Entiat River Basin

Regressions for Predicting Gaged Streamflows

DEPARTMENT OF
ECOLOGY
State of Washington

March 2009

Publication and Contact Information

This report is available on the Department of Ecology's website at
www.ecy.wa.gov/biblio/0903016.html

Ecology's Study Tracker Code for this study is 08-522.

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/

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

Cover photo: Ecology gaging stations in the Entiat basin.

*Any use of product or firm names in this publication is for descriptive purposes only and
does not imply endorsement by the author or the Department of Ecology.*

*If you need this publication in an alternate format, call Joan LeTourneau at (360) 407-6764.
Persons with hearing loss can call 711 for Washington Relay Service.
Persons with a speech disability can call 877-833-6341.*

Entiat River Basin

Regressions for Predicting Gaged Streamflows

by
Paul J. Pickett

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

Waterbody Numbers:
WA-46-1010 and WA-46-1020

This page is purposely left blank

Table of Contents

List of Figures

List of Tables

Abstract

Since 2002, the Washington State Department of Ecology (Ecology) has operated 14 flow gaging stations in the Entiat River basin.

The goal of this project is to identify modeling tools for determining streamflows in the Entiat River basin and to evaluate the quality of those tools. These tools could serve as alternative methods to support Ecology and the Entiat Watershed Planning Unit in meeting overall flow monitoring goals for the basin.

For this study, Ecology developed regression modeling tools using the hydrograph separation method to predict flows for these stations from flow data collected from 2002 through 2008 at two U.S. Geological Survey stations. The quality of the regressions was evaluated and reported.

Recommendations are provided for use of the modeling tools for future flow assessment needs in the Entiat basin and to guide Ecology in making decisions about the use of agency flow gaging resources statewide.

Acknowledgements

For helping to improve the quality of this report with their knowledge, suggestions, and advice, the author of this report would like to thank:

- Mike Rickel of the Cascadia Conservation District.

- Phil Archibald and Richard Woodsmith of the U.S. Forest Service.

- Robert Parrish of the U.S. Fish and Wildlife Service.

- Other members of the Entiat Watershed Planning Unit.

Thanks also go to the following Department of Ecology staff:

- Dave Holland

- Howard Christianson

- Bill Zachmann

- Brad Hopkins

- Karol Erickson

- Members of the agency's Gaging Strategy Workgroup.

Introduction

Background

WRIA planning process

The Entiat Water Resources Inventory Area (WRIA) Watershed Planning Unit, which includes a variety of local interests, undertook the challenging task of developing a watershed management plan to guide current and future water management in the Entiat basin (WRIA 46). It was the first watershed plan with recommendations on instream flows and a reserve of water that received unanimous support by the Planning Unit and the full approval of Chelan County.

The planning process has passed several critical benchmarks:

- The plan was approved by the Planning Unit in May 2004 and the Chelan County Board of County Commissioners in September 2004.
- The watershed management rule, based on recommendations from the watershed plan, was adopted in August 2005 (Chapter 173-546 WAC).
- A Detailed Implementation Plan was approved in February 2006 (Chelan County CD, 2006).

The WRIA management plan includes several recommendations for the Washington State Department of Ecology (Ecology) which have been incorporated into the rule:

- Establish instream flows.
- Establish a reserve of water for future uses.
- Set maximum allocation limits.

Ecology has implemented these recommendations from the WRIA Plan, establishing a water management program that will guide current and future water management in the Entiat basin.

Instream flows were established for the Entiat and Mad Rivers by the watershed management rule. The term *instream flow* is defined as the streamflows needed in the river to protect and preserve resources such as fish, wildlife, aesthetics, and recreation. Water rights with seniority dates older than the watershed rule adoption date are not affected by the regulation of instream flows.

In addition to protecting instream resources, the proposed flow levels will help Ecology and the Planning Unit determine if water is available for new uses not eligible for use of reserved water. Two control stations on the Entiat River and one on the Mad River have been set by the watershed management rule for regulating instream flows (Table 1 and Figure 1).

The instream flow rule creates a reserve of up to 5 cubic feet of water per second (cfs) or 3.23 million gallons a day (mgd). The reserve of water will be designated for future domestic, commercial, irrigation, and light industrial uses in the Entiat watershed. It is anticipated that this reserve will be sufficient to meet projected needs over the next 22 years.

Table 1. Stream management units in the Entiat basin (copied from WAC 173-546-040).

Stream Management Unit Name Control Station Gauge #	Control Station by River Mile (RM); Section, Township and Range; Latitude (Lat.) and Longitude (Long.); Hydrologic Unit Code (HUC)	Stream Management Reach Description
USGS Gauge #12452990 Entiat River near Entiat, WA. ("Keystone Gauge") (Lower Entiat)	River Mile 1.4	From the confluence of the Entiat and Columbia rivers to the terminal glacial moraine at RM 16.2, including all tributaries except the Mad River.
	Sec. 18, T.25 N., R.21 E.W.M.	
	Lat. 47°39'48"	
	Long. 120°14'58" NAD 27	
	HUC 17020010	
USGS Gauge #12452800 Entiat River near Ardenvoir, WA (Upper Entiat)	River Mile 18	From the terminal glacial moraine at RM 16.2, to the Entiat River headwaters, including all tributaries.
	Sec. 27, T.27 N., R.19 E.W.M.	
	Lat. 47°49'07"	
	Long. 120°25'19" NAD 27	
	HUC 17020010	
USGS Gauge #12452890, Mad River at Ardenvoir	River Mile 0.35	From the confluence of the Mad River with the Entiat River to the Mad River headwaters, including all tributaries.
	Sec.19, T.26, R.20 E.W.M.	
	Lat. 47°44'13"	
	Long. 120°22'03" NAD 27	
	HUC 17020010	

Sec. – Section.   T. – Township.   R. – Range.

The instream flow rule establishes maximum flow allocations. Ecology and the Planning Unit have determined that at certain times of the year there is some water available above the instream flows. In order to preserve the environmental benefits of high flows, a limit is placed on how much is available for allocation at these times. High flows provide critical ecological functions such as channel and riparian zone maintenance, flushing of sediments, and fish migration. Maximum allocations are set for the three control stations on the Entiat and Mad Rivers.

Flow monitoring

In support of the WRIA planning process, Ecology's Environmental Assessment (EA) Program in 2002 established 14 active flow monitoring stations in the Entiat basin (Table 2 and Figure 1). Half of the stations are *telemetry* stations that provide real-time gage height measurements, while the rest are stations where *manual stage* readings are collected. Three manual stage stations are no longer supported by Ecology.

The U.S. Geological Survey (USGS) operates three flow gaging stations in the Entiat basin (Table 3). Two stations are available as *real-time* stations, with data reported to the USGS website within several hours. The third *non-real-time* station posts data on the website within four to six weeks. These three stations serve as the control stations in the watershed rule (Table 1).

Gaged flow measurements at all 17 stations are based on continuous or manual stage height readings. Stage readings are converted to gaged flow using a rating curve, which is developed and updated from direct measurements of flow made on a regular basis. Flow data are initially coded as "provisional" until they undergo quality review and are finalized.

Table 2. Ecology Entiat basin flow monitoring stations.

Station ID	Station Name	Station Label	Station Type
46A170	Entiat River at North Fork Campground	Entiat-NFCG	Telemetry
46A160	Entiat River below Entiat Falls	Entiat-Falls	Telemetry
46A150	Entiat River at Tommy Creek Bridge	Entiat-Tommy	Telemetry
46A110	Entiat River at Dill Creek Bridge	Entiat-Dill	Telemetry
46K050	Lake Creek at Mouth	Lake	Telemetry
46C100	Mad River above Camp Nine	Mad-C9	Telemetry
46D050	Tillicum Creek at Mouth	Tillicum	Telemetry
46B060	Roaring Creek near Mouth	Roaring	Telemetry
46L050	Pope Creek at Mouth	Pope	Manual Stage[†]
46J080	Tommy Creek below USFS Quarry	Tommy	Manual Stage[†]
46H050	Preston Creek at Mouth	Preston	Manual Stage
46G060	Stormy Creek near Mouth	Stormy	Manual Stage
46F060	Potato Creek near Mouth	Potato	Manual Stage[†]
46E070	Mud Creek at Bisping Canyon Road	Mud	Manual Stage
			[†]Discontinued

Table 3. USGS Entiat basin flow monitoring stations.

Station ID	Station Name	Station Label	Discharge Daily Data	
			Begin Date	Station Type
12452800	Entiat River near Ardenvoir, WA	Entiat-Ard	1-Sep-1957	Real-time
12452890	Mad River at Ardenvoir, WA	Mad-Ard	26-Apr-2002	Non-real-time
12452990	Entiat River near Entiat, WA	Entiat-Ent	15-Mar-1996	Real-time

The original purpose of Ecology's gages was to provide data to inform the development of the Entiat WRIA plan. With the completion of the Plan and the beginning of Plan implementation, the Planning Unit has identified a variety of management efforts that are supported by flow information from the gages (Rickel, 2008):

- Implementation of minimum instream flows
- Temperature monitoring
- Salmon recovery efforts
- Instream and stream corridor restoration projects
- Water balancing and budgeting activities
- Ground/surface water interaction investigations
- Water storage assessment
- Hydrologic modeling

Because of the number of remaining gaging stations in the Entiat basin, and because none of Ecology's gages are used as control stations for the instream flow regulation, Ecology's EA Program is evaluating whether modeling tools could be used instead of stream gaging at some or all of the Ecology stations. This could potentially provide information of a quality that still meets the needs of Ecology and basin stakeholders, while freeing up stream gaging resources for use in other areas of the state.

Overview of the Watershed

The Entiat River is located along the eastern slopes of the Cascade Mountains in north-central Washington (Figure 1). The Entiat WRIA management plan addresses the Entiat and Mad River watersheds as well as some of the minor Columbia River tributaries that lie to the north and south of the mouth of the Entiat River. The Entiat River supports a number of important fish species including Chinook salmon, steelhead, and bull trout. The scarcity of juvenile-rearing habitat in the lower Entiat River during the winter limits the watershed's ability to fully sustain bull trout, steelhead, and salmon populations.

More than 90% of the river basin is publicly owned property, primarily the Wenatchee National Forest. The watershed includes several perennial and intermittent tributaries. The Entiat River experiences high streamflows in the spring and early summer, and very low flows during late summer to early spring. Snowmelt is the predominant source of both surface water and groundwater in the Entiat basin, and generally there is a high degree of connectivity between surface water and groundwater sources in the watershed.

The primary geologic components that comprise the Entiat River watershed are metamorphic and plutonic rock, sediment of glacial and alluvial origins, and volcanic ash. Volcanic ash, from the Glacier Peak volcano, covers most of the slopes within the watershed. The valley bottoms contain sediments eroded from the surrounding hills by streams and glaciers. These sediments now form the principal aquifers within the watershed. Underlying the mantle of ash and valley sediments is a basement of crystalline bedrock.

The climate of the Entiat watershed varies markedly and is largely influenced by topography. Precipitation is heaviest in the northwest portion of the watershed and decreases in the lower elevations toward the Columbia River. Average annual precipitation ranges from about 100 inches in the higher elevations to about 10 inches near the town of Entiat. Precipitation is light during the summer months, increases to a maximum in winter, and then decreases in the spring. Much of the winter precipitation occurs as snowfall. Summer precipitation frequently occurs as rain showers associated with thunderstorms.

Runoff within the watershed can vary widely from one year to the next. Data from the Entiat River streamflow gage near Ardenvoir show that, in water year 1972, the runoff was 451,140 acre-feet. The next year, the runoff was 178,970 acre-feet, which is a reduction of 272,170 acre-feet (Kirk et al., 1995).

The alluvial and glaciofluvial sediments in the valleys serve as the primary aquifers and contain the vast majority of groundwater in the Entiat watershed. Well yields in the Entiat River Valley reportedly range from 10 gallons per minute (gpm) to 600 gpm. Yields of about 35 gpm for domestic wells are typical. The bedrock valley floors are sloped in the same direction as the Entiat River and its tributaries so it is likely that groundwater is flowing in the same general direction as surface water. This means the groundwater under the Entiat watershed tributaries probably discharges to the aquifer that underlies the Entiat River. The Entiat River aquifer either discharges to the Entiat River, the Columbia River aquifer, or both. The coarse nature of the sediments which make up the Entiat River most likely allow fairly unrestricted interaction between the river and the aquifer to occur (Kirk et al., 1995).

Study Goals and Objectives

The goal of this project is to identify modeling tools for determining flows in the Entiat River basin and to evaluate the quality of those tools. These tools could serve as alternative methods to support Ecology and the Entiat Planning Unit in meeting overall flow monitoring goals for the basin. The outcomes of the study will also be used to guide Ecology in making decisions about the use of agency flow gaging resources statewide.

To meet this goal, the following objectives were identified for this study:

1. Develop statistical and simple hydrologic models that describe the relationships between the USGS and Ecology flow gages in the Entiat basin.

2. Assess the quality of the results of modeling the relationships between gages.

3. Recommend approaches that would estimate flows at Ecology flow gages using modeling results instead of direct measurements.

4. Recommend 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.

5. Identify any data gaps and, if warranted, recommend more complex modeling approaches that might reasonably improve the use of models for flow discharge assessment.

Methods

Data Sources and Characteristics

Daily average flow data were compiled for the 14 Ecology stations and the three USGS stations. Flows at Ecology stations were analyzed from the beginning of the record in late September 2002 through recent data (October 2008). These data were compared to USGS data for the same period.

Some of the Ecology and USGS flow data have been labeled as *provisional*, meaning that final data quality checks had not been completed. These data were used for the development of the regressions with the understanding that the regressions would need to be updated as the flow information was finalized. This is reasonable since the provisional data are likely to be similar to the final values, and because the regressions would be updated with additional data collected after October 2008.

Figures 2 through 15 show the streamflows for each of the Ecology stations as compared to the USGS flows. Flows are shown using a logarithmic scale on the vertical axis, which more clearly illustrates patterns over time and allows comparison of flows of varying discharge amounts from different stations.

Notable characteristics of the flow patterns are:

- The peak flows of the spring freshet dominate the annual volumes of flow but vary from year to year.

- Spring freshet flows in the mainstem Entiat River and the upper tributaries (Lake Creek and Pope Creek, for example) have a stronger snowmelt hydrograph that lasts longer into the early summer.

- Baseflow conditions typically occur in August and September but can extend into the fall. Winter baseflow can also occur, especially in the mainstem and upper tributaries.

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.

Meteorological data that best characterize the basin are available from three stations (Figure 1):

1. Pope Ridge SNOTEL station (www.wcc.nrcs.usda.gov/snotel/snotel.pl?sitenum=699&state=wa).

2. The Entiat RAWS station (www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?waWENT).

3. The Dry Creek RAWS station (www.raws.dri.edu/cgi-bin/rawMAIN.pl?waWDRY).

Each of the Ecology telemetry station data converted to areal flow are shown in Figures 16 through 23. Precipitation data from Pope Ridge SNOTEL and the Entiat RAWS are also shown, which represent the extremes of data from the upper watershed and from near the mouth. Non-snow precipitation and snowmelt were calculated from the daily change in snow water equivalent (SWE). The change in SWE was subtracted from total precipitation to get the non-snow precipitation, while negative changes in SWE were used to represent snowmelt. Losses in SWE can also occur from evaporation or sublimation, but this method provides a good estimate of the contribution of snow pack loss to river flows.

Some characteristics in the data patterns in Figures 16 through 23 are of interest:

- Peak spring freshet flows can be seen to occur slightly later than peak snowmelt. However, flows in the lower tributaries occur earlier, reflecting a smaller snow pack that melts off quickly.

- Areal flow values vary widely between the stations, with maximum values in the upper watershed exceeding 1 inch per day, while maximum values in the lower watershed barely exceed 0.1 inch per day. This likely reflects how precipitation and evaporation rates change with elevation.

- 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 observed and of the meteorological and flow stations.

  For example, the precipitation event in October 2003 observed at Pope Ridge shows a strong response in the upper watershed, but not in the lower watershed. However, a strong precipitation event at the Entiat RAWS station in early August 2004 showed very little effect on flows. In additions, some precipitation events show up at both meteorological stations (December 2005, for example) while other events are observed at only one station.

Regressions and Other Analysis Methods

Flow data were first evaluated by comparing each Ecology station with the three USGS stations using linear and power relationships. A power equation is arithmetically identical to the linear relationship of two log-transformed data sets. The station and regression with the best fit was selected for further analysis.

Flow data were then evaluated to determine whether a hydrograph separation technique would improve the relationship. Baseflows were determined by comparison of the flow time series to precipitation and snowmelt. A baseflow threshold for the USGS gage was selected that produced baseflow periods most similar to the Ecology gage under consideration. The data were then segregated into four categories:

- *Summer baseflows* – less than the baseflow limit occurring from July through September.
- *Winter baseflows* – less than the baseflow limit occurring from October through June.
- *Freshet flows* – greater than the baseflow limit occurring from March through September.
- *Storm flows* – greater than the baseflow limit occurring from October through February.

Because of the limited data available for staff gages, flows were divided into only two categories for this analysis at those sites:

- *Baseflows* – less than the baseflow limit occurring all year.
- *Freshet and storm flows* – greater than the baseflow limit occurring all year.

Summer and winter baseflows were combined into a single regression for baseflow year-round in Lake Creek, because it resulted in a better fit between the model and measured data.

Flow data at 15-minute intervals were analyzed for the Entiat River at Dill Creek Bridge station. A regression was developed from 15-minute data using the same methodology as for the daily average data. The modeled flows using this regression were compared to the model based on daily average data to determine the applicability of daily average models to 15-minute data. Data for this station available in March 2009 had been updated through the data quality process, so regressions were compared between the updated data and the provisional data available in November 2008.

Other possible regression relationships were explored, such as predicting flow as function of snowmelt. Some initial assessment was also conducted of the BASINS modeling platform. BASINS uses a GIS (Geographic Information System) analysis to develop input parameters for the HSPF model. BASINS 4.0 was recently released by the U.S. Environmental Protection Agency (www.epa.gov/waterscience/basins/). HSPF is a widely used hydrologic model supported by USGS (http://water.usgs.gov/cgi-bin/man_wrdapp?hspf).

Quality Analysis

As described in the project plan (Pickett, 2008), 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), while precision was assessed with the absolute percent error (APE) and the percent relative standard deviation (%RSD).

The robustness and sensitivity analyses described in the project plan are typically applied to deterministic models rather than regression models, so those analyses were not conducted for this report.

Model uncertainty was evaluated for baseflow, high flow, and all flow conditions using the %RSD. This allows comparison to the quality of direct flow measurement methods. USGS evaluates their flow data from the 95th percentile of the flow measurement error, and a similar metric was applied to the modeling results.

Results

Regression Model Analysis

Table 4 presents the results of the regression modeling analysis. Only the two Entiat River USGS gages were used as benchmark stations (the independent variable of the regression) because they are real-time stations. The USGS Mad River near the Ardenvoir station produced regressions with better fits for some of the tributary stations, but was not used because it is a non-real-time station.

All regressions use a power function, and the coefficient and exponent for these functions are shown in Table 4. The results from these models are illustrated in Figures 24 through 37.

Quality of Regression Models

The goodness-of-fit of the regression models are indicated by the r^2 values in Table 4. In general, the regressions are better on the mainstem than on the tributaries, and better for telemetry stations than for staff gage stations.

For each station, the relative percent difference (RPD) was calculated between paired modeled and measured values. Figures 24 through 37 show these values on the right-hand scale. A few patterns should be noted:

- Small difference in very low flows can produce an RPD of high magnitude. 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 USGS and Ecology station.

- 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.

The results for APE and %RSD were similar, except the APE was more affected by data outliers. For simplicity, Table 5 provides the quality results summarized by placing the median of %RSD results into range categories. A detailed summary of quality results is provided in Appendix B.

In general, the regression models for the mainstem stations perform the best, with median %RSD values at 10% or less for both all flows and summer baseflows. The models for the tributary stations perform more poorly. The summer baseflow predictions for Mad River and Tillicum Creek fall below 10% median %RSD, but Lake Creek predictions have median %RSDs of about 15% and Roaring Creek predictions exceed 20% median %RSD.

Table 4. Regressions for Ecology gages from USGS gages using hydrograph separation method.

Station ID	Station Name	USGS benchmark	Baseflow Threshold (cfs)	Hydrograph Separation Unit	Coefficient	Exponent	r^2	n
Telemetry Gages								
46A170	Entiat River at North Fork Campground	Entiat-Ard	305	Summer baseflow[1]	0.3920	1.0925	0.94	446
				Winter baseflow[2]	0.7790	0.8994	0.78	1141
				Freshet[3]	0.5011	1.0277	0.86	558
				Storm[4]	0.4276	1.0689	0.89	40
46A160	Entiat River below Entiat Falls	Entiat-Ard	291	Summer baseflow	0.4610	1.0930	0.98	450
				Winter baseflow	1.5220	0.8100	0.42	1134
				Freshet	1.2049	0.8954	0.90	568
				Storm	0.7930	1.0013	0.91	44
46A150	Entiat River at Tommy Creek Bridge	Entiat-Ard	313	Summer baseflow	1.2730	0.9000	0.85	449
				Winter baseflow	1.4200	0.8340	0.61	1147
				Freshet	0.4533	1.0779	0.79	552
				Storm	0.2465	1.1835	0.87	37
46A110	Entiat River at Dill Creek Bridge	Entiat-Ard	266	Summer baseflow	1.4434	0.8967	0.94	446
				Winter baseflow	1.6370	0.8583	0.92	1137
				Freshet	0.5457	1.0770	0.98	589
				Storm	0.6784	1.0258	0.95	51
46K050	Lake Creek at Mouth	Entiat-Ard	313	Baseflow[5]	0.6122	0.4600	0.33	1611
				Freshet	0.0440	0.9411	0.70	541
				Storm	0.4304	0.5837	0.85	33
46C100	Mad River above Camp Nine	Entiat-Ent	202	Summer baseflow	0.6168	0.7107	0.54	349
				Winter baseflow	0.4575	0.7395	0.21	809
				Freshet	0.0583	1.1638	0.88	827
				Storm	0.3876	0.8083	0.39	176
46D050	Tillicum Creek at Mouth	Entiat-Ent	175	Summer baseflow	0.5588	0.3711	0.20	374
				Winter baseflow	0.3786	0.5278	0.28	1022
				Freshet	0.2628	0.5900	0.31	742
				Storm	1.7691	0.1711	0.10	111
46B060	Roaring Creek near Mouth	Entiat-Ent	140	Summer baseflow	0.0021	1.3373	0.27	286
				Winter baseflow	0.0592	0.8749	0.16	817
				Freshet	0.1267	0.6527	0.25	885
				Storm	2.8424	0.0709	0.00	198

Table 4, continued. Regressions for Ecology gages from USGS gages using hydrograph separation method.

Station ID	Station Name	USGS benchmark	Baseflow Threshold (cfs)	Hydrograph Separation Unit	Coefficient	Exponent	r^2	n
Staff Gages								
46L050	Pope Creek at Mouth	Entiat-Ard	338	Baseflow Freshet & Storm[6]	0.2073 0.1849	0.5048 0.5126	0.54 0.39	32 26
46J080	Tommy Creek below USFS	Entiat-Ent	225	Baseflow Freshet & Storm	9.394E-04 8.816E-04	1.4460 1.4943	0.15 0.93	29 29
46H050	Preston Creek at Mouth	Entiat-Ent	225	Baseflow Freshet & Storm	4.086E-02 0.0280	0.6987 0.7036	0.04 0.20	55 60
46G060	Stormy Creek near Mouth	Entiat-Ent	225	Baseflow Freshet & Storm	2.6525 1.3212	-0.1170 0.1796	0.01 0.01	25 58
46F060	Potato Creek near Mouth	Entiat-Ent	192	Baseflow Freshet & Storm	2.405E-04 0.0089	1.4320 0.7350	0.02 0.10	30 57
46E070	Mud Creek at Bisping Canyon Road	Entiat-Ent	225	Baseflow Freshet & Storm	6.231E-06 0.1484	2.3250 0.3341	0.26 0.03	52 58

[1] Below threshold; July through September.
[2] Below threshold; October through June.
[3] Above threshold; March through September.
[4] Above threshold; October through February.
[5] Below threshold; year-round.
[6] Above threshold; year-round.

The quality of model predictions for staff gage flows are poorer than for telemetry station flows, but this is not surprising considering the small number of data points used for the regressions. In general, the predictions are better at higher elevations and poorer at lower elevations.

Table 6 shows a comparison of regression models for the Entiat River at the Dill Creek Bridge station. Regression models were developed using:

- Provisional daily average data, downloaded November 2008.
- Quality-checked daily average data, downloaded March 2008.
- Provisional 15-minute data, downloaded March 2009.

In addition, the regression model developed from quality-checked March 2008 daily average data was applied to 15-minute data.

A few observations can be made from a comparison of the model quality results in Table 6:

- Quality checking of provisional data slightly improves model regression relationships.

- Conclusions drawn from models developed with provisional data should hold true after data are quality checked and the models updated. Therefore the models developed from November 2008 data have not been updated for this report, but the models should be updated when data are finalized.

- The models developed from daily average data can be applied to 15-minute data. The poorer quality of the regression results with the higher frequency data should be taken into account in using the regressions this way. However, the development of a regression directly from 15-minute data does not improve the quality of the regressions; therefore, the additional time expended is not justified.

Other Analyses

Statistical relationships between measured flows and precipitation (non-snow precipitation and snowmelt) were explored, but they produced relationships that were much poorer than the hydrograph separation, so that line of analysis was abandoned.

The BASINS 4.0 program was explored, and a watershed coverage was successfully developed with subbasin delineation and burned-in flow lines using the 1:24,000 hydrography stream line data set and the 30-meter Digital Elevation Model (DEM). Initial attempts to use a 10-meter DEM were not successful. The analysis has not been pursued past this point.

Table 5. Quality assessment: median relative standard deviations for model predictions.

Station ID	Station Name	Metric	<5%	5-10%	10-15%	15-20%	20-30%	30-40%	40-50%
Telemetry Gages									
46A170	Entiat River at North Fork Campground	All flows		X					
		Summer baseflow		X					
46A160	Entiat River below Entiat Falls	All flows		X					
		Summer baseflow	X						
46A150	Entiat River at Tommy Creek Bridge	All flows		X					
		Summer baseflow	X						
46A110	Entiat River at Dill Creek Bridge	All flows	X						
		Summer baseflow	X						
46K050	Lake Creek at Mouth	All flows					X		
		All baseflow					X		
46C100	Mad River above Camp Nine	All flows			X				
		Summer baseflow		X					
46D050	Tillicum Creek at Mouth	All flows					X		
		Summer baseflow		X					
46B060	Roaring Creek near Mouth	All flows						X	
		Summer baseflow					X		
Staff Gages									
46L050	Pope Creek at Mouth	All flows			X				
		All baseflow		X					
46J080	Tommy Creek below USFS	All flows			X				
		All baseflow			X				
46H050	Preston Creek at Mouth	All flows					X		
		All baseflow					X		
46G060	Stormy Creek near Mouth	All flows					X		
		All baseflow			X				
46F060	Potato Creek near Mouth	All flows							X
		All baseflow							X
46E070	Mud Creek at Bisping Canyon Road.	All flows							X
		All baseflow							X

Table 6. Comparison of regression models for Entiat River at Dill Creek Bridge (Station ID 46A110; telemetry gage).

Model Scenario	Hydrograph Separation Unit	Coefficient	Exponent	r^2	n	Median %RSD
November 2008 daily average data	Summer baseflow	1.5586	0.8895	0.94	427	4%
	Winter baseflow	1.8668	0.8339	0.92	1,117	5%
	Freshet	0.6397	1.0579	0.98	586	4%
	Storm	0.6233	1.0437	0.94	51	10%
	All flows					4%
March 2009 daily average data	Summer baseflow	1.4434	0.8967	0.94	446	4%
	Winter baseflow	1.6370	0.8583	0.92	1,137	4%
	Freshet	0.5457	1.0770	0.98	589	3%
	Storm	0.6784	1.0258	0.95	51	7%
	All flows					3%
March 2009 15-minute data	Summer baseflow	1.4588	0.8943	0.94	42,569	8%
	Winter baseflow	1.6510	0.8566	0.91	61,214	12%
	Freshet	0.5427	1.0777	0.98	56,769	6%
	Storm	0.7033	1.0182	0.95	2,792	17%
	All flows					8%
March 2009 15-minute data (using March 2009 daily average model)	Summer baseflow					8%
	Winter baseflow					12%
	Freshet					6%
	Storm					17%
	All flows					8%

Discussion

The results of the regression analysis provide a tool that should allow the replacement of some gages with regressions that meet a level of quality sufficient to serve most purposes. This is especially true for Ecology's mainstem gages which regress closely to the USGS gage at Ardenvoir. This strong relationship is not surprising, since the gages are in close proximity, hydrologically similar, and should exhibit high levels of auto-correlation.

Tributary measurements are more problematic. Relationships were generally poor, especially for freshet flows. Upper tributaries tended to regress better than lower tributaries. This probably reflects the higher elevation snowpack conditions that dominate freshet flows at the lower mainstem gages. Lower elevation tributaries show characteristics where spring freshet flows begin with similar rising legs, but the freshet ends earlier with less overall flow. This would be consistent with a smaller snowpack at lower elevations where snowmelt ends sooner.

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.

The use of a GIS-based hydrologic model looks very promising, although the scope of this project did not allow a thorough analysis. The BASINS 4.0 program allows several potential advantages over the regression model:

- Local meteorological data can be used to generate flow on a near-real-time basis.

- BASINS 4.0 uses an open-source GIS platform that allows technology transfer at no expense.

- The HSPF hydrology model is widely used and supported.

- Flows generated will be physically-based instead of based on statistical relationships, potentially allowing for a more accurate calibration of the model. Results can also be extrapolated to conditions outside calibration conditions with less error.

- The model would provide flows basin-wide for other ungaged tributaries.

- The model would allow "what-if" scenarios to be run to aid in basin water management decisions.

- BASINS is a packaged system that potentially could yield a "toolbox" approach for use in other watersheds in the state.

The principal disadvantages of using BASINS would be:

- The initial investment of time to develop the procedures for watershed modeling with BASINS.

- The time necessary to appropriately calibrate the model.

- The time and expertise needed to adapt the model for near-real-time updates.

This page is purposely left blank

Conclusions and Recommendations

Conclusions

This study draws the following conclusions:

- The hydrograph separation method can be used to develop regression-based models to estimate streamflow at Ecology gaging stations in the Entiat River basin.

- The quality of the streamflow estimates from these regressions varies between stations. The best results were found for the mainstem stations closest to the USGS reference station. Results from Ecology tributary stations were of poorer quality, with the Mad River showing relatively better results and Roaring Creek showing poorest results.

- The regression tool should provide an adequate replacement for Ecology's mainstem Entiat River gages for most purposes, particularly for those closest to the USGS Ardenvoir station.

- All regression-based modeling tools for Ecology flow stations should be used for specific purposes with consideration as to whether their accuracy serves that purpose. Conceptually the regressions should be used as "screening tools" to trigger a direct evaluation of flow, or to use for purposes where a rough estimate is acceptable.

- Regression tools developed from daily average data can be applied to 15-minute data without the development of a separate model. However, the quality of 15-minute flow predictions will be poorer than the quality of daily average flow predictions.

- 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.

Recommendations

This study makes the following recommendations:

- The accuracy of the regression tools should be evaluated against Ecology's flow monitoring needs to determine whether the tools provide an acceptable substitute for flow gaging.

- The regression tools should be implemented on the website for Ecology's Statewide Flow Monitoring Network and made available to members of the Entiat Watershed Planning Unit for their use.

- Regression tools should be updated when additional measured flow data are available and when flow data quality review is complete.

- The BASINS 4.0 modeling framework should be evaluated for use in the Entiat River basin.

References

Kirk, T., O. Kerr, and H. Riddle. 1995. Initial Watershed Assessment - Water Resources Inventory Area 46 - Entiat River Watershed. Open File Report 95-02. Washington State Department of Ecology, Yakima, WA.

Pickett, P.J., 2008. Project Plan For: Entiat Basin Assessment of Gaged Flows. Memorandum to Bill Zachmann, Brad Hopkins, and Dave Holland. Washington State Department of Ecology, Olympia, WA. October 24, 2008.

Rickel, M., 2008. Letter to Dave Holland, Washington State Department of Ecology. Cascadia Conservation District, Wenatchee, WA. July 27, 2008.

USGS, 2007. Water Resources of the United States – 2007 Annual Report. U.S. Geological Survey, Washington, DC. http://wdr.water.usgs.gov/wy2007/documentation.html#stage
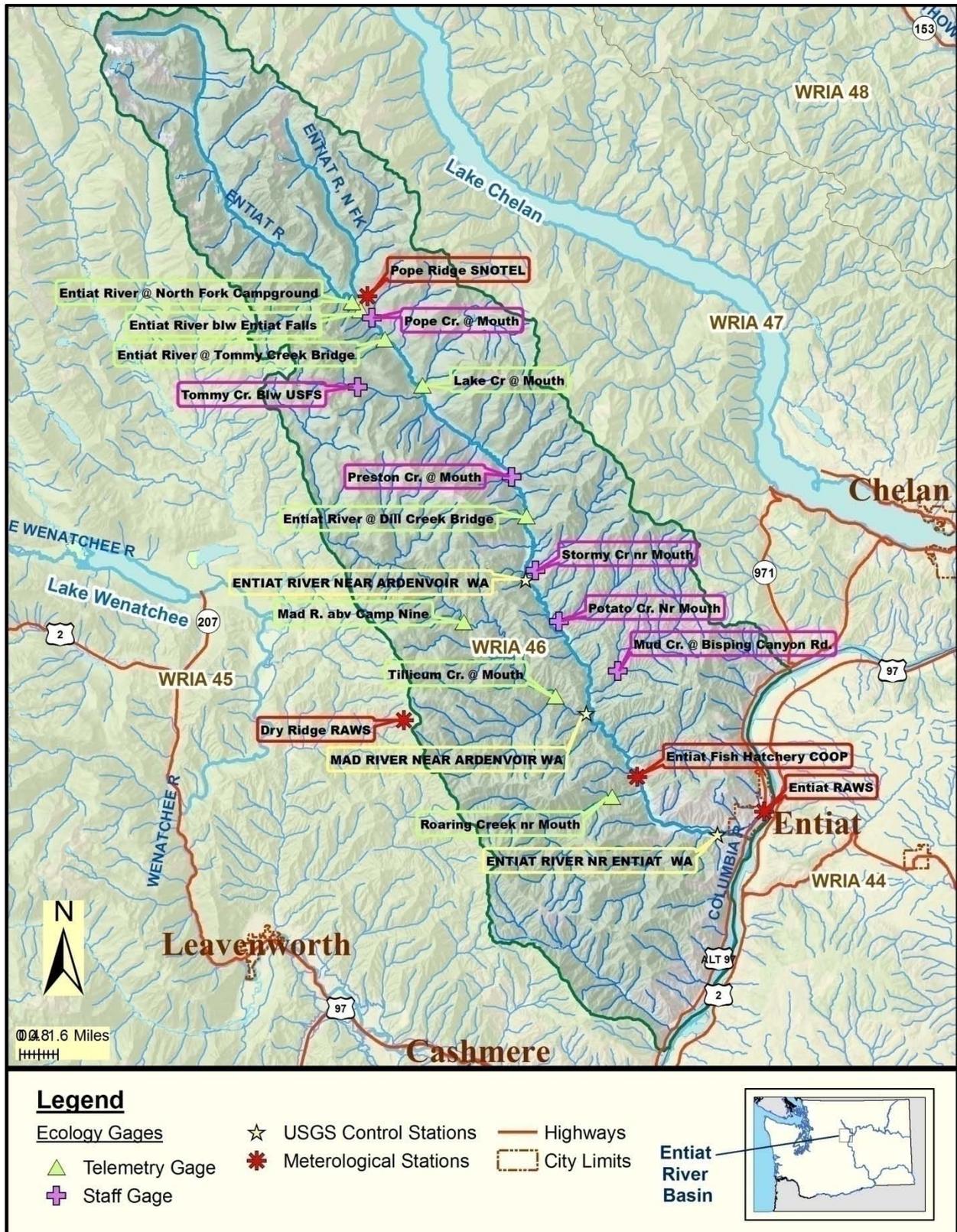
Figures

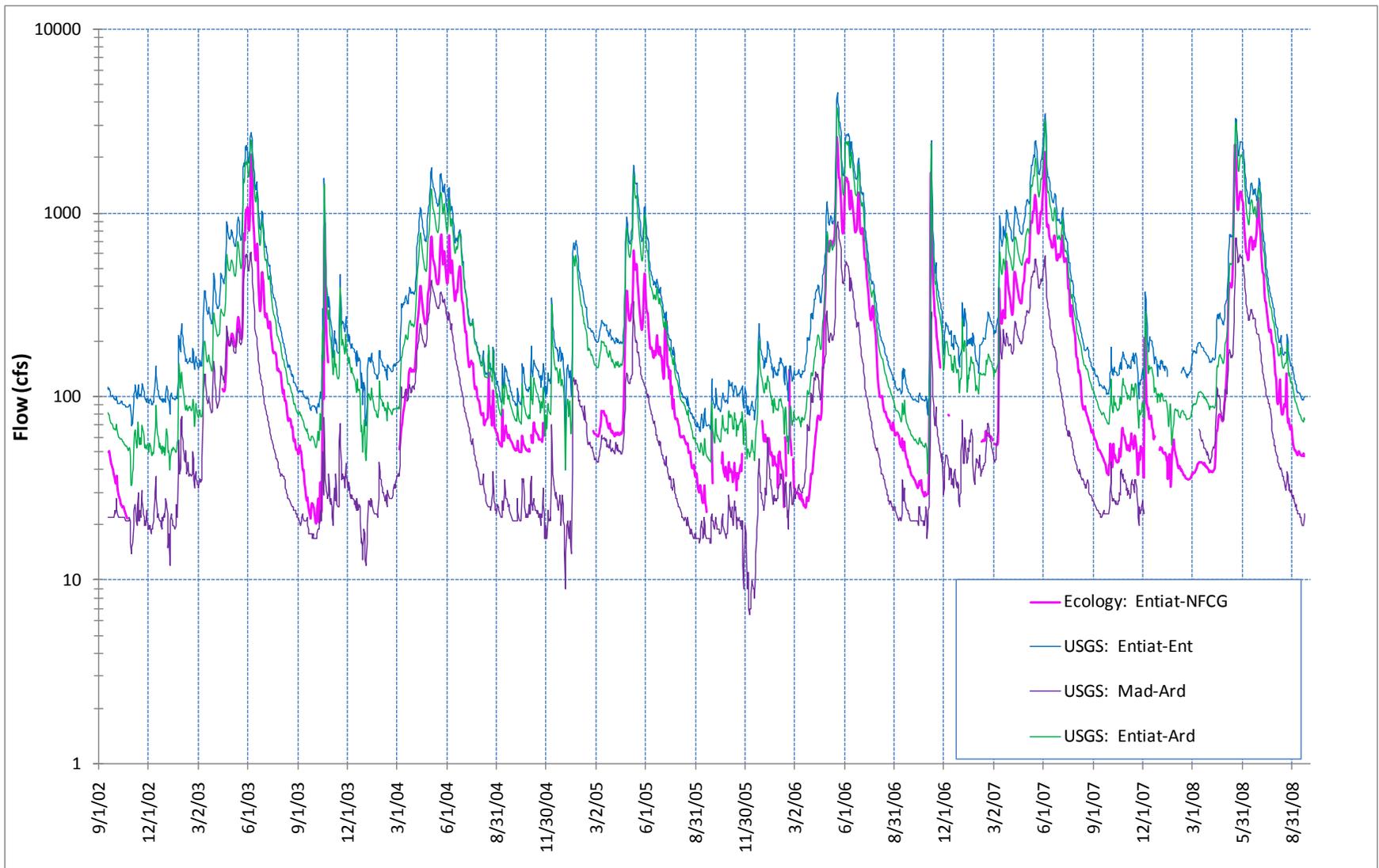Figure 1. Entiat watershed with flow gaging and control stations.

Figure 2. Measured flows at the "Entiat River at North Fork Campground (NFCG)" gaging station, with USGS gaged flows.
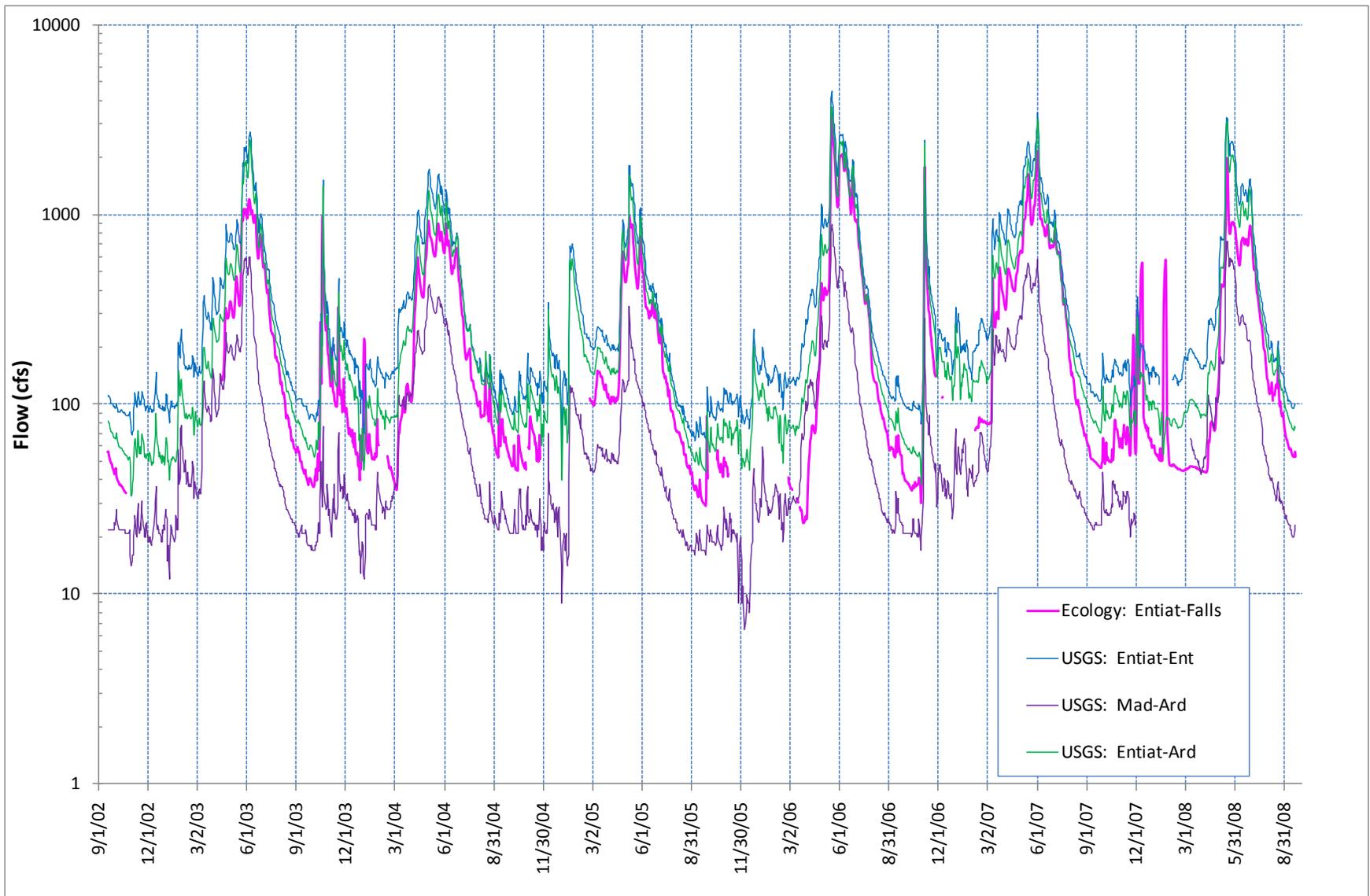
Figure 3. Measured flows at the "Entiat River below Entiat Falls" gaging station, with USGS gaged flows.
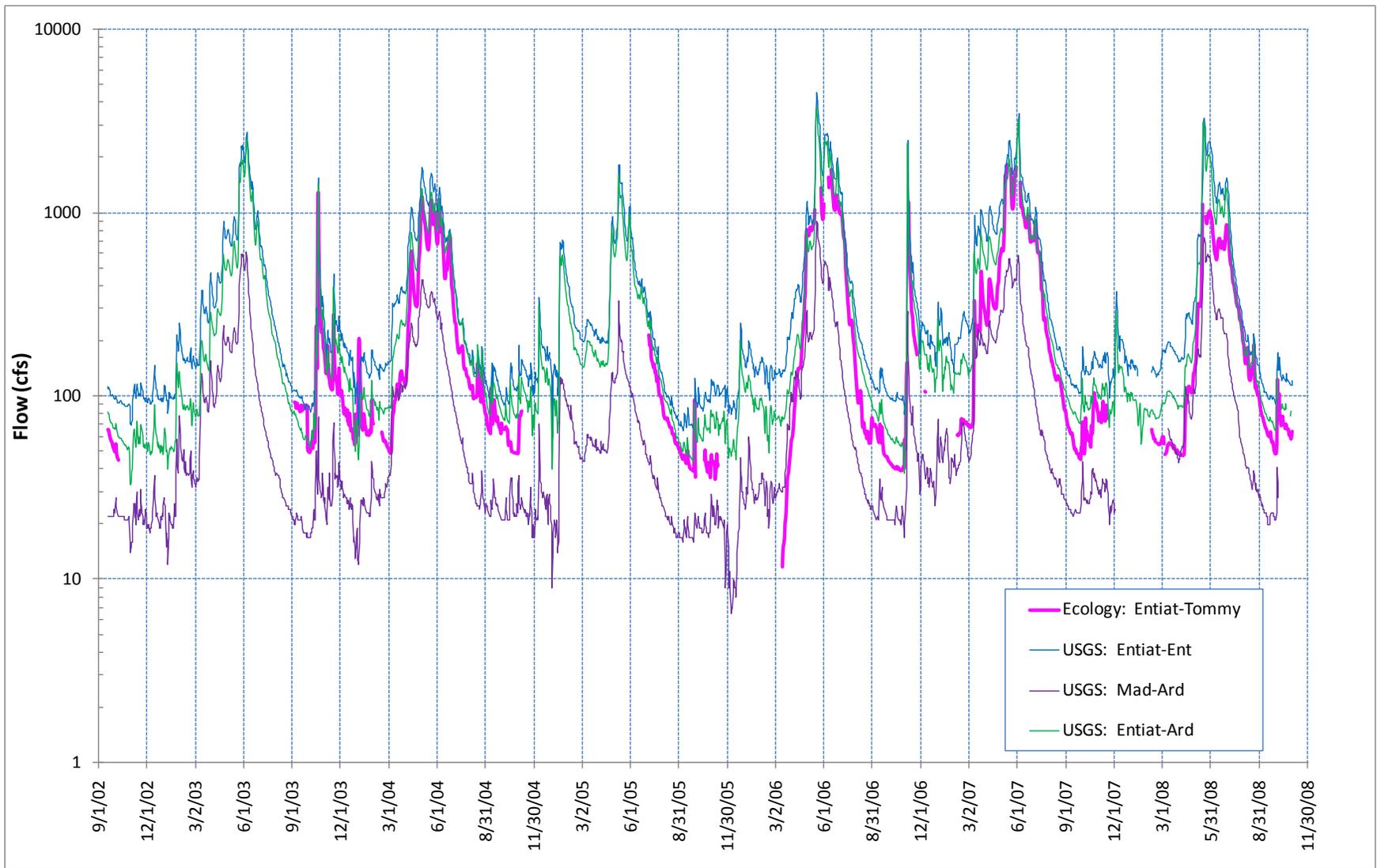
Figure 4. Measured flows at the "Entiat River at Tommy Creek Bridge" gaging station, with USGS gaged flows.

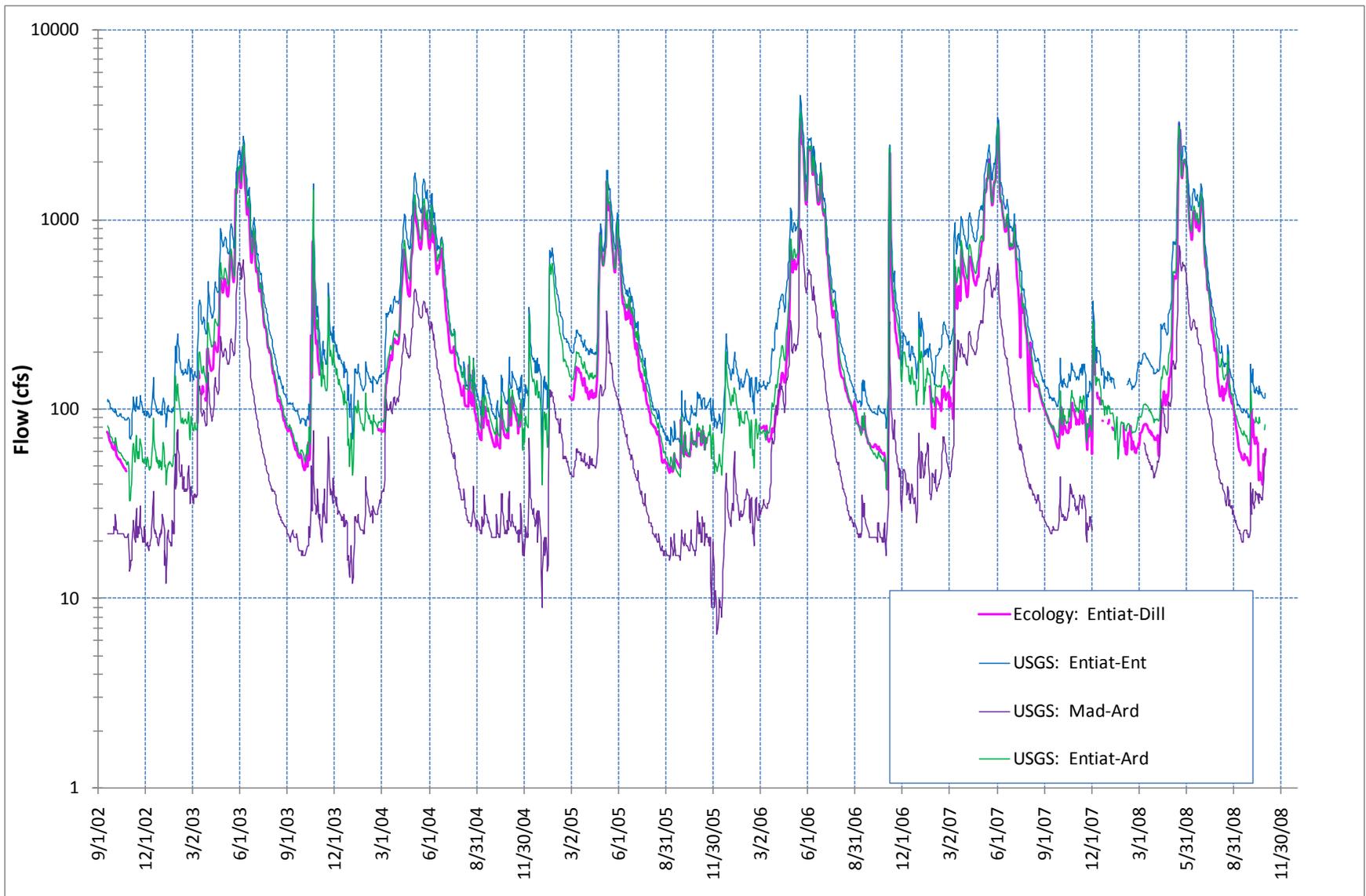Figure 5. Measured flows at the "Entiat River at Dill Creek Bridge" gaging station, with USGS gaged flows.

Figure 6. Measured flows at the "Lake Creek at mouth" gaging station, with USGS gaged flows.

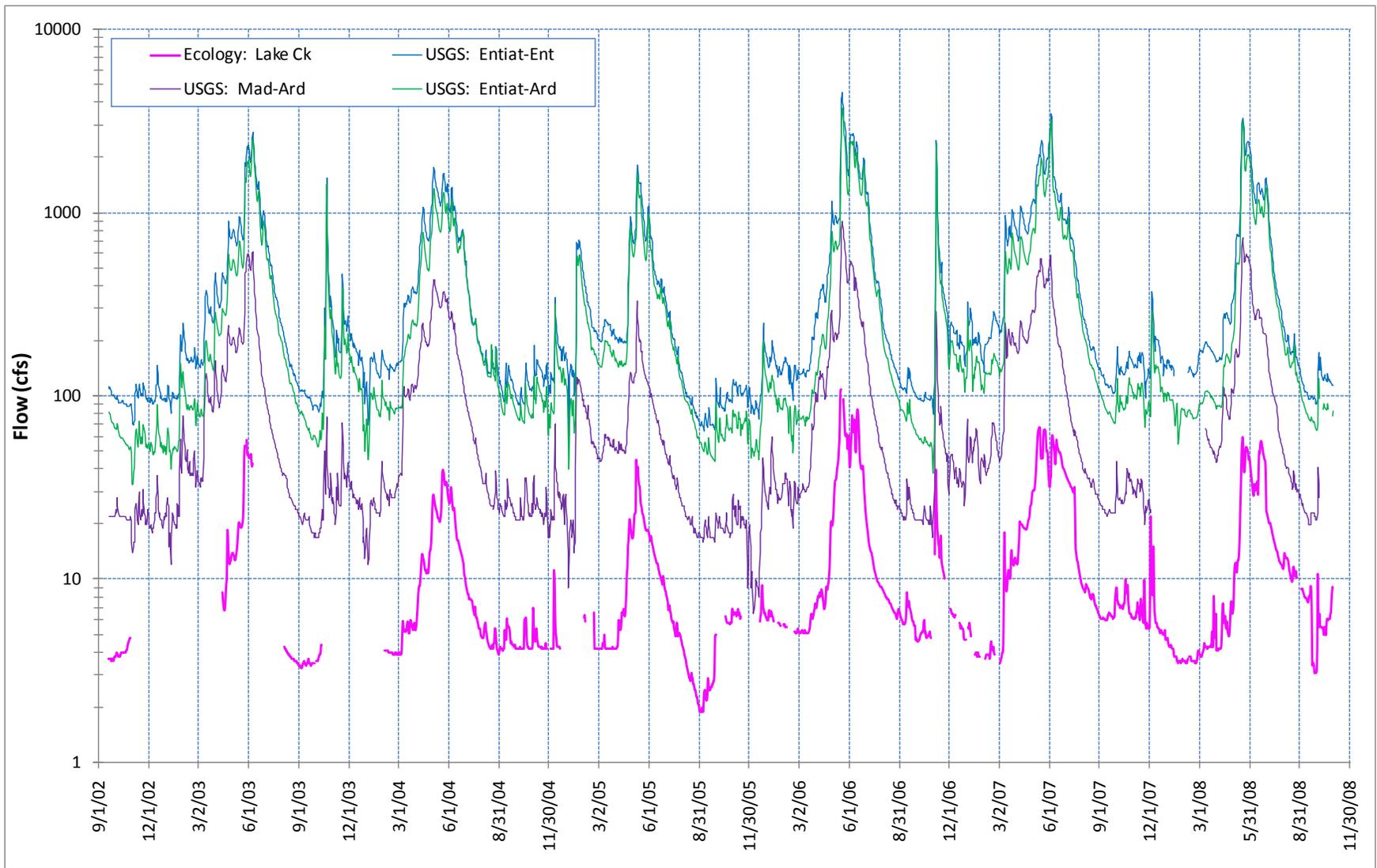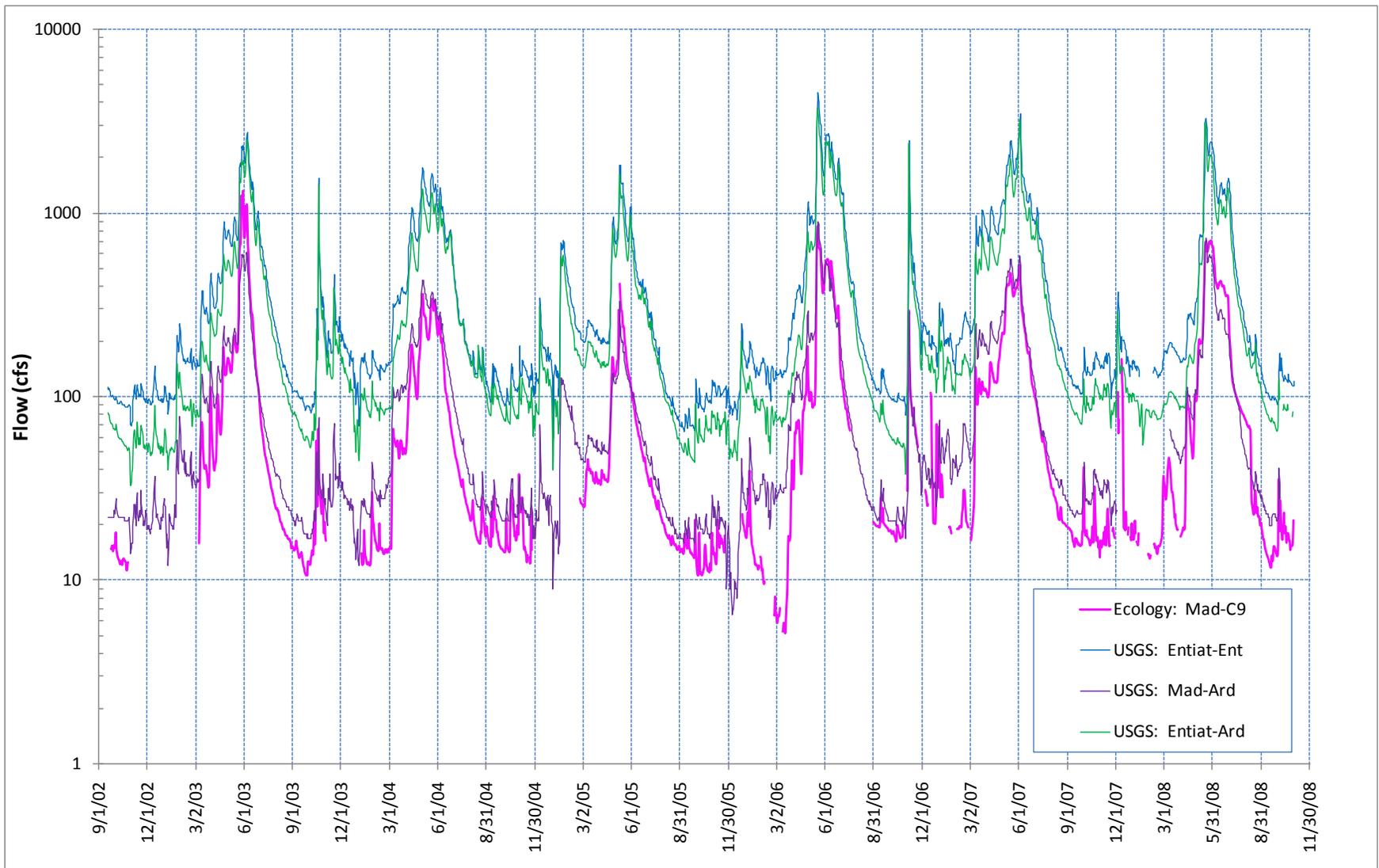Figure 7. Measured flows at the "Mad River above Camp Nine" gaging station, with USGS gaged flows.
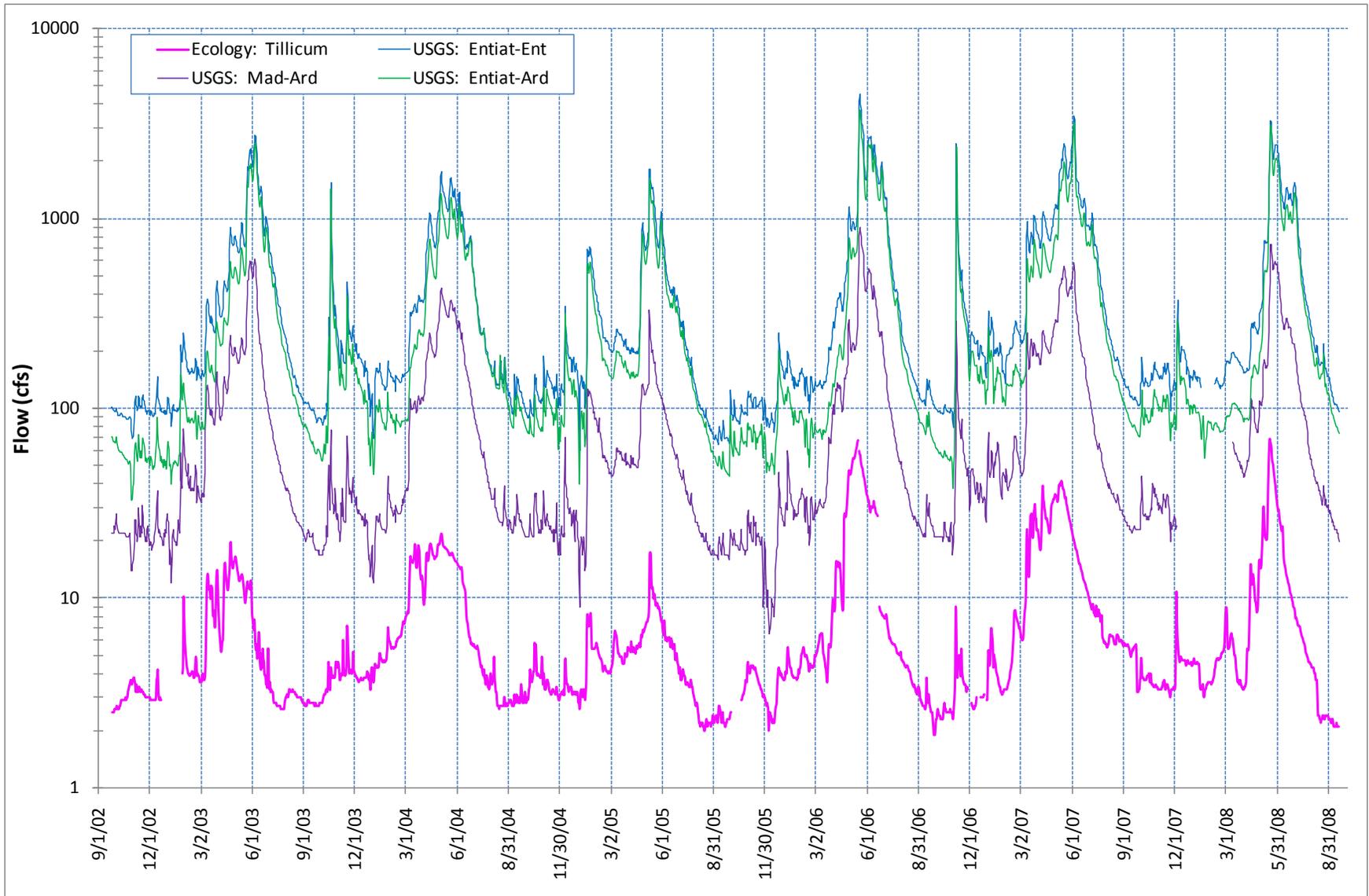
Figure 8. Measured flows at the "Tillicum Creek at mouth" gaging station, with USGS gaged flows.
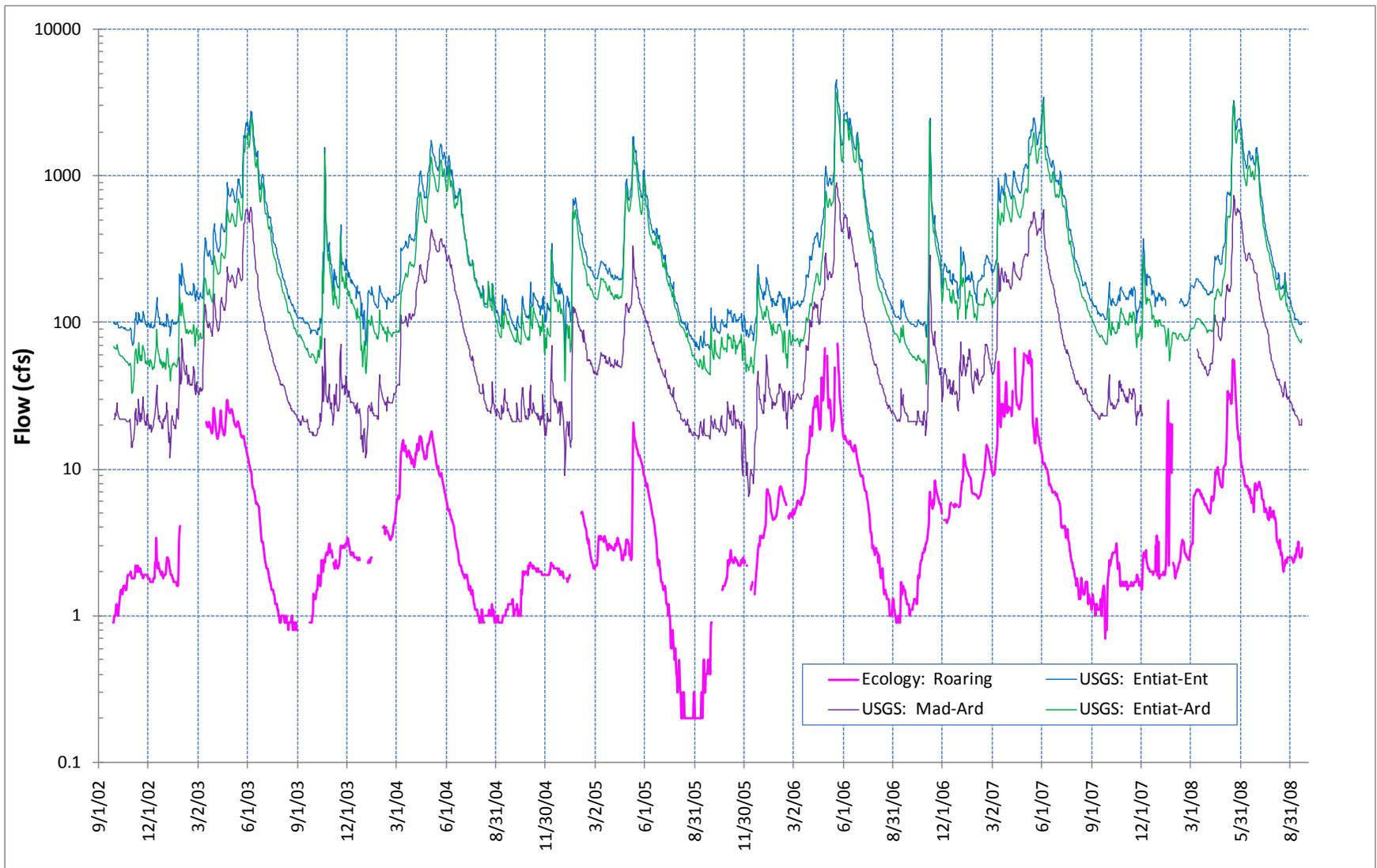
Figure 9. Measured flows at the "Roaring Creek at mouth" gaging station, with USGS gaged flows.
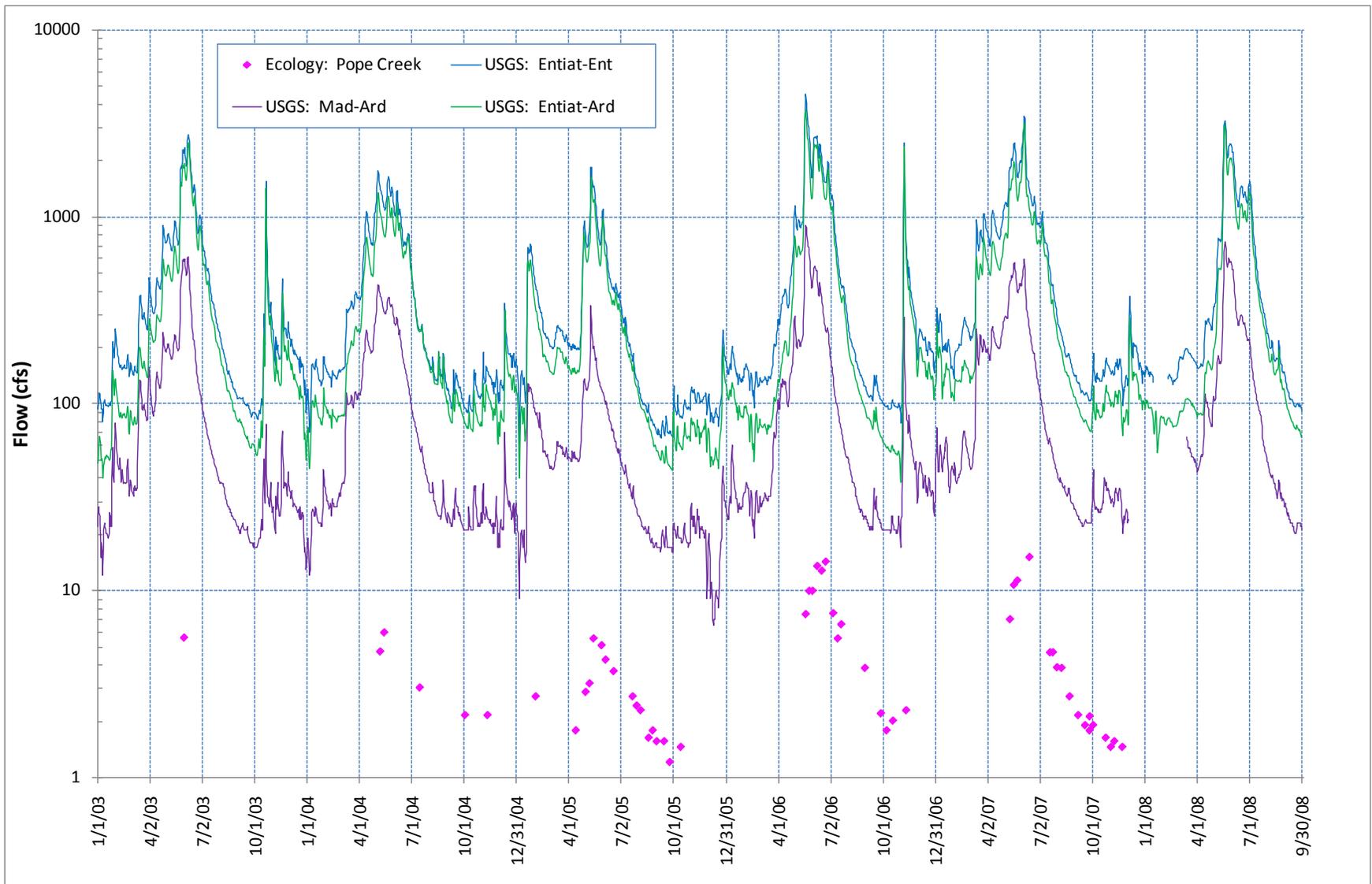
Figure 10 Measured flows at the "Pope Creek at mouth" staff gage site, with USGS gaged flows.

Figure 11. Measured flows at the "Tommy Creek below USFS Quarry" staff gage site, with USGS gaged flows.
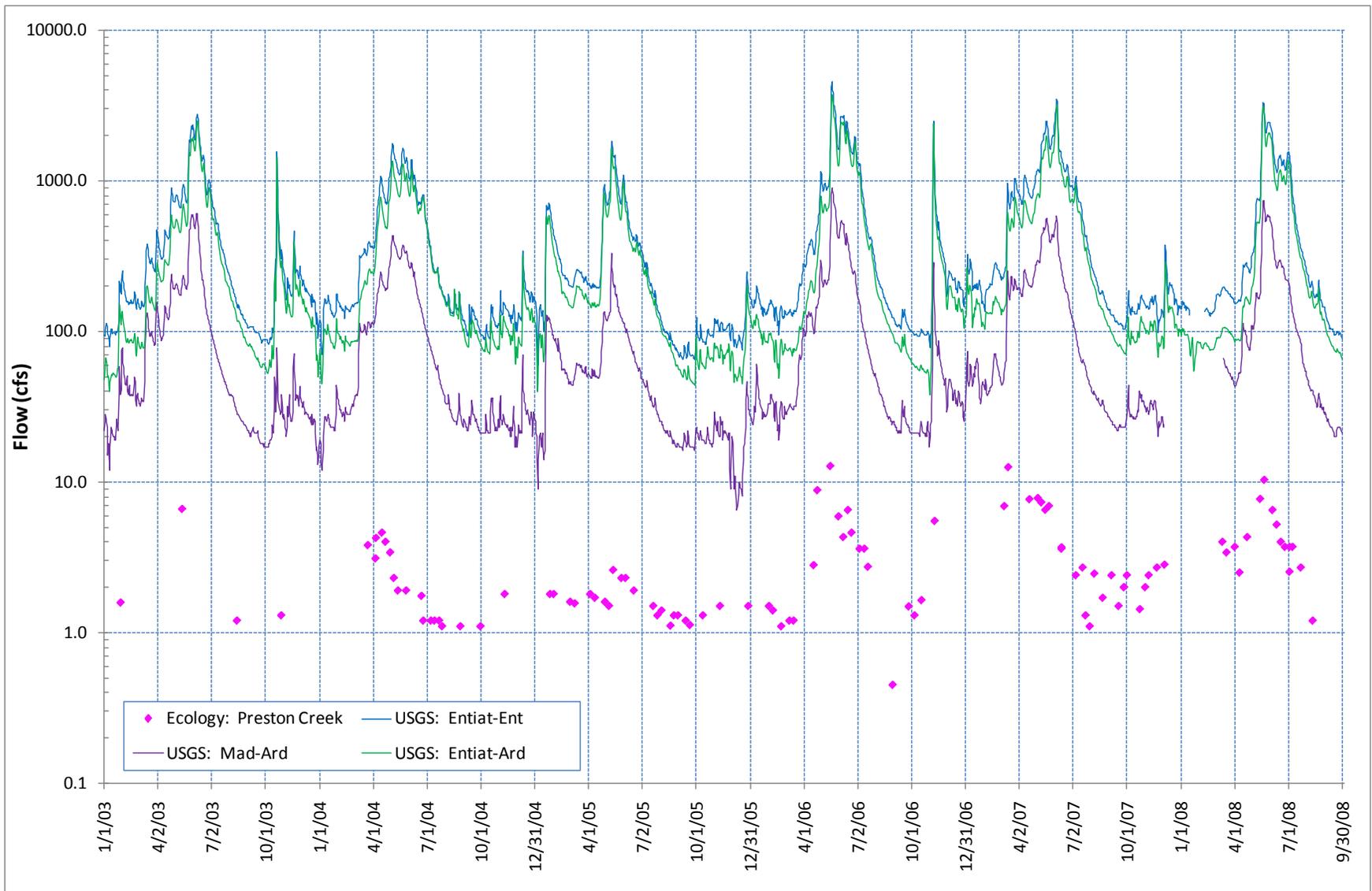
Figure 12. Measured flows at the "Preston Creek at mouth" staff gage site, with USGS gaged flows.
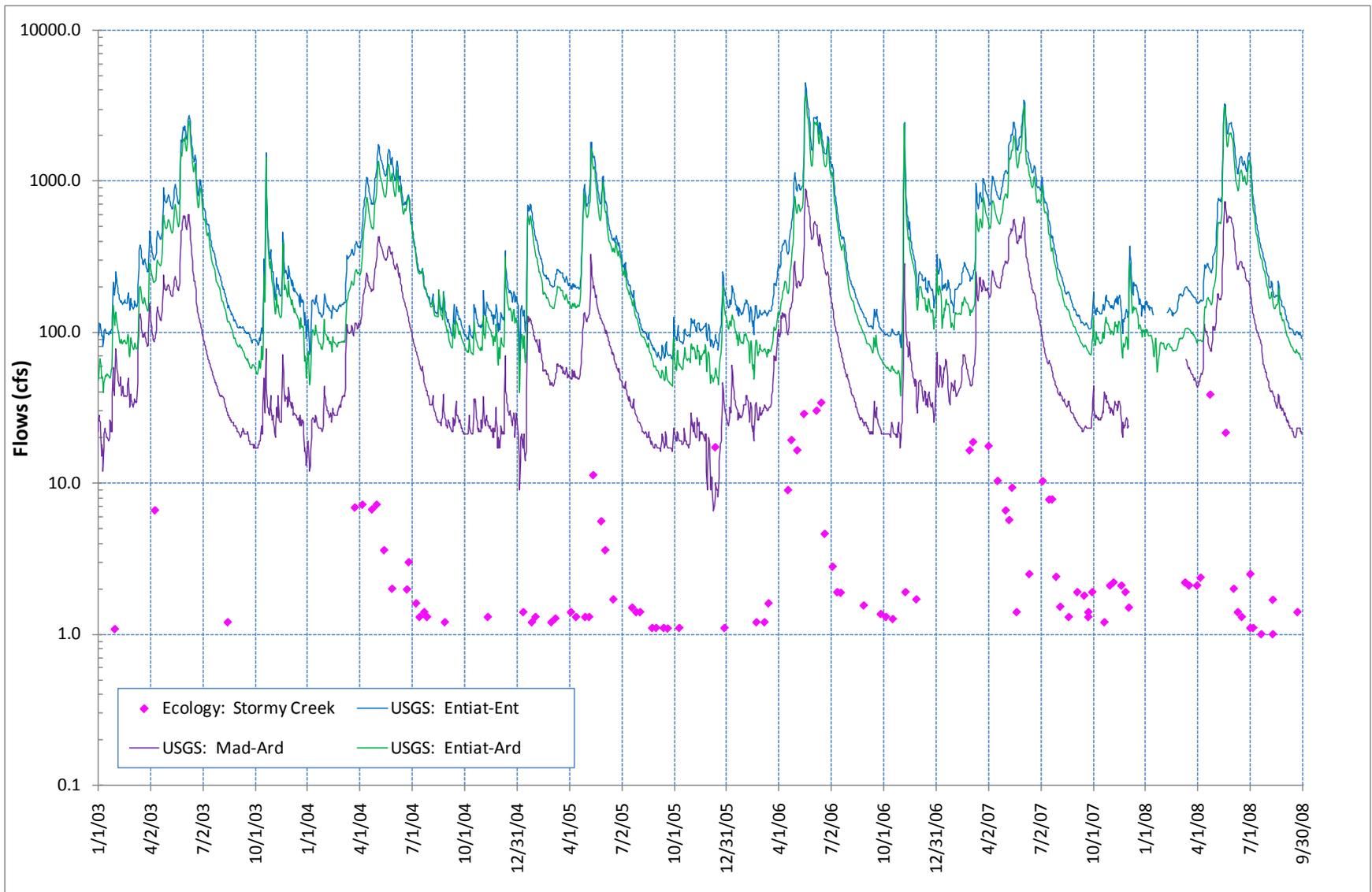
Figure 13. Measured flows at the "Stormy Creek near mouth" staff gage site, with USGS gaged flows.
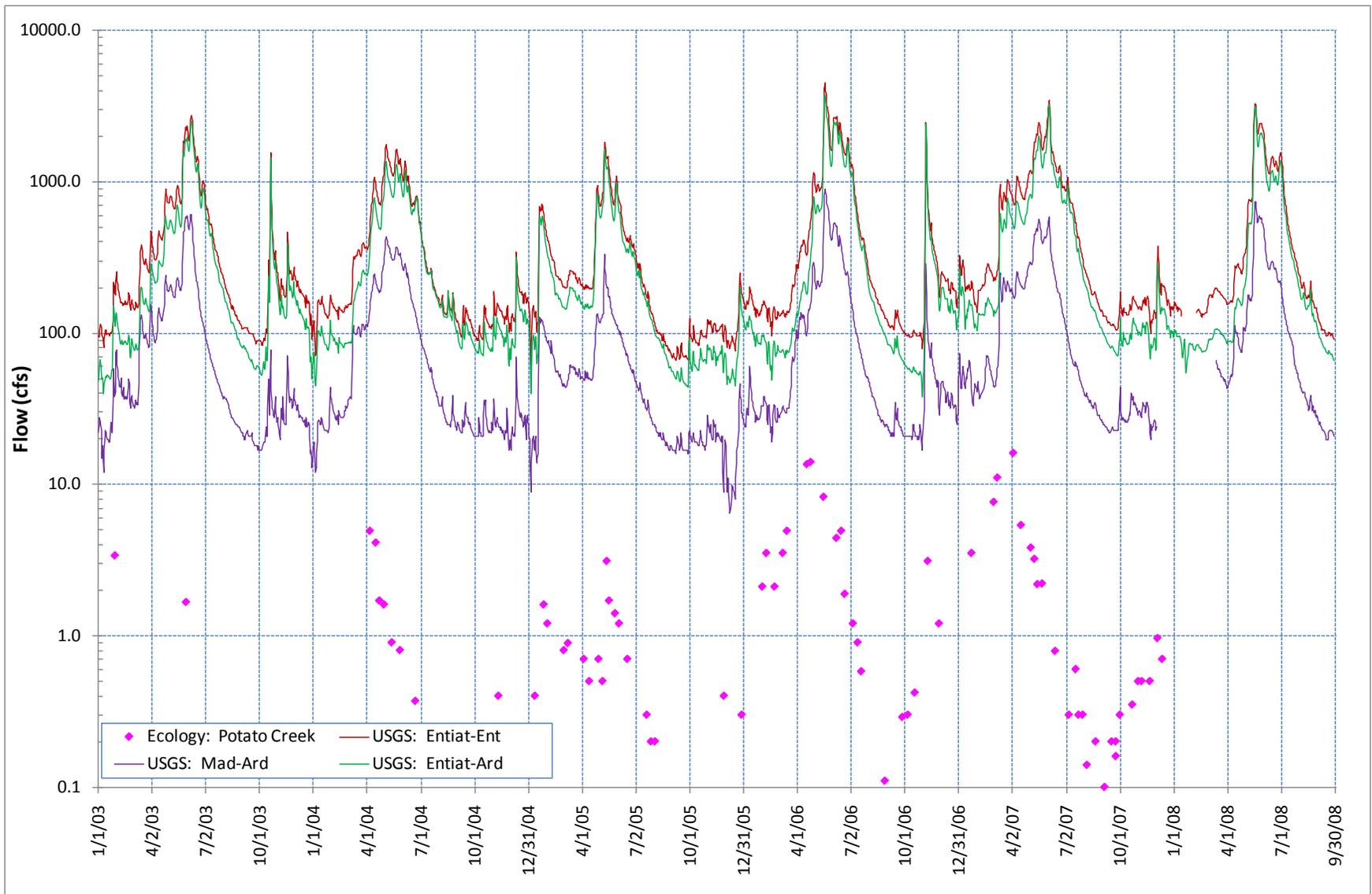
Figure 14. Measured flows at the "Potato Creek near mouth" staff gage site, with USGS gaged flows.
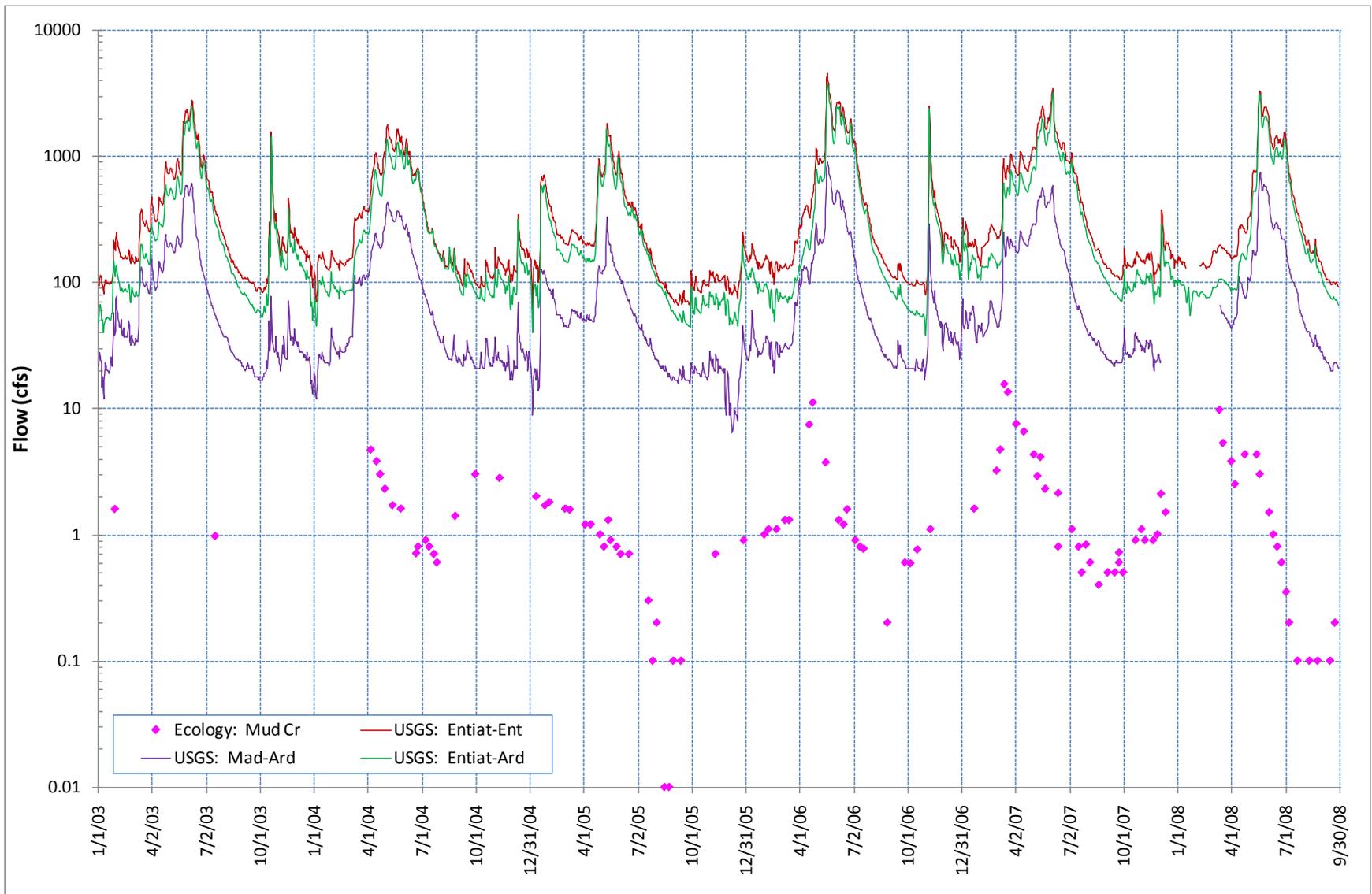
Figure 15. Measured flows at the "Mud Creek near mouth" staff gage site, with USGS gaged flows.
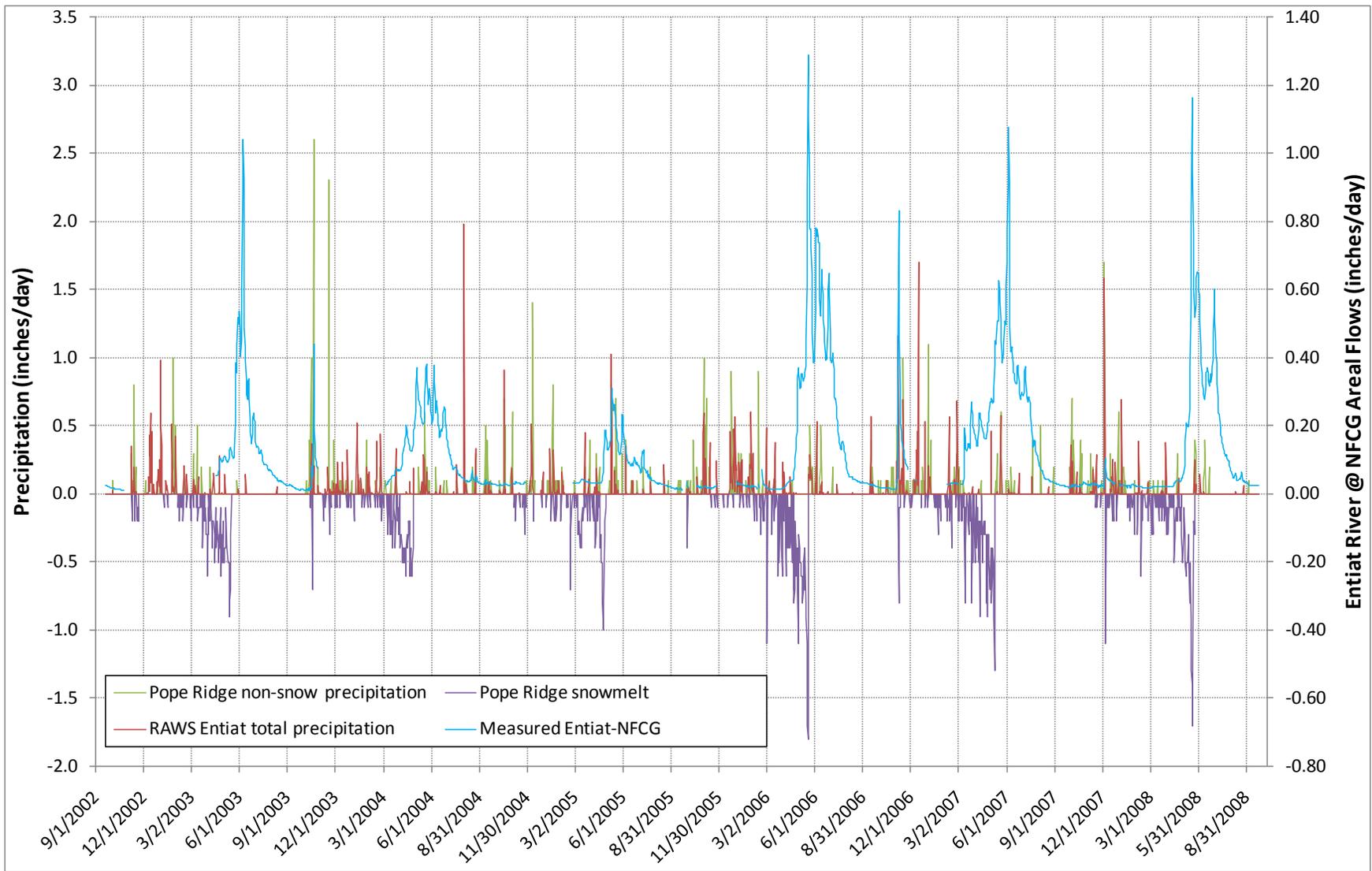
Figure 16. Measured areal flows at the "Entiat River at North Fork Campground (NFCG)" gaging station, with precipitation and snowmelt data.
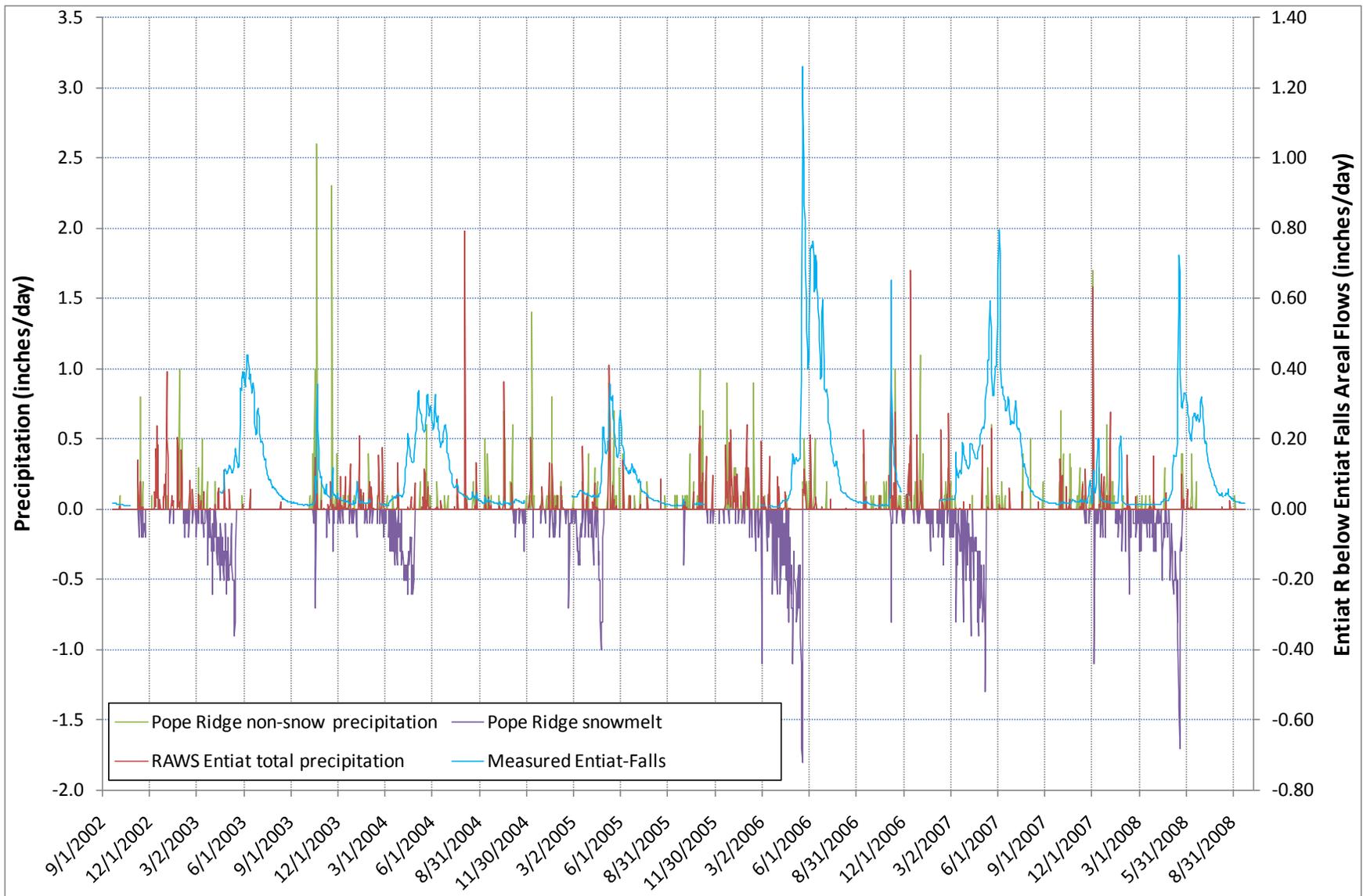
Figure 17. Measured areal flows at the "Entiat River below Entiat Falls" gaging station, with precipitation and snowmelt data.
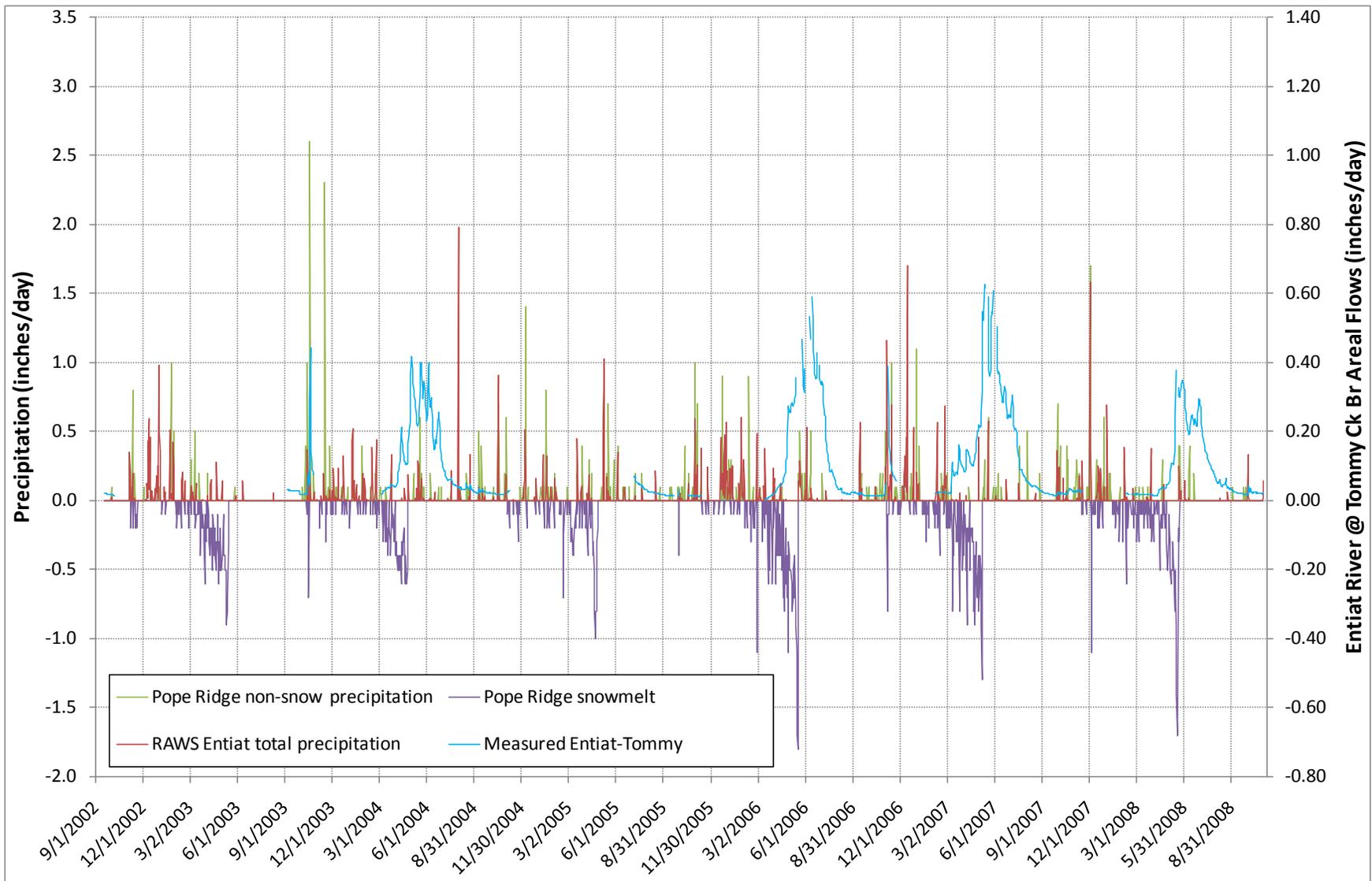
Figure 18. Measured areal flows at the "Entiat River at Tommy Creek Bridge" gaging station, with precipitation and snowmelt data.
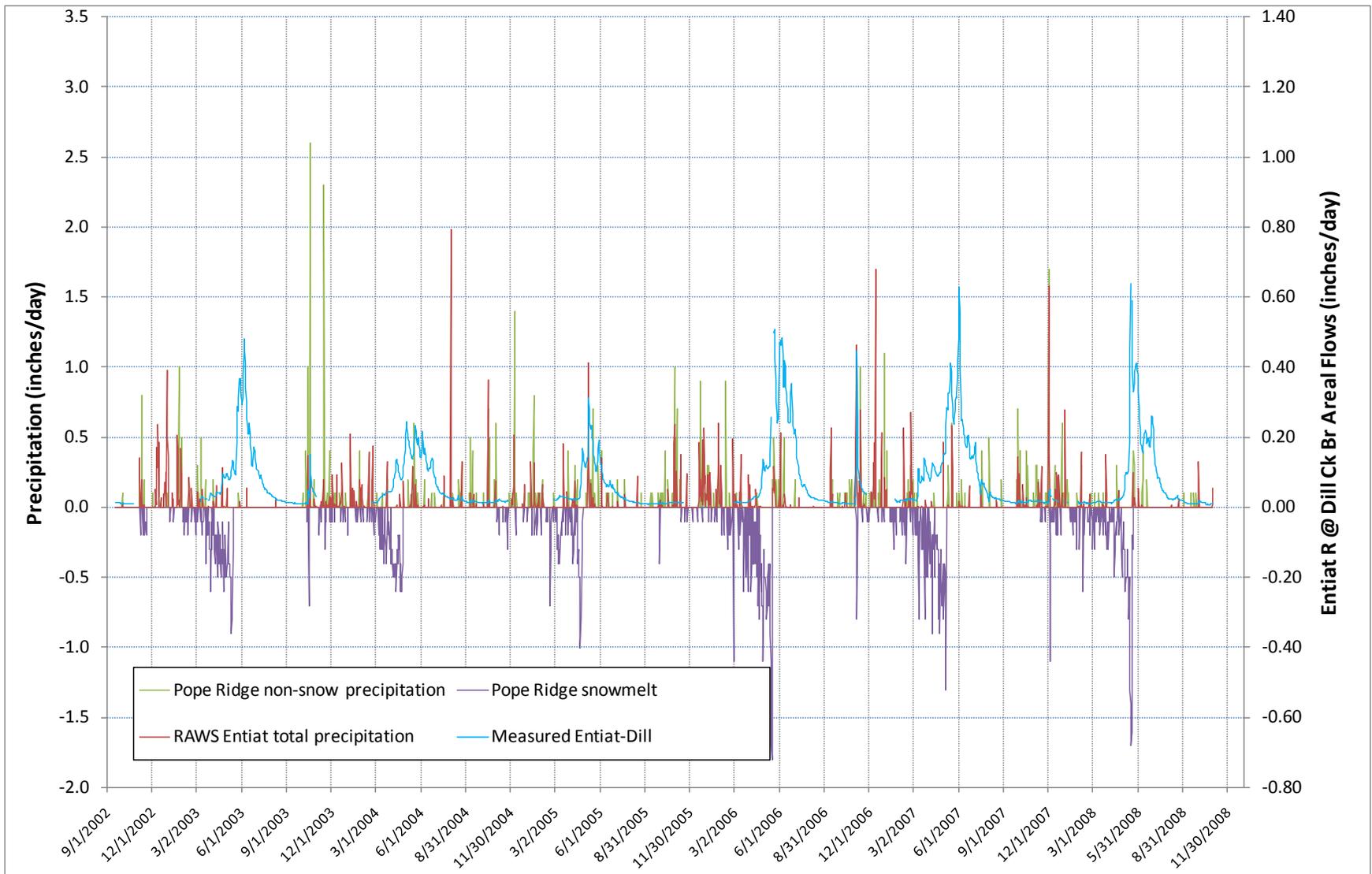
Figure 19. Measured areal flows at the "Entiat River at Dill Creek Bridge" gaging station, with precipitation and snowmelt data.
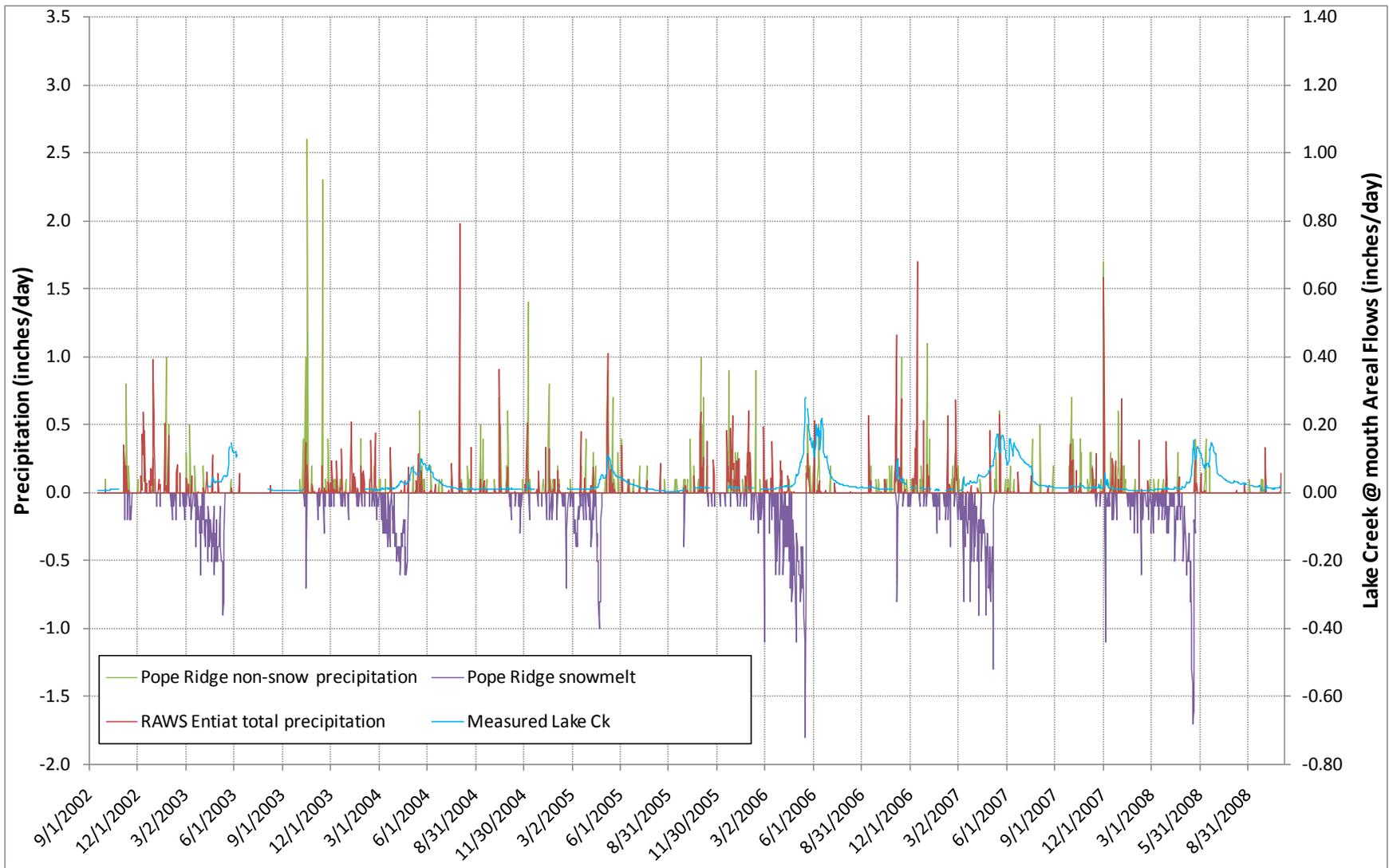
Figure 20. Measured areal flows at the "Lake Creek at mouth" gaging station, with precipitation and snowmelt data.
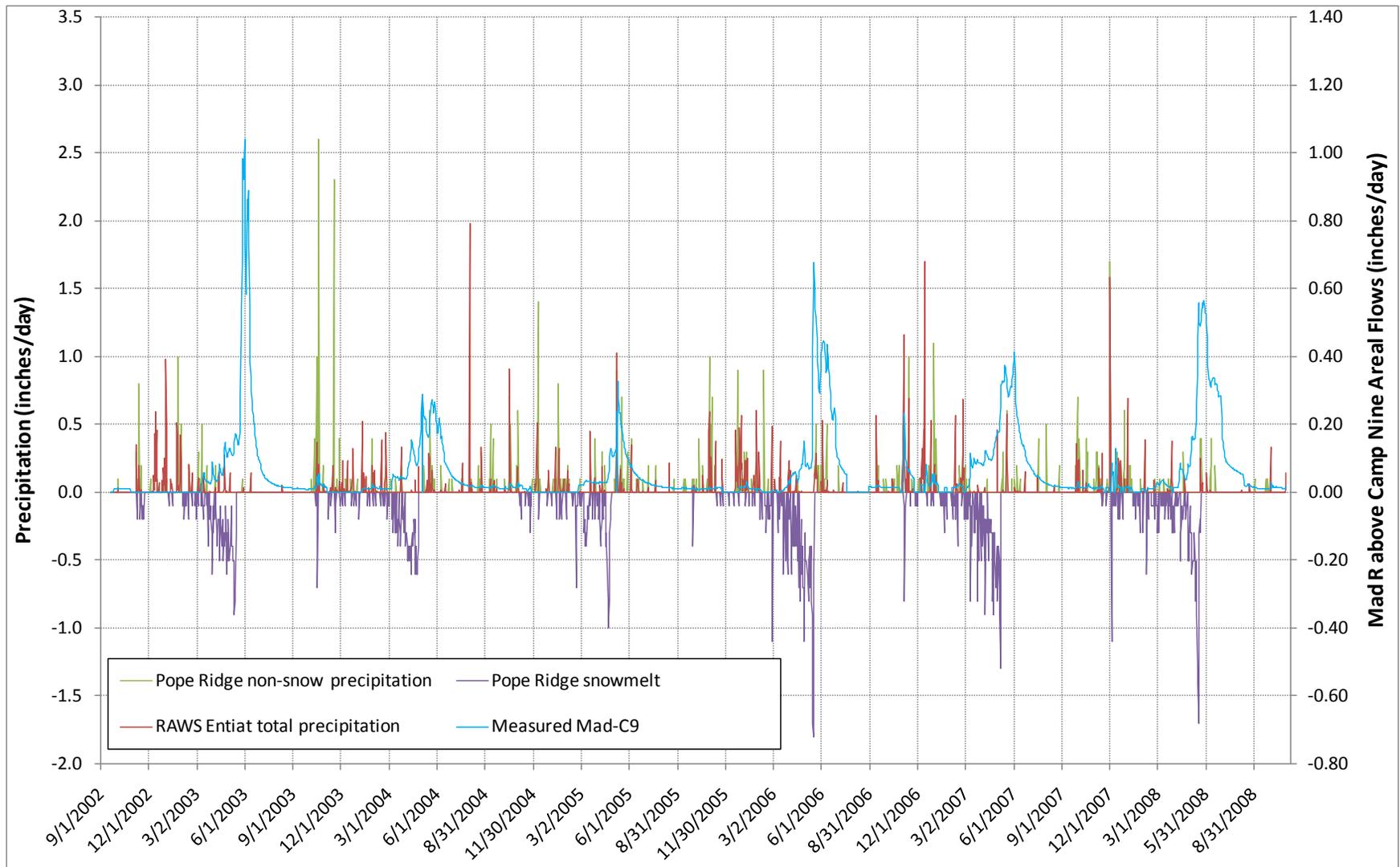
Figure 21. Measured areal flows at the "Mad River above Camp Nine" gaging station, with precipitation and snowmelt data.
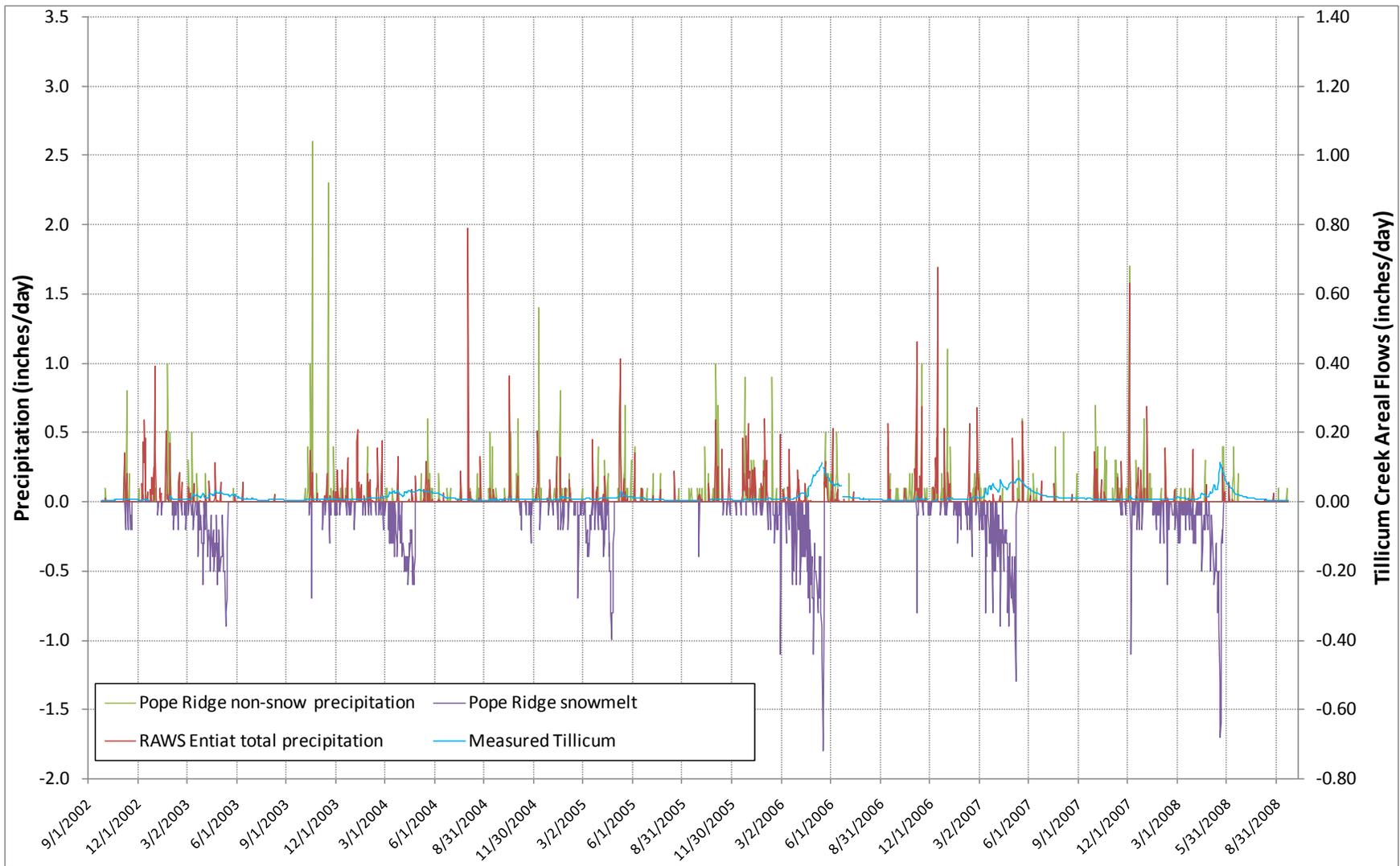
Figure 22. Measured areal flows at the "Tillicum Creek at mouth" gaging station, with precipitation and snowmelt data.
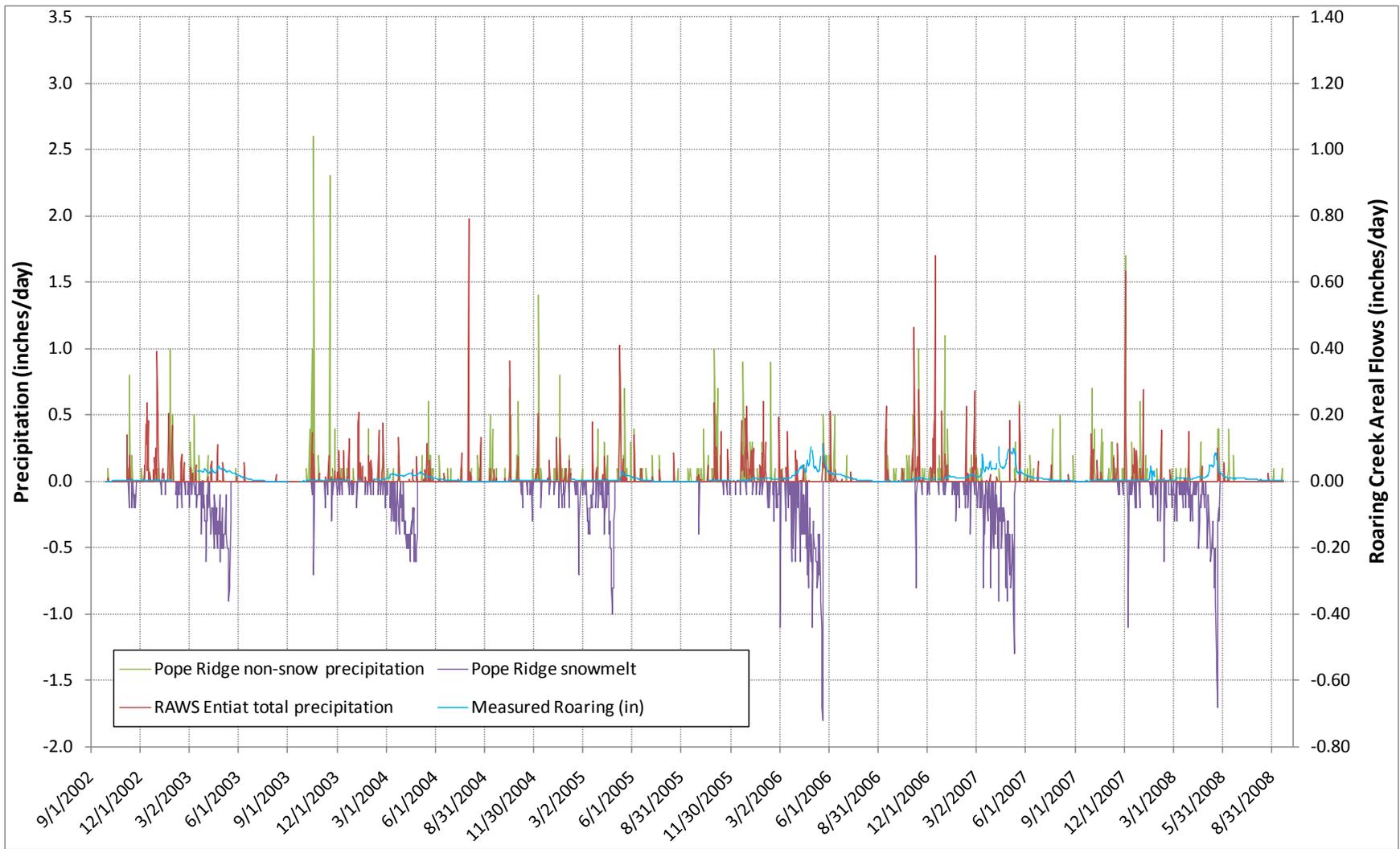
Figure 23. Measured areal flows at the "Roaring Creek at mouth" gaging station, with precipitation and snowmelt data.
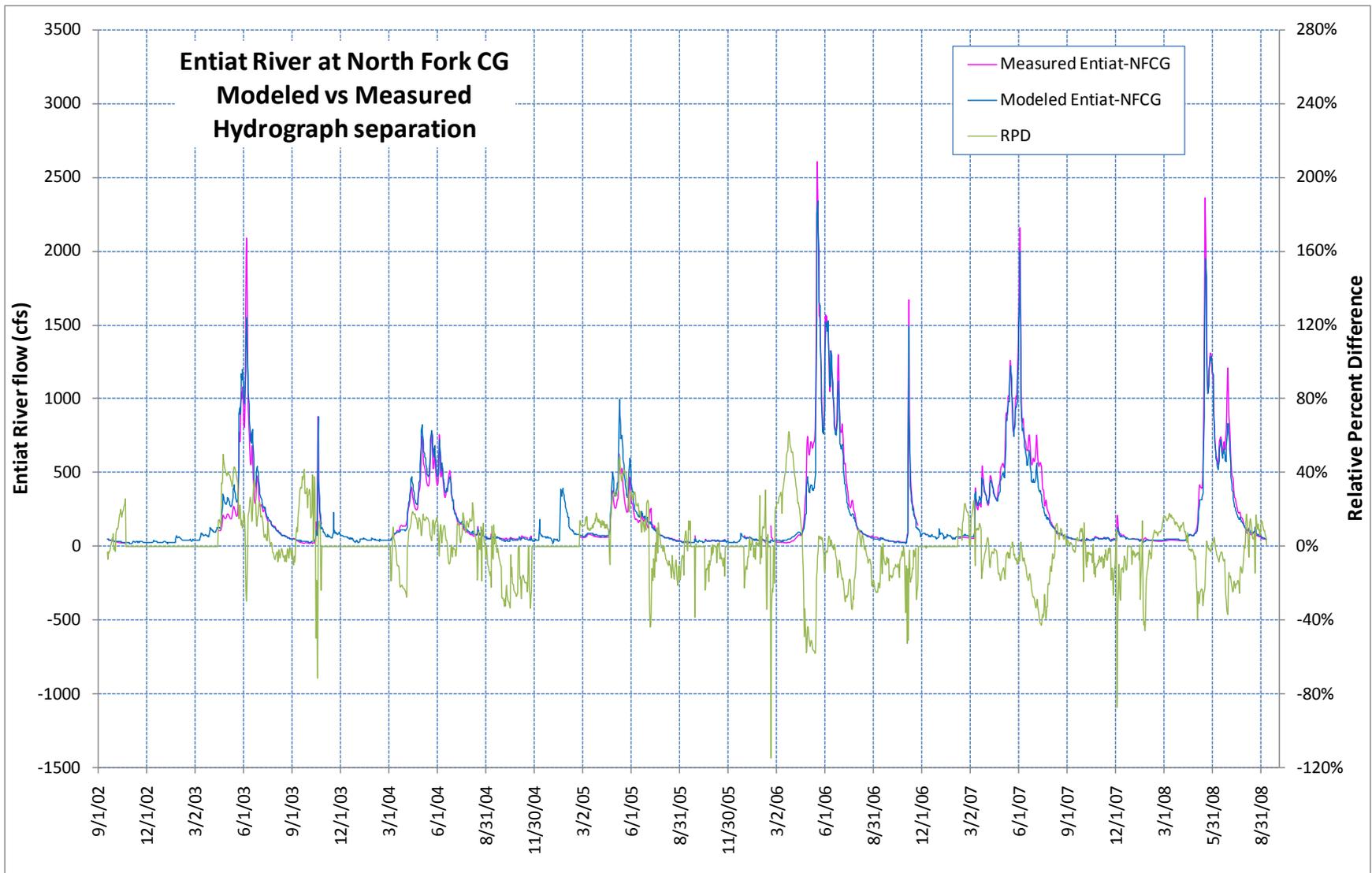
Figure 24. Modeled and measured flows at the "Entiat River at North Fork Campground" gaging station with relative percent difference of paired values.
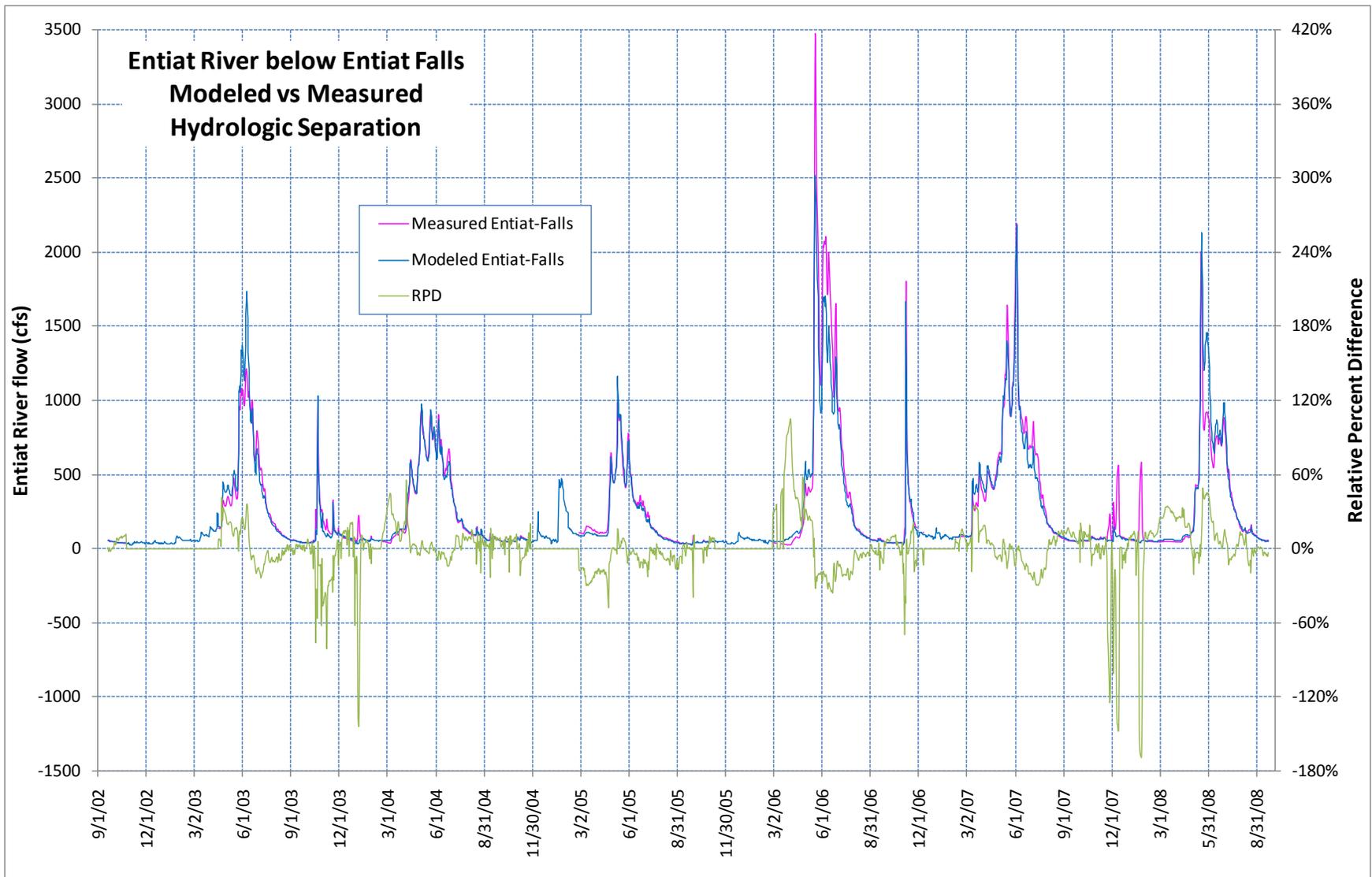
Figure 25. Modeled and measured flows at the "Entiat River below Entiat Falls" gaging station with relative percent difference of paired values.
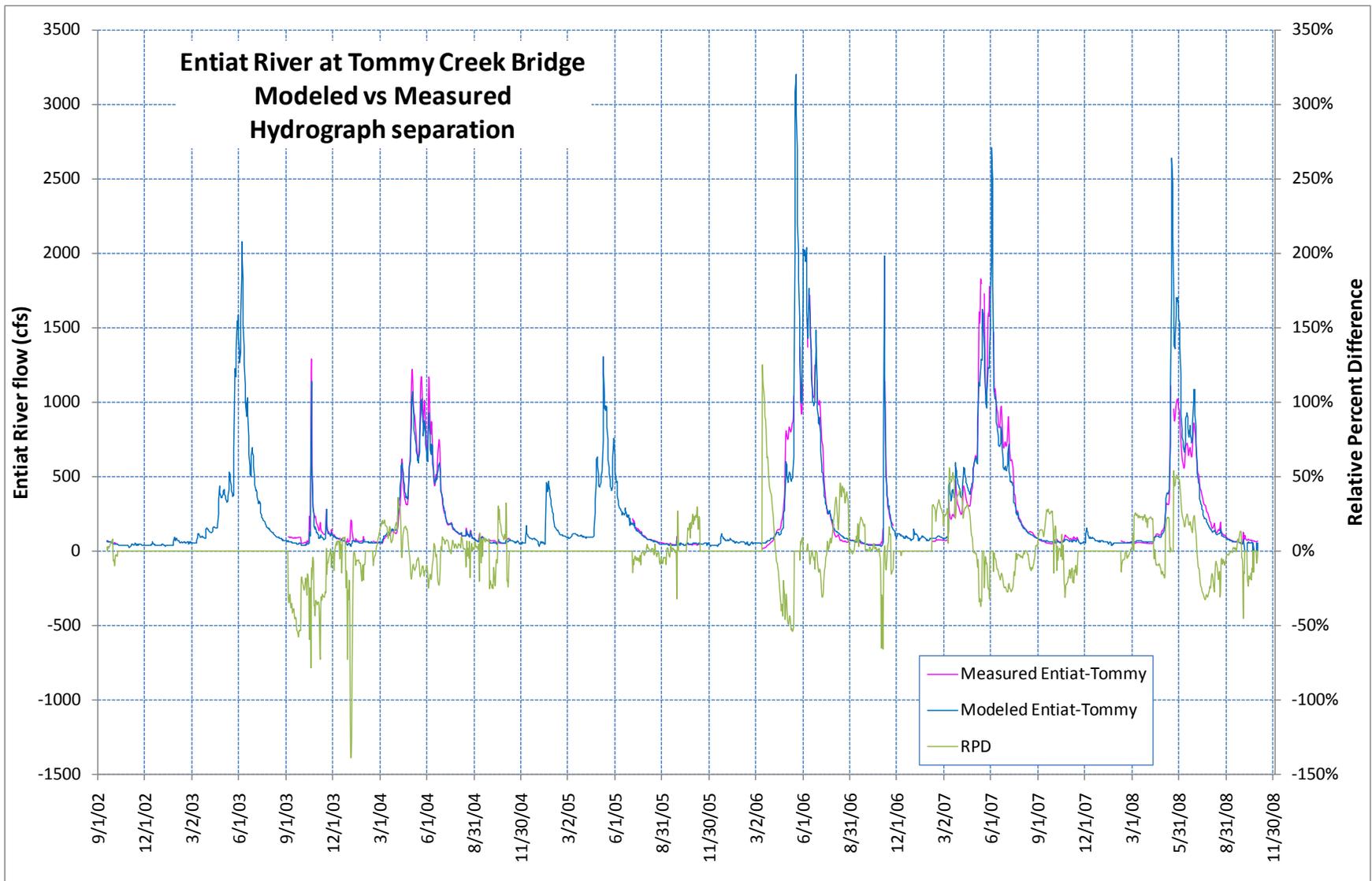
Figure 26. Modeled and measured flows at the "Entiat River at Tommy Creek Bridge" gaging station with relative percent difference of paired values.
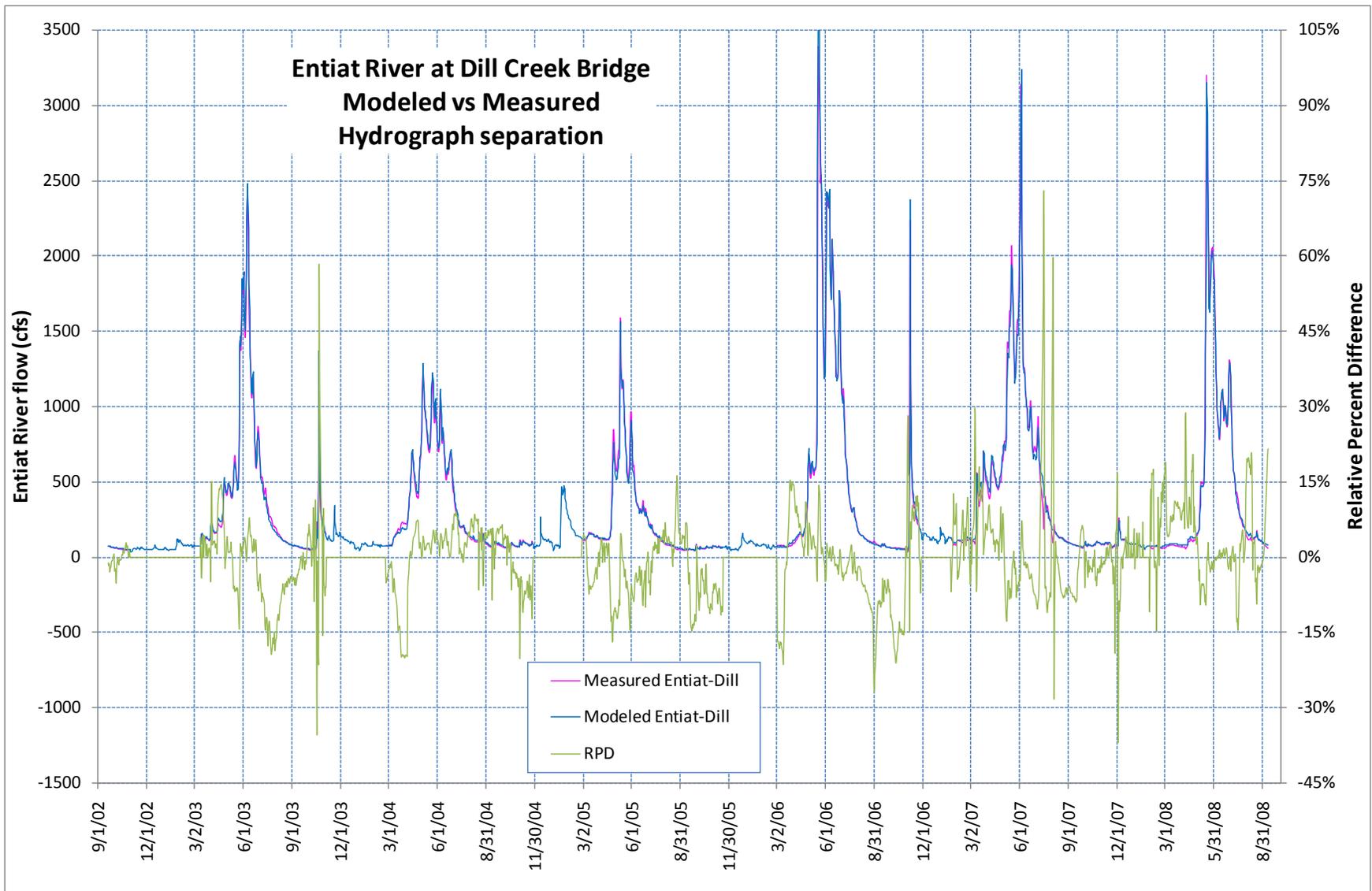
Figure 27. Modeled and measured flows at the "Entiat River at Dill Creek Bridge" gaging station with relative percent difference of paired values.
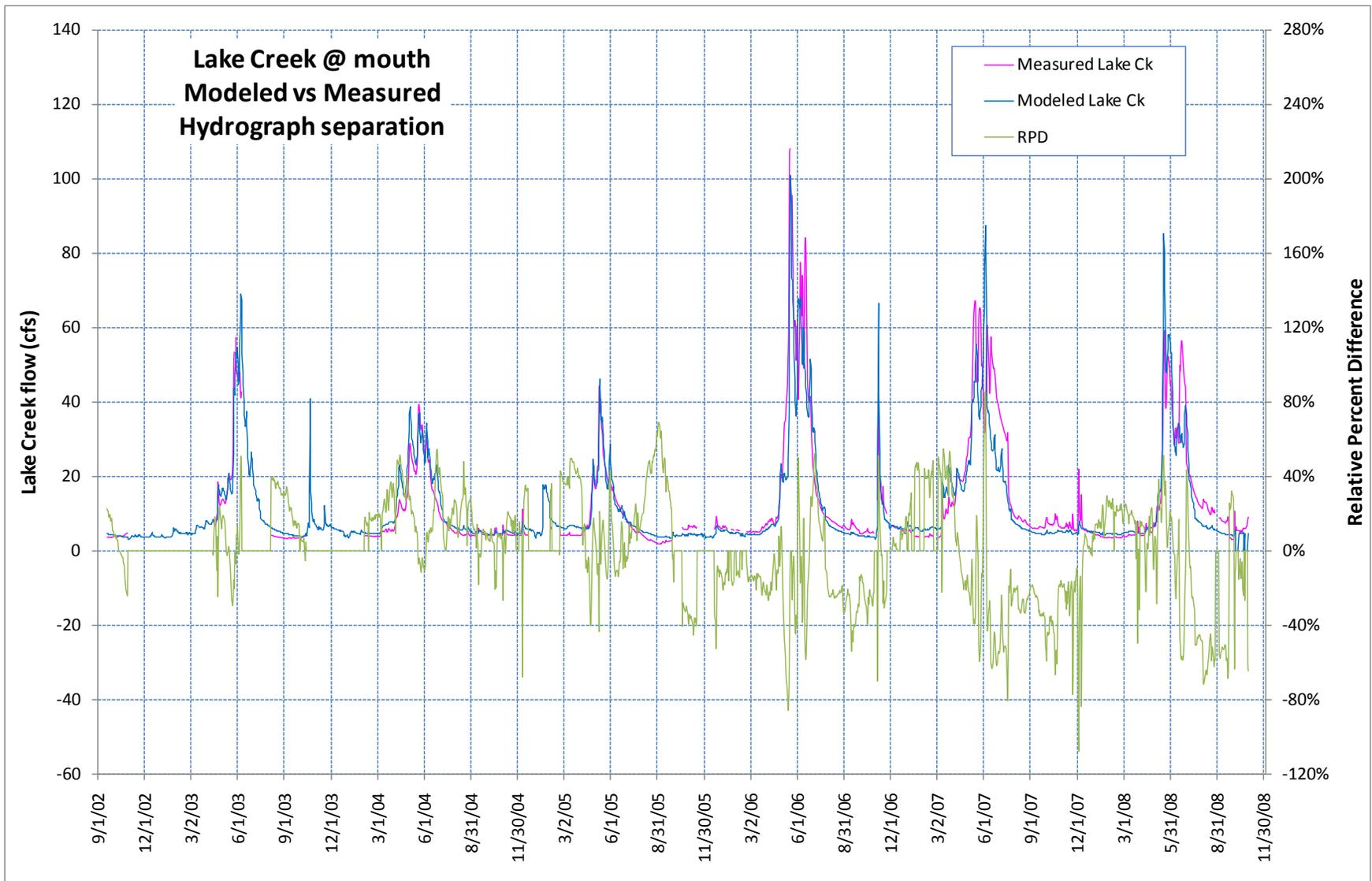
Figure 28. Modeled and measured flows at the "Lake Creek at mouth" gaging station with relative percent difference of paired values.
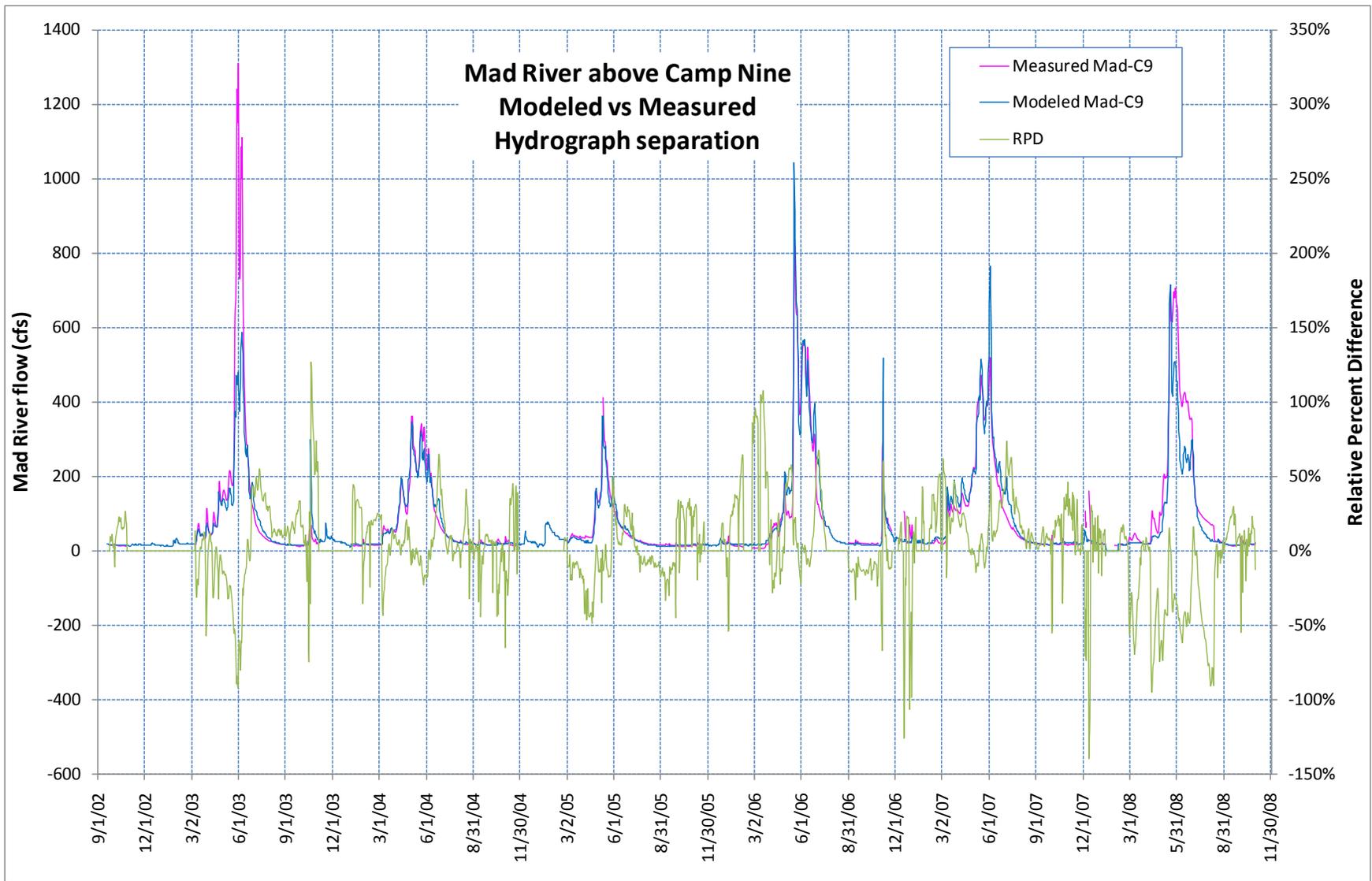
Figure 29. Modeled and measured flows at the "Mad River above Camp Nine" gaging station with relative percent difference of paired values.
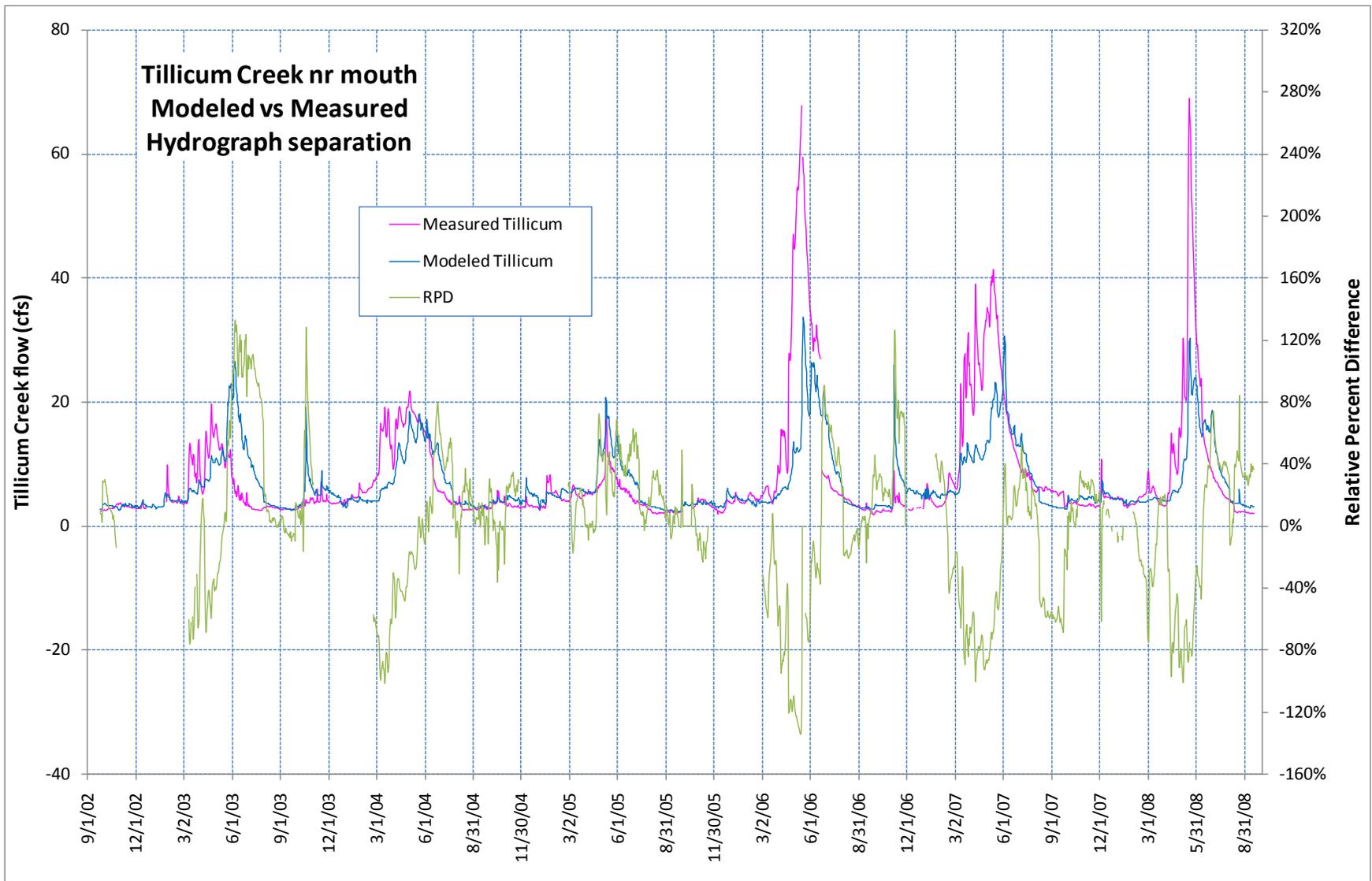
Figure 30. Modeled and measured flows at the "Tillicum Creek at mouth" gaging station with relative percent difference of paired values.
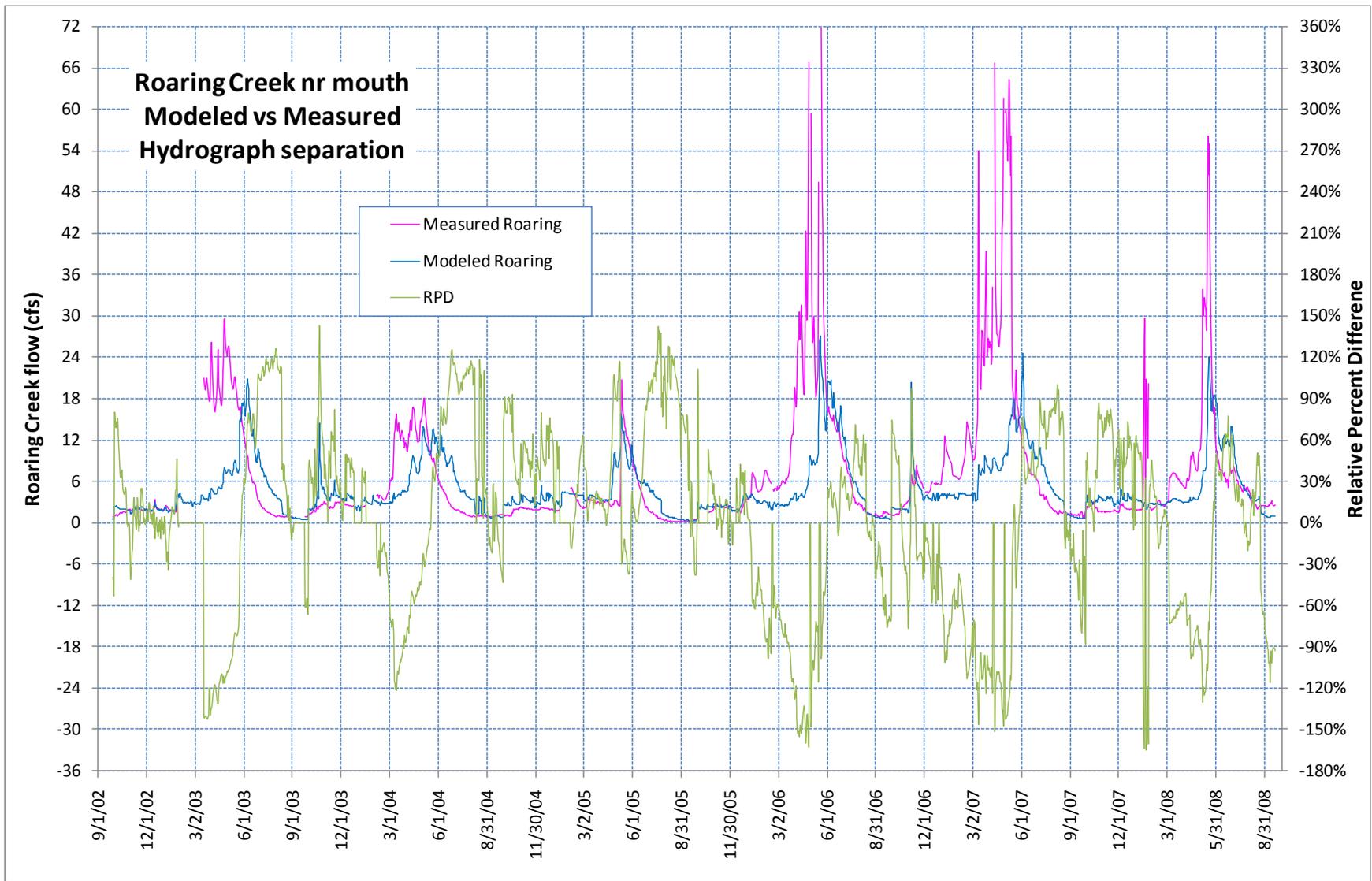
Figure 31. Modeled and measured flows at the "Roaring Creek at mouth" gaging station with relative percent difference of paired values.
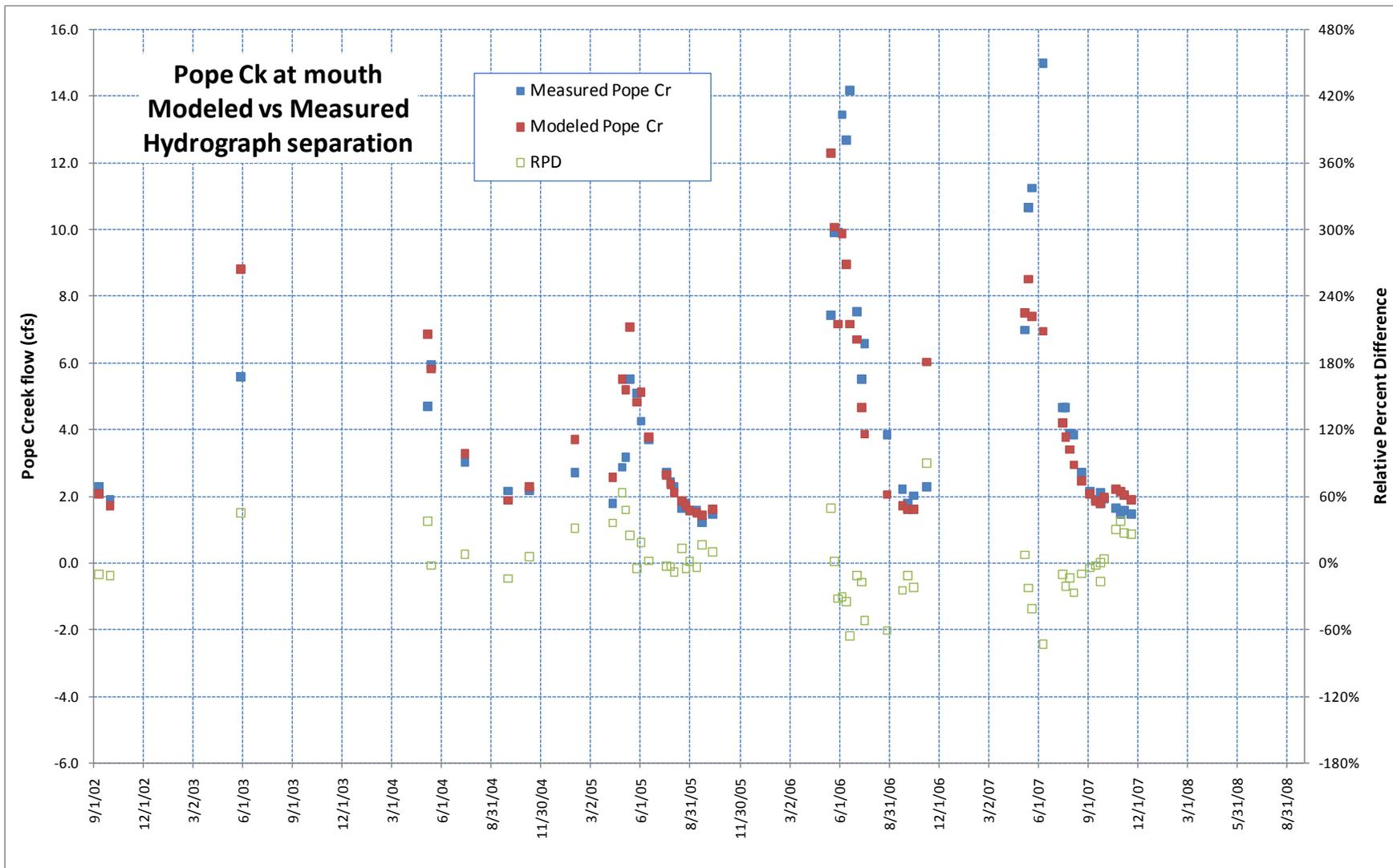
Figure 32. Modeled and measured flows at the "Pope Creek at mouth" staff gage site with relative percent difference of paired values.
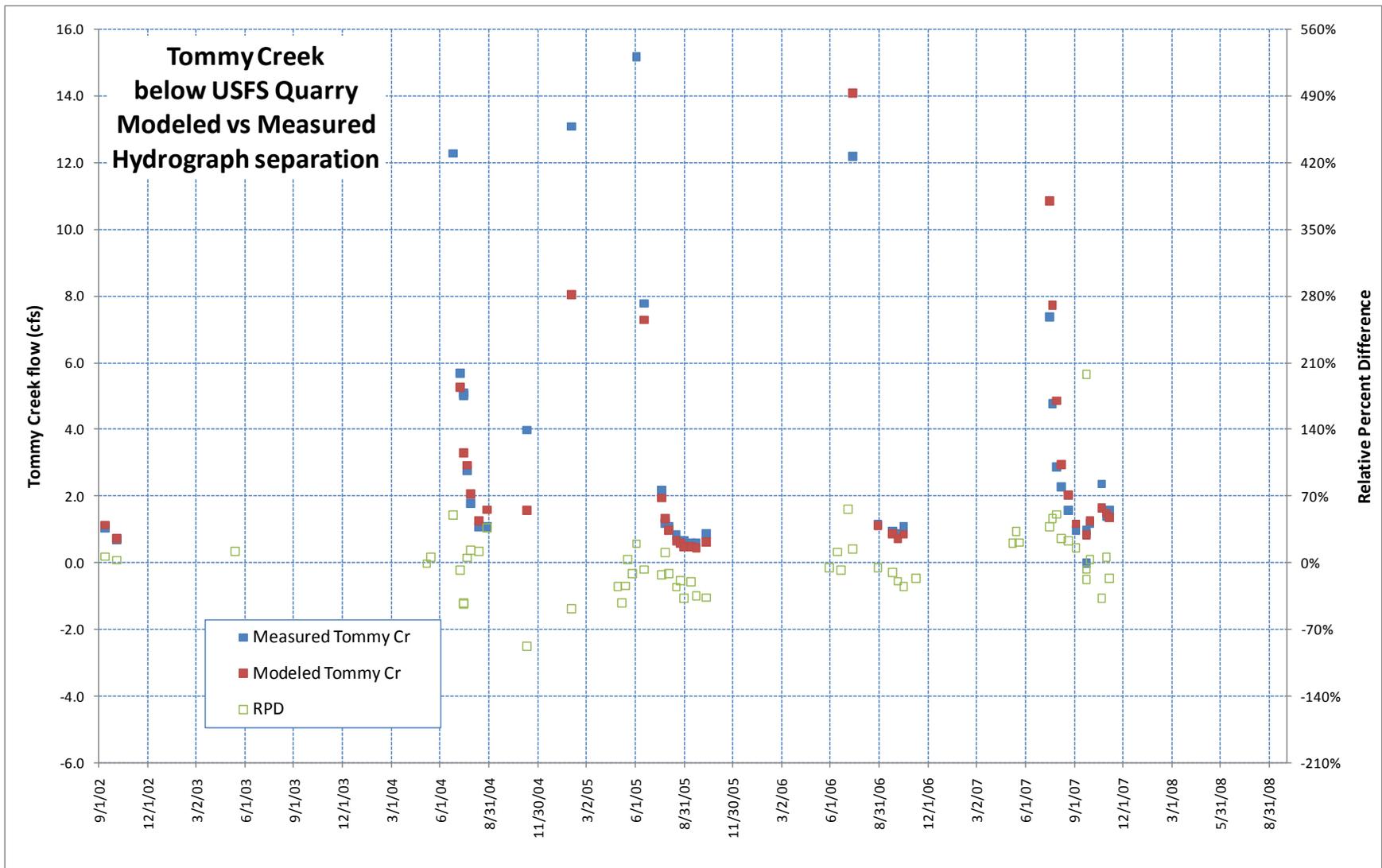
Figure 33. Modeled and measured flows at the "Tommy Creek at mouth" staff gage site with relative percent difference of paired values.
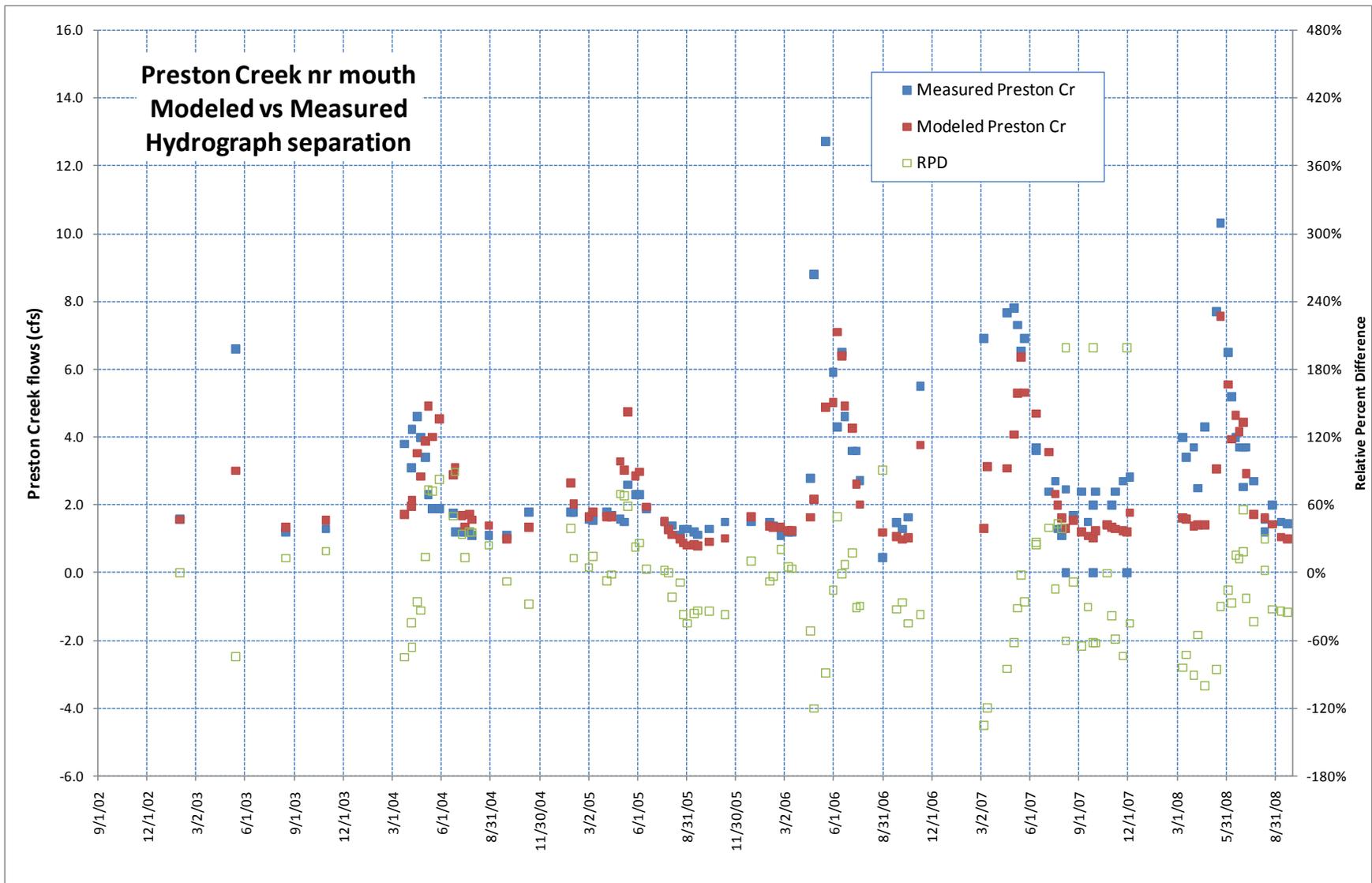
Figure 34. Modeled and measured flows at the "Preston Creek at mouth" staff gage site with relative percent difference of paired values.
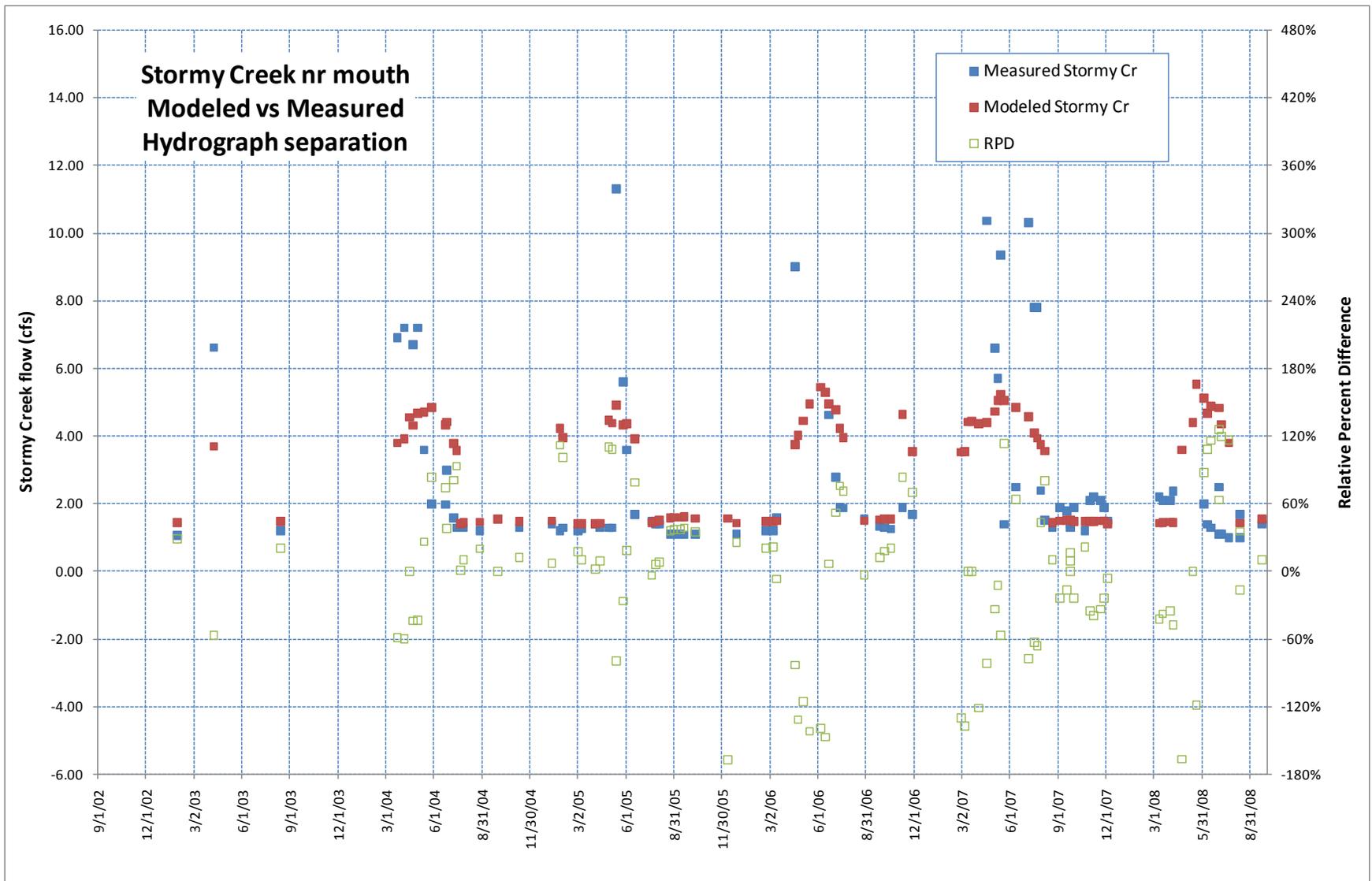
Figure 35. Modeled and measured flows at the "Stormy Creek at mouth" staff gage site with relative percent difference of paired values.
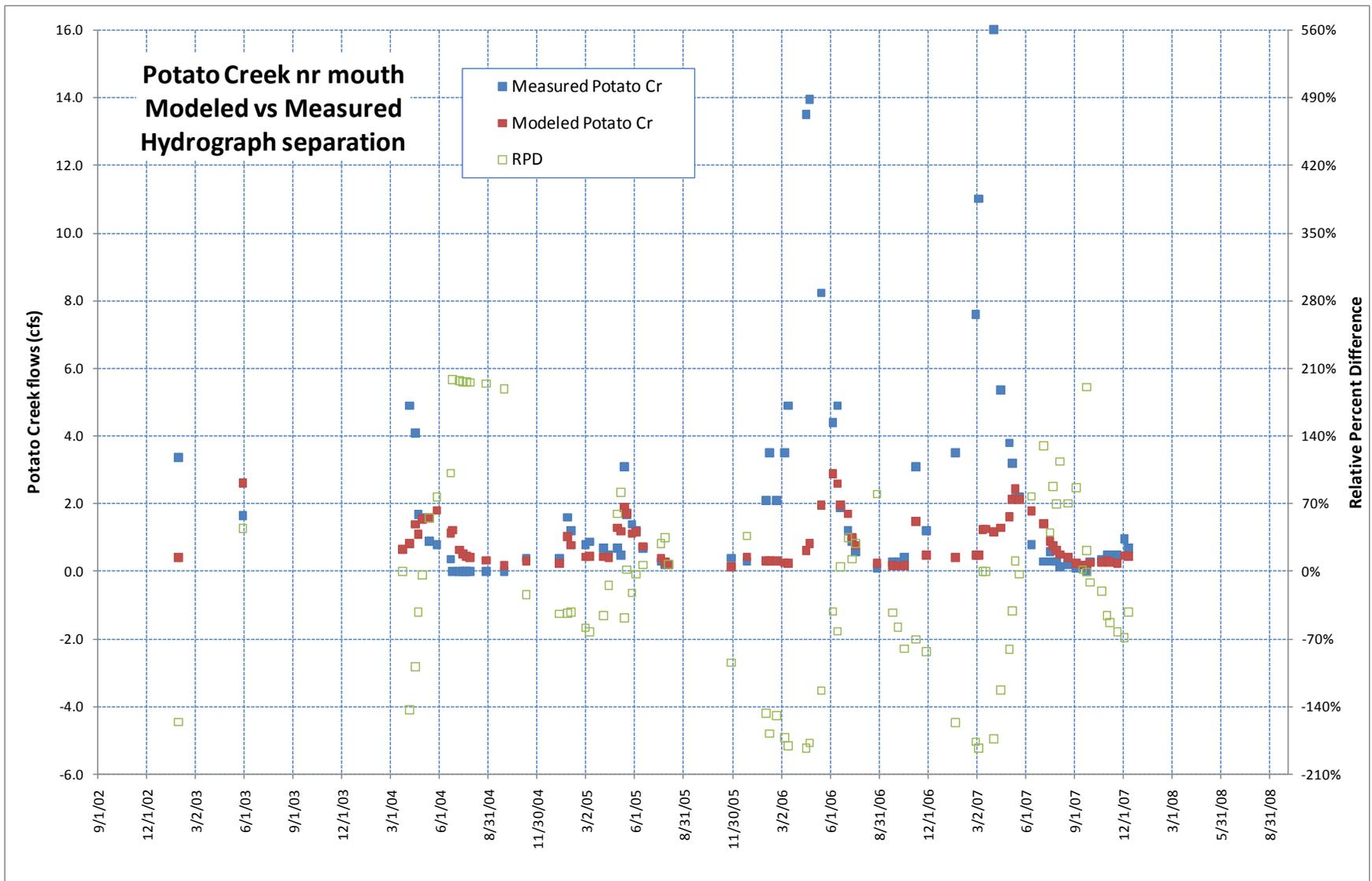
Figure 36. Modeled and measured flows at the "Potato Creek at mouth" staff gage site with relative percent difference of paired values.
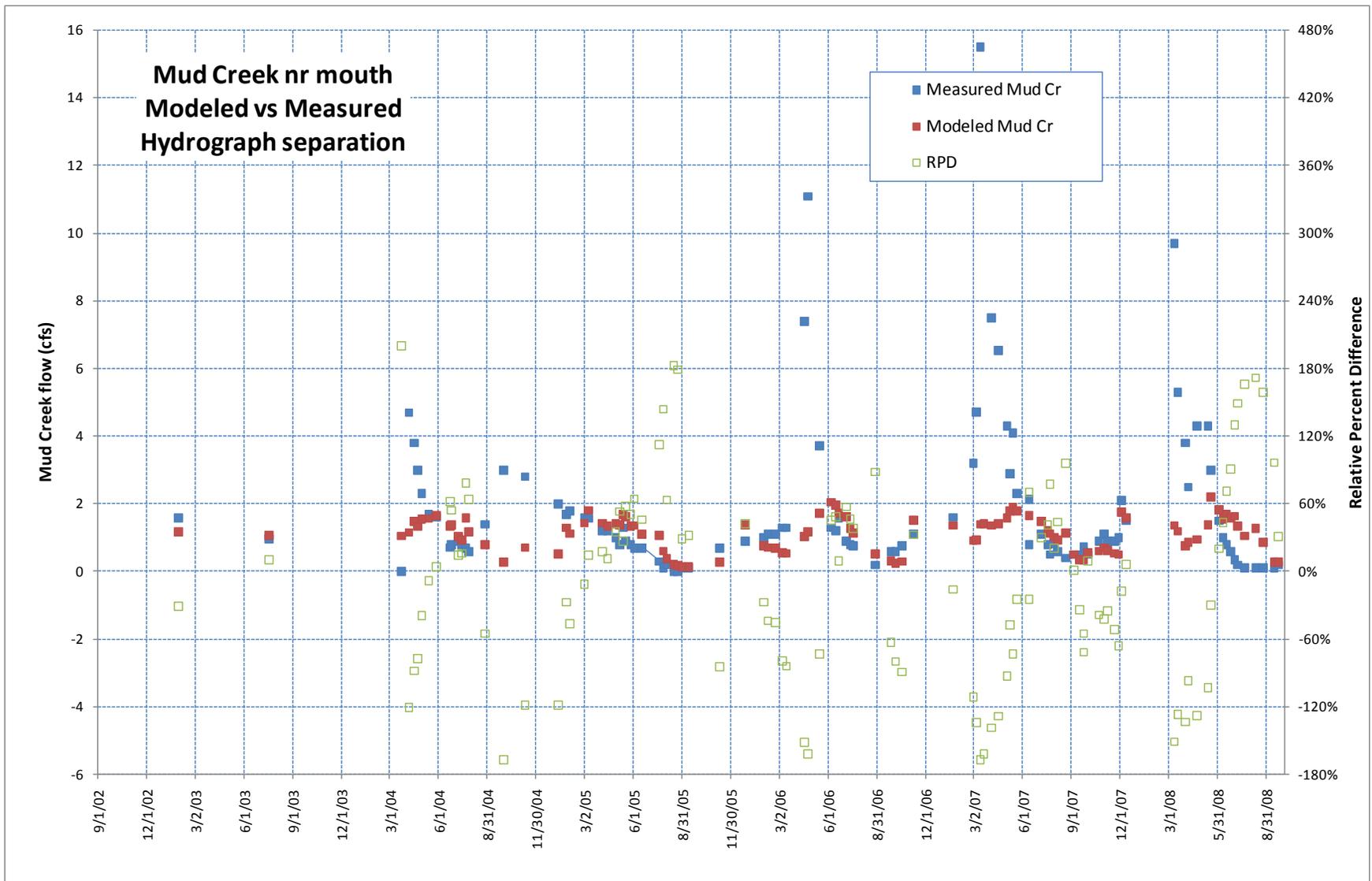
Figure 37. Modeled and measured flows at the "Mud Creek near mouth" staff gage site with relative percent difference of paired values.

Appendices

This page is purposely left blank

Appendix A. Abbreviations and Acronyms

%RSD	Percent relative standard deviation
APE	Absolute percent error
CD	Conservation District
cfs	cubic feet per second
DEM	Digital elevation model
EA	Environmental Assessment (Program)
Ecology	Washington State Department of Ecology
E.W.M.	East of the Willamette Meridian
GIS	Geographic information system
gpm	gallons per minute
HSPF	Hydrologic Simulation Program - Fortran
HUC	Hydrologic Unit Code
mgd	million gallons per day
n	number of values
NAD	North American Datum
Planning Unit	Entiat WRIA Watershed Planning unit
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
USFS	United States Forest Service
USGS	United States Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area

Appendix B. Detailed Summary of Regression Quality Statistics

Table B-1. Entiat River at North Fork Campground.

	All flow			Summer Baseflow			Winter Baseflow			Freshet flow			Storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	62%	91%	81%	42%	53%	31%	62%	91%	81%	50%	66%	41%	14%	53%	51%
95%	32%	43%	28%	19%	27%	18%	31%	40%	27%	39%	48%	30%	13%	41%	36%
Average	-0.2%	15%	10%	0%	10%	7%	0%	15%	11%	0.05%	18%	13%	-10%	13%	10%
Median	-1%	11%	8%	0%	8%	5%	-1%	12%	9%	-0.5%	15%	10%	-6%	12%	8%
Minimum	-115%	0.00%	0.00%	-44%	0.0%	0.00%	-115%	0.0%	0.01%	-58%	0.04%	0.03%	-72%	0.5%	0.4%

Table B-2. Entiat River below Entiat Falls.

	All flow			Summer Baseflow			Winter Baseflow			Freshet flow			Storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	105%	223%	120%	17%	33%	28%	105%	223%	120%	58%	82%	41%	21%	43%	39%
95%	33%	48%	30%	13%	15%	10%	41%	75%	56%	33%	40%	24%	19%	34%	28%
Average	0.3%	15%	10%	0.0%	6%	5%	1.0%	22%	15%	-0.01%	14%	10%	-3%	12%	9%
Median	1.2%	9%	7%	0.1%	5%	4%	6.2%	13%	9%	-2%	11%	8%	-3%	11%	8%
Minimum	-169%	0.00%	0.00%	-39%	0.00%	0.00%	-169%	0.02%	0.01%	-36%	0.01%	0.00%	-55%	1.3%	0.9%

Table B-3. Entiat River at Tommy Creek Bridge.

	All flow			Summer Baseflow			Winter Baseflow			Freshet flow			Storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	125%	335%	98%	46%	59%	41%	125%	335%	98%	55%	77%	39%	16%	56%	56%
95%	36%	48%	33%	29%	42%	28%	31%	48%	32%	46%	61%	35%	12%	22%	18%
Average	0.0%	18%	12%	-0.1%	12%	9%	0.8%	21%	13%	-0.04%	21%	14%	-5%	11%	9%
Median	0%	13%	9%	1%	7%	5%	0%	16%	11%	-4%	17%	12%	-4%	8%	6%
Minimum	-139%	0.01%	0.01%	-58%	0.01%	0.01%	-139%	0.05%	0.04%	-54%	0.2%	0.2%	-79%	2%	1.2%

Table B-4a. Entiat River at Dill Creek Bridge (daily average data, downloaded November 2008).

	All flow			Summer Baseflow			Winter Baseflow			Freshet flow			Storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	74%	118%	52%	73%	116%	52%	39%	49%	28%	74%	118%	52%	58%	81%	41%
95%	16%	18%	13%	11%	17%	13%	18%	20%	14%	14%	17%	11%	35%	43%	25%
Average	0.2%	8%	5%	0.0%	7%	5%	0.0%	9%	6%	0.0%	7%	5%	11%	16%	10%
Median	0.3%	6%	4%	0.6%	5%	4%	1.0%	7%	5%	-0.9%	5%	4%	10%	14%	10%
Minimum	-35%	0.0%	0.0%	-28%	0.0%	0.0%	-35%	0.1%	0.0%	-23%	0.0%	0.0%	-17%	0.4%	0.3%

Table B-4b. Entiat River at Dill Creek Bridge (daily average data, downloaded March 2009).

	All flow			Summer Baseflow			Winter Baseflow			Freshet flow			Storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	71%	111%	51%	60%	85%	42%	54%	73%	38%	71%	111%	51%	56%	78%	40%
95%	15%	18%	13%	19%	22%	14%	15%	18%	14%	11%	14%	10%	32%	38%	22%
Average	0.2%	7%	5%	0.0%	7%	5%	0.0%	8%	5%	0.0%	5%	4%	10%	14%	9%
Median	0.0%	5%	3%	-0.7%	5%	4%	-0.4%	5%	4%	0.1%	4%	3%	10%	11%	7%
Minimum	-37%	0.0%	0.0%	-27%	0.0%	0.01%	-37%	0.0%	0.0%	-18%	0.0%	0.00%	-21%	3.7%	2.6%

Table B-4c. Entiat River at Dill Creek Bridge (15-minute data, downloaded March 2009).

	All flow			Summer Baseflow			Winter Baseflow			Freshet flow			Storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	112%	257%	79%	58%	81%	63%	112%	257%	79%	29%	63%	65%	92%	171%	65%
95%	4%	27%	22%	3%	27%	22%	6%	28%	23%	2%	22%	18%	-5%	36%	31%
Average	-13%	13%	10%	-12%	12%	9%	-17%	16%	13%	-9%	9%	7%	-24%	22%	17%
Median	-12%	11%	8%	-11%	11%	8%	-17%	16%	12%	-9%	8%	6%	-24%	22%	17%
Minimum	-92%	0.0%	0.0%	-89%	0.0%	0.0%	-68%	0.0%	0.0%	-92%	0.0%	0.0%	-77%	0.0%	0.0%

Table B-4d. Entiat River at Dill Creek Bridge (15-minute data, using March 2009 daily average data model).

	All flow			Summer Baseflow			Winter Baseflow			Freshet flow			Storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	112%	257%	79%	58%	81%	63%	112%	257%	79%	29%	63%	65%	92%	171%	65%
95%	4%	27%	22%	3%	27%	22%	6%	28%	23%	2%	22%	18%	-5%	36%	31%
Average	-13%	13%	10%	-12%	12%	9%	-17%	16%	13%	-9%	9%	7%	-24%	22%	17%
Median	-12%	11%	8%	-11%	11%	8%	-17%	16%	12%	-8%	8%	6%	-24%	22%	17%
Minimum	-92%	0.0%	0.0%	-89%	0.0%	0.0%	-68%	0.0%	0.0%	-92%	0.0%	0.0%	-77%	0.0%	0.0%

Table B-5. Lake Creek at mouth.

	All flow			Baseflow			Freshet flow			Storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	86%	149%	76%	69%	105%	76%	86%	149%	61%	51%	68%	36%
95%	45%	58%	39%	43%	56%	38%	48%	63%	41%	46%	60%	33%
Average	0.1%	25%	17%	0.6%	25%	17%	0.01%	26%	18%	4%	20%	13%
Median	4%	21%	15%	6%	21%	15%	3%	21%	14%	-0.7%	14%	11%
Minimum	-108%	0.1%	0.05%	-108%	0.1%	0.05%	-86%	0.1%	0.1%	-28%	0.7%	0.5%

Table B-6. Mad River above Camp Nine.

	All flow			Summer Baseflow			Winter Baseflow			Freshet flow			Storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	127%	347%	99%	41%	62%	64%	107%	232%	87%	74%	117%	67%	127%	347%	99%
95%	50%	69%	46%	24%	34%	23%	54%	78%	51%	50%	67%	44%	81%	135%	79%
Average	3.4%	25%	16%	0.3%	12%	9%	9.2%	28%	17%	0.02%	25%	17%	13%	50%	28%
Median	5.0%	16%	11%	2.5%	10%	7%	11.9%	20%	13%	2%	18%	12%	13%	35%	22%
Minimum	-140%	0.0%	0.0%	-91%	0.1%	0.1%	-124%	0.2%	0.2%	-95%	0.0%	0.0%	-140%	0.5%	0.4%

Table B-7. Tillicum Creek at mouth.

	All flow			Summer Baseflow			Winter Baseflow			Freshet flow			Storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	133%	393%	95%	48%	64%	49%	80%	132%	70%	133%	393%	95%	128%	355%	90%
95%	74%	117%	67%	37%	48%	41%	39%	56%	44%	98%	191%	79%	92%	170%	65%
Average	0%	41%	26%	0.5%	19%	14%	0.2%	23%	16%	-0.7%	59%	36%	31%	66%	31%
Median	5%	30%	21%	4%	12%	8%	5%	21%	14%	7%	48%	33%	34%	41%	26%
Minimum	-134%	0.05%	0.03%	-69%	0.20%	0.14%	-99%	0.05%	0.03%	-134%	0.2%	0.2%	-60%	0.3%	0.2%

Table B-8. Roaring Creek near mouth.

	All flow			Summer Baseflow			Winter Baseflow			Freshet flow			Storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	143%	505%	117%	128%	357%	91%	110%	244%	117%	143%	496%	115%	143%	505%	101%
95%	107%	232%	86%	106%	225%	75%	76%	121%	63%	114%	265%	98%	77%	126%	72%
Average	1.1%	67%	39%	-2.8%	60%	33%	0.9%	47%	31%	2%	89%	50%	3%	52%	32%
Median	11%	51%	36%	-10%	36%	26%	8%	45%	30%	18%	68%	52%	16%	44%	29%
Minimum	-165%	0.1%	0.1%	-116%	0.2%	0.1%	-165%	0.2%	0.1%	-163%	0.1%	0.1%	-113%	2%	1.2%

Table B-9. Pope Creek at mouth.

	All flow			Baseflow			Freshet & storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	90%	163%	64%	38%	47%	43%	90%	163%	64%
95%	48%	63%	45%	33%	45%	26%	60%	86%	51%
Average	-1.0%	24%	16%	-2%	15%	11%	-0.1%	36%	23%
Median	-4%	16%	12%	-4%	11%	8%	-4%	28%	22%
Minimum	-73%	0.3%	0.2%	-61%	0.3%	0.2%	-73%	2%	1.1%

Table B-10. Tommy Creek below USFS Quarry.

	All flow			Baseflow			Freshet & storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	198%	16,670%	140%	198%	16,670%	140%	56%	77%	39%
95%	50%	67%	36%	45%	65%	51%	50%	67%	36%
Average	2%	310%	18%	-1.4%	595%	20%	5%	26%	17%
Median	-3%	18%	14%	-10%	17%	12%	5%	22%	14%
Minimum	-88%	1.1%	0.8%	-88%	3%	2%	-48%	1.1%	0.8%

Table B-11. Preston Creek at mouth.

	All flow			Baseflow			Freshet & storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	198%	26,146%	140%	198%	24,278%	140%	198%	26,146%	140%
95%	75%	121%	75%	52%	93%	64%	73%	115%	85%
Average	-8%	656%	30%	-12%	849%	27%	-5%	480%	34%
Median	-9%	30%	24%	-22%	29%	24%	0.5%	36%	27%
Minimum	-136%	0.7%	0.5%	-91%	0.7%	0.5%	-136%	1.6%	1.2%

Table B-12. Stormy Creek near mouth.

	All flow			Baseflow			Freshet & storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	126%	338%	118%	39%	91%	118%	126%	338%	117%
95%	111%	251%	96%	37%	46%	29%	116%	276%	99%
Average	2%	68%	39%	1.5%	23%	17%	2%	110%	59%
Median	10%	43%	27%	10%	21%	14%	23%	82%	57%
Minimum	-167%	1.2%	0.9%	-167%	1.2%	0.9%	-166%	7%	5%

Table B-13. Potato Creek near mouth.

	All flow			Baseflow			Freshet & storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	198%	24,321%	140%	195%	8,387%	138%	198%	24,321%	140%
95%	195%	8,120%	138%	192%	5,380%	136%	196%	9,437%	138%
Average	-11%	994%	58%	-13%	790%	61%	-10%	1,107%	56%
Median	-18%	54%	44%	-22%	52%	47%	-9%	54%	44%
Minimum	-183%	0.5%	0.4%	-180%	0.5%	0.4%	-183%	2%	1.3%

Table B-14. Mud Creek at Bisping Canyon Road.

	All flow			Baseflow			Freshet & storm flow		
	RPD	APE	%RSD	RPD	APE	%RSD	RPD	APE	%RSD
Max	200%	104,953%	141%	182%	2,023%	129%	200%	104,953%	141%
95%	157%	733%	117%	164%	954%	119%	133%	401%	115%
Average	-5%	1,087%	51%	-5%	184%	52%	-4%	1,897%	50%
Median	5%	58%	40%	-23%	53%	45%	18%	61%	38%
Minimum	-167%	0.6%	0.4%	-167%	0.6%	0.4%	-167%	4%	3%