Middle Snake Watershed Planning Area

Prediction of Gaged Streamflows by Modeling

January 2013

Publication No. 13-03-006

DEPARTMENT OF
ECOLOGY
State of Washington

Publication and Contact Information

This report is available on the Department of Ecology's website at
https://fortress.wa.gov/ecy/publications/SummaryPages/1303006.html

The Activity Tracker Code for this study is 12-002.

For more information contact:

Publications Coordinator
Environmental Assessment Program
P.O. Box 47600, Olympia, WA 98504-7600
Phone: (360) 407-6764

Washington State Department of Ecology - www.ecy.wa.gov

- Headquarters, Olympia (360) 407-6000
- Northwest Regional Office, Bellevue (425) 649-7000
- Southwest Regional Office, Olympia (360) 407-6300
- Central Regional Office, Yakima (509) 575-2490
- Eastern Regional Office, Spokane (509) 329-3400

Cover photos: Department of Ecology flow measurement stations in the Middle Snake Watershed Planning Area

Middle Snake Watershed Planning Area

Prediction of Gaged Streamflows by Modeling

by

Paul J. Pickett

Environmental Assessment Program
Washington State Department of Ecology
Olympia, Washington 98504-7710

Water Resource Inventory Area 35

This page is purposely left blank

Table of Contents

This page is purposely left blank

List of Figures

List of Tables

.

Abstract

This study evaluates flow gaging stations in the Middle Snake watershed planning area, which includes Water Resource Inventory Area (WRIA) 35. The study addresses six telemetry flow stations that the Washington State Department of Ecology (Ecology) currently operates, three Ecology active continuous flow stations, four Ecology continuous and manual staff gages no longer in operation, and two active United States Geological Survey (USGS) flow stations funded by Ecology.

This study developed regression-based models using data through June 2012 from Ecology study gages, based on other reference gages in the basin using power or linear relationships and a hydrograph separation method. The quality of these regressions was assessed using statistical methods.

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

Recommendations were made based on study results:

- *Asotin Creek above George Creek* and *Tucannon River near Marengo*: Decommissioning or transfer of these stations should be considered.
- *Joseph Creek near Mouth*, *Couse Creek at Mouth*, *George Creek at Mouth*, and *Tenmile Creek at Mouth*: These stations should be reviewed for decommissioning, cooperative funding, or transfer.
- USGS *Asotin Creek at Asotin*: Review this station for possible elimination of Ecology funding.
- USGS *Tucannon River near Starbuck*: Continued funding of this station is recommended.
- *Alpowa Creek at Mouth*, *Deadman Creek near Gould City*, and *Pataha Creek near Mouth*: Continued funding and operation of these stations is recommended.

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

Acknowledgements

The author of this report is grateful for the help and support from the following people:

- Brad Johnson, Asotin Public Utility District
- Steve Martin, Snake River Salmon Recovery Board
- Terry Bruegman, Columbia County Conservation District
- Stephen Bennett, Eco Logical Research, Inc.
- Del Groat, United States Forest Service
- Joe Bumgarner and Ethan Crawford, Washington Department of Fish and Wildlife
- Washington State Department of Ecology staff:
    - Rusty Post
    - Mitch Wallace
    - John Covert
    - Jaime Short
    - Jim Pacheco
    - Karol Erickson
    - Will Kendra
    - Bill Zachmann
    - Brad Hopkins
    - Jean Maust

Introduction

Overview of the Watershed

The project study area is Water Resource Inventory Area (WRIA) 35, which is also referred to as the Middle Snake watershed planning area (Figure 1). The descriptions of the basin in this section are summarized from the Final Middle Snake Watershed Plan (Middle Snake Watershed Planning Unit, 2005).

Geography

The Middle Snake watershed planning area (WRIA 35) includes about 2,250 square miles in the southeast corner of Washington State (Figure 1). WRIA 35 encompasses tributaries of the Snake River upstream of the confluence with the Palouse River, including the Tucannon River, Asotin Creek, and the northern portion of the Grand Ronde River.

Elevations in WRIA 35 range from approximately 540 feet (165 meters) at the downstream end to 6,380 feet (1,945 meters) at Diamond Peak in the Tucannon River watershed. The highest elevations are forested areas of the Blue Mountains. Most of the area outside the Blue Mountains is rangeland or agriculture. The northern portion lies in the Palouse region, and the southern portion drains basalt plateaus. River and stream bottoms are often in canyons or valleys cut into the basalt.

Climate

The climate in the study area is typical of the inland central Columbia basin, characterized by hot, dry summers and cold, moist winters. At low elevations, air temperatures average around 75^{o} F in July and 35^{o} F in January (or 24 to 2° C). Average precipitation at low elevations ranges from 9 to 20 inches (230 to 500 mm) per year, falling mainly from October through June, with some snow in the winter. At higher elevations, average air temperatures are 64^{o} F (18^{o} C) in July and 25^{o} F (-4^{o} C) in January, with precipitation of about 20 inches (500 mm) per year, between October and March falling mainly as snow.

Seasonal peak snow depths in the Blue Mountains are typically two to eight feet, although in heavy snow years depths can approach twenty feet in some locations.

Hydrology

The headwaters of the Tucannon River, Pataha Creek, Asotin Creek, and the northern tributaries of the Grand Ronde River lie in the Blue Mountains. Therefore, these streams are influenced by the melting of the mountain snowpack in the late spring and early summer. For the rest of the year, and year-round for the smaller tributaries of the Snake River, flows are primarily influenced by groundwater baseflow and by rainfall from late fall through early spring. Short-term flow events may also occur from the melting of snow from intermittent winter storms or from summer thunderstorms.

Groundwater resources are primarily in the underlying basalt aquifer. The shallow, high-head basalt formations are in hydraulic continuity with the streams. Virtually all baseflow, especially in the late summer and early fall, comes from groundwater inflows.

Land Ownership, Land Use, and Water Use

Political jurisdictions in WRIA 35 include Asotin, Whitman, Garfield, and Columbia Counties; the City of Clarkston; and the towns of Starbuck, Pomeroy, and Asotin. Other local jurisdictions include the Asotin County, Palouse, Columbia, Whitman, and Pomeroy Conservation Districts; Port of Clarkston; and Asotin County Public Utility District. The Snake River Salmon Recovery Board is also deeply involved in the basin. The Umatilla National Forest includes much of the upland areas of the Blue Mountains. WRIA 35 includes the Usual and Accustomed fishing areas for the Confederated Tribes of the Umatilla Indian Reservation and the Nez Perce Tribe.

Rivers and streams in WRIA 35 are mostly unregulated by dams. The major exception is the Snake River: Little Goose Dam and Lower Granite Dam fall within WRIA 35 boundaries. The farthest downstream free-flowing reaches of the Snake River lie on the Washington-Idaho border along the eastern boundary of WRIA 35.

The main vegetative cover in WRIA 35 is scrubland (29%), small grains (23%), grassland (20%), forest (13%), and fallow (10%). The primary land uses in the study area are pasture and rangeland, cropland, and forest management. The population in WRIA 35 was approximately 30,000 in 2010, and is expected to increase by about 10% through 2025. About two-thirds of the population live in the Clarkston urban area, where most of future growth is expected to occur.

Municipal and domestic water use in the Clarkston urban area was estimated at about 4,860 acre-feet of water per year in 2000 and is expected to grow to 5,920 acre-feet per year in 2025. Water use by the City of Pomeroy was 431 acre-feet per year and is expected to increase to 510 acre-feet per year in 2025. The City of Asotin used about 394 acre-feet of water in 2000, and use is expected to increase to 475 acre-feet per year in 2025. About another 1,200 acre-feet per year was used in the rural areas of WRIA 35 in 2000, and use is expected to remain fairly stable or decline slightly. These water uses tend to have a steady base consumption rate throughout the year, with a seasonal increase during hot weather due to landscape and home garden irrigation.

In the basins of Asotin Creek, Pataha Creek, and the Middle Snake tributaries, between 1,500 and 1,600 acres are irrigated for agriculture, and about three-quarters of water use is from groundwater. In the Tucannon River basin, there are about 1,950 acres of irrigated cropland using water primarily diverted from surfaces sources. In the Washington portion of the Grand Ronde basin there are about 3,711 acres of cropland, little of which is irrigated (NRCS, 2006).

Watershed Planning and Instream Flow Rules

The Middle Snake WRIA 35 Planning Unit produced a variety of technical and planning documents between 2002 and 2011. The WRIA 35 Middle Snake Watershed Plan was adopted in 2007 and made recommendations for the management of instream flows for many of the rivers and streams in the planning area. Ecology is planning to develop regulations for instream flows in WRIA 35; these regulations would eventually become adopted as Chapter 173-535 WAC. A schedule for writing and adopting these regulations has not been established and will likely be several years in the future.

These regulatory instream flows would be set at specific regulatory *control stations* throughout the basin, with seniority set by the date of rule adoption. When water flow at a control station reaches the rule's flow levels, water users with more junior (newer) appropriations cannot diminish or negatively affect the regulated flow. The gages that have been designated as potential future control stations are identified in Tables 1 and 2.

Flow Monitoring

Department of Ecology Stations

Ecology has historically operated 14 flow monitoring stations in the study area (Figure 1 and www.ecy.wa.gov/programs/eap/flow/shu_main.html). These stations consist of:

- Five active *telemetry* gages where real-time data is provided.
- Three historical staff gages where *manual stage-height* readings were collected infrequently (at least once per month) from a staff gage and converted to instantaneous flow values. Two gages were operated for about seven years, and one gage was operated for slightly over one year.
- Three active *continuous* gages where gaging data is recorded for later download. These three gages were historically manual stage-height gages.
- Three historical gages where multiple years of *continuous* data were collected.

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

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

USGS Stations

The USGS has gaged streamflow in WRIA 35 and in neighboring basins at a variety of sites historically and currently (USGS, 2009). The three active USGS stations in WRIA 35 and two active gages in neighboring basins that will be used in this study are listed in Table 2. Two of the stations have Ecology as a *cooperator* (in other words, the stations are partially funded by Ecology), while other stations have other cooperators.

Table 1. Ecology flow monitoring stations in the Middle Snake watershed planning area (WRIA 35).

ID	Station Name	Code	Status	Type[1]	Proposed Control Station?	Start	End	No. Days[2]	Comment
35K050	Alpowa Creek at Mouth	Alpowa	Active	T	yes	6-Jun-03	present	3188	
35D100	Asotin Creek above George Creek	Aso-aGC	Active	T		10-Feb-05	present	2563	
35M100	Deadman Creek near Gould City	Dead-GC	Active	T	yes	4-Jun-03	present	3144	
35F050	Pataha Creek near Mouth	Pat-Mth	Active	T	yes	4-Jun-03	present	3145	
35B150	Tucannon River near Marengo	Tuc-Mar	Active	T	yes	4-Jun-03	present	3233	
35H050	Couse Creek at Mouth	Couse	Active	C	yes	4-Jun-03	present	603	MSH until 8/18/2010
35P050	George Creek at Mouth	George	Active	C	yes	1-Oct-08	present	389	MSH until 8/20/2010
35J050	Tenmile Creek at Mouth	Tenmile	Active	C	yes	4-Jun-03	present	575	MSH until 8/19/2010
35L050	Almota Creek at Mouth	Almota	Historical	C	yes	5-Jun-03	13-Jul-10	2520	Former telemetry station
35M060	Deadman Creek near Mouth	Dead-Mth	Historical	C	yes	4-Jun-03	12-Jul-10	2394	Former telemetry station
35G060	Joseph Creek near Mouth	Joseph	Historical	C	yes	5-Jun-03	30-Sep-12	3205	Former telemetry station
35N050	Meadow Creek at Mouth	Meadow	Historical	MSH		19-Jun-03	7-Jul-10	225	
35F100	Pataha Creek near Pataha	Pat-Pat	Historical	MSH	yes	19-Jun-03	7-Jul-10	228	

[1]MSH = Manual Stage Height; C = Continuous; T = Telemetry; [2]Used in this study.

Table 2. USGS flow monitoring stations in and adjacent to the Middle Snake watershed planning area (WRIA 35).

ID	Station Name	Code	Status	Type[1]	Proposed Control Station?	Start	End	No. Days[2]	Cooperator[3]
13344500	Tucannon River near Starbuck, WA	Tuc-Star	Active	RT	yes	1-Oct-1914	present	3561	ECY
13335050	Asotin Creek at Asotin, WA	Aso-Aso	Active	NRT	yes	22-Mar-1991	30-Sep-2010	3299	ECY
13334450	Asotin Creek below Confluence Near Asotin, WA	Aso-Con	Active	RT		1-Jan-2001	Present	3561	
13351000	Palouse River at Hooper, WA	Pal-Hoop	Active	RT		10/1/1897	Present	3561	BPA
13333000	Grande Ronde River at Troy, OR	GRR-Troy	Active	RT		1-Oct-1944	Present	3561	USACE

[1]RT = Real-time (Telemetry), NRT = Near-Real Time (Continuous); [2]Used in this study
[3]ECY = Ecology; USBR = U.S. Bureau of Reclamation; USACE = U.S. Army Corps of Engineers

Study Goals and Objectives

The goals of this project are to:

1. Develop computer modeling tools that can estimate streamflows in WRIA 35 for each Ecology flow monitoring station and USGS flow monitoring station funded by Ecology.
2. Assess the ability of computer modeling tools to support Ecology and other agencies as well as members of the watershed planning unit and other local stakeholders in their water management activities in the basin.
3. Support Ecology in making decisions about use of its flow gaging resources statewide.

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

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

Methods

The methods used in this study were described in the Quality Assurance Project Plan (Pickett, 2012). The implementation of that plan is described in this section.

Data Sources and Characteristics

Flow Data

Daily average flow data were compiled for eleven Ecology stations and five USGS stations with continuous data, and instantaneous flows were compiled for the two Ecology stations with manual staff gage readings (Tables 1 and 2). Flows at Ecology stations were analyzed from the beginning of the data sets (June 4, 2003 or later) through June 30, 2012. Flows at USGS stations were analyzed from October 1, 2002 through June 30, 2012. Flow data were withheld from the analysis when derived using interpolations or correlations.

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

Some of the flow data have been labeled as *provisional* because final data quality checks had not been completed. Ecology and USGS flow data are constantly under review and are updated as the review is completed. Provisional data were used for the development of the regressions with the understanding that the regressions would likely be updated in the future using the finalized flow information. This is reasonable since the provisional data are likely to be similar to the final values, and because the regressions will likely also be updated with additional data collected after June 2012. However, provisional data were not used if they showed extreme deviations from neighboring values in space and time, and if Ecology monitoring staff confirmed the likelihood of technical problems.

Figures 2 through 16 show the streamflows for the Ecology stations and the two USGS stations analyzed in this study, with flows from other selected reference gaging stations shown for comparison. Flows are presented using a logarithmic scale to more clearly illustrate patterns over time and allow comparison of flows of varying discharge amounts from different stations.

Areal Flows

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

Six stations were selected to analyze meteorological conditions in the basin as compared to areal flows:

1. Silcott Island AGRIMET station (Station Code "SILW") http://www.usbr.gov/pn/agrimet/agrimetmap/silwda.html
2. Sourdough Gulch SNOTEL station (Station Code "SGUW1") http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=985&state=wa
3. Spruce Springs SNOTEL station (Station Code "SPGW1") http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=984&state=wa
4. Lewiston Airport National Weather Service station (Station Codes "KLWS") http://www.wunderground.com/history/airport/KLWS/2002/10/1/CustomHistory.html
5. Pullman-Moscow Airport National Weather Service station (Station Codes "KPUW") http://www.wunderground.com/history/airport/KPUW/2012/8/10/CustomHistory.html
6. Roberts Butte RAWS station (Station Code "ROBER") http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?orOROB

Areal flows from the Ecology telemetry and stand-alone stations are shown in Figures 17 through 31. Also shown are (1) precipitation data from one of the AGRIMET, RAWS, or Airport stations listed above, and (2) non-snow precipitation, snowmelt, and average daily air temperatures from one of the two SNOTEL stations listed above.

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

Some characteristics in the data patterns shown in Figures 17 through 31 are of interest:

- The strongest snowmelt responses can be seen with Asotin Creek, Joseph Creek, and the Tucannon River, (Figures 18, 20, 22, 30, and 31).
- Streams with a weak snowmelt signal and a primarily rainfall-based hydrology include Alpowa, Pataha, Couse, George, Tenmile, and Almota Creeks (Figures 17, 21, 23, 24, 25, 26, 29).
- Deadman and Meadow Creeks are lower elevation streams with low areal flows and weak snowmelt and rainfall responses (Figures 19, 27, 28).

Regressions and Other Analysis Methods

Flow data were first evaluated by comparing daily average flows from each study station for the entire record (October 1, 2002 through June 30, 2012) with flows from several USGS and Ecology reference stations using either linear or power regressions. A linear regression is in the form $y=mx+b$, while a power regression takes the form of $y=cx^d$. The regression between paired values of x and y determines either the coefficient m and the intercept b, or the coefficient c and the exponent d. A power regression is arithmetically identical to the linear regression of two log-transformed data sets.

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

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

Two blocks of data for the Tucannon River at Marengo were removed: May 16 through June 14, 2006; and December 17 through 22, 2008. These data were all more than 70% higher than flows during the same timeframe at the downstream USGS gage near Starbuck, and all had identified technical problems.

To select reference stations from existing real-time or telemetry stations, correlations between the stations were evaluated (Table 3). Reference stations were chosen from the best correlations in the following order:

1. At least one station with the best correlation at a stable, long-term USGS gage.
2. At least one station with the best correlation at a USGS gage or Ecology gage most likely to be retained, such as critical control stations.
3. Two more correlations at any gage with a long data record.

Regressions were then developed using the following process:

1. Simple regressions were developed between the study stations and the reference stations, and quality metrics were calculated. For these and all other regressions, linear and power regressions were evaluated, and the one that produced a better fit with data was chosen.
2. Areal flows were calculated for the study and reference stations.
3. Where the time-of-travel in the streams differ, offsetting or lagging flow information in time can sometimes improve the relationship between gages. To evaluate whether time-of-travel differences existed, flow time series were compared to determine whether transient flow peaks coincided or were offset by one or two days.
4. The baseflow threshold at each study gage was determined by comparison of the flow time series to precipitation and snowmelt. The threshold was selected to capture the majority of flows unaffected by precipitation events from early summer through mid-autumn. At some stations, flows below the baseflow threshold were also observed during cold spells in the winter.

Table 3. Correlations between study area flow monitoring stations.

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

	Alpowa	Aso-aGC	Dead-GC	Joseph*	Pat-Mth	Tuc-Mar	Almota*	Dead-Mth*	Couse +	George +	Tenmile +	Meadow*	Pat-Pat*	Tuc-Star	Aso-Aso +	Aso-Con	Pal-Hoop
Aso-aGC	0.47																
Dead-GC	0.65	0.49															
Joseph*	0.64	*0.75*	0.58														
Pat-Mth	*0.74*	*0.77*	0.66	***0.83***													
Tuc-Mar	0.56	**0.92**	0.62	***0.82***	***0.87***												
Almota*	0.69	0.39	*0.75*	0.60	0.67	0.55											
Dead-Mth*	0.67	0.56	***0.85***	0.55	0.68	0.61	0.69										
Couse +	0.62	0.51	0.50	*0.73*	0.63	0.58	0.59	0.34									
George +	*0.75*	***0.86***	0.65	***0.90***	**0.91**	***0.88***	*0.76*	***0.88***	*0.79*								
Tenmile +	*0.72*	0.61	0.56	***0.80***	*0.72*	0.66	0.58	0.51	***0.86***	***0.86***							
Meadow*	0.19	0.04	0.19	0.09	0.02	-0.02	0.13	0.18	-0.36	*0.74*	0.03						
Pat-Pat*	0.52	*0.79*	0.47	*0.75*	***0.86***	***0.87***	0.47	0.53	0.61		0.55	-0.03					
Tuc-Star	0.61	**0.92**	0.63	***0.82***	***0.89***	**0.97**	0.60	0.64	0.60	***0.90***	0.68	0.03	***0.85***				
Aso-Aso +	0.41	**0.96**	0.45	*0.78*	*0.72*	***0.89***	0.41	0.46	0.55	**0.91**	0.59	0.07	*0.78*	***0.89***			
Aso-Con	0.37	**0.97**	0.42	0.67	0.69	***0.88***	0.32	0.43	0.45	*0.79*	0.54	0.05	*0.74*	***0.87***	**0.94**		
Pal-Hoop	0.66	0.57	0.62	*0.75*	*0.77*	0.69	***0.80***	0.60	*0.75*	***0.86***	***0.84***	0.10	0.65	*0.73*	0.52	0.47	
GRR-Troy	0.40	***0.89***	0.52	*0.75*	0.66	***0.85***	0.39	0.49	0.52	*0.79*	0.57	0.15	0.69	***0.84***	***0.85***	***0.84***	0.54

ECY-Telemetry
ECY-Continuous Historic
ECY-Continuous Current
ECY-Manual Staff
USGS

Potential Control Station

* **Historical gage**

\+ **Not real time/telemetry**

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

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

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

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

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

    c. Three categories, either:
        - *Summer baseflows* – less than the baseflow threshold occurring from mid-summer through early autumn.
        - *Summer non-baseflows* – greater than the baseflow threshold occurring from mid-summer through early autumn.
        - *Winter flows* – flows occurring from November through June.

        or:

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

    Quality metrics were evaluated for all combinations.

Quality Analysis

As described in the project plan (Pickett, 2012), model accuracy was assessed by comparison of paired daily flow values from the measured and modeled time series. Bias was assessed by calculating the relative percent difference (RPD) for all predicted and observed pairs individually, and then evaluating the median of RPD values for all predicted and observed pairs.

$RPD_i = [100 * (P_i – O_i)] / [(O_i + P_i) / 2]$, where

P_i = i^{th} prediction

O_i = i^{th} observation

RPD_i = relative percent difference of the i^{th} predicted and observed pair

Precision was assessed with the percent relative standard deviation (%RSD) for predicted and observed pairs individually and using the median of values for all pairs of results. The %RSD presents variation in terms of the standard deviation divided by the mean of predicted and observed values.

$\%RSD_i = (SD_i * 100) / [(P_i + O_i) / 2]$, where

SD_i = standard deviation of the i^{th} predicted and observed pair

$\%RSD_i$ = percent relative standard deviation of the i^{th} predicted and observed pair

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

The following terminology is used to describe model results:

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

Results

Regression-based Model Parameters

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

Table 4 presents the results of the regression modeling analysis. For each study gage, regressions from a primary and a secondary reference station are presented. Alternative regression options are presented because of the possibility that some of the gages could be discontinued or data might not be available for other reasons.

For each study station, the following is shown:

- The reference flow monitoring station (see Tables 1 and 2 for station codes and full station information).
- The reference station baseflow threshold used for hydrograph separation.
- The season and flow category for separating flow for each regression.
- Whether the regression is a linear or a power regression.
- The coefficient and y-intercept of the linear regression, or the coefficient and exponent of the power regression.
- The r^2 of the regression (a measure of the goodness-of-fit for each individual regression).
- The number of values (n) that each regression is based on.

Regression-based Model Quality

Table 5 shows the quality of each regression. Goodness-of-fit is indicated by the median %RSD values for all flows and for the summer baseflows.

- Primary regression-based models had an **excellent** fit for both summer baseflow and all flows (%RSD values below 5%) at *Asotin Creek above George Creek*
- Primary regression-based models had an **excellent** fit for summer baseflow (%RSD values below 5%), and a **good** fit for all flows (%RSD values between 5% and 10%), at:
  - *Tucannon River near Marengo*
  - *Asotin Creek at Asotin*
- Primary regression-based models had a **good** fit for both summer baseflows and all flows at *Tucannon River near Starbuck*
- Five stations had primary regression-based models with a **good** fit for summer baseflow and a **fair** fit for all flows (%RSD values between 10% and 20%):
  - *Joseph Creek near Mouth*
  - *Couse Creek at Mouth*

- *George Creek at Mouth*
- *Tenmile Creek at Mouth*
- *Almota Creek at Mouth*

- Three stations had primary regression-based models with a **fair** fit for both summer baseflow and all flows:
  - *Alpowa Creek at Mouth*
  - *Deadman Creek near Gould City*
  - *Deadman Creek near Mouth*
- Primary regression-based models had a **poor** fit for both summer baseflows and all flows at *Pataha Creek near Mouth*
- The two staff gage stations had primary regression-based models with a **fair** fit for all flows:
  - *Meadow Creek at Mouth*
  - *Pataha Creek near Pataha*

Figures 32 through 46 show the measured and modeled values for each study station based on the primary reference station, along with the goodness-of-fit as RPD shown on the right axis. Note that the right-hand scale on the graph varies between figures so that the temporal patterns can be seen clearly. A few patterns can be observed:

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

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

- Over all flows, the median RPD was good, with a range of +/- 3% for all stations, except for Pataha Creek near Mouth station which was below -6%, and the two staff gage stations which were between 4% and 6%. The larger bias in the median RPD for these three stations indicates a poorer quality regression-based model for these sites.

- For baseflows, the RPD values were biased high, with most stations between 0% and 6%, while three stations had median values between 11% and 13%, and one station (Pataha Creek near Mouth again) at 35.6%. This is consistent with the tendency of RPD at low flows to produce high values.

- The range of RPD values varied among the stations: from the narrowest range of -48% to 37% at the Asotin Creek above George Creek station, to the widest range of -180% to 196% at the Pataha Creek near Mouth station. A narrow RPD range indicates that the quality regression-based model is relatively good, while a wide range suggests a poorer quality model.

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

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

Ecology Telemetry Gages										
Station ID	Station Name	Reference Station Code	Baseflow Threshold (cfs)	Hydrograph Separation		Linear or Power?	Coefficient	Intercept or Exponent	r^2	n
				Season	Flow level					
35K050	Alpowa Creek at Mouth	Pat-Mth (Primary)	4.0	Jun-Sep Jun-Sep Oct-May	base nonbase all flows	Power Linear Linear	6.07 0.102 0.147	-0.0095 6.19 8.48	0.0006 0.2524 0.55	700 366 1971
35K050	Alpowa Creek at Mouth	Pal-Hoop (Secondary)	77.0	Jul-Sep Jul-Sep Oct-Jun	base nonbase all flows	Power Power Linear	5.25 2.79 0.00307	0.0309 0.160 8.66	0.0022 0.0425 0.55	716 90 2382
35D100	Asotin Creek above George Creek	Aso-Con (Primary)	27.4	Aug-Sep Aug-Sep Oct-Jul Oct-Jul	base nonbase base nonbase	Power Linear Power Power	2.70 1.43 3.37 2.54	0.766 -8.20 0.724 0.822	0.76 0.73 0.16 0.96	297 130 341 1795
35D100	Asotin Creek above George Creek	Tuc-Star (Secondary)	70.6	Sep-Oct Nov-Aug All year	base base nonbase	Power Power Power	6.29 4.83 0.880	0.390 0.482 0.840	0.46 0.20 0.87	182 271 2110
35M100	Deadman Creek near Gould City	Tuc-Star (Primary)	76.0	Jul-Oct Nov-Jun All year	base base nonbase	Linear Linear Linear	0.0203 0.00112 0.00662	1.01 2.92 2.98	0.07 0.0004 0.31	749 97 2298
35M100	Deadman Creek near Gould City	Pat-Mth (Secondary)	2.85	Jul-Oct Jul-Oct Nov-Jun Nov-Jun	base nonbase base nonbase	Power Linear Linear Linear	2.07 -0.0474 0.0226 0.0510	0.184 2.92 3.28 3.67	0.12 0.12 0.0006 0.35	613 402 320 1645
35G060	Joseph Creek near Mouth	GRR-Troy (Primary)	736	Jul-Sep Jul-Sep Oct-Jun Oct-Jun	base nonbase base nonbase	Power Power Power Power	0.452 0.387 4.649 0.0419	0.573 0.589 0.273 0.984	0.27 0.69 0.02 0.68	460 350 235 2160
35G060	Joseph Creek near Mouth	Tuc-Star (Secondary)	68.6	Aug-Sep Aug-Sep Oct-Jul Oct-Jul	base nonbase base nonbase	Power Linear Power Power	0.548 0.398 0.690 0.0574	0.864 -9.71 0.886 1.43	0.38 0.44 0.08 0.74	371 160 238 2436

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

Station ID	Station Name	Reference Station Code	Baseflow Threshold (cfs)	Hydrograph Separation		Linear or Power?	Coefficient	Intercept or Exponent	r^2	N
				Season	Flow level					
Ecology Telemetry Gages										
35F050	Pataha Creek near Mouth	Tuc-Star (Primary)	67.7	Aug Aug Sep-Jul	base nonbase all flows	Power Power Power	0.0394 0.00155 0.00371	0.939 1.70 1.52	0.03 0.10 0.62	182 87 2876
35F050	Pataha Creek near Mouth	Joseph (Secondary)	23.3	Aug Aug Sep-Jul	base nonbase all flows	Power Linear Linear	0.463 0.221 0.0862	0.478 -1.98 3.06	0.001 0.33 0.69	244 25 2434
35B150	Tucannon River near Marengo	Tuc-Star (Primary)	68.3	Sep-Oct Sep-Oct Nov-Aug Nov-Aug	base nonbase base nonbase	Linear Linear Power Linear	0.556 0.648 5.29 0.884	27.5 23.1 0.619 1.15	0.29 0.49 0.44 0.94	248 300 365 2316
35B150	Tucannon River near Marengo	Aso-Con (Secondary)	25.7	Jul-Sep Jul-Sep Oct-Jun Oct-Jun	base nonbase base nonbase	Linear Linear Power Power	1.61 2.75 41.5 5.37	22.3 -6.61 0.162 0.838	0.12 0.65 0.002 0.78	332 496 223 2178
Ecology Active Continuous Gages										
35H050	Couse Creek at Mouth	Joseph (Primary)	27.0	Aug-Oct Nov-Jul All year	base base nonbase	Linear Linear Power	0.0109 0.0124 0.0708	0.435 0.551 0.685	0.07 0.09 0.74	159 17 405
35H050	Couse Creek at Mouth	Pal-Hoop (Secondary)	82.0	Aug-Oct Nov-Jul All year	base base nonbase	Linear Linear Power	0.000870 0.219 0.0369	0.613 0.345 0.646	0.01 0.16 0.66	205 23 375
35P050	George Creek at Mouth	Tuc-Mar (Primary)	85.8	Jul-Oct Jul-Oct Nov-Jun Nov-Jun	base nonbase base nonbase	Power Linear Power Power	0.000910 0.0799 0.0000139 0.00385	1.75 -4.51 2.75 1.58	0.43 0.96 0.27 0.71	139 55 21 172
35P050	George Creek at Mouth	Tuc-Star (Secondary)	85.4	Aug-Oct Aug-Oct Nov-Jul	base nonbase all flows	Power Power Power	0.00574 2.39 0.000795	1.33 0.0150 1.82	0.41 0.000 0.86	147 27 215

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

Station ID	Station Name	Reference Station Code	Baseflow Threshold (cfs)	Hydrograph Separation		Linear or Power?	Coefficient	Intercept or Exponent	r^2	N
				Season	Flow level					
Ecology Active Continuous Gages										
35J050	Tenmile Creek at Mouth	Joseph (Primary)	27.3	Jul-Oct Jul-Oct Nov-Jun	base nonbase all flows	Power Linear Power	0.242 0.0492 0.0605	0.354 -0.784 0.854	0.05 0.90 0.41	167 64 323
35J050	Tenmile Creek at Mouth	Pal-Hoop (Secondary)	67.0	Jun-Oct Jun-Oct Nov-May	base nonbase all flows	Power Power Linear	0.393 0.00259 0.00711	0.155 1.25 2.37	0.04 0.94 0.61	184 116 275
Ecology Historical Continuous Gages										
35L050	Almota Creek at Mouth	Pal-Hoop (Primary)	55.5	Aug-Oct Nov-Jul All year	base base nonbase	Power Power Power	0.433 0.0335 0.145	0.260 0.952 0.506	0.12 0.39 0.64	515 134 1871
35L050	Almota Creek at Mouth	Dead-GC (Secondary)	2.5	Aug Aug Sep-Jul Sep-Jul	base nonbase base nonbase	Power Linear Power Linear	0.756 2.21 1.03 1.41	0.0502 -4.75 0.107 -2.31	0.01 0.68 0.01 0.53	145 72 406 1808
35M060	Deadman Creek near Mouth	Dead-GC (Primary)	2.9	Aug-Sep Aug-Sep Oct-Jul Oct-Jul	base nonbase base nonbase	Power Power Power Linear	0.728 1.31 0.828 1.05	1.00 0.592 1.11 0.157	0.21 0.02 0.25 0.69	488 143 347 1332
35M060	Deadman Creek near Mouth	Pat-Mth (Secondary)	2.7	Aug-Sep Aug-Sep Oct-Jul Oct-Jul	base nonbase base nonbase	Linear Power Power Linear	0.389 1.78 2.37 0.0660	1.15 0.0600 0.368 3.74	0.10 0.004 0.18 0.44	371 250 459 1223
Ecology Manual Staff Gages										
35N050	Meadow Creek at Mouth	Alpowa Dead-GC	(Primary) (Secondary)	All year All year	All year All year	Power Power	0.478 0.870	0.469 0.370	0.15 0.12	219 216
35F100	Pataha Creek near Pataha	Pat-Mth Tuc-Mar	(Primary) (Secondary)	All year All year	All year All year	Linear Linear	0.897 0.110	3.12 -2.16	0.75 0.76	218 221

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

USGS Gages										
Station ID	Station Name	Reference Station Code	Baseflow Threshold (cfs)	Hydrograph Separation		Linear or Power?	Coefficient	Intercept or Exponent	r^2	N
				Season	Flow level					
13344500	Tucannon River near Starbuck	Tuc-Mar (Primary)	69.7	Jul-Sep	base	Power	3.17	0.704	0.13	478
				Jul-Sep	nonbase	Linear	0.926	-2.25	0.81	350
				Oct-Jun	base	Linear	0.336	50.5	0.03	280
				Oct-Jun	nonbase	Linear	1.06	13.1	0.94	2121
13344500	Tucannon River near Starbuck	Aso-Con (Secondary)	27.1	Aug-Sep	base	Linear	2.74	-7.13	0.29	400
				Aug-Sep	nonbase	Linear	1.76	20.4	0.31	149
				Oct-Jul	base	Power	1.38	1.25	0.13	579
				Oct-Jul	nonbase	Power	5.90	0.839	0.74	2433
13335050	Asotin Creek at Asotin	Aso-aGC (Primary)		Jul-Oct	base	Power	0.647	1.13	0.42	653
				Jul-Oct	nonbase	Linear	0.772	12.9	0.64	189
				Nov-Jun	base	Power	6.07	0.524	0.05	209
				Nov-Jun	nonbase	Power	0.456	1.24	0.94	1256
13335050	Asotin Creek at Asotin	Aso-Con (Secondary)		Aug-Oct	base	Power	0.609	1.25	0.53	676
				Aug-Oct	nonbase	Linear	1.01	9.89	0.35	164
				Nov-Jul	base	Power	2.66	0.829	0.21	457
				Nov-Jul	nonbase	Power	1.63	0.988	0.90	2002

Table 5. Model quality results for regressions as median %RSD for study gaging stations.

Station ID	Station Name	Reference Station Code	Hydrograph Separation Unit	Median %RSD for regression-based model				
				<5%	5-10%	10 - 15%	15 - 20%	20 - 25%
Ecology Telemetry Gages				**Excellent**	**Good**	**Fair**	**Fair**	**Poor**
35K050	Alpowa Creek at Mouth	Pat-Mth	Summer baseflow			X		
			All flows			X		
35K050	Alpowa Creek at Mouth	Pal-Hoop	Summer baseflow			X		
			All flows			X		
35D100	Asotin Creek above George Creek	Aso-Con	Summer baseflow	X				
			All flows	X				
35D100	Asotin Creek above George Creek	Tuc-Star	Summer baseflow		X			
			All flows	X				
35M100	Deadman Creek near Gould City	Tuc-Star	Summer baseflow			X		
			All flows			X		
35M100	Deadman Creek near Gould City	Pat-Mth	Summer baseflow			X		
			All flows			X		
35G060	Joseph Creek near Mouth	GRR-Troy	Summer baseflow		X			
			All flows				X	
35G060	Joseph Creek near Mouth	Tuc-Star	Summer baseflow		X			
			All flows				X	
35F050	Pataha Creek near Mouth	Tuc-Star	Summer baseflow					X
			All flows					X
35F050	Pataha Creek near Mouth	Joseph	Summer baseflow					X
			All flows					X
35B150	Tucannon River near Marengo	Tuc-Star	Summer baseflow	X				
			All flows		X			
35B150	Tucannon River near Marengo	Aso-Con	Summer baseflow	X				
			All flows			X		
Ecology Active Continuous Gages				**Excellent**	**Good**	**Fair**	**Fair**	**Poor**
35H050	Couse Creek at Mouth	Joseph	Summer baseflow		X			
			All flows			X		
35H050	Couse Creek at Mouth	Pal-Hoop	Summer baseflow		X			
			All flows				X	
35P050	George Creek at Mouth	Tuc-Mar	Summer baseflow		X			
			All flows			X		
35P050	George Creek at Mouth	Tuc-Star	Summer baseflow			X		
			All flows				X	

Table 5, continued. Model quality results for regressions as median %RSD for study gaging stations.

Station ID	Station Name	Reference Station Code	Hydrograph Separation Unit	Median %RSD for regression-based model				
				<5%	5-10%	10 - 15%	15 - 20%	20 - 25%
Ecology Active Continuous Gages				**Excellent**	**Good**	**Fair**	**Fair**	**Poor**
35J050	Tenmile Creek at Mouth	Joseph	Summer baseflow All flows		X	 X		
35J050	Tenmile Creek at Mouth	Pal-Hoop	Summer baseflow All flows		X		 X	
Ecology Historical Continuous Gages				**Excellent**	**Good**	**Fair**	**Fair**	**Poor**
35L050	Almota Creek at Mouth	Pal-Hoop	Summer baseflow All flows		X		 X	
35L050	Almota Creek at Mouth	Dead-GC	Summer baseflow All flows		X			 X
35M060	Deadman Creek near Mouth	Dead-GC	Summer baseflow All flows			 X	X	
35M060	Deadman Creek near Mouth	Pat-Mth	Summer baseflow All flows				 X	X
Ecology Manual Staff Gages				**Excellent**	**Good**	**Fair**	**Fair**	**Poor**
35N050	Meadow Creek at Mouth	Alpowa Dead-GC	All flows All flows				X	 X
35F100	Pataha Creek near Pataha	Pat-Mth Tuc-Mar	All flows All flows				X X	
35N050	Meadow Creek at Mouth	Alpowa Dead-GC	All flows All flows				X	 X
35F100	Pataha Creek near Pataha	Pat-Mth Tuc-Mar	All flows All flows				X X	
USGS Gages				**Excellent**	**Good**	**Fair**	**Fair**	**Poor**
13344500	Tucannon River near Starbuck	Tuc-Mar	Summer baseflow All flows		X X			
13344500	Tucannon River near Starbuck	Aso-Con	Summer baseflow All flows		X	 X		
13335050	Asotin Creek at Asotin	Aso-aGC	Summer baseflow All flows	X	 X			
13335050	Asotin Creek at Asotin	Aso-Con	Summer baseflow All flows	X	 X			

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

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

Reference stations → / Study Stations ↓	Alpowa	Aso-aGC	Dead-GC	Joseph	Pat-Mth	Tuc-Mar	Tuc-Star	Aso-Con	Pal-Hoop	GRR-Troy
Alpowa					1^o				2^o	
Aso-aGC							2^o	1^o		
Dead-GC	1^o						2^o			
Joseph							2^o			1^o
Pat-Mth				2^o			1^o			
Tuc-Mar							1^o	2^o		
Couse				1^o					2^o	
George						1^o	2^o			
Tenmile				1^o					2^o	
Almota			2^o						1^o	
Dead-Mth			1^o		2^o					
Meadow	1^o		2^o							
Pat-Pat					2^o	1^o				
Tuc-Star						1^o		2^o		
Aso-Aso		1^o						2^o		
No. Primary	2	1	1	2	1	3	2	1	1	1
No. Secondary	-	-	2	1	2	-	4	3	3	-
TOTAL	2	1	3	3	3	3	6	4	4	1

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

Discussion

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

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

- Model quality results were excellent to good for gages on Asotin Creek where there are three gages and on the Tucannon River where there are two gages. This suggests redundancy for these streams. The two Ecology active gaging stations on these streams (*Asotin Creek above George Creek* and *Tucannon River near Marengo*) would be a high priority for decommissioning or transfer.

- The two USGS gaging stations funded by Ecology also have excellent or good model quality results.

    - The USGS *Tucannon River near Starbuck* station is an important reference station for other gages and if the Ecology gage on the Tucannon River is discontinued, funding for this station should be maintained.

    - The USGS *Asotin Creek at Asotin* station is redundant with upstream USGS *Asotin Creek below Confluence* station and is not useful as a reference station because it is not real time. Therefore based on this modeling, Ecology might consider not continuing funding for this gage. However, water management needs may be identified that justify the funding.

- Three active Ecology stations with continuous gaging had a good fit for summer baseflows and a fair fit for all flows: *Couse Creek at Mouth*, *George Creek at Mouth*, and *Tenmile Creek at Mouth*. Modeling could possibly replace direct measurement of flows at these stations. The water management needs that depend on this data should be reviewed to determine whether the regression-based model would meet those needs or if continued operation of these gages is justified.

- Ecology's gaging station on Joseph Creek had a good fit for summer baseflows and a fair fit for all flows. This gage has already been reviewed for data needs and has been proposed for decommissioning. The regression-based model is available for use for flows at this station if needed.

- Three active Ecology telemetry stations have regression-based models that show fair or poor fits for summer baseflows and for all flows: *Alpowa Creek at Mouth*, *Deadman Creek near Gould City*, and *Pataha Creek near Mouth*. Based on the modeling analysis, these stations should be the highest priority for continued funding and operation.

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

Most of the gages evaluated in this study are proposed for regulatory control stations as part of the Middle Snake watershed plan. Most of the active stations now have nine full years of data, which is sufficient for use in statistical evaluation of flow patterns at these locations. Stations considered for decommissioning as a result of this study could be kept active with cooperative funding, transferred to another agency for operation, or restored in the future if real-time data is needed for water management.

Conclusions and Recommendations

This study draws the following conclusions and recommendations:

- The hydrograph separation method can be used to develop regression-based computer models to estimate streamflow at Ecology gaging stations in the Middle Snake watershed planning area (WRIA 35).
- The quality of the streamflow estimates from these regression-based models was evaluated. Based on the results of that evaluation, recommendations are provided for Ecology's support of flow gaging stations:
    - *Asotin Creek above George Creek* and *Tucannon River near Marengo*: Based on the quality of models, decommissioning or transfer of these stations could be considered.
    - *Joseph Creek near Mouth*, *Couse Creek at Mouth*, *George Creek at Mouth*, and *Tenmile Creek at Mouth*: Flow data needs should be reviewed to determine if direct measurements are needed at these stations or if the regression-based models suffice to meet those needs. Based on that review, these stations could be reviewed for decommissioning, cooperative funding, or transfer.
    - USGS *Asotin Creek at Asotin*: Review data needs for this station to determine if elimination of Ecology funding is appropriate.
    - USGS *Tucannon River near Starbuck*: Continued funding of this station is recommended.
    - *Alpowa Creek at Mouth*, *Deadman Creek near Gould City*, and *Pataha Creek near Mouth*: Continued funding and operation of these stations are recommended if flow data from these stations are needed for water and environmental management.
- Regressions are available to predict flows for staff and continuous gage stations that have been decommissioned.
- If water management efforts increase, resources become available, and the need for direct flow gaging is identified at stations that have been discontinued, those stations should be reevaluated for possible reactivation.
- The accuracy of the regression-based models should be evaluated against flow monitoring needs for Ecology and the local community to determine whether the models provide an acceptable substitute for flow gaging. All regression-based models for study flow stations should be used for specific purposes with consideration as to whether their accuracy serves that purpose. Stations may be redundant in terms of the ability of the regression to predict flows, but removal of a station may lose other information or the ability to use that flow data for other analyses. Conceptually the regressions should be used as "screening tools" to trigger a direct evaluation of flow, or used for purposes where a rough estimate is acceptable.
- Regressions from provisional data should be of sufficient quality to be applied to the regression-based models. Updating of regression models with quality-checked data could slightly improve the quality of the regressions. Regression-based models should be updated

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

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

- Where real-time access to flow estimates using the regression-based model are needed for a particular gage, the model should be programmed into an internet platform so that the public can access predicted flows from real-time reference station flow data.

- If a regression-based model is in active use, a flow study should be done at regular intervals to check and update the model.

References

Ecology, 2011. Procedures for Evaluating the Department of Ecology's Statewide Flow Gaging Network. Washington State Department of Ecology, Olympia, WA. Publication No. 11-03-064. https://fortress.wa.gov/ecy/publications/SummaryPages/1103064.html

Middle Snake Watershed Planning Unit, 2005. Middle Snake River Watershed Level 1 Assessment. Asotin Public Utility District, Clarkston, WA. www.asotinpud.org/watershedplanning/documents.html

NRCS, 2006. Lower Grande Ronde Watershed, HUC: 17060106, Rapid Watershed Assessment. Natural Resources Conservation District, U.S. Department of Agriculture, Spokane, WA.

Pickett, P., 2012. Quality Assurance Project Plan: Middle Snake Watershed Planning Area Assessment of Gaged Streamflows by Modeling. Washington State Department of Ecology, Olympia, WA. Publication No. 12-03-107. https://fortress.wa.gov/ecy/publications/SummaryPages/1203107.html.

USGS, 2012. USGS Surface-Water Daily Data for Washington. U.S. Geological Survey, Tacoma, WA. http://waterdata.usgs.gov/wa/nwis/

This page is purposely left blank

Figures

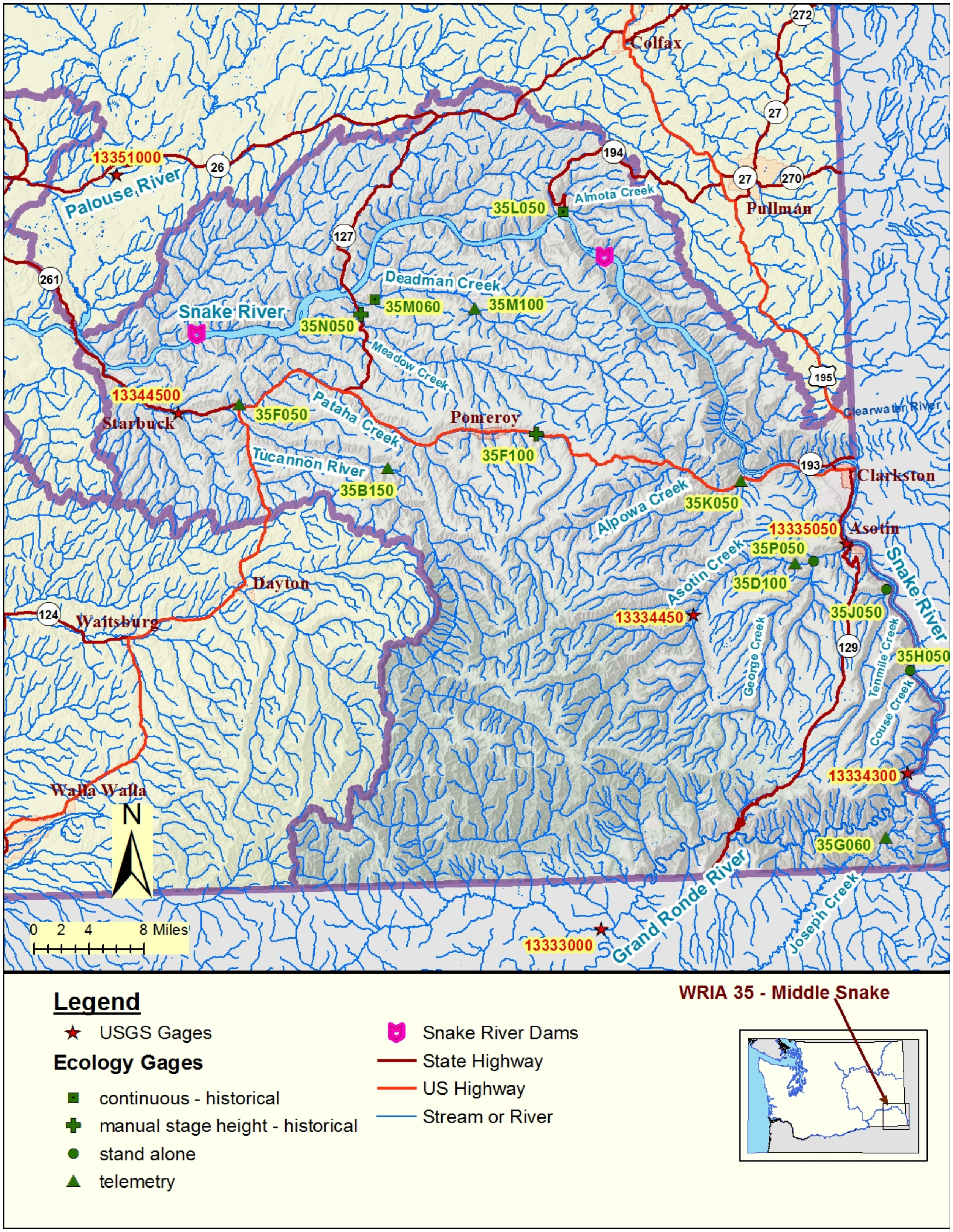

Figure 1. Middle Snake watershed study area.

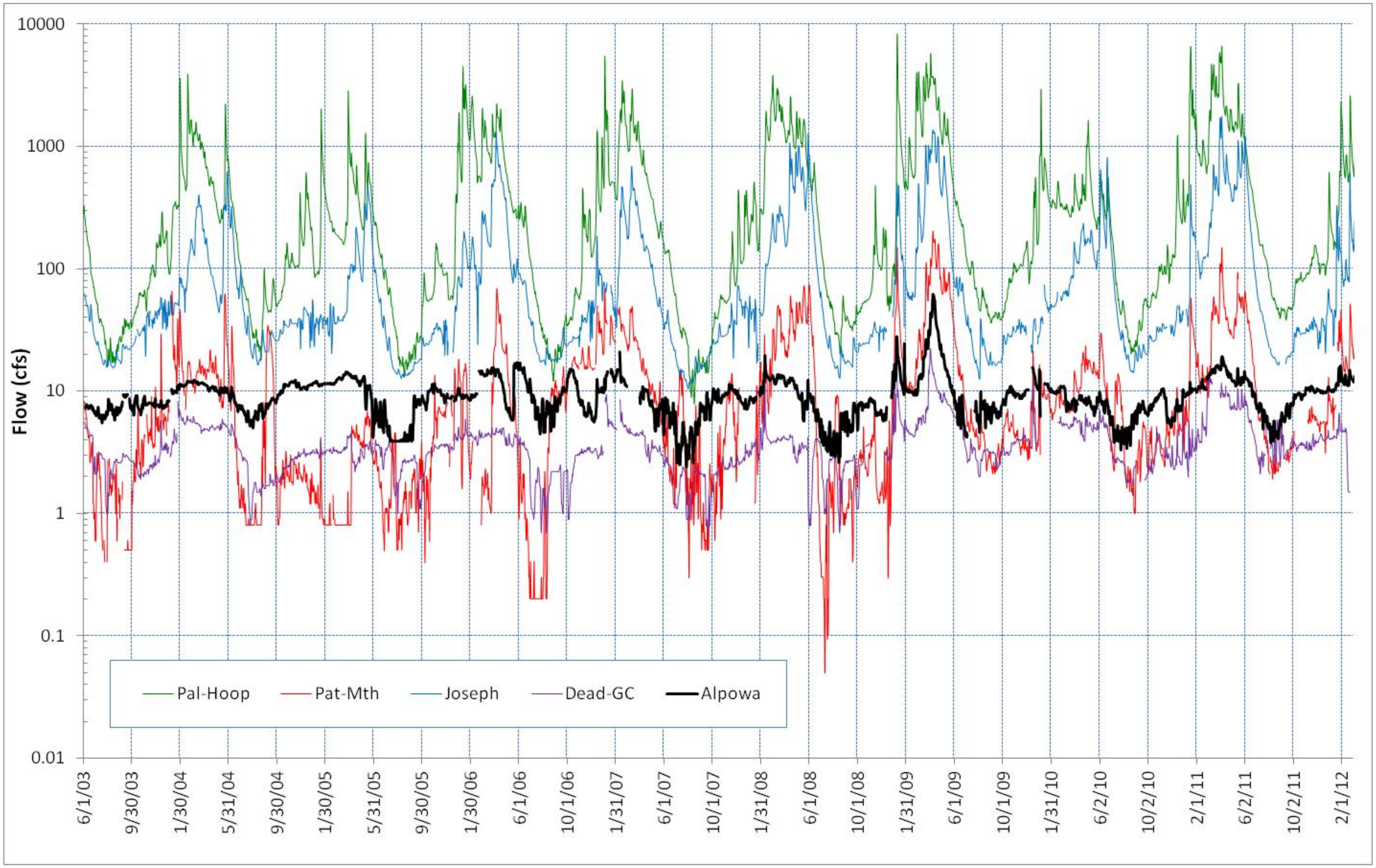

Figure 2. Measured flows at the Ecology “Alpowa Creek at Mouth” gaging station, with flows from other selected gages.

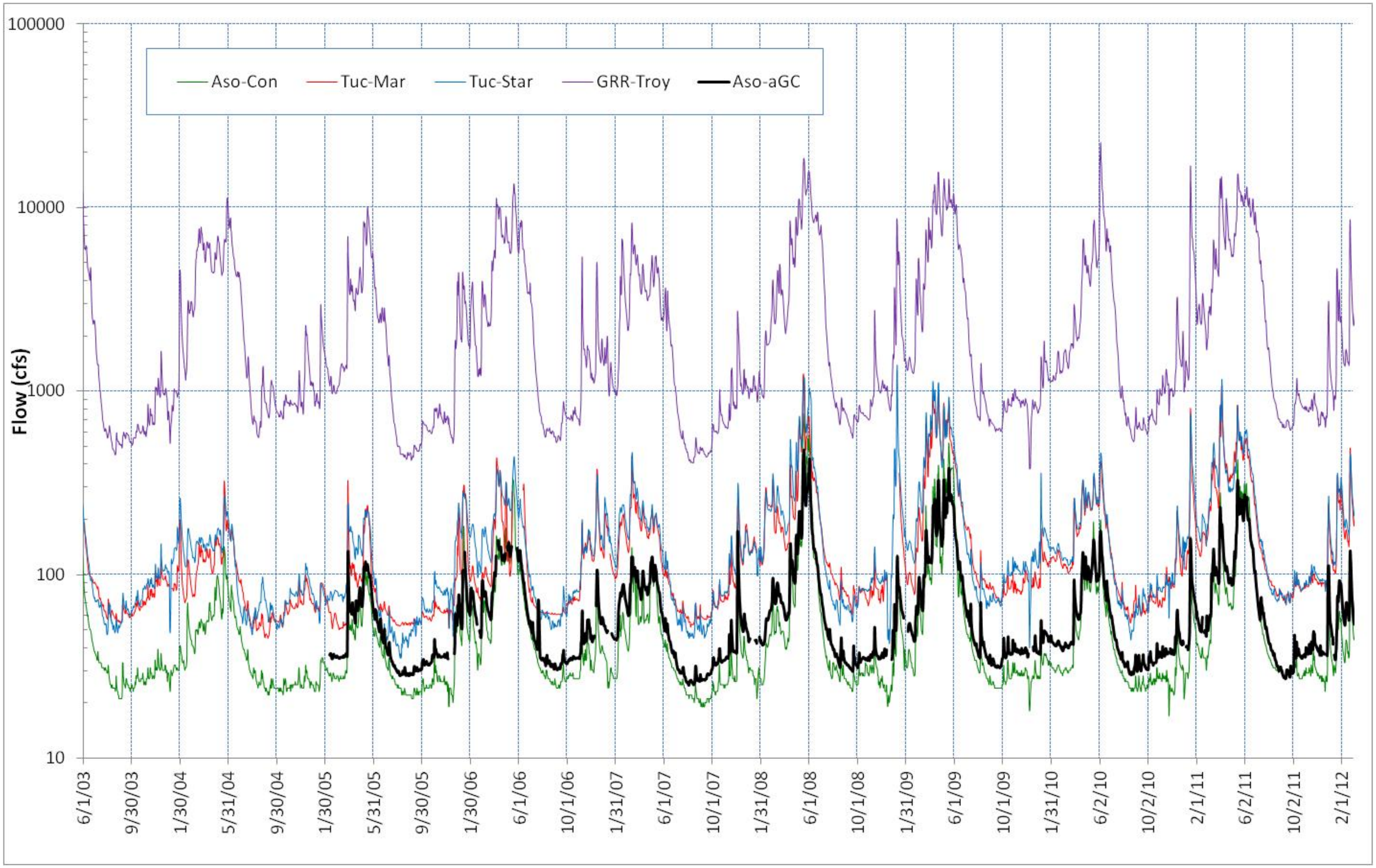

Figure 3. Measured flows at the Ecology “Asotin Creek above George Creek” gaging station, with flows from other selected gages.

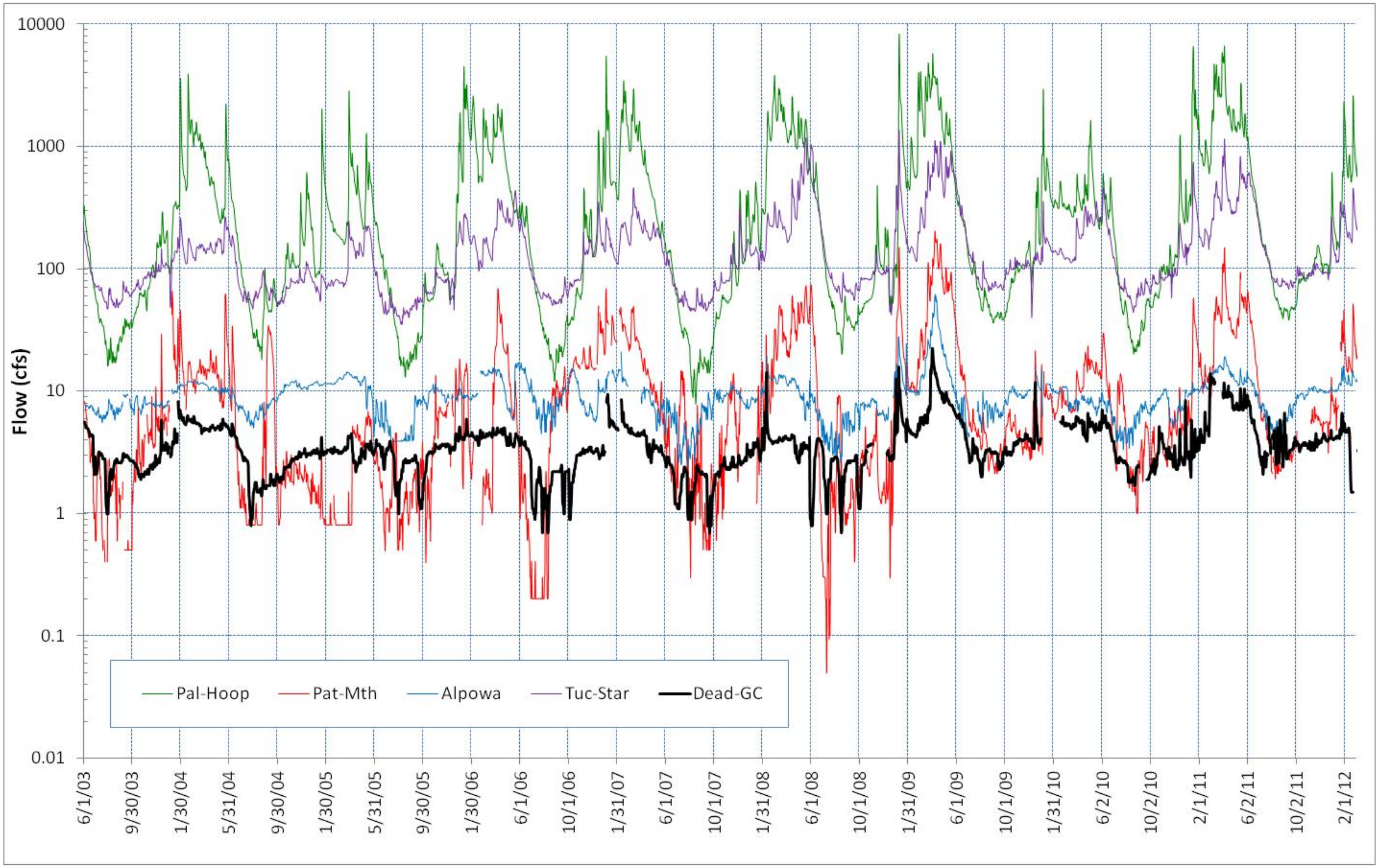

Figure 4. Measured flows at the Ecology “Deadman Creek near Gould City” gaging station, with flows from other selected gages.

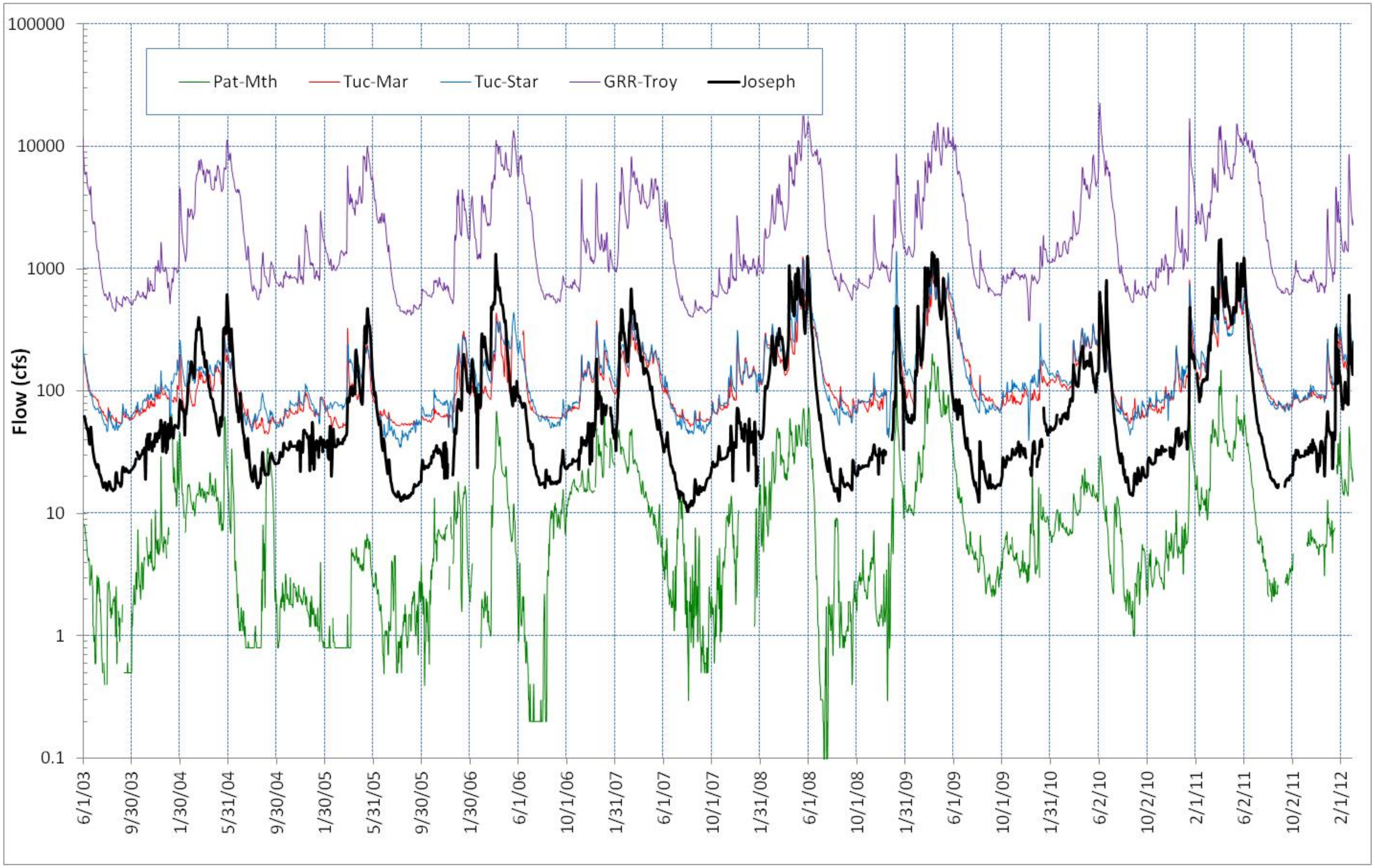

Figure 5. Measured flows at the Ecology “Joseph Creek near Mouth” gaging station, with flows from other selected gages.

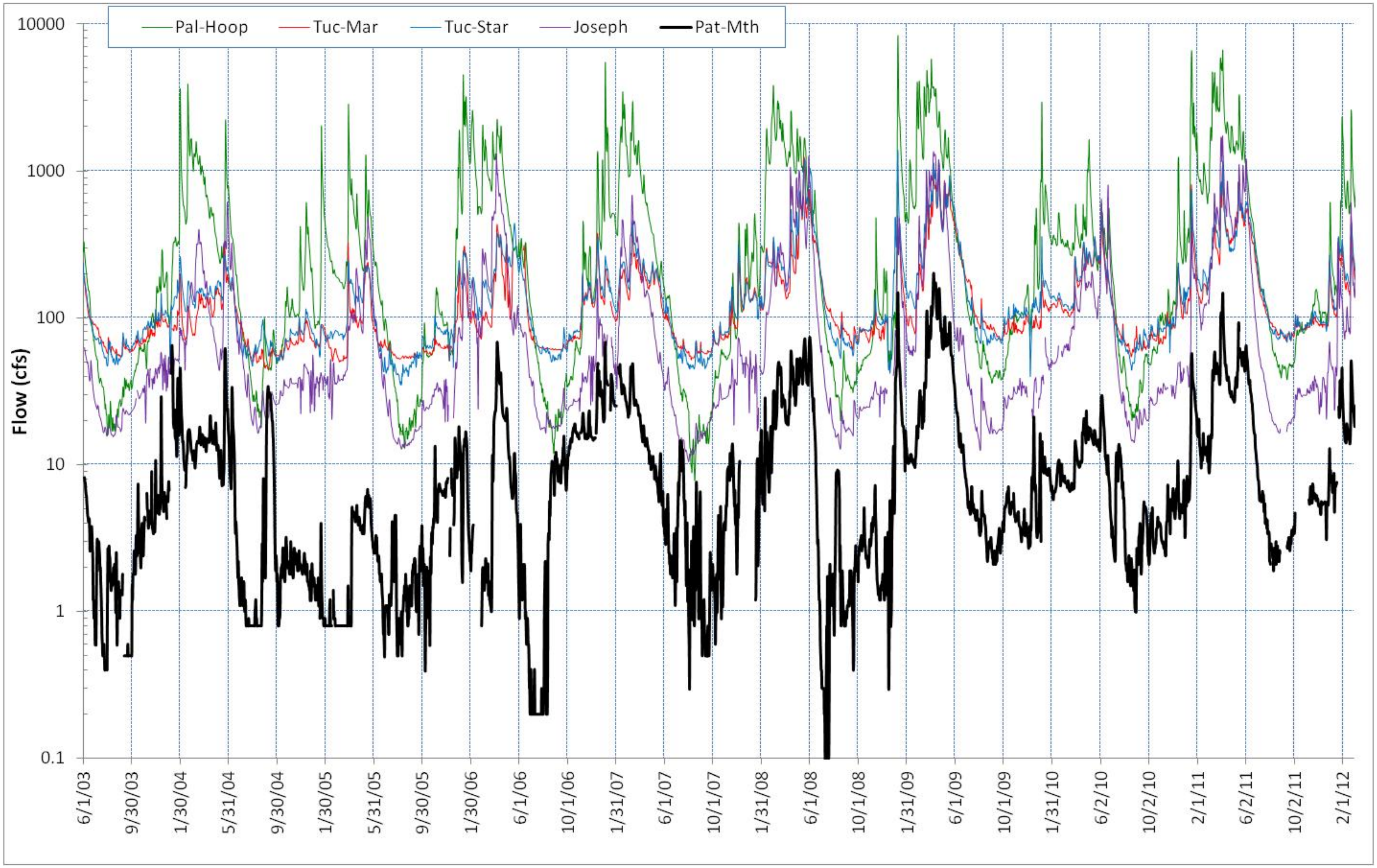

Figure 6. Measured flows at the Ecology “Pataha Creek near Mouth” gaging station, with flows from other selected gages.

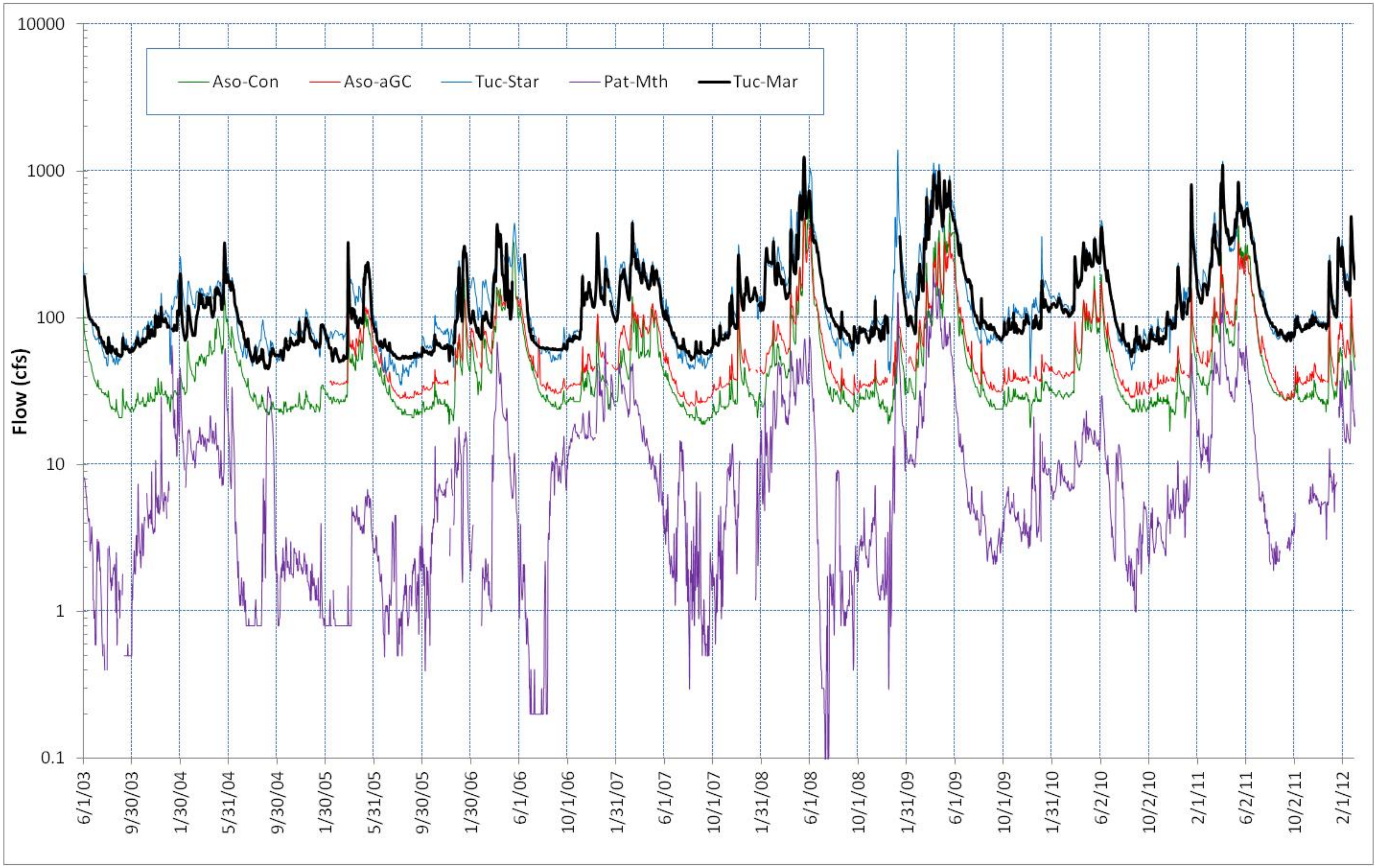

Figure 7. Measured flows at the Ecology "Tucannon River near Marengo" gaging station, with flows from other selected gages.

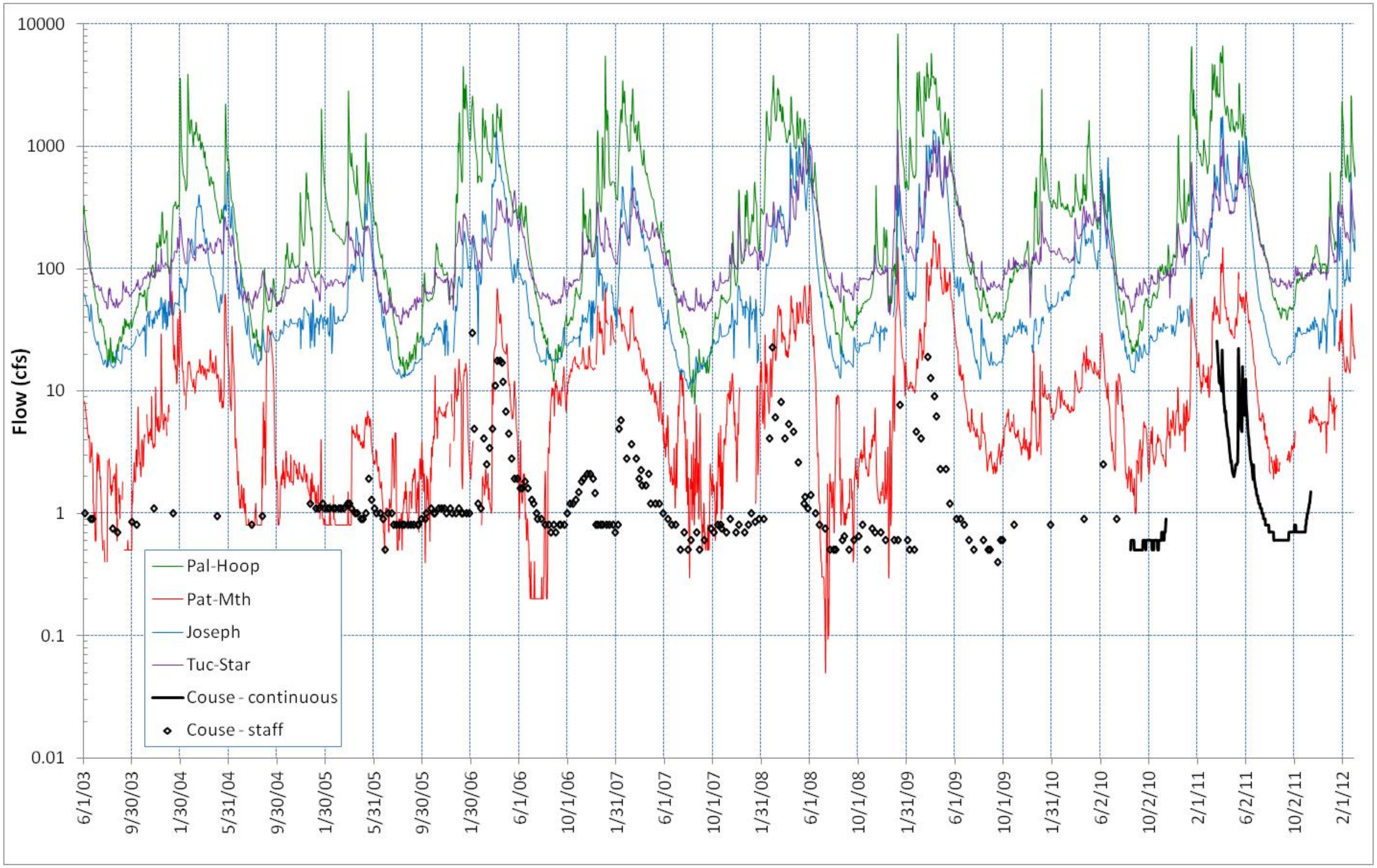

Figure 8. Measured flows at the Ecology “Couse Creek at Mouth” gaging station, with flows from other selected gages.

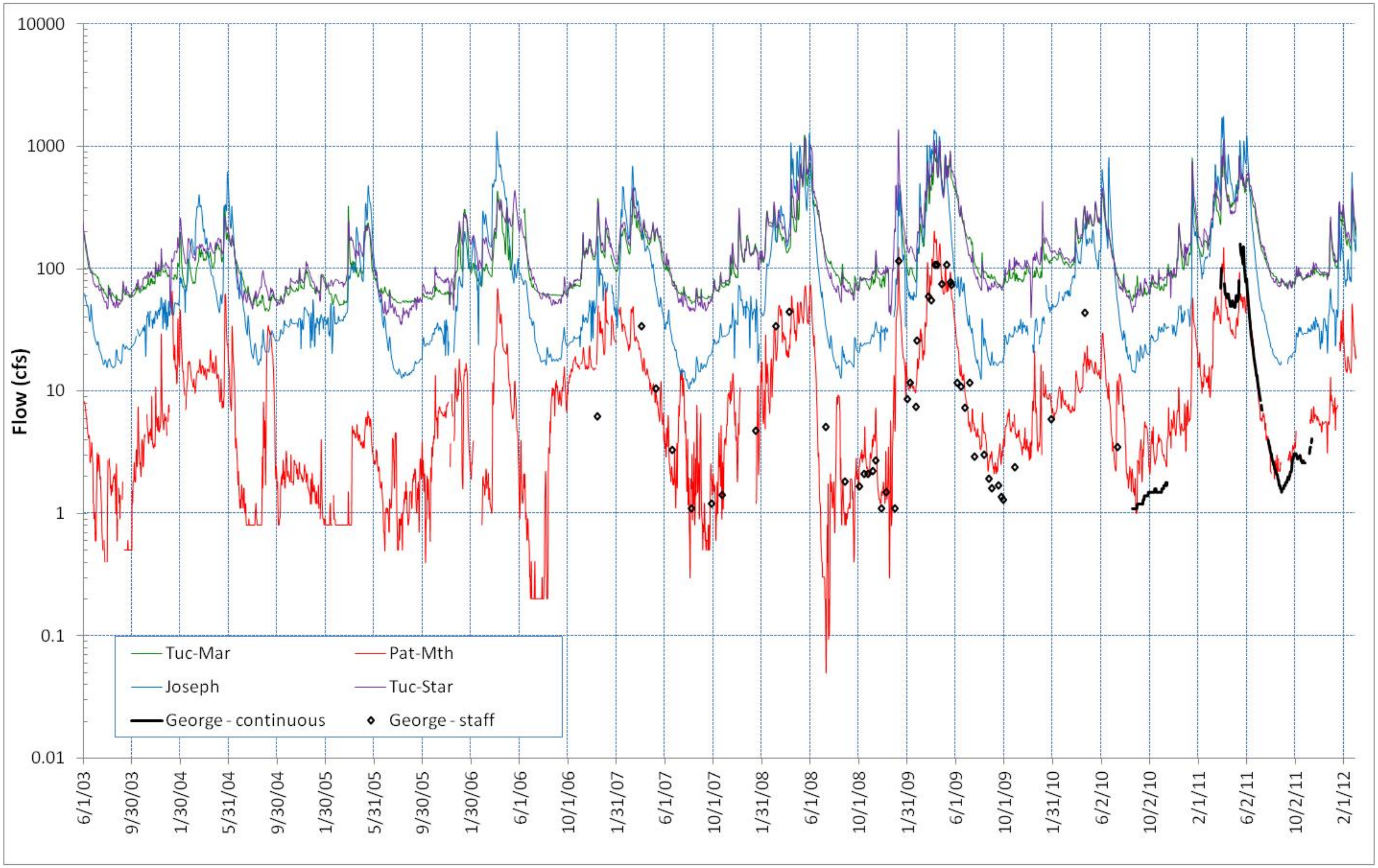

Figure 9. Measured flows at the Ecology “George Creek at Mouth” gaging station, with flows from other selected gages.

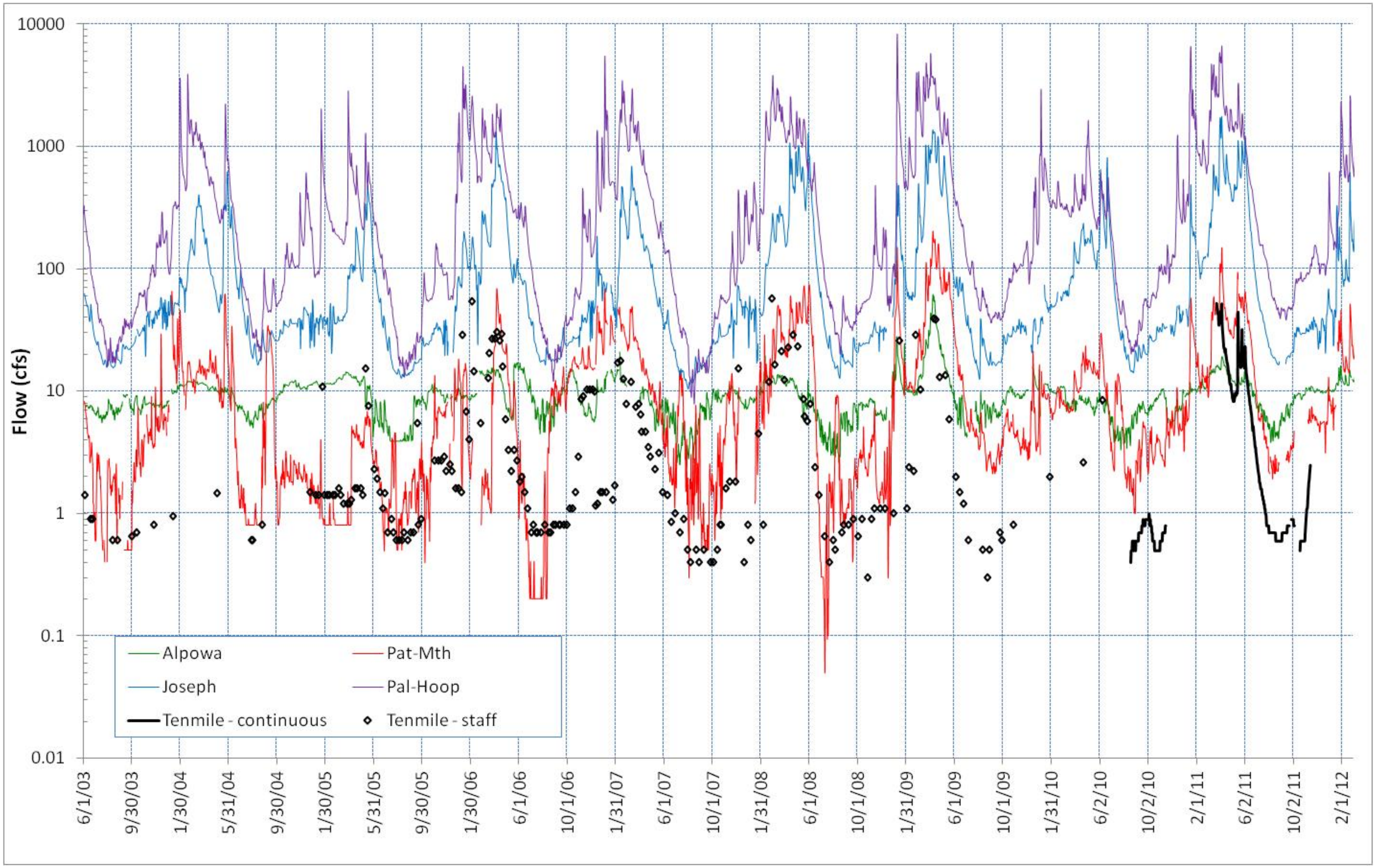

Figure 10. Measured flows at the Ecology “Tenmile Creek atMouth” gaging station, with flows from other selected gages.

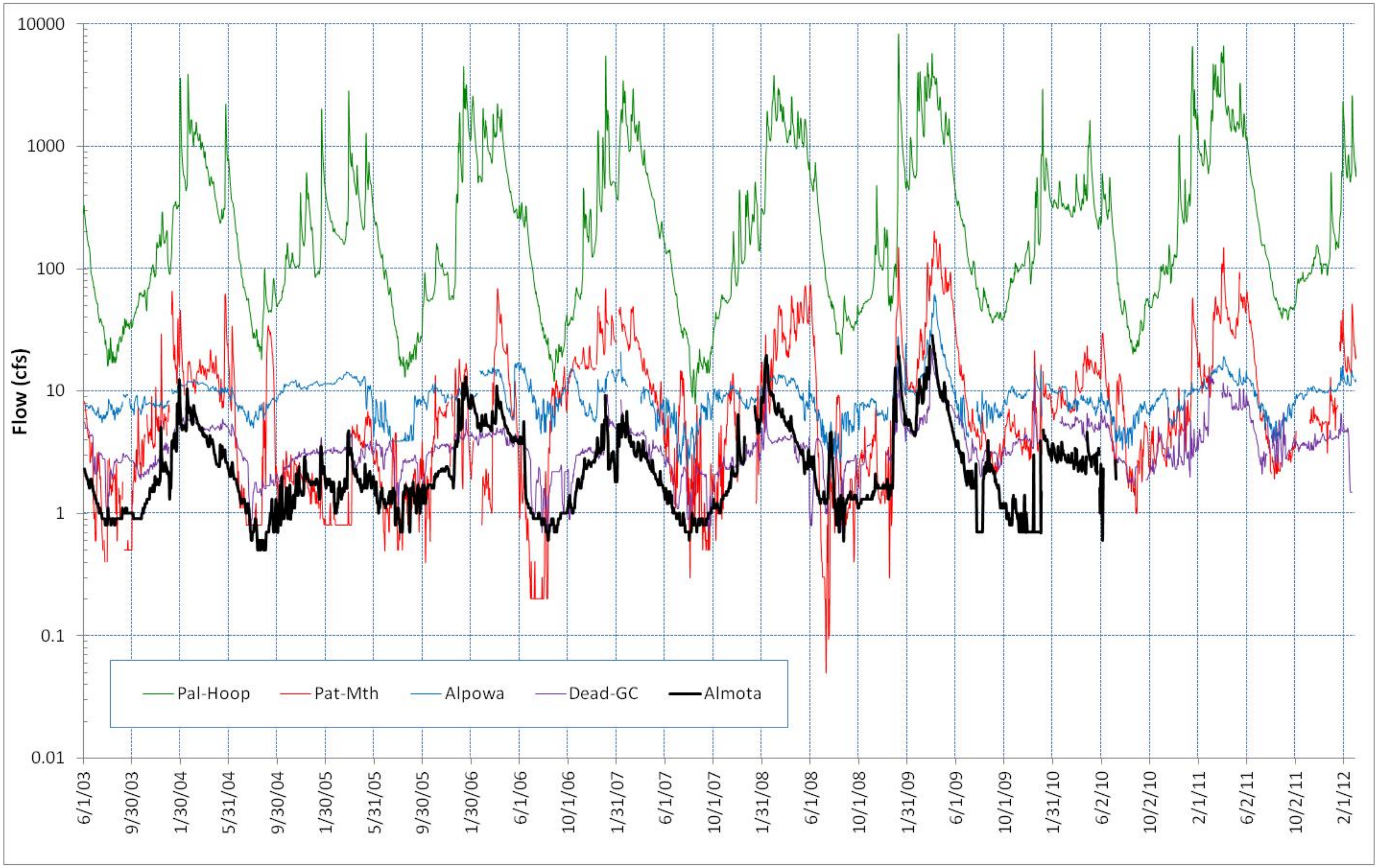

Figure 11. Measured flows at the Ecology “Almota Creek at Mouth” gaging station, with flows from other selected gages.

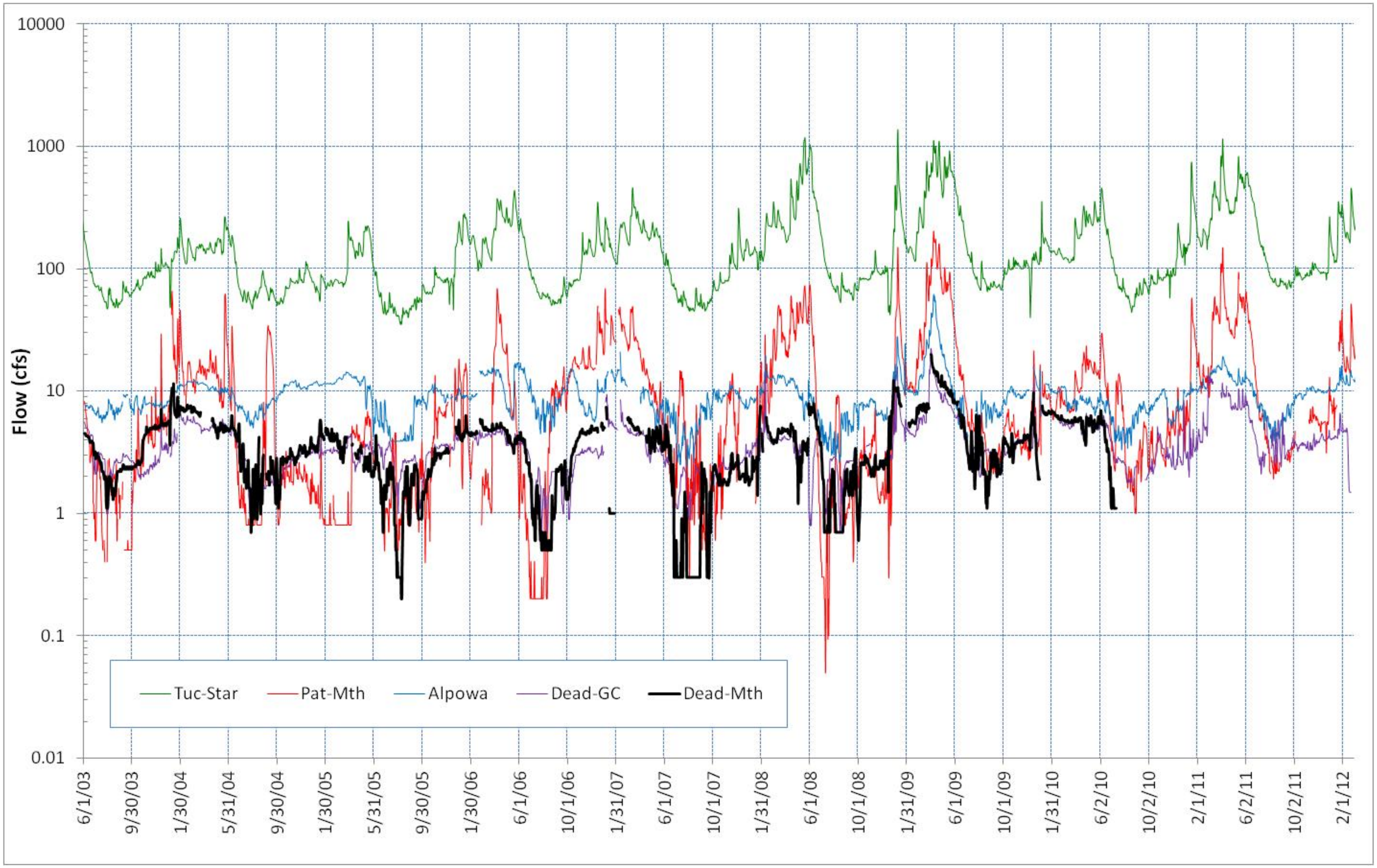

Figure 12. Measured flows at the Ecology "Deadman Creek near Mouth" gaging station, with flows from other selected gages.

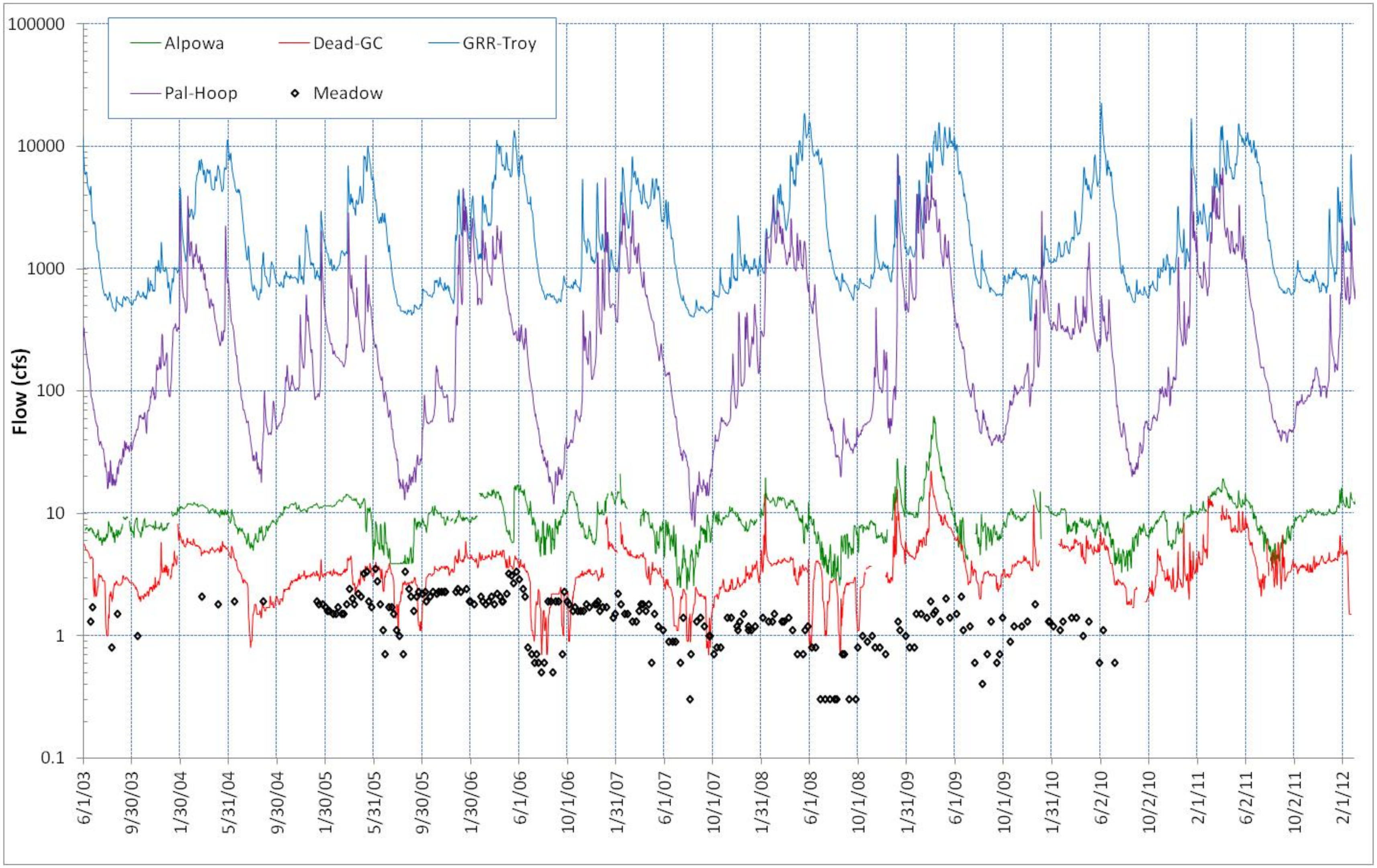

Figure 13. Measured flows at the Ecology “Meadow Creek at Mouth” gaging station, with flows from other selected gages.

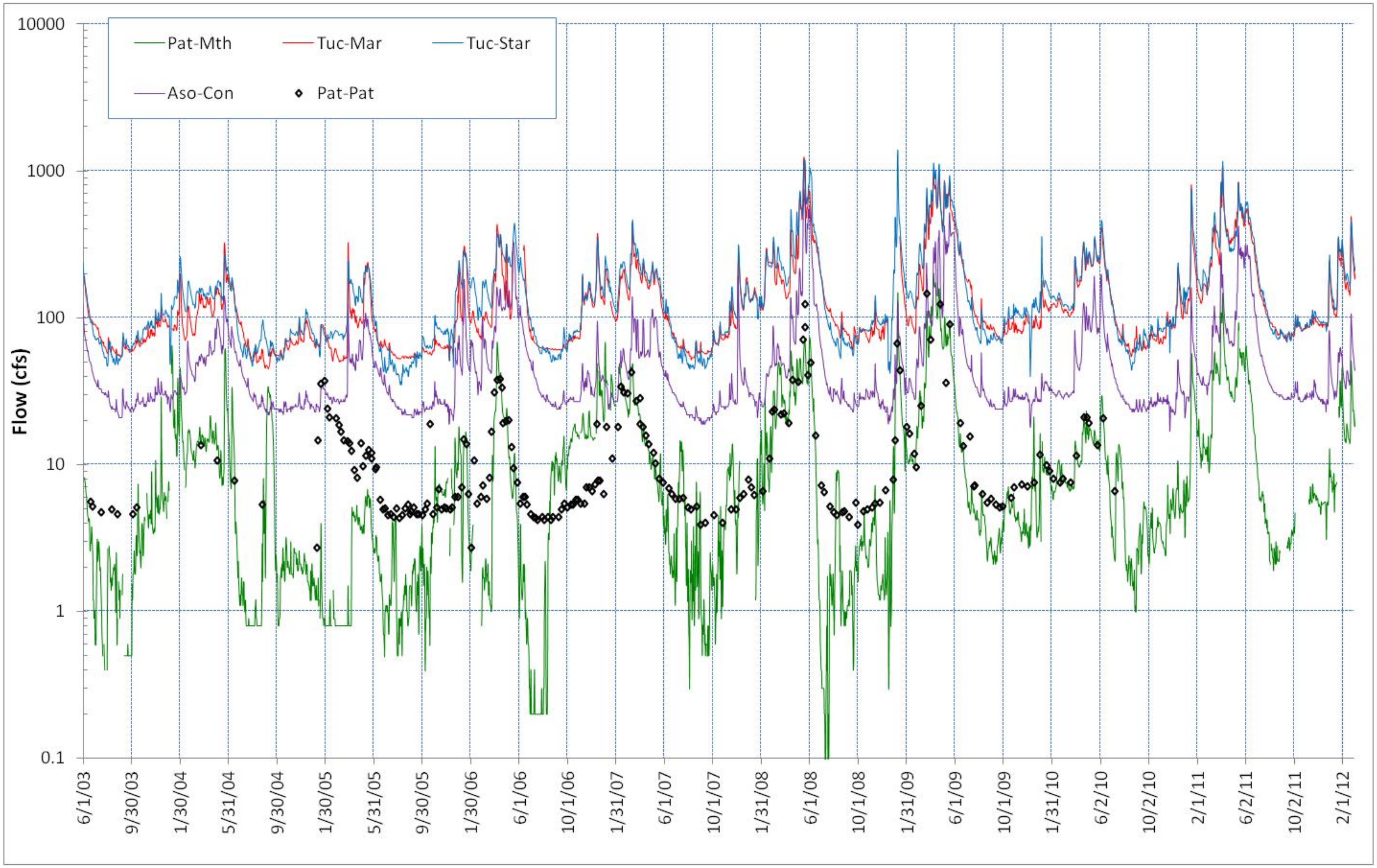

Figure 14. Measured flows at the Ecology "Pataha Creek near Pataha" gaging station, with flows from other selected gages.

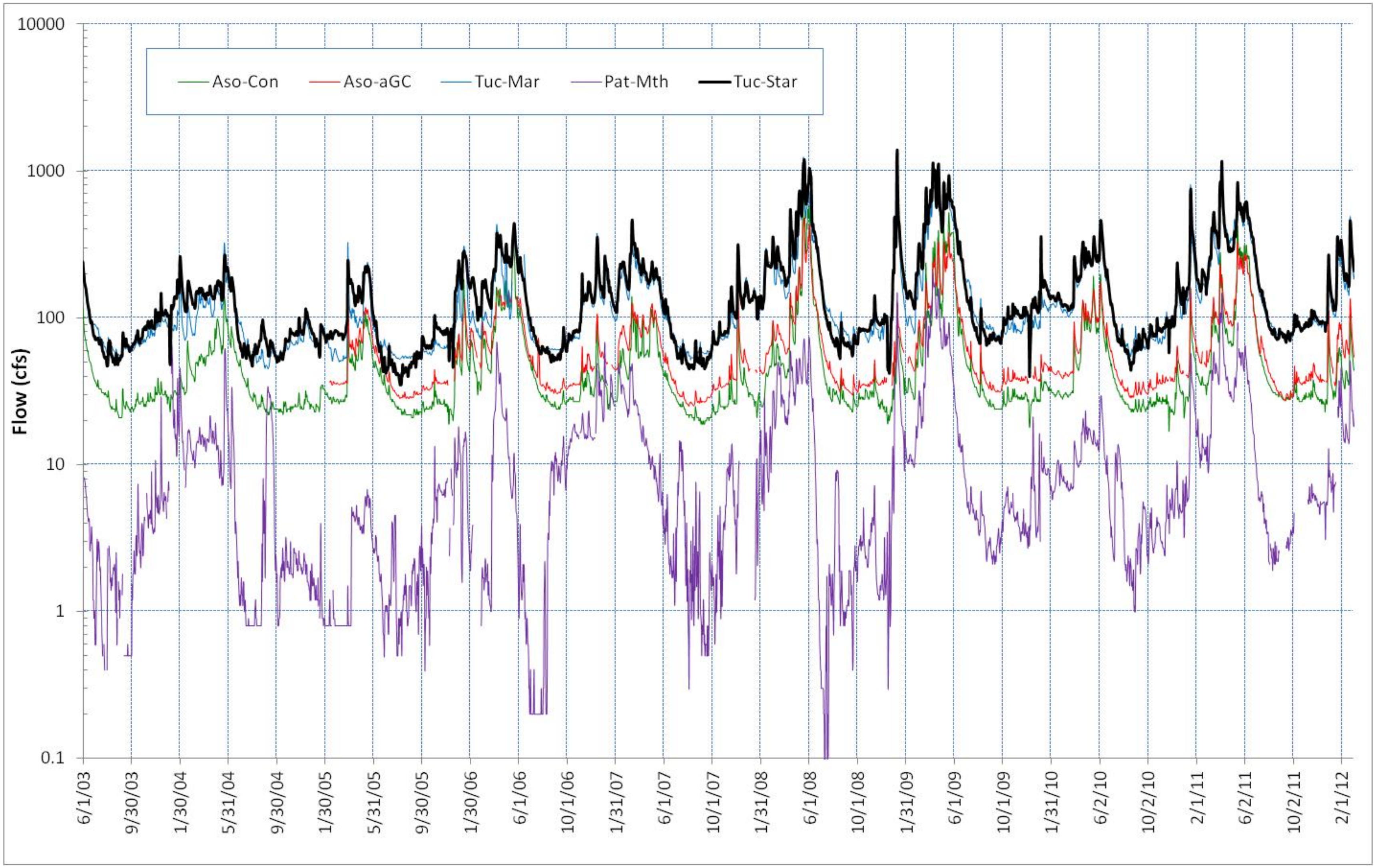

Figure 15. Measured flows at the USGS "Tucannon River near Starbuck" gaging station, with flows from other selected gages.

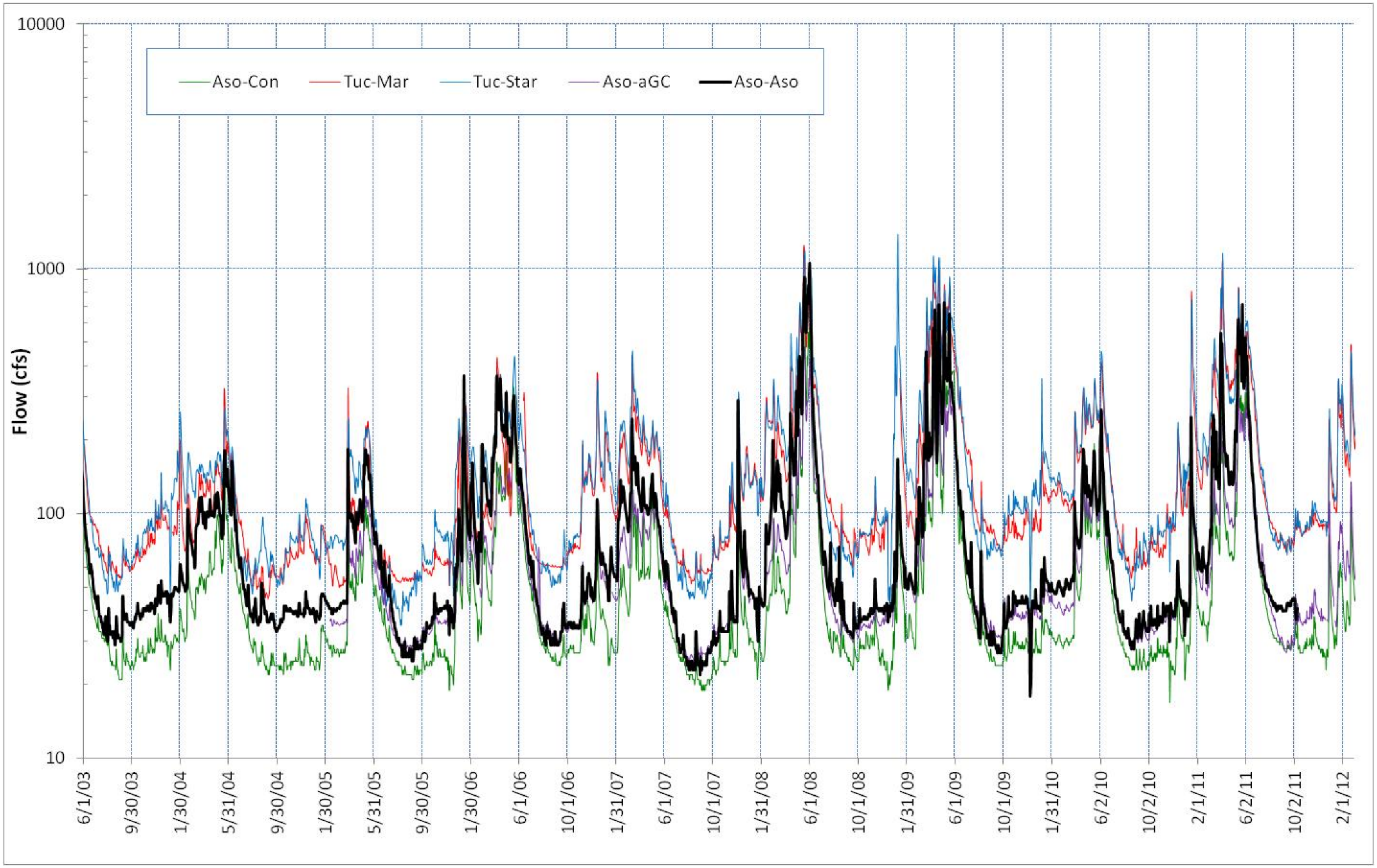

Figure 16. Measured flows at the USGS "Asotin Creek at Asotin" gaging station, with flows from other selected gages.

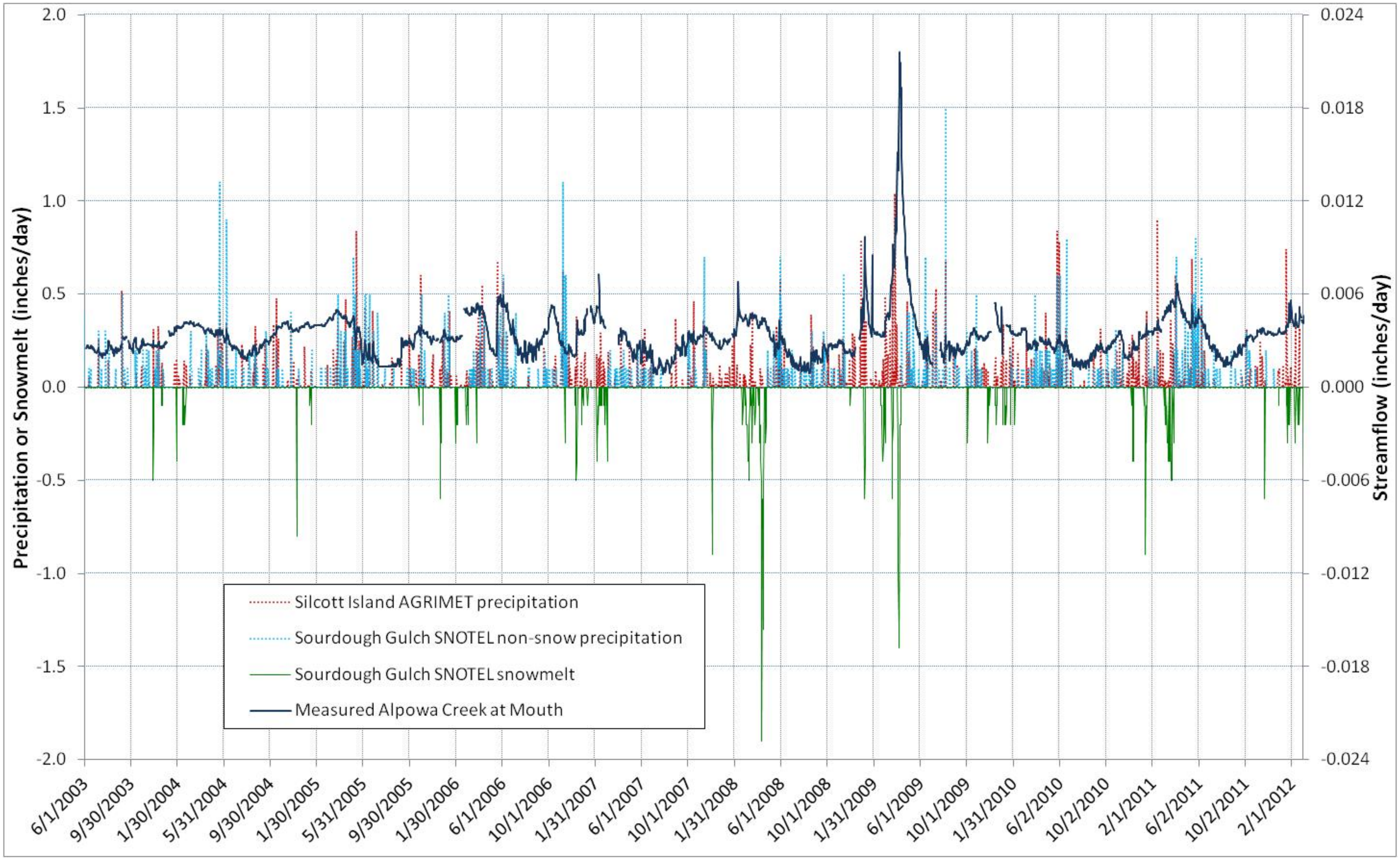

Figure 17. Measured areal flows at the Ecology “Alpowa Creek at Mouth” gaging station, with precipitation and snowmelt data.

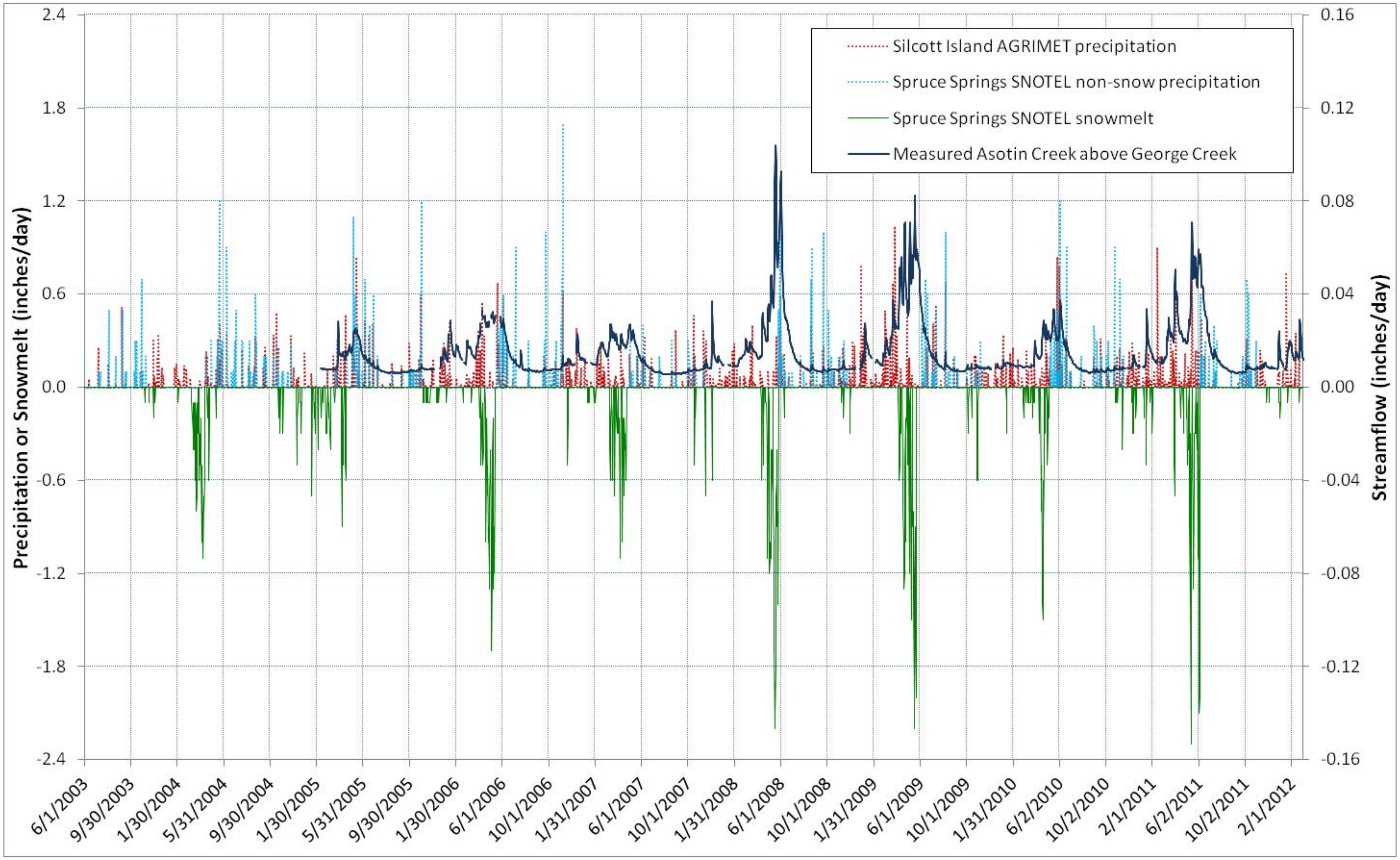

Figure 18. Measured areal flows at the Ecology "Asotin Creek above George Creek" gaging station, with precipitation and snowmelt data.

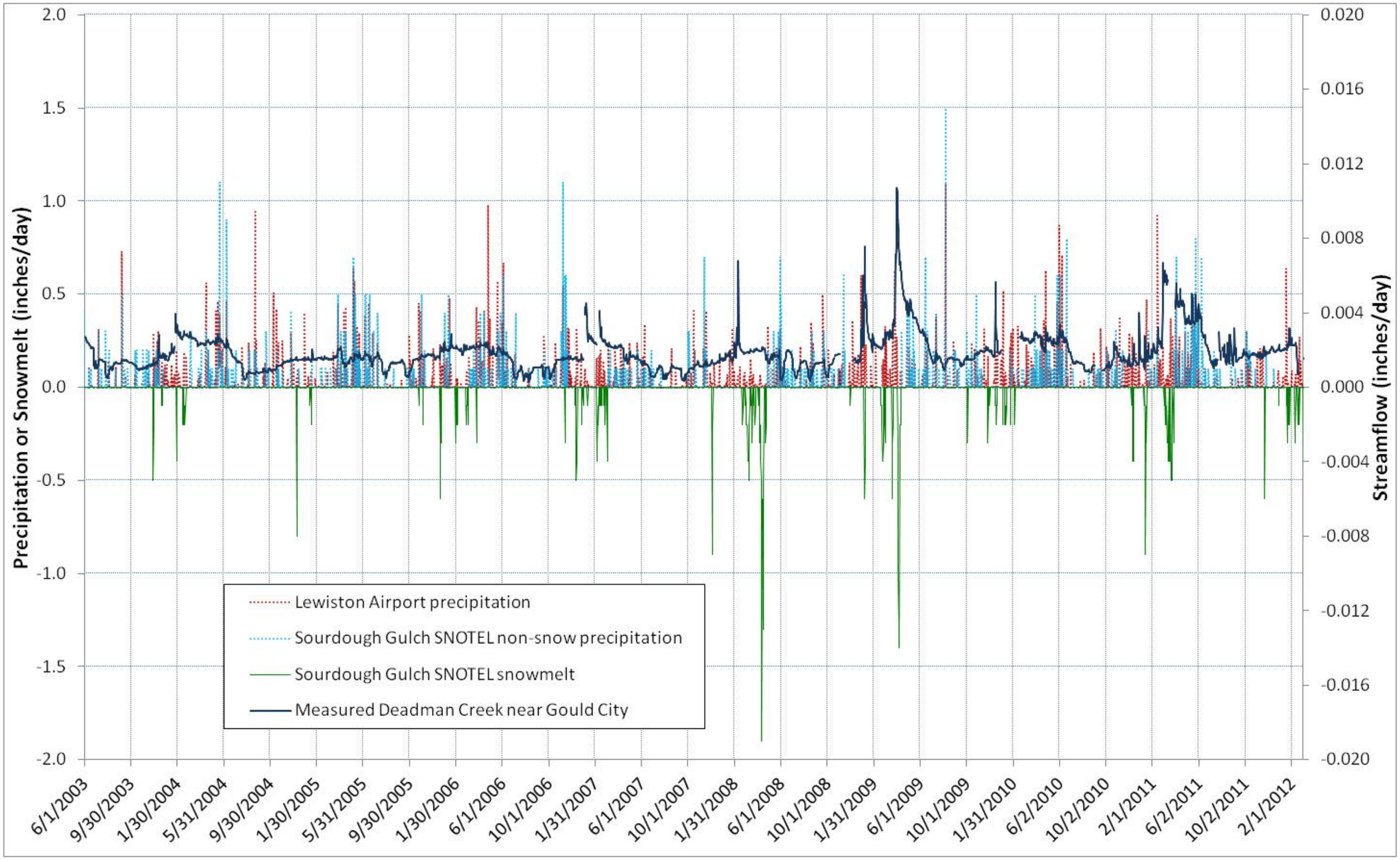

Figure 19. Measured areal flows at the Ecology “Deadman Creek near Gould City” gaging station, with precipitation and snowmelt data.

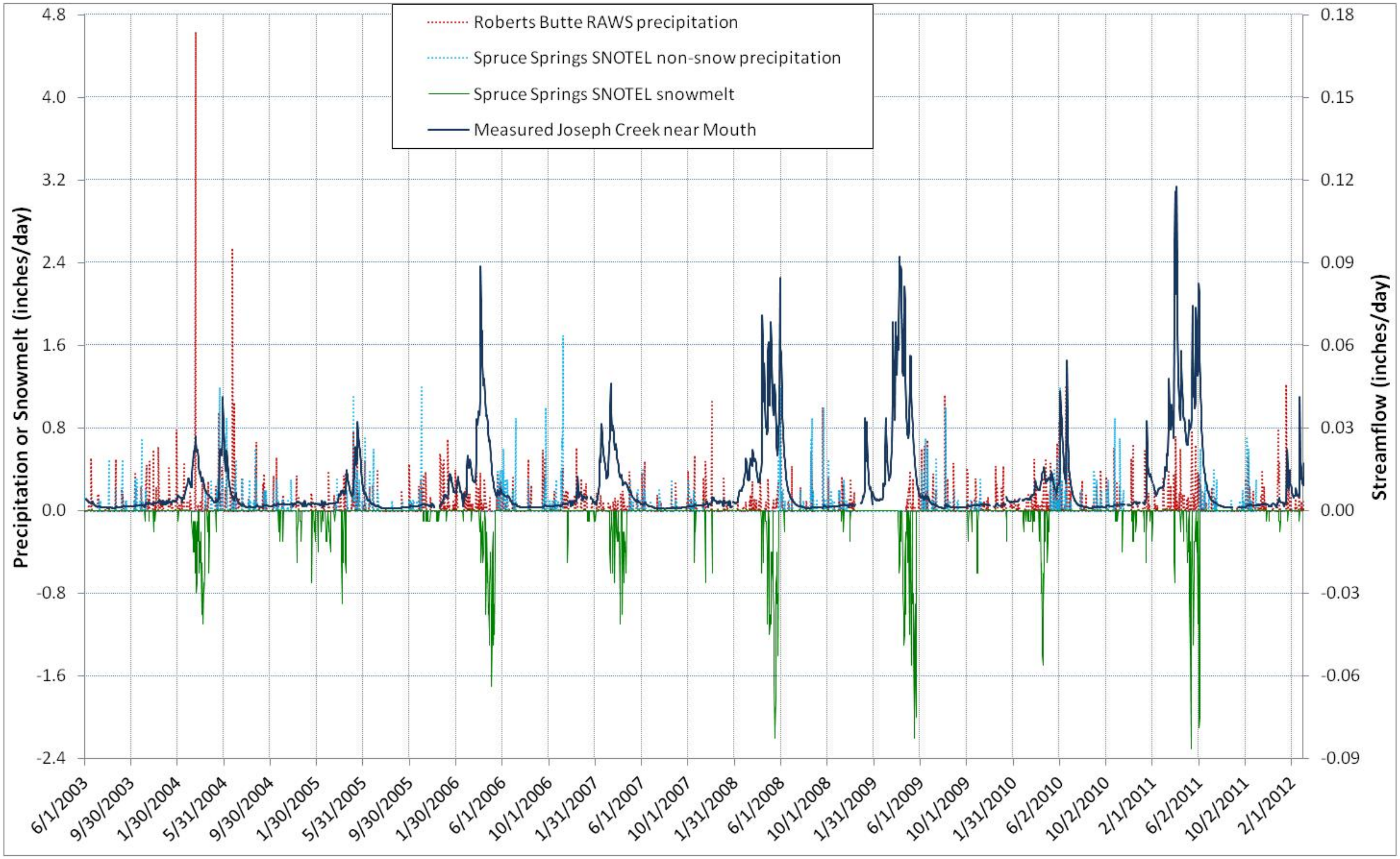

Figure 20. Measured areal flows at the Ecology “Joseph Creek near Mouth” gaging station, with precipitation and snowmelt data.

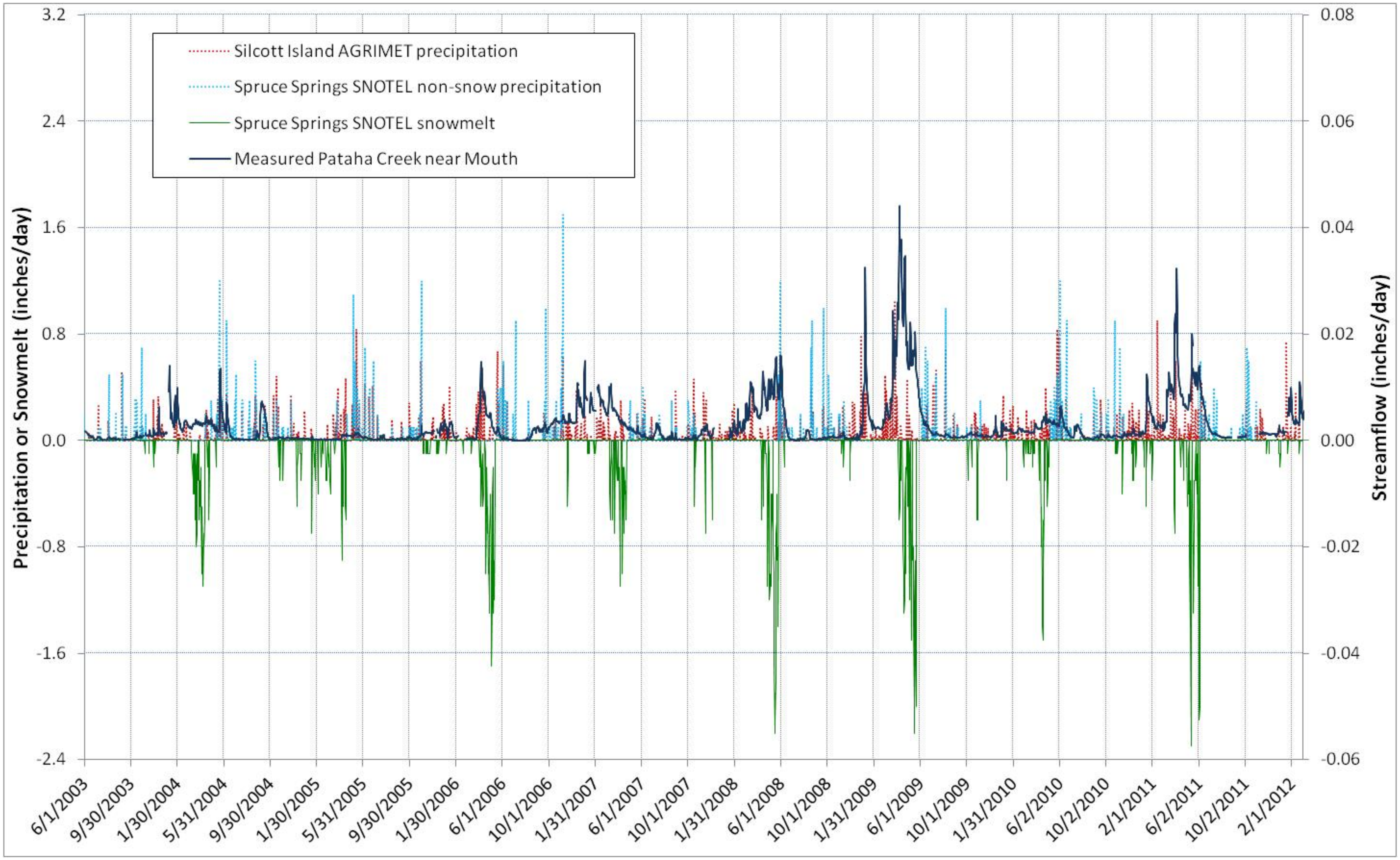

Figure 21. Measured areal flows at the Ecology “Pataha Creek near Mouth” gaging station, with precipitation and snowmelt data.

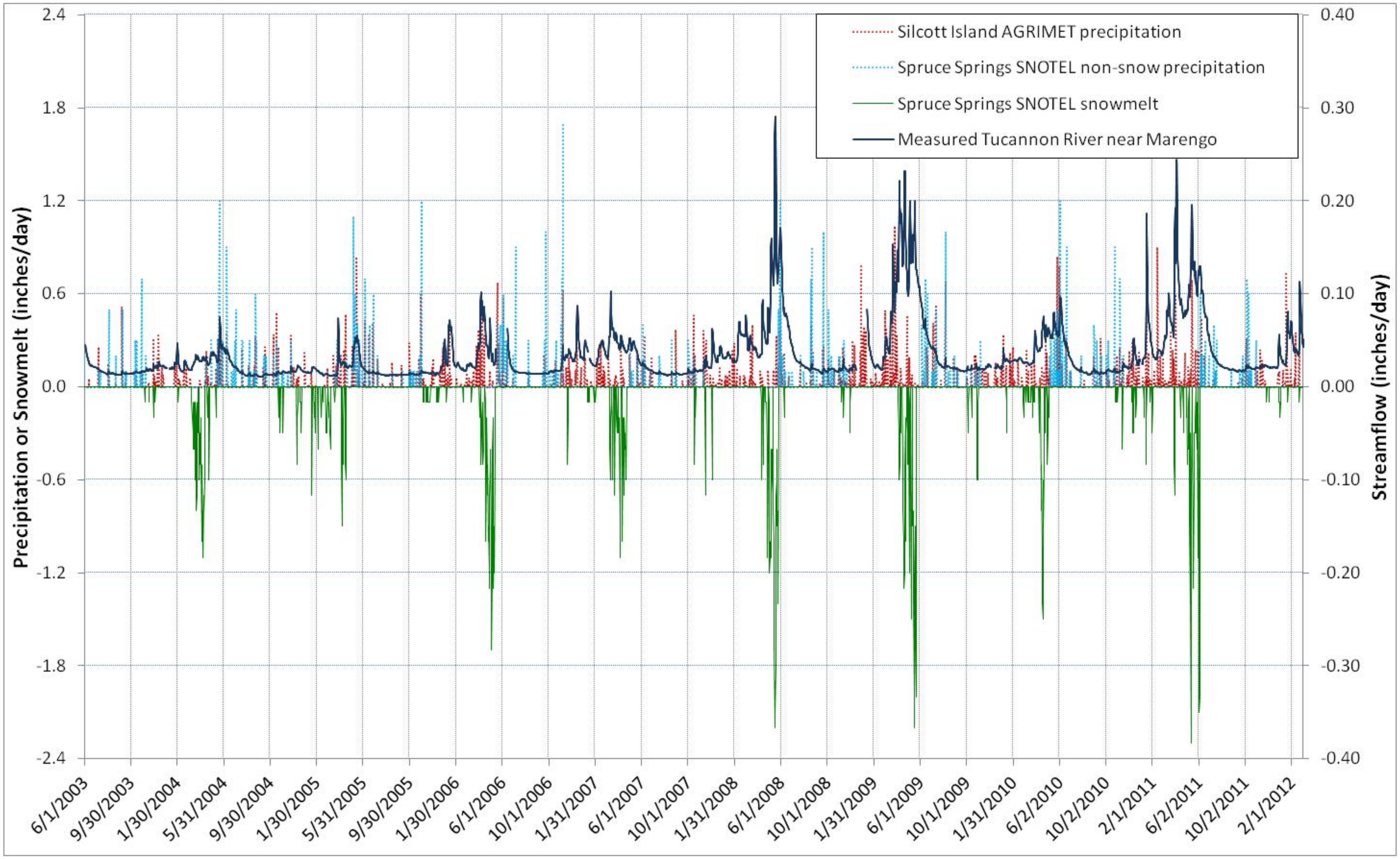

Figure 22. Measured areal flows at the Ecology "Tucannon River near Marengo" gaging station, with precipitation and snowmelt data.

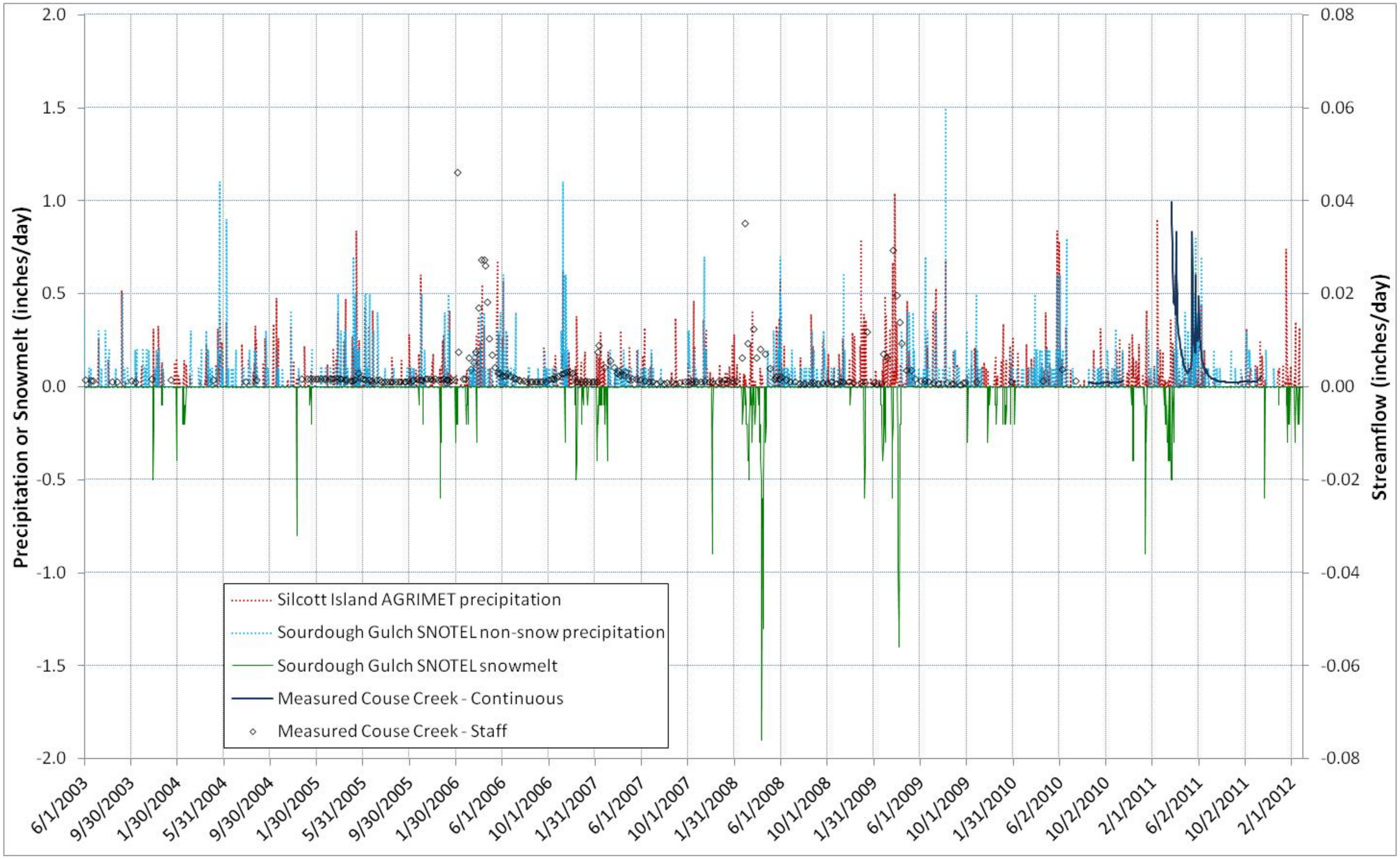

Figure 23. Measured areal flows at the Ecology “Couse Creek at Mouth” gaging station, with precipitation and snowmelt data.

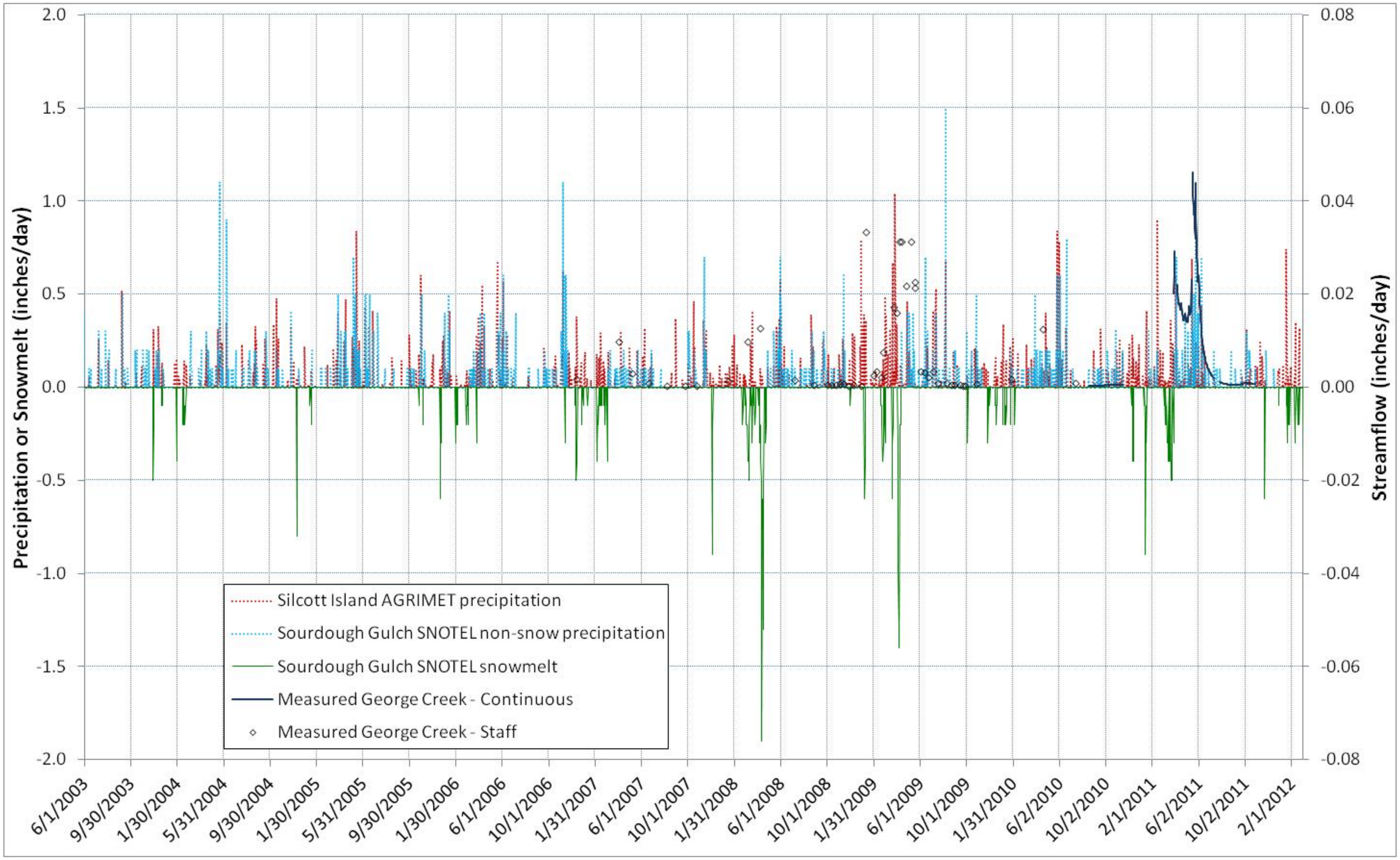

Figure 24. Measured areal flows at the Ecology "George Creek at Mouth" gaging station, with precipitation and snowmelt data.

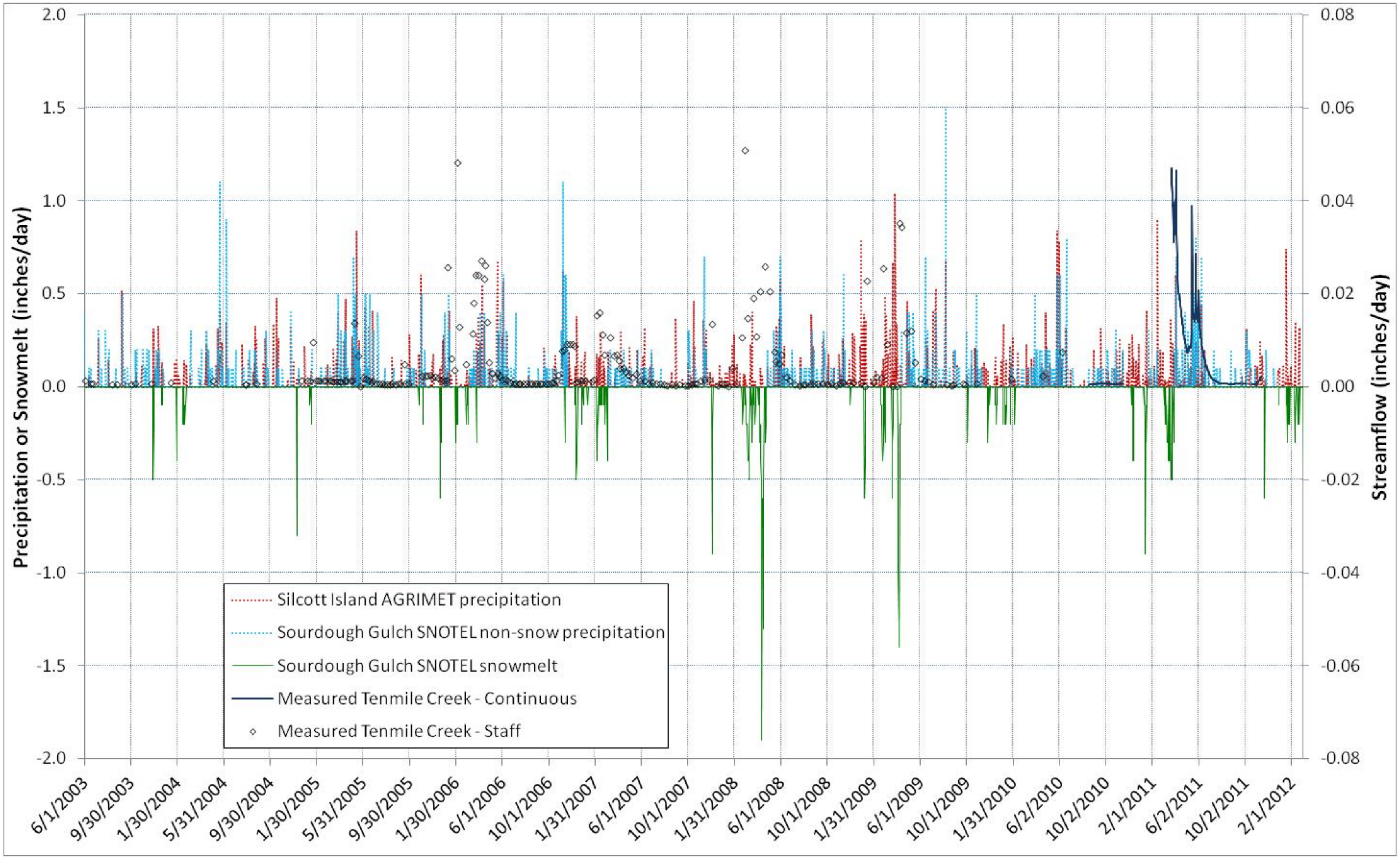

Figure 25. Measured areal flows at the Ecology "Tenmile Creek at Mouth" gaging station, with precipitation and snowmelt data.

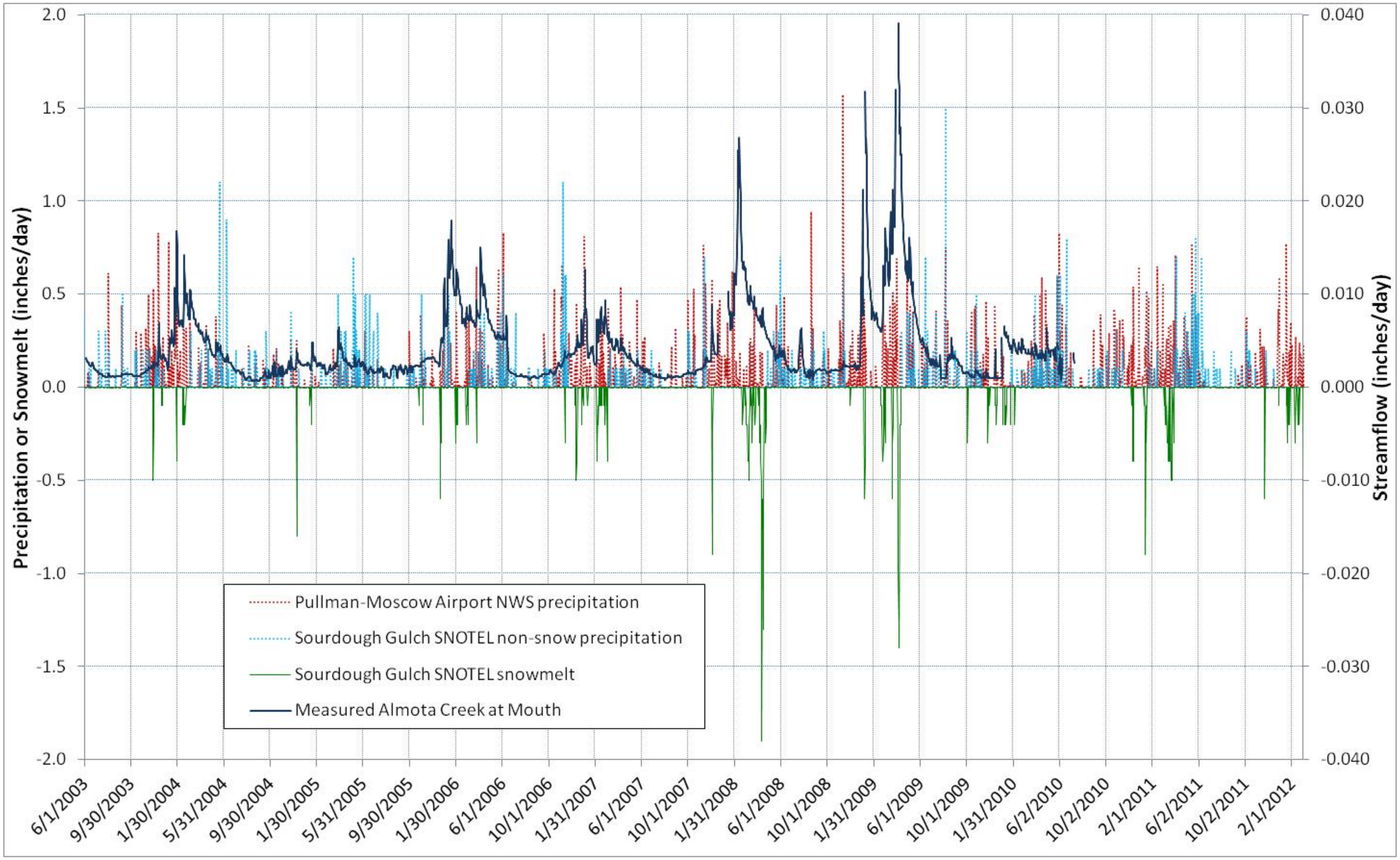

Figure 26. Measured areal flows at the Ecology "Almota Creek at Mouth" gaging station, with precipitation and snowmelt data.

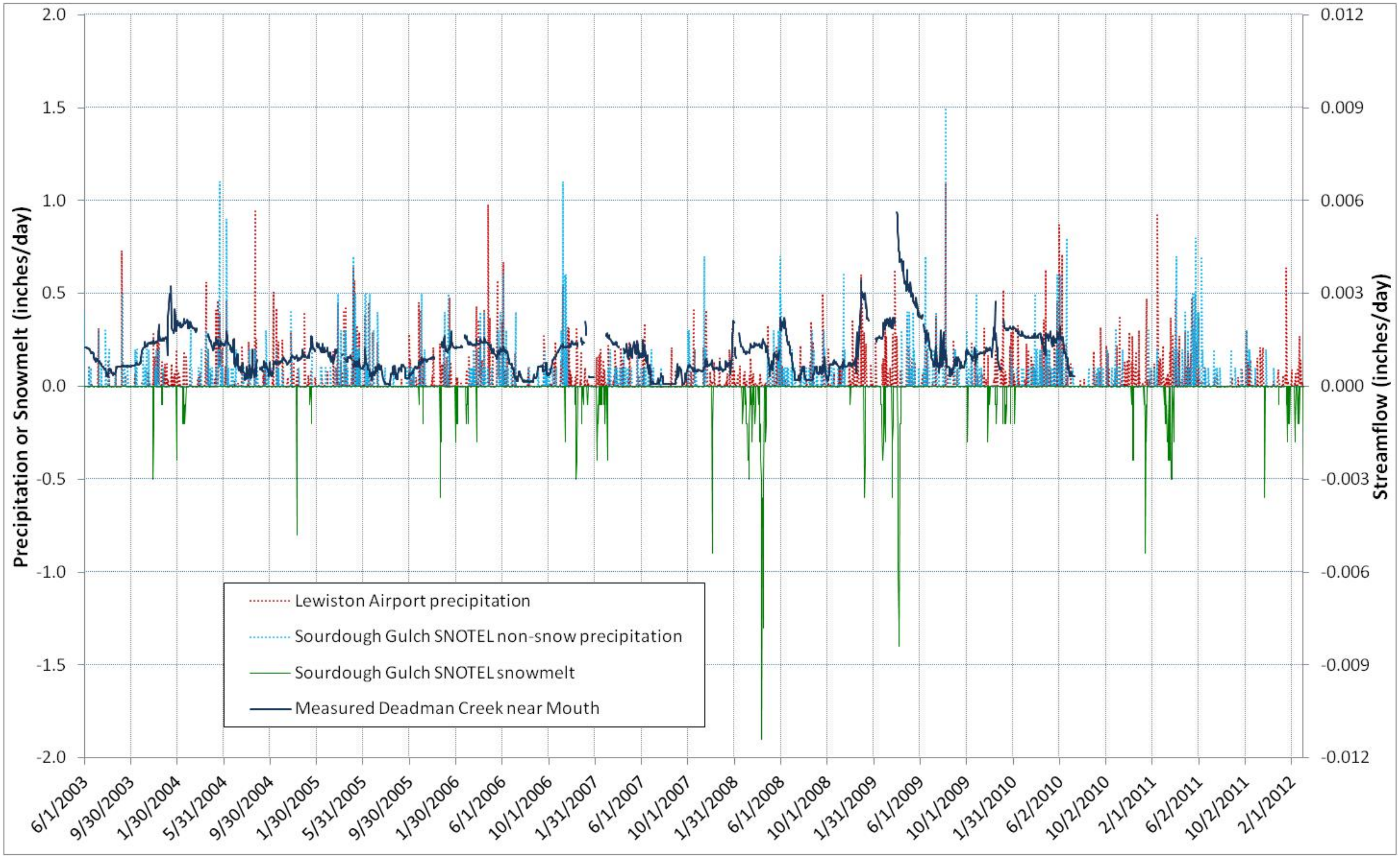

Figure 27. Measured areal flows at the Ecology “Deadman Creek near Mouth” gaging station, with precipitation and snowmelt data.

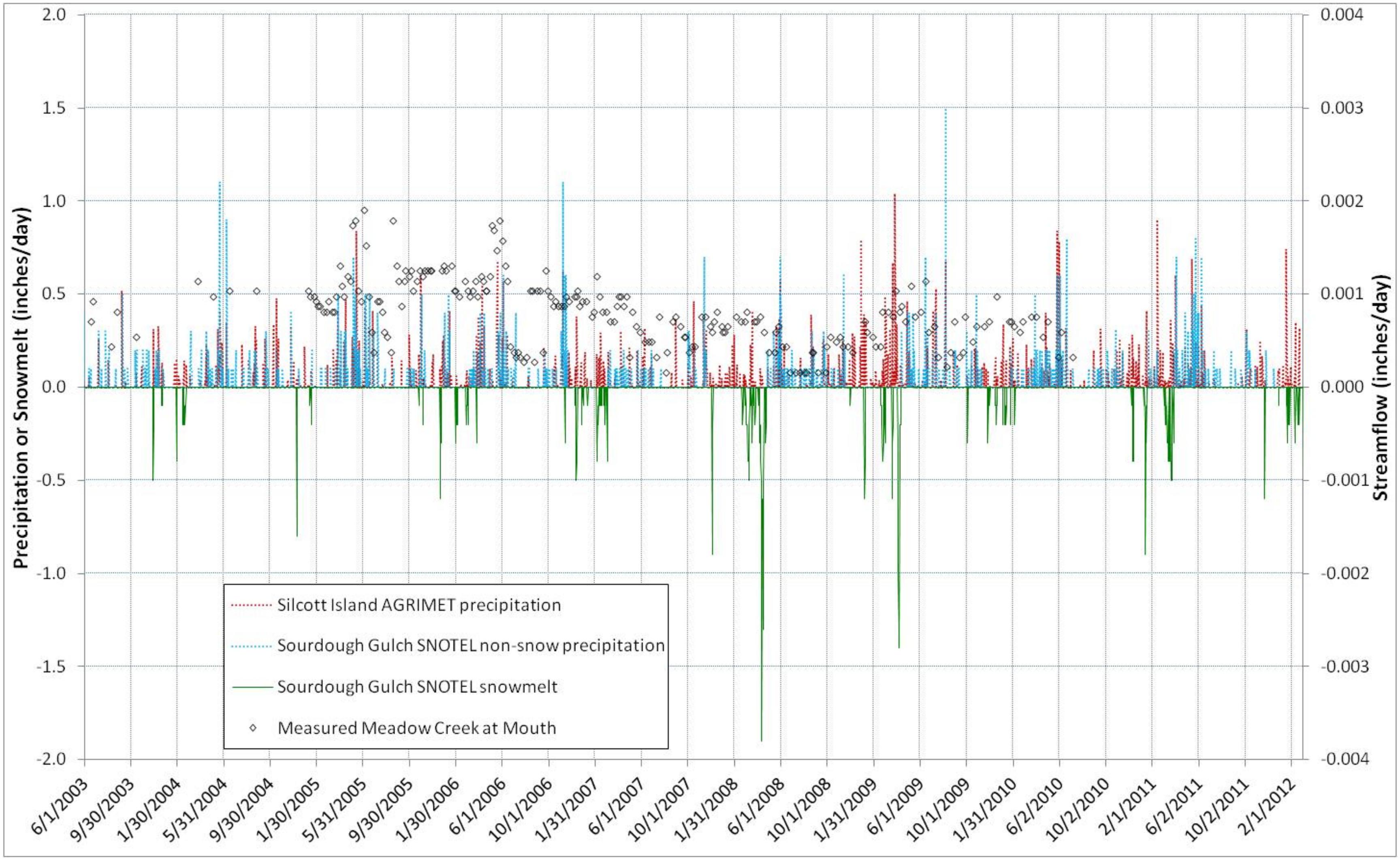

Figure 28. Measured areal flows at the Ecology "Meadow Creek at Mouth" gaging station, with precipitation and snowmelt data.

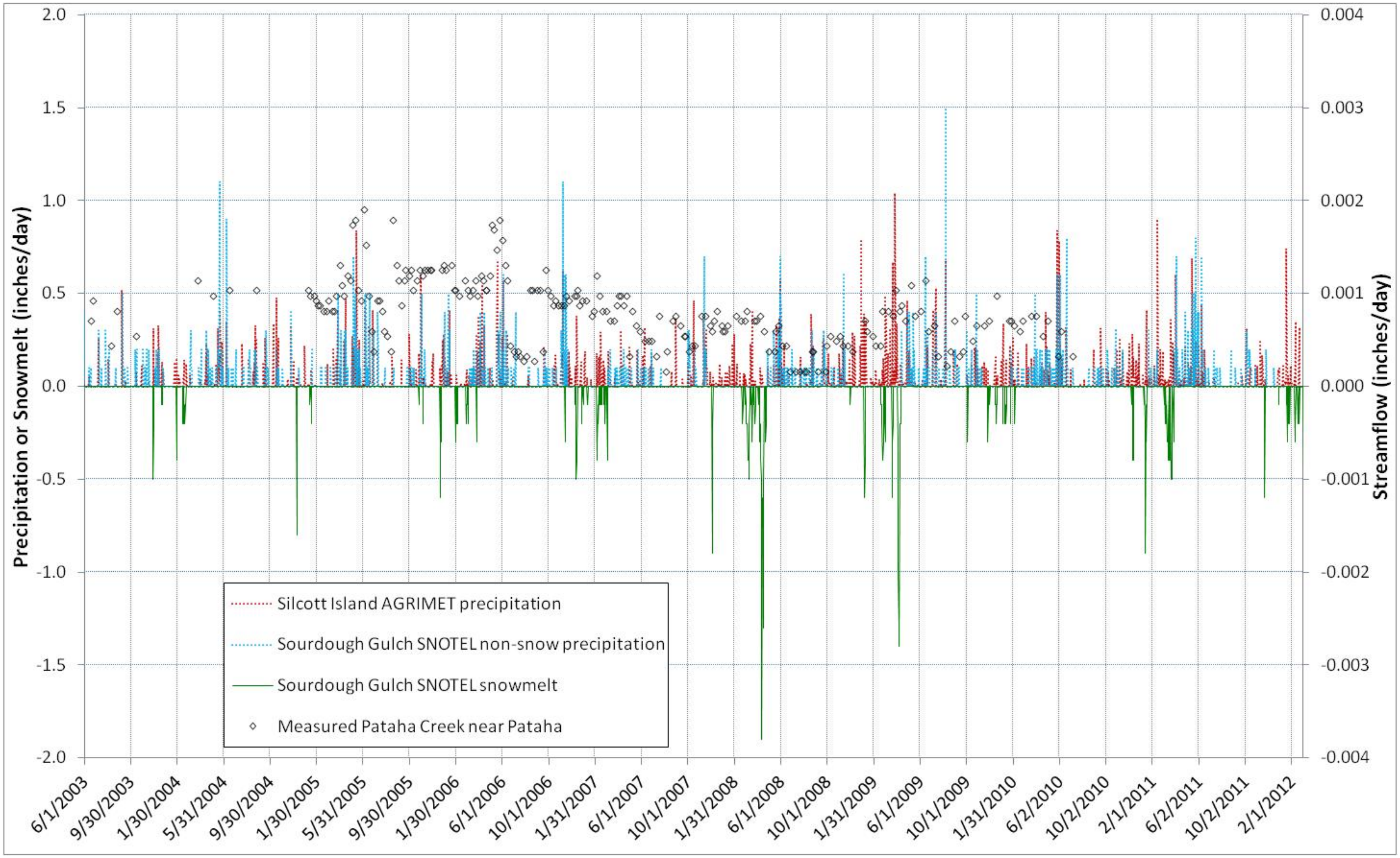

Figure 29. Measured areal flows at the Ecology "Pataha Creek near Pataha" gaging station, with precipitation and snowmelt data.

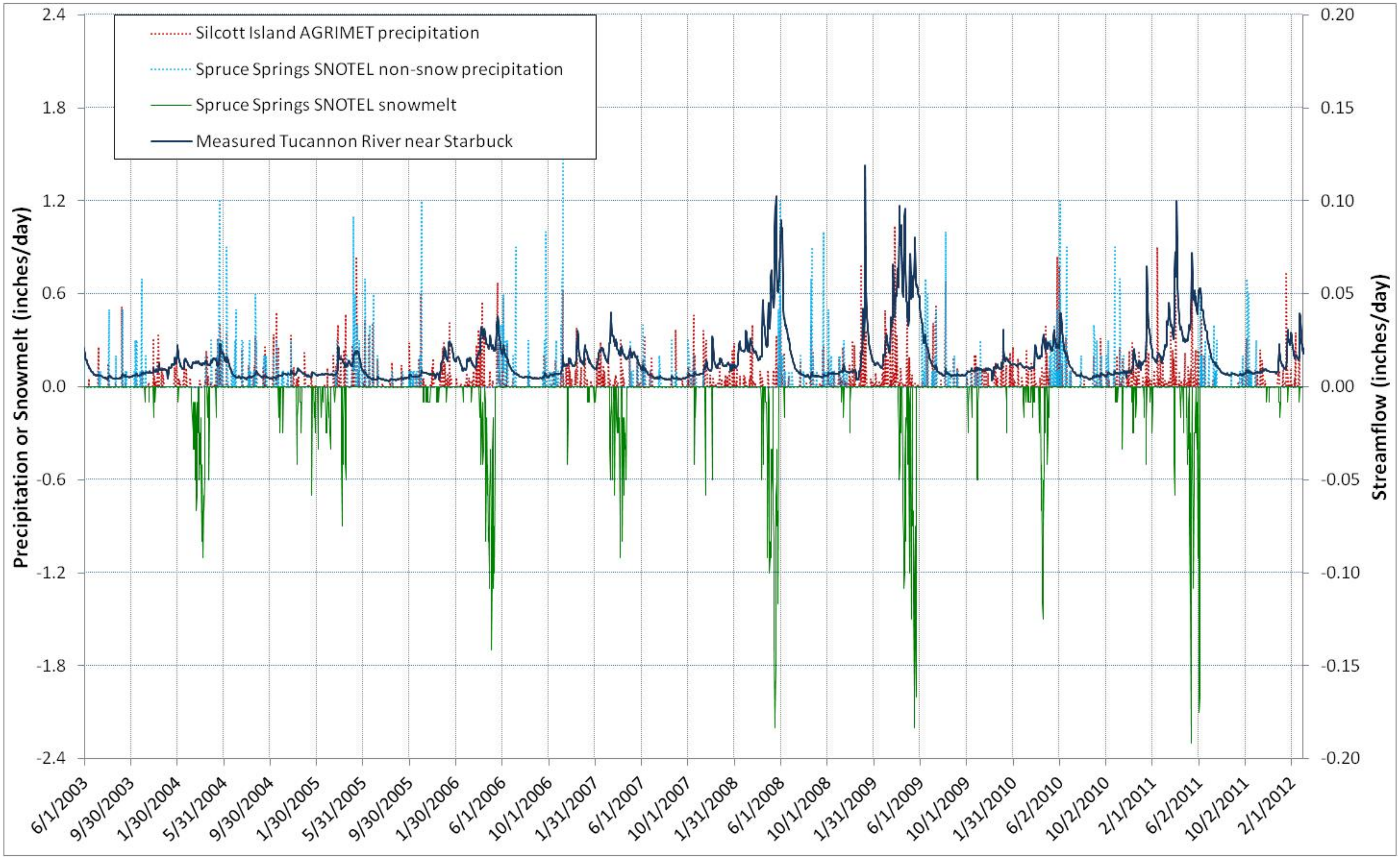

Figure 30. Measured areal flows at the USGS "Tucannon River near Starbuck" gaging station, with precipitation and snowmelt data.

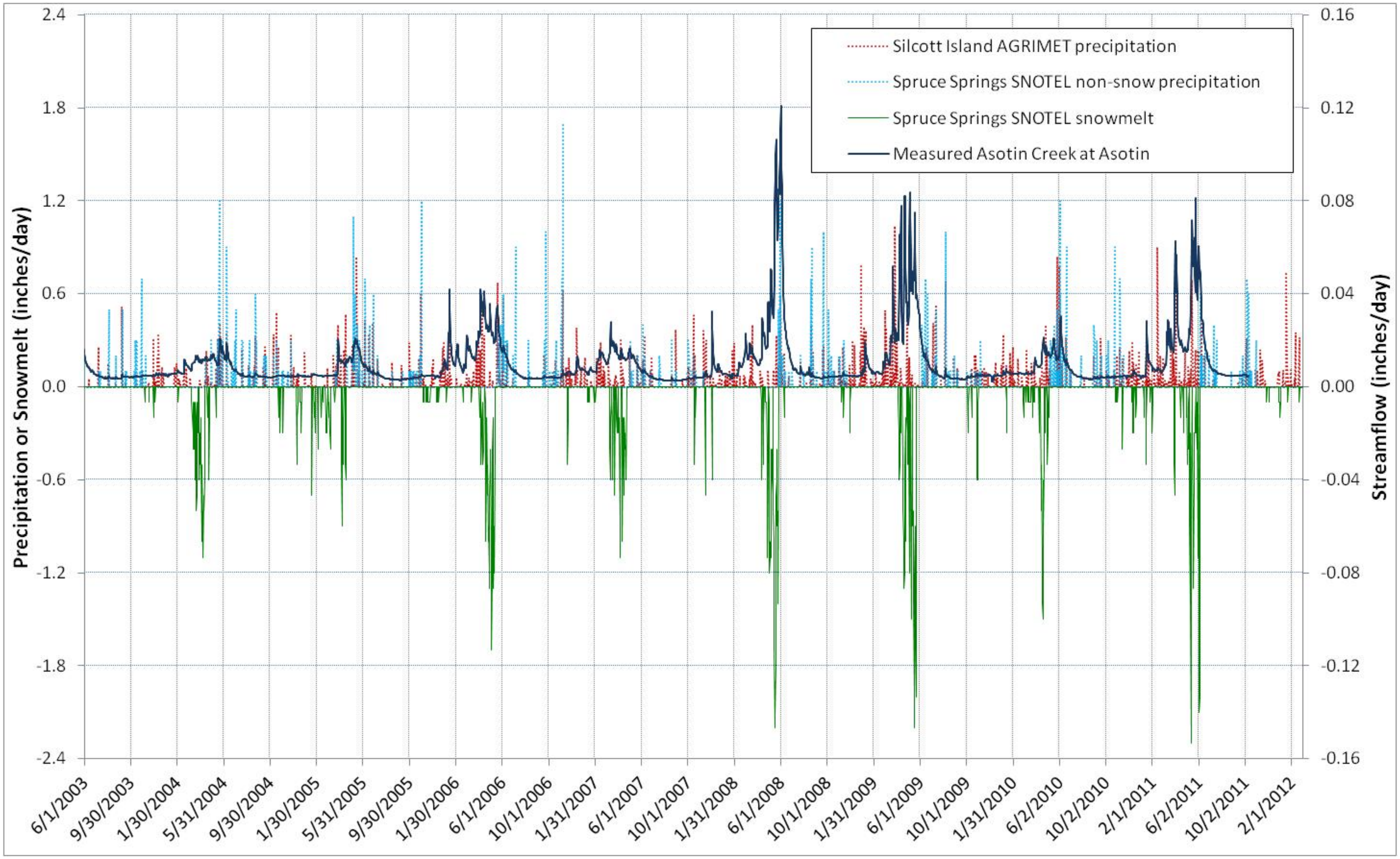

Figure 31. Measured areal flows at the USGS "Asotin Creek at Asotin" gaging station, with precipitation and snowmelt data.

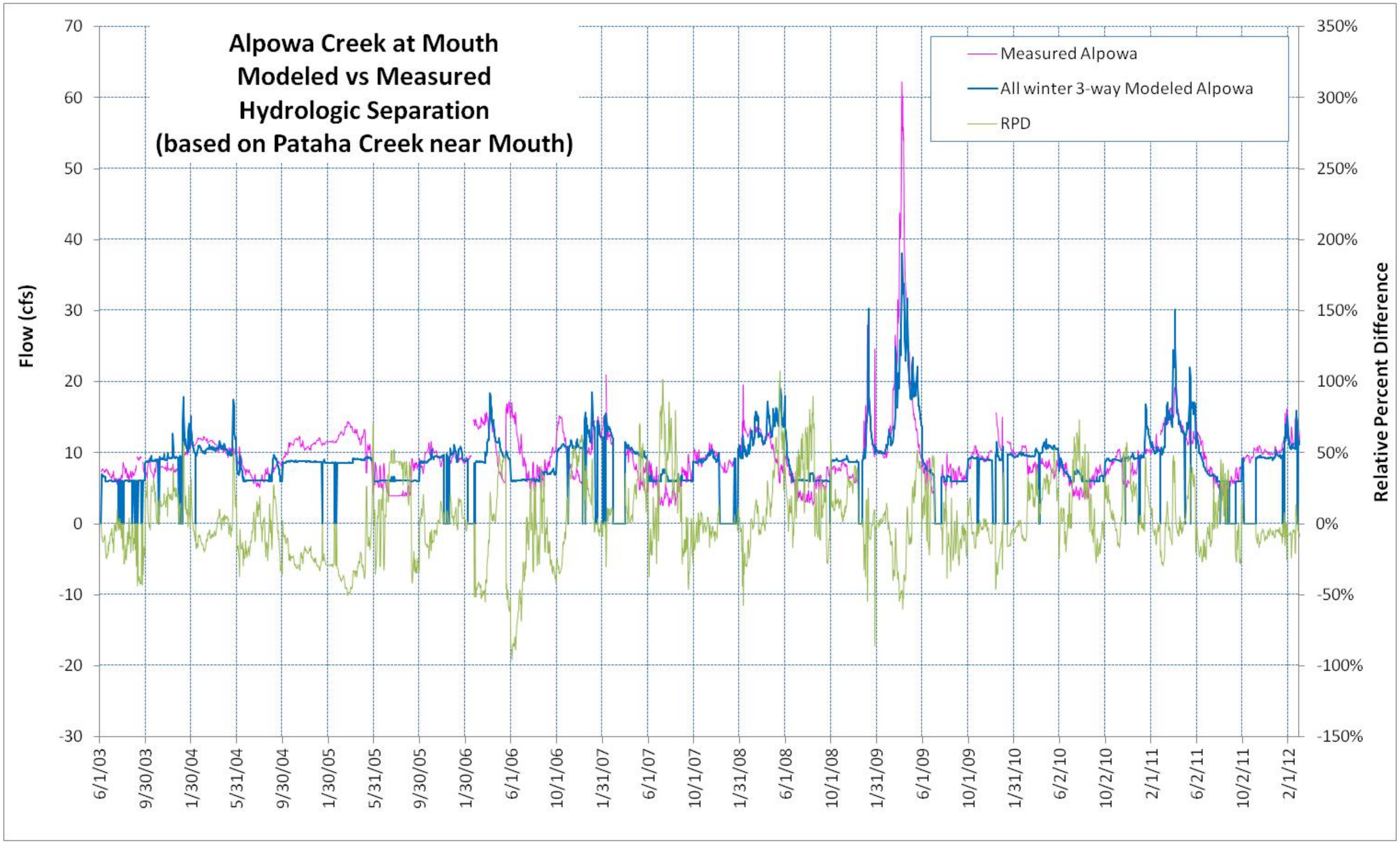

Figure 32. Measured flows at the Ecology "Alpowa Creek at Mouth" gaging station, and modeled flows based on the Ecology "Pataha Creek near Mouth" station, with relative percent difference of paired values.

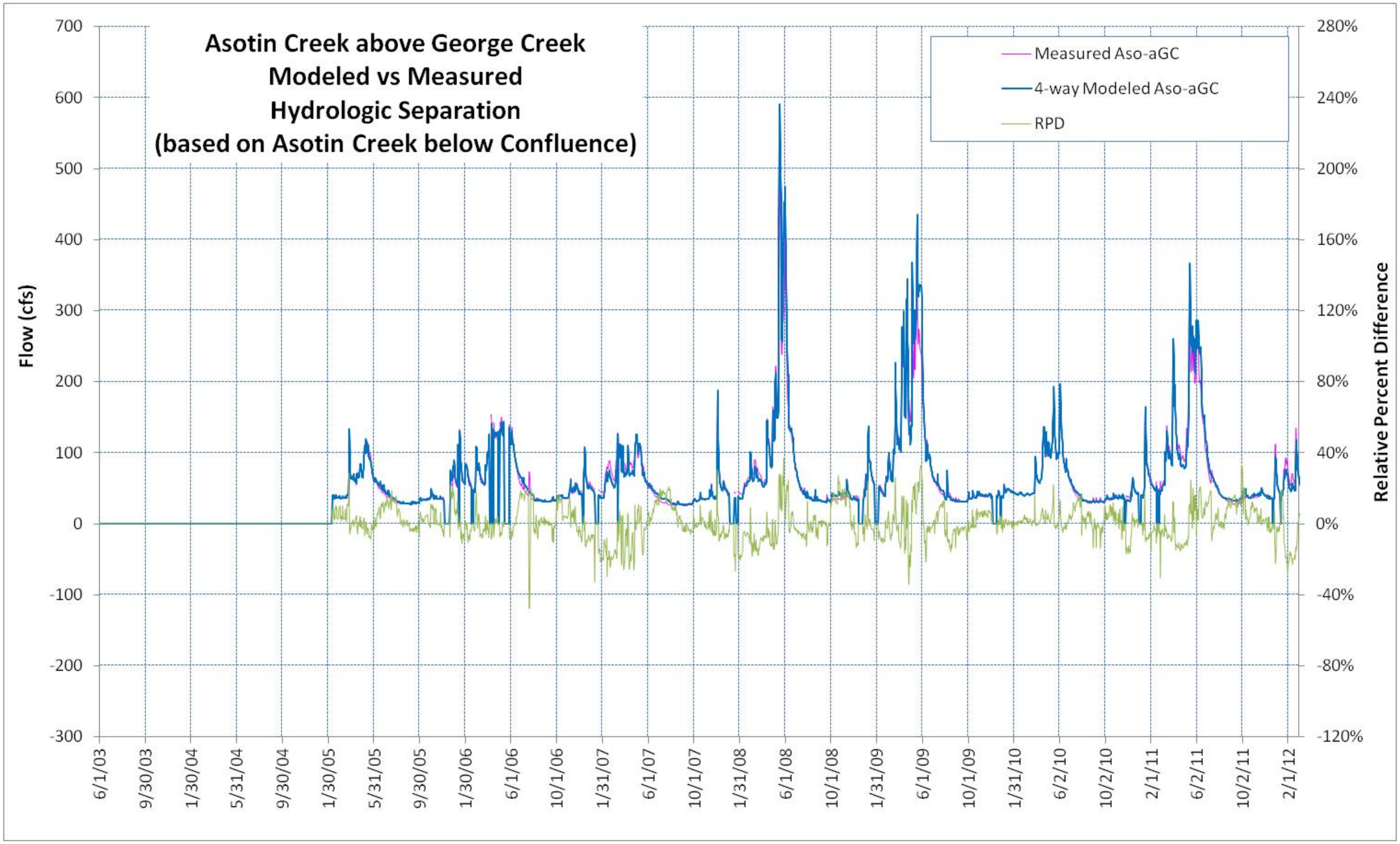

Figure 33. Measured flows at the Ecology "Asotin Creek above George Creek" gaging station, and modeled flows based on the USGS "Asotin Creek below Confluence near Asotin" station, with relative percent difference of paired values.

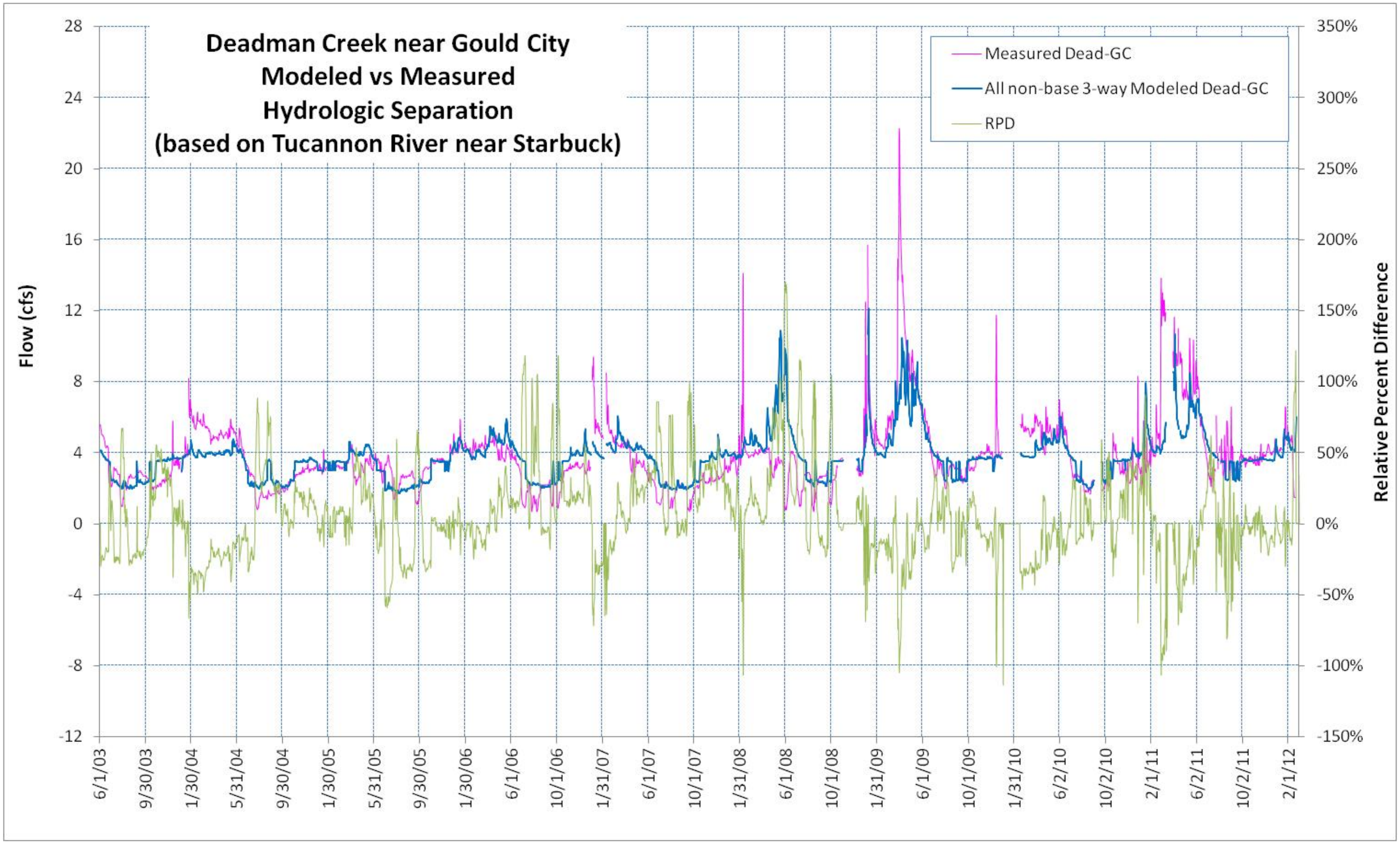

Figure 34. Measured flows at the Ecology "Deadman Creek near Gould City" gaging station, and modeled flows based on the USGS "Tucannon River near Starbuck" station, with relative percent difference of paired values.

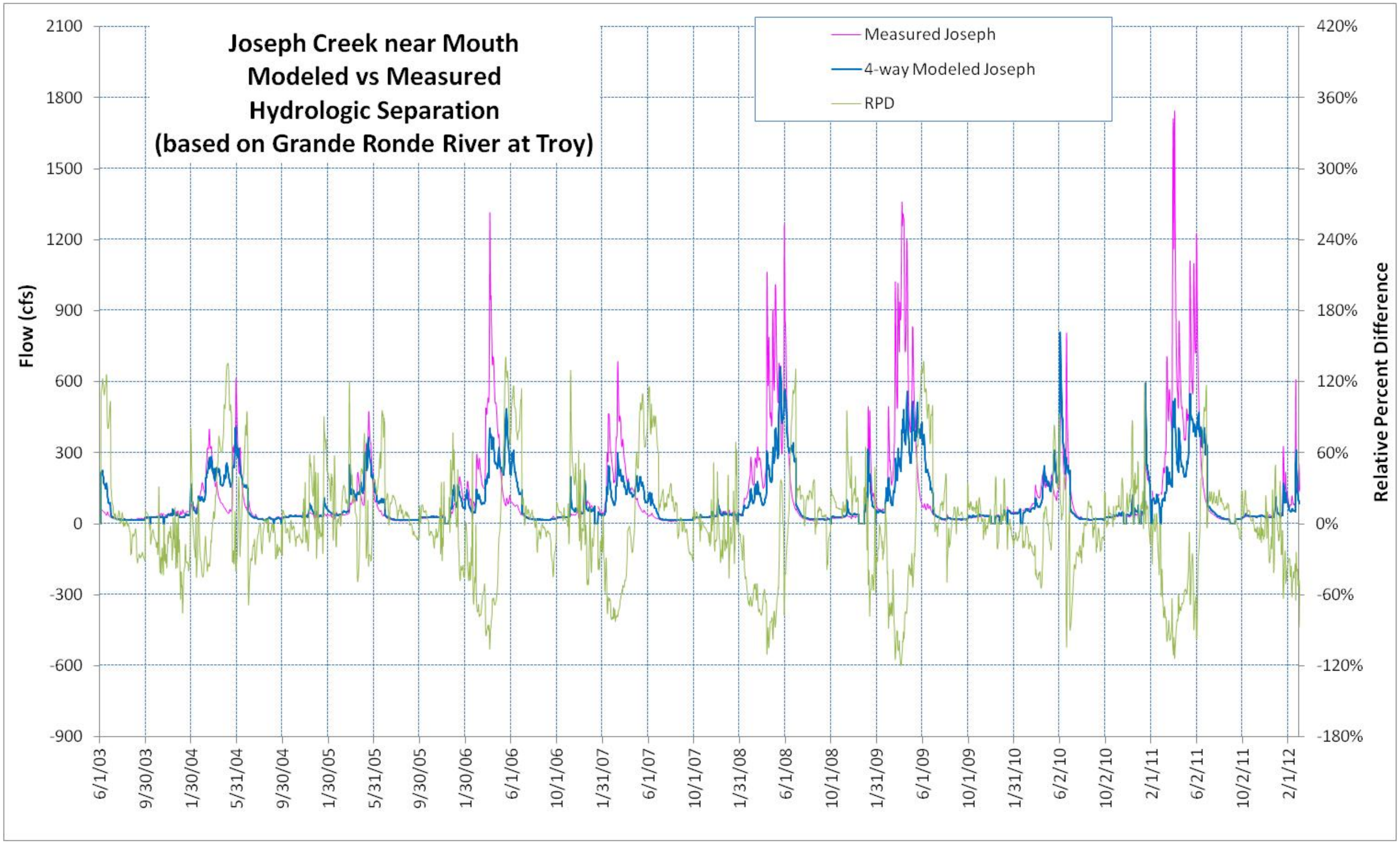

Figure 35. Measured flows at the Ecology "Joseph Creek near Mouth" gaging station, and modeled flows based on the USGS "Grande Ronde River at Troy" station, with relative percent difference of paired values.

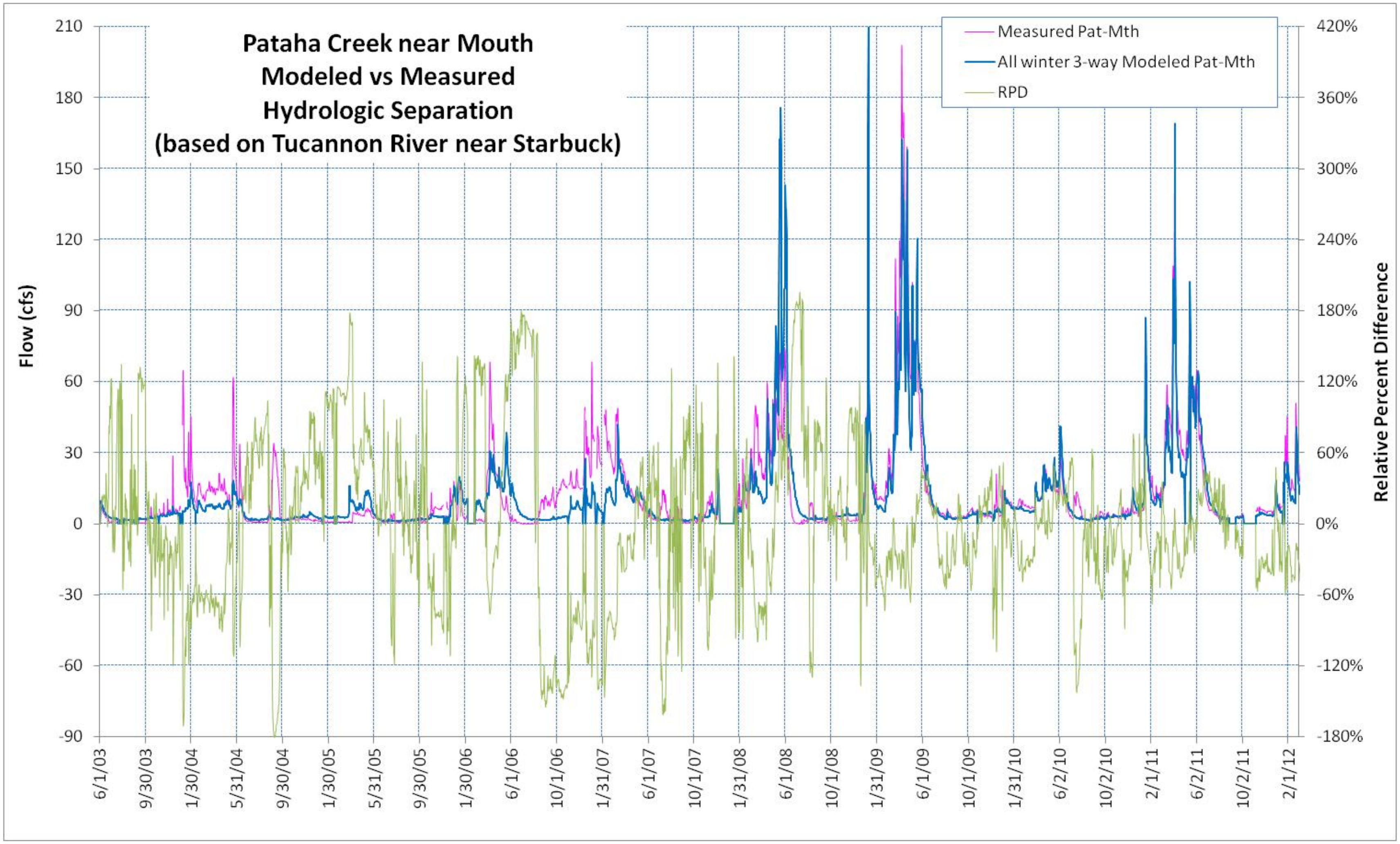

Figure 36. Measured flows at the Ecology "Pataha Creek near Mouth" gaging station, and modeled flows based on the USGS "Tucannon River near Starbuck" station, with relative percent difference of paired values.

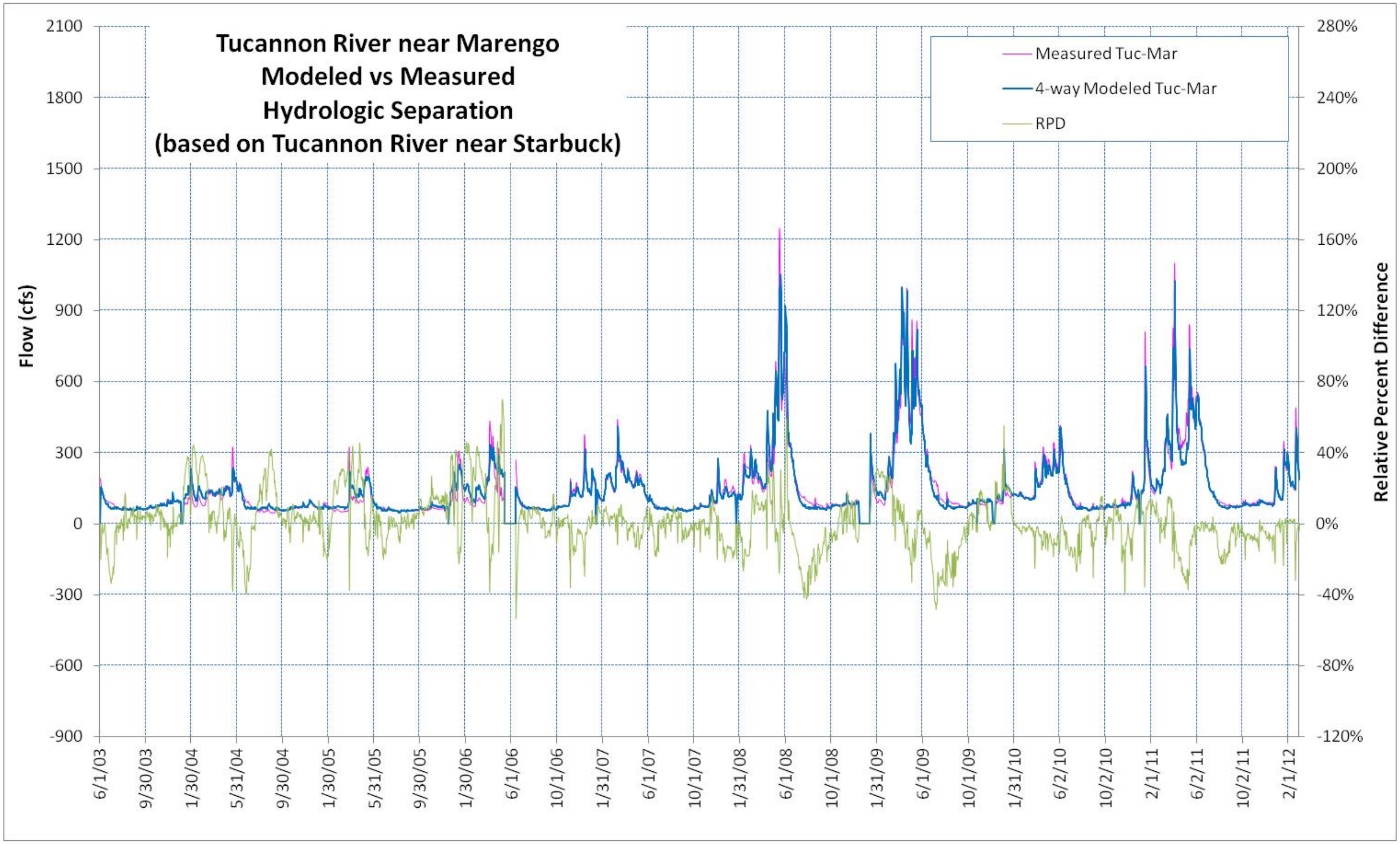

Figure 37. Measured flows at the Ecology "Tucannon River near Marengo" gaging station, and modeled flows based on the USGS "Tucannon River near Starbuck" station, with relative percent difference of paired values.

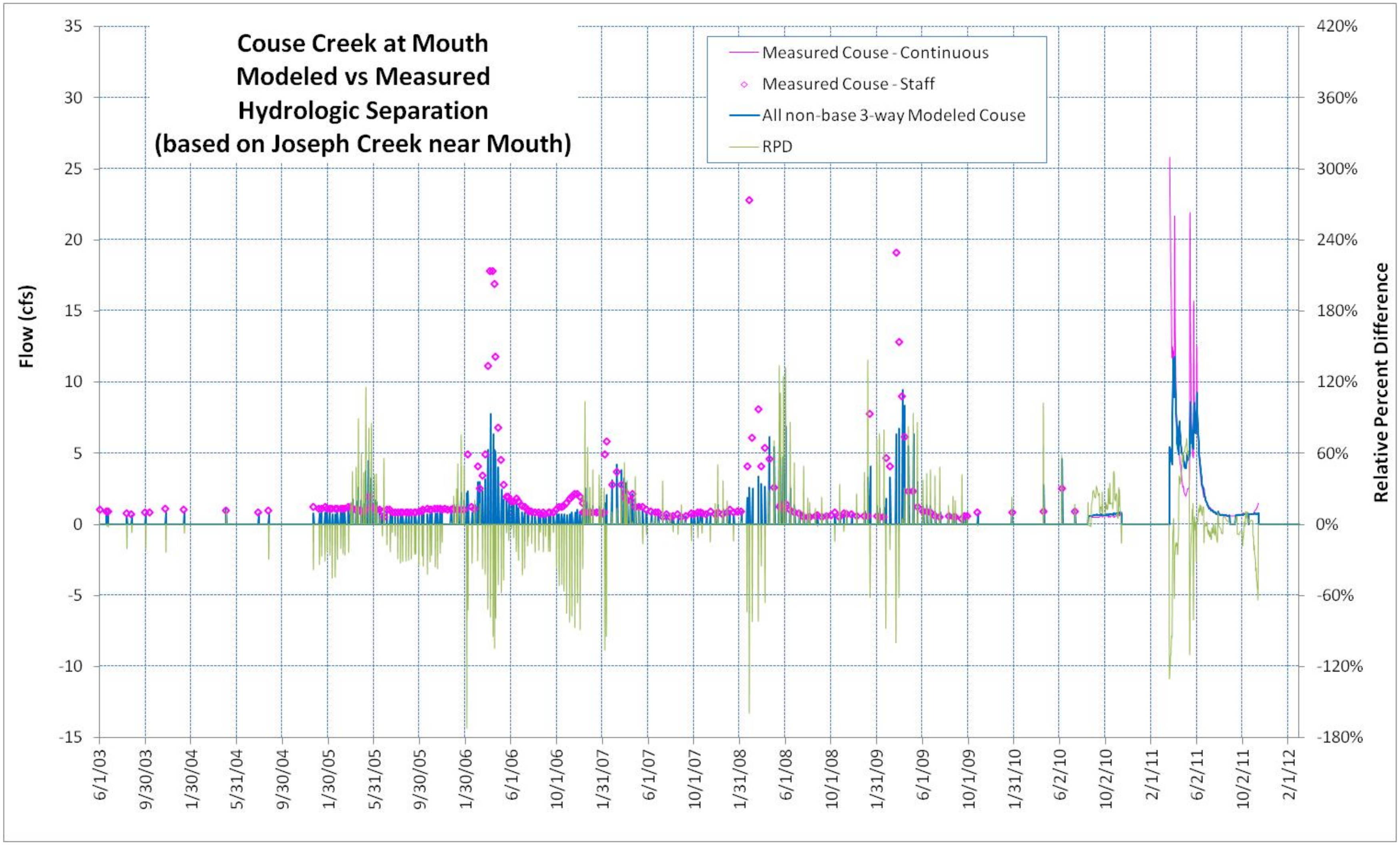

Figure 38. Measured flows at the Ecology "Couse Creek at Mouth" gaging station, and modeled flows based on the Ecology "Joseph Creek near Mouth" station, with relative percent difference of paired values.

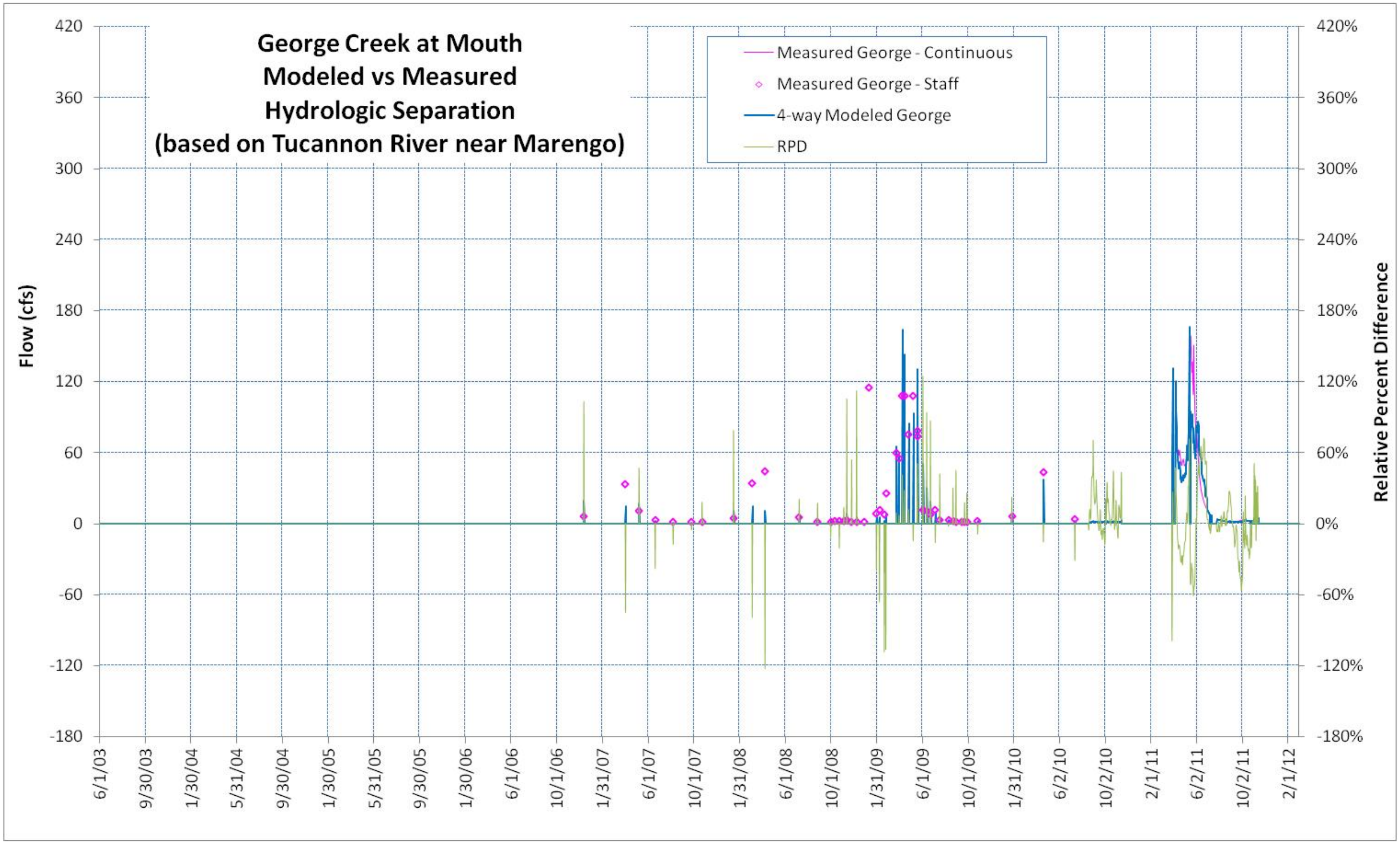

Figure 39. Measured flows at the Ecology "George Creek at Mouth" gaging station, and modeled flows based on the Ecology "Tucannon River near Marengo" station, with relative percent difference of paired values.

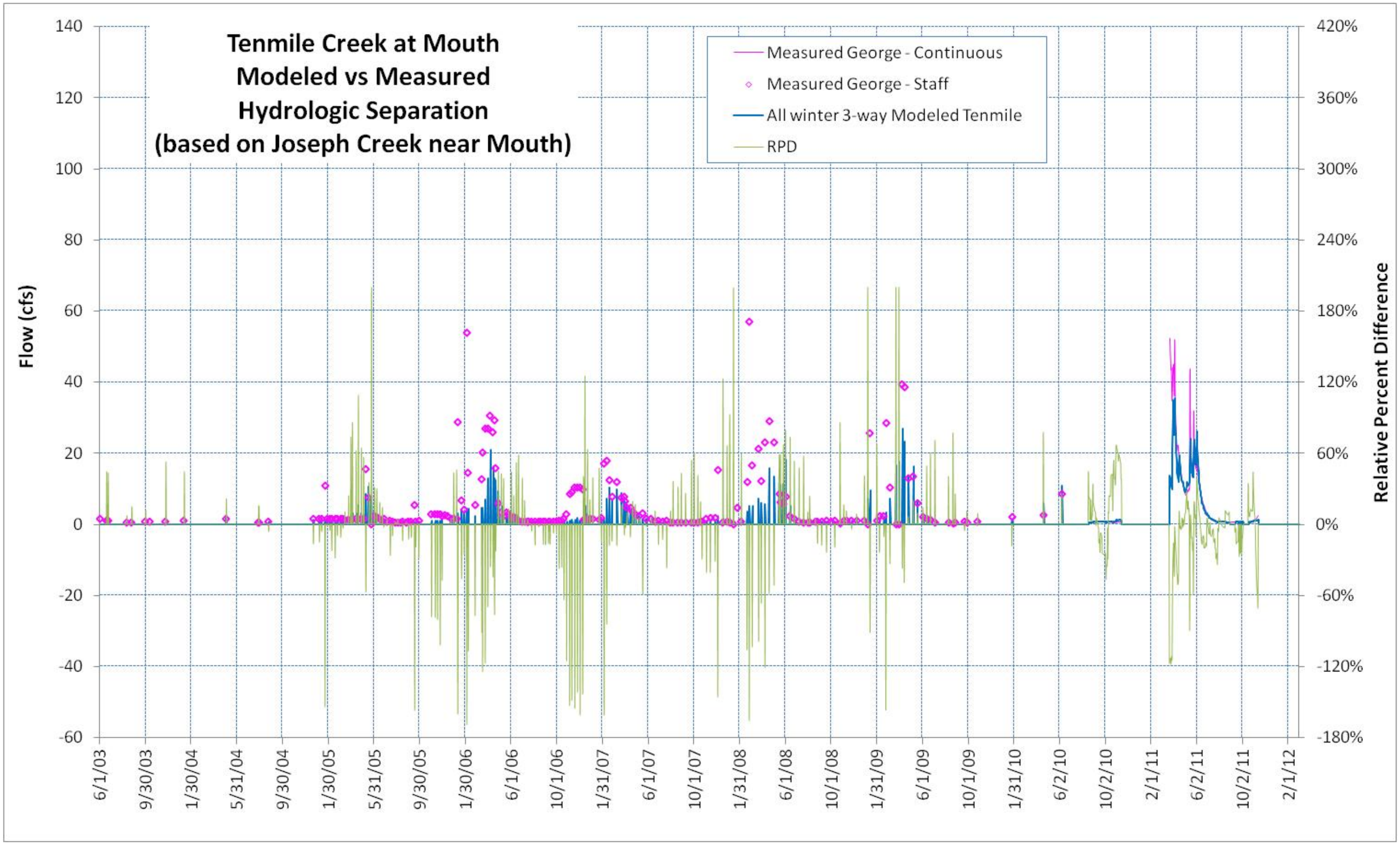

Figure 40. Measured flows at the Ecology “Tenmile Creek at Mouth” gaging station, and modeled flows based on the Ecology “Joseph Creek near Mouth” station, with relative percent difference of paired values.

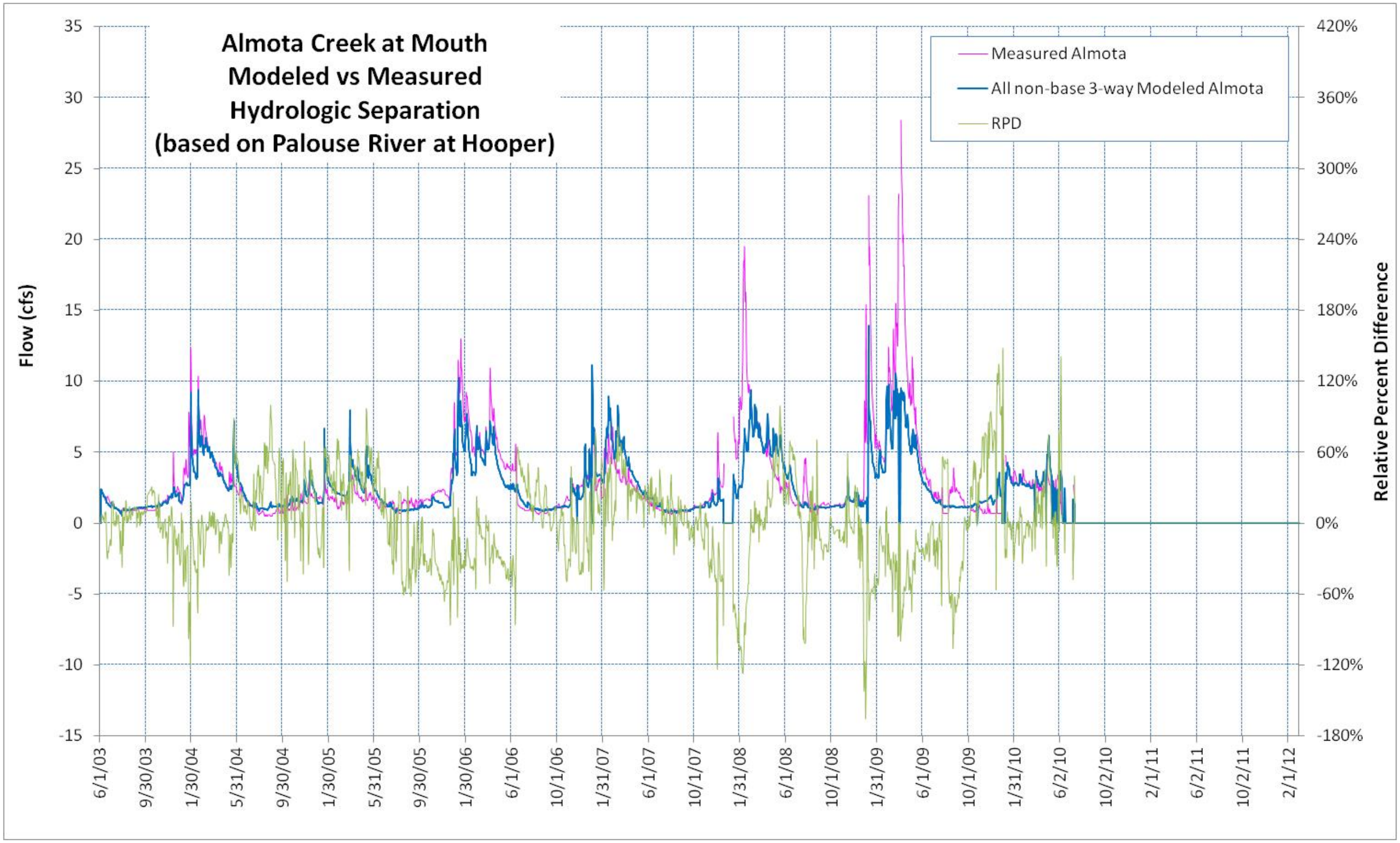

Figure 41. Measured flows at the Ecology "Almota Creek at Mouth" gaging station, and modeled flows based on the USGS "Palouse River at Hooper" station, with relative percent difference of paired values.

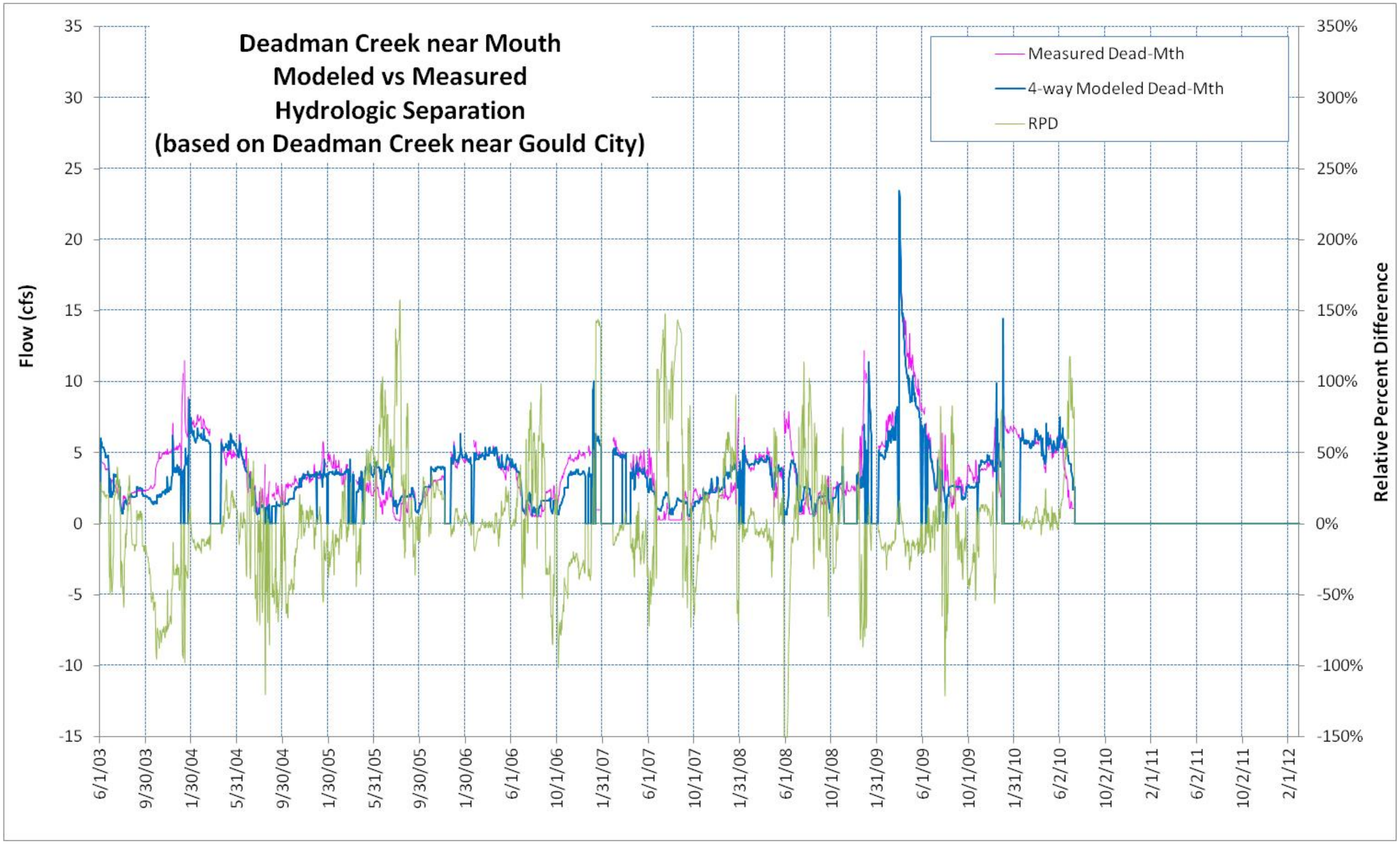

Figure 42. Measured flows at the Ecology "Deadman Creek near Mouth" gaging station, and modeled flows based on the Ecology "Deadman Creek near Gould City" station, with relative percent difference of paired values.

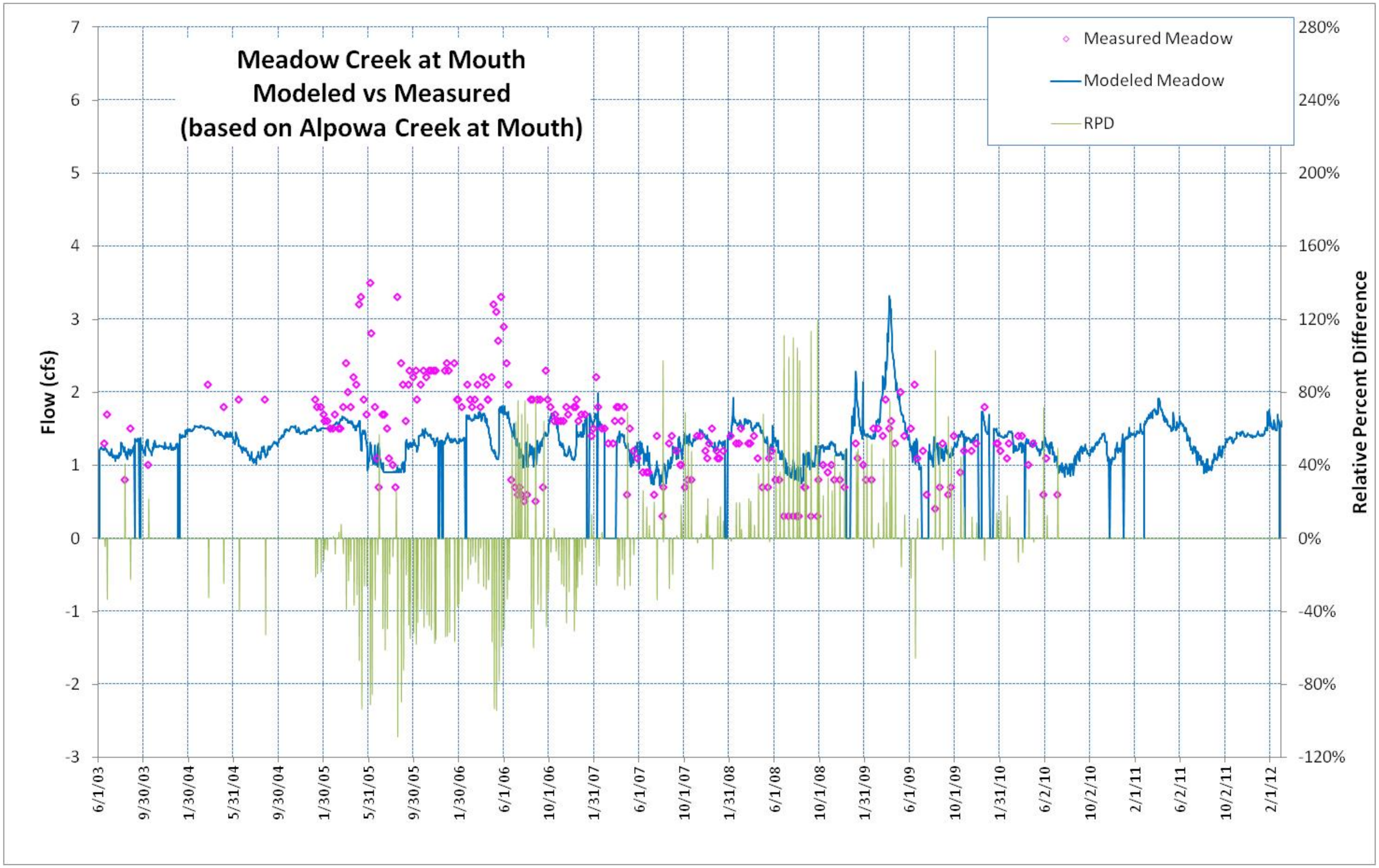

Figure 43. Measured flows at the Ecology “Meadow Creek at Mouth” gaging station, and modeled flows based on the Ecology “Alpowa Creek at Mouth” station, with relative percent difference of paired values.

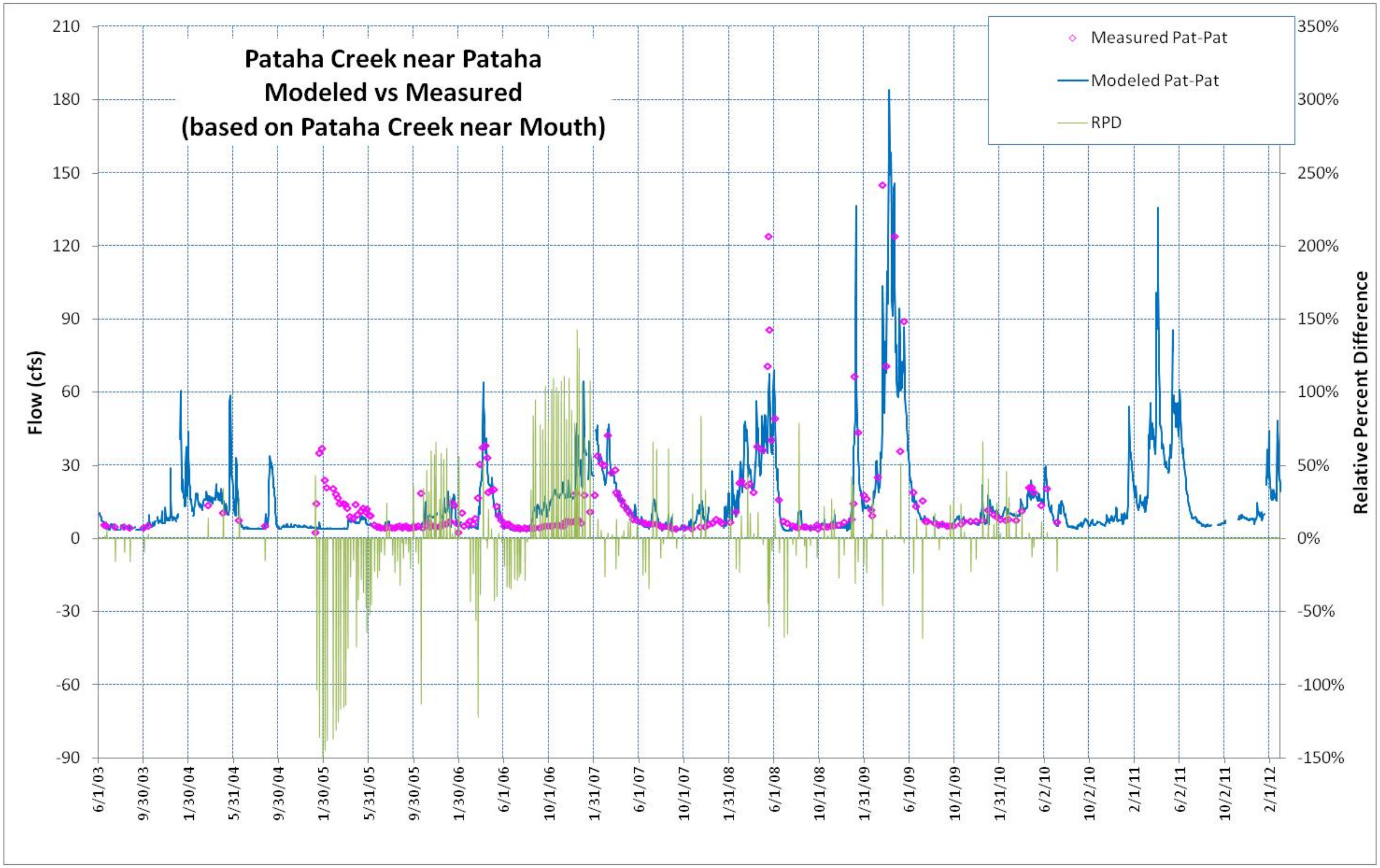

Figure 44. Measured flows at the Ecology "Pataha Creek near Pataha" gaging station, and modeled flows based on the Ecology "Pataha Creek near Mouth" station, with relative percent difference of paired values.

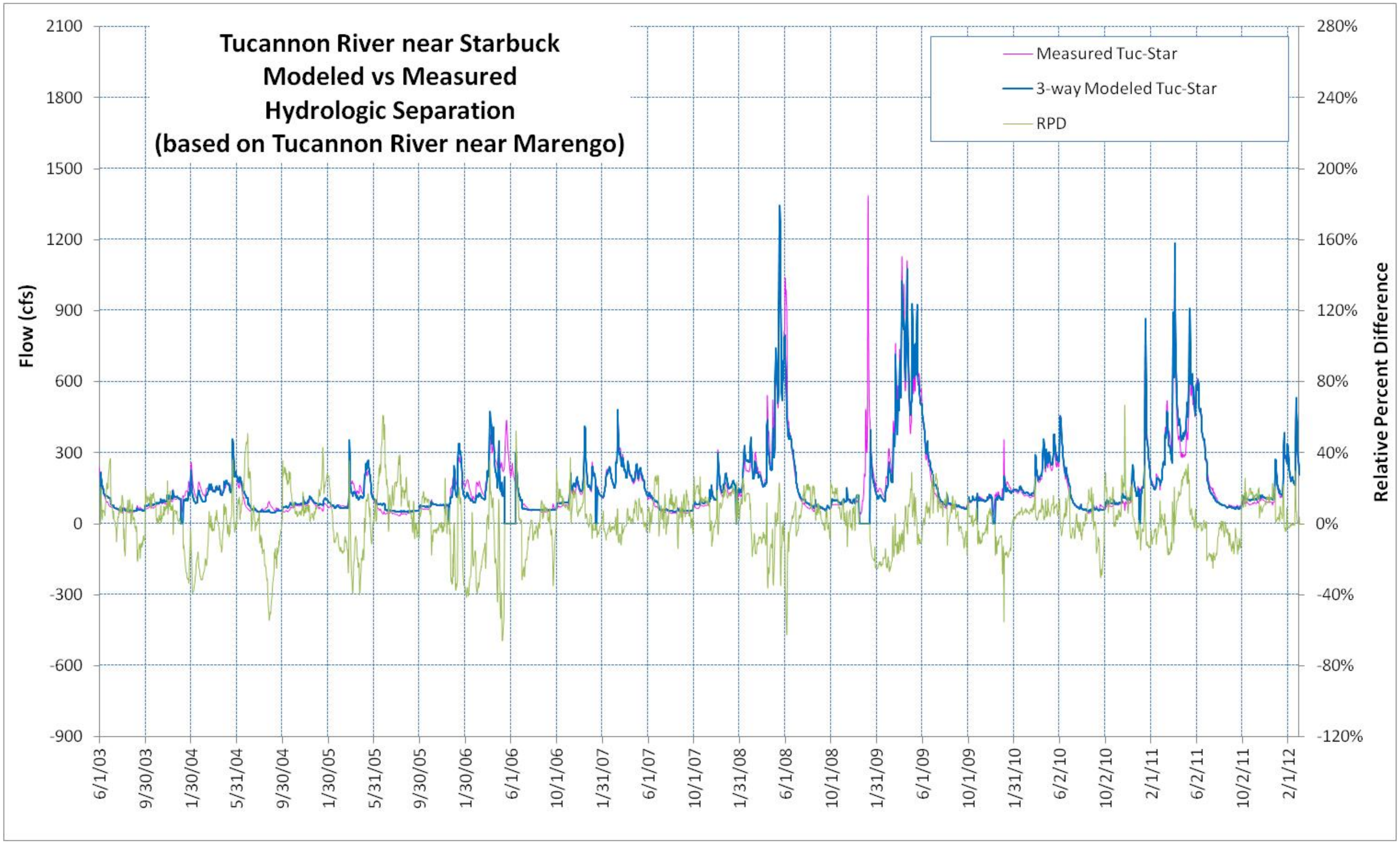

Figure 45. Measured flows at the USGS "Tucannon River near Starbuck" gaging station, and modeled flows based on the Ecology "Tucannon River near Marengo" station, with relative percent difference of paired values.

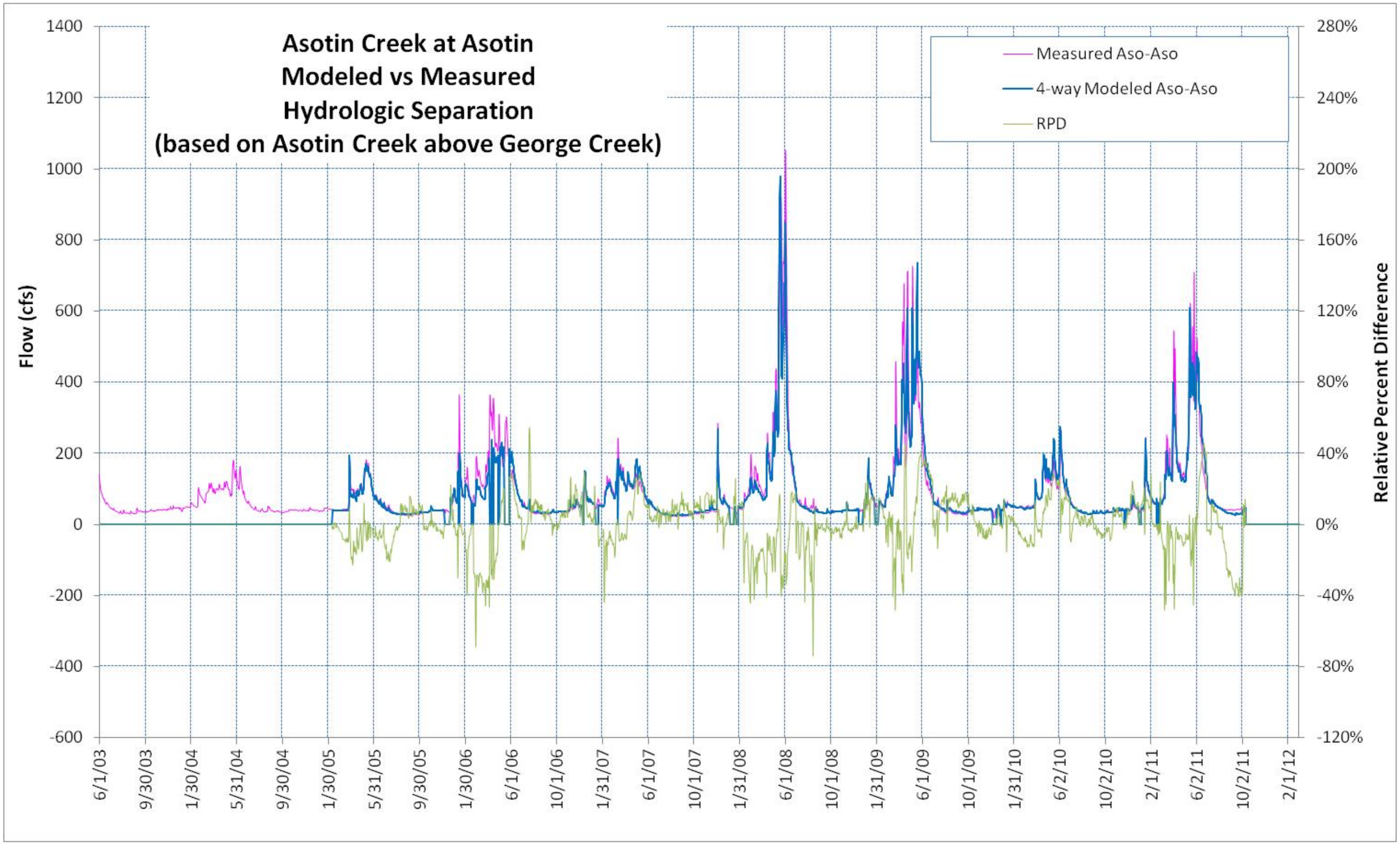

Figure 46. Measured flows at the USGS "Asotin Creek at Asotin" gaging station, and modeled flows based on the Ecology "Asotin Creek above George Creek" station, with relative percent difference of paired values.

Appendix. Glossary, Acronyms, and Abbreviations

Glossary

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

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

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

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

Middle Snake watershed planning area: Contiguous with Water Resource Inventory Area (WRIA) 35 in its entirety.

Reach: A specific portion or segment of a stream.

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

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

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

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

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

WRIA 35: Water Resource Inventory Area 35, also called the "Middle Snake", which includes the Snake River and its tributaries in Washington State upstream of the mouth of the Palouse River.

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

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report.

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