


Walla Walla Watershed Planning Area

Prediction of Gaged Streamflows by Modeling

DEPARTMENT OF
ECOLOGY
State of Washington

January 2011
Publication No. 11-03-002

Publication and Contact Information

This report is available on the Department of Ecology's website at
www.ecy.wa.gov/biblio/1103002.html

The Activity Tracker Code for this study is 09-528.

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 photo: Department of Ecology flow measurement stations in the Walla Walla basin.

Walla Walla 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

Waterbody Numbers:
WA-32-1010; -1020; -1022; -1024; -1025; -1026; -1027;
-1030; -1040; -1050; -1060; -1070; -1075; -1080

This page is purposely left blank

Table of Contents

This page is purposely left blank

List of Figures

List of Tables

.

Abstract

The Washington State Department of Ecology (Ecology) has operated 14 flow gaging stations in Water Resource Inventory Area (WRIA) 32. WRIA 32 includes the Walla Walla River watershed in Washington State.

This study developed regression tools for the Ecology gages based on other Ecology and United States Geological Survey (USGS) gages using power or linear relationships and a hydrograph separation method. The quality of these regressions was assessed using statistical tools. Regression quality was varied between stations, with good quality fits (median percent relative standard deviation less than 15%) at six telemetry stations, and poor fits (greater than 15%) at the other four telemetry stations. Staff gages stations generally had poor fits.

Recommendations were made regarding the discontinuation or retention of the gages based on study results.

- The best regressions were found between Ecology and USGS gages at the three regulatory control stations (Walla Walla River at East Detour Road, North Fork Touchet River above Dayton, and Touchet River at Bolles), but because of their legal status may not be appropriate to discontinue.
- The other two stations in the Walla Walla River mainstem (at Beet Road and at Pepper Bridge) and the Touchet River station at Cummins road have good to poor regressions but could be candidates for decommissioning.
- The Coppei Creek station has a poor regression but could be decommissioned if the quality of the regression tool meets the data needs for this station.

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

Acknowledgements

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

- Matt Rajnus, Walla Walla Watershed Management Partnership.
- Brian Wolcott, Will Lewis, and Troy Baker, Walla Walla Basin Watershed Council.
- Don Butcher, Oregon Department of Environmental Quality.
- Washington State Department of Ecology staff:
  - Hedia Adelsman
  - Brad Hopkins
  - Bill Zachmann
  - Mitch Wallace
  - Victoria Leuba
  - Jim Pacheco
  - Jean Maust
  - Joan LeTourneau
  - Karol Erickson
  - John Covert

Introduction

Overview of the Watershed

The focus of this study is Water Resource Inventory Area 32 (WRIA 32 – see Figure 1), which is also referred to as the Walla Walla watershed planning area. The description of the basin below is summarized from the WRIA 32 Phase II, Level 1 Watershed Assessment (Economic and Engineering Services, 2002).

Geography

The Walla Walla River is a tributary of the Columbia River, with its mouth just south (downstream) of the mouth of the Snake River near Pasco, Washington. The headwaters of the Walla Walla basin lie in the Blue Mountains to the east. The basin area is 1758 square miles (1,295,000 hectares). Most of the basin (73%) is in the state of Washington, while the rest is in Oregon (Figure 1). WRIA 32 is the portion of the basin in Washington State.

The Walla Walla basin is diverse geographically and hydrologically. Its upper reaches are mountainous and forested, while the downstream low-lying areas are semi-arid and mostly agricultural.

Climate

Winters are cold (averaging 20 to 25° F, or -7 to -4° C) with rain and snow, especially in the mountains. Summers are hot (averaging 90 to 95° F, or 32 to 35° C) and dry. Elevations range from 340 feet (104 meters) at the mouth of the river to 6,250 feet (1,905 meters) at the highest point in the watershed.

The lower west end of the basin lies in the rain shadow of the Cascade Mountains with average precipitation of less than 10 inches (250 millimeters) per year. Precipitation increases towards the Blue Mountains in the east end of the basin, where precipitation averages 40-60 inches (1,000 to 1,500 millimeters) per year. This precipitation falls mainly in winter (October through March), with thunderstorms occurring rarely (about 11 days per year) during the summer. In the lower parts of the basin, precipitation comes mainly as rain, while the uplands receive both rain and snow. Snow depths during an average winter are typically less than a foot on the lowlands and several feet in the Blue Mountains.

Hydrology

Groundwater in the basin is found in two primary formations:

- A gravel aquifer consisting of shallow unconsolidated sediments in the central lowlands and valley bottoms. The gravel aquifers tend to be in continuity with the streams in the basin, with groundwater flowing into or out of streams depending on the relative elevations of the water table and stream water surface.

- Deeper fractured basalt aquifers underlying the entire basin. The basalt aquifers support summer stream baseflows in the higher elevations, but otherwise tend to discharge regionally to the Columbia and Snake Rivers.

Snowmelt from the Blue Mountains often produces high flows in the spring for the Walla Walla and Touchet Rivers and other high elevation tributaries. Lower elevation tributaries are dominated by rainfall runoff in the wet season (typically November through May). During the dry season (typically June through October), the natural process governing flows is groundwater interactions. However, diversions of water (e.g., irrigation) are extensive in the basin and dominate streamflows in the summer throughout most of the basin.

An example of the summer-time flow regime in the basin can be seen in Figure 2. This figure depicts the August monthly average flow recorded at various gages during 2007. More than 159 cfs of flow is coming out of the higher elevation tributaries into the watershed but only 18 cfs was leaving the Basin at the downstream gage. Discharge to groundwater and irrigation withdrawals dominate the flow regime during the low flow months.

Land Ownership, Land Use, and Water Use

Political jurisdictions in WRIA 32 include Walla Walla and Columbia Counties, the City of Walla Walla, and smaller cities and towns (College Place, Waitsburg, and Dayton). The Walla Walla basin is within the Usual and Accustomed fishing areas for the Confederated Tribes of the Umatilla Indian Reservation. Other local jurisdictions include the Columbia and Walla Walla County Conservation Districts, the Port of Walla Walla, and several Irrigation Districts. About 9% of the basin is federally owned, mostly U.S. Forest Service lands in the Blue Mountains.

The primary land use in the Walla Walla basin is agriculture (75% of the land area), primarily irrigated and dryland farming. About 11% of the basin area is rangeland, and 10% is forested. The remainder of the basin is urbanized. About two-thirds of the basin's population lives around Walla Walla and the other four incorporated areas. Population is expected to increase by 24% from 2000 to 2020.

Agriculture dominates water use in the Walla Walla basin. About 40,000 acres are irrigated for crops, using an estimated 92,500 acre-feet of water per year. This requires about 255 cfs continuously during a six-month irrigation season. About half the water used is surface water and the rest groundwater. Some summer irrigation occurs in Oregon for orchard crops. However, surface water irrigation occurs mostly in the spring and fall when surface water is relatively abundant. Crop water needs in the summer are provided by residual soil moisture and groundwater. Crops are chosen that respond well to this irrigation regime.

Residential, commercial, and industrial water use has been estimated at about 17,000 acre-feet of surface water per year, with groundwater contributing an estimated 11,000 acre-feet per year for these uses. These water uses tend to have a steady base consumption rate throughout the year, with a significant seasonal increase in residential irrigation use during hot weather. Residential, commercial, and industrial water use is expected to increase with population growth.

Watershed Planning Process

The key group for watershed planning in WRIA 32 is the Walla Walla Watershed Management Partnership. The Partnership is described on its website (www.wallawallawatershed.org):

> *The Walla Walla Watershed Management Partnership is a public agency operating under RCW 90.92 (2SHB 1580, Chapter 183, Session Laws of 2009). The Partnership is charged with piloting local water management in the Walla Walla Basin. Efforts leading up to the formation of the Partnership were made up of community members including landowners, local governments, conservation groups, tribes, state and federal agencies, and many other entities working to develop local solutions to the unique water issues in the Walla Walla Basin. The Partnership is currently in the process of beginning implementation of the ten-year pilot local water management program approved by last year's legislature.*

The Partnership grew out of watershed planning that began in 1998 under RCW 90.82. The Walla Walla watershed planning group successfully completed Levels 1 through 4: Watershed Assessment, Watershed Studies, Watershed Plan, and Detailed Implementation Plan. In 2007two reports from The Ruckelshaus Center provided the basis for a proposal, which in 2009 resulted in legislation creating the Partnership.

The Partnership focuses on activities to protect instream flows, water quality, and fish habitat. The Partnership Board administers the partnership, and there is also a Policy Advisory Group and a Water Resources Panel. Most of the affected stakeholder groups are represented in the Partnership. These groups include federal, state and local government; the Umatilla Tribe; conservation and irrigation districts; universities; water rights holders; environmental and other non-profit groups; and local citizens.

Another watershed group that works closely with the Partnership is the Walla Walla Basin Watershed Council (WWBWC). WWBWC is focused primarily on the Oregon side of the watershed, but has played a lead role in scientific studies of the watershed as a whole.

Flow Monitoring

Department of Ecology stations

The Washington State Department of Ecology (Ecology) has historically operated 26 flow monitoring stations (www.ecy.wa.gov/programs/eap/flow/shu_main.html, (Table 1 and Figure 1). These stations consist of:

- Seven active *telemetry* gages providing real-time data.
- Three historical gages (discontinued in 2009) with *continuous* data.
- Six historical staff gages (discontinued in 2009) where *manual stage height* readings are collected infrequently (at least once per month) and converted to instantaneous flow values.

- Ten historical gages with continuous data that were operated seasonally for one to three years in support of Total Maximum Daily Load studies (Johnson et al., 2004; Joy and Swanson, 2005; Joy et al., 2007; Stohr et al., 2007). These stations were not included in the study.

Streamflow discharge is measured directly at all stations on a regular basis, and rating curves are developed and updated for determining flow from gage height data.

USGS stations

The U.S. Geological Survey (USGS) has gaged streamflow throughout the Walla Walla basin at a variety of sites historically and currently (USGS, 2009a; 2009b):

- Four active stations in WRIA 32. These are listed in Table 2. One station – Mill Creek at Five Mile Road Bridge – is partially funded by Ecology.
- Nine historical stations in WRIA 32 with continuous flow.
- Four historical stations in Oregon.

The USGS historical stations have no data after 1989 and were not used for this analysis.

Other stations

The State of Oregon Water Resources Department (OWRD) measures streamflow at several sites in the upper Walla Walla River basin (Table 3). The North and South Fork Walla Walla River stations are representative of headwater flows prior to diversions into the agricultural ditch system.

In 2002, the Walla Walla Basin Watershed Council began flow monitoring in the Walla Walla basin (WWBWC, 2009). The network has grown to 50 stations, which include small-order streams, source springs, and irrigation ditches. Fifteen of the sites currently monitored are in Washington State. These streams are much smaller than most of the streams where Ecology monitors streamflow.

Instream Flow Rule

In 2007, Ecology established minimum instream flows for WRIA 32 in Chapter 173-532 WAC of state regulations (State of Washington, 2007). These regulatory flows are set at specific regulatory *control stations* throughout the basin with seniority set by the date of rule adoption. When water volume at a control station reaches the rule's flow levels, water users with more junior rights, new water appropriations, or changes or transfers of water rights cannot diminish or negatively affect the regulated flow.

Regulatory flow control stations established by WAC 173-532 are shown in Table 4. All control stations correspond to active Ecology or USGS flow monitoring stations (Figure 1, Tables 1 and 2).

Table 1. Ecology flow monitoring stations in WRIA 32 addressed by this study.

ID	Station Name	Code	Status	Type[1]	Start	End[2]	Days[3]
32A120	Walla Walla R. at East Detour Road	WW_Det	Active	T	18-Jan-2007	present	1406
32A105	Walla Walla R. at Beet Road	WW_Beet	Active	T	26-Jul-2002	present	2709
32A100	Walla Walla R. at Pepper Bridge	WW_Pep	Active	T	26-Jun-2002	present	3029
32F150	Touchet R. at Cummins Road	Tou_Cum	Active	T	28-Jun-2002	present	3067
32E150	Touchet R. at Bolles	Tou_Bol	Active	T	31-May-2002	present	1487
32E050	North Fork Touchet R. above Dayton	NFT_Day	Active	T	12-Dec-2002	present	2789
32G060	Coppei Creek near mouth	Cop_Mou	Active	T	13-Dec-2002	present	2756
32B110	Touchet R. at County Line	Tou_Cty	Recent	C	14-Aug-2002	30-Sep-2009	2605
32B100	North Fork Touchet R. above Jim Creek	NFT_Jim	Recent	C	11-Dec-2002	30-Sep-2009	2399
32B075	Dry Creek at Hwy 125	Dry_125	Recent	C	13-Dec-2002	30-Sep-2009	2277
32H090	Mill Creek at Swegle Road	Mill_Swe	Recent	M	7-May-2003	13-Jul-2009	272
32C070	Dry Creek near mouth	Dry_Mou	Recent	M	7-May-2003	15-Jul-2009	260
32F060	East Prong Little Walla Walla R. at Stateline Road	EPLWW	Recent	M	13-Feb-2003	4-Dec-2009	336
32J070	Robinson Fork above Wolf Fork Touchet R.	RobFkTou	Recent	M	11-Feb-2003	14-Jul-2009	270
32K070	Wolf Fork Touchet R. at Mountain Home Park	WolFkTou	Recent	M	11-Feb-2003	14-Jul-2009	284
32L070	South Fork Touchet R. above Dayton	SFT_Day	Recent	M	10-Apr-2003	14-Jul-2009	289

[1] T = Telemetry; C = Continuous; MSH = Manual Gage Height
[2] present = real-time data available; this study used data through 14-Dec-2009
[3] number of days with flow data used for this analysis

Table 2. USGS active flow monitoring stations in WRIA 32.

ID	Station Name	Code	Status	Type[1]	Start	End	Total no. days
14013700	Mill Creek at Five Mile Road Bridge near Walla Walla, WA	Mill_5mi	Active	RT	24-Dec-1997	Present	3373
14018500	Walla Walla River near Touchet, WA	WW_nrT	Active	RT	1-Oct-1951	Present	21280
14013000	Mill Creek near Walla Walla, WA	Mill_nrWW	Active	RT	1-Oct-1913	Present	26212
14015000	Mill Creek at Walla Walla, WA	Mill_atWW	Active	RT	1-Oct-1982	Present	8654

[1]RT = Real-time (Telemetry).

Table 3. Oregon Water Resources Department flow monitoring stations in the Walla Walla River basin.

ID	Station Name	Code	Type[1]	Status	Start	End	Total no. days
14010000	South Fork Walla Walla River near Milton, OR	OR-SFWW	SA	Active	1-Feb-1903	Present minus 6 weeks	28765
14010800	North Fork Walla Walla River near Milton Freewater, OR	OR-NFWW	RT	Active	1-Oct-1969	Present	10680
14012100	Little Walla Walla River near Milton, OR	OR-LWW	RT	Active	19-May-1932	Present	27886
14012300	Hudson Bay D near Freewater, OR	OR-HBD	RT	Active	1-Jun-1929	Present	22287

[1]SA = Stand-alone (Continuous); RT = Real-time (Telemetry)

Table 4. Regulatory flow control stations in WRIA 32.

Stream Management Unit Name	Control Station Gage Name	Control Station Gage No.	River Mile (RM)	Township/ Range/ Section	Latitude Longitude	Stream Management Reach Description
Mill Creek	Mill Creek at Kooskooskie	USGS 14013000	RM 21.2	6N/37E/12	46°00'29"N -118°07'03"W	Mill Creek at confluence with Walla Walla River (Walla Walla River, RM 33) to headwaters, including tributaries.
Walla Walla River	Walla Walla River at East Detour Road	Ecology 32A100	RM 32.4	7N/35E/31	46°02'36"N -118°29'24"W	Walla Walla River, RM 32.4 (below confluence of Walla Walla River and Mill Creek) to state line at Walla Walla, including tributaries.
North Fork Touchet River	North Fork Touchet above Dayton	Ecology 32E050	RM 0.5	10N/38E/32	46°17'50"N -117°57'04"W	Mouth of North Fork Touchet River to headwaters, including tributaries.
Touchet River	Touchet River at Bolles	Ecology 32B100	RM 40.4	9N/37E/7	46°16'27"N -118°13'12"W	Touchet River, RM 40.1 to RM 54.9 (confluence of North Fork Touchet River and South Fork Touchet River), including tributaries, excluding North Fork Touchet River and its tributaries.

Study Goals and Objectives

The goals of this project are to:

1. Develop computer modeling tools that can estimate streamflows in WRIA 32 for Ecology flow monitoring stations and USGS flow monitoring stations funded by Ecology.

2. Assess the ability of computer modeling tools to support Ecology and the Walla Walla Water Management Partnership 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 Ecology or Ecology-funded flow monitoring stations in WRIA 32 based on relationships with active long-term USGS flow stations or other Ecology flow stations.

2. Evaluate any existing hydrologic models for WRIA 32, determine whether they can be applied to predict flows at Ecology flow monitoring stations at a level of effort within the schedule designated for this project, and, if so, develop those applications.

3. Assess the quality of the results of the modeling tools developed for objectives one and two.

4. Provide support in determining a long-term approach to flow discharge assessment that combines direct monitoring of gage height with modeling approaches, thus allowing the total number of flow monitoring stations using continuous stream gage measurements to be reduced.

5. 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.

6. 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, 2010). The implementation of that plan is described in this section.

Data Sources and Characteristics

Flow Data

Daily average flow data were compiled for 16 Ecology stations – 10 with continuous data and 6 with manual staff gage readings (Table 1). Flows at Ecology stations were analyzed from the beginning of the data sets through December 2010. Flow data were withheld from the analysis when derived using interpolations or correlations.

Daily average flow data for 4 active USGS flow stations and 4 active OWRD stations were used in the analysis (Tables 2 and 3). Data for these stations were obtained from the USGS National Water Information System website (http://waterdata.usgs.gov/wa/nwis/sw) and the OWRD website (http://apps2.wrd.state.or.us/apps/sw/hydro_near_real_time/).

Some of the flow data have been labeled as *provisional* (Ecology and USGS) or *preliminary* (OWRD), meaning that final data quality checks had not been completed. Ecology, USGS, and OWRD flow data are constantly under review and are updated as the review is completed. Provisional or preliminary 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 and preliminary data are likely to be similar to the final values, and because the regressions will likely also be updated with additional data collected after December 2010.

Figures 3 through 18 show the streamflows for each of the Ecology stations as compared to flows from other selected gaging stations. Flows are presented using a logarithmic scale to more clearly illustrate patterns over time and allow comparison of flows of varying discharge amounts from different stations.

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

- Walla Walla River mainstem flows are highly variable. Flows at Ecology gages are close to or above 1000 cfs in the winter and spring, with patterns reflecting a mixed rain-snow regime (peaks both from rain events and spring snowmelt). However, summer low flows drop to near 10 cfs. Upstream stations in the mainstem and North Fork Touchet River show a similar pattern.
- Stations lower in the basin show very low summer flows, such as the Dry Creek, Coppei Creek, and Mill Creek stations. The Robinson and South Forks of the Touchet River show similar patterns.

- At most stations, low flows are occasionally seen in the late fall and winter, which could be due to late season irrigation diversion or because of dry spells or cold periods.
- Summer low flows show more variability at downstream stations than at upstream stations, likely reflecting more intensive irrigation withdrawals and return flows in the lower basin.
- The East Prong Little Walla Walla River has very low but very stable flows over the year. This suggests a spring-fed source.
- Data from the Walla Walla River at Beet Road station showed some serious data problems from July through September in many years. During these months, local residents have usually built a weir below the station to create a swimming hole, and the backwater from the weir creates spuriously high flow levels. Criteria were established for the censoring of this data based on relationships with upstream and downstream stations and on information from seepage runs (Bower et al., 2007; Baker, 2009). A total of 201 daily values were removed.

Areal Flows

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

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

1. Touchet SNOTEL station (TOHW1) www.wcc.nrcs.usda.gov/nwcc/site?sitenum=824&state=wa.
2. Walla Walla Airport National Weather Service (KALW) www.wunderground.com/history/airport/KALW/2010/3/25/CustomHistory.html.

Areal flows from the Ecology telemetry and stand-alone stations are shown in Figures 19 through 28. Precipitation data from Walla Walla Airport is shown for low elevation stations. Non-snow precipitation, snowmelt data, and average daily air temperature are shown from the Touchet SNOTEL station for high elevation tributaries.

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 snowpack loss to river flows.

Some characteristics in the data patterns in Figures 19 through 28 are of interest:

- The mixed rain-snow regime in the Walla Walla River (Figures 19-21) is again illustrated with the peak flows that correspond both to rain events and to snowmelt.
- Areal flows in the Touchet River (Figures 23, 24, 26, and 27) start relatively high with a strong snowmelt signal at the upstream station. As the stations proceed downstream, the

areal flow and the snowmelt component declines and the rainfall component makes up a greater proportion of flows.

- Two stations showed very low areal flows: Dry Creek at Highway 125 (Figure 22) and Touchet River at Cummins Road (Figure 28). Note that the right axis scales for these gages are half of the other graphs. Areal flows may be low because precipitation amounts are low compared to the watershed size, or because flow is lost to diversion or groundwater recharge. In the case of Dry Creek the watershed may have low precipitation and flow may also be lost to ground water. At the Touchet River site, comparison to the other Touchet River gages suggests that while the watershed area of this downstream gage is larger, most of the flow is generated in the headwaters. This site is also downstream of a significant diversion that reduces flow before it reaches this gage.
- Coppei Creek (Figure 25) shows relatively low areal flows with a rainfall-dominated hydrograph. This is consistent with the basin's lower elevation and relatively low precipitation.

Regressions and Other Analysis Methods

Flow data were first evaluated by comparing daily average flows from each study station (16 Ecology gages) 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. Mathematically a power regression between2 data sets is identical to the linear regression of 2 data sets after log-transformation of both.

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

Flow data were first reviewed and values removed that were not direct measurements. Data were also reviewed for periods of spurious values; data clearly of poor quality were removed.

Reference stations for each study gage were selected by evaluating correlations[1] between the stations (Table 5). Reference stations were chosen from the best correlations in the following order:

1. At least1 station with the best correlation at a stable, long-term USGS gage.

[1] The correlation coefficient (Pearson's product-moment coefficient) is a measure of the extent to which two measurement variables "vary together." The value of any correlation coefficient must be between -1 and +1 inclusive. (From http://en.wikipedia.org/wiki/Correlation and Excel Help: http://office.microsoft.com/client/helppreview.aspx?AssetId=HP100908429990&lcid=1033&NS=EXCEL&Version=12&respos=0&CTT=1&queryid=ba15e0a667df4b52a347f11843796867)

2. At least1 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 station and the reference stations, and quality metrics 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 based on the quality metrics.
2. Areal flows were calculated for the study and reference stations.
3. Where the times of travel in the streams differ, offsetting or lagging flow information in time can sometimes improve the relationship between gages. To evaluate whether time of travel differences existed, flow time series were compared to determine whether transient flow peaks coincided or were offset by one or two days.
4. The baseflow threshold at each study gage was determined by comparison of the flow time series to precipitation and snowmelt. The threshold was selected to capture the majority of flows unaffected by precipitation events from early summer through mid-autumn. At some stations, flows below the baseflow threshold were also observed during cold spells in the winter.
5. For each reference gage (the independent variable in the regression) a baseflow threshold was then selected that produced baseflow periods most similar to the study gage. (Specifically, this was the median of the flows from the reference gage on the dates at the beginning and ending of a baseflow period for the evaluation gage.)
6. The "Summer" season was separated from the "Winter" Season by determining the month when spring freshet flows ended and baseflows began, and the month when baseflows ended. Different choices of beginning and ending months were evaluated to determine the split that produced the best quality regressions.
7. For each reference station, several hydrograph separation approaches were evaluated. The flow record for paired study and reference station flows were separated 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 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.

8. Quality metrics were calculated and compared for the non-separation regression and for these different separation approaches.

Table 5. Correlation coefficients for paired Walla Walla River basin flow monitoring stations.

Coefficient colors emphasize strongest correlations (blue = greater than 0.9, green = between 0.8 and 0.9, red = between 0.7 and 0.8). Station colors explained in legend (upper right). Station ID defined in Tables 1 through 3.

	WW_Pep	WW_Beet	WW_Det	WW_nrT	Mill_nrWW	Mill_5mi	Mill_atWW	Dry_125	Tou_Bol	Tou_Cum	Tou_Cty	NFT_Day	NFT_Jim	Cop_Mou	OR-SFWW	OR-NFWW	OR-LWW	OR-HBD	EPLWW	Mill_Swe	Dry_Mou	RobFkTou	WolFkTou
WW_Beet	0.97																						
WW_Det	0.96	0.93																					
WW_nrT	0.92	0.92	0.97																				
Mill_nrWW	0.89	0.90	0.94	0.89																			
Mill_5mi	0.89	0.89	0.95	0.92	0.98																		
Mill_atWW	0.88	0.89	0.95	0.94	0.98	0.98																	
Dry_125	0.80	0.79	0.84	0.90	0.84	0.88	0.90																
Tou_Bol	0.84	0.81	0.91	0.96	0.89	0.92	0.94	0.91															
Tou_Cum	0.83	0.84	0.92	0.96	0.86	0.88	0.90	0.87	0.97														
Tou_Cty	0.83	0.83	0.79	0.88	0.86	0.85	0.87	0.84	0.80	0.85													
NFT_Day	0.87	0.84	0.91	0.89	0.87	0.85	0.87	0.79	0.90	0.89	0.85												
NFT_Jim	0.82	0.75	0.87	0.79	0.76	0.73	0.74	0.64	0.77	0.75	0.74	0.91											
Cop_Mou	0.65	0.67	0.71	0.79	0.78	0.83	0.84	0.87	0.84	0.77	0.73	0.63	0.46										
OR-SFWW	0.92	0.86	0.85	0.76	0.78	0.74	0.72	0.62	0.71	0.69	0.71	0.84	0.89	0.43									
OR-NFWW	0.95	0.92	0.93	0.86	0.88	0.86	0.84	0.75	0.82	0.79	0.79	0.87	0.84	0.62	0.93								
OR-LWW	-0.09	-0.14	-0.15	-0.20	-0.07	-0.13	-0.14	-0.19	-0.14	-0.17	-0.07	0.03	0.13	-0.27	0.20	0.08							
OR-HBD	0.10	0.01	0.04	0.01	0.08	0.01	0.03	0.09	0.05	0.04	0.17	0.17	0.23	-0.03	0.30	0.21	0.76						
EPLWW	0.07	0.08	0.10	-0.01	0.05	0.03	0.01	-0.05	0.00	-0.04	-0.04	-0.01	0.07	-0.10	0.16	0.13	0.44	0.25					
Mill_Swe	0.78	0.77	0.92	0.86	0.86	0.87	0.89	0.83	0.93	0.87	0.78	0.75	0.70	0.78	0.67	0.78	-0.15	0.10	0.04				
Dry_Mou	0.76	0.73	0.82	0.89	0.78	0.86	0.87	0.91	0.91	0.88	0.74	0.74	0.63	0.89	0.60	0.70	-0.26	0.06	-0.20	0.81			
RobFkTou	0.79	0.75	0.86	0.85	0.85	0.84	0.85	0.82	0.96	0.88	0.78	0.90	0.85	0.74	0.74	0.80	-0.08	0.08	-0.10	0.82	0.76		
WolFkTou	0.87	0.81	0.89	0.86	0.88	0.86	0.85	0.81	0.85	0.86	0.86	0.95	0.93	0.68	0.87	0.85	0.10	0.33	0.02	0.65	0.62	0.89	
SFT_Day	0.81	0.78	0.93	0.94	0.91	0.92	0.93	0.89	0.99	0.96	0.85	0.92	0.79	0.83	0.70	0.81	-0.09	0.12	-0.07	0.84	0.86	0.95	0.87

USGS
ECY-Telemetry
ORWD
ECY-Manual Staff
Control Station

Quality Analysis

The quality analysis approach was described in detail in the project plan (Pickett, 2010), and is summarized here.

Model accuracy was assessed by comparison of paired daily flow values from the measured and modeled time series. Bias was assessed by calculating the relative percent difference (RPD) for predicted and observed pairs individually and using the median of RPD values for all pairs of results.

$$RPD = (|P_i - O_i| * 2) / (O_i + P_i), \text{ where}$$

P_i = i[th] prediction
O_i = i[th] observation

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

$$\%RSD = (SD_i * 200) / (P_i + O_i) \text{ , where}$$

SD_i = 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 will be selected to describe model results:

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

Results

For all pairs of stations evaluated, peak flows occurred most often on the same date, except that flows at the Walla Walla River at Touchet station tended to lag1 day later than upstream stations. The improvement in the regression with time-lagged data was very small. Also, using data from a downstream reference station lagged by1 day would not have practical value since predictions from that station would be a day late. In other words, using a regression with a1-day lag, you would use today's flows at the downstream station to predict yesterday's flows. This would not be useful for real-time forecasting. For these reasons, time-lagging of data was not used in this study.

Table 6 presents the results of the regression modeling analysis. For each study gage a regression from a primary reference station is presented, which is the station with the best median %RSD quality metric. Also, another regression based on a secondary reference station (the station with the second best quality metric) is offered. Several regression options are presented because of the possibility that some the reference gages could be discontinued.

For each study station the following is shown:

- The reference flow monitoring station (see Tables 1 through 3 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.
- The identification of the regression as 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.

Table 7 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 regressions had good fits, with %RSD values below 15% for both baseflows and all flows, at the continuous flow stations:
  - Walla Walla River at Pepper Bridge.
  - Walla Walla River at East Detour Road.
  - North Fork Touchet River above Jim Creek (summer baseflows had a very good fit).
  - North Fork Touchet River above Dayton (summer baseflows had a very good fit).
  - Touchet River at County Line.
  - Touchet River at Bolles.

Table 6. Regressions for study gages using 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 Real-Time Gages										
32A120	Walla Walla River at Pepper Bridge	WW_nrT (Primary)	75	Jul-Oct Jul-Oct Nov-Jun	Baseflow Non-baseflow All flows	Power Power Linear	11.61 0.424 0.164	0.112 0.932 10.956	0.051 0.868 0.25	984 1838 207
32A120	Walla Walla River at Pepper Bridge	WW_Det (Secondary)	46	Jul-Oct Jul-Oct Nov-Jun	Baseflow Non-baseflow All flows	Power Linear Power	2.095 0.453 1.105	0.551 -2.453 0.901	0.025 0.306 0.92	292 197 917
32A105	Walla Walla River at Beet Road	WW_Det (Primary)	86	Jul-Nov Jul-Nov Dec-Jun Dec-Jun	Baseflow Non-baseflow Baseflow Non-baseflow	Linear Linear Linear Power	0.32 0.654 0.552 0.398	9.998 -23.42 -1.41 1.106	0.076 0.798 0.351 0.91	546 59 62 739
32A105	Walla Walla River at Beet Road	WW_nrT (Secondary)	150	Jul-Nov Jul-Nov Dec-Jun Dec-Jun	Baseflow Non-baseflow Baseflow Non-baseflow	Linear Linear Linear Power	-0.081 0.321 0.189 0.263	35.45 -28.05 16.285 1.042	0.033 0.774 0.07 0.82	1212 163 155 1552
32A100	Walla Walla River at East Detour Road	WW_nrT (Primary)	55.6	Jul-Oct Jul-Oct Nov-Jun Nov-Jun	Baseflow Non-baseflow Baseflow Non-baseflow	Power Linear Power Power	27.382 0.270 27.136 0.439	0.128 35.4 0.065 1.00	0.125 0.252 0.02 0.95	897 208 56 1921
32A100	Walla Walla River at East Detour Road	WW_Pep (Secondary)	21.8	Jul-Oct Jul-Oct Nov-Jun Nov-Jun	Baseflow Non-baseflow Baseflow Non-baseflow	Power Linear Linear Power	21.321 0.933 -0.120 1.248	0.250 27.4 35.2 1.043	0.124 0.291 0.01 0.90	840 254 108 1827
32F150	Dry Creek at Highway 125	WW_nrT (Primary)	37	Aug-Sep Aug-Sep Oct-Jul	Baseflow Non-baseflow All flows	Linear Linear Power	0.028 0.016 0.141	0.342 0.886 0.781	0.16 0.26 0.86	360 128 2312
32F150	Dry Creek at Highway 125	Tou_Bol (Secondary)	47	Jul-Sep Jul-Sep Oct-Jun	Baseflow Non-baseflow All flows	Power Linear Power	0.00037 0.071 0.058	2.112 -2.428 1.047	0.29 0.6 0.81	235 108 834
32E150	North Fork Touchet River above Jim Creek	NFT_Day (Primary)	49	Aug-Oct Aug-Oct Nov-Jul Nov-Jul	Baseflow Non-baseflow Baseflow Non-baseflow	Power Power Power Power	1.38 1.56 2.72 1.19	0.742 0.705 0.565 0.776	0.342 0.356 0.23 0.89	480 98 259 1801

Table 6, continued. Regressions for study gages using 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					
32E150	North Fork Touchet River above Jim Creek	WW_nrT (Secondary)	55	Aug-Oct	Baseflow	Power	17.6	0.063	0.09	622
				Aug-Oct	Non-baseflow	Power	17.8	0.064	0.03	114
				Nov-Jul	Baseflow	Linear	0.192	19.8	0.26	259
				Nov-Jul	Non-baseflow	Power	3.55	0.421	0.58	1933
32E050	North Fork Touchet River above Dayton	Tou_Bol (Primary)	50	Jul-Oct	Baseflow	Power	7.380	0.482	0.37	361
				Jul-Oct	Non-baseflow	Linear	0.936	1.775	0.78	224
				Nov-Jun	All flows	Power	2.861	0.720	0.86	902
32E050	North Fork Touchet River above Dayton	Tou_Cum (Secondary)	28	Jul-Oct	Baseflow	Power	33.23	0.101	0.38	820
				Jul-Oct	Non-baseflow	Linear	0.557	31.74	0.38	285
				Nov-Jun	All flows	Linear	0.379	52.08	0.75	1924
32G060	Coppei Creek near Mouth	Tou_Bol (Primary)	46.6	Jul-Sep	Baseflow	Linear	-0.010	1.039	0.02	270
				Jul-Sep	Non-baseflow	Power	0.0017	1.487	0.23	165
				Oct-Jun	All flows	Power	0.060	1.017	0.69	1052
32G060	Coppei Creek near Mouth	Mill_atWW (Secondary)	3.2	Jun-Oct	Baseflow	Linear	-0.174	0.836	0.12	608
				Jun-Oct	Non-baseflow	Linear	0.0540	0.364	0.27	220
				Nov-May	All flows	Linear	0.225	2.27	0.67	2257
32B110	Touchet River at County Line	NFT_Day (Primary)	53	Jul-Sep	Baseflow	Power	0.239	1.367	0.40	548
				All flows	Non-baseflow	Power	1.464	1.011	0.65	1630
				Oct-Jun	Baseflow	Power	0.567	1.255	0.06	301
32B110	Touchet River at County Line	Mill_nrWW (Primary)	31	Jul-Sep	Baseflow	Linear	0.830	17.07	0.02	503
				Jul-Sep	Non-baseflow	Linear	3.572	-74.49	0.47	233
				Oct-Jun	Baseflow	Power	2.492	0.954	0.73	2065
32B100	Touchet River at Bolles	Tou_Cum (Primary)	22.9	Jul-Sep	Baseflow	Power	26.594	0.168	0.60	636
				Jul-Sep	Non-baseflow	Linear	0.828	25.76	0.83	191
				Oct-Jun	Baseflow	Power	89.722	-0.23	0.20	122
				Oct-Jun	Non-baseflow	Power	1.604	0.931	0.92	2118
32B100	Touchet River at Bolles	WW_nrT (Secondary)	33.4	Jul-Sep	Baseflow	Linear	0.573	30.1	0.28	638
				Oct-Jun	All flows	Power	2.93	0.697	0.90	2444
32B075	Touchet River at Cummins Road	Tou_Bol (Primary)	47.5	Jul-Oct	Baseflow	Power	8.55E-07	4.459	0.69	320
				Jul-Oct	Non-baseflow	Linear	1.069	-20.792	0.62	265
				Nov-Jun	All flows	Linear	0.827	23.40	0.91	902
32B075	Touchet River at Cummins Road	WW_nrT (Primary)	37.8	Jul-Oct	Baseflow	Linear	0.510	1.490	0.24	686
				Jul-Oct	Non-baseflow	Linear	0.405	7.004	0.43	419
				Nov-Jun	All flows	Power	0.988	0.84	0.91	1977

Table 6, continued. Regressions for study gages using 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					
Manual Staff Gages										
32H090	East Prong Little Walla Walla River at Stateline	OR-LWW OR-HBD	(Primary) (Secondary)	All flows All flows	All flows All flows	Linear Linear	0.012 0.0092	3.142 3.584	0.18 0.06	313 328
32C070	Mill Creek at Swegle Road	WW_Det Tou_Bol	(Primary) (Secondary)	All flows All flows	All flows All flows	Power Power	0.138 0.051	1.168 1.352	0.80 0.85	106 105
32F060	Dry Creek near Mouth	Tou_Bol WW_nrT	(Primary) (Secondary)	All flows All flows	All flows All flows	Power Linear	0.0043 0.026	1.44 1.438	0.84 0.80	258 106
32J070	Robinson Fork above Wolf Fork Touchet River	Tou_Bol NFT_Day	(Primary) (Secondary)	All flows All flows	All flows All flows	Power Power	0.0144 0.0016	1.252 1.807	0.87 0.87	107 249
32K070	Wolf Fork Touchet River at Mountain Home Park	NFT_Day Mill_nrWW	(Primary) (Secondary)	All flows All flows	All flows All flows	Power Power	1.861 3.238	0.681 0.600	0.92 0.82	265 284
32L070	South Fork Touchet River above Dayton	Tou_Bol Tou_Cum	(Primary) (Secondary)	All flows All flows	All flows All flows	Linear Linear	0.201 0.202	-4.633 3.351	0.97 0.91	112 283

Table 7. Model quality results for regressions as median %RSD for study gaging stations.

Station ID	Station Name	Reference Station Code	Hydrograph Separation Unit	<5%	5-10%	10 - 15%	15 - 20%	20 - 30%	>40%
Ecology Real-Time Gages									
32A120	Walla Walla River at Pepper Bridge	WW_nrT	Summer baseflow All flows			X X			
32A120	Walla Walla River at Pepper Bridge	WW_Det	Summer baseflow All flows			 X	X 		
32A105	Walla Walla River at Beet Road	WW_Det	Summer baseflow All flows			 X		X 	
32A105	Walla Walla River at Beet Road	WW_nrT	Summer baseflow All flows				X X		
32A100	Walla Walla River at East Detour Road	WW_nrT	Summer baseflow All flows		X X				
32A100	Walla Walla River at East Detour Road	WW_Pep	Summer baseflow All flows		X 	 X			
32F150	Dry Creek at Highway 125	WW_nrT	Summer baseflow All flows					X X	
32F150	Dry Creek at Highway 125	Tou_Bol	Summer baseflow All flows					X X	
32E150	North Fork Touchet River above Jim Creek	NFT_Day	Summer baseflow All flows	X 	 X				
32E150	North Fork Touchet River above Jim Creek	WW_nrT	Summer baseflow All flows		X 	 X			
32E050	North Fork Touchet River above Dayton	Tou_Bol	Summer baseflow All flows	X 	 X				
32E050	North Fork Touchet River above Dayton	Tou_Cum	Summer baseflow All flows	X 		 X			
32G060	Coppei Creek near Mouth	Tou_Bol	Summer baseflow All flows					X X	
32G060	Coppei Creek near Mouth	Mill_atWW	Summer baseflow All flows					 X	X
32B110	Touchet River at County Line	NFT_Day	Summer baseflow All flows		X 	 X			
32B110	Touchet River at County Line	Mill_nrWW	Summer baseflow All flows			X 	 X		

Table 7, continued. Model quality results for regressions as median %RSD for study gaging stations.

Station ID	Station Name	Reference Station Code	Hydrograph Separation Unit	<5%	5-10%	10 - 15%	15 - 20%	20 - 30%	>40%
32B100	Touchet River at Bolles	Tou_Cum	Summer baseflow All flows	X	 X				
32B100	Touchet River at Bolles	WW_nrT	Summer baseflow All flows		X	 X			
32B075	Touchet River at Cummins Road	Tou_Bol	Summer baseflow All flows			 X		X	
32B075	Touchet River at Cummins Road	WW_nrT	Summer baseflow All flows				 X		X
Manual Staff Gages									
32H090	East Prong Little Walla Walla River at Stateline	OR-LWW OR-HBD	All flows All flows			X X			
32C070	Mill Creek at Swegle Road	WW_Det Tou_Bol	All flows All flows					X	 X
32F060	Dry Creek near Mouth	WW_nrT Tou_Bol	All flows All flows					X	 X
32J070	Robinson Fork above Wolf Fork Touchet River	Tou_Bol NFT_Day	All flows All flows					X X	
32K070	Wolf Fork Touchet River at Mountain Home Park	NFT_Day Mill_nrWW	All flows All flows		X X				
32L070	South Fork Touchet River above Dayton	Tou_Bol Tou_Cum	All flows All flows		X			 X	

- Two stations had good quality regressions for all flows, but poor regressions for summer baseflows:
  - Walla Walla River at Beet Road.
  - Touchet River at Cummins Road.
- Two stations had poor quality of regressions for all flows:
  - Dry Creek at Highway 125
  - Coppei Creek.

Figures 29 through 44 show the measured and modeled values for each study station based on the primary reference station. The goodness of fit as the RPD of paired daily values is also shown on the right axis. A few patterns of note:

- Small difference in very low flows can produce an RPD of high magnitude[2]. This is not representative of the goodness-of-fit for low flows and would tend to inflate the average RPD for the model.
- For higher flows, extreme RPD values highlight the differences in the hydrograph behavior between the study and reference station.
- Over all flows, the median RPD was good – with a range of +/- 10% for all stations, except for a value or 11% at1 staff gage station. However, for baseflows the RPD values were biased high and three stations had median values between 23% and 27%. This is consistent with the tendency of RPD at low flows to produce high values.
- The range of RPD values vary widely among the stations: from the narrowest range of -47% to 75% at the Wolf Fork Touchet River staff gage, to the widest range of -159% to 155% at the Mill Creek staff gage. The right-hand scale on the graph varies between figures so that the temporal patterns can be seen clearly.

Table 8 summarizes the reference stations analyzed for the Ecology study stations. The numbers in the grid indicate whether the regression based on the active reference station is the primary (1^o) or secondary (2^o) recommendation for the study station. Totals for each station are shown at the bottom. This table gives some sense of which gages were most useful as reference stations.

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

Discussion

The gaged streams in the Walla Walla River basin vary widely in flow characteristics. This is a highly managed system, with extensive irrigation water diversions and return flows. Despite this complexity, some reasonably good relationships were found between gages.

Table 8. Summary of study and reference flow monitoring stations.

Reference Station Code: / Study Station Code	WW_Pep	WW_Beet	WW_Det	WW_nrT	Mill_nrWW	Mill_5mi	Mill_atWW	Tou_Bol	Tou_Cum	NFT_Day	Cop_Mou	OR-SFWW	OR-NFWW	OR-LWW	OR-HBD
WW_Pep			2^o	1^o											
WW_Beet			1^o	2^o											
WW_Det	2^o			1^o											
Dry_125				1^o				2^o							
NFT_Jim				2^o						1^o					
NFT_Day								1^o	2^o						
Cop_Mou							2^o	1^o							
Tou_Cty					2^o					1^o					
Tou_Bol				2^o					1^o						
Tou_Cum				2^o				1^o							
EPLWW														1^o	2^o
Mill_Swe			1^o					2^o							
Dry_Mou				2^o				1^o							
RobFkTou								1^o		2^o					
WolFkTou					2^o					1^o					
SFT_Day								1^o	2^o						
No. Primary	-	-	2	3	-	-	-	6	1	3	-	-	-	1	-
No. Secondary	1	-	1	5	2	-	1	2	2	1	-	-	-	-	1
TOTAL	1	-	3	8	2	-	1	8	3	4	-	-	-	1	1
Preferences: 1^o = Primary; 2^o = Secondary															

Ecology's gages can be grouped roughly into four categories:

- Mainstem Walla Walla River stations
- Touchet River system stations
- Lowland creek stations (Dry and Coppei Creeks)
- The East Prong Little Walla Walla River (unique compared to Ecology's other stations)

The three Walla Walla River stations appear to have some redundancy. The station at East Detour Road has the best regressions, but because it is a control station and a potential reference station for other stations, it may not be a good candidate for a model-only station. The Pepper Bridge station has regressions of good to poor quality, and it may also serve important needs due to its location.

The Beet Road station has model quality that is good to poor and has data quality problems in the summer months. An analysis of flow balance (Bower, 2007) showed that flows at Beet Road and at East Detour Road were similar. For these reasons it may be a good candidate to decommission. However, the Gardena Farms Irrigation District uses this gage for flow management during the non-summer months, so the need for real-time data may still be sufficient to rule out the use of a regression. Funding of this gage by the Irrigation District or with fish restoration funds should be considered.

A physically-based model of the Walla Walla River is under development (Petrides Jimenez, 2008). When this model is available, it could be reviewed to determine if it could provide flow information instead of direct measurements.

Of the five continuous stations on the Touchet River and its tributary forks, two have already been decommissioned. Of the three still in service, two are control stations and are a high priority to retain. However, the North Fork Touchet above Dayton station has good to very good regressions with the Touchet River at Bolles station and the use of a model to meet flow assessment needs should be considered. The Touchet River at Cummins site has good to fair quality regressions and is in a fairly unique location. The needs for this station should be weighed against the quality of the models.

Of the two lowland creek sites, the Dry Creek station has been decommissioned while Coppei Creek station is still in service. The regression for Coppei Creek is of poor quality, so unless the needs for flow data at this station can be met with this quality of model, this site should be retained.

Of the six manual staff stations in the basin, only one is still in service, but has been transferred to the Walla Walla Basin Watershed Council. The model is available if the quality of the model is sufficient to meet flow data needs, but continued direct measurement is recommended if obtaining better quality flow measurements is important.

Models were developed for use at the discontinued station sites for flow assessment and are available should the need arise.

Conclusions and Recommendations

This study draws the following conclusions and makes these recommendations:

- The hydrograph separation method can be used to develop regression-based models to estimate streamflow at Ecology gaging stations in the WRIA 32 Walla Walla River basin.
- The quality of the streamflow estimates from these regressions varies between stations. The best results were found at three gages that are regulatory control stations (Walla Walla River at East Detour Road, North Fork Touchet River above Dayton, Touchet River at Bolles).
- The regression tool could provide an adequate replacement for the Walla Walla River at Beet Road station, which has measurement quality problems.
- The regression tool might serve instead of direct measurement at the Walla Walla River at Pepper Bridge and Touchet River at Cummins Road stations. However, a decision should be made based on comparing flow data needs to the quality of the regression models.
- The quality of regression tools for the Coppei Creek and the East Prong Little Walla Walla River stations are poor. These tools could serve instead of direct flow measurement, but only if the quality of the regression tool meets the data needs for these stations.
- The regressions are available for use for decommissioned stations.
- Regression tools could be automated and the resulting flow estimates provided in real time if there is sufficient need.
- The accuracy of the regression tools should be evaluated against flow data needs for Ecology and the local community to determine whether the tools provide an acceptable substitute for flow gaging. All regression-based modeling tools for study flow stations should be used for specific purposes with consideration as to whether their accuracy serves that purpose. Stations may be redundant in terms of the ability of the regression to predict flows, but removal of a station may still lose other information or the ability to use that flow data for other analyses. Conceptually the regressions should be used as "screening tools" to trigger a direct evaluation of flow or for purposes where a rough estimate is acceptable.
- Regressions from provisional data should be of sufficient quality to be applied to identified uses. Updating of regression models with quality-checked data could slightly improve the quality of the regressions. Regression tools should be updated when additional measured flow data are available and when flow data quality reviews are completed.

References

Baker, T.W., 2009. Water Management Initiative Monitoring Program Phase II: Final Report, Seasonal Seepage Assessments (WMI Task 4.2). Walla Walla Basin Watershed Council, Milton-Freewater, OR.

Bower, B., 2007. Walla Walla River Surface Water Budget Assessment. Walla Walla Basin Watershed Council, Milton-Freewater, OR.

Bower, B, D. Butcher, and M.E. Barber, 2007. Habitat Conservation Planning: Evaluating the Thermal Impacts of Streamflow and Irrigation Bypass in the Walla Walla River. Walla Walla Basin Watershed Council, Milton-Freewater, OR.

Covert, J., 2010. Personal communication. Hydrogeologist, Water Resources Program, Washington State Department of Ecology, Spokane, WA.

Economic and Engineering Services, 2002. Walla Walla Watershed, WRIA 32, Level I Assessment. Kennewick, Washington. Prepared for Walla Walla County, Walla Walla, WA.

Johnson, A., B. Era-Miller, R. Coots, and S. Golding, 2004. A Total Maximum Daily Load Evaluation for Chlorinated Pesticides and PCBs in the Walla Walla River. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-032. www.ecy.wa.gov/biblio/0403032.html.

Joy, J., G. Pelletier, and K. Baldwin, 2007. Walla Walla River Basin pH and Dissolved Oxygen Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 07-03-010. www.ecy.wa.gov/biblio/0703010.html.

Joy, J. and T. Swanson, 2005. Walla Walla River Basin Fecal Coliform Bacteria Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-041. www.ecy.wa.gov/biblio/0503041.html.

Petrides Jimenez, A.C., 2008. Modeling surface water and groundwater interactions near Milton- Freewater, Oregon. Masters Thesis, Oregon State University, Corvallis, OR. http://ir.library.oregonstate.edu/jspui/handle/1957/8583.

Pickett, P., 2010. Quality Assurance Project Plan: Walla Walla Watershed Planning Area Prediction of Gaged Streamflows by Modeling. Washington State Department of Ecology, Olympia, WA. Publication No. 10-03-108 www.ecy.wa.gov/biblio/1003108.html.

State of Washington, 2007. Chapter 173-532 Washington Administrative Code, Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/biblio/wac173532.html.

Stohr, A., M. LeMoine, and G. Pelletier, 2007. Walla Walla River Tributaries Temperature Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 07-03-014. www.ecy.wa.gov/biblio/0703014.html.

USGS, 2009a. USGS Surface-Water Daily Data for Washington. U.S. Geological Survey, Tacoma, WA. http://waterdata.usgs.gov/wa/nwis/.

USGS, 2009b. USGS Surface-Water Daily Data for Oregon. U.S. Geological Survey, Portland, OR. http://waterdata.usgs.gov/or/nwis/.

WWBWC, 2009. Surface Water Monitoring in the Walla Walla Basin. Walla Walla Basin Watershed Council, Milton-Freewater, OR http://wwbwc.org/index.php?option=com_content&view=article&id=221&catid=69&Itemid=55.

Figures

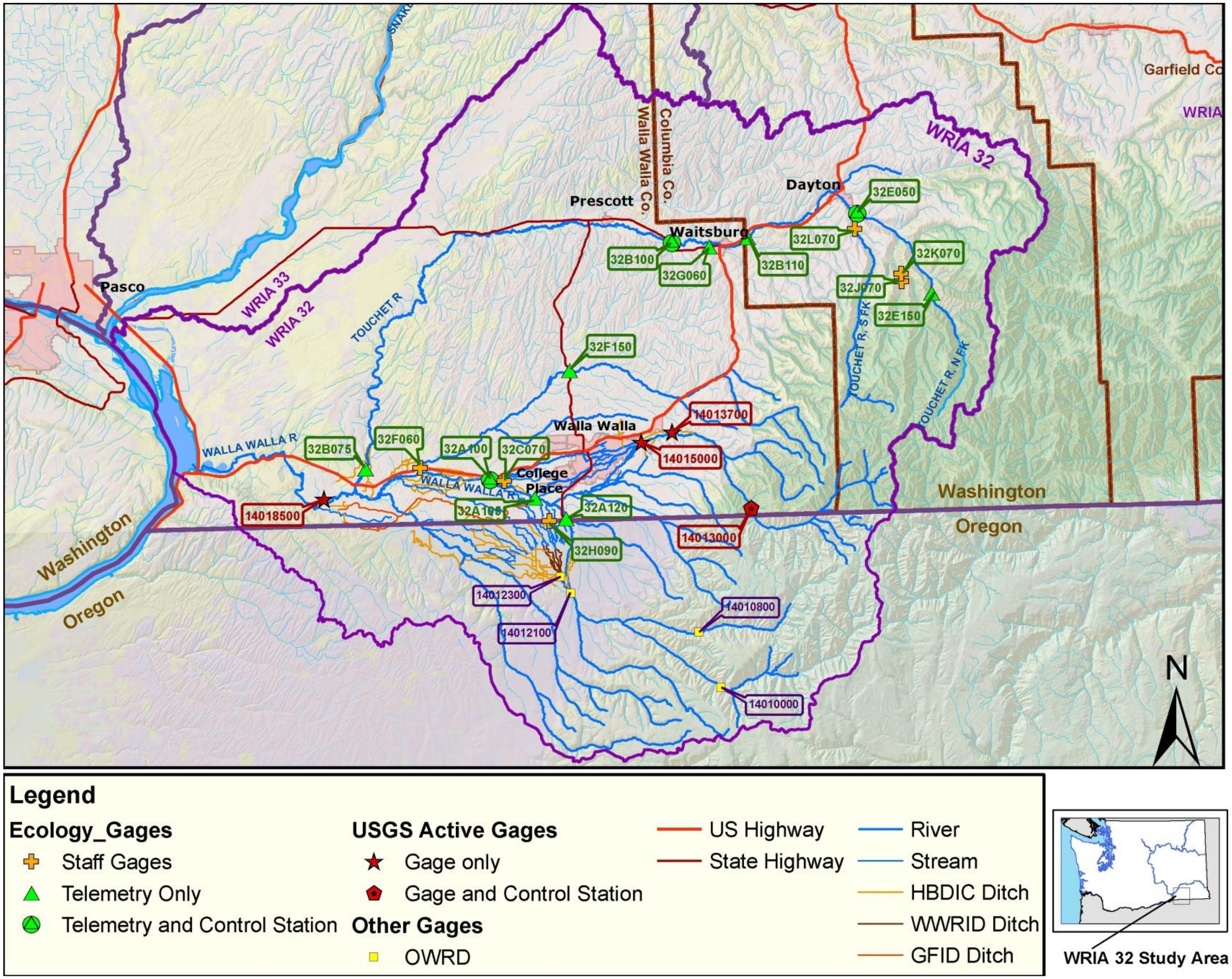


Figure 1. Walla Walla watershed and study area (Water Resource Inventory Area 32).

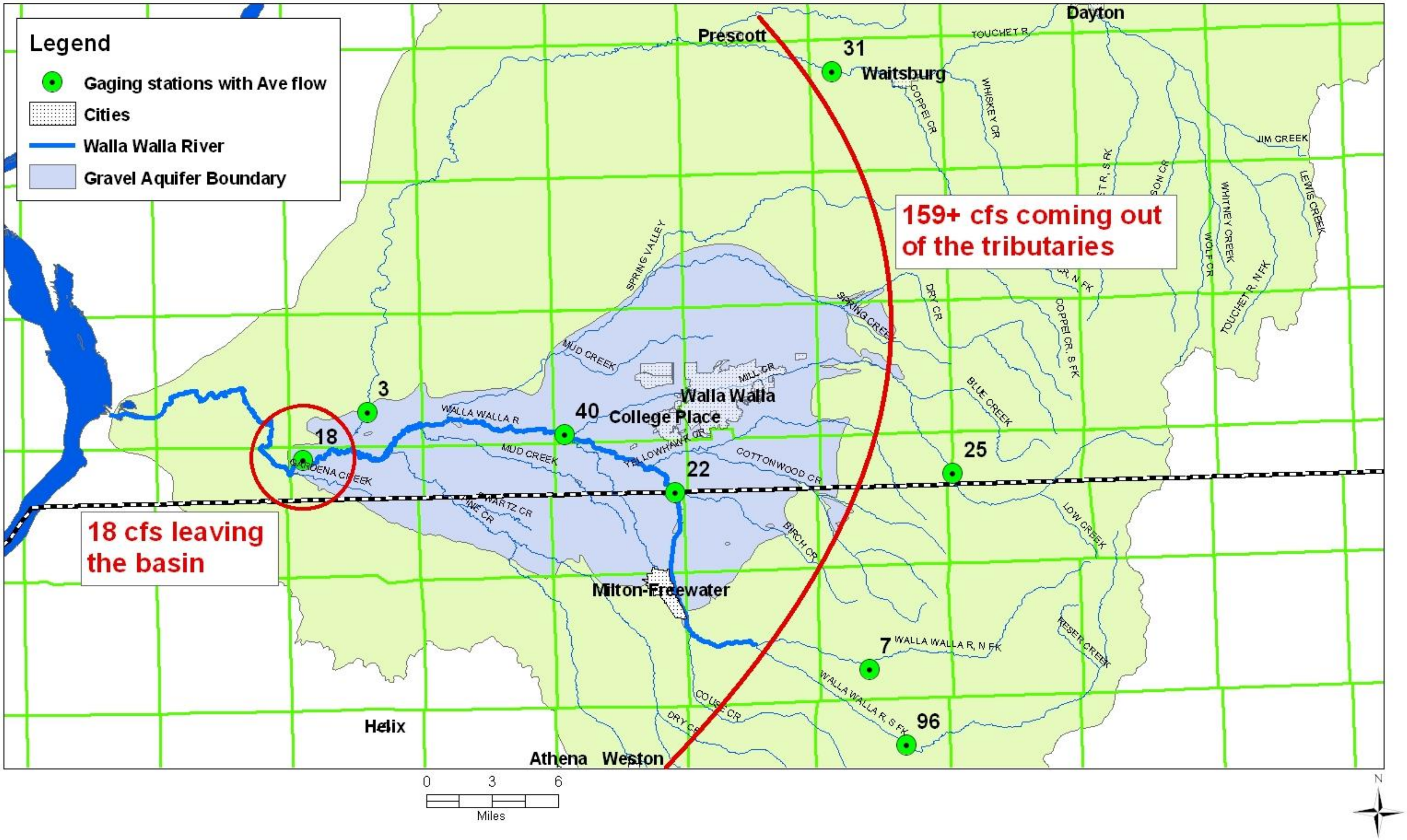


Figure 2. Walla Walla basin August monthly flow for 2007, from Ecology, USGS, and OWRD data (Covert, 2010).

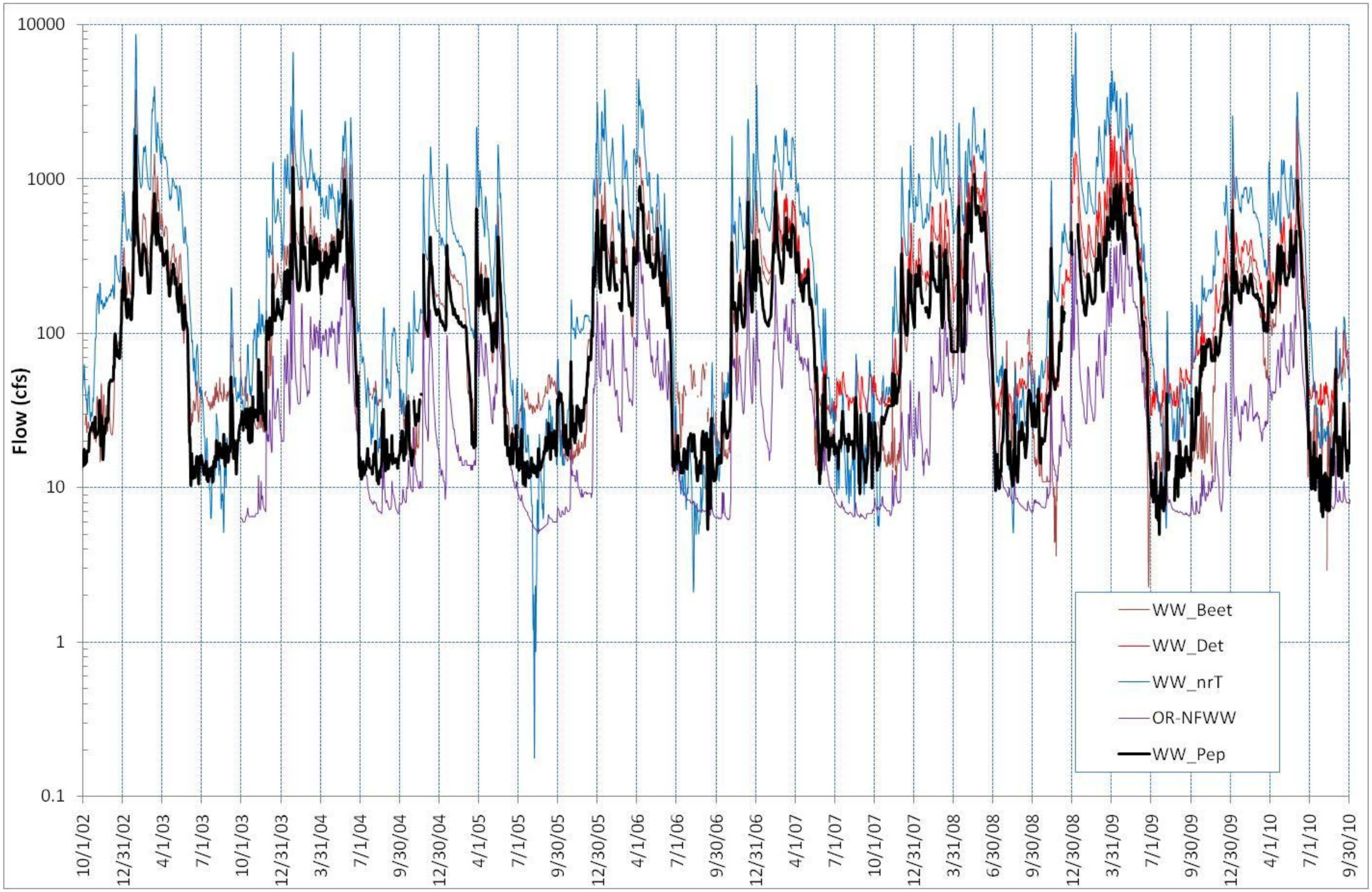


Figure 3. Measured flows at the "Walla Walla River at Pepper Bridge" gaging station, with flows from other selected gages.

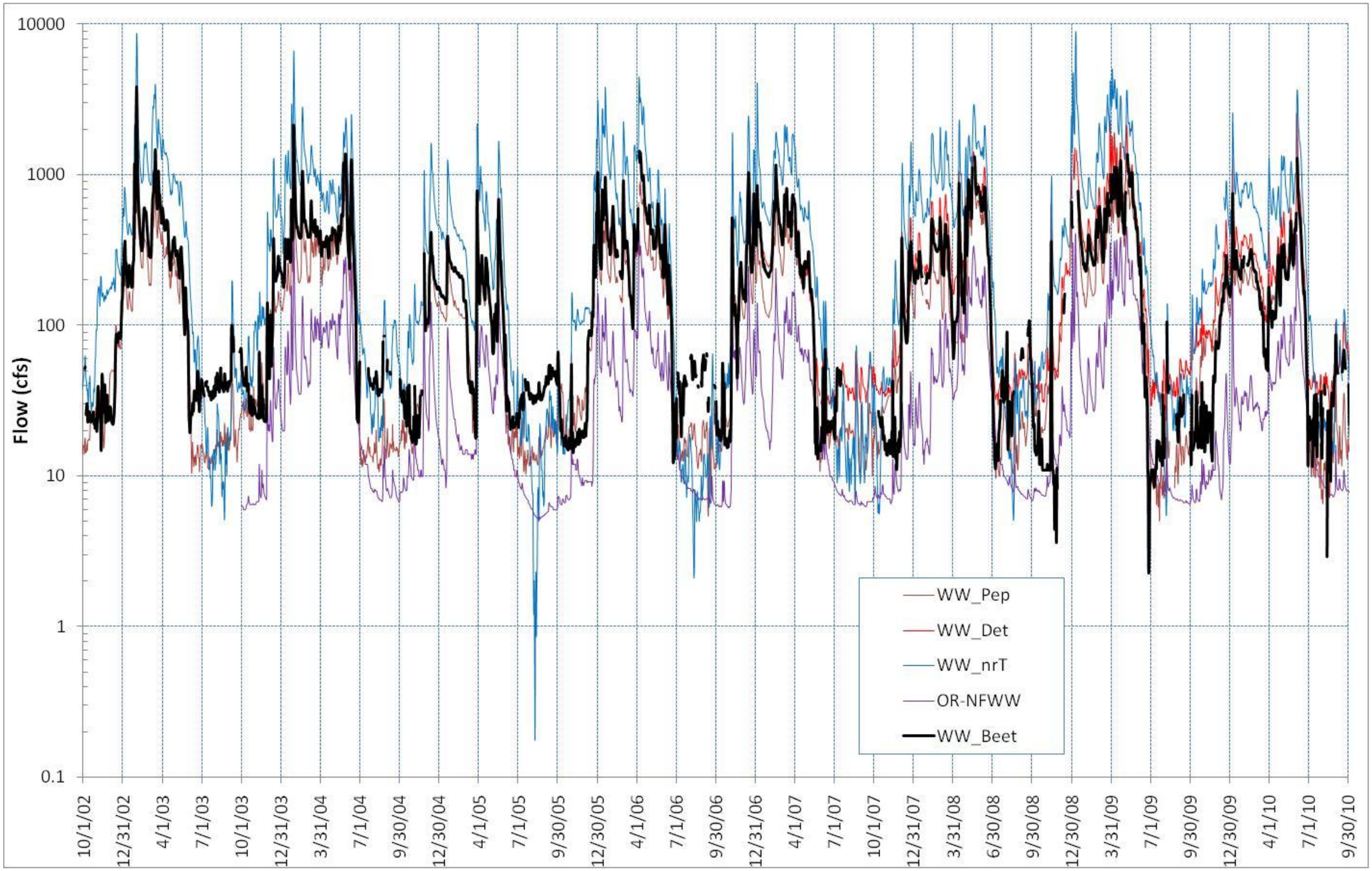


Figure 4. Measured flows at the "Walla Walla River at Beet Road" gaging station, with flows from other selected gages.

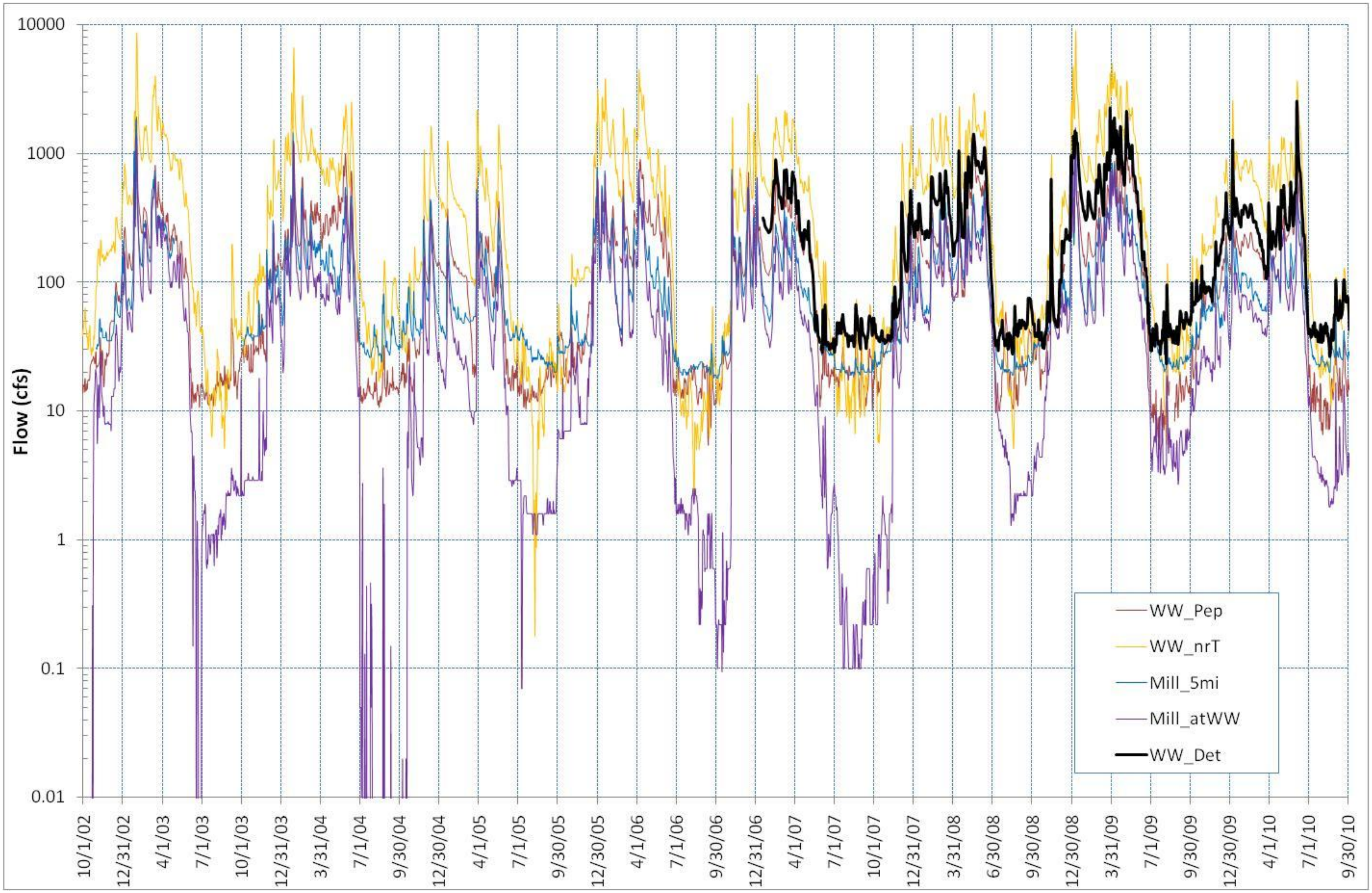


Figure 5. Measured flows at the "Walla Walla River at East Detour Road" gaging station, with flows from other selected gages.

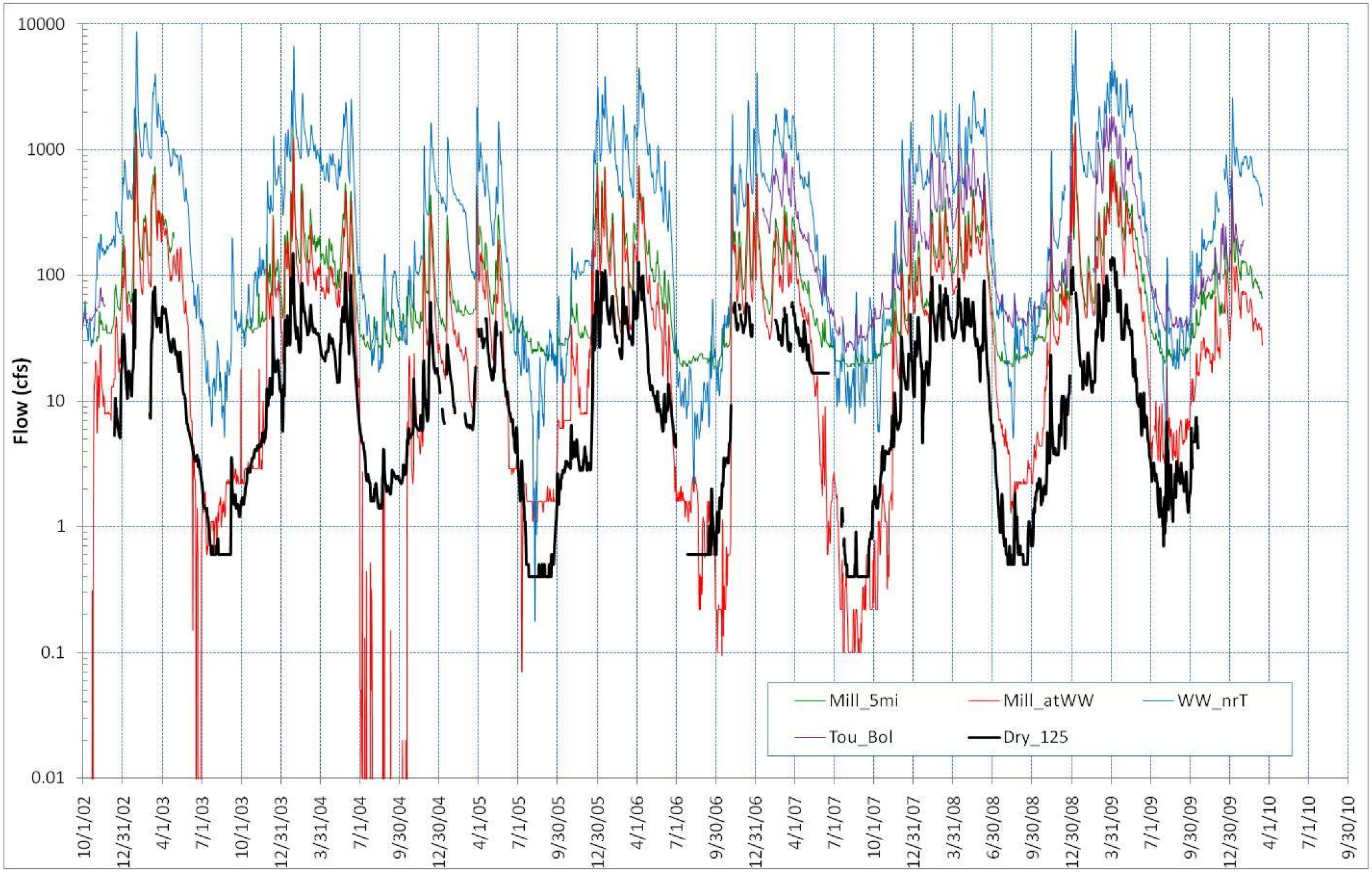


Figure 6. Measured flows at the "Dry Creek at Highway 125" gaging station, with flows from other selected gages.

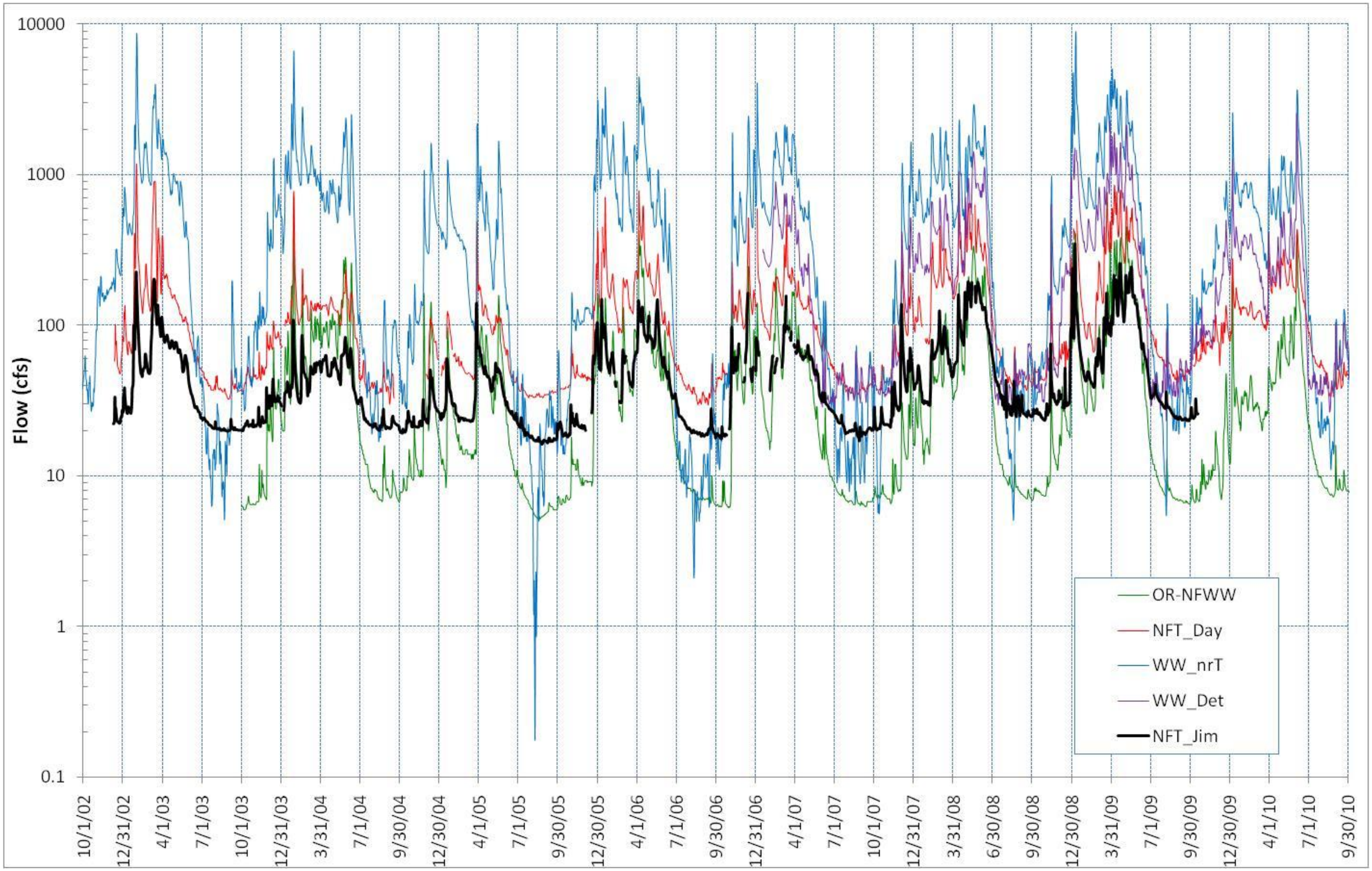


Figure 7. Measured flows at the “North Fork Touchet River above Jim Creek” gaging station, with flows from other selected gages.

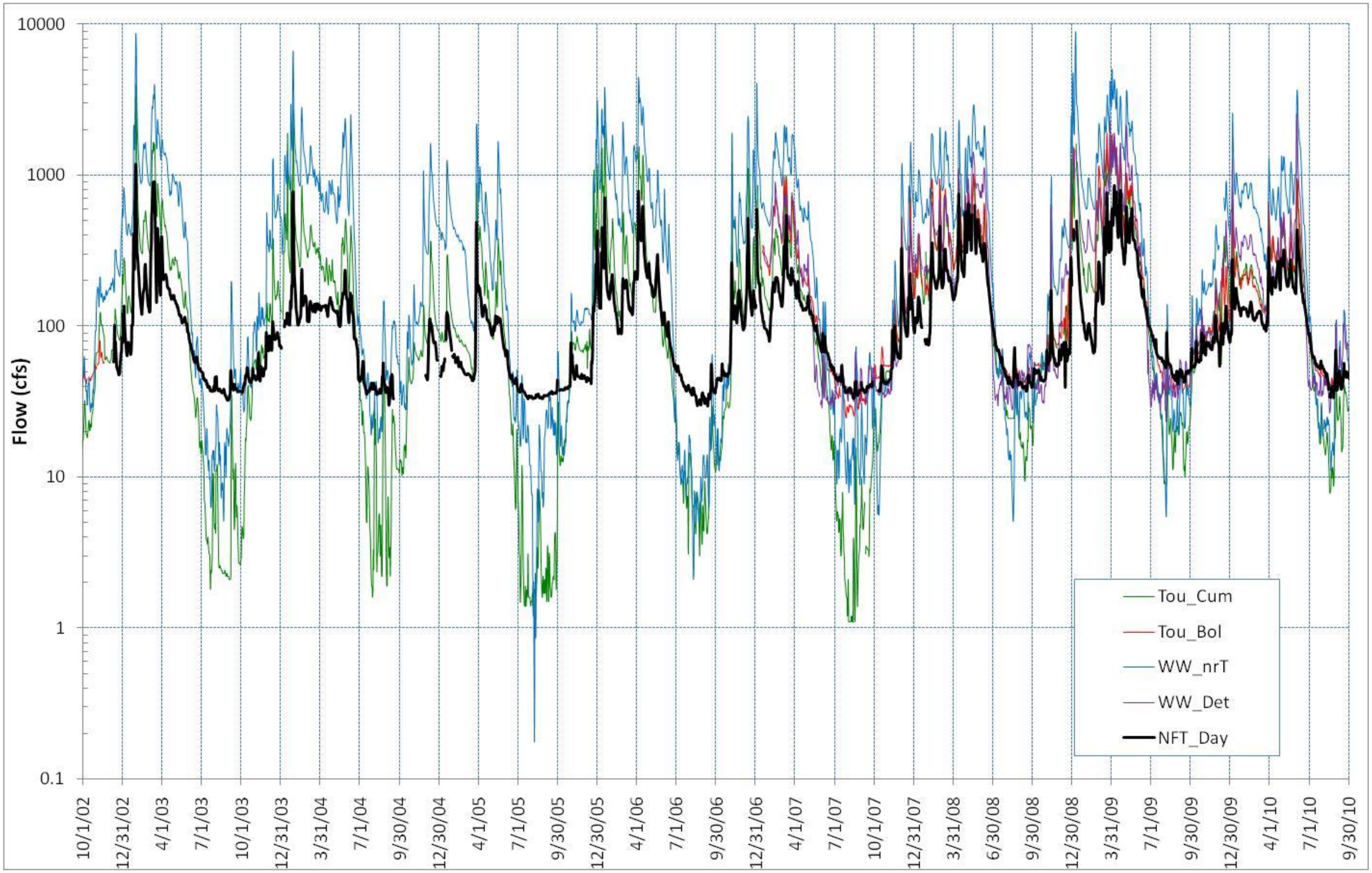


Figure 8. Measured flows at the "North Fork Touchet River above Dayton" gaging station, with flows from other selected gages.

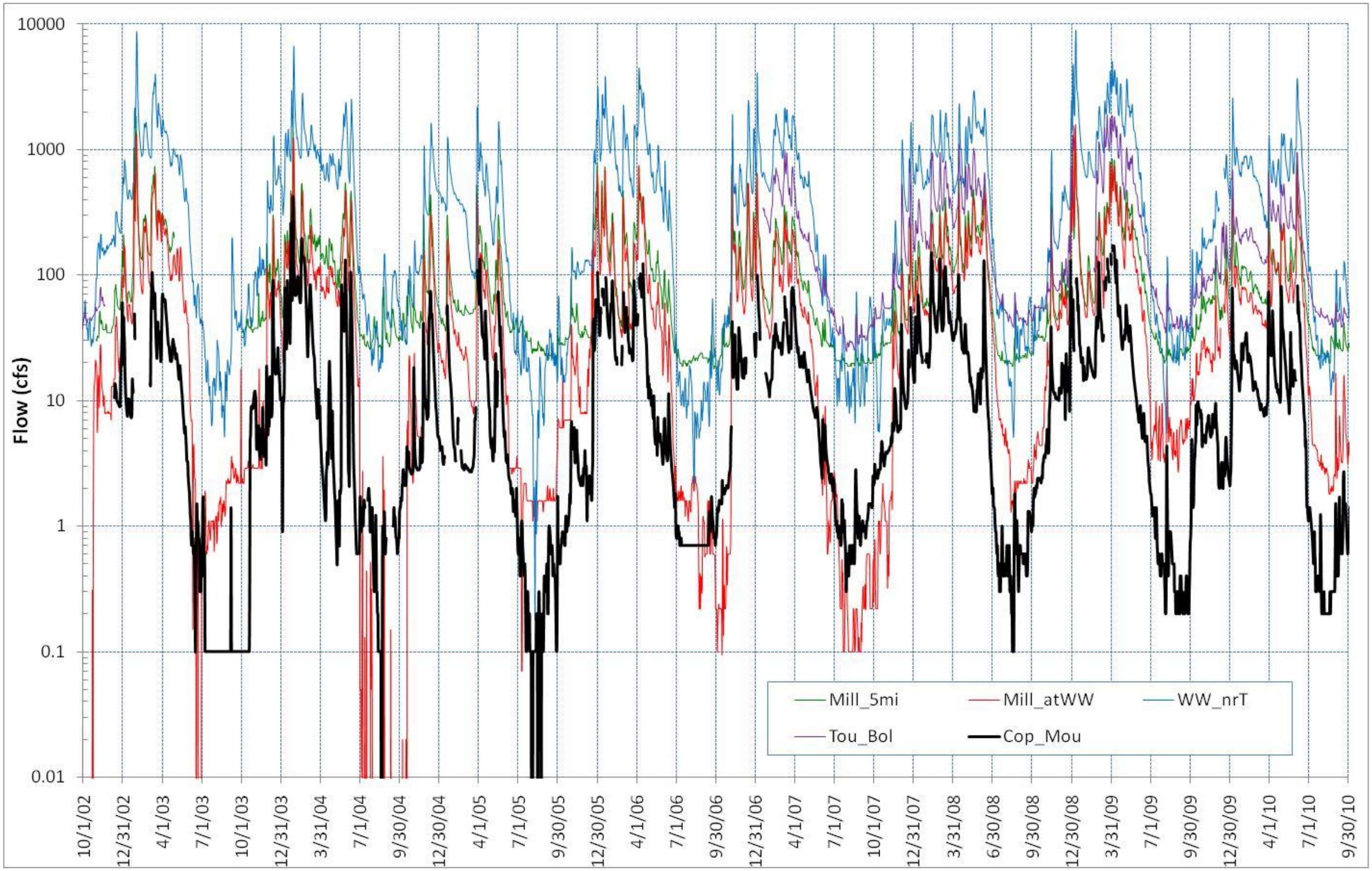


Figure 9. Measured flows at the "Coppei Creek near Mouth" gaging station, with flows from other selected gages.

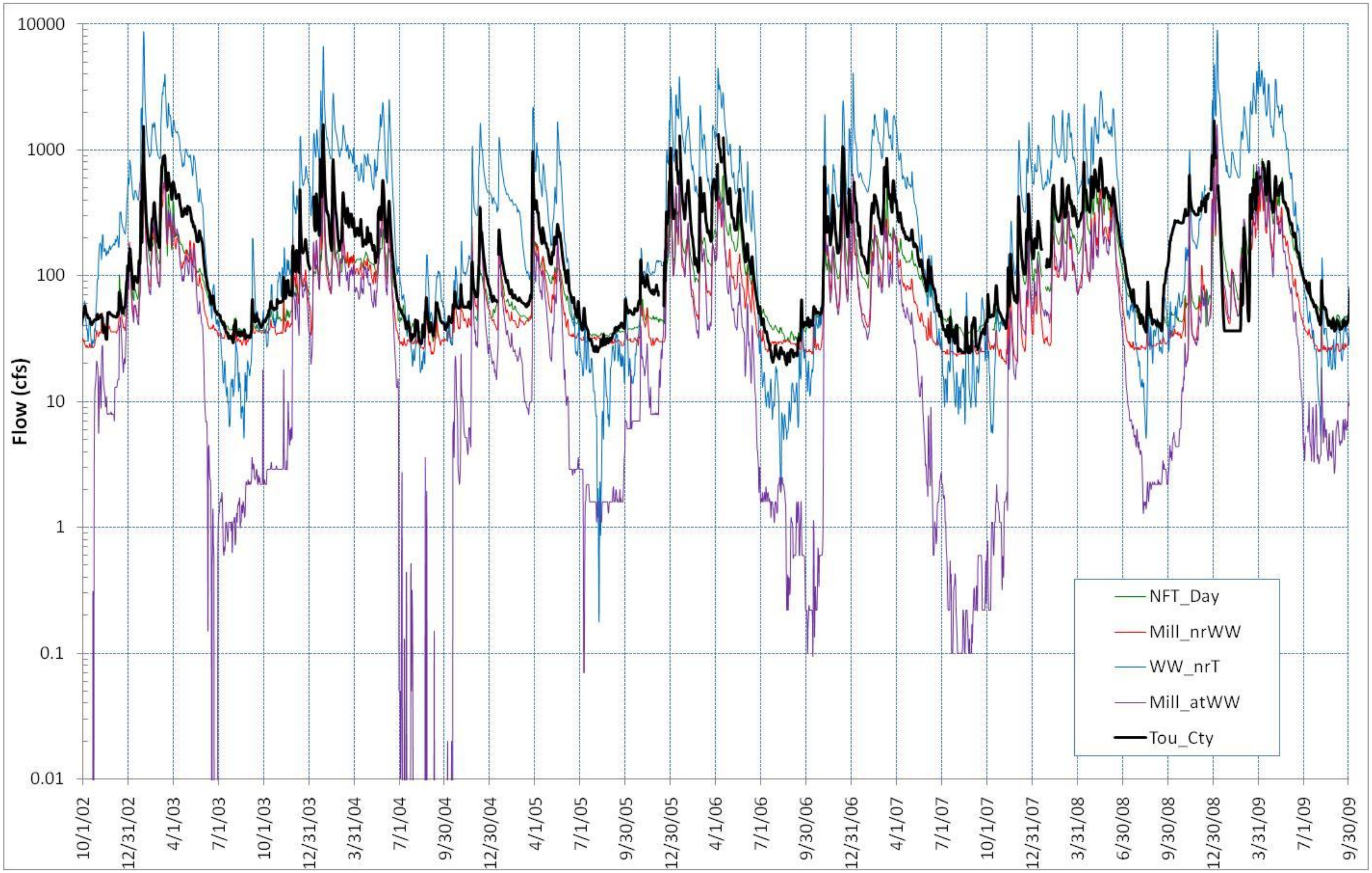


Figure 10. Measured flows at the "Touchet River at County Line" gaging station, with flows from other selected gages.

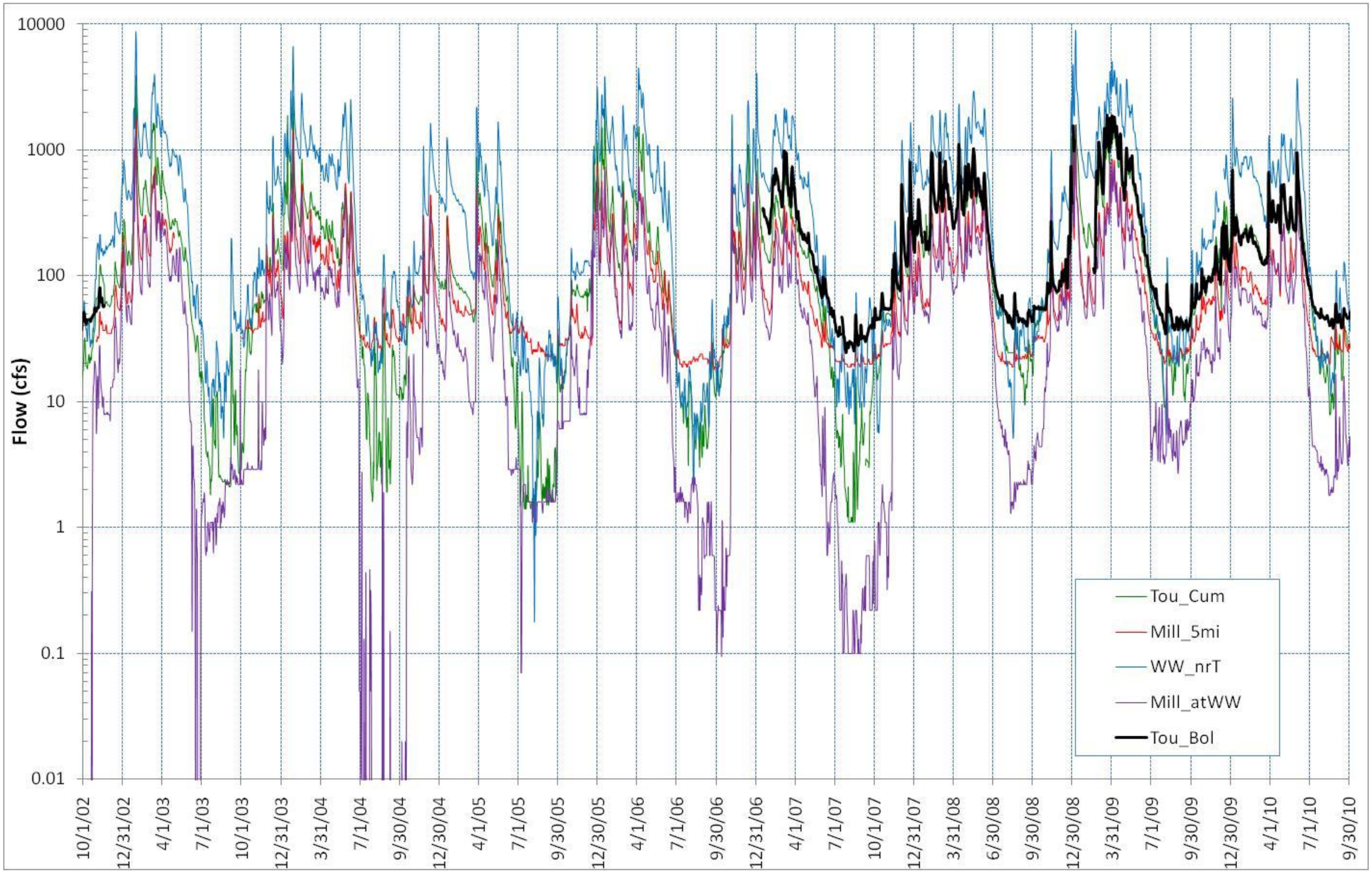


Figure 11. Measured flows at the "Touchet River at Bolles" gaging station, with flows from other selected gages.

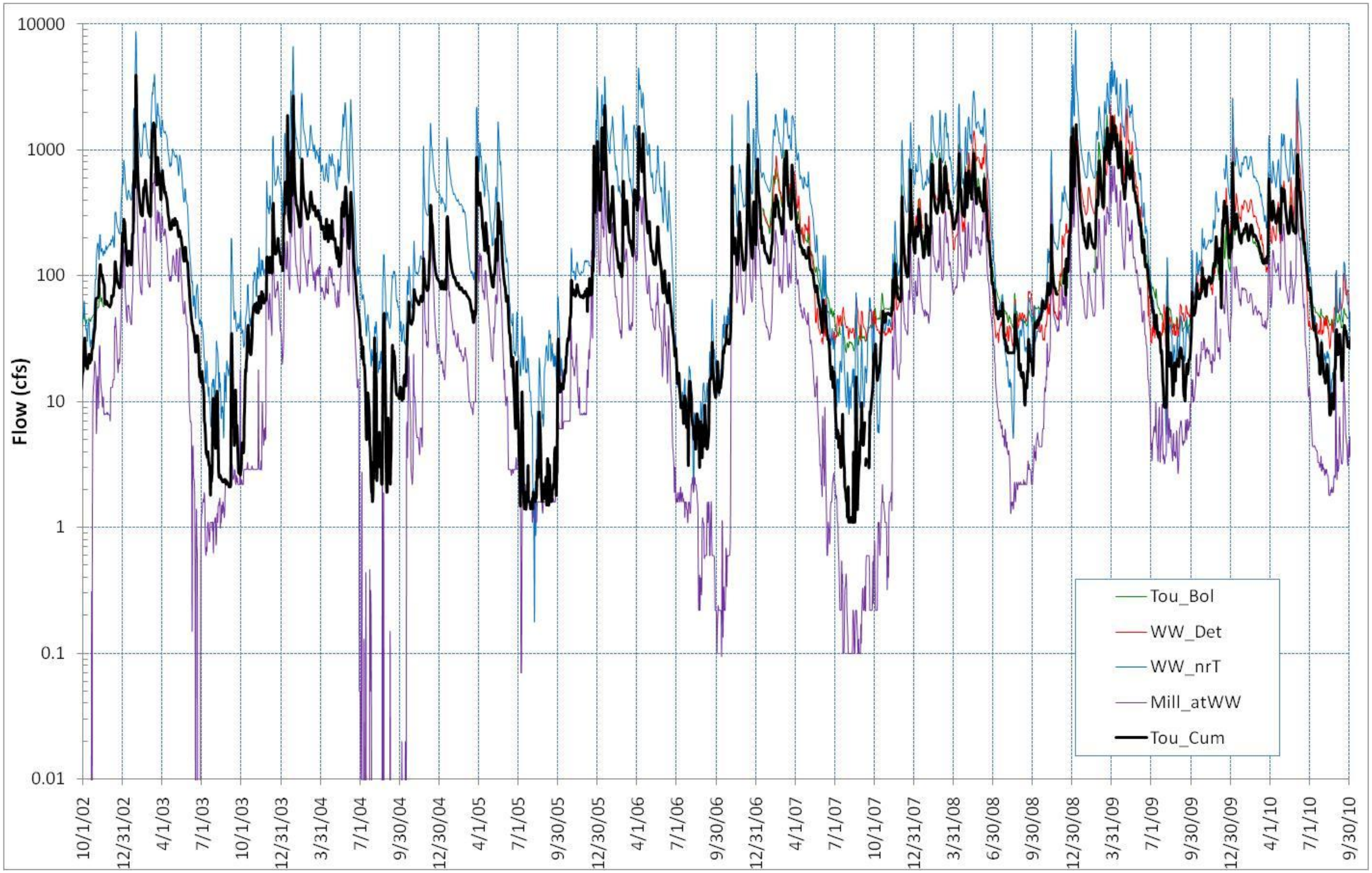


Figure 12. Measured flows at the "Touchet River at Cummins Road" gaging station, with flows from other selected gages.

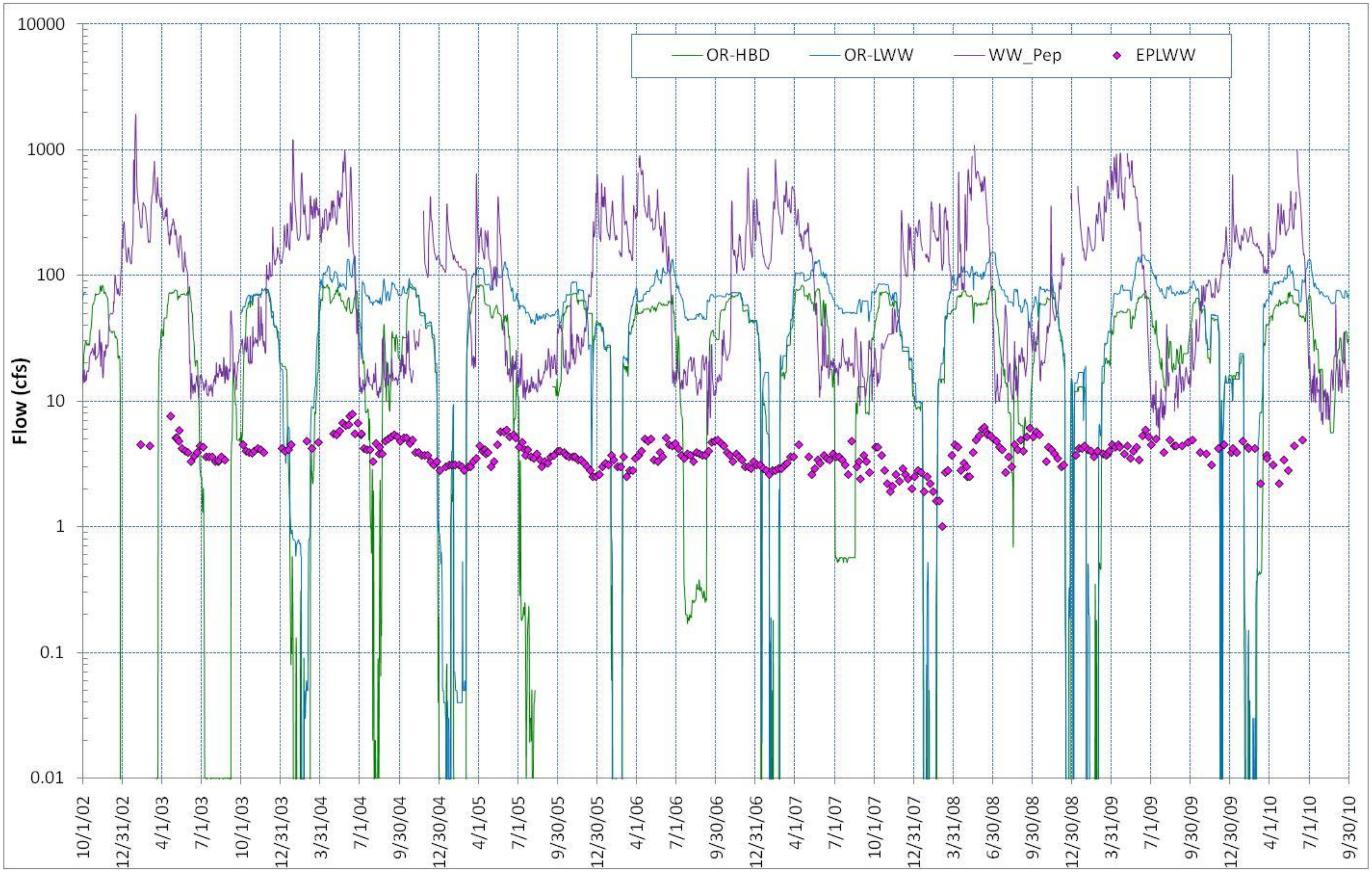


Figure 13. Measured flows at the "East Prong Little Walla Walla River at Stateline" gaging station, with flows from other selected gages.

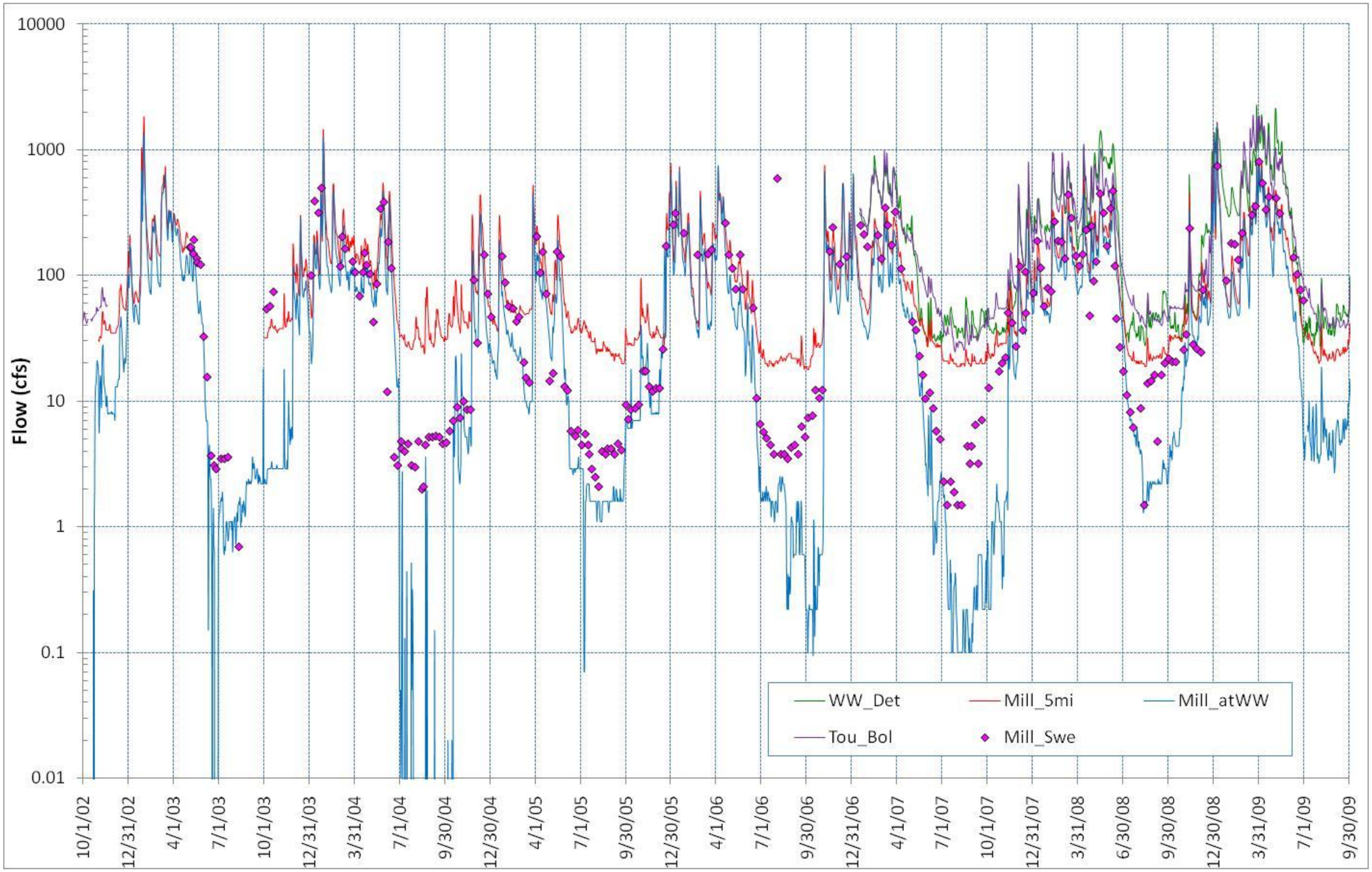


Figure 14. Measured flows at the "Mill Creek at Swegle Road" gaging station, with flows from other selected gages.

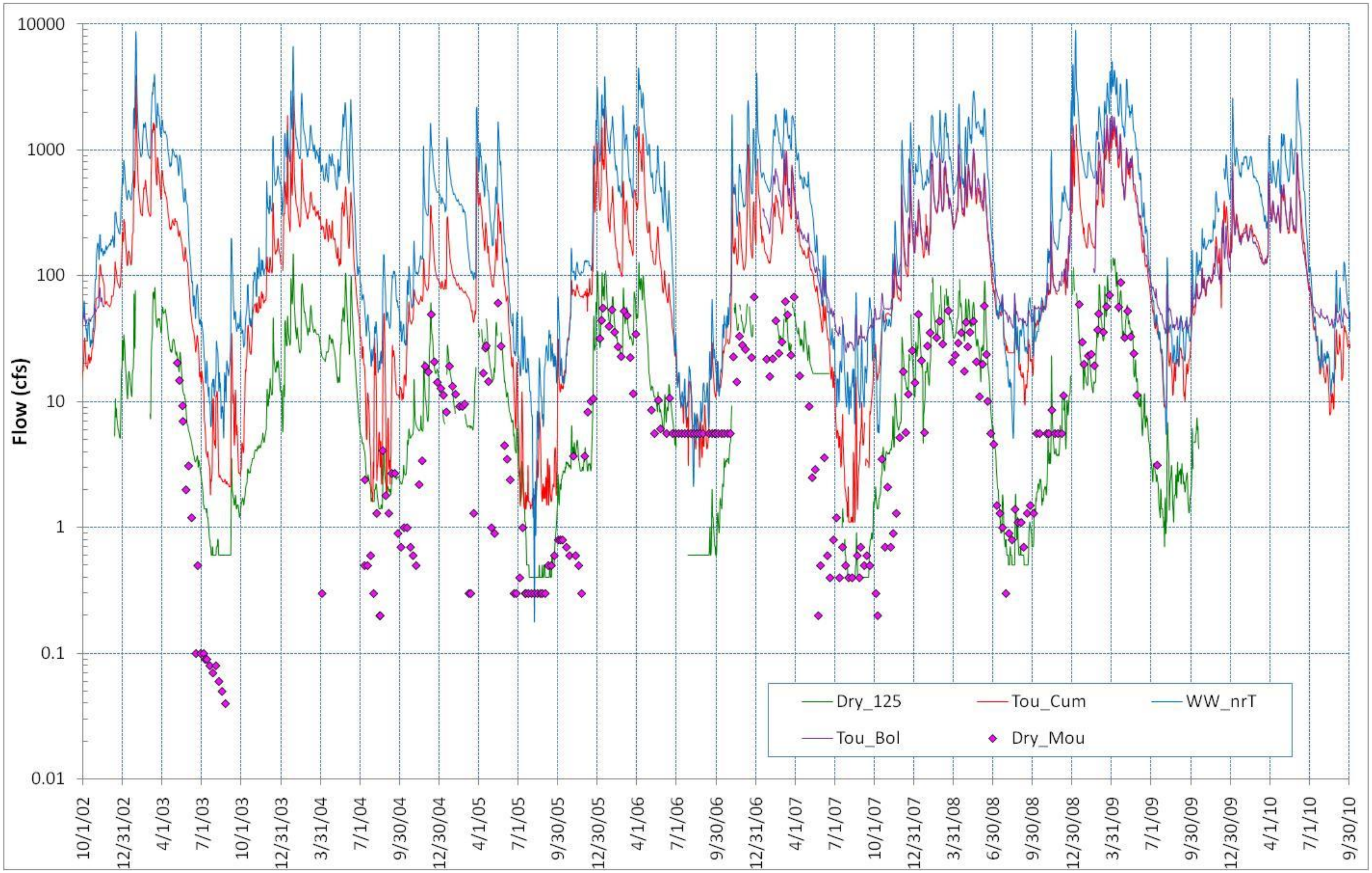


Figure 15. Measured flows at the “Dry Creek near Mouth” gaging station, with flows from other selected gages.

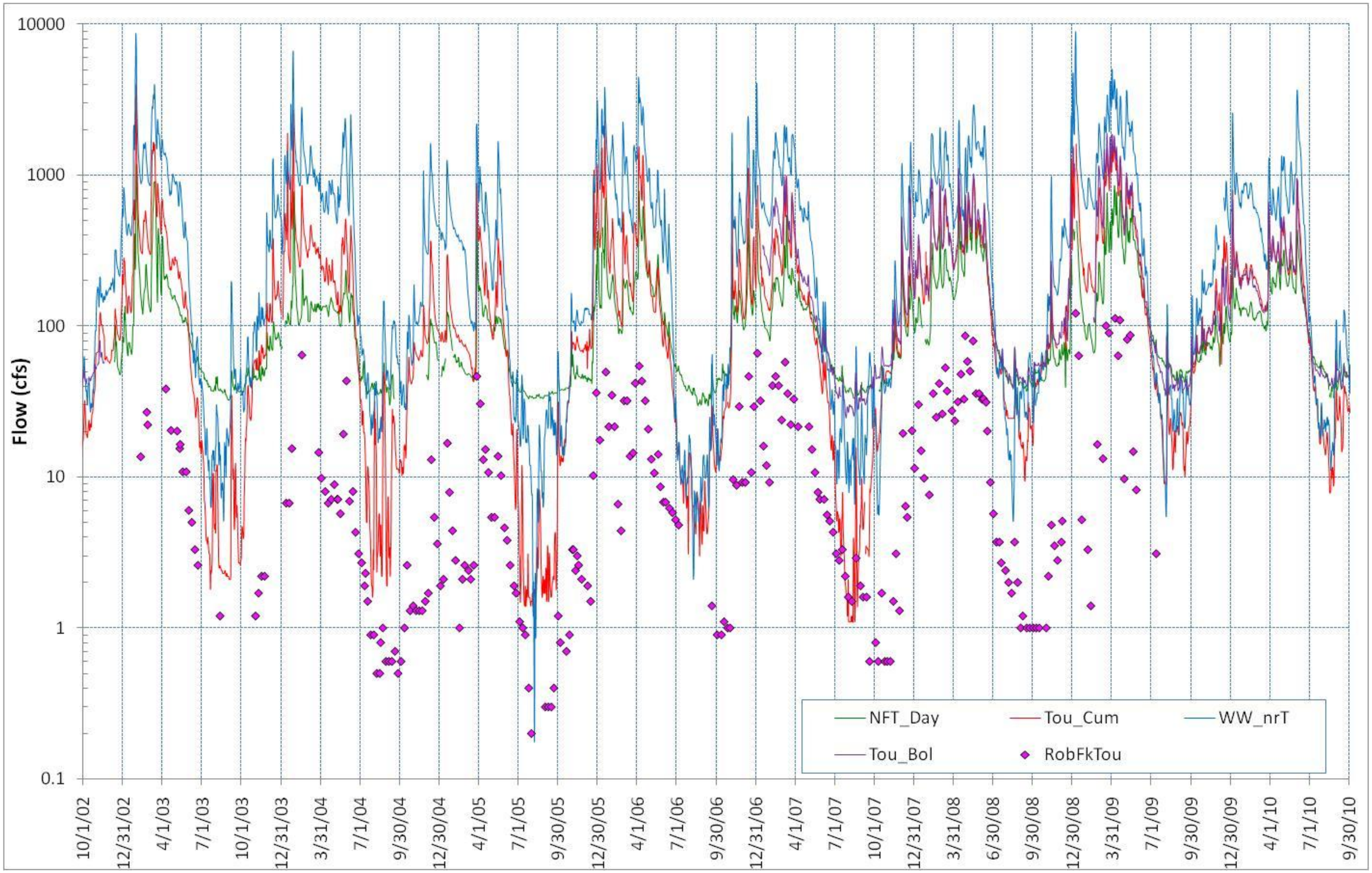


Figure 16. Measured flows at the "Robinson Fork above Wolf Fork Touchet River" gaging station, with flows from other selected gages.

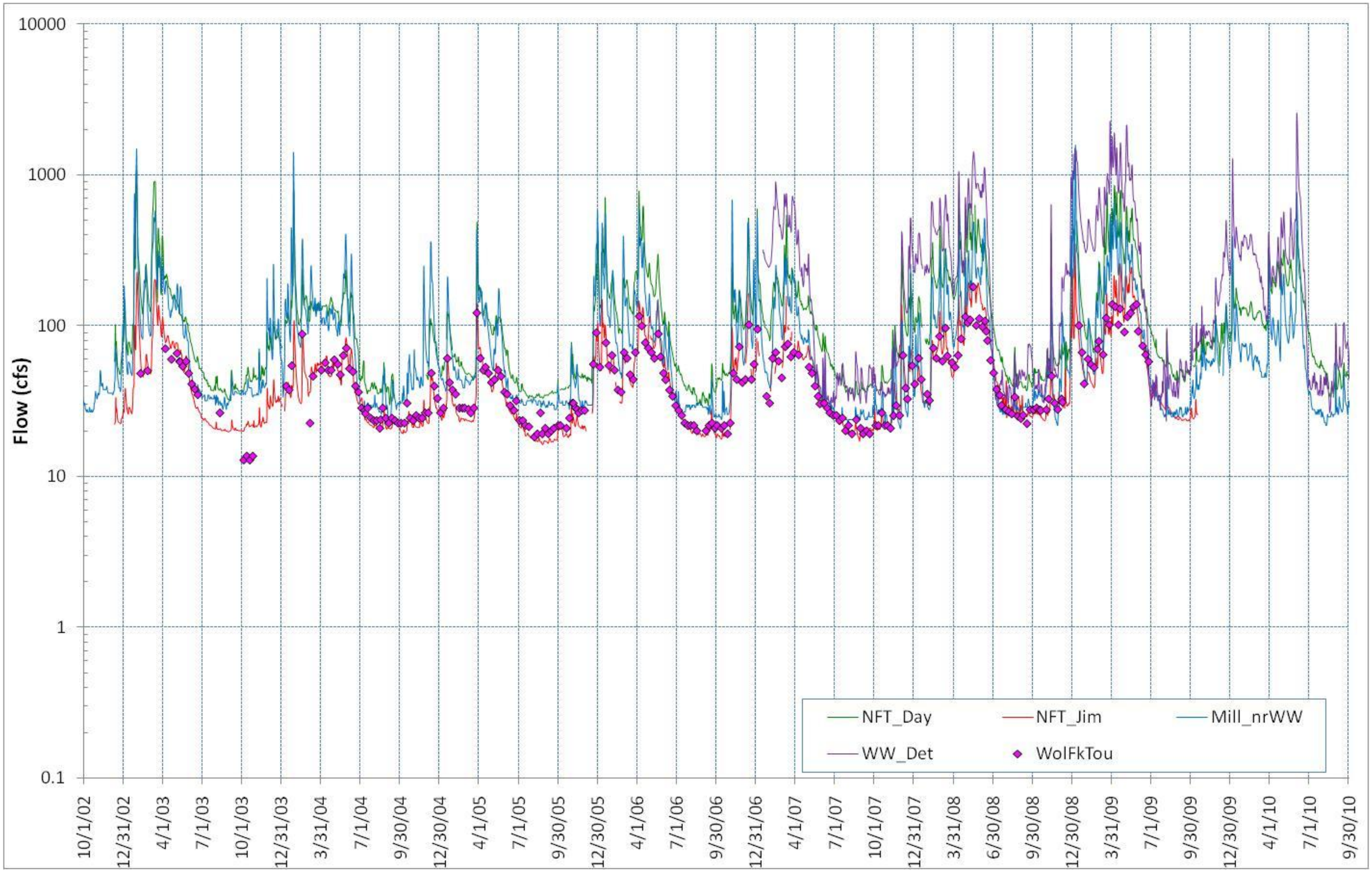


Figure 17. Measured flows at the "Wolf Fork Touchet River at Mountain Home Park" gaging station, with flows from other selected gages.

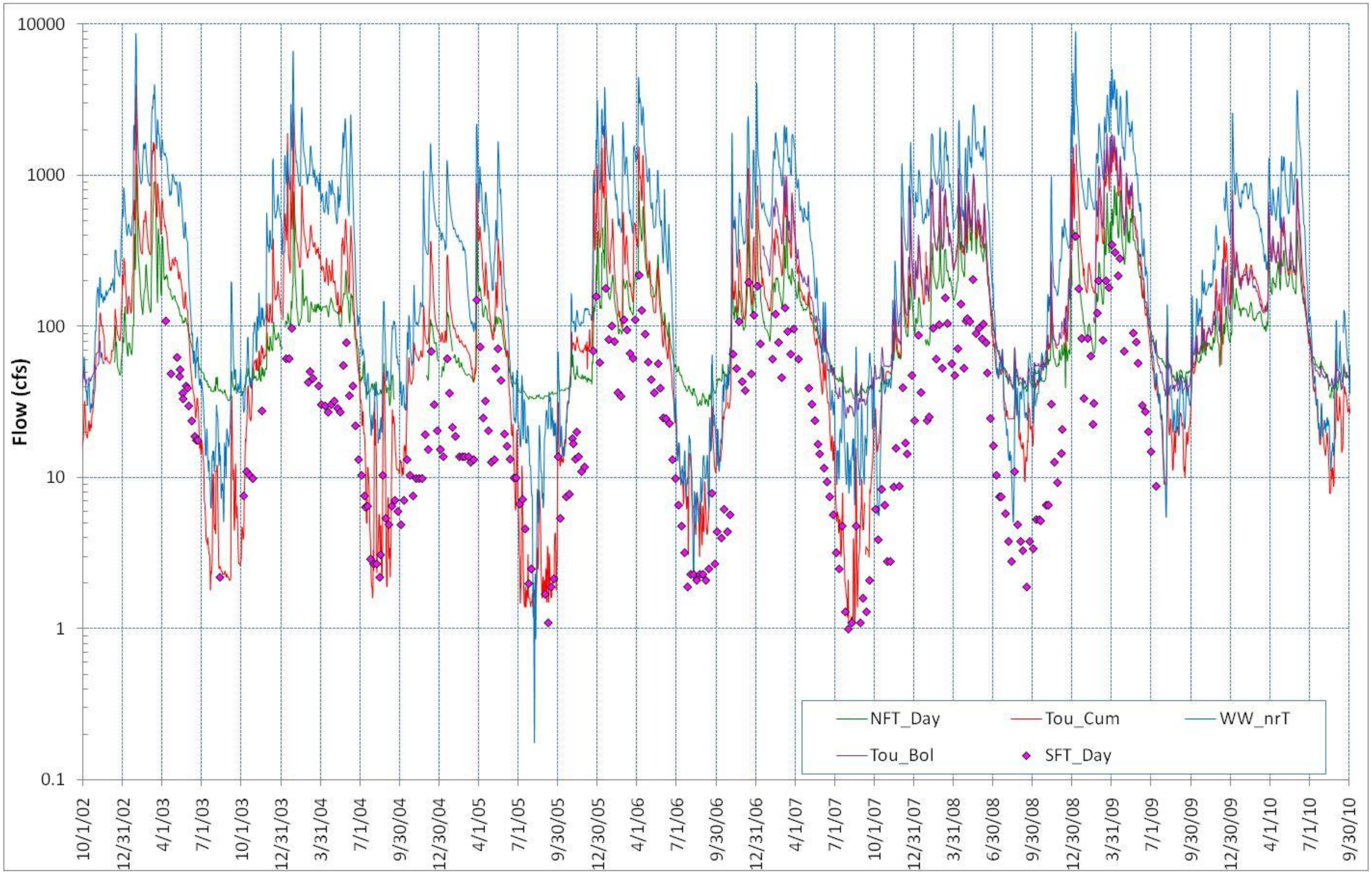


Figure 18. Measured flows at the “South Fork Touchet River above Dayton” gaging station, with flows from other selected gages.

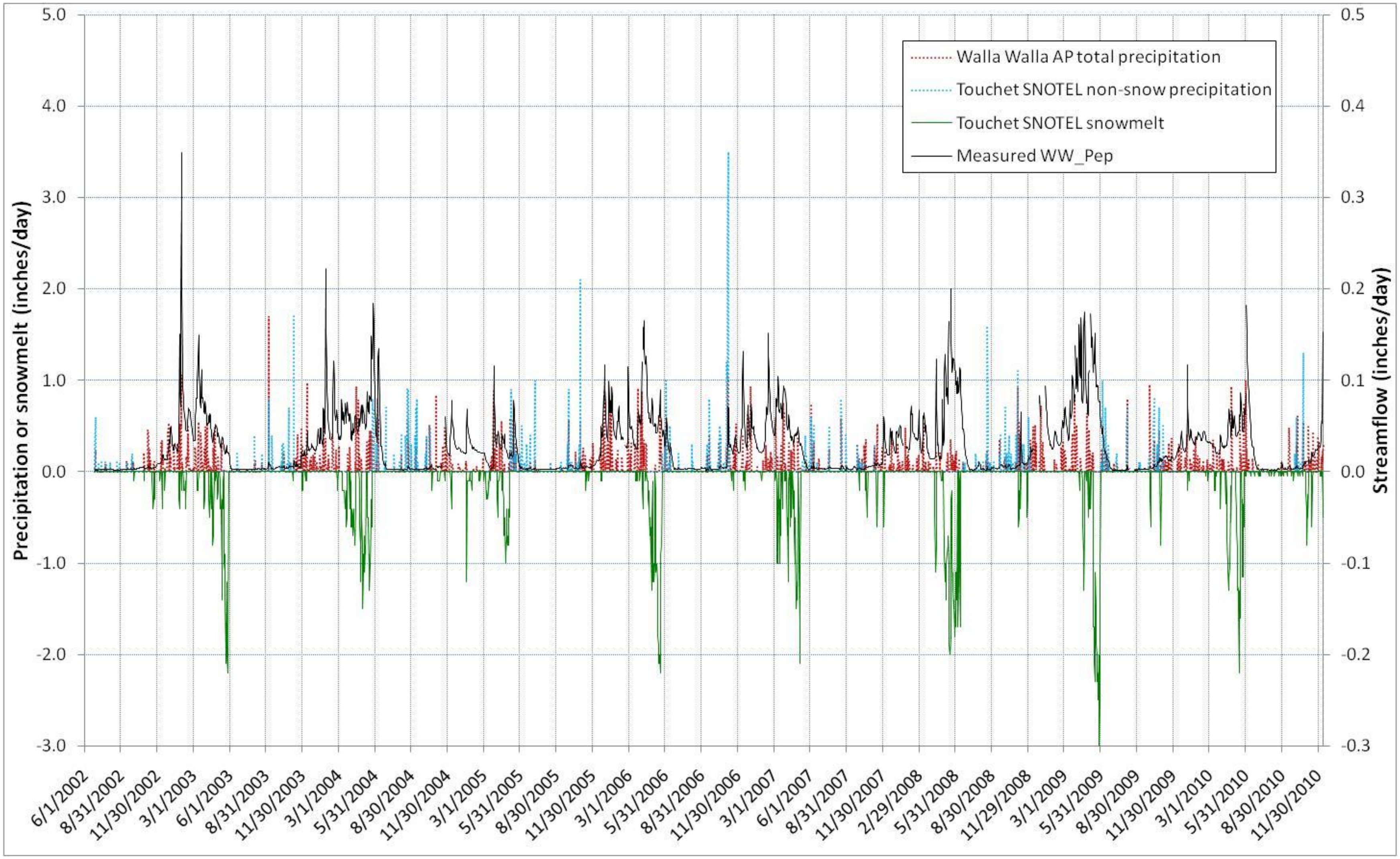


Figure 19. Measured areal flows at the “Walla Walla River at Pepper Bridge” gaging station, with precipitation and snowmelt data.

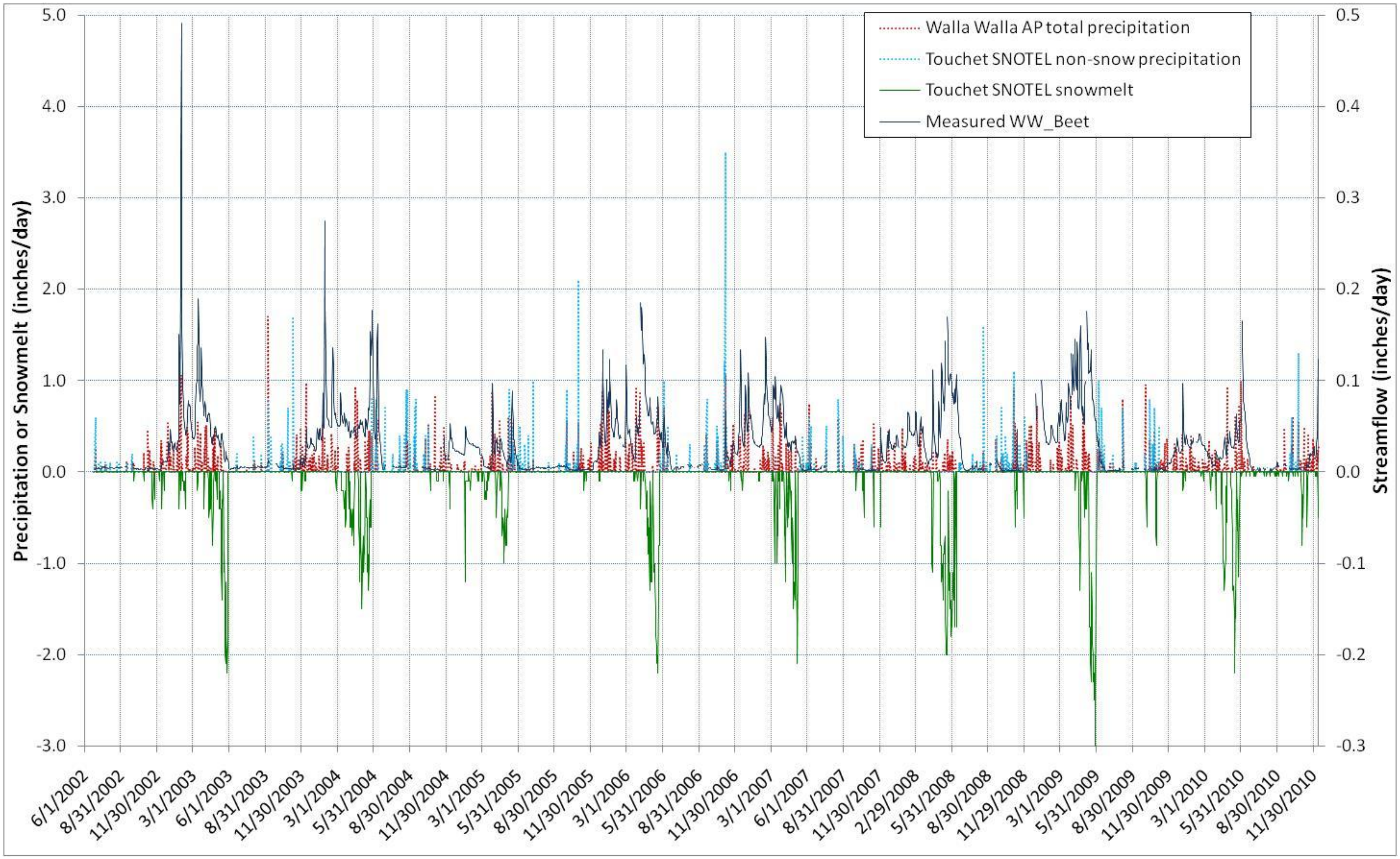


Figure 20. Measured areal flows at the “Walla Walla River at Beet Road” gaging station, with precipitation and snowmelt data.

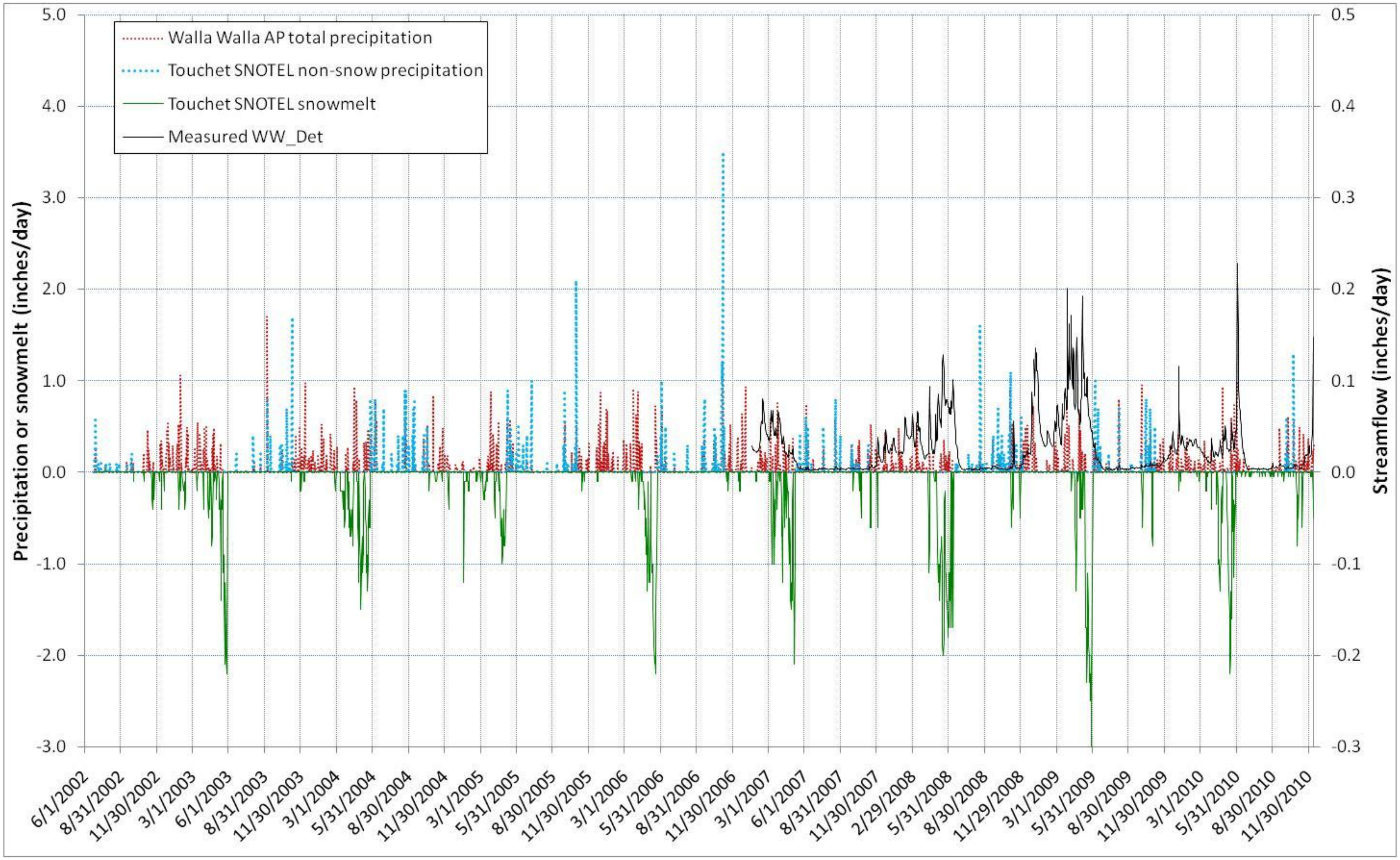


Figure 21. Measured areal flows at the "Walla Walla River at East Detour Road" gaging station, with precipitation and snowmelt data.

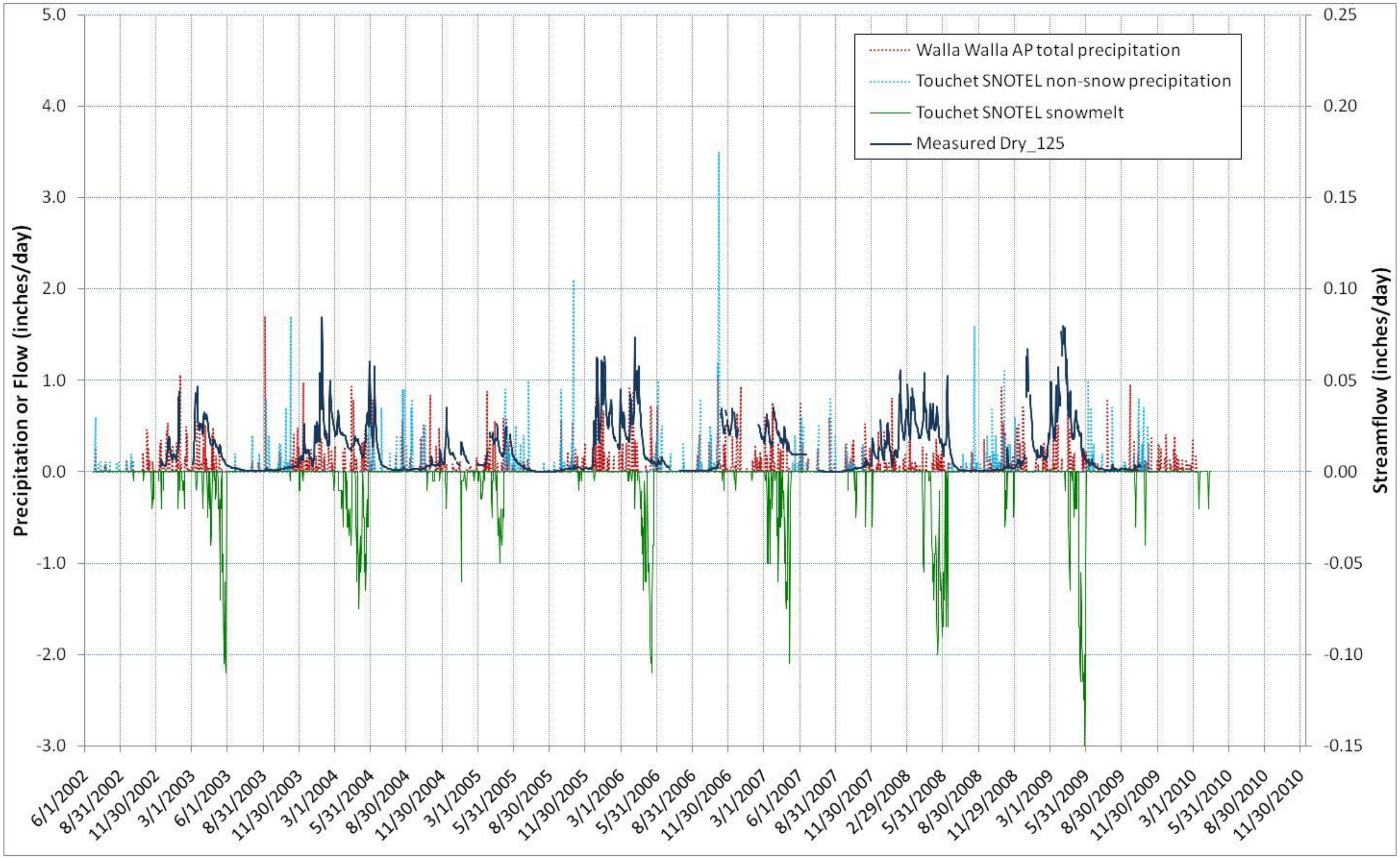


Figure 22. Measured areal flows at the "Dry Creek at Highway 125" gaging station, with precipitation and snowmelt data.

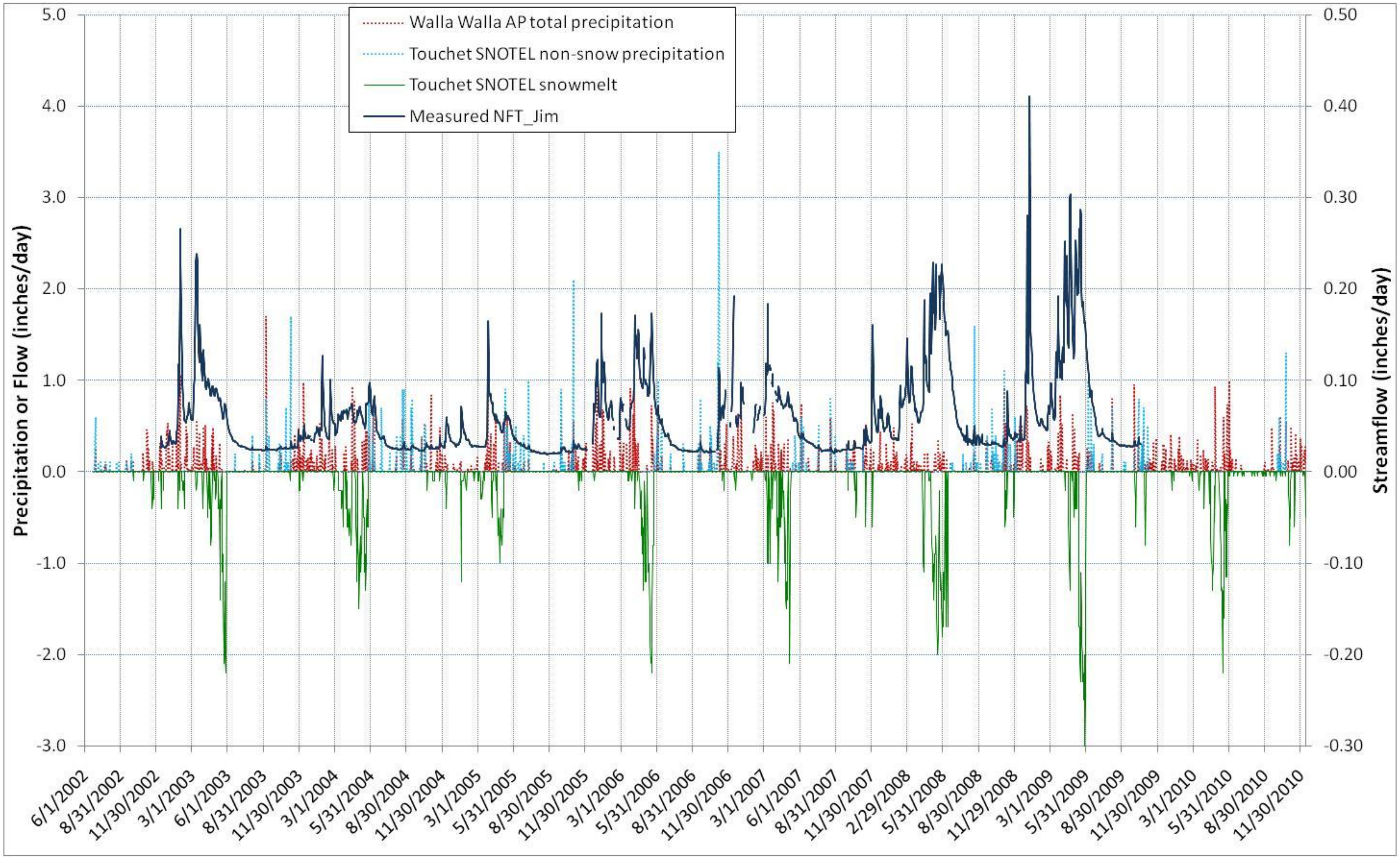


Figure 23. Measured areal flows at the "North Fork Touchet River above Jim Creek" gaging station, with precipitation and snowmelt data.

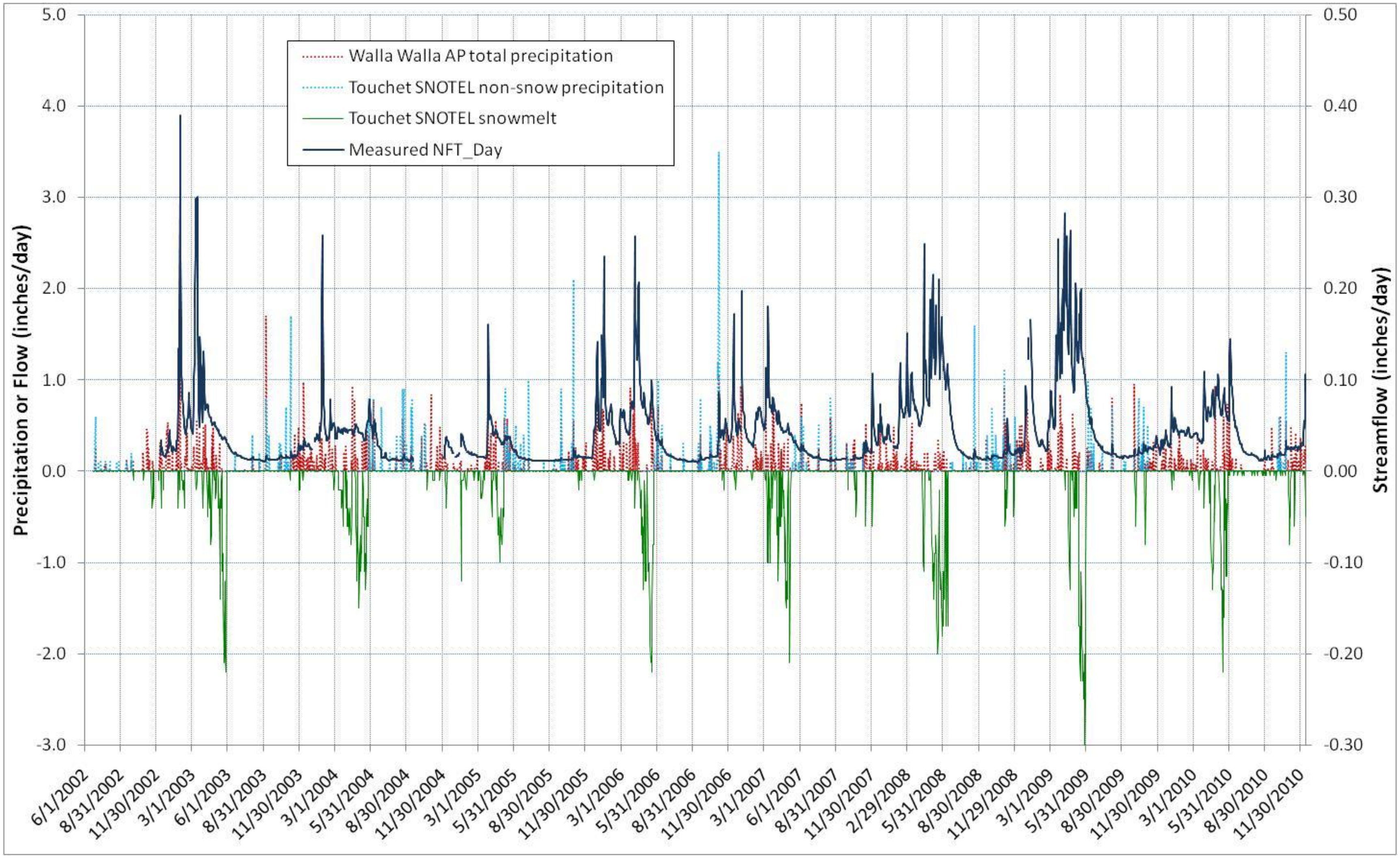


Figure 24. Measured areal flows at the "North Fork Touchet River above Dayton" gaging station, with precipitation and snowmelt data.

.

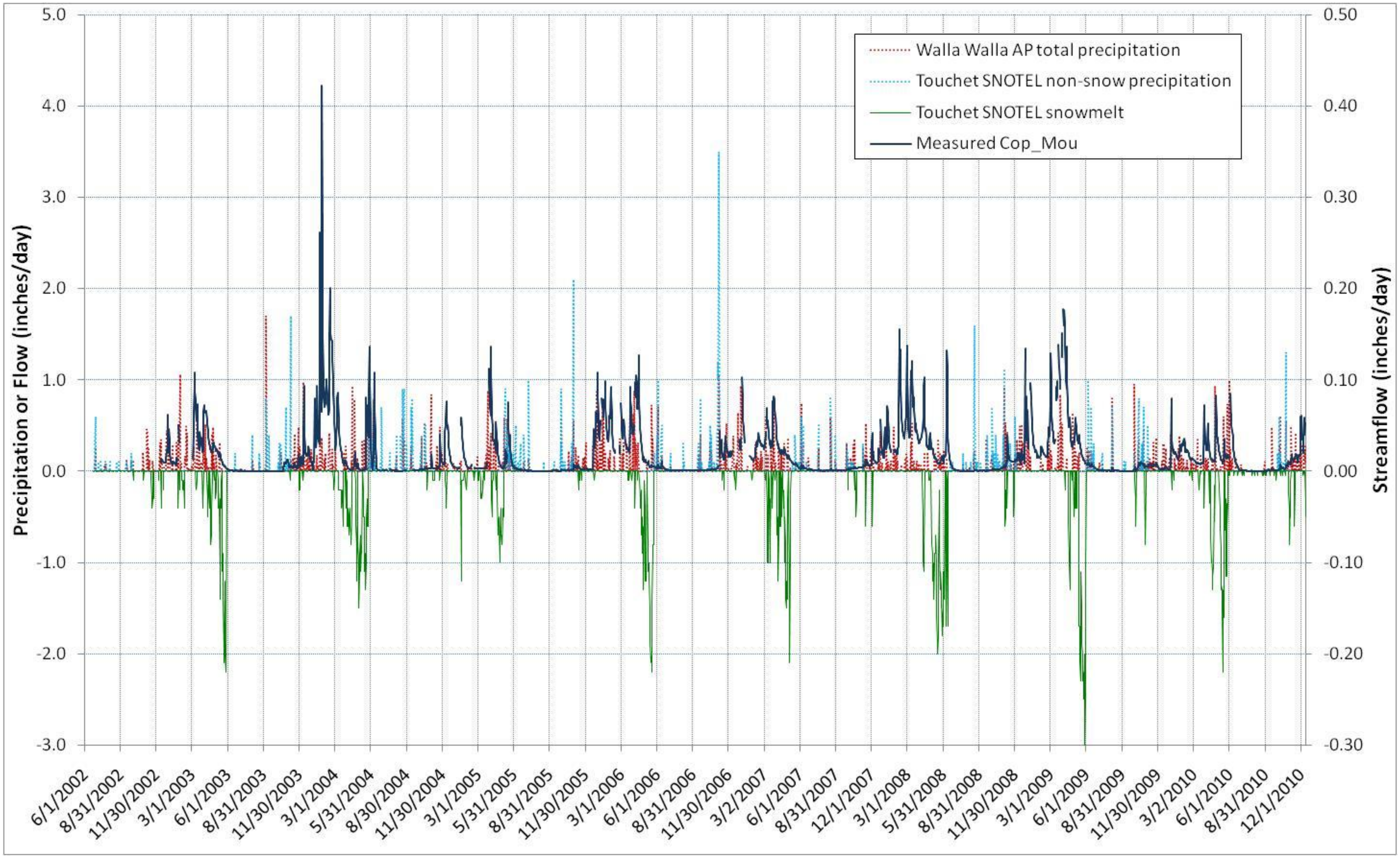
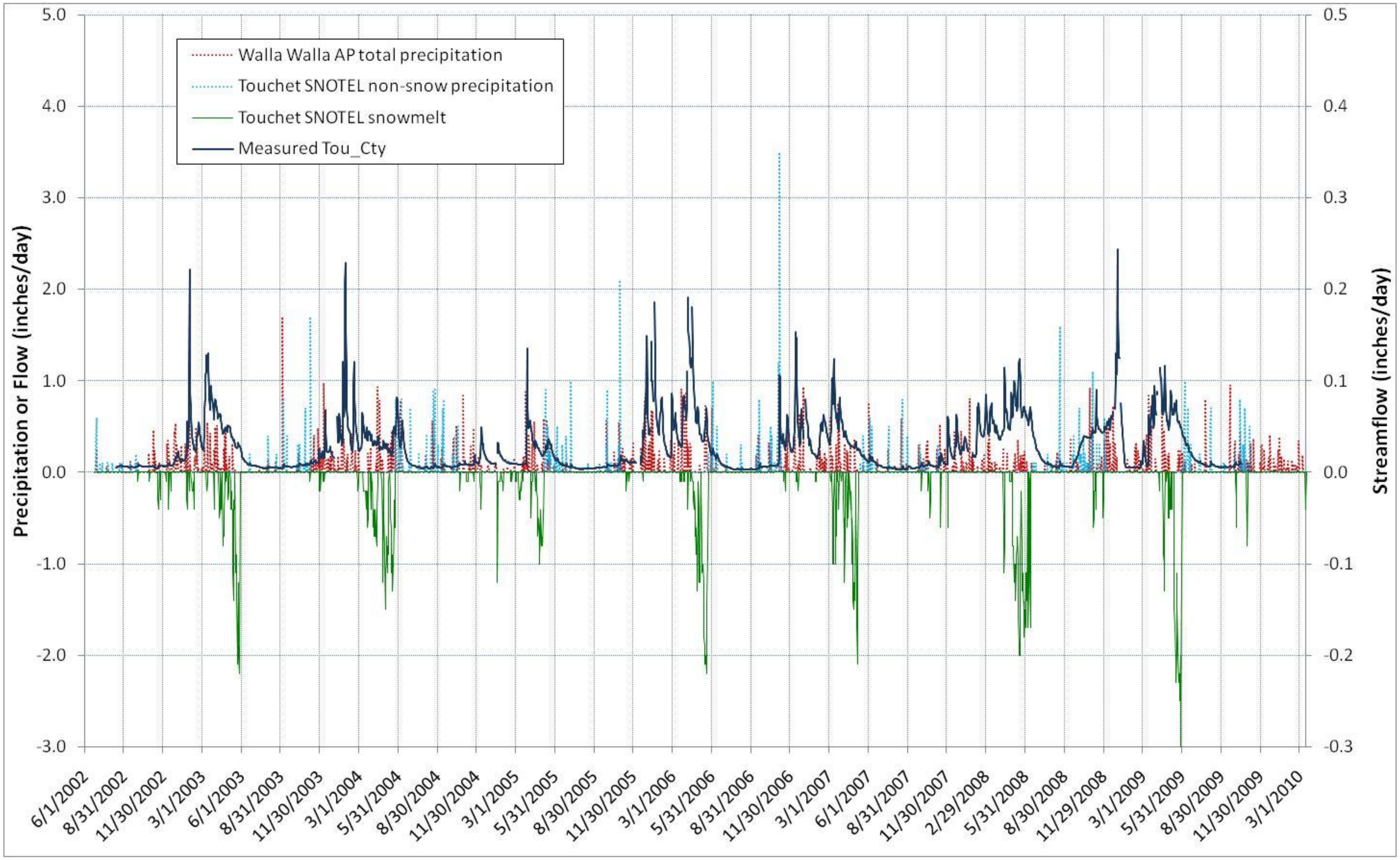


Figure 25. Measured areal flows at the "Coppei Creek near Mouth" gaging station, with precipitation and snowmelt data.



ta

Figure 26. Measured areal flows at the "Touchet River at County Line" gaging station, with precipitation and snowmelt data.

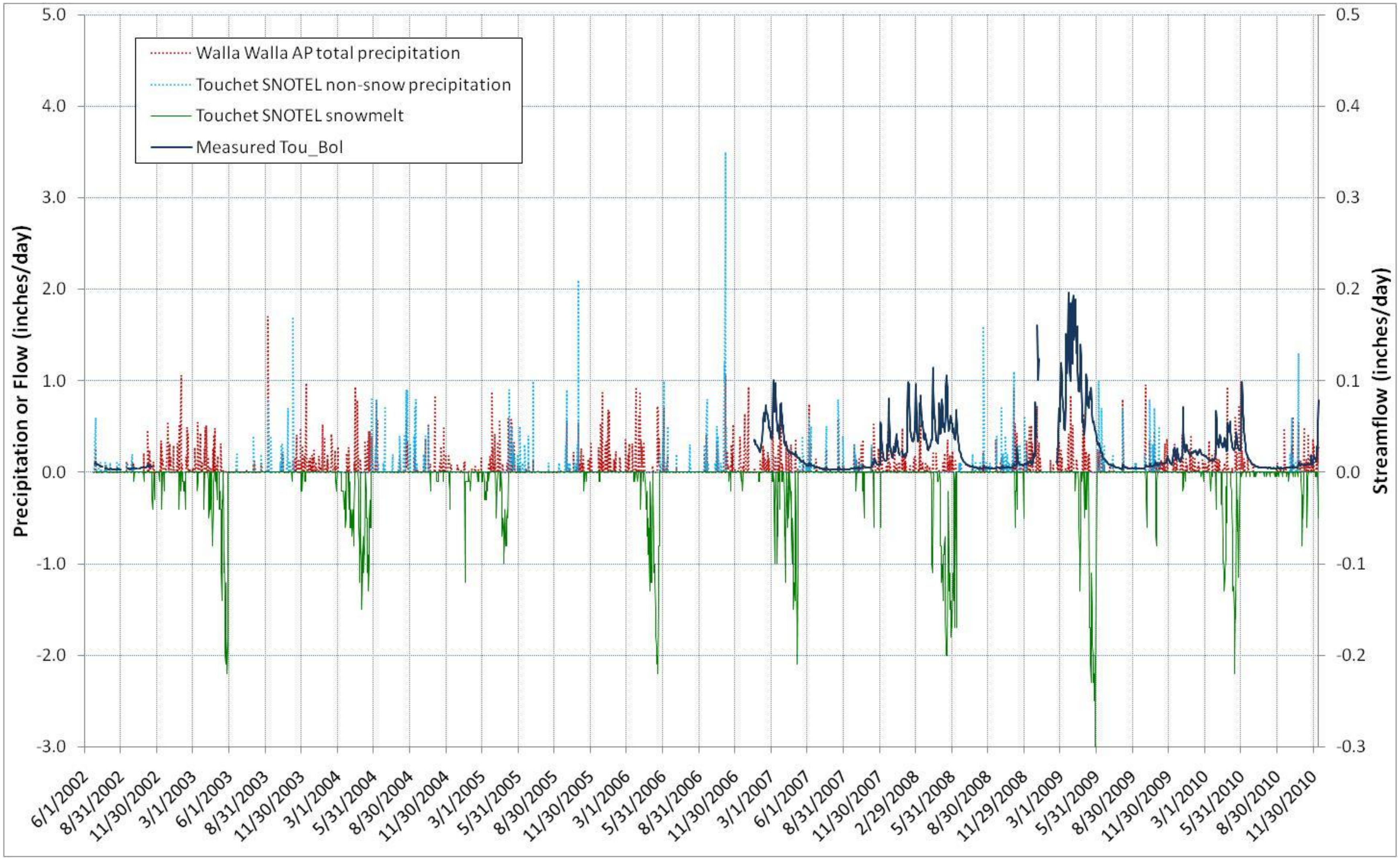


Figure 27. Measured areal flows at the "Touchet River at Bolles" gaging station, with precipitation and snowmelt data.

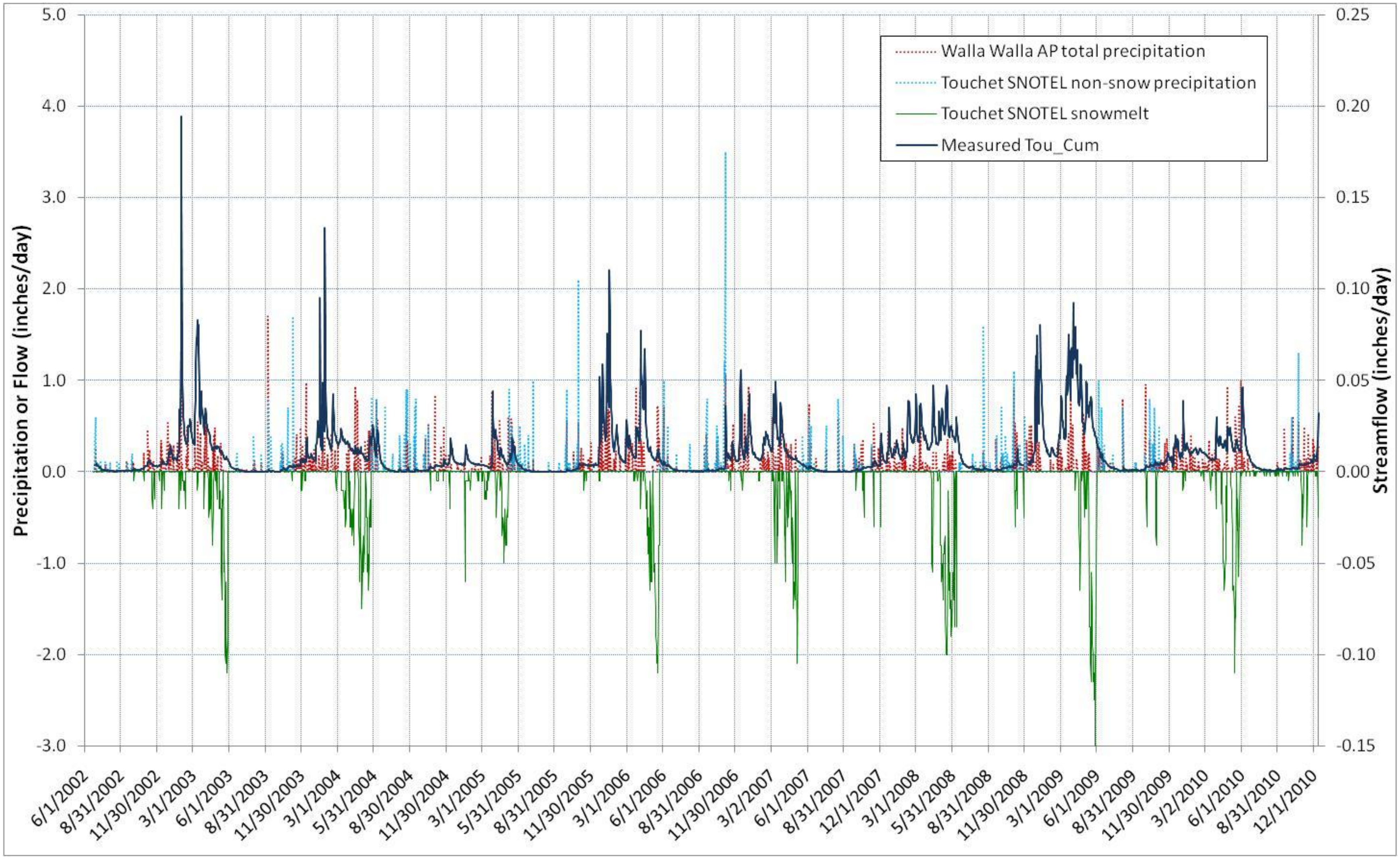


Figure 28. Measured areal flows at the “Touchet River at Cummins Road” gaging station, with precipitation and snowmelt data.

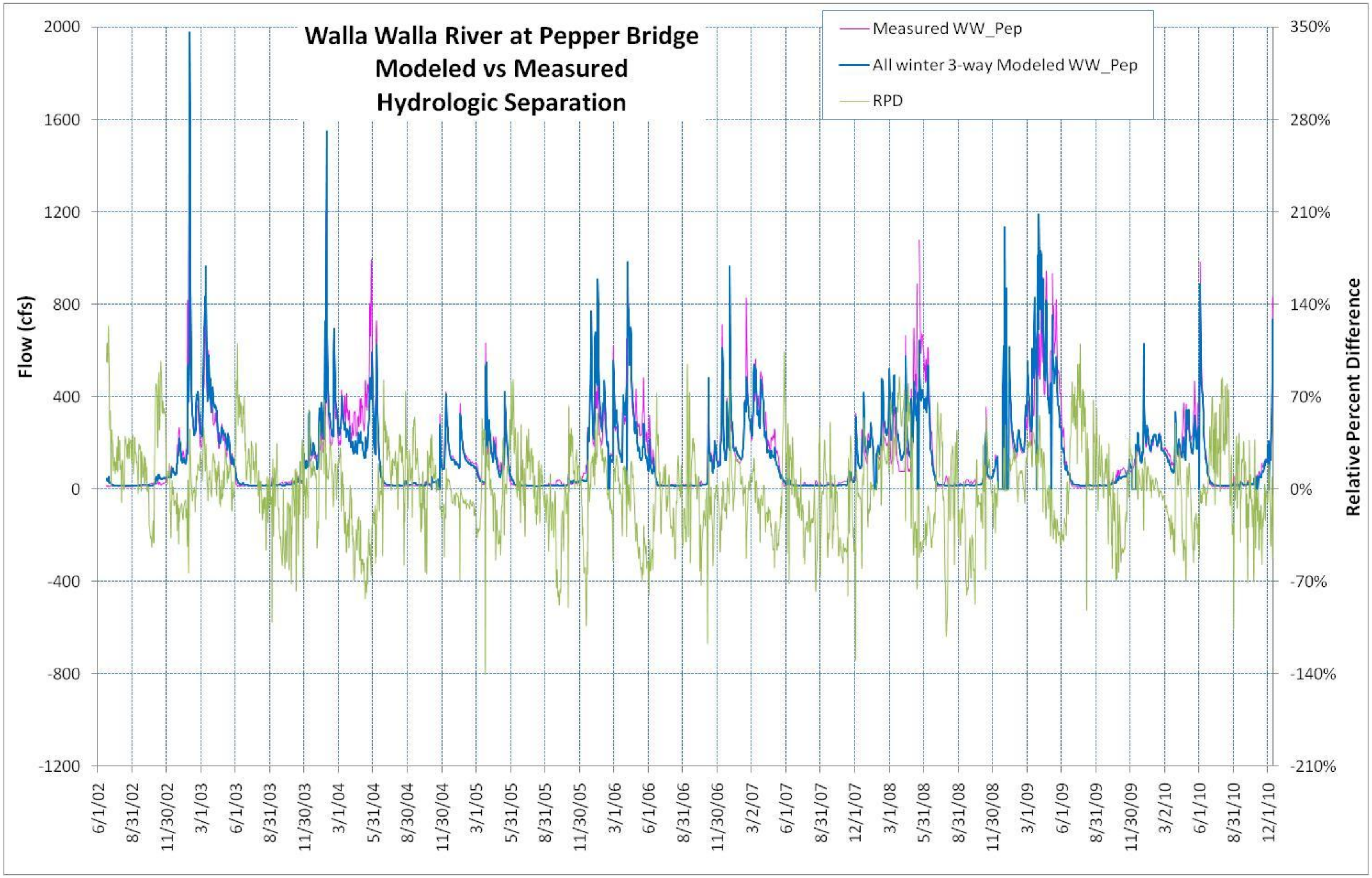


Figure 29. Measured flows at the Ecology “Walla Walla River at Pepper Bridge” gaging station, and modeled flows based on the “Walla Walla River near Touchet” station, with relative percent difference of paired values.

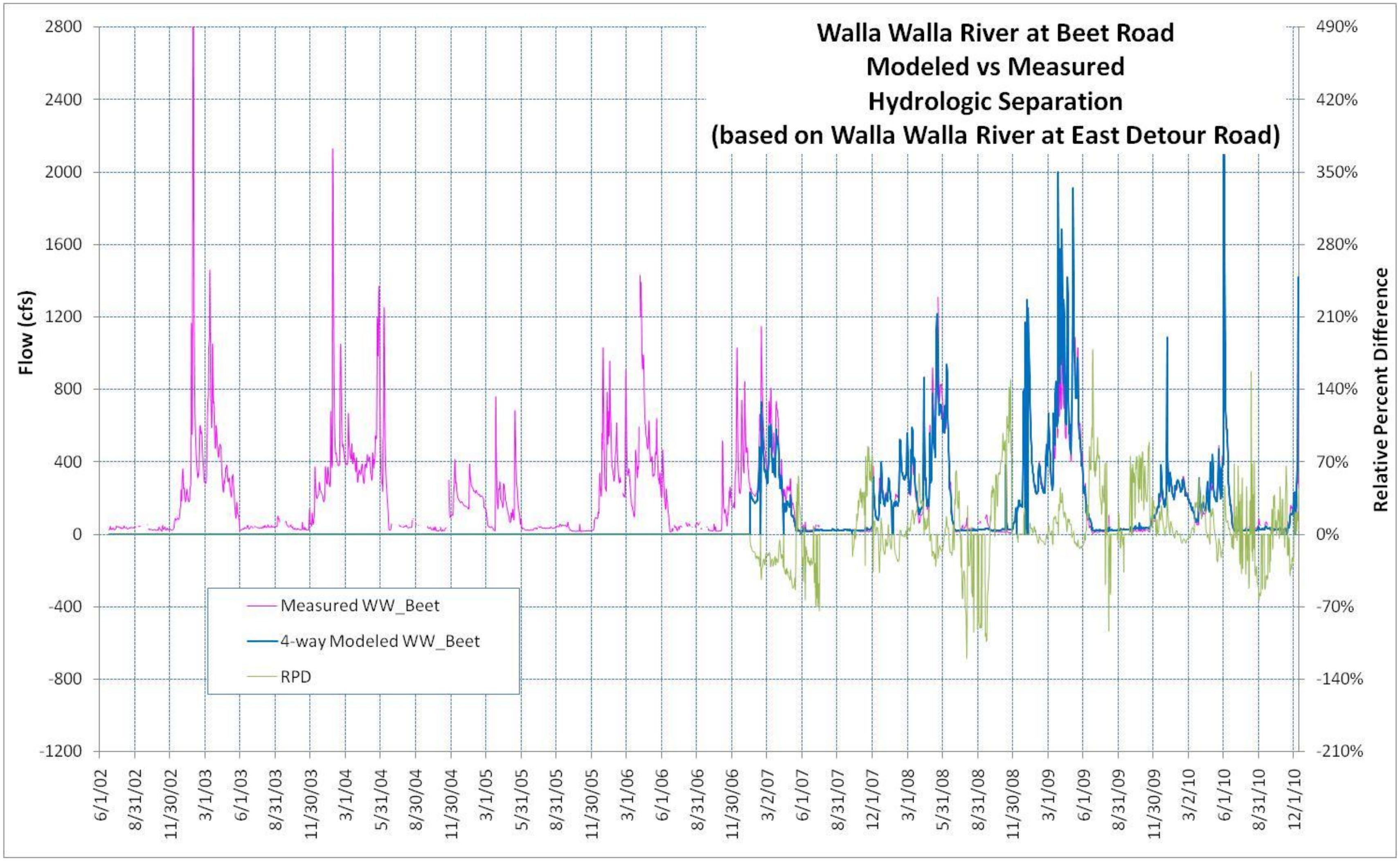


Figure 30. Measured flows at the Ecology “Walla Walla River at Beet Road” gaging station, and modeled flows based on the “Walla Walla River at East Detour Road” station, with relative percent difference of paired values.

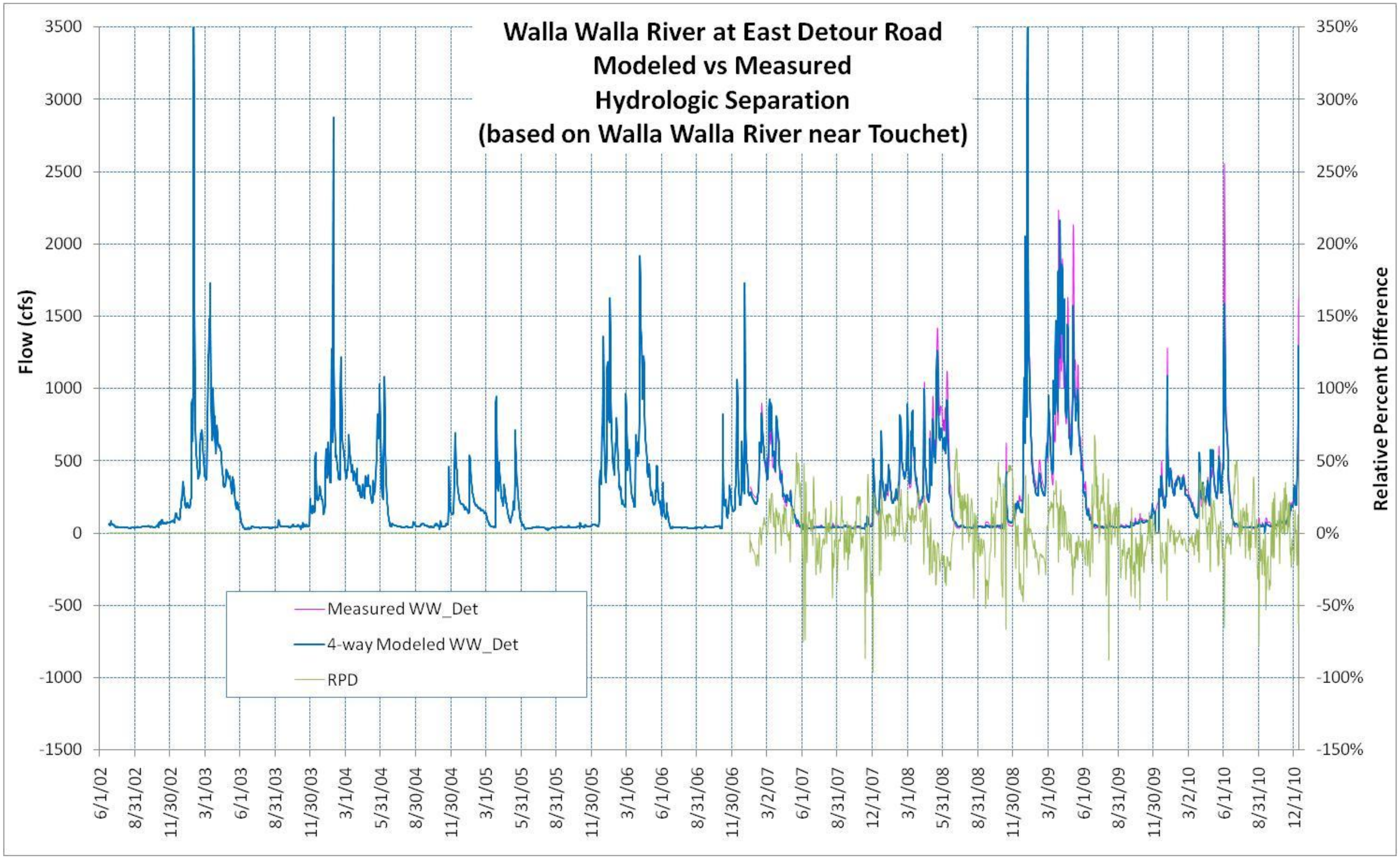


Figure 31. Measured flows at the Ecology "Walla Walla River at East Detour Road" gaging station, and modeled flows based on the "Walla Walla River near Touchet" station, with relative percent difference of paired values.

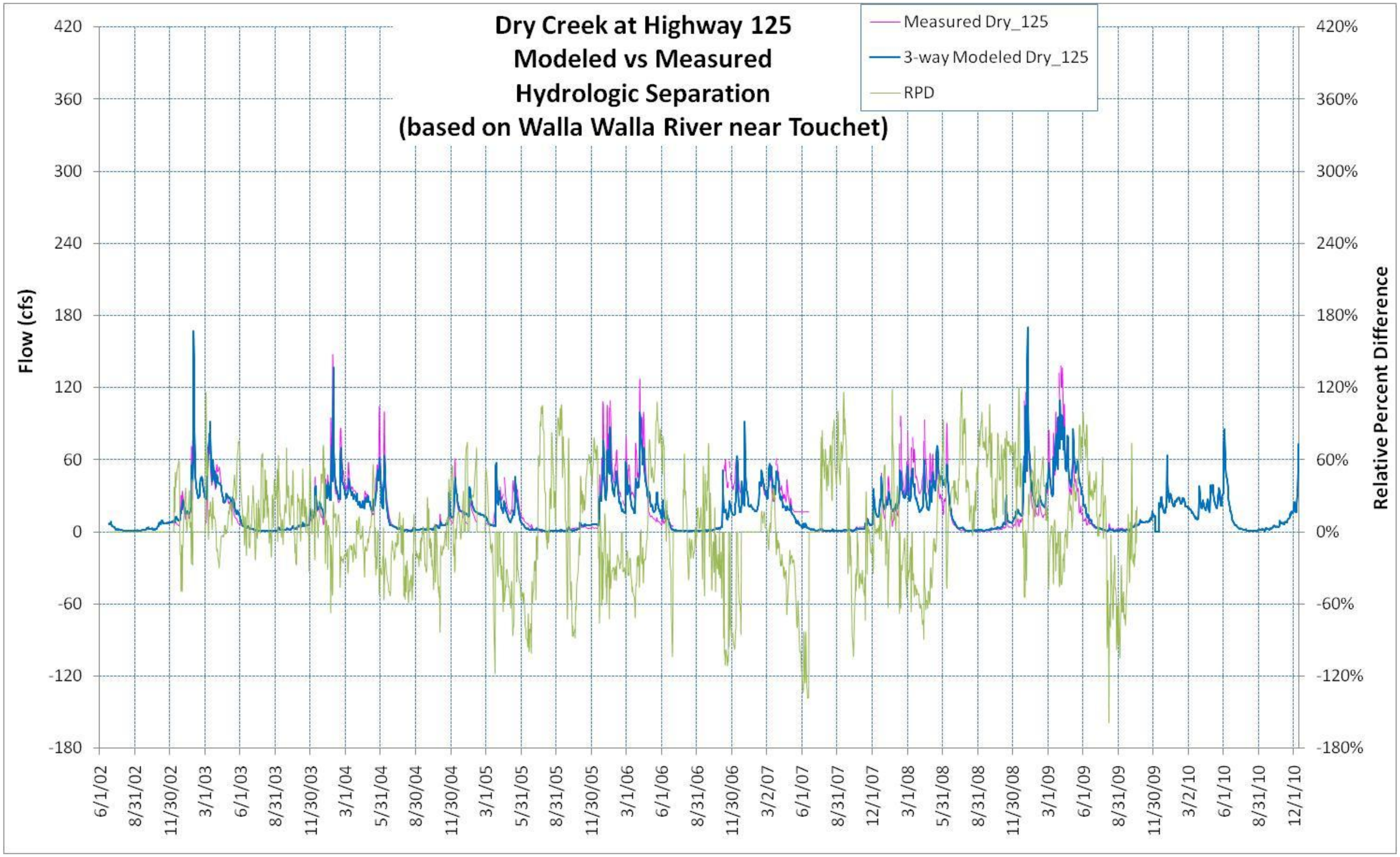


Figure 32. Measured flows at the Ecology "Dry Creek at Highway 125" gaging station, and modeled flows based on the "Walla Walla River near Touchet" station, with relative percent difference of paired values.

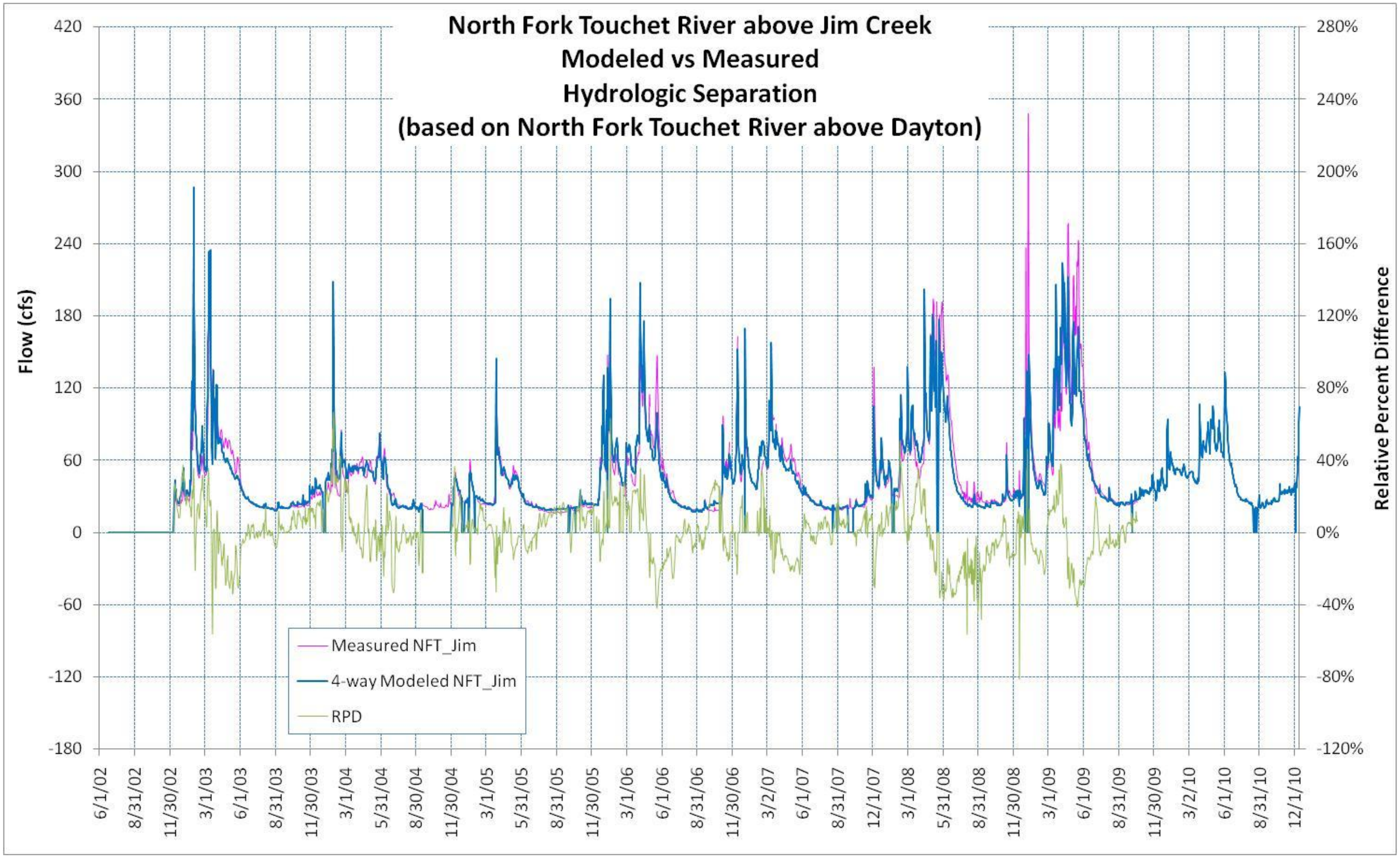


Figure 33. Measured flows at the Ecology "North Fork Touchet River above Jim Creek" gaging station, and modeled flows based on the "North Fork Touchet River above Dayton" station, with relative percent difference of paired values.

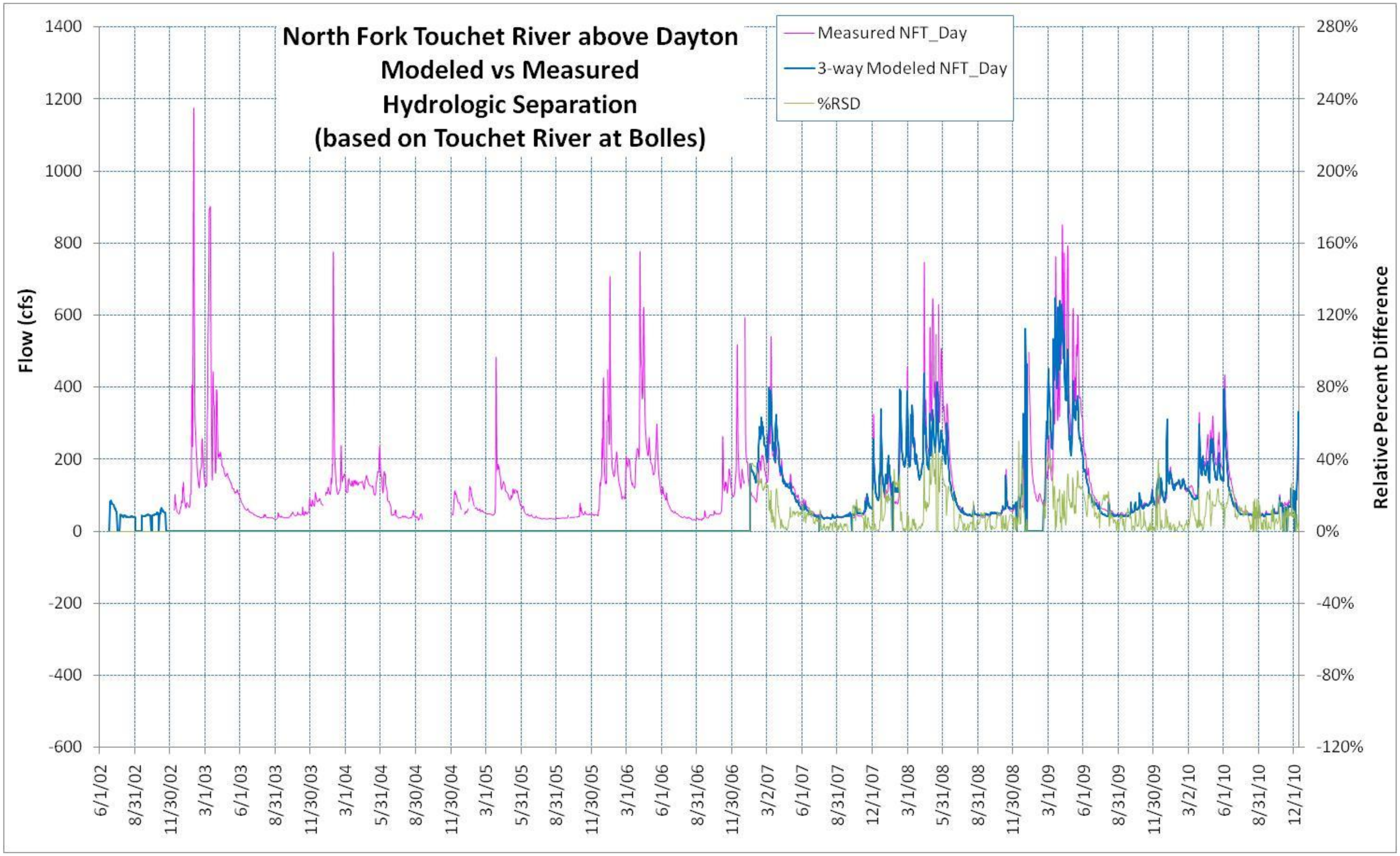


Figure 34. Measured flows at the Ecology "North Fork Touchet River above Dayton" gaging station, and modeled flows based on the "Touchet River at Bolles" station, with relative percent difference of paired values.

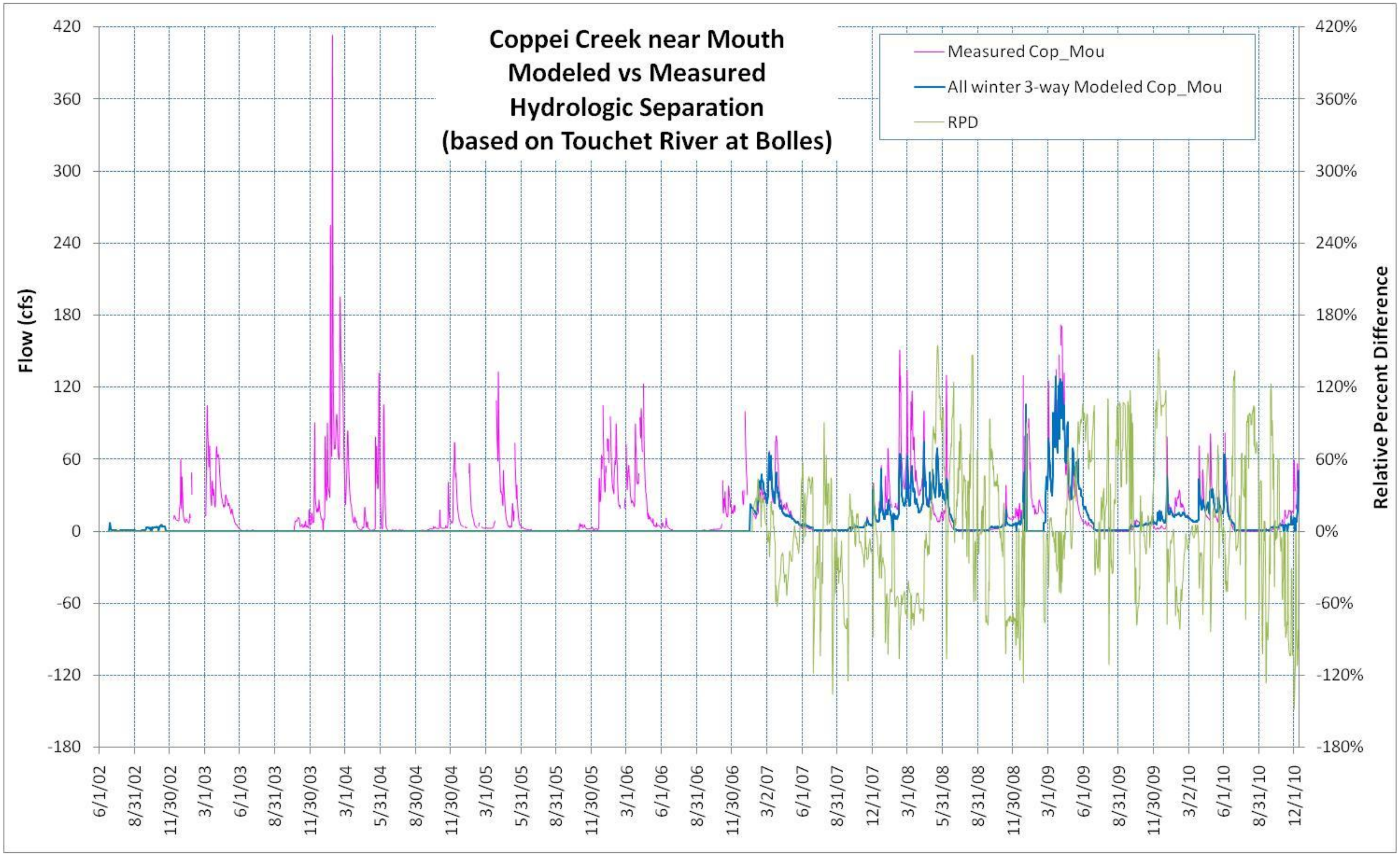


Figure 35. Measured flows at the Ecology "Coppei Creek near Mouth" gaging station, and modeled flows based on the "Touchet River at Bolles" station, with relative percent difference of paired values.

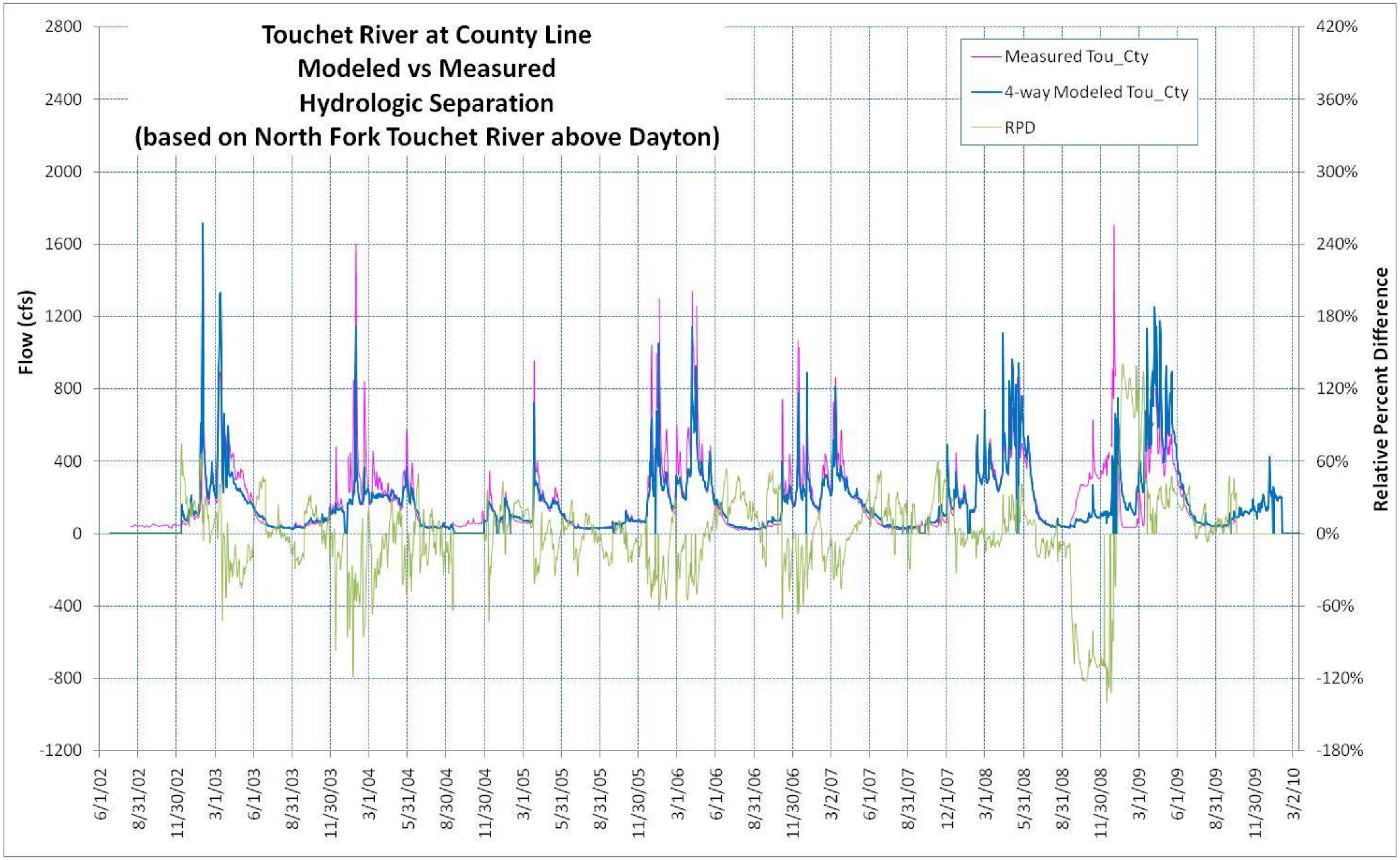


Figure 36. Measured flows at the Ecology "Touchet River at County Line" gaging station, and modeled flows based on the "North Fork Touchet River above Dayton" station, with relative percent difference of paired values.

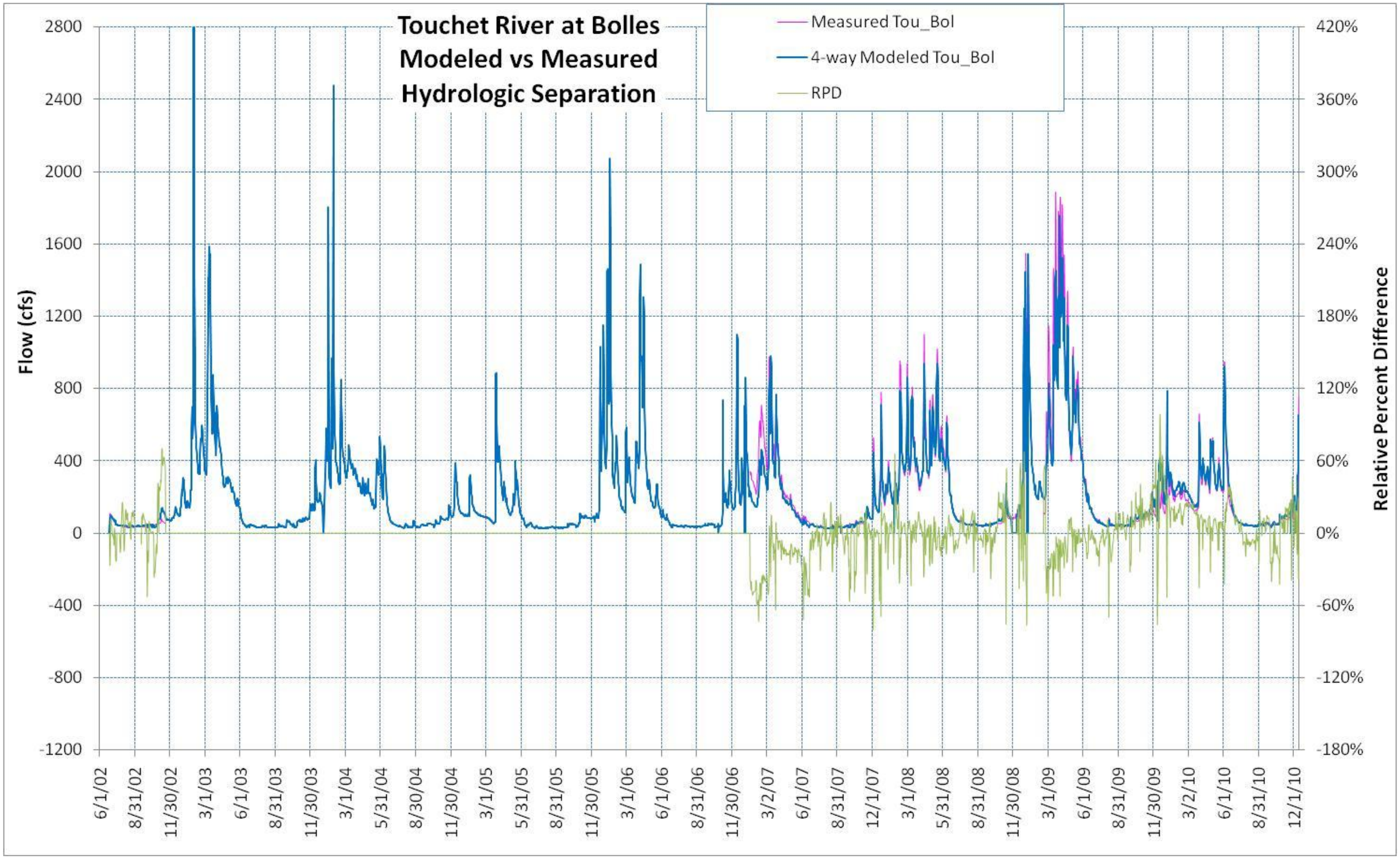


Figure 37. Measured flows at the Ecology "Touchet River at Bolles" gaging station, and modeled flows based on the "Touchet River at Cummins Road" station, with relative percent difference of paired values.

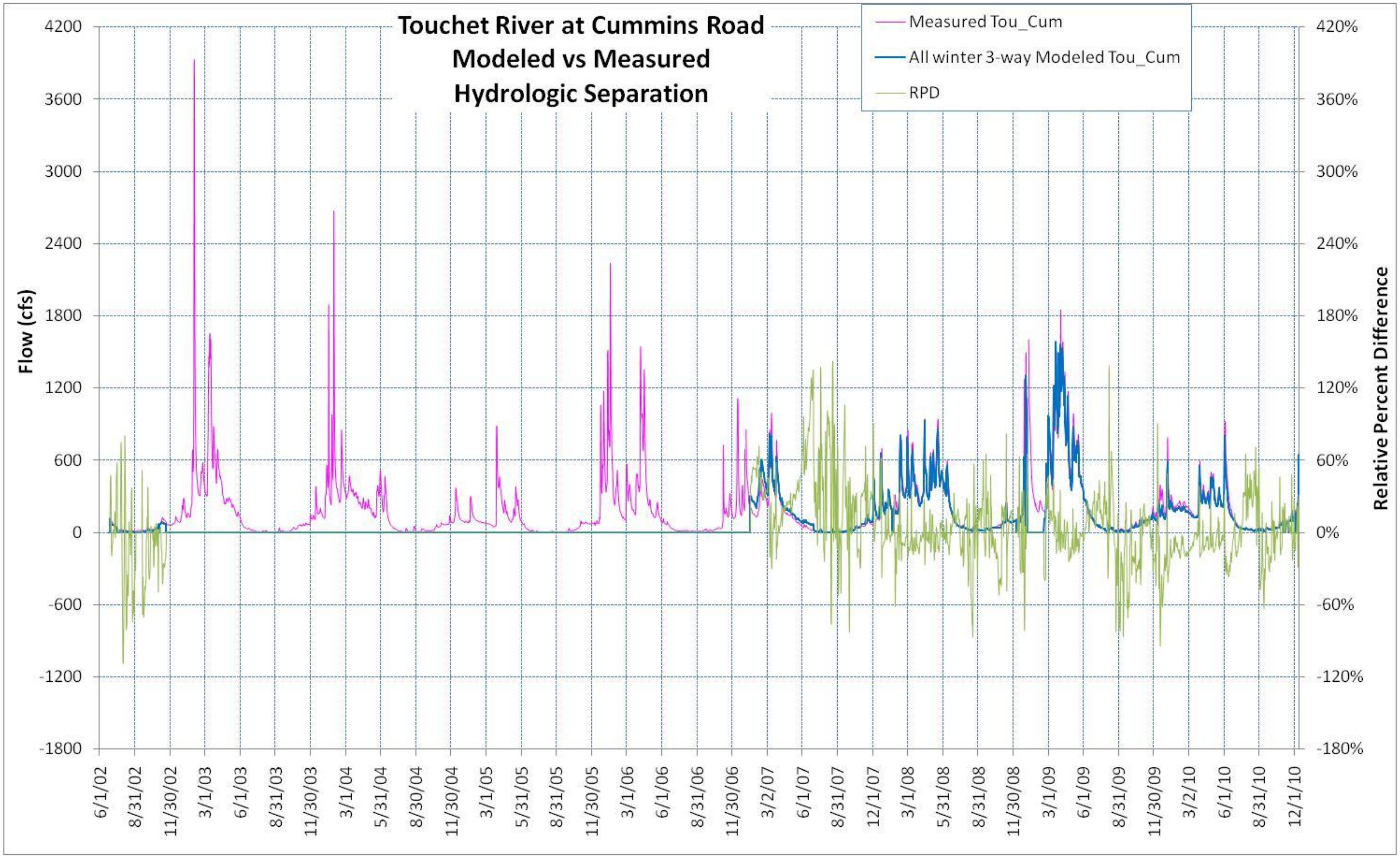


Figure 38. Measured flows at the Ecology "Touchet River at Cummins Road" gaging station, and modeled flows based on the "Touchet River at Bolles" station, with relative percent difference of paired values.

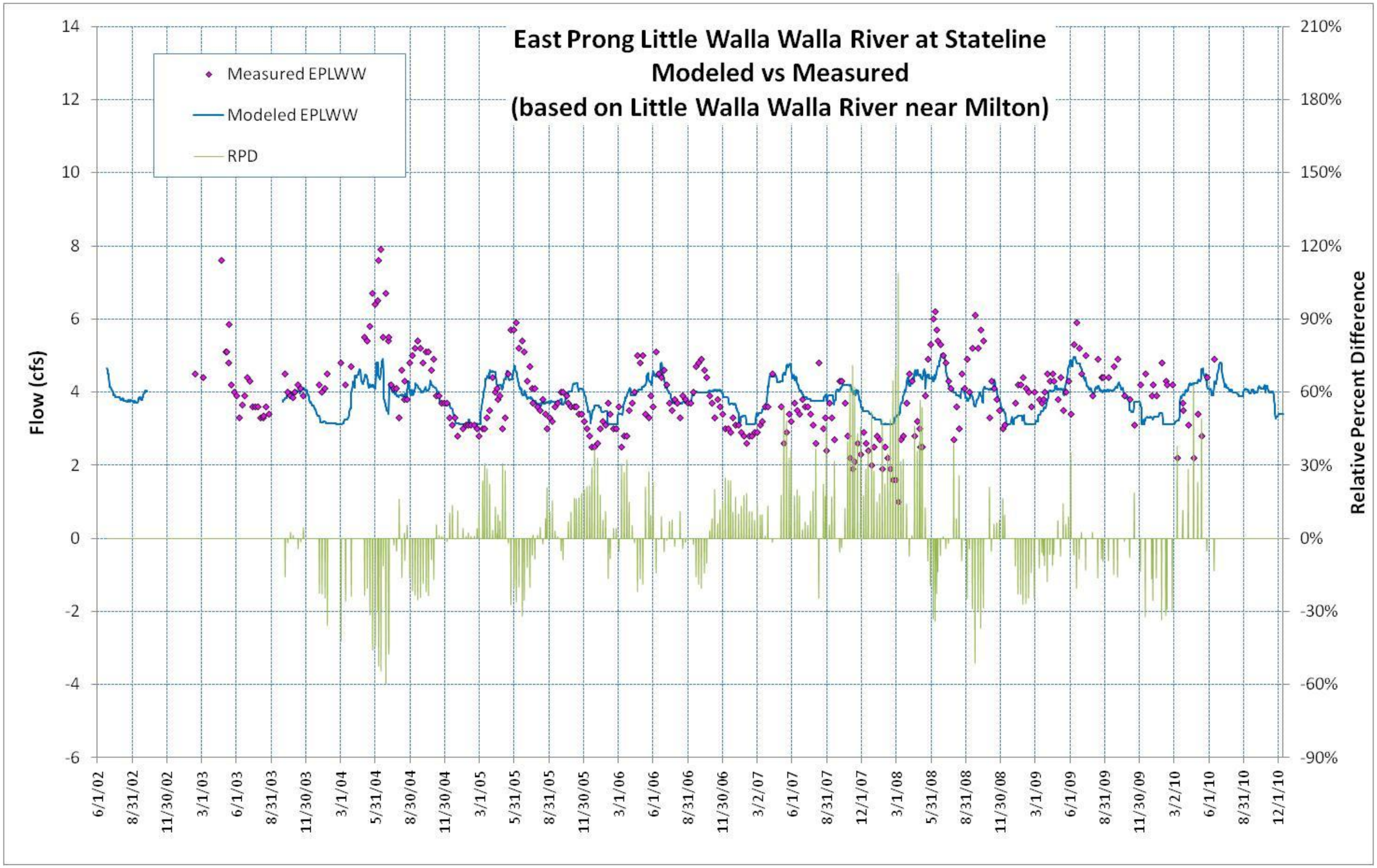


Figure 39. Measured flows at the Ecology "East Prong Little Walla Walla River at Stateline" gaging station, and modeled flows based on the "Little Walla Walla River near Milton" station, with relative percent difference of paired values.

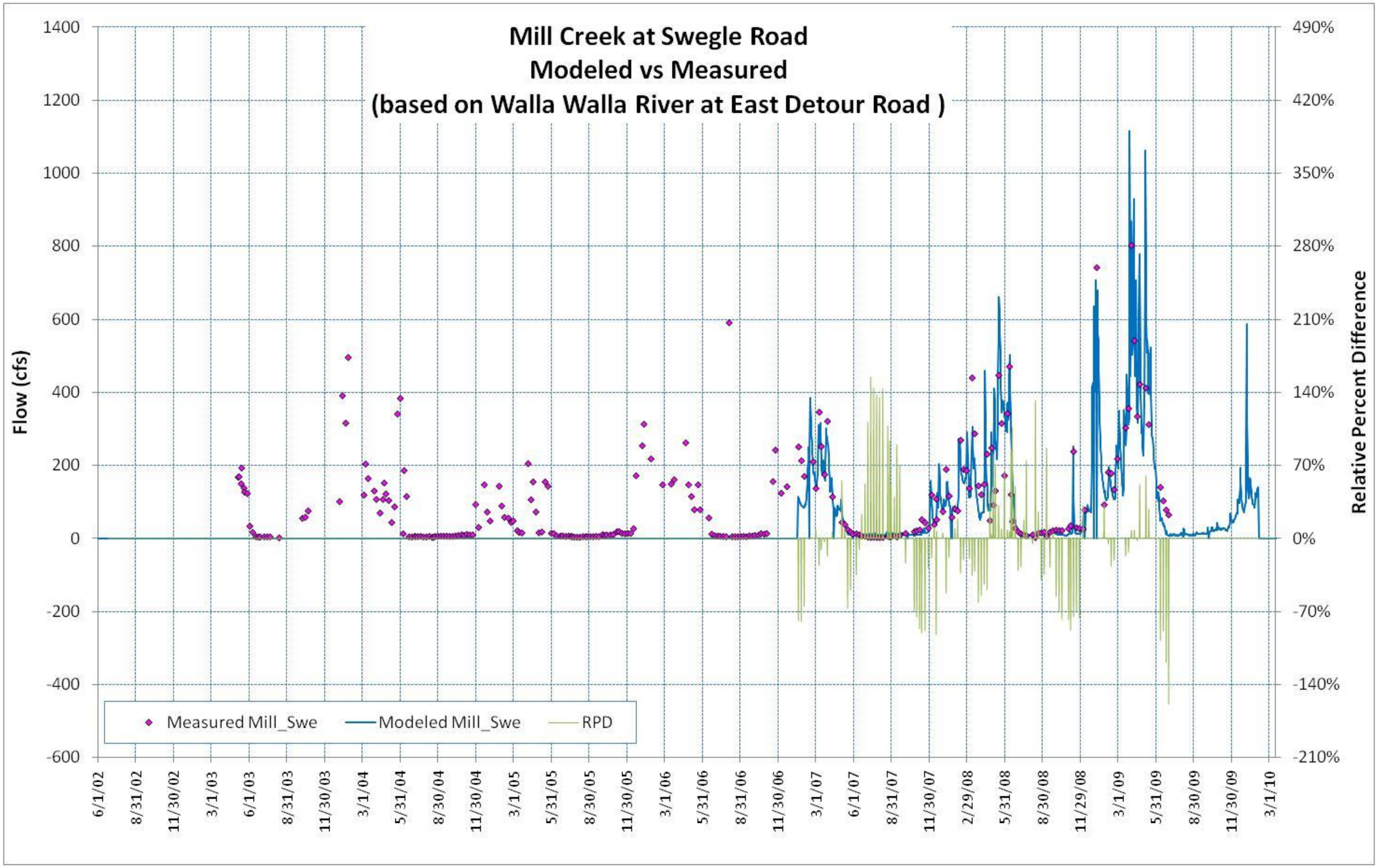


Figure 40. Measured flows at the Ecology "Mill Creek at Swegle Road" gaging station, and modeled flows based on the "Walla Walla River at East Detour Road" station, with relative percent difference of paired values.

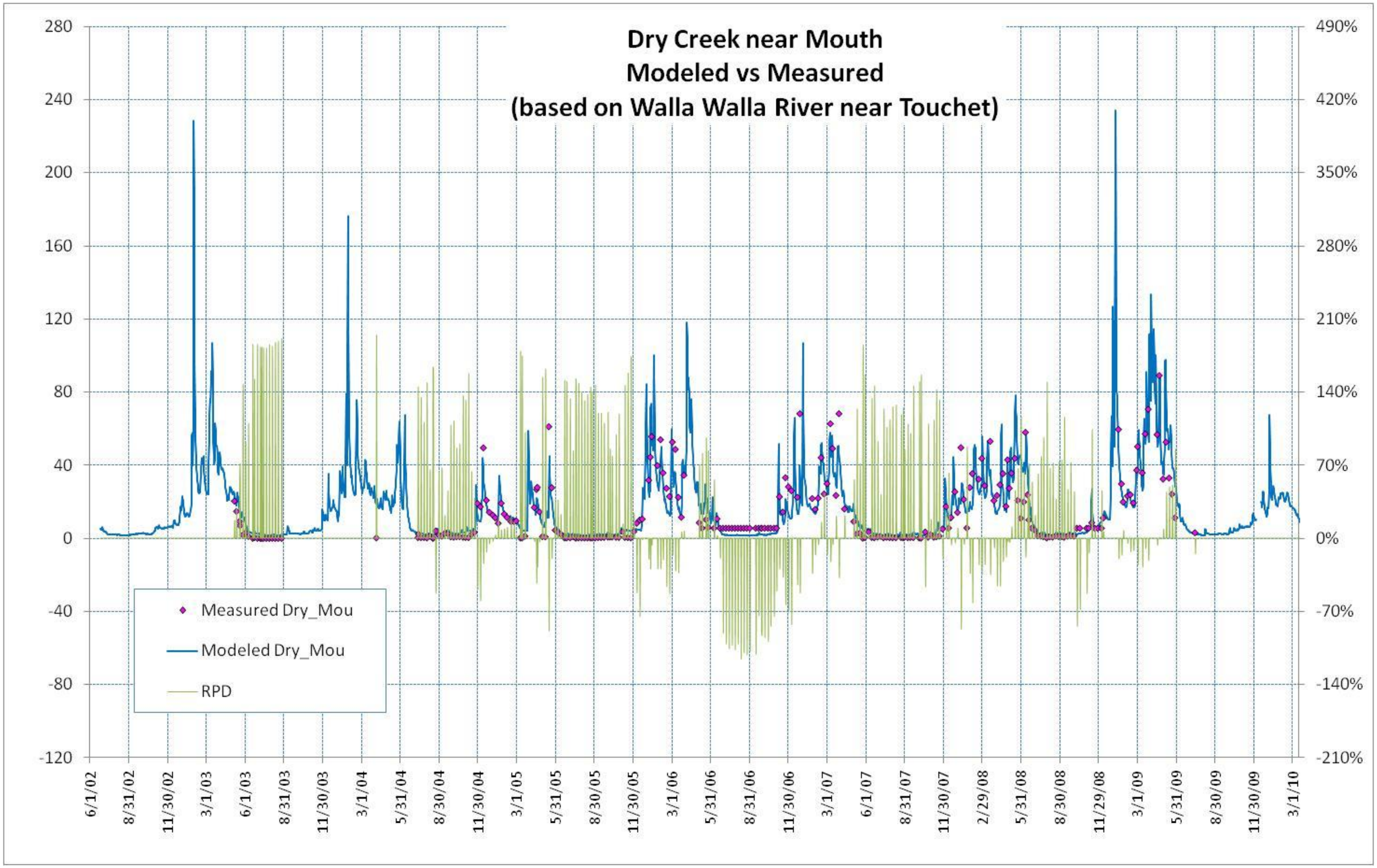


Figure 41. Measured flows at the Ecology "Dry Creek near Mouth" gaging station, and modeled flows based on the "Walla Walla River near Touchet" station, with relative percent difference of paired values.

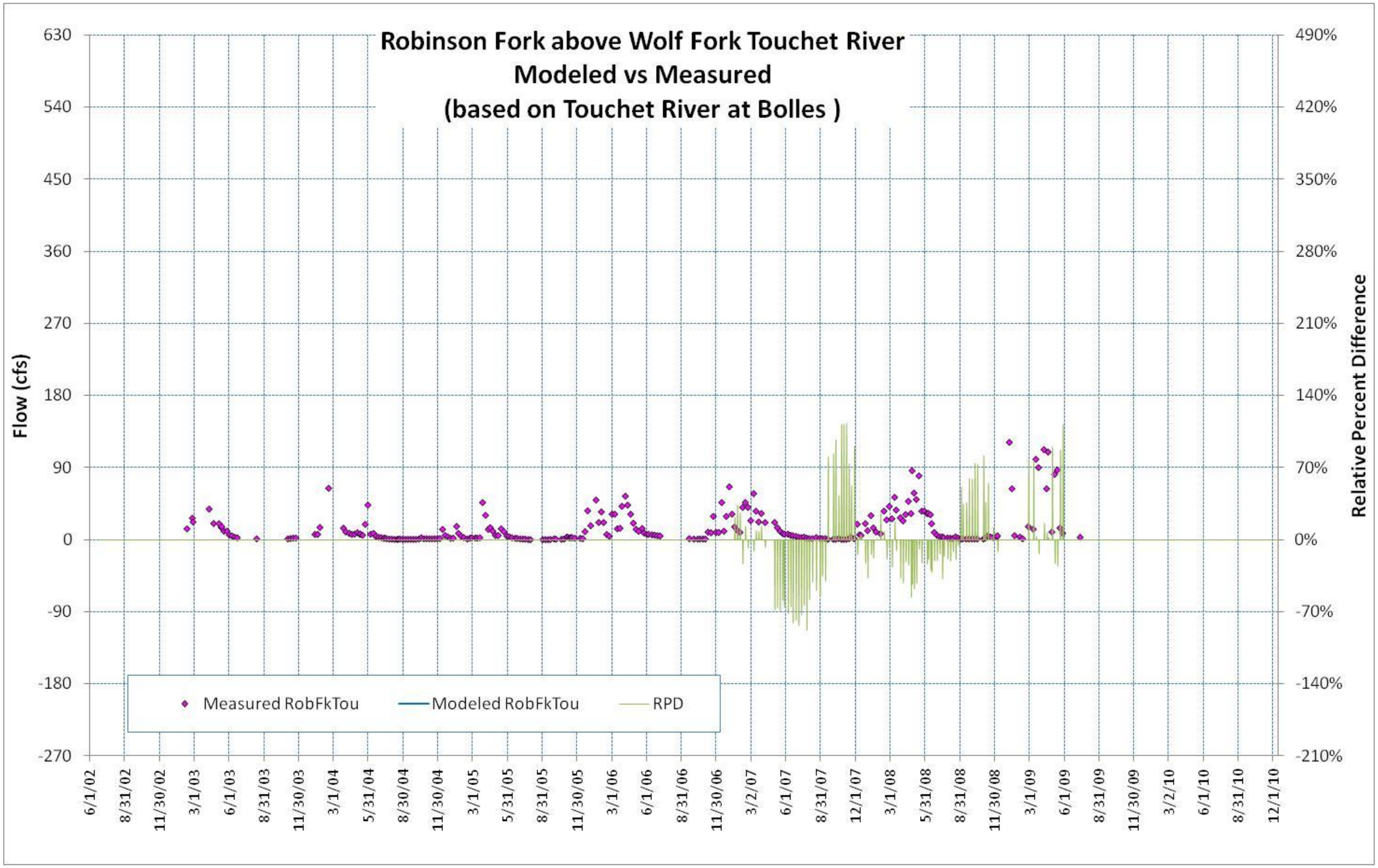


Figure 42. Measured flows at the Ecology "Robinson Fork above Wolf Fork Touchet River" gaging station, and modeled flows based on the "Touchet River at Bolles" station, with relative percent difference of paired values.

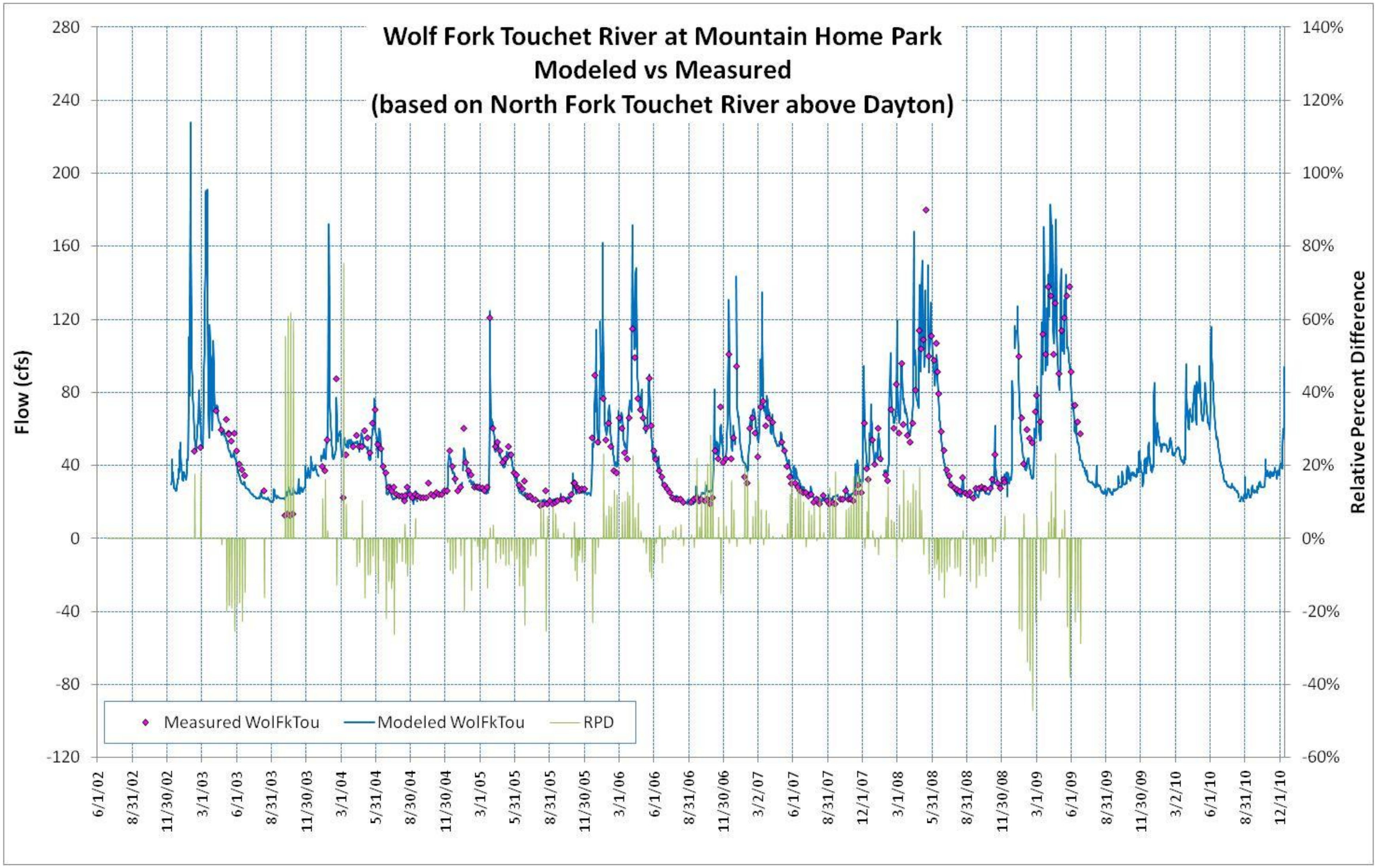


Figure 43. Measured flows at the Ecology "Wolf Fork Touchet River at Mountain Home Park" gaging station, and modeled flows based on the "North Fork Touchet River above Dayton" station, with relative percent difference of paired values.

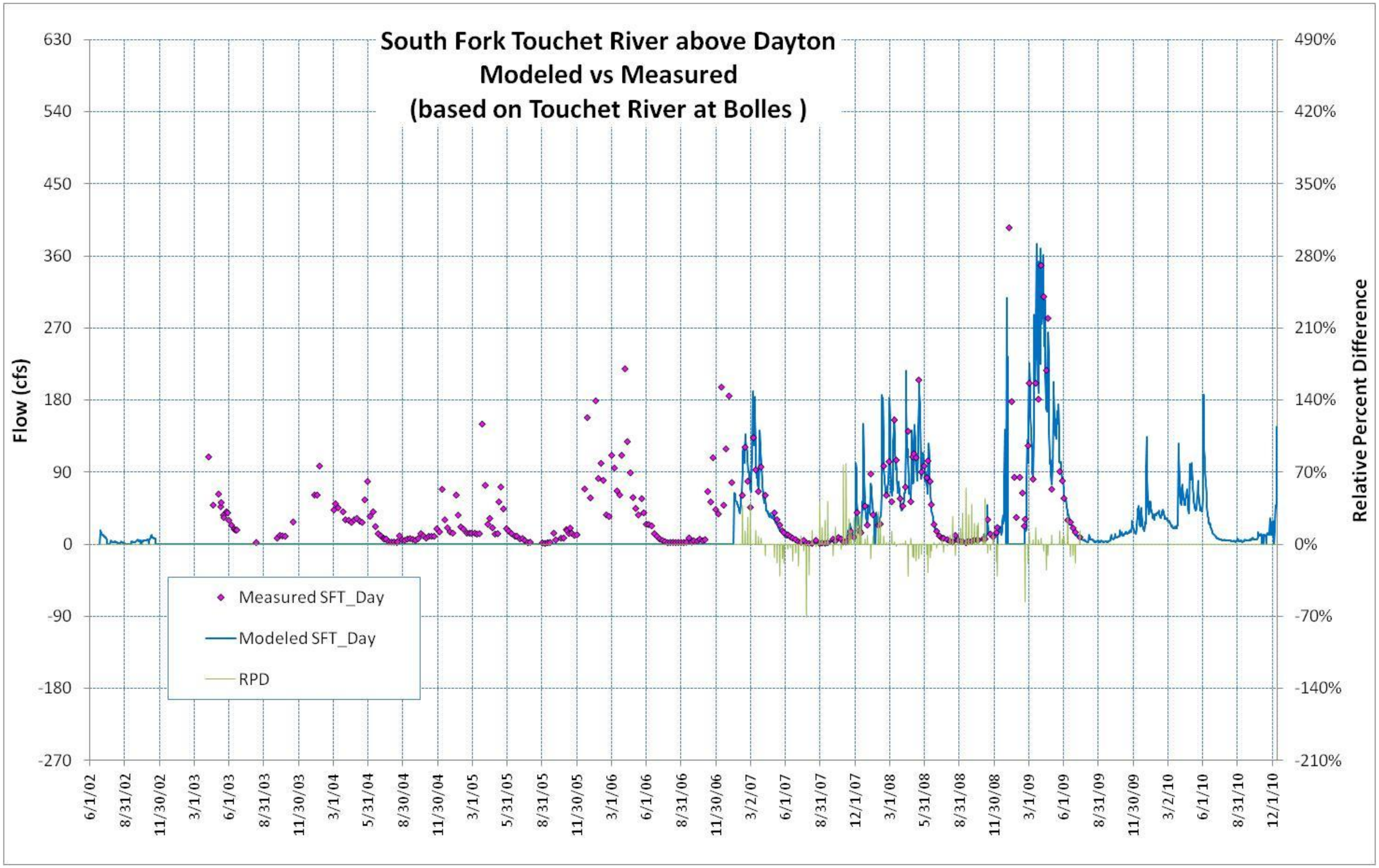


Figure 44. Measured flows at the Ecology "South Fork Touchet River above Dayton" gaging station, and modeled flows based on the "Touchet River at Bolles" station, with relative percent difference of paired values.

This page is purposely left blank

Appendix. Glossary Acronyms, and Abbreviations

Glossary

Areal flow: Surface water discharge per unit of watershed area, in units of length per time (for example, inches per day).

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

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.

Hyporheic zone: The area beneath and adjacent to a stream where surface water and groundwater intermix.

Parameter: A physical chemical or biological property whose values determine environmental characteristics or behavior.

Partnership: The Walla Walla Watershed Management Partnership, a local inter-governmental jurisdiction established by the Washington State legislature.

Reach: A specific portion or segment of a stream.

Seepage run: A study of streamflow that identifies gaining and losing reaches and determines reach-specific magnitudes of groundwater/surface water exchange by calculating a detailed flow balance for the stream from a synoptic series of flow measurements.

Stage height: Water surface elevation.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snowmelt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

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

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

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

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Water year (WY): An annual period defined by hydrologic characteristics. The water year used in this study is October 1 through September 30, and the number of the year represents the calendar year at the end of the water year. For example, "WY 2003" describes the water year beginning October 1, 2002 and ending September 30, 2003.

Weir: a small dam in a stream or river to raise the water level or divert its flow.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

%RSD	Percent relative standard deviation
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
GFID	Gardena Farms Irrigation District
GIS	Geographic information system
gpm	gallons per minute
HBDIC	Hudson Bay District Improvement Company
HUC	Hydrologic Unit Code
ID	Identification Code
mgd	million gallons per day
n	number of values
NAD	North American Datum
No.	Number
OWRD	Oregon Water Resources Department
Partnership	(See Glossary above)
QAPP	Quality Assurance Project Plan
r^2	Coefficient of determination
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
WMP	Watershed Management Project
WRIA	Water Resource Inventory Area
WWBWC	Walla Walla Basin Watershed Council
WWRID	Walla Walla River Irrigation District
WY	Water Year (See Glossary above)