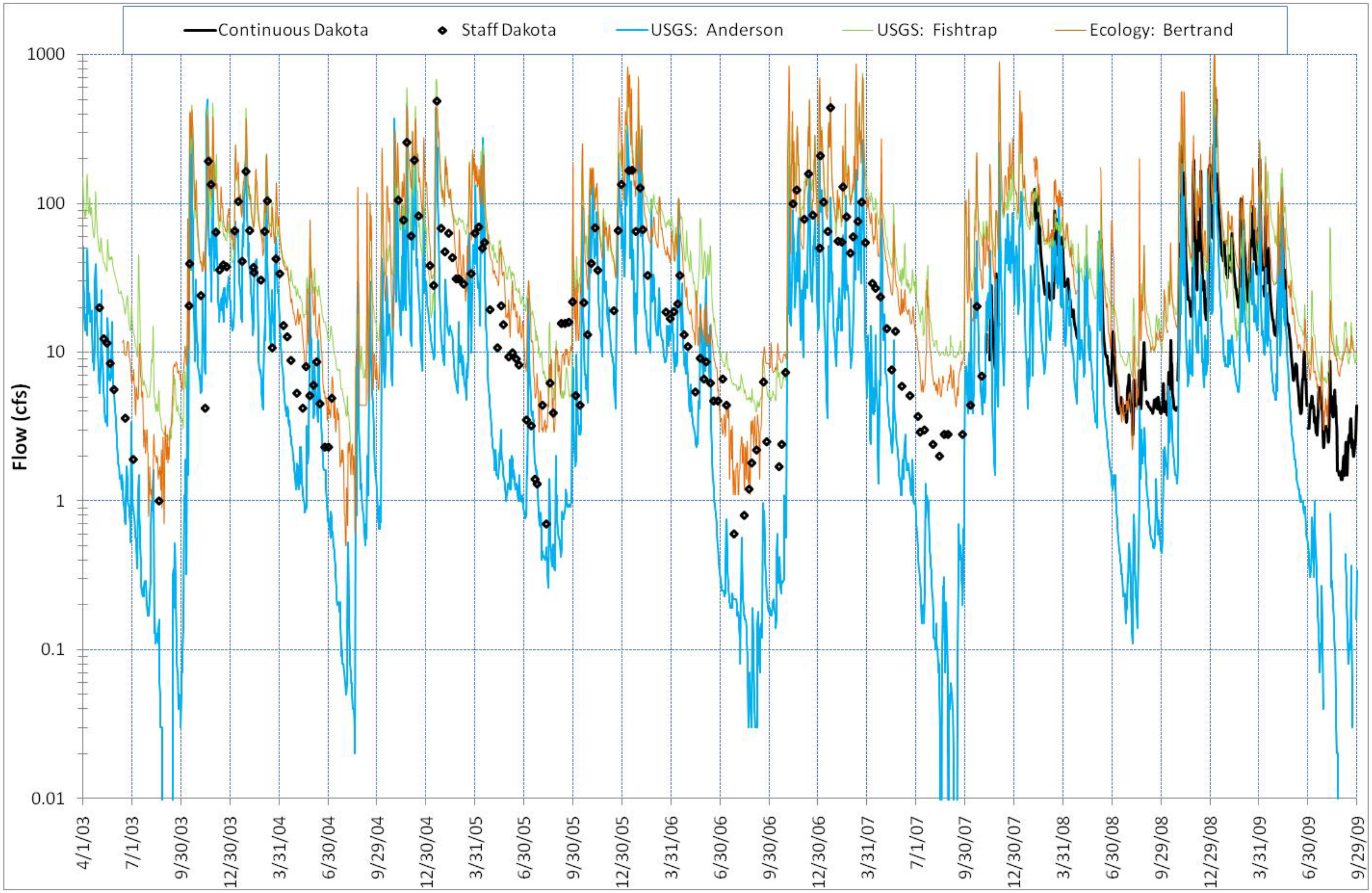

Figure 11. Measured flows at the “Dakota Creek at Giles Road” gaging station, with flows from other selected gages.

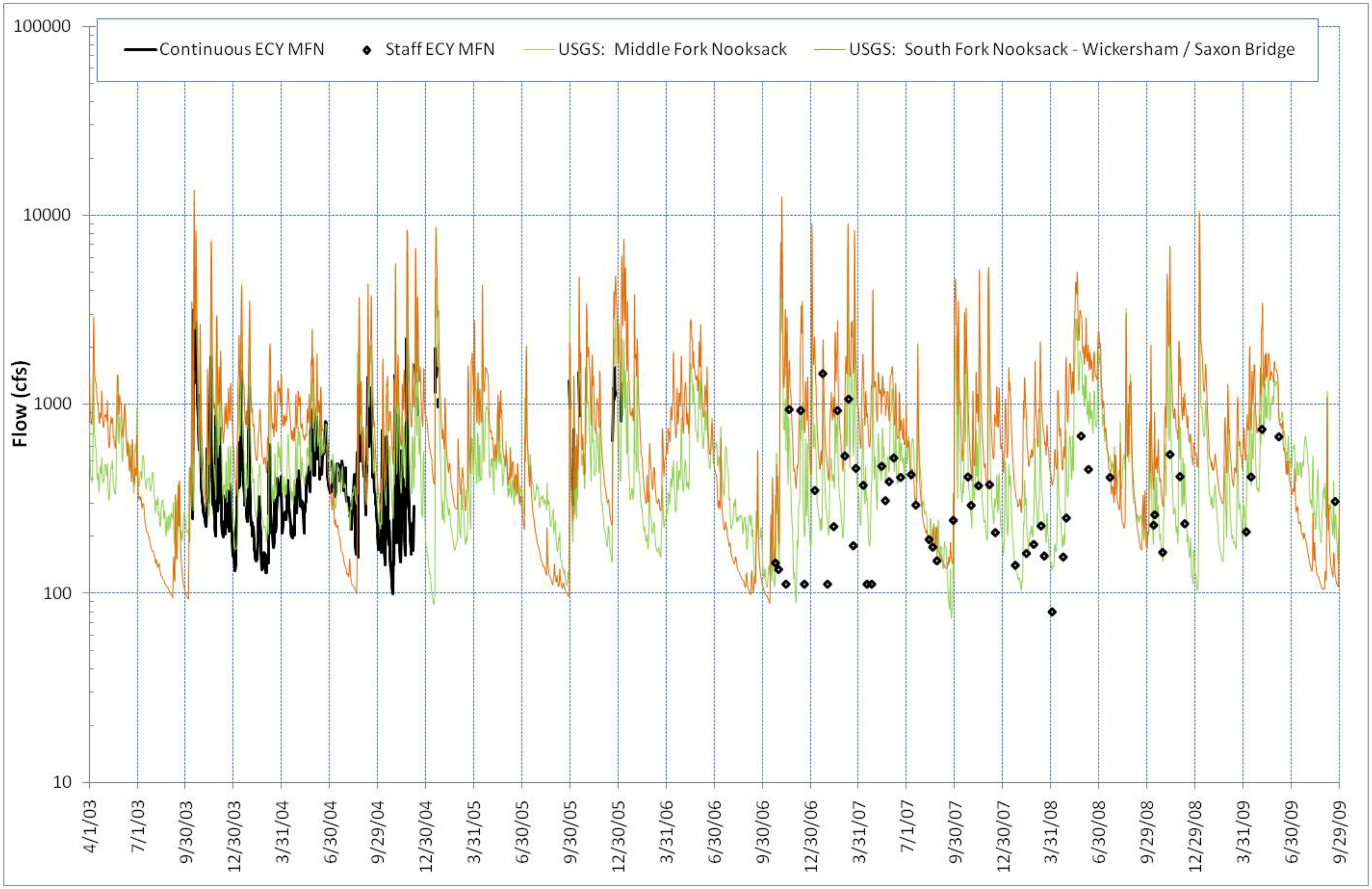

Figure 12. Measured flows at the "Middle Fork Nooksack River above Clearwater Creek" gaging station, with flows from other selected gages.

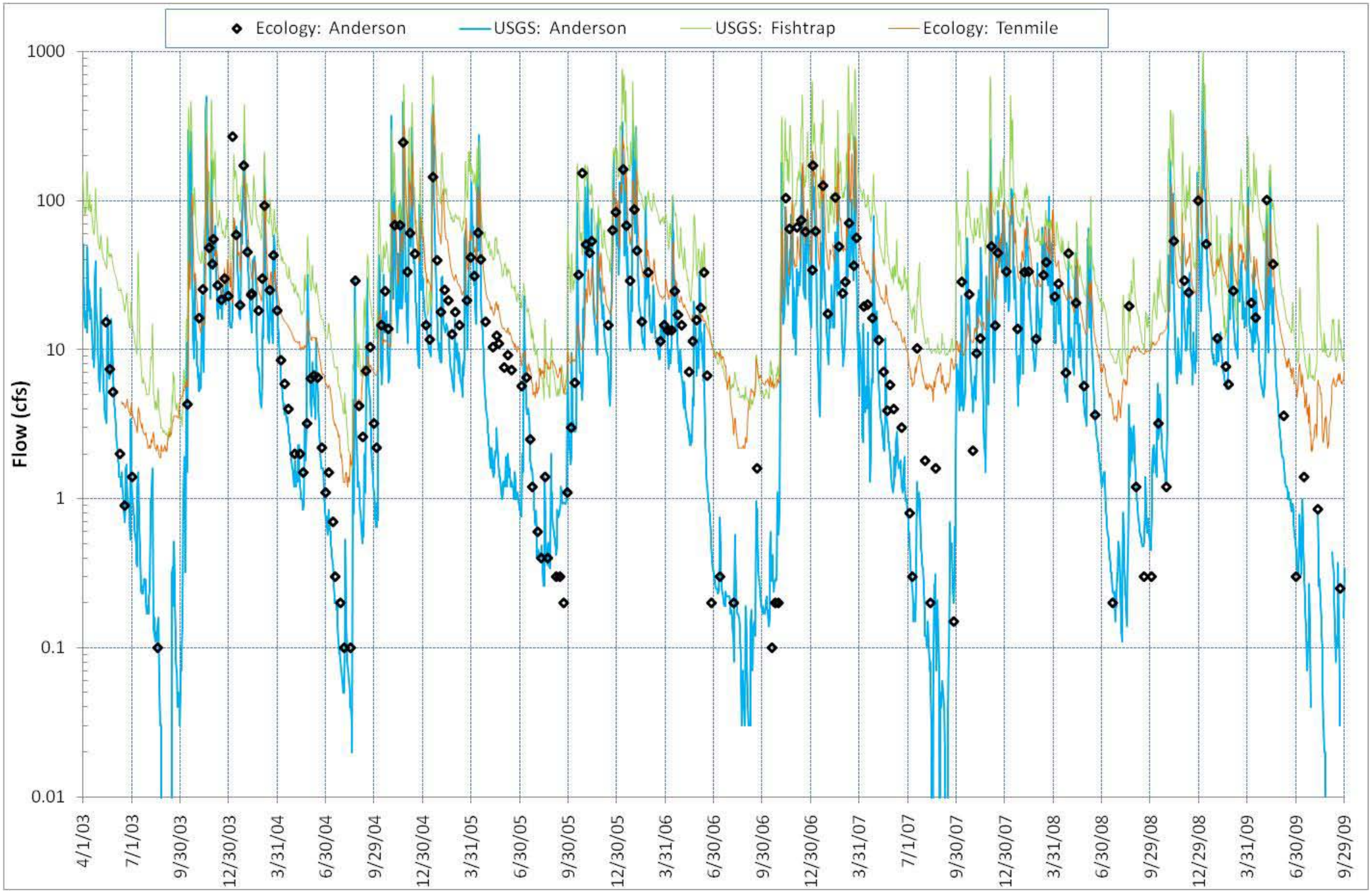

Figure 13. Measured flows at the “Anderson Creek at mouth” gaging station, with flows from other selected gages.

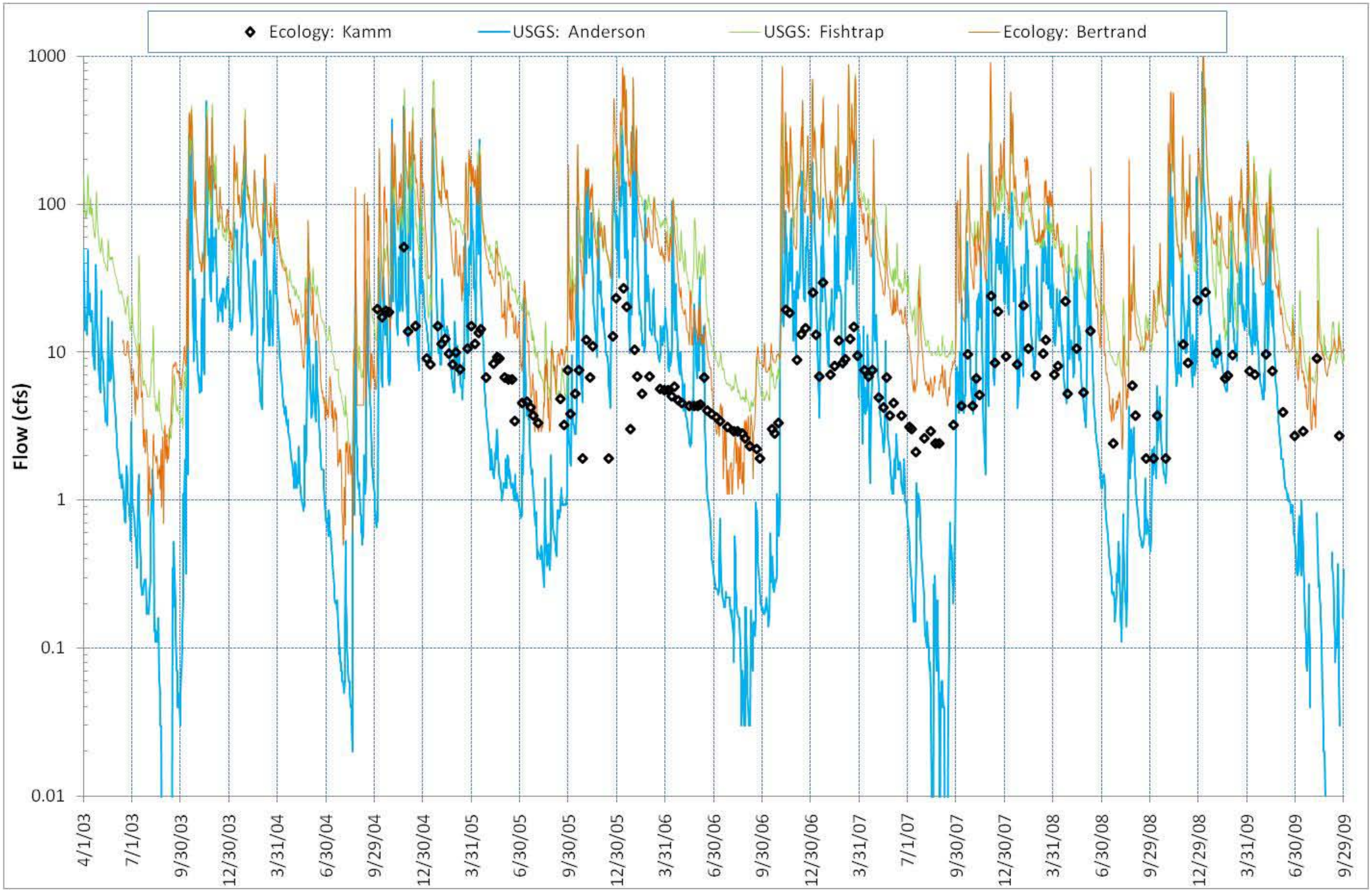

Figure 14. Measured flows at the "Kamm Slough at Northwood Road" gaging station, with flows from other selected gages.

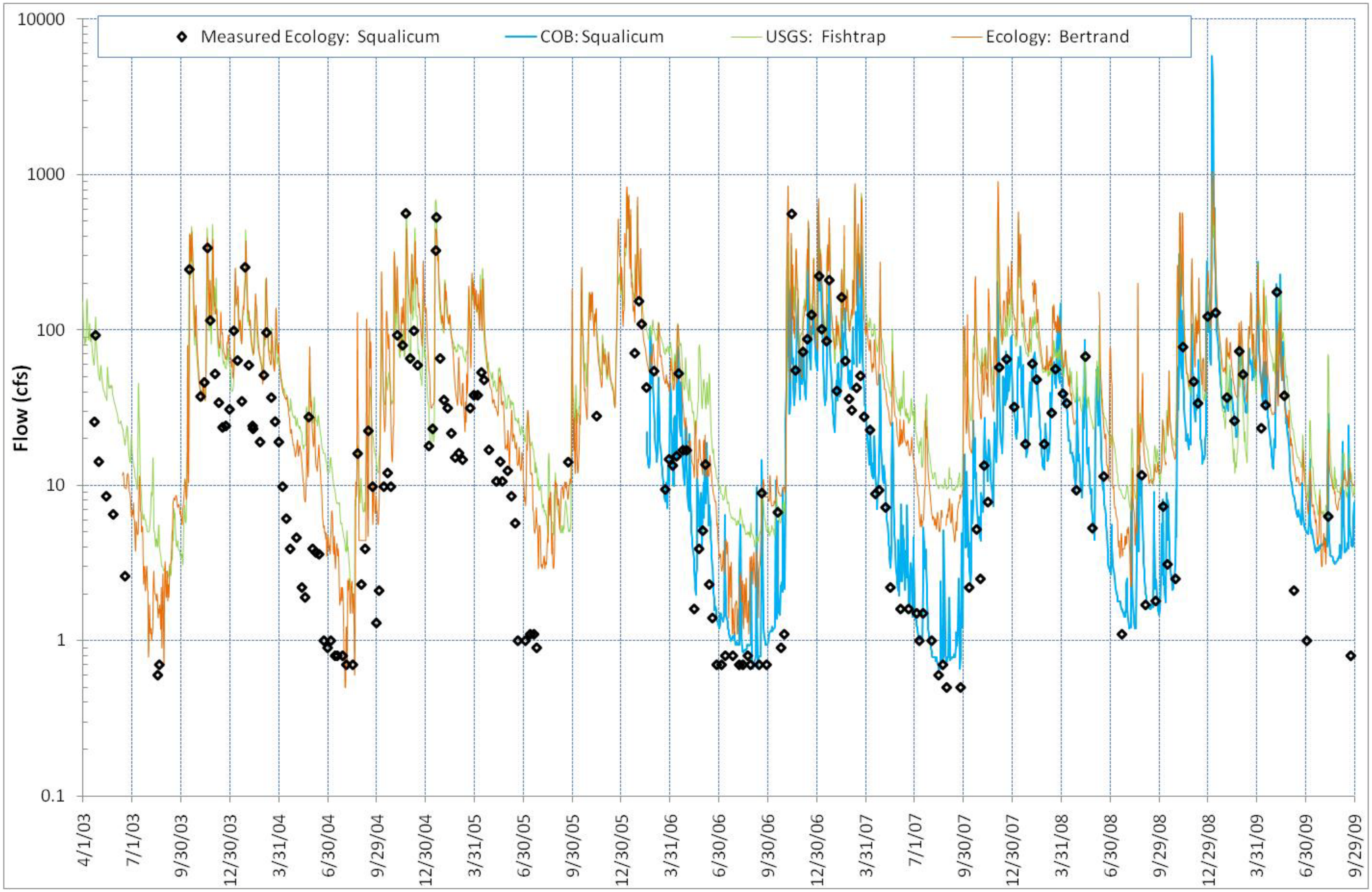

Figure 15. Measured flows at the “Squalicum Creek at West Street” gaging station, with flows from other selected gages.

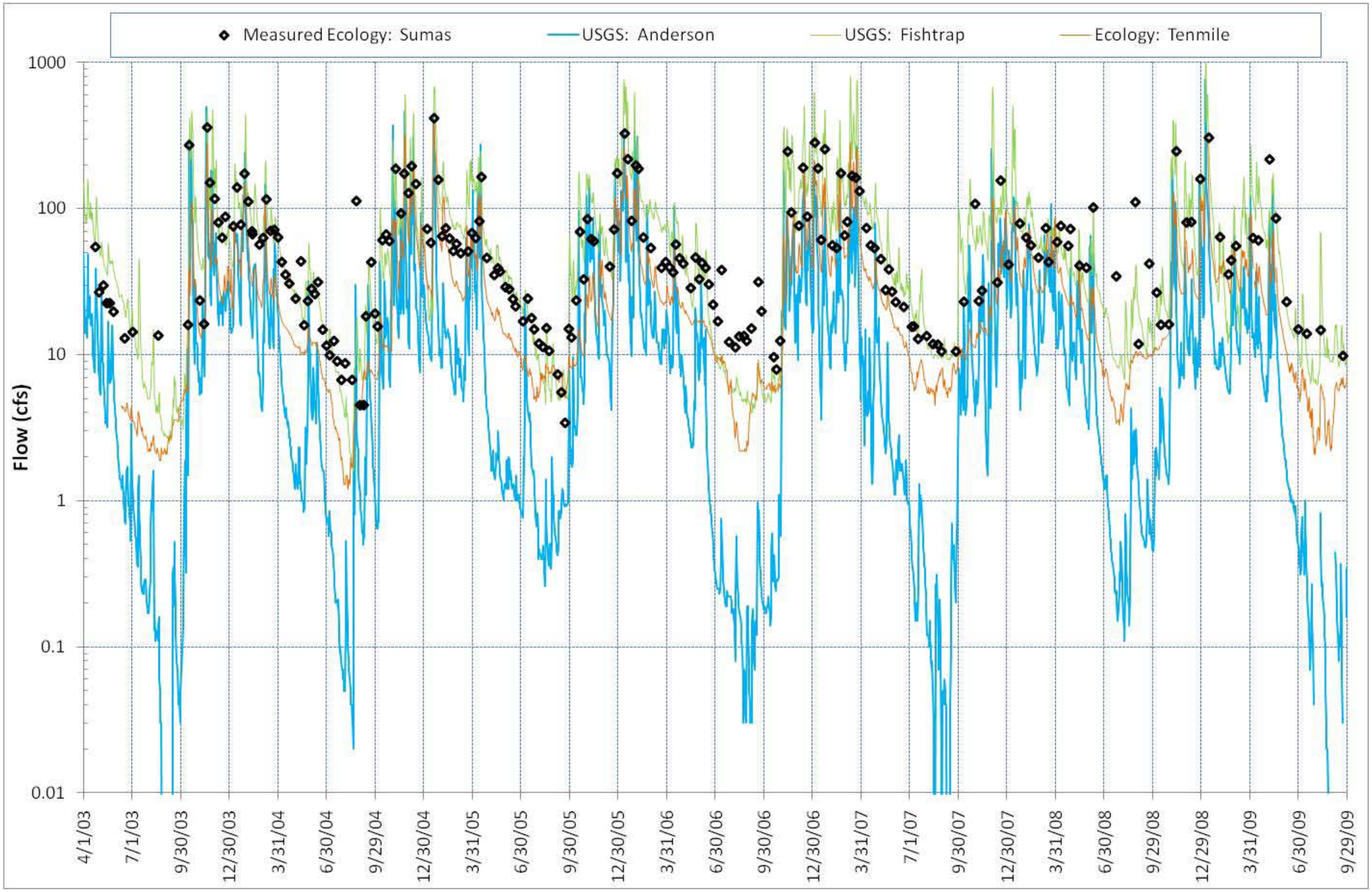

Figure 16. Measured flows at the “Sumas R. at Telegraph Road” gaging station, with flows from other selected gages.

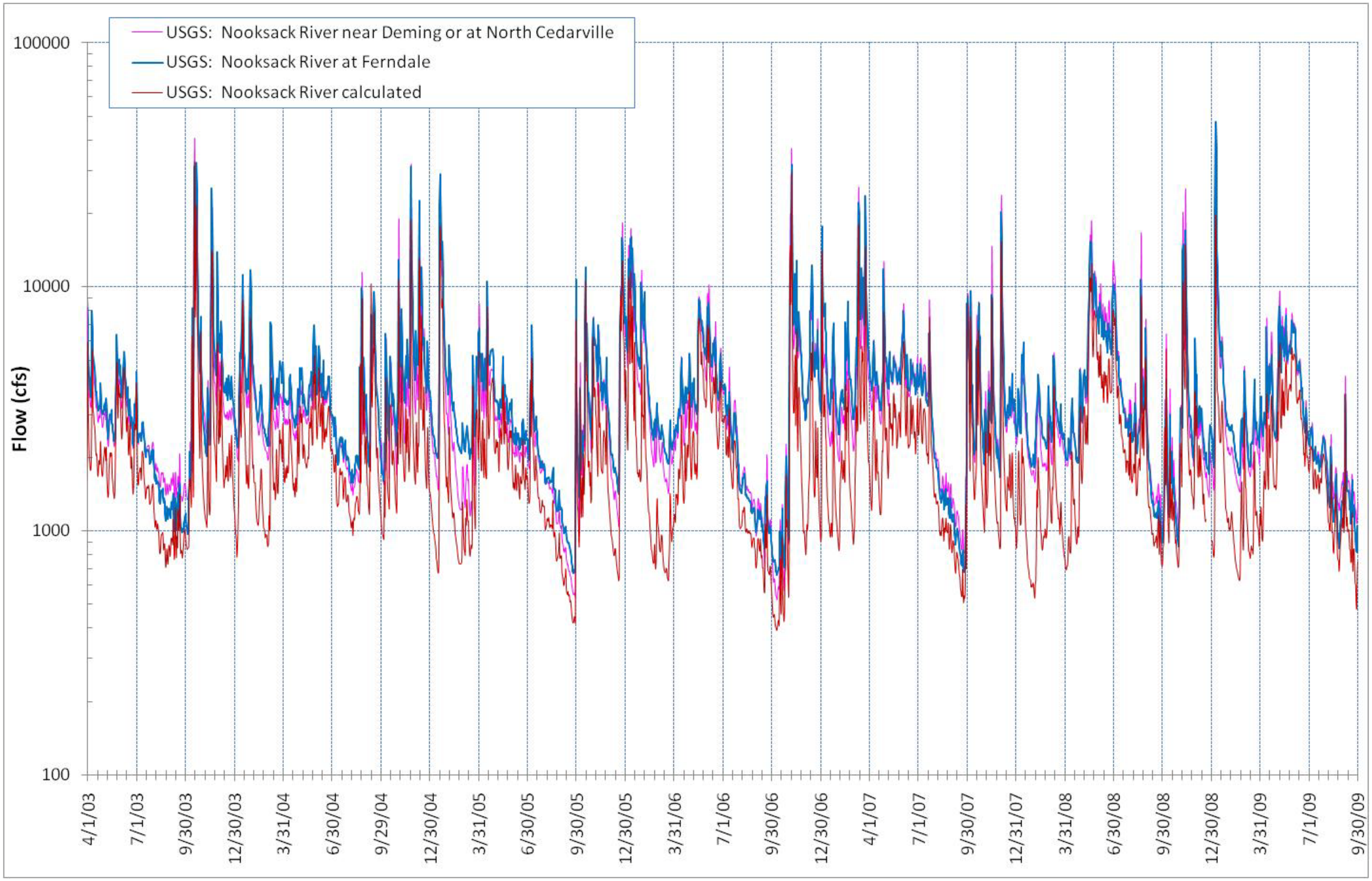

Figure 17. Recent measured flows in the Nooksack River from the gaging stations “near Deming”, “at North Cedarville”, and “at Ferndale” and from the sums of daily flows from gages in the three Forks of the Nooksack River.

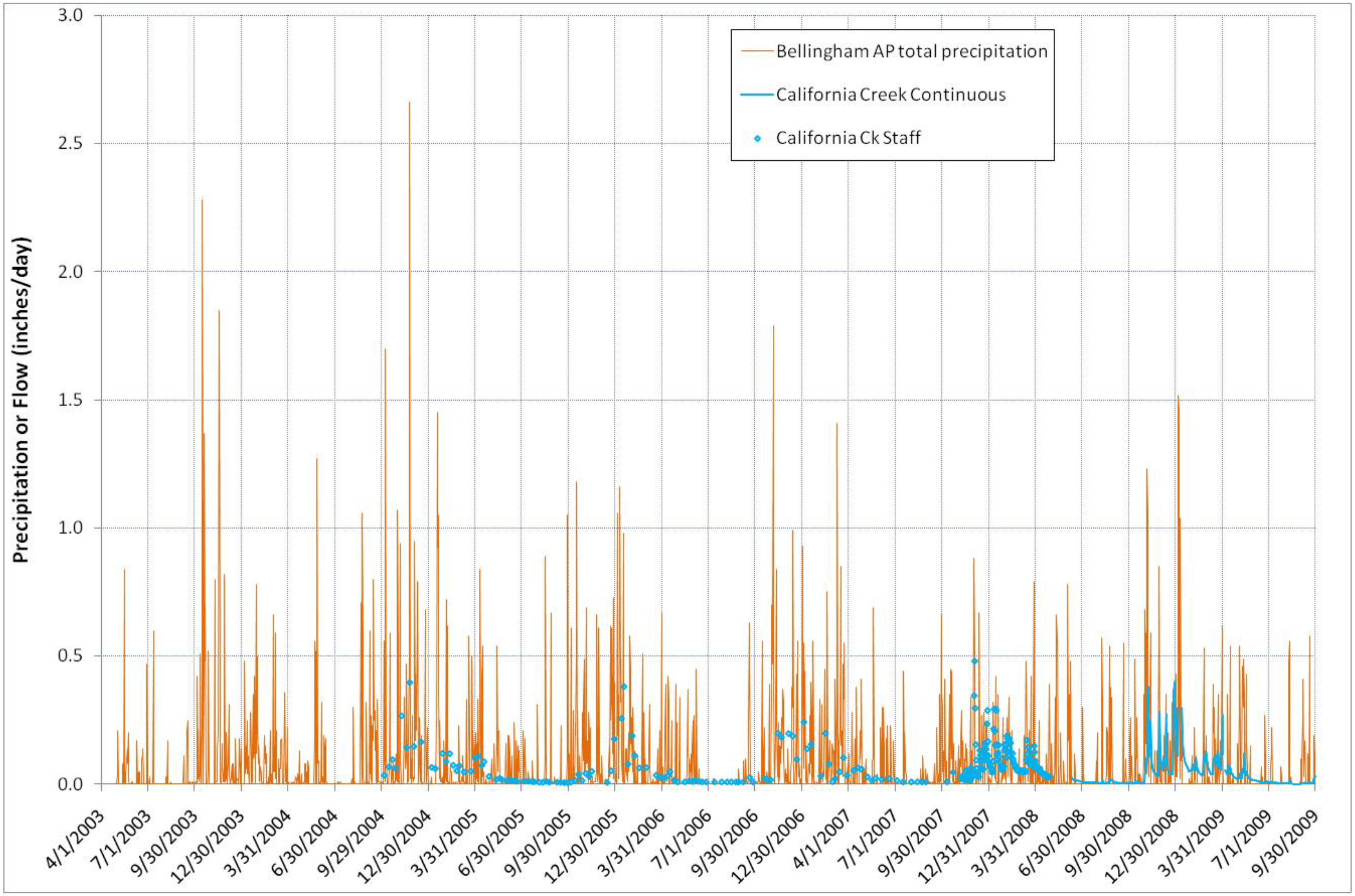

Figure 18. Measured areal flows at the “California Creek at Valley View Road” gaging station, with precipitation data.

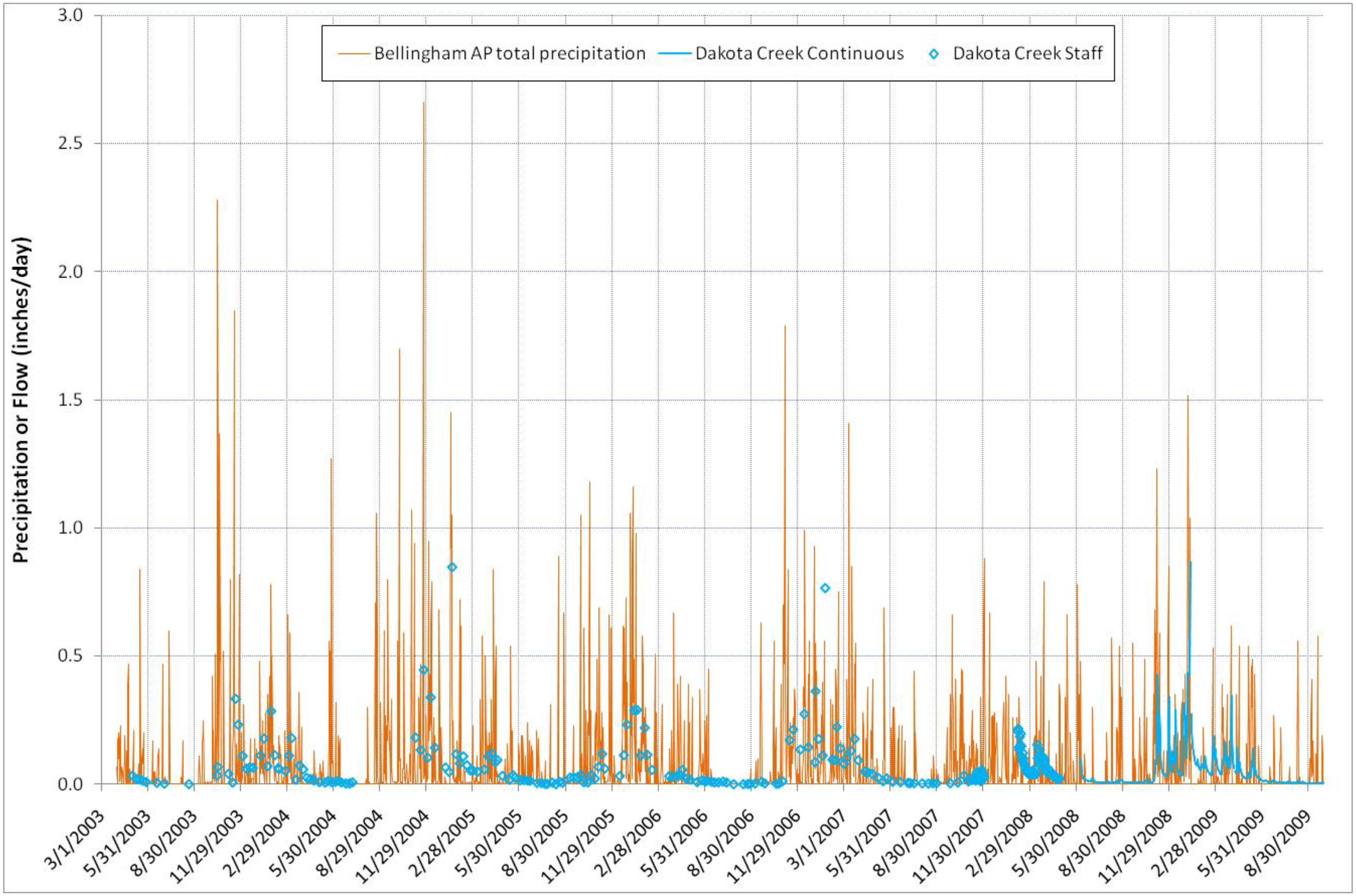

Figure 19. Measured areal flows at the “Dakota Creek at Giles Road” gaging station, with precipitation data.

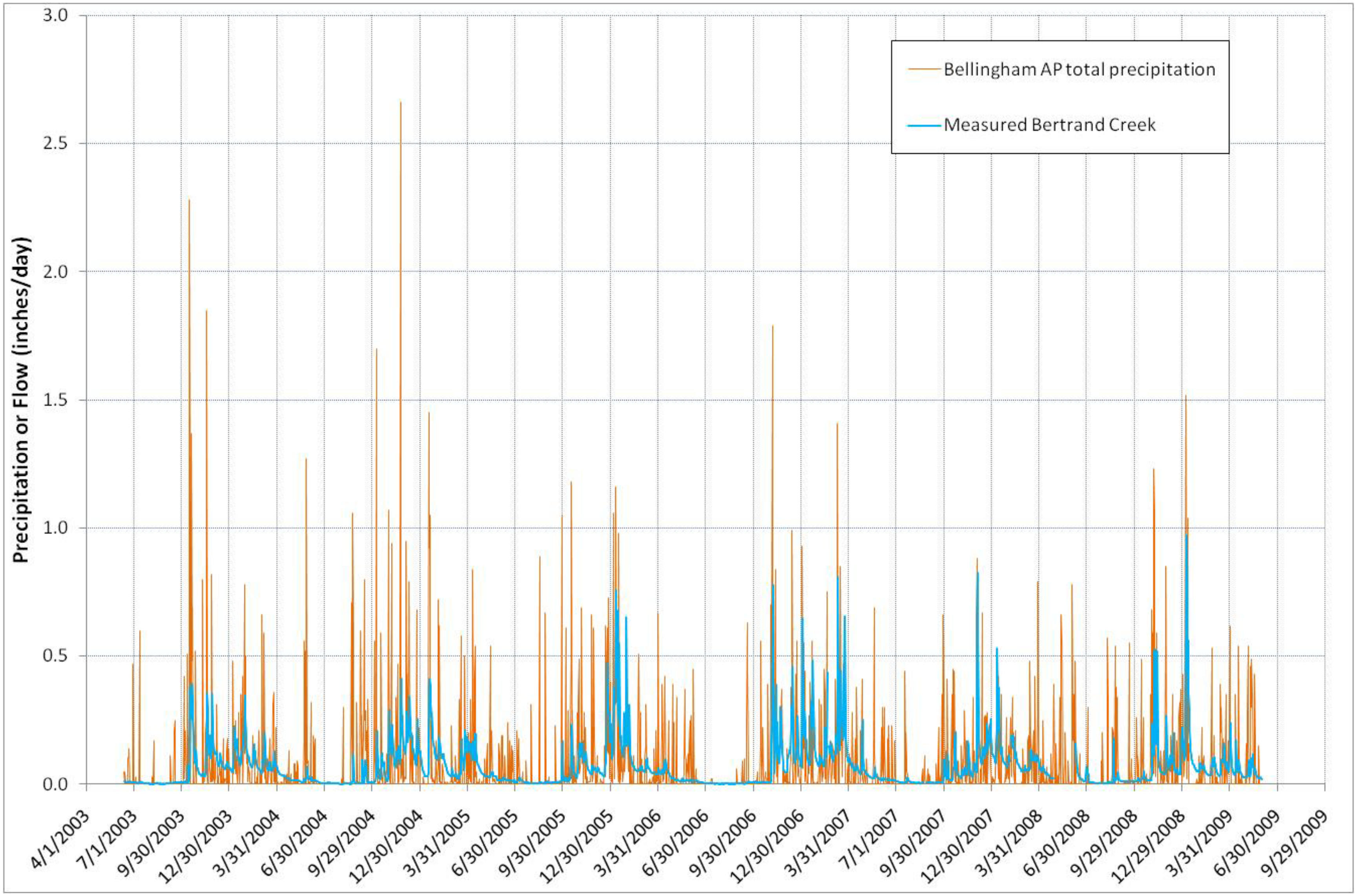

Figure 20. Measured areal flows at the "Bertrand Creek near mouth" gaging station, with precipitation data.

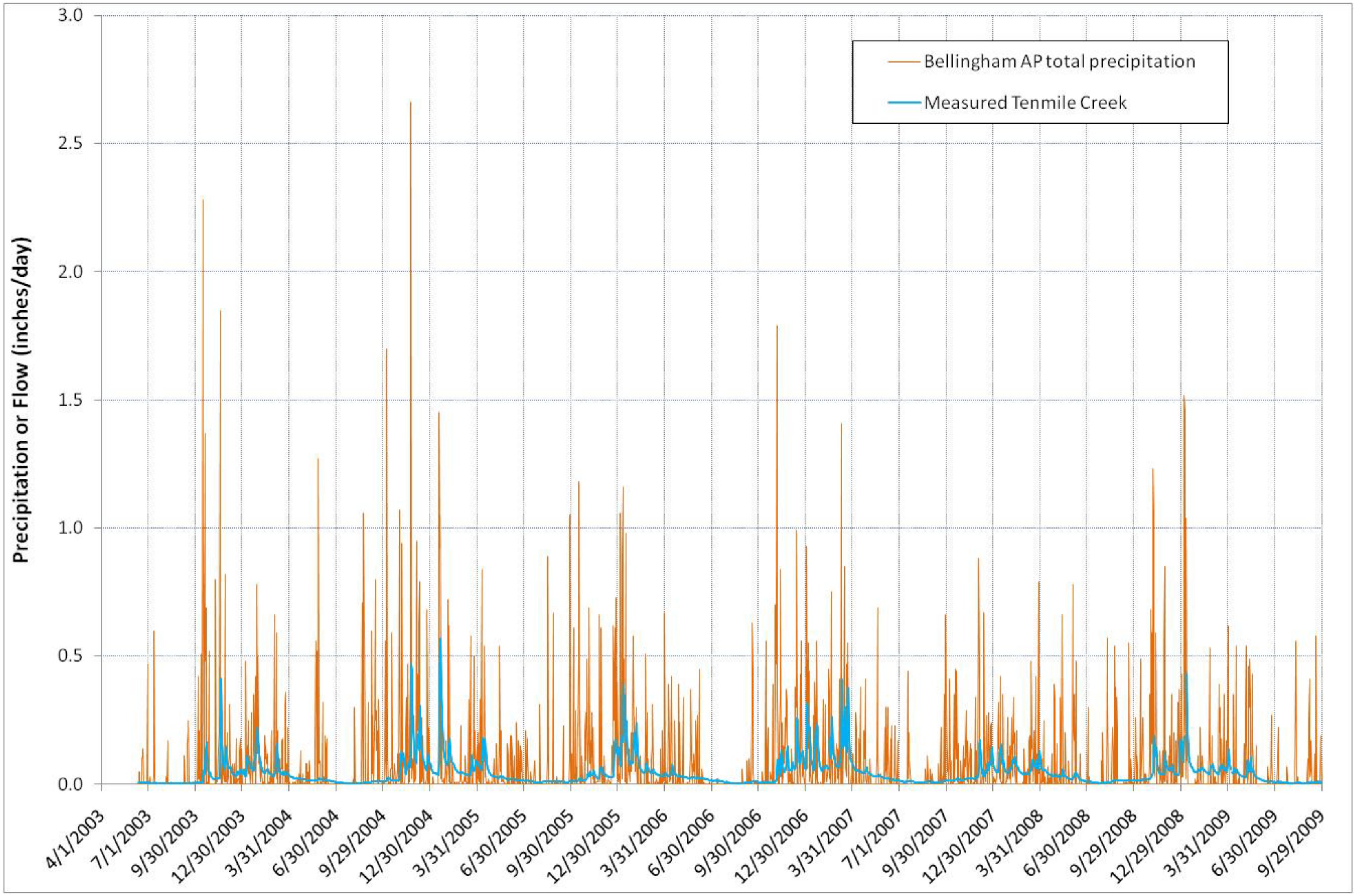

Figure 21. Measured areal flows at the “Tenmile Creek above Barrett Lake” gaging station, with precipitation data.

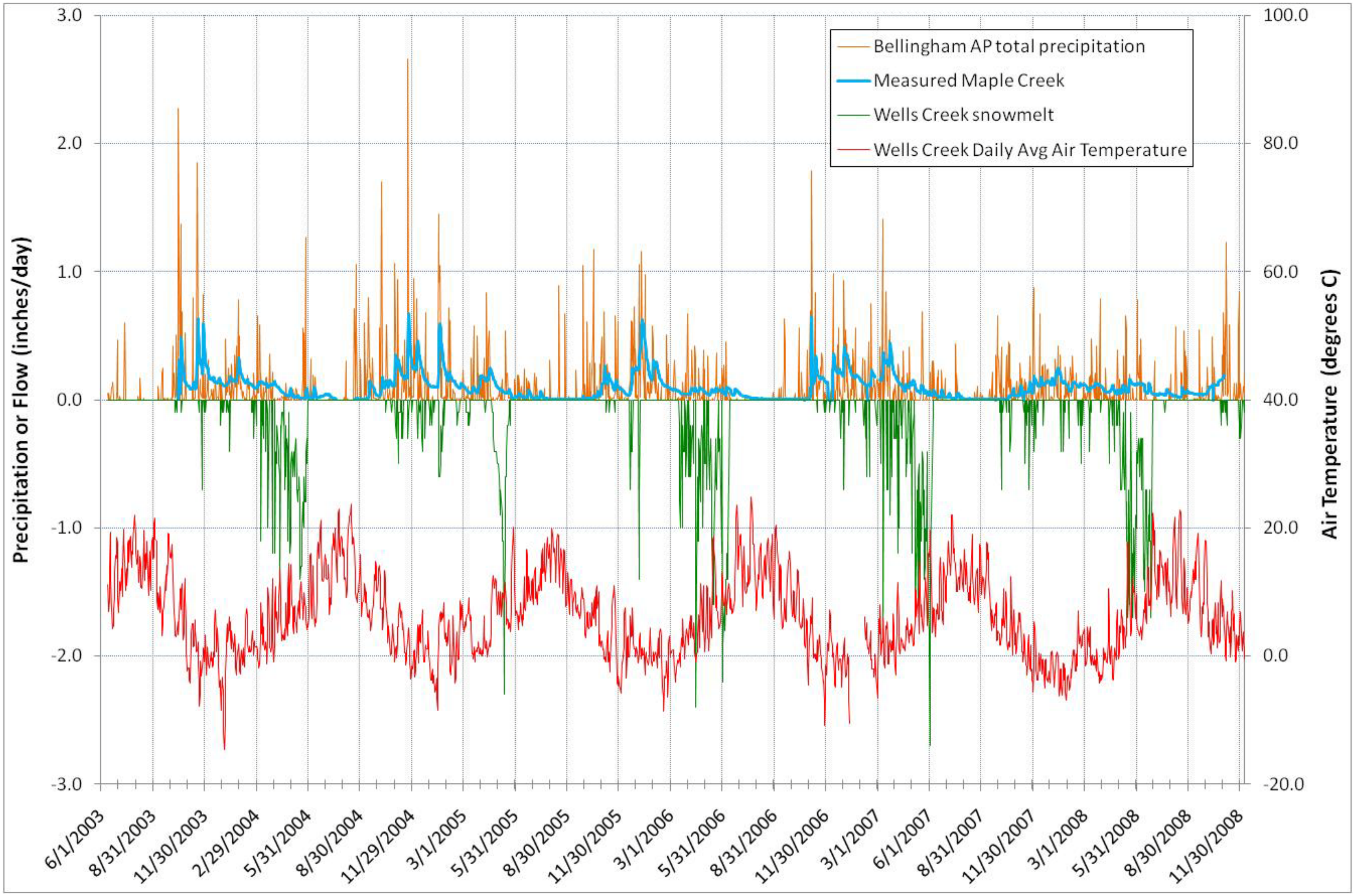

Figure 22. Measured areal flows at the “Maple Creek at mouth” gaging station, with precipitation, snowmelt, and air temperature data.

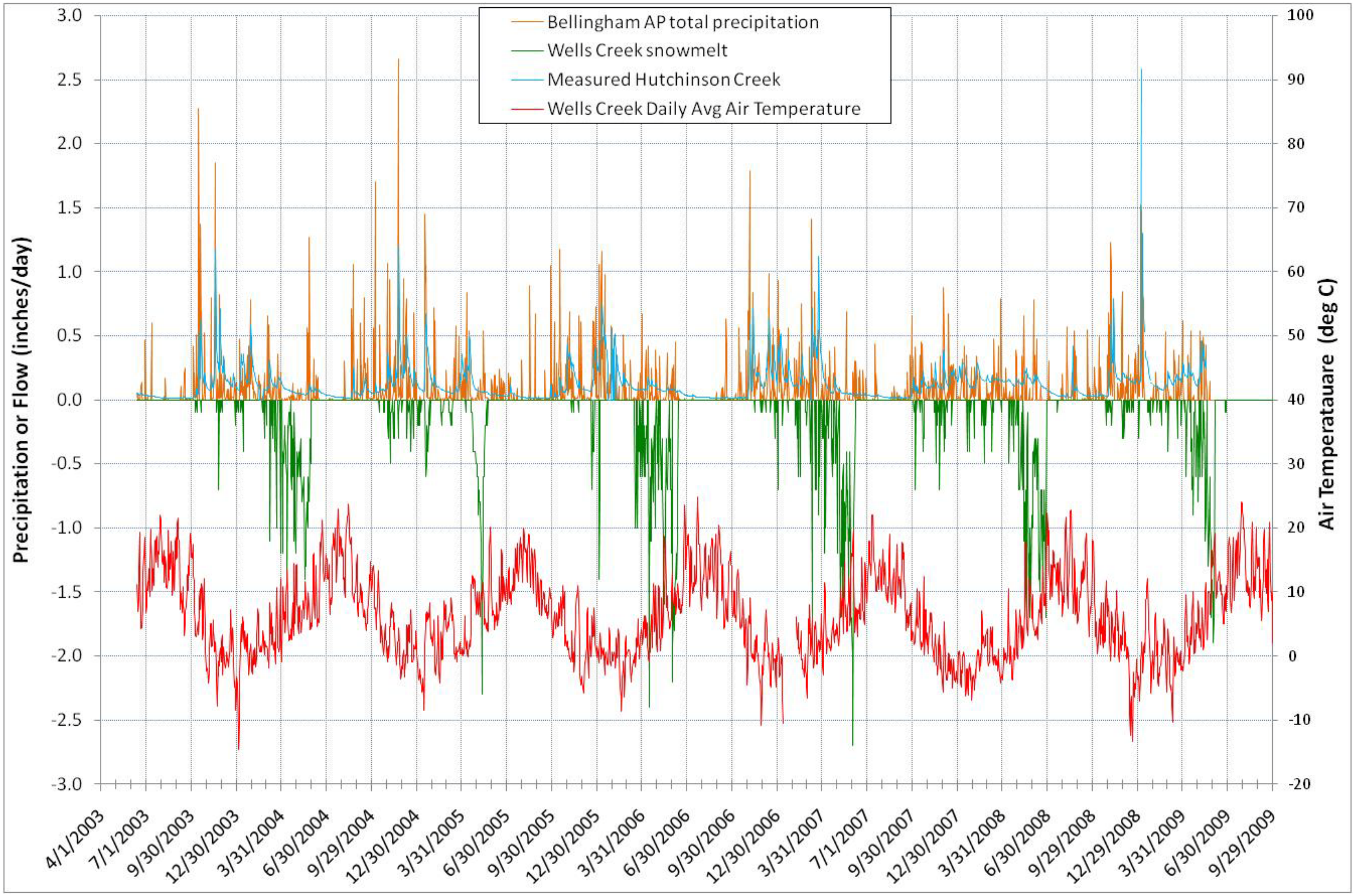

Figure 23. Measured areal flows at the “Hutchinson Creek near Acme” gaging station, with precipitation, snowmelt, and air temperature data.

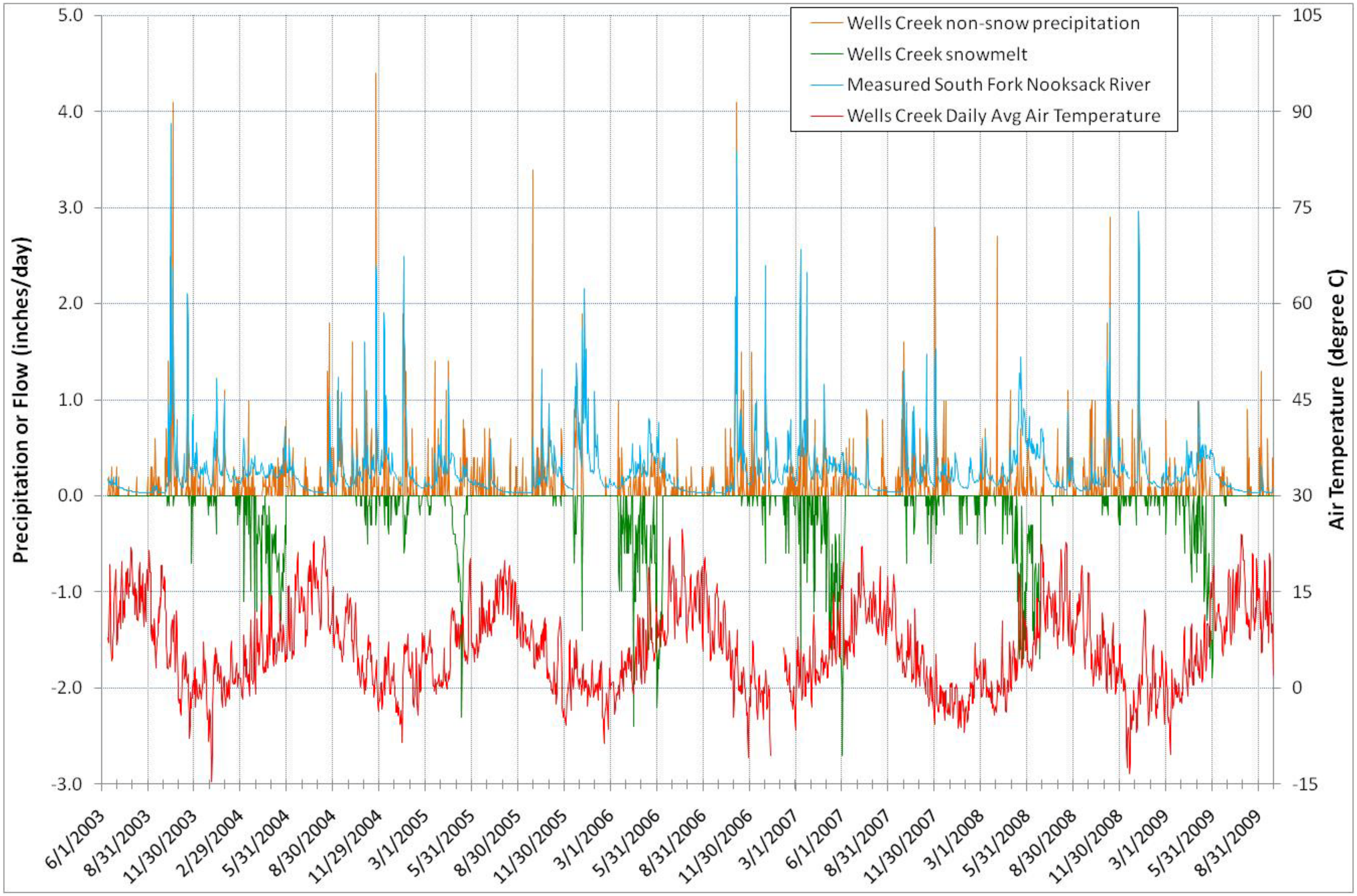

Figure 24. Measured areal flows at the "South Fork Nooksack River at Potter Road" gaging station, with precipitation, snowmelt, and air temperature data.

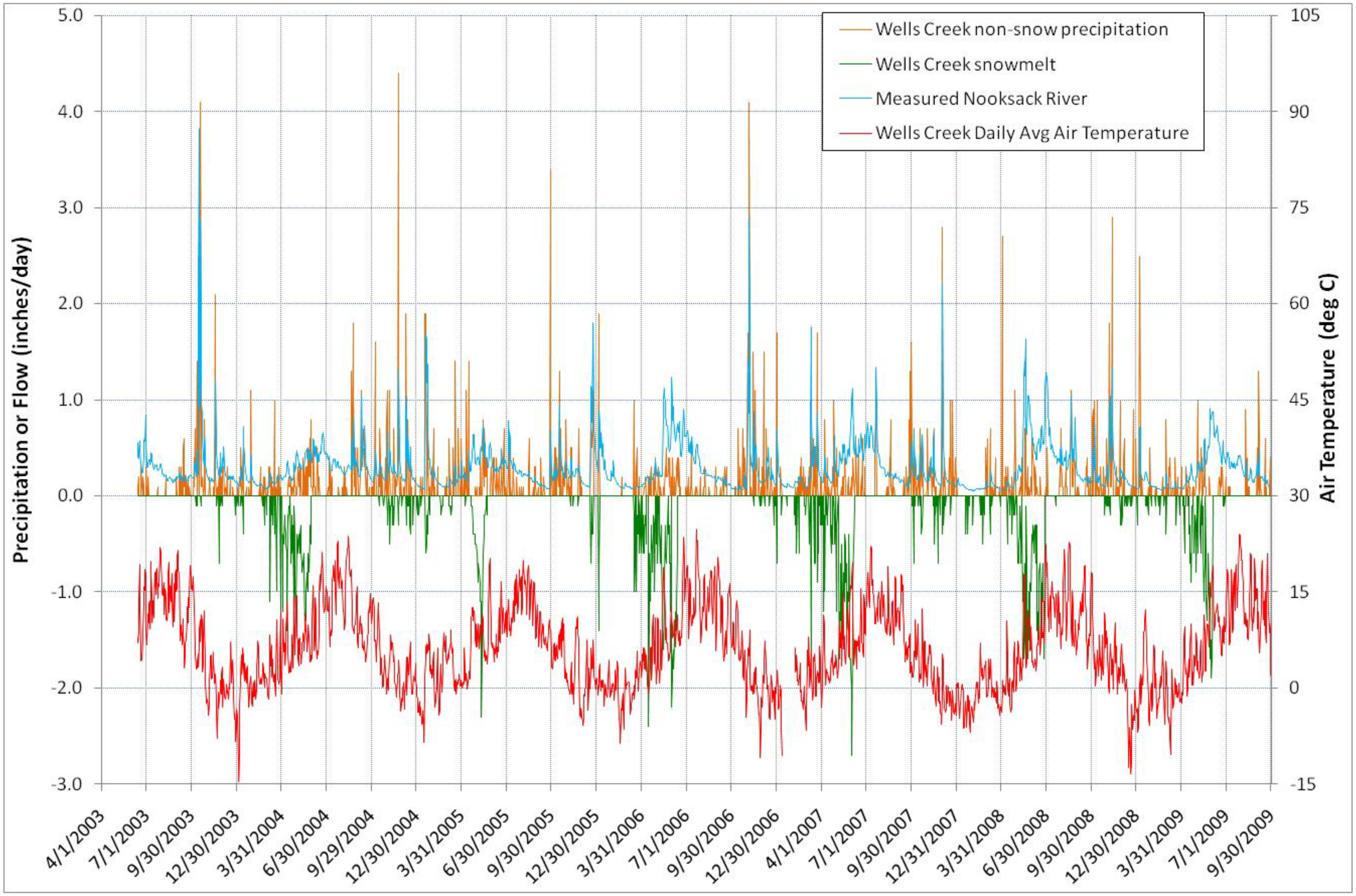

Figure 25. Measured areal flows at the “Nooksack River above the Middle Fork” gaging station, with precipitation, snowmelt, and air temperature data.

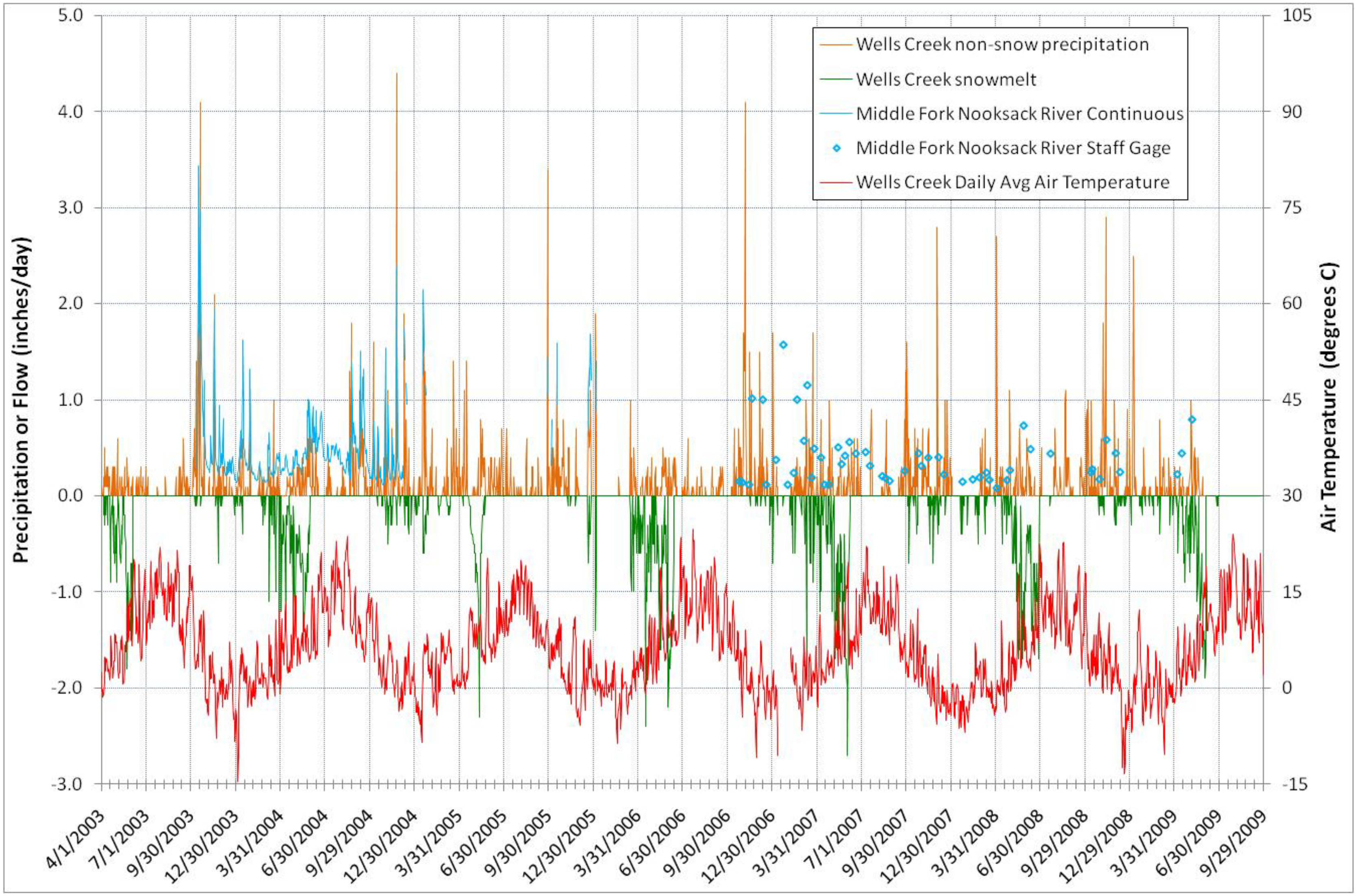

Figure 26. Measured areal flows at the "Middle Fork Nooksack River above Clearwater Creek" gaging station, with precipitation, snowmelt, and air temperature data.

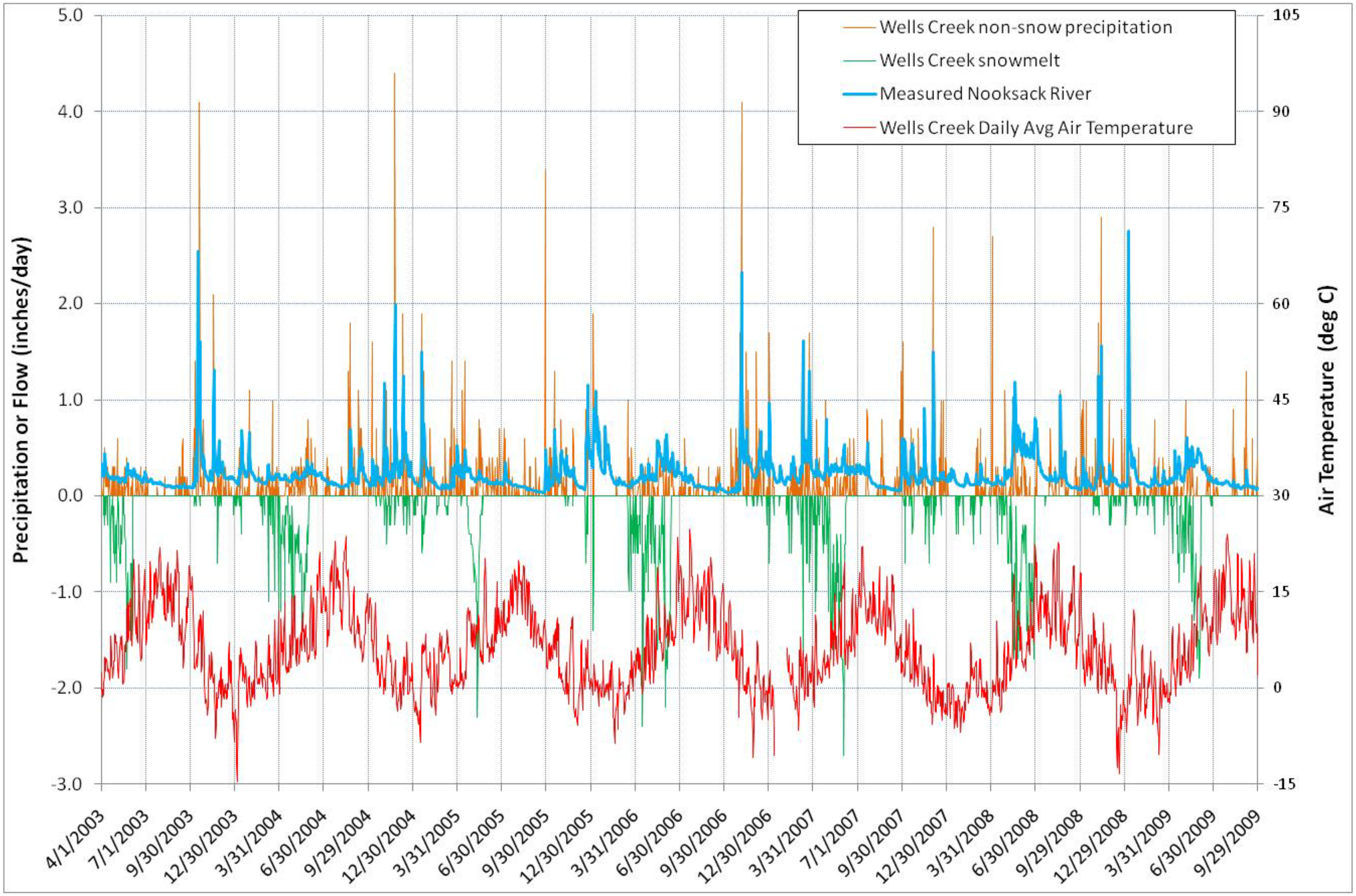

Figure 27. Measured areal flows at the "Nooksack River near Deming" and "Nooksack River at North Cedarville" gaging stations, with precipitation, snowmelt, and air temperature data.

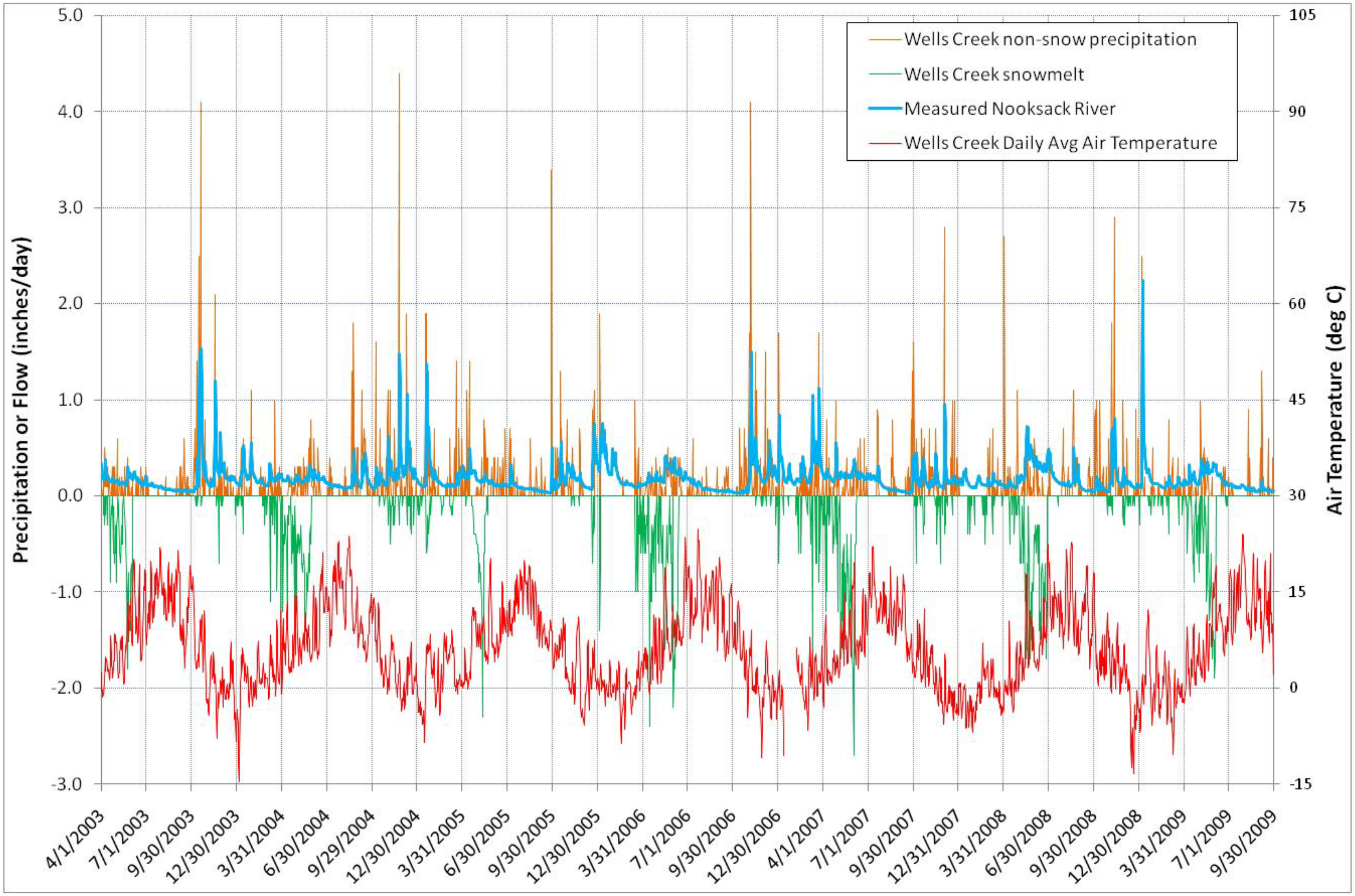

Figure 28. Measured areal flows at the "Nooksack River at Ferndale" gaging station, with precipitation, snowmelt, and air temperature data.

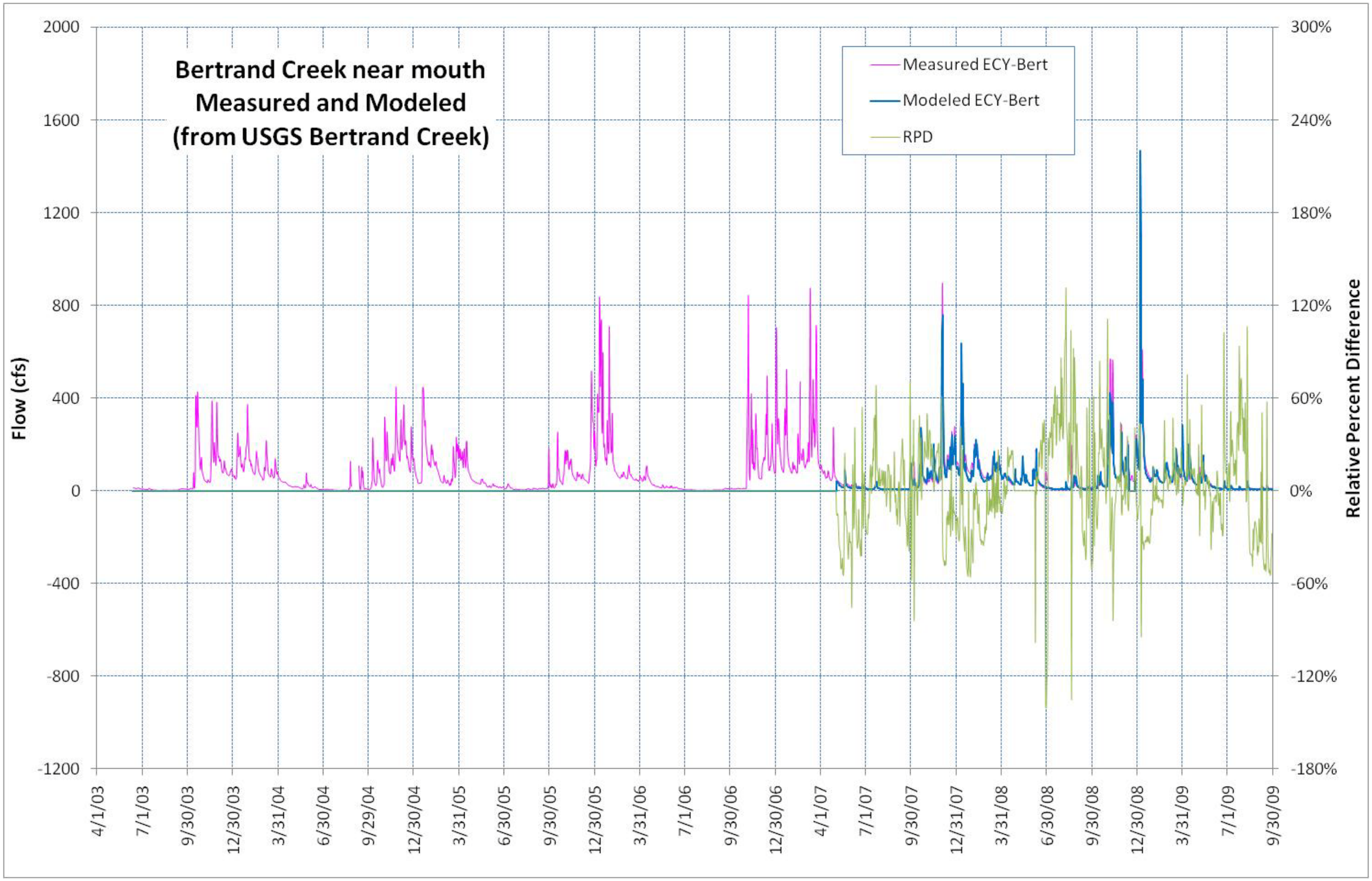

Figure 29. Modeled and measured flows at the Ecology "Bertrand Creek near mouth" gaging station with relative percent difference of paired values.

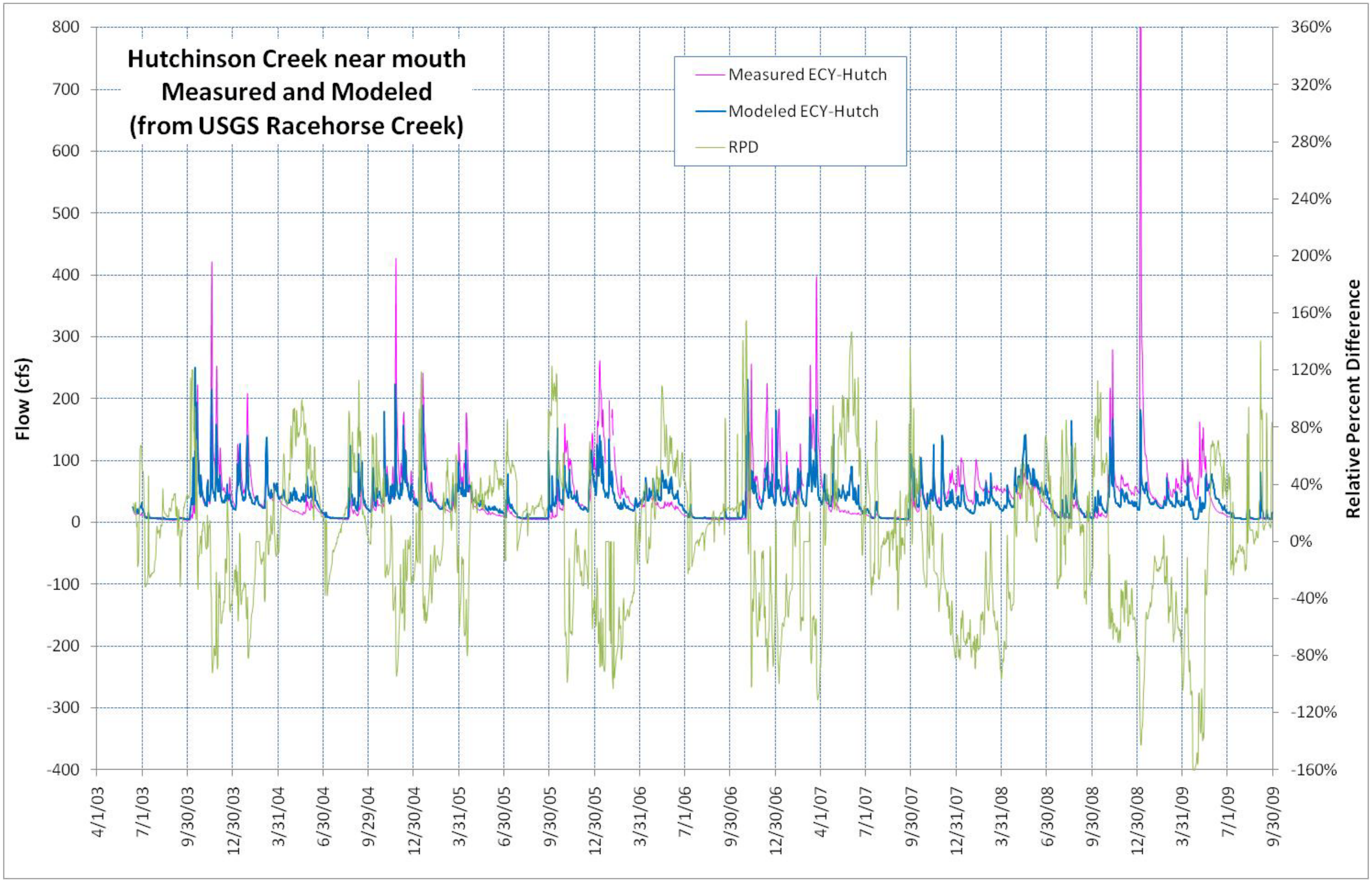

Figure 30. Modeled and measured flows at the Ecology “Hutchinson Creek near Acme” gaging station with relative percent difference of paired values.

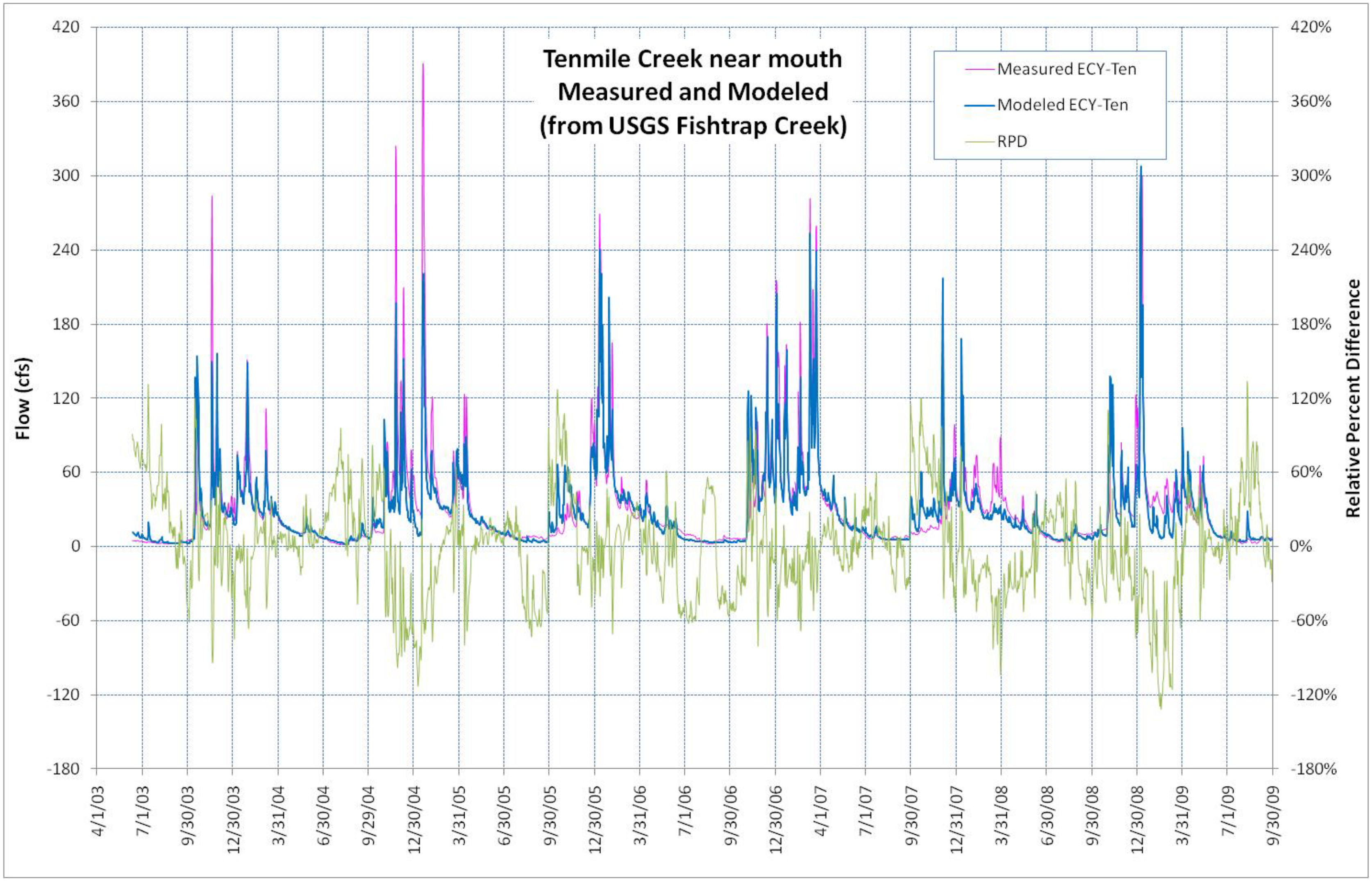

Figure 31. Modeled and measured flows at the Ecology “Tenmile Creek above Barrett Lake” gaging station with relative percent difference of paired values.

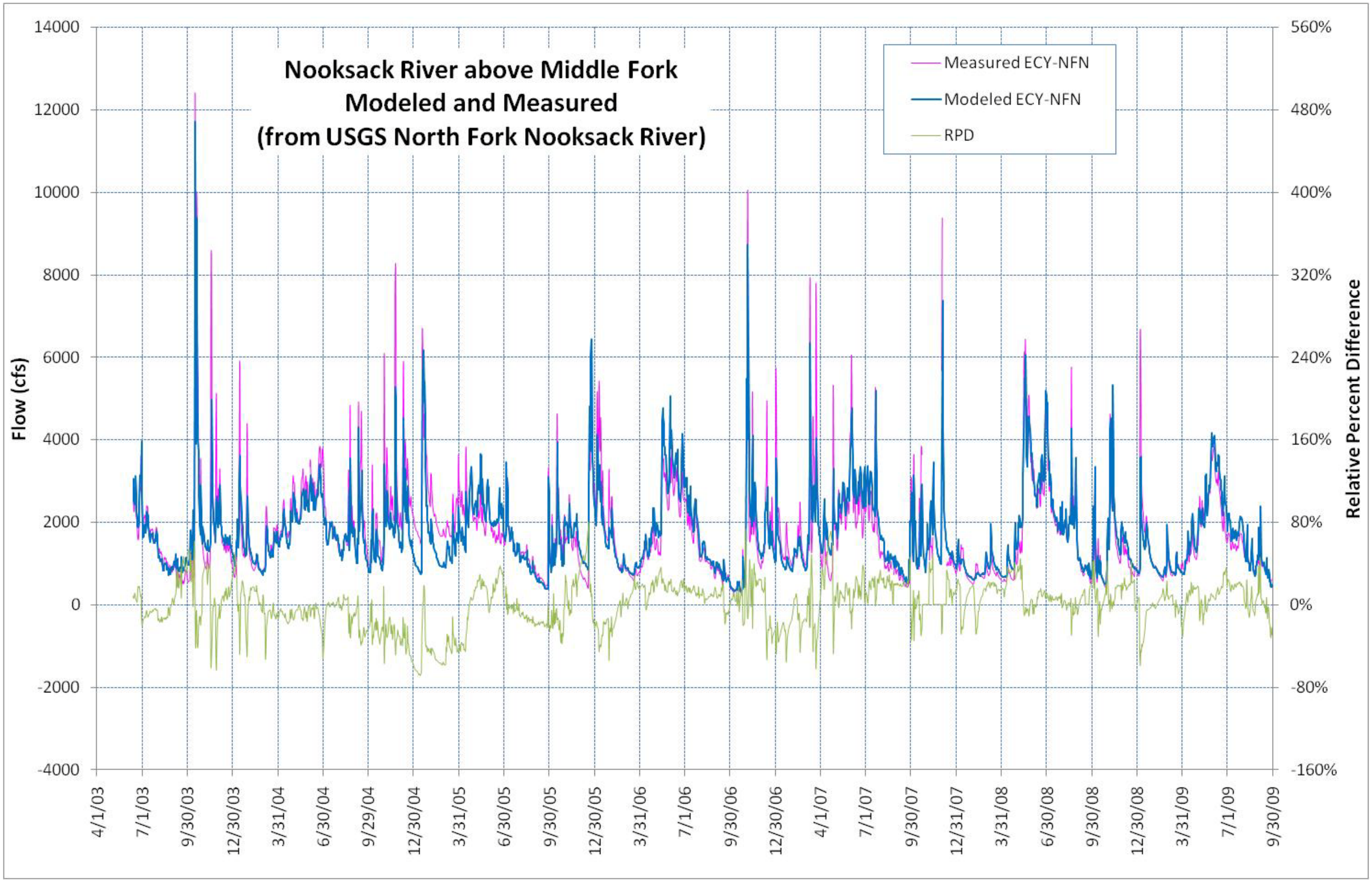

Figure 32. Modeled and measured flows at the Ecology “Nooksack River above the Middle Fork” gaging station with relative percent difference of paired values.

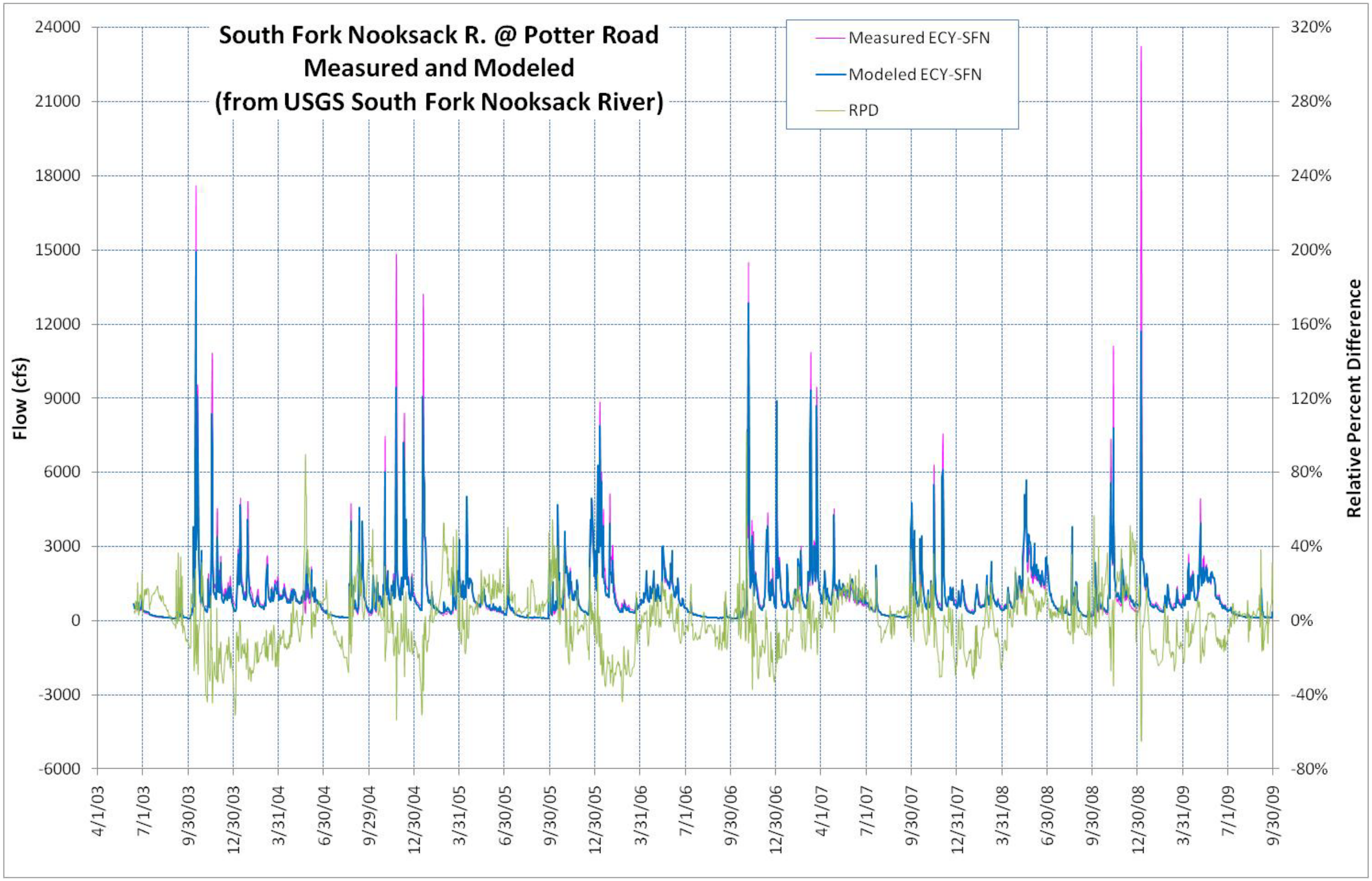

Figure 33. Modeled and measured flows at the "South Fork Nooksack River at Potter Road" gaging station with relative percent difference of paired values.

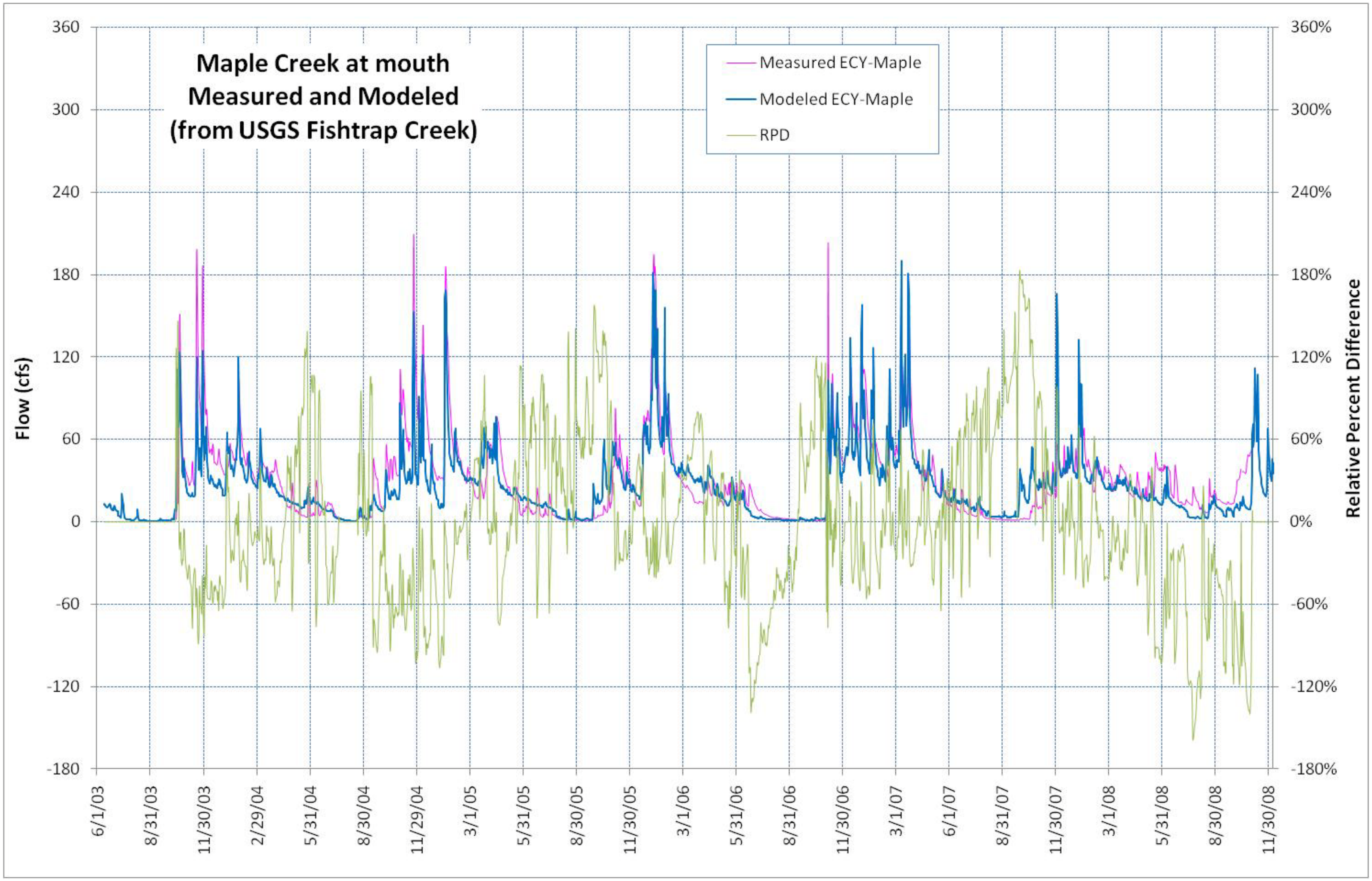

Figure 34. Modeled and measured flows at the “Maple Creek at mouth” gaging station with relative percent difference of paired values.

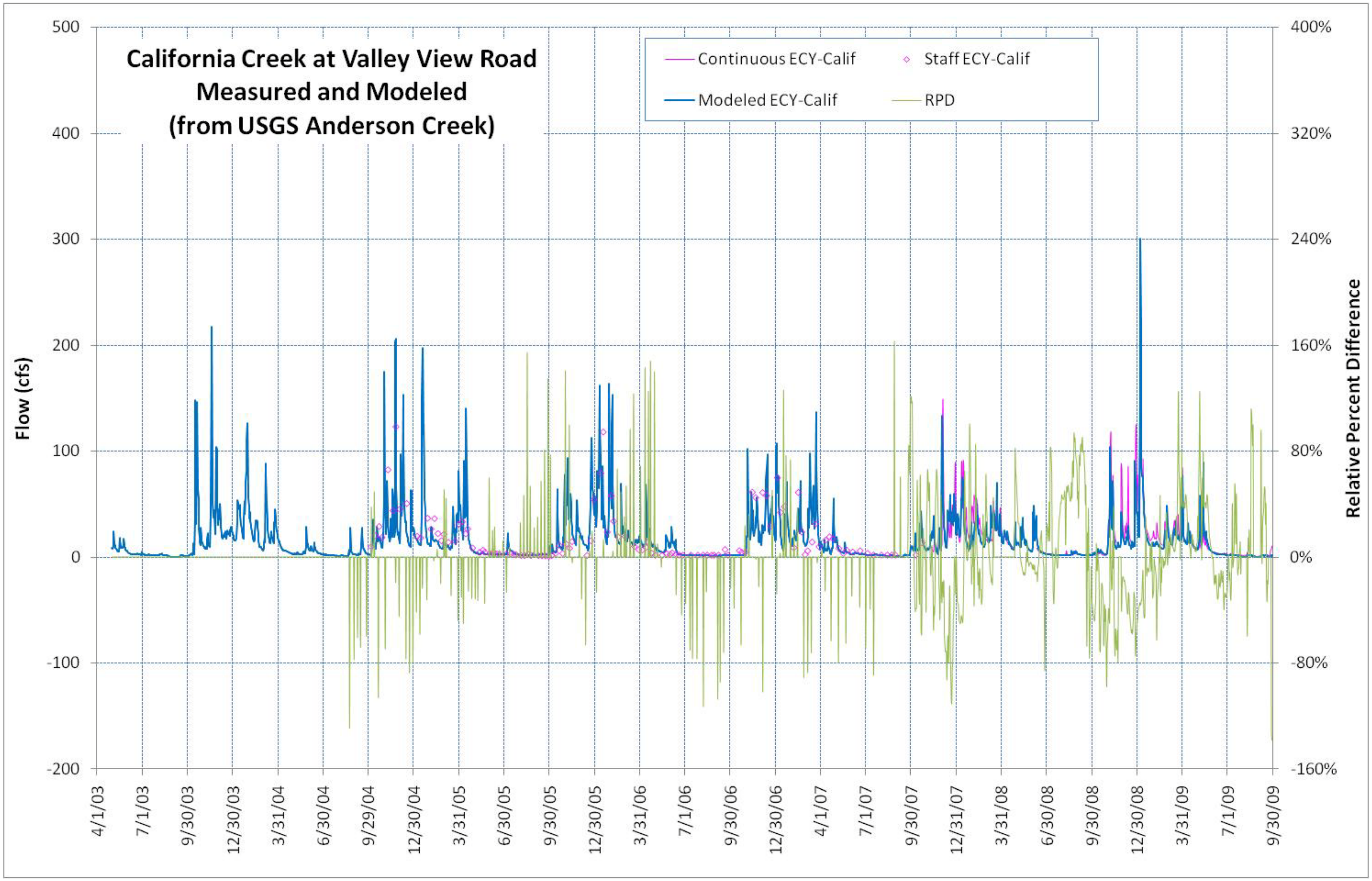

Figure 35. Modeled and measured flows at the "California Creek at Valley View Road" gaging station with relative percent difference of paired values.

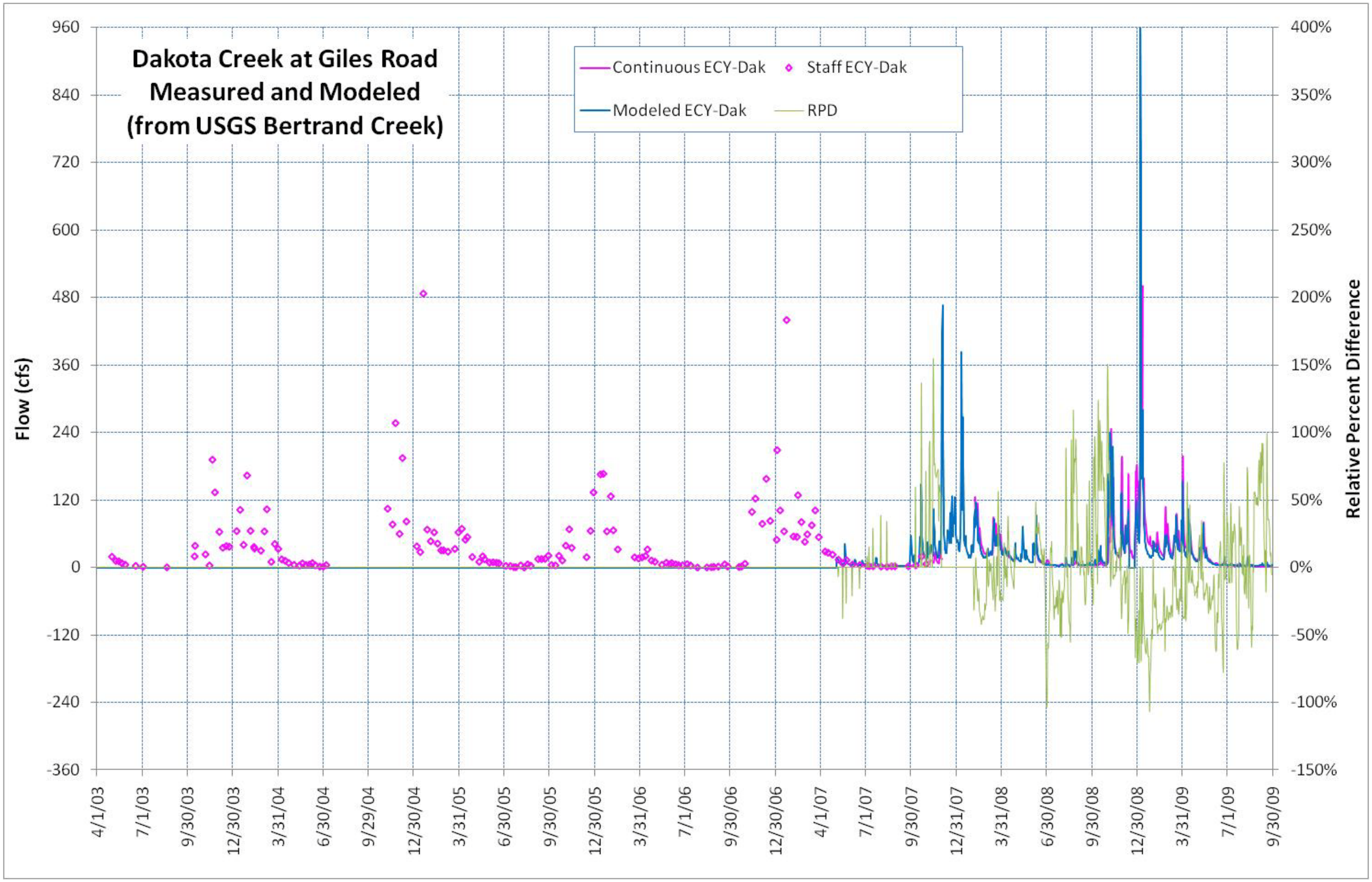

Figure 36. Modeled and measured flows at the “Dakota Creek at Giles Road” gaging station with relative percent difference of paired values.

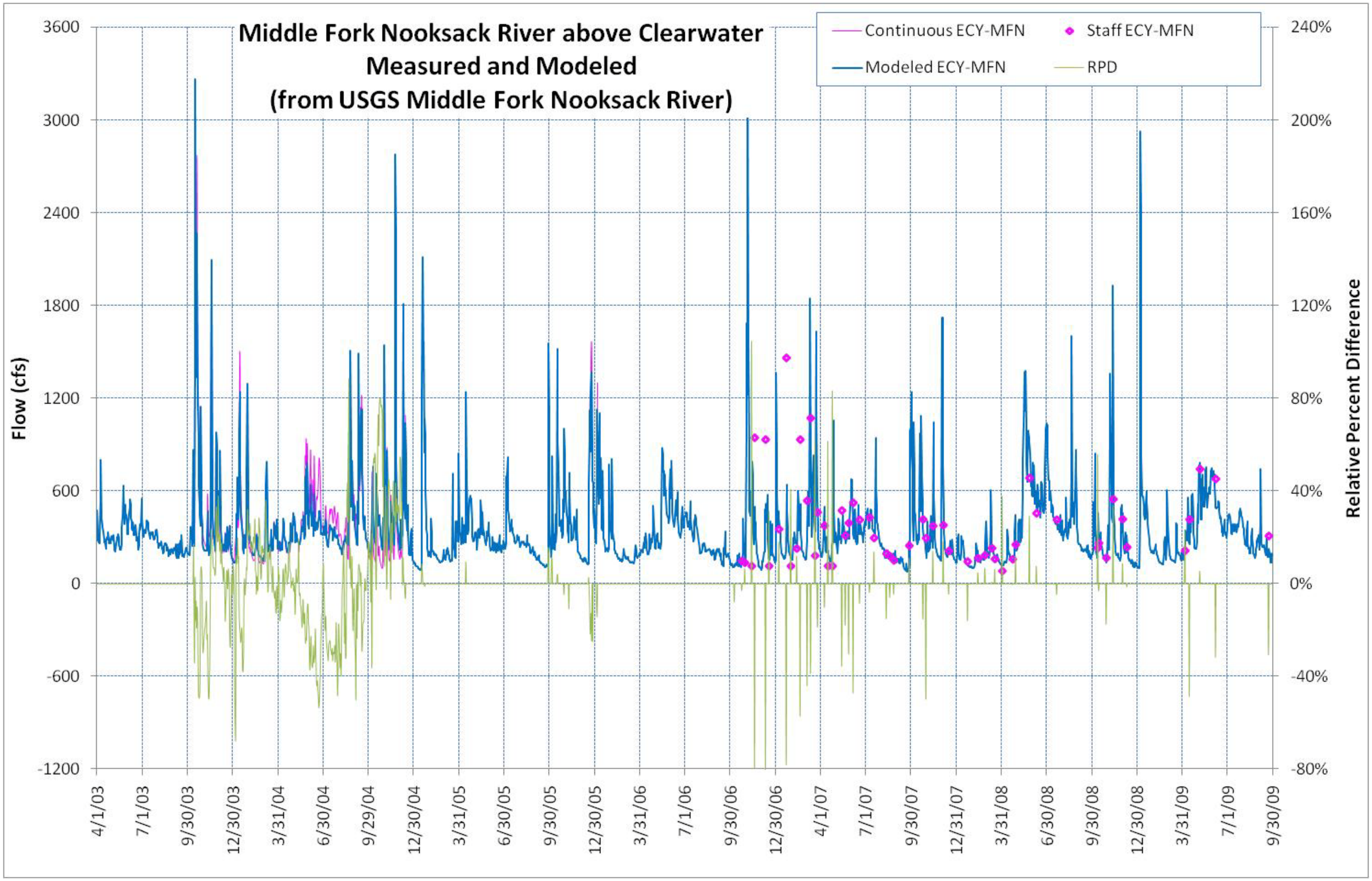

Figure 37. Modeled and measured flows at the "Middle Fork Nooksack River above Clearwater Creek" gaging station with relative percent difference of paired values.

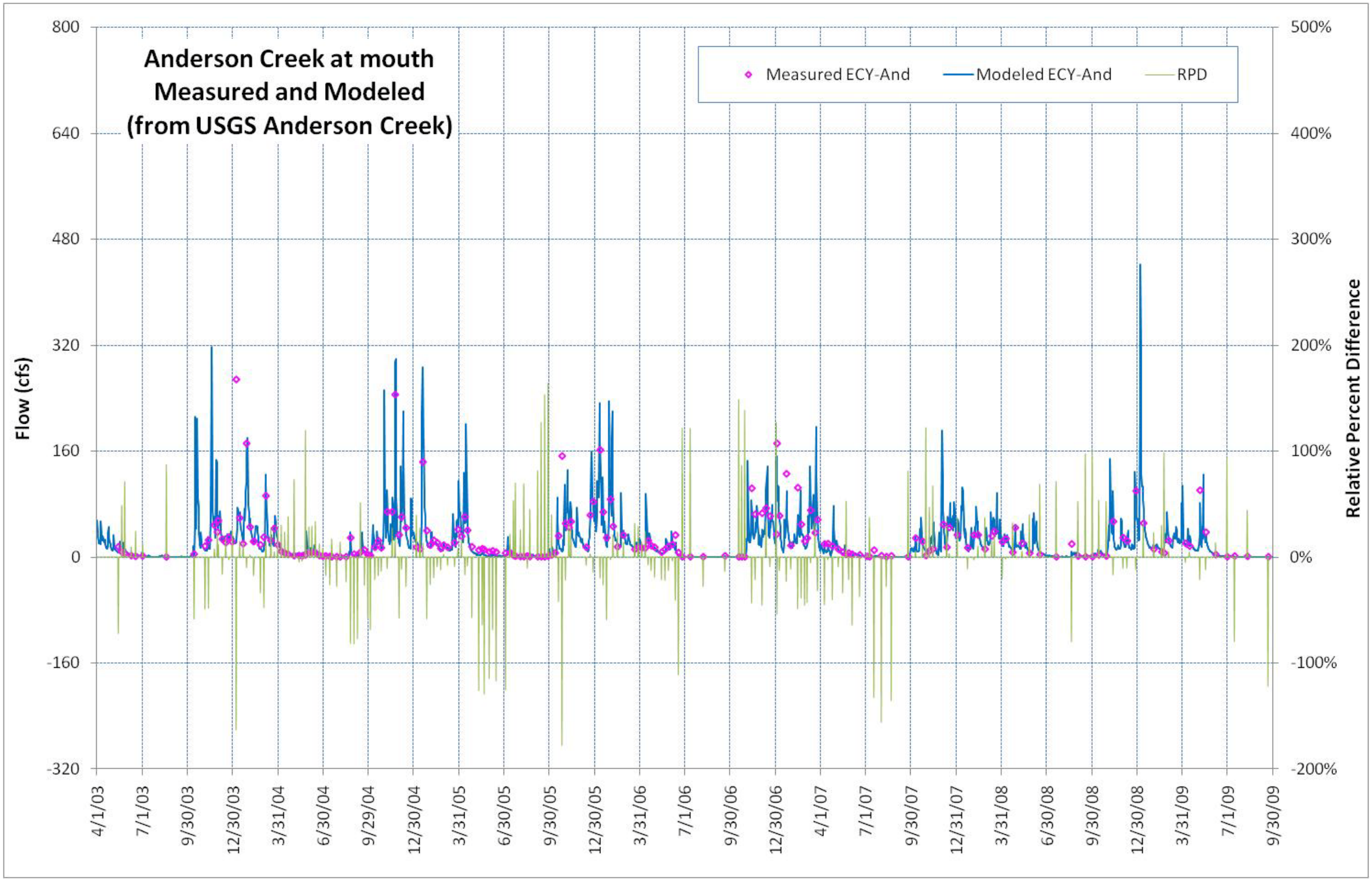

Figure 38. Modeled and measured flows at the "Anderson Creek at mouth" gaging station with relative percent difference of paired values.

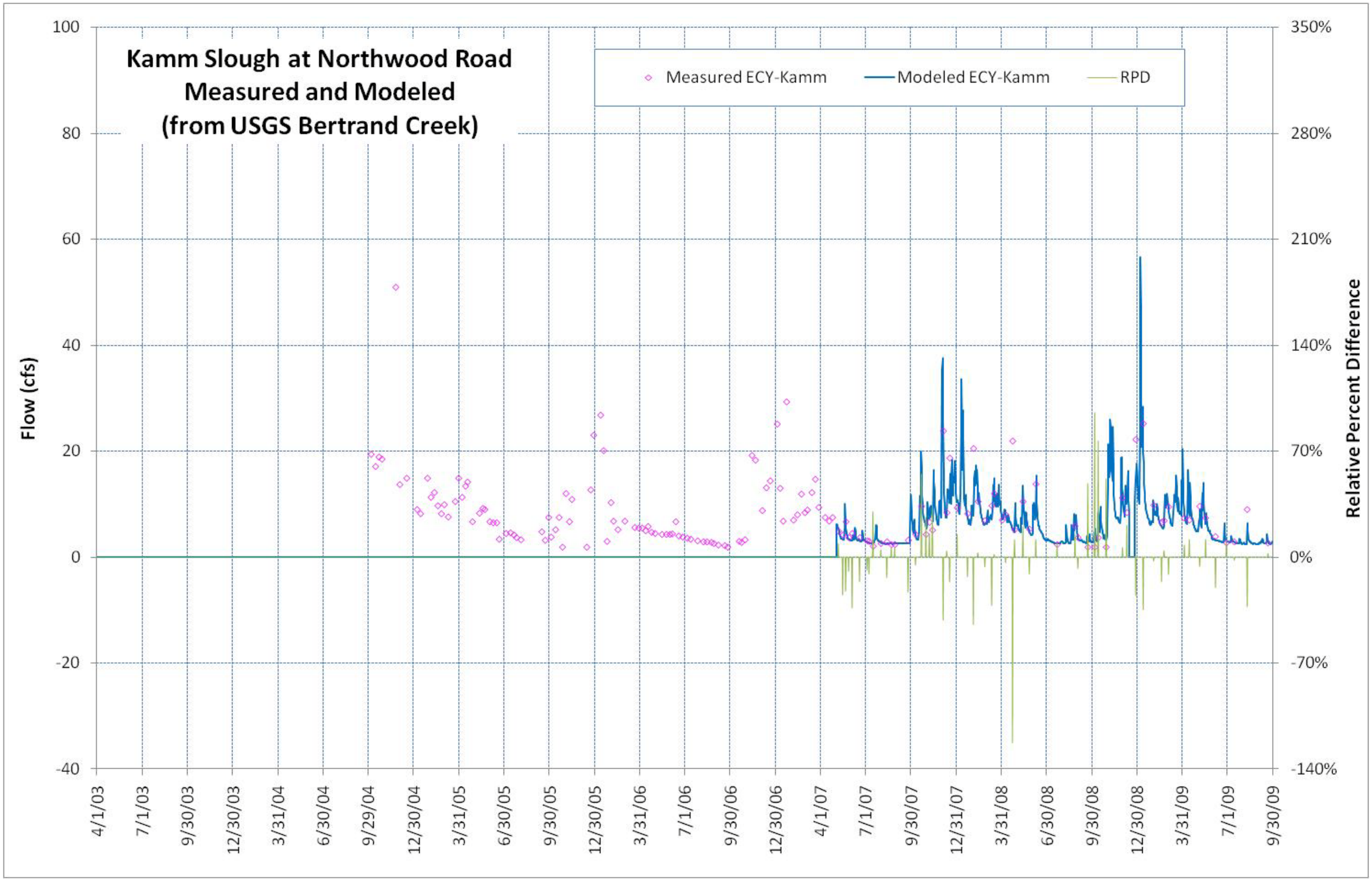

Figure 39. Modeled and measured flows at the "Kamm Slough at Northwood Road" gaging station with relative percent difference of paired values.

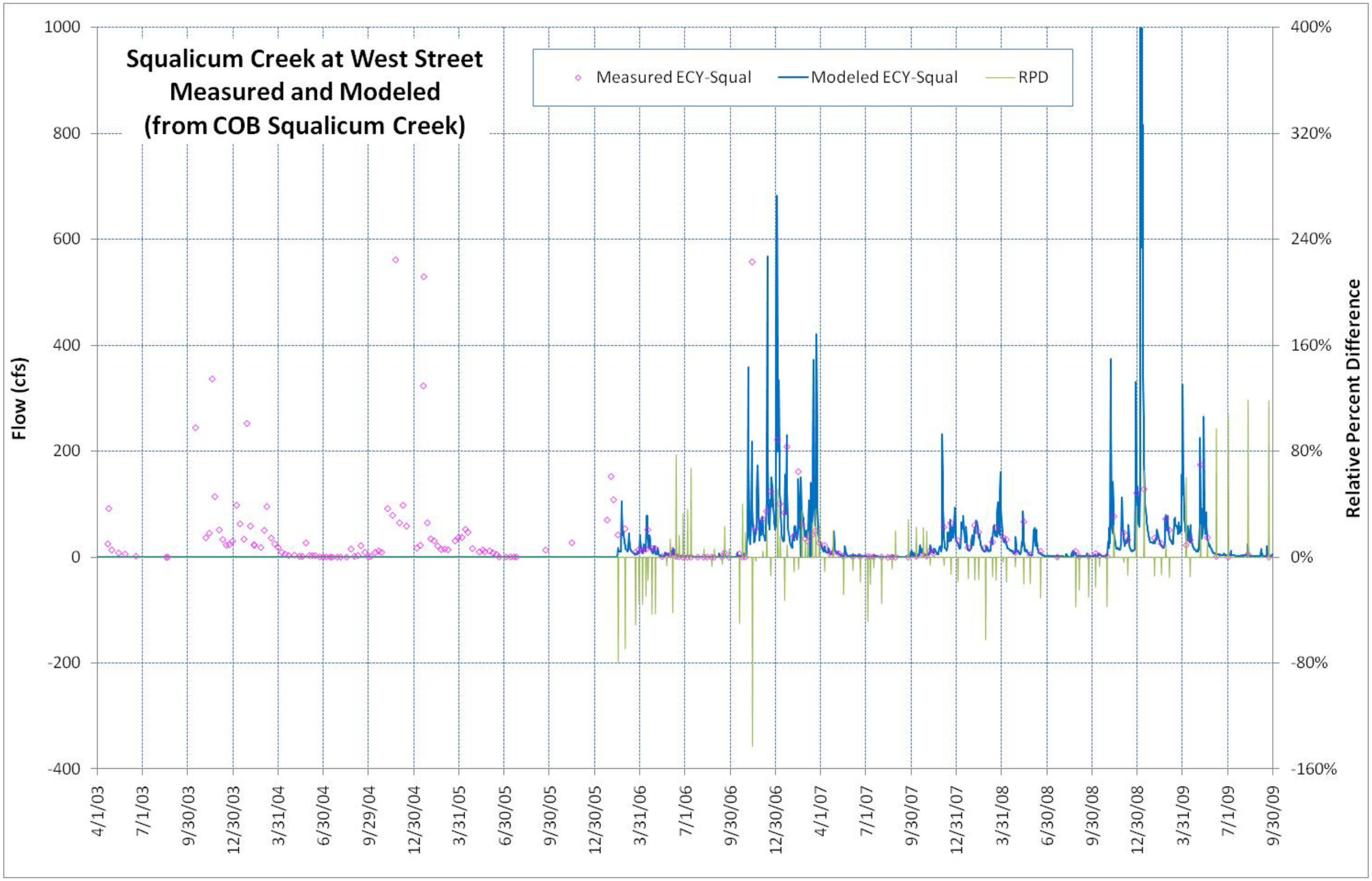

Figure 40. Modeled and measured flows at the Ecology "Squalicum Creek at West Street" gaging station with relative percent difference of paired values.

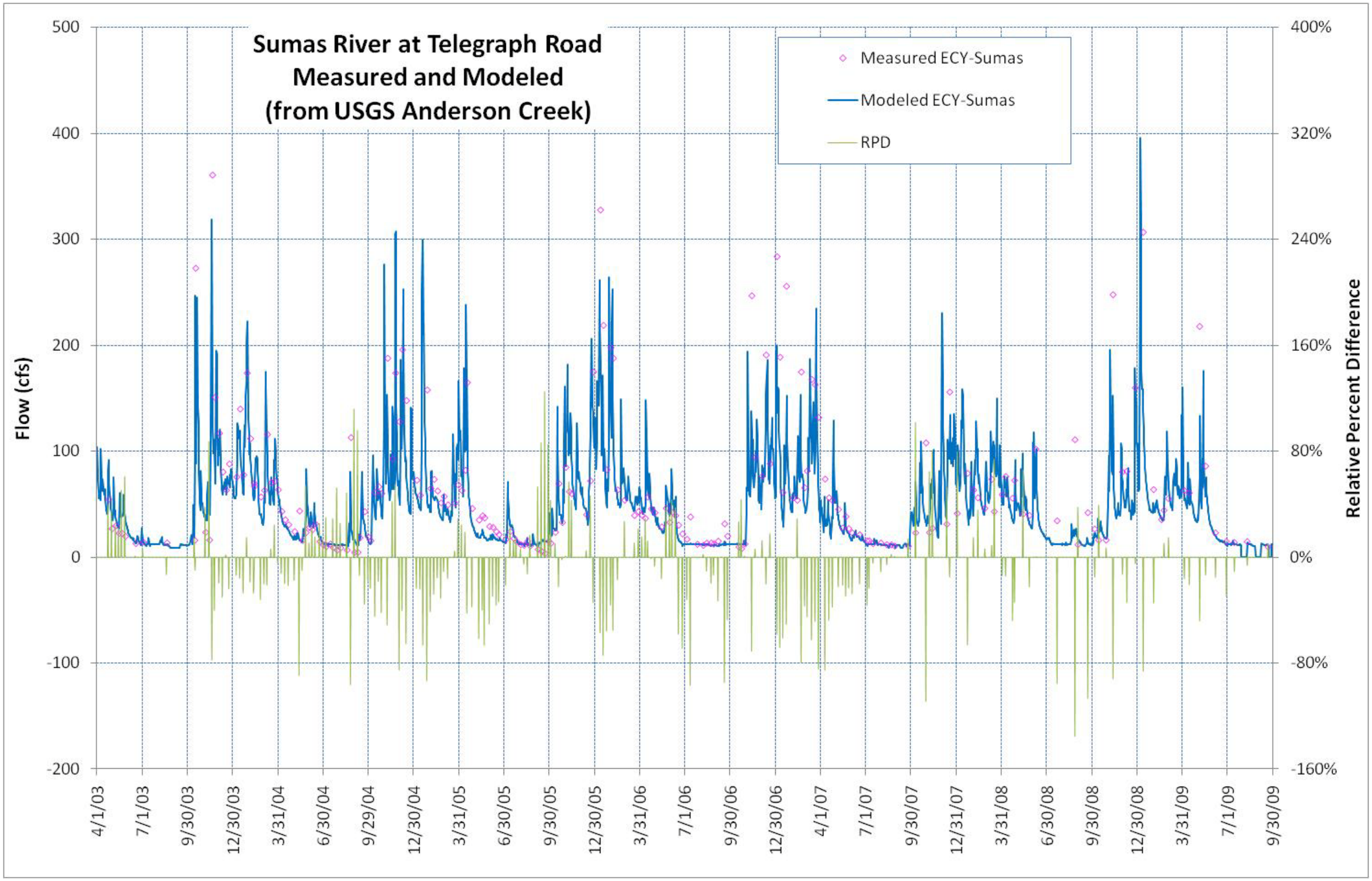

Figure 41. Modeled and measured flows at the Ecology “Sumas River at Telegraph Road” gaging station with relative percent difference of paired values.

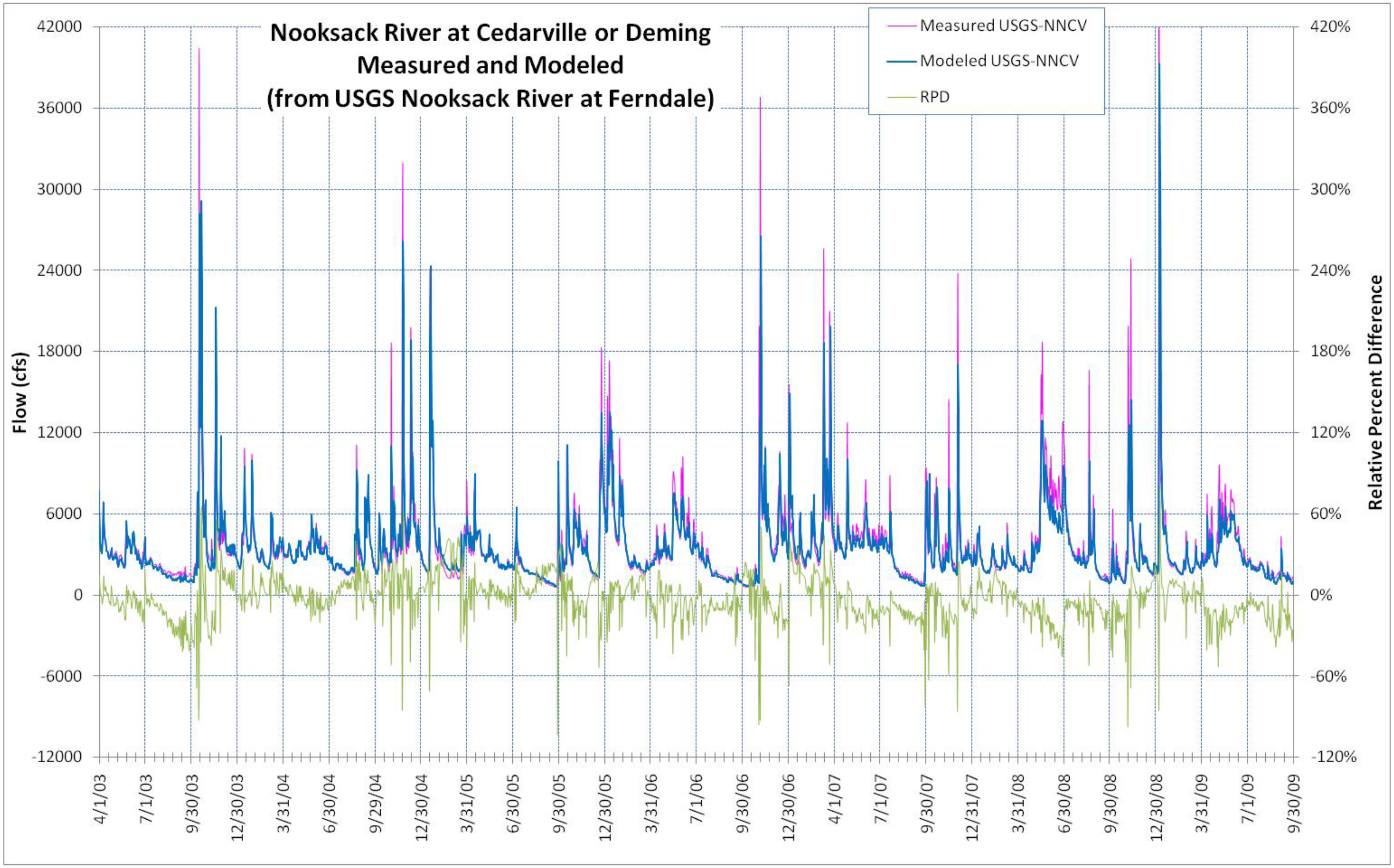

Figure 42. Modeled and measured flows at the USGS “Nooksack River at North Cedarville” gaging station with relative percent difference of paired values.

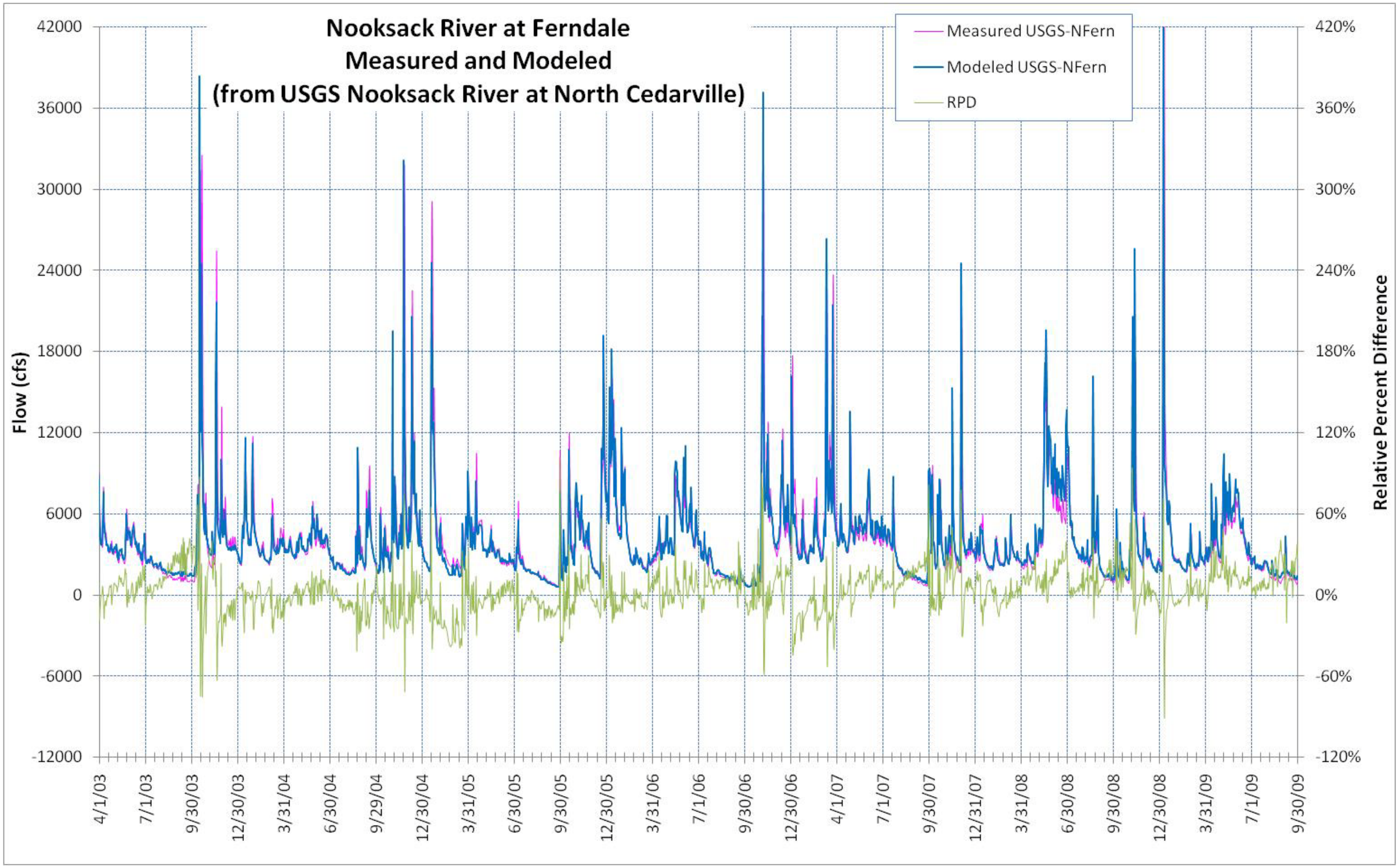

Figure 43. Modeled and measured flows at the USGS “Nooksack River at Ferndale” gaging station with relative percent difference of paired values.

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Appendices

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Appendix A. Glossary, Acronyms, and Abbreviations

Glossary

Areal flow: Streamflow at a gaging station divided by watershed area above the gage, in units of length/time (e.g. inches per day).

Control station: A location in a stream where instream flows are regulated, as defined by rule in the Washington Administrative Code.

Continuous data: Data (such as water surface elevations) collected at very short intervals (such as every 15 minutes) by automated sensors, with the goal of producing an uninterrupted time series of the data.

Hydrologic: Relating to the properties, distribution, and circulation of water on or below the earth's surface and in the atmosphere.

Manual stage station: A flow measurement station where water surface elevation data are collected by visual readings from a staff gage installed in the stream, which are later converted to streamflow data.

Real-time station: A term used by USGS to describe a flow measurement station which collects continuous surface elevation data using automated sensors and transmits the data by telemetry. The elevation data is then converted to streamflow data, which is presented on the internet within a few minutes or hours of collection. (See "Telemetry station")

Regression: A functional relationship between two or more correlated variables that is often empirically determined from data and is used especially to predict values of one variable when given values of the others.

Stand-alone station: A flow measurement station which collects continuous surface elevation data using automated sensors and records that data on-site. The data must be collected by field staff and converted to flow measurements at a later date.

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

Telemetry station: Telemetry station: A term used by Ecology to describe a flow measurement station which collects continuous surface elevation data using automated sensors and transmits the data by telemetry. The elevation data is then converted to streamflow data, which is presented on the internet within a few minutes or hours of collection. (See "Real-time station")

TOPNET: A hydrologic model of streams developed by Utah State University.

Acronyms and Abbreviations

%RSD	Percent relative standard deviation
cfs	cubic feet per second
COB	City of Bellingham
EA	Environmental Assessment (Program)
Ecology	Washington State Department of Ecology
GIS	Geographic information system
gpm	gallons per minute
ID	Identification Code
IRPP	Instream Resources Protection Plan
mgd	million gallons per day
n	number of values
NAD	North American Datum
Planning Group	WRIA 1 Watershed Planning Group
QA	Quality Assurance
r^2	Coefficient of determination
RAWS	Remote Automated Weather Stations, U.S. Forest Service
RM	River mile
RPD	Relative percent difference
SNOTEL	Snowpack Telemetry system, U.S. Department of Agriculture
SWE	Snow water equivalent
USGS	United States Geological Survey
USU	Utah State University
WAC	Washington Administrative Code
WMP	Watershed Management Project
WRIA	Water Resource Inventory Area

Appendix B. Guidelines for Interpreting Locations of Regulatory Control Stations in WRIA 1 (WAC 173-501)

DEPARTMENT OF ECOLOGY

September 29, 2009

To:	Richard Grout, Bellingham Field Office Andy Dunn, NWRO WR Program Brian Walsh, WR Program
From:	Doug Allen, HWTR Program Paul Pickett, EA Program Tom Buroker, Bellingham Field Officer Dave Nazy, WR Program
Subject:	Guidelines for interpreting locations of regulatory control stations in WRIA 01 (WAC 173-501)

As part of Paul Pickett's project to evaluate modeling tools for flows in the WRIA 01 Nooksack Basin (www.ecy.wa.gov/biblio/0903117.html), he will be determining how modeling and other flow monitoring might be able to assess flows at WRIA 01 control stations. In reviewing the locations described in the regulations and the GIS coverages developed for the stations, he has discovered that the locations of several of the stations as described in the regulation are ambiguous or contradictory.

We have reviewed those locations, including visiting the sites and discussing the history of the WRIA 01 Instream Flow Protection Plan with staff who have historically been involved. As a result we would like to recommend guidelines for how to interpret the location of the stations that are most uncertain. We would like your concurrence with these guidelines so that these guidelines can be used for Paul's work and for future water resource decisions in WRIA 01.

Nine of the 30 control stations were determined to have significant questions about location. These are:

1. Terrell Creek
2. Smith Creek
3. Saar Creek
4. Anderson Creek
5. Johnson Creek
6. Hutchinson Creek
7. Racehorse Creek
8. Kendall Creek
9. Silver Creek

The locations of the other stations are unambiguous.

For each of these stations the problems and recommended resolutions are provided below. Table 1 at the end of this document summarizes the recommendations. Table 2 summarizes the locations of the other control stations whose locations are well-defined.

1. Terrell Creek

Problem: The River Mile (RM) listed is not consistent with the Section, and the RM is uncertain.

Recommendation: The control station is located between Helwig and Jackson Roads. Helwig Road is the primary location for flow measurements, and Jackson Road is an alternative site.

Analysis: The RM indicates a location between Helwig and Jackson Roads, perhaps behind a home in this reach, but not aligned with a bridge. The Section appears to be incorrect. The best flow measurement sites are at Helwig and Jackson Roads. The downstream Helwig Road bridge location is more representative of the creek as a whole and closer to the RM. A small tributary enters Terrell Creek between the approximate RM location and Jackson Road.

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2. Smith Creek

Problem: The RM does not coincide with the Section.

Recommendation: The control station is located at the State Route 9 bridge. This is also a reasonable site for flow measurement.

Analysis: The RM is uncertain because the Nooksack River bed is dynamic and the mouth of Smith Creek has likely changed location over time. The SR 9 bridge is in the correct Section, close to the indicated RM, a good site for flow measurement, and representative of most of the watershed.

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3. Saar Creek

Problem: The RM does not coincide with the location of the USGS station.

Recommendation: The control station is located at the Rock Road Bridge. This is also a reasonable site for flow measurement.

Analysis: USGS indicates that their historical station was located on Rock Road, which is in the correct Section. The RM for Saar Creek is ambiguous because the stream flows into Canada. If the RM is calculated from the border, the location is in the middle of a field and not near any landmark where flow measurements were likely taken.

---

4. Anderson Creek

Problem: RM is uncertain.

Recommendation: The control station is located between Goshen and Roberts Road. The best location for flow measurement is at the Ecology gage on Roberts Road.

Analysis: There is a historic USGS flow measurement site at this location. The RM is ambiguous and uncertain because the Nooksack River bed is dynamic and the mouth of Anderson Creek has likely changed location over time. However the RM is close to the recommended location and the Section is correct. An existing Ecology gage is also nearby.

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5. Johnson Creek

Problem: The RM does not indicate a logical location.

Recommendation: The control station is located at Sumas Street, which is also the best location for flow measurements.

Analysis: The RM location is in an inaccessible location and not near any landmark where flow measurements were likely taken. The Sumas Street location is an historic USGS flow measurement location and in the correct Section. The difference in watershed area between the Sumas Street site and the RM location is very small.

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6. Hutchinson Creek

Problem: The RM is ambiguous, and the Section is nowhere near the RM and illogically high in the watershed.

Recommendation: The control station is located near the old campground downstream of the Ecology flow station. The Ecology station is an effective location for measuring flows.

Analysis: The RM is ambiguous, but is close to an old campground (now abandoned) on a very straight stream reach. This site would have provided public access and is good for flow measurement. However, the Ecology station is a short ways upstream and provides near-real-time data. The final report for this project will determine the approximate difference in flows at the control station and at the Ecology gage.

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7. Racehorse Creek

Problem: The RM is uncertain.

Recommendation: The control station is located at the North Fork Road Bridge, and the USGS flow gage at this site is available for flows.

Analysis: The RM is uncertain because the North Fork Nooksack River bed is dynamic and the mouth of Racehorse Creek has likely changed location over time. The North Fork Bridge is close to the correct RM, in the correct Station, and in a good location for stream flow measurement.

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8. Kendall Creek

Problem: The RM doesn't coincide with the USGS gaging station location.

Recommendation: The control station is located at the State Route 542 bridge. The best location to measure flows would likely be downstream at the fish hatchery.

Analysis: The RM is nowhere near the location USGS reports for the flow measurement station listed in the regulation. The USGS station was clearly at the SR 542 bridge. However, this is no longer a good site for flow measurement. The fish hatchery downstream looks like the most likely best site for flow measurement, but more investigation is needed. Another likely flow site is the historic USGS flow station at a private bridge upstream of SR 542, but it is less representative of stream flows.

9. Silver Creek

Problem: The RM does not indicate a logical location.

Recommendation: The control station is located just upstream of Shady Lane. The best location for flow measurement is at Slater Road.

Analysis: The RM is ambiguous due to the slough-like nature of the creek mouth, and is most likely in the middle of a wetland area with difficult access. The Shady Lane bridge downstream is close to the RM, but appears to be in a tidal location. If it were the control location, flows would have to have been measured at low tide. The new culvert on Slater Road currently looks like the best location for flow measurements.

Table 1. Summary of control stations with locations needing interpretation.

Control Station Name	Proposed Longitude	Proposed Latitude	Item from the Rule Incorrect or Uncertain	Flow Measurement Location
Terrell Creek	122° 46' 07"	48° 54' 05"	RM, section and flow station	Hellwig Road
Smith Creek	122° 17' 18"	48° 50' 59"	RM and flow station	SR 9
Saar Creek	122° 12' 35"	48° 59' 34"	RM	Rock Road
Anderson Creek	122° 20' 25"	48° 51' 19"	RM and flow station	Roberts Road
Johnson Creek	122° 15' 46"	48° 59' 48"	RM and flow station	Sumas Street
Hutchinson Creek	122° 09' 25"	48° 43' 13"	RM, section and flow station	Ecology flow station
Racehorse Creek	122° 07' 56"	48° 53' 06"	RM and flow station	North Fork Road
Kendall Creek	122° 08' 26"	48° 54' 18"	RM	Fish Hatchery?
Silver Creek	122° 34' 01"	48° 48' 41"	RM and flow station	Slater Road

Table 2. Summary of control stations with well-defined locations.

Control Station Name	Longitude	Latitude	Control Station Location	Flow Measurement Location (if different)
Bells Creek	122° 09' 40"	48° 50' 55"	SR 542 bridge	Downstream of bridge
Bertrand Creek	122° 31' 49"	48° 55' 27"	Rathbone Road Bridge	Ecology gage 01N060
California Creek	122° 41' 19"	48° 56' 09"	Birch Bay-Lynden Road bridge	Ecology gage 01R090
Canyon Creek	121° 59' 26"	48° 54' 29"	0.2 miles upstream of mouth	--
Cornell Creek	121° 57' 43"	48° 53' 31"	SR 542 bridge	--
Deer Creek	122° 33' 31"	48° 50' 44"	West Axton Road	--
Gallop Creek	121° 56' 35"	48° 53' 23"	SR 542 bridge	--
Maple Creek	122° 04' 19"	48° 55' 16"	SR 542 bridge	Old Ecology gage 01K050 or upstream near Maple Falls
Porter Creek	122° 06' 59"	48° 47' 38"	Mosquito Lake Road bridge	--
Wiser Lake Creek	122° 32' 25"	48° 53' 33"	Northwest Drive bridge	--
Canyon Creek at Kulshan	122° 08' 10"	48° 50' 02"	Mosquito Lake Road bridge	--
Dakota Creek near Blaine	122° 39' 36"	48° 57' 27"	Benme Road bridge	Ecology gage 01Q070
Fishtrap Creek at Lynden	122° 25' 53"	48° 57' 52"	SR 546 bridge (East Badger Rd)	USGS gage 12212050
Nooksack River (at Deming)	122° 12' 17"	48° 48' 36"	Old USGS gage 12210500	USGS gage 12210700
Nooksack River (at Ferndale)	122° 35' 21"	48° 50' 41"	USGS gage 12213100	--
Nooksack River (Middle Fork)	122° 06' 24"	48° 46' 43"	USGS gage 12208000	--
Nooksack River (North Fork)	122° 09' 02"	48° 52' 22"	Old USGS gage 12207200	Ecology gage 01A140
Nooksack River (South Fork)	122° 08' 00"	48° 39' 51"	Old USGS gage 12209000	USGS gage 12210000
Skookum Creek near Wickersham	122° 08' 30"	48° 40' 17"	Old USGS gage 12209500	USGS gage 12209490
Sumas River near Sumas	122° 15' 02"	48° 58' 29"	Old USGS gage 12214500 (Hill Rd)	Ecology gage 01D100
Tenmile Creek at Laurel	122° 29' 49"	48° 51' 49"	Old USGS gage 12212900 (Old Guide Rd)	Ecology gage 01P080