DEPARTMENT OF
ECOLOGY
State of Washington

Quality Assurance Project Plan

Wenatchee Watershed Planning Area Assessment of Gaged Streamflows by Modeling

March 2011
Publication No. 11-03-104

Publication Information

Each study conducted by the Washington State Department of Ecology must have an approved Quality Assurance Project Plan. The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completing the study, Ecology will post the final report of the study to the Internet.

The plan for this study is available on the Department of Ecology's website at www.ecy.wa.gov/biblio/1103104.html.

Ecology's Activity Tracker Code for this study is 09-529.

Waterbody Numbers: WA-45-1011, -1012, -1013, -1014, -1015, -1017, -1020, -1100, -1200, -1900, -1901, -2000, -3000, -3900, -4000, -5000.

Author and Contact Information

Paul Pickett
P.O. Box 47600
Environmental Assessment Program
Washington State Department of Ecology
Olympia, WA 98504-7710

For more information contact: Communications Consultant, phone 360-407-6834.

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

Quality Assurance Project Plan

Wenatchee Watershed Planning Area
Assessment of Gaged Streamflows by Modeling

March 2011

Approved by:

Signature:	Date: March 2011
Dave Holland, Client, SEA Program, Central Regional Office	
Signature:	Date: March 2011
Bill Zachmann, Client, SEA Program	
Signature:	Date: March 2011
Brad Hopkins, Client, EA Program	
Signature:	Date: March 2011
Robert F. Cusimano, Client's Section Manager, EA Program	
Signature:	Date: March 2011
Paul Pickett, Author / Project Manager, EA Program	
Signature:	Date: March 2011
Karol Erickson, Author's Unit Supervisor, EA Program	
Signature:	Date: March 2011
Will Kendra, Author's Section Manager, EA Program	
Signature:	Date: March 2011
Gary Arnold, Section Manager for Project Study Area, EA Program	
Signature:	Date: March 2011
Bill Kammin, Ecology Quality Assurance Officer	

Signatures are not available on the Internet version
SEA: Shorelands and Environmental Assistance
EA: Environmental Assessment

Table of Contents

List of Figures and Tables

Page

Figures

Tables

Abstract

The Washington State Department of Ecology (Ecology) is proposing a study during 2011 to evaluate Ecology streamflow monitoring gages in the Wenatchee River basin in central Washington State. This area is also called the Wenatchee watershed planning area and makes up most of Water Resource Inventory Area (WRIA) 45. (WRIA 45 also includes some small watersheds that drain directly to the Columbia River but these are not included in the planning area or in this study.)

To predict flows at Ecology stations, regression-based streamflow models will be developed and applied. Existing hydrologic models will also be evaluated for possible use to predict flows at Ecology flow monitoring stations.

The quality of all computer modeling tools applied will be evaluated, and recommendations will be made for use of the models for water management by Ecology and the Wenatchee Watershed Planning Unit. The Planning Unit is comprised of local citizens and local, state, and federal government representatives.

Background

Overview of the Watershed

The focus of this study is WRIA 45 (see Figure 1), which is also referred to as the Wenatchee Watershed Planning Area. The descriptions of the basin in this section are summarized from the Final Wenatchee Watershed Management Plan (WRIA 45 Planning Unit, 2006).

Geography

The Wenatchee River is a tributary of the Columbia River, with its mouth at the city of Wenatchee, Washington. The basin area is 1,330 square miles (344,500 hectares) and includes 230 miles of major rivers and streams. The headwaters of the Wenatchee basin lie in the Cascade Mountains to the west. The Little Wenatchee and White Rivers flow into Lake Wenatchee, and the Wenatchee River mainstem begins at the outlet of the lake.

The Wenatchee basin is diverse geographically and hydrologically. Elevations range from 600 feet (180 meters) at the mouth of the river to over 8,200 feet (2,500 meters) in the highest areas of the watershed. Its upper reaches are mountainous and forested, with alpine and glaciated areas at the highest elevations, while the downstream low-lying areas are semi-arid and mostly agricultural. There are several small towns in the basin and the City of Wenatchee urban area lies at the mouth.

Climate

Winters are cold (averaging 15 to 30° F, or -9 to -1° C) with much of the precipitation as snow, especially in the mountains. Summers are hot (averaging 60 to 90° F, or 16 to 32° C) and dry.

The lower east end of the basin lies in the rain shadow of the Cascade Mountains with average precipitation of 8 inches (200 millimeters) per year. Precipitation increases towards the Cascade Mountains crest in the west end of the basin, where precipitation averages 130-150 inches (3,000 to 3,800 millimeters) per year. This precipitation falls mainly in winter (November through March), with thunderstorms occurring occasionally during the summer (typically 7-8 per year). In the lower parts of the basin, precipitation comes mainly as rain, while the uplands receive mostly snow. Snow depths during an average winter are typically less than a half foot on the lowlands, but the higher elevations receive, on average, between 10 and 20 feet of snow.

Hydrology

Five major tributaries account for over 90% of the surface water in the watershed:

- Little Wenatchee River
- White River
- Chiwawa River
- Nason Creek
- Icicle Creek

These tributaries combined are the "headwaters" of the Wenatchee River and drain the highest elevations at the crest of the Cascades.

Other important tributaries include:

- Chiwaukum Creek
- Chumstick Creek
- Peshastin Creek
- Mission Creek

Flows in the higher elevations and main tributaries are dominated by snowmelt during the late spring and early summer. Low flows in summer and early fall are generally produced by groundwater inflows and irrigation return flows. Rainfall events can increase flows in the lower elevations in the fall, winter, and spring.

Groundwater resources are located primarily in bedrock or overlying sediment deposits. Productive aquifers can be found in alluvial and glacial outwash sediments. The geology of aquifers is varied and not continuous across the watershed. Little is known about the total amount of groundwater available.

Land Ownership, Land Use, and Water Use

Political jurisdictions in WRIA 45 include Chelan County, the City of Wenatchee, and the smaller cities of Cashmere and Leavenworth. The Wenatchee basin is within the Usual and Accustomed fishing areas for the Yakama Nation established by treaty. Other local jurisdictions include the Chelan County Conservation District, Wenatchee Reclamation District, Chelan Public Utility District, and several Irrigation Districts. Less than 20% of the basin is privately owned, and much of the basin is U.S. Forest Service land.

The primary land uses in the Wenatchee basin are forest management and production, orchard production, residential and lodging, agricultural support, and home-based industry. The population was approximately 23,850 in 2005, and is expected to increase by 2.4% per year from 2000 to 2025.

Municipal and domestic water use has been estimated at about 5,400 acre-feet of water per year in 2002 and is expected to grow to 7,950 acre-feet per year in 2025. These water uses tend to have a steady base consumption rate throughout the year, with a seasonal increase during hot weather due to irrigation of landscape, lawn, and home gardens. Residential, commercial, and industrial water use is expected to increase with population growth.

Agriculture dominates water use in the Wenatchee basin. Total water right applications, claims, permits, and certificates total over 1,000 cubic feet per second (cfs) of instantaneous use. However, there is certainly overlap in some of the claims, permits, and certificates; actual irrigation use is less than that amount. However, this volume of use compares to a maximum daily demand of less than 20 cfs for municipal and domestic use and another 4.4 cfs for commercial and industrial use. Fish propagation uses about 124 cfs.

Watershed Planning

The key group for watershed planning in WRIA 45 is the Wenatchee Watershed Planning Unit. Chelan County is the Lead Agency, and a variety of organizations participated.

The Wenatchee Watershed Planning Unit is described on its website:

> *The Wenatchee Watershed Planning Unit is made up of a diverse group of stakeholders representing a wide range of interests throughout the watershed. These interests include local governments, tribes, state and federal agencies, irrigation, agriculture, forestry, community groups, conservation groups, economic development, recreation, and individual citizens. In addition to the required water quantity component, the Planning Unit decided to address the instream flow, water quality, and habitat components as well. The efforts of the Wenatchee Watershed Planning Unit have led to the development of the final Wenatchee Watershed Management Plan which was completed in April 2006. Since then, a detailed implementation plan (completed in 2008) prioritizes projects for implementation.*
> (www.co.chelan.wa.us/nr/planning/watershed_planning/default.htm)

The Wenatchee Watershed Planning Unit is the primary forum for stakeholder input into this project.

Streamflow Gages and Models

Streamflow Measurement

The Washington State Department of Ecology (Ecology) has historically operated 27 flow monitoring stations (www.ecy.wa.gov/programs/eap/flow/shu_main.html, and Figure 1) in the Wenatchee basin. These stations consist of:

- Ten active *telemetry* gages providing real-time data.
- Seven historical staff gages where *manual stage height* readings were collected infrequently (at least once per month) over several years and converted to instantaneous flow values. Most of these stations were used for total maximum daily load (TMDL) studies. (Two of these stations are now active telemetry gages.)
- Six historical season gages with less than one year of *continuous* data.
- Six historical staff gages with less than one year of manual stage height readings.

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

The Ecology stations that will be analyzed in this study are shown in Table 1. The ten active gages have sufficient data to be included, although the Icicle Creek station was a staff gage only until recently. The stations with manual staff gage data over multiple years will also be analyzed. The other stations with less than one year of data will not be included in this study.

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

- Five active stations in WRIA 45. These are listed in Table 2. Four of the five stations are partially funded by Ecology.
- Nine historical stations in WRIA 45 with continuous flow. The USGS historical stations have no data after 1983 and will not be used for this analysis.

Hydrologic Modeling

Hammond, et al. (1997) conducted a detailed statistical analysis of stream hydrology in the Wenatchee National Forest. This study includes the five active USGS gaging stations and several stations in locations close to Ecology's current gages.

Karrer (2005) developed regressions between gages in the Wenatchee basin in order to develop exceedance hydrographs for five stations: Peshastin, Nason, and Chumstick Creeks; and the Wenatchee River above and below Icicle Creek. An extended synthetic record was developed for each of these sites using a USGS gage with a long historic record of flow data.

Although the method and purposes described in these two reports are somewhat different from this proposed study, they provide a useful reference point for comparison.

Table 1. Ecology flow monitoring stations in WRIA 45 included in this study.

ID	Station Name	Code	Status	Type[1]	Start	End	No. days	Comment
45N060	Rock Creek near Mouth	Rock	Active	T	20-Sep-02	present	1304	
45K090	White River near Plain	White	Active	T	20-Sep-02	present	2807	
45L110	Little Wenatchee River below Rainy Creek	LWen	Active	T	18-Sep-02	present	1791	
45J070	Nason Creek near mouth	Nason	Active	T	16-May-02	present	2639	
45A240	Wenatchee River below Lake Wenatchee	Wen-Lk	Active	T	14-May-02	present	953	
45G060	Chiwaukum Creek near mouth	Chwkm	Active	T	15-May-02	present	2037	Off-line June 2, 2009 through August 25, 2010
45C060	Chumstick Creek near mouth	Chmstk	Active	T	10-Aug-03	present	2005	
45B070	Icicle Creek near Leavenworth	Ici-EC	Active	T	23-Nov-10	present	33	
45F070	Peshastin Creek at Green Bridge Road	Psh-GB	Active	T	21-Sep-02	present	2724	
45E070	Mission Creek near Cashmere	Miss-EC	Active	T	21-Nov-02	present	2639	
45M060	Rainy Creek near Mouth	Rainy	Historical	M	9-Oct-02	9-Dec-08	107	Converted to telemetry
45P050	White Pine Creek at Mouth	WPine	Historical	M	9-Oct-02	26-Nov-07	75	
45Q060	Eagle Creek near Mouth	Eagle	Historical	M	18-Dec-02	26-May-09	26	
45B070	Icicle Creek near Leavenworth	Ici-EC	Historical	M	3-May-07	19-Jul-10	173	
45F110	Peshastin Creek above Ingalls	Psh-AIn	Historical	M	14-Jan-03	4-Jul-08	100	
45F100	Peshastin Creek below Ingalls	Psh-BIn	Historical	M	25-Jun-03	9-Apr-09	105	
45D070	Brender Creek near Cashmere	Bren	Historical	M	3-Oct-96	26-May-09	243	
45E070	Mission Creek near Cashmere	Miss-EC	Historical	M	3-Oct-96	4-Sep-00	58	

[1] T: Telemetry; M: Manual Gage Height.

Table 2. USGS flow monitoring stations in WRIA 45 included in this study.

Station Name	Code	status	Type[1]	Start Date	End Date	No. days	Ecology Funding[2]
Chiwawa River Near Plain	Chww	Active	RT	1-Oct-2001	present	13929	O&M
Wenatchee River At Plain	Wen-Pln	Active	RT	7-Oct-1989	present	32194	O&M + GOES
Icicle Creek Above Snow Creek Near Leavenworth	Ici-GS	Active	NRT	2-Oct-1993	20-Oct-2010	19019	O&M
Wenatchee River At Peshastin	Wen-Psh	Active	RT	22-Nov-1991	present	29837	None
Mission Creek at Cashmere	Miss-GS	Historical	C	19-May-1954	30-Sep-1958	1596	
Wenatchee River At Monitor	Wen-Mon	Active	RT	26-Jun-1987	present	17570	GOES

[1]RT: Real-time (Telemetry); NRT: Near-Real time; C: Continuous.
[2]O&M: Operation and Maintenance ($7750 in 2010); GOES: telemetry ($1390 in 2010).

The National Oceanic and Atmospheric Administration (NOAA) supports the Advanced Hydrologic Prediction Service (www.weather.gov/oh/ahps/). This program uses hydrologic models to forecast flows in the Wenatchee River at Peshastin. Forecast products are available on the website, but the modeling framework itself is managed by NOAA.

The University of Washington Climate Impacts group has developed hydrologic models based on the VIC modeling framework that include streamflow forecasts for climate change scenarios (http://cses.washington.edu/cig/fpt/fpt.shtml). Its forecasts include the three USGS gages in the Wenatchee River. Forecast products are available (www.hydro.washington.edu/2860/), but the modeling itself is managed by University of Washington researchers.

Streamflow Patterns

To provide a comparison of flows at gages in the watershed, Figures 2 through 6 show distributions of flows at 21 Ecology and USGS continuous and manual staff flow monitoring stations during water years 2003 through 2010.

- Figure 2 shows the wide range of flows at the mainstem Wenatchee River stations. Flows increase steadily as tributaries enter in the downstream direction. High flows approach and likely exceed 10,000 cfs at Monitor, while low flows are typically only a couple hundred cfs throughout the river system.
- The tributaries in the northern basin show similar patterns of wide flow ranges (Figure 3). The Little Wenatchee and White Rivers drain directly into Lake Wenatchee, and along with Nason Creek account for most of the flow in the Wenatchee River below the Lake. Rainy Creek is a tributary of the Little Wenatchee and Rock Creek is a tributary of the Chiwawa River. The Chiwawa River enters the Wenatchee River just below the Lake outlet, and combined with flows leaving the Lake makes up most of the water in Wenatchee River at Plain.
- Figure 4 shows streams in the northeastern portion of the basin. Nason Creek drains from the Cascade crest and shows similar wide ranges of flows as the other headwater tributaries. White Pine Creek is a tributary of Nason Creek, and Chiwaukum Creek is a smaller tributary draining directly to the Wenatchee River. Flows of the latter two creeks are much lower than the headwater tributaries, reflecting that their watersheds are smaller and lower in elevation.
- Southeastern tributaries, Figure 5, show a similar pattern to those in Figure 4. Flows are higher in Icicle Creek, which drains a large, high elevation area, while Peshastin Creek has lower flows due to a smaller and lower elevation drainage. Flow ranges are still quite broad.
- Figure 6 shows the tributaries in the lower basin. Flows are in a range several orders of magnitude lower than the higher elevation tributaries, reflecting less precipitation and snowpack. Summer low flows are extremely low.

Figures 7 through 11 illustrate seasonal flow patterns at gaging stations for water years 2003 through 2010.

- Figure 7 shows flows at the mainstem Wenatchee River stations. The dominant pattern of high flows is spring snowmelt freshet in late spring and early summer. Occasional peak flows from storm events can also be observed. Low flows can be observed both in summer and winter.
- Much like the mainstem, flows for the northern tributaries (Figure 8) show a snowmelt-dominated flow regime with occasional rain events and both summer and winter low flows.
- Flows for the northeastern and southeastern tributaries (Figures 9 and 10) continue to show the strong snowmelt signal, but autumn rainfall also shows a strong contribution to high flows.
- In the lower tributaries (Figure 11) the snowmelt signal is still present but the overall pattern is much closer to a mixed rain-snow regime. Winter low flows are mostly absent and summer flows are very low.
- The interannual patterns can also be observed in these figures. For example, water year 2005 had relatively low flows, while water year 2007 had relatively high flows.

Instream Flow Rule

In 2007, Ecology established minimum instream flows for WRIA 45 in Chapter 173-545 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 or new water appropriations cannot diminish or negatively affect the regulated flow.

Regulatory flow control stations established by WAC 173-545 are shown in Table 3. All control stations correspond to active Ecology or USGS flow monitoring stations, except for the USGS Mission Creek station which is a historical site (Figure 1, Tables 1 and 2).

Table 3. Regulatory flow control stations in WRIA 45.

Stream Management Unit Name	Control Station Gage No.	River Mile (RM)	Township	Range	Section	Latitude (N) Deg	Min	Sec	Longitude (W) Deg	Min	Sec	Stream Management Reach Description	Comment
Chiwawa River near Plain	USGS 12456500	6.2	27 N	17 E	13	47	50	16	120	39	40	From the confluence of the Chiwawa River and the Wenatchee River upstream to the headwaters of the Chiwawa River	
Nason Creek near mouth	ECY 45J070	0.2	27 N	17 E	33	47	48	2	120	43	1	From the confluence of Nason Creek and the Wenatchee River upstream to the Nason Creek headwaters	
Wenatchee River at Plain	USGS 12457000	46.2	26 N	17 E	12	47	45	47	120	39	59	From Beaver Valley Hwy, RM 46.2, to headwaters	
Icicle Cr. near Leavenworth	USGS 12458000	5.8	24 N	17 E	28	47	32	28	120	43	11	Headwaters of Icicle Creek to its mouth	Former Control Station, still in rule
Icicle Cr. near Leavenworth	ECY 45B070	2.2	24 N	17 E	24	47	33	49	120	40	4	Headwaters of Icicle Creek to its mouth	New Control Station, not yet in rule
Chumstick Cr. at North Road	ECY 45C060	0.3	24 N	18 E	6	47	36	18	120	38	55		Flow to be determined
Wenatchee River at Peshastin	USGS 12459000	21.5	24 N	18 E	8	47	34	60	120	37	10	From confluence of Derby Creek to Beaver Valley Hwy, RM 46.2 excluding Derby Creek and Icicle Creek	
Peshastin Creek at Green Bridge Rd.	ECY 45F070	1.4	24 N	18 E	28	47	33	9	120	36	11	From the confluence of Peshastin Creek and the Wenatchee River upstream to the Peshastin Creek headwaters	
Mission Creek near Cashmere	ECY 45E070	0.2	23 N	19 E	5	47	31	16	120	28	33	From mouth to headwaters	For 1983 Instream flows (WAC 173-545-050)
Mission Creek at Cashmere	USGS 12462000	1.5	23 N	19 E	9	47	30	35	120	28	24	From mouth to headwaters	For 2001 Instream flows (WAC 173-545-060)
Wenatchee River at Monitor	USGS 12462500	7.0	23 N	19 E	11	47	29	58	120	25	28	From mouth to confluence of Derby Creek, including Derby Creek and excluding Mission Creek	

Project Description

Goals and Objectives

The goals of this project are to:

1. Develop computer modeling tools that can estimate streamflows in WRIA 45 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 Wenatchee Watershed Planning Unit 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 45, based on relationships with active long-term USGS flow stations or other Ecology flow stations.
2. Assess the quality of the results of the modeling tools developed for objective 1.
3. Provide support in determining a long-term approach to flow discharge assessment that combines direct monitoring of gage height with modeling approaches, thus allowing the total number of flow monitoring stations using continuous stream gage measurements to be reduced.
4. Identify any data gaps found in the modeling analysis and, if warranted, recommend more complex modeling approaches that might reasonably improve the use of models for flow discharge assessment.
5. Provide training and technology transfer of project products to Ecology staff and local partners.

Model Development

The first study objective will be met by an analysis of (1) the streamflow records for the gages in the WRIA 45 basin and (2) other relevant information such as geographical, geological, or meteorological data. The planned approach is to select *reference stations*, such as active long-term USGS flow stations, and then predict flow data at Ecology-funded stations (*study stations)* from one or more of the reference stations. Based on the results of the analysis, one or more Ecology flow stations may also be selected as a reference station.

Several methods will be explored for this analysis, including:

- Simple linear regression or correlation with data transformations such as log-transformation.
- Areal flows (discharge per watershed area) and drainage area ratios.
- Time-lagging of data.
- Hydrograph separation.
- Simple hydrologic routing models.
- Inclusion of meteorological, geographical, and other non-hydrologic data to adjust predictive equations.

This list is provided roughly in order from the simplest to the most complex approach. The analysis will begin with the simplest approach and will only progress to more complex approaches depending on:

- The quality of the results from the simpler approach.
- Whether the available data support a more complex approach.
- The time available in the project schedule to pursue a more complex approach.
- The potential use of the modeling tools.
- The priority of the station to the Wenatchee Watershed Planning Unit and Ecology.

An example of the simplest kind of correlation is provided in Table 4. Correlations were developed[1] between continuous flow time series from the Ecology and USGS stations. This initial analysis shows how some gages will correlate well but others will have much poorer relationships. These correlations will be used as the starting point to choose reference stations with the closest statistical relationship to each study station.

- One reference station will be the USGS station with the best correlation.
- A second reference station will be the station with the best correlation (other than the first choice) that is either a USGS station or an Ecology station that is also a control station.
- Two more stations will be selected for analysis from the stations with the best correlations (other than the first two choices).

Model Quality Assessment

Best practices of computer modeling should be applied to help determine when a model, despite its *uncertainty*, can be appropriately used to inform a decision (Pascual et al., 2003).

Specifically, model developers and users should:

1. Subject their model to credible, objective peer review.
2. Assess the quality of the data they use.
3. Corroborate their model by evaluating how well it corresponds to the natural system.
4. Perform sensitivity and uncertainty analyses.

The study will follow this approach to meet the fourth study objective of assessing the quality of model results.

Study results will undergo a technical peer review by a designated Ecology employee with appropriate qualifications. Review of the study by Ecology staff, local stakeholders, and the public will also ensure quality.

[1] The Correlation analysis tool was used from the Excel® Analysis ToolPak.

Table 4. Correlations between flows from gages in the Wenatchee watershed.

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 and 2.

Legend:
- **ECY-Telemetry**
- **USGS**
- **ECY-Manual Staff**
- ***Control Station***

	Rock	White	LWen	*Nason*	Wen-Lk	Chwkm	*Chmstk*	*Ici-EC*	*Psh-GB*	*Miss-EC*	*Chww*	*Wen-Pln*	Ici-GS	*Wen-Psh*	*Wen-Mon*	Rainy	WPine	Eagle	Psh-AIn	Psh-BIn
White	0.44																			
LWen	0.34	**0.88**																		
Nason	0.34	**0.86**	**0.93**																	
Wen-Lk	0.38	**0.94**	**0.91**	**0.91**																
Chwkm	0.53	**0.90**	**0.82**	**0.83**	**0.91**															
Chmstk	0.06	0.18	0.31	0.34	0.26	0.16														
Ici-EC	0.22	**0.91**	**0.84**	**0.97**	**0.95**	0.45	0.27													
Psh-GB	0.30	**0.76**	**0.85**	**0.83**	**0.82**	**0.74**	0.48	**0.89**												
Miss-EC	0.12	0.33	0.43	0.49	0.45	0.32	**0.76**	0.67	**0.70**											
Chww	0.68	**0.94**	**0.85**	**0.87**	**0.96**	**0.96**	0.23	**0.91**	**0.77**	0.31										
Wen-Pln	0.41	**0.94**	**0.89**	**0.90**	**0.99**	**0.92**	0.28	**0.94**	**0.80**	0.42	**0.98**									
Ici-GS	0.36	**0.95**	**0.91**	**0.92**	**0.96**	**0.92**	0.24	**0.98**	**0.85**	0.42	**0.94**	**0.96**								
Wen-Psh	0.40	**0.94**	**0.89**	**0.91**	**0.99**	**0.93**	0.29	**0.95**	**0.82**	0.44	**0.97**	**1.00**	**0.97**							
Wen-Mon	0.42	**0.93**	**0.89**	**0.91**	**0.99**	**0.95**	0.29	**0.96**	**0.84**	0.46	**0.97**	**1.00**	**0.97**	**1.00**						
Rainy	0.57	**0.93**	**0.93**	**0.86**	**0.93**	**0.87**	**0.88**	**0.93**	**0.83**	0.63	**0.91**	**0.92**	**0.91**	**0.92**	**0.92**					
WPine	0.25	**0.90**	**0.90**	**0.87**	**0.96**	**0.95**	0.66		**0.84**	**0.73**	**0.92**	**0.96**	**0.95**	**0.96**	**0.96**	**0.96**				
Eagle	-0.04	-0.12	-0.16	0.05	-0.06	-0.07	**0.81**	0.30	0.31	**0.84**	-0.15	-0.07	-0.08	-0.04	-0.03					
Psh-AIn	0.08	0.58	**0.71**	**0.72**	0.69	0.66	**0.77**		**0.88**	**0.85**	0.63	0.67	0.66	0.69	**0.71**	**0.96**	**0.91**	**0.96**		
Psh-BIn	0.24	**0.72**	**0.77**	**0.82**	**0.81**	**0.79**	0.63		**0.91**	**0.73**	**0.77**	**0.83**	**0.81**	**0.83**	**0.85**	**0.97**	**0.98**	**0.92**	**0.85**	
Bren	0.26	0.36	0.37	0.40	0.34	0.47	0.32	0.28	0.45	0.44	0.42	0.40	0.40	0.41	0.41	0.29	0.23	0.22	0.34	0.33

Practices 2 through 4 above are addressed through *Model Evaluation.* This is the process for generating information over the life cycle of the project that helps to determine whether a model and its analytical results are of a quality sufficient to serve as the basis for a decision. Model quality is an attribute that is meaningful only within the context of a specific model application. Evaluating the uncertainty of data from models is conducted by considering the models' accuracy and reliability.

Accuracy Analysis

Accuracy refers to the closeness of a measured or computed value to its *true* value, where the *true* value is obtained with perfect information. Due to the natural heterogeneity and random variability of many environmental systems, this *true* value exists as a distribution rather than a discrete value.

In this project, accuracy is determined from measures of the *bias* and *precision* of the predicted value from model results, as compared to the observed value from flow measurements on the assumption that measured flows are closer to the *true* value. The known precision and bias of flow measurement values will also be taken into account in interpreting results.

Bias describes any systematic deviation between a measured (i.e., observed) or computed value and its *true* value. Bias in this context could result from uncertainty in modeling or from the choice of parameters used in calibration.

Bias will be inferred by the precision statistic of relative percent difference (RPD)[2]. This statistic provides a relative estimate of whether a protocol produces values consistently higher or lower than a different protocol. Bias will be evaluated using RPD values for predicted and observed pairs individually and using the median of RPD values for all pairs of results.

RPD =

where:

P_i = ith prediction
O_i = ith observation

The RPD was chosen over other measures of bias because of the wide range in flows found in hydrologic records. Using residuals or mean error would tend to underemphasize predictive error during critical low-flow periods and overemphasize error during the highest flows. On the other hand, percent error tends to overemphasize error for low flows. RPD provides the most balanced estimate of error over a wide range of flows.

[2] RPD commonly uses the absolute value of the error, but a formulation without an absolute value is used in this report to retain the sign, which indicates the bias of the predicted value relative to the observed value.

Precision of modeled results will be expressed with percent relative standard deviation (%RSD). Precision will be evaluated using this statistic for predicted and observed pairs individually and using the mean 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.

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

Percent error measures have been selected for assessment of accuracy because of the wide range of values expected in the flow record. Uncertainty in flow measurements is usually reported as a percentage; the same approach is being adopted for flow modeling.

Reliability Analysis

Reliability is the confidence that potential users have in a model and its outputs such that the users are willing to use the model and accept its results (Sargent, 2000). Specifically, reliability is a function of the performance record of a model and its conformance to best available, practicable science. Reliability can be assessed by determining the robustness and sensitivity.

Robustness is the capacity of a model to perform equally well across the full range of environmental conditions for which it was designed and which are of interest. Model calibration is achieved by adjusting model input parameters until model accuracy measures are minimized. Robustness will then be evaluated by examining the quality of calibration for different seasons and flow regimes. The variation between accuracy measures for model results from different seasons and flow regimes provides a measure of robustness of model performance.

Sensitivity analysis is the study of how the response of a model can be apportioned to changes in a model's inputs (Saltelli et al., 2000). A model's sensitivity describes the degree to which the model result is affected by changes in a selected input parameter. Sensitivity analysis is recommended as the principal evaluation tool for characterizing the most- and least-important sources of uncertainty in environmental models. Uncertainty analysis investigates the lack of knowledge about a certain population or the real value of model parameters.

Sensitivity analysis can be conducted using Morris's one-at-a-time (OAT) approach (Saltelli et al., 2000). With this approach, each input value is perturbed by a given percentage away from the base value while holding all other input variables constant. Morris's OAT sensitivity analysis methods yield local measures of sensitivity that depend on the choice of base case values. Morris's OAT approach provides a measure of the importance of an input factor in generating output variation. While this approach does not quantify interaction effects, it does provide an indication of the presence of interaction. This test will be applied if the complexity of the model, importance of model results, and the need for additional model quality information are sufficient to justify the level of effort needed.

Other approaches may also be explored to evaluate the sensitivity of regression models to changes in instream flows caused by implementing water management programs in the Wenatchee basin.

Quality Characterization

The uncertainty and applicability of model results will be assessed by evaluating model *quality* results on an annual basis and for summer baseflow conditions. The median %RSD value will be used for comparison for each model at each station within the season or range of flow measurements being considered. The following terminology will be used to describe model results:

Median %RSD for annual streamflow and summer baseflow	Characterization
Both less than 5%	Very Good
Summer less than 5% and annual greater than 5%; or both less than 15%	Good
Summer less than 15% and annual greater than 15%; or both less than 30%	Fair
Does not meet either criteria above	Poor

Flow Gaging Assessment

Project Objectives 3 and 4 will be accomplished by evaluating the results of the model assessments described above. Each flow monitoring study station will have a preferred modeling approach identified and an evaluation of the quality of the model. That evaluation will include a recommendation for the gage at each station based on the quality of the model and redundancy of flow information with other gages.

This information will be provided to Ecology staff and local stakeholders to support decisions about allocation of resources for flow gaging. The overall process of assessing both Ecology's and local stakeholders' needs for gaging information will occur as a separate process on a parallel track.

Possible recommendations for use of the Ecology flow monitoring stations resulting from this project could include:

- Continuing operation of the gage as a telemetry gage.
- Reallocating the station to a *manual-stage-height* station using modeling combined with spot-flow measurements for confirmation of modeled flows.
- Abandoning the station, possibly with continued spot-flow measurements at the site.
- Transferring the station to another party.

Project results will also be used to make recommendations regarding the continuation of Ecology funding for USGS flow monitoring stations.

As a result of the analysis, data gaps may be identified that limit the ability to use modeling tools to estimate streamflows. Recommendations for potential changes in data acquisition to fill these gaps will be made where warranted.

In addition, if the analysis in this study points towards other, more complex, models that could improve the quality of flow estimation, recommendations will be made for using those models in possible future work.

Project Report and Public Involvement

During the course of the project, internal review, input, and guidance will be provided by the Gaging Strategy Workgroup (GSW) and other Ecology staff identified in the Organization and Schedule section below. Input from local partners and the public during the project will be through the Wenatchee Watershed Planning Unit. The form and timing of input during the project will be determined by the project and client leads.

A project report will present the results of the study. Review of the draft report will be the primary mechanism for providing input to the final conclusions and recommendations.

Training and Technology Transfer

The final objective will be achieved by providing (1) modeling tools to interested parties through the internet or other means and (2) presentations and training to Ecology staff and local partners. The timing and content of presentations and training during this project will be determined through consultation with project clients and responsible staff and groups.

Organization and Schedule

The people listed in Table 5 are involved in this project. All are employees of the Washington State Department of Ecology.

Table 5. Organization of project staff and responsibilities.

Staff	Role	Responsibilities
Dave Holland SEA Program Central Regional Office (509) 457-7112	Client, Regional Watershed Lead	Clarifies scopes of the project. Provides internal review of the QAPP and approves the final QAPP. Reviews the project report. Serves as Ecology liaison between the project manager and the Wenatchee Watershed Planning Unit.
Bill Zachmann SEA Program Phone: (360) 407-6548	Client, Statewide Watershed Coordinator	Clarifies scopes of the project. Provides internal review of the QAPP and approves the final QAPP. Reviews the project report. Serves as liaison with Ecology WAG and SEA Program.
Brad Hopkins Freshwater Monitoring Unit Western Operations Section, EAP Phone: (360) 407-6686	Client, Manager of Ecology's Statewide Flow Monitoring Network	Clarifies scopes of the project. Provides internal review of the QAPP and approves the final QAPP. Reviews the project report.
Robert F. Cusimano Western Operations Section, EAP Phone: (360) 407-6698	Section Manager for EAP's client	Reviews the project scope and budget. Reviews the draft QAPP and approves the final QAPP. Approves the project report.
Paul J. Pickett MISU, SCS, EAP Phone: (360) 407-6882	Project Manager/ Principal Investigator	Writes the QAPP. Organizes, analyzes, and interprets data. Develops model and analyzes quality of data and model. Writes the draft report and final report.
Karol Erickson MISU, SCS, EAP Phone: (360) 407-6694	Unit Supervisor for the Project Manager	Provides internal review of the QAPP. Approves the budget and approves the final QAPP. Tracks progress. Reviews and approves the project report.
Will Kendra SCS, EAP Phone: (360) 407-6698	Section Manager for the Project Manager	Reviews the project scope and budget. Reviews the draft QAPP and approves the final QAPP. Approves the project report.
Gary Arnold Eastern Operations Section, EAP Phone: (509) 454-4244	Section Manager for the Study Area	Reviews the project scope and budget. Tracks progress. Reviews the draft QAPP and approves the final QAPP.
William R. Kammin Phone: (360) 407-6964	Ecology Quality Assurance Officer	Reviews the draft QAPP and approves the final QAPP.

SEA: Shorelands and Environmental Assistance.
EAP: Environmental Assessment Program.
MISU: Modeling and Information Support Unit.
SCS: Statewide Coordination Section.
QAPP: Quality Assurance Project Plan.

As described above, updates to the Planning Unit and any internal decision-making will be determined on an as-needed basis by the project manager and clients. Table 6 shows the schedule proposed for completion of the reports for this study.

Table 6. Proposed schedule for completing reports.

Final report	
Author lead	Paul Pickett
Schedule	
Draft due to supervisor	May 2011
Draft due to client/peer reviewer	May 2011
Draft due to external reviewer(s)	June 2011
Final report due on web	September 2011

Training and technology transfer will begin with the review of draft reports and will continue after the publication of the Project Report on an as-needed basis.

References

References Cited

Hammond, C., L. Huber, C. Slaughter, and P. Pradeep, 1997. Estimation of Hydrologic Characteristics for Ungaged Streams, Wenatchee National Forest. Publication No. NWRC-97-1, Northwest Watershed Research Center, USDA – Agricultural Research Service, Boise, ID.

Karrer, M., 2005. Development of Exceedance Hydrographs to Support Instream Flow Incremental Methodology for the Wenatchee Watershed Planning Effort. U.S. Forest Service, Wenatchee, WA.

Pascual, P., N. Stiber, and E. Sunderland, 2003. Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models. Council for Regulatory Environmental Modeling. Office of Science Policy, U.S. Environmental Protection Agency, Washington D.C.

Saltelli, A., S. Tarantola, and F. Campolongo, 2000. Sensitivity Analysis as an Ingredient of Modeling. Statistical Science, 2000. 15: 377-395.

Sargent, R.G., 2000. Verification, Validation, and Accreditation of Simulation Models, Proceedings of the 2000 Winter Simulation Conference. J.A. Joines et al. (Eds).

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

WAC 173-545. Instream Resources Protection Program – Wenatchee River Basin. Water Resource Inventory Area (WRIA) 45. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/biblio/wac173545.html.

WRIA 45 Planning Unit, 2006. Final Wenatchee Watershed Management Plan. Publication No. 043-1284.203. Chelan County, Wenatchee, WA. www.co.chelan.wa.us/nr/planning/watershed_planning/watershed_plan/default.htm.

Other References

Anderson, R., 2007. Mission Creek Watershed DDT Total Maximum Daily Load Water Quality Improvement Report. Publication No. 07-10-046. Washington State Department of Ecology, Yakima, WA. www.ecy.wa.gov/biblio/0710046.html.

Anderson, R., D.L. Clark, M. Kasch, and A. Meilleur, 2009. Wenatchee River Watershed Dissolved Oxygen and pH Total Maximum Daily Load Water Quality Implementation Plan – DRAFT. Publication No. 09-10-075. Washington State Department of Ecology, Yakima, WA. www.ecy.wa.gov/biblio/0910075.html.

Carroll, J., S. O'Neal, and S. Golding, 2006. Wenatchee River Basin Dissolved Oxygen, pH, and Phosphorus Total Maximum Daily Load Study. Publication No. 06-03-018. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/biblio/0603018.html.

Carroll, J. and R. Anderson, 2009. Wenatchee River Watershed Dissolved Oxygen and pH Total Maximum Daily Load Water Quality Improvement Report. Publication No. 08-10-062. Washington State Department of Ecology, Yakima, WA. www.ecy.wa.gov/biblio/0810062.html.

Cristea, N. and G. Pelletier, 2005. Wenatchee River Temperature Total Maximum Daily Load Study. Publication No. 05-03-011. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/biblio/0503011.html.

Ecology, 2007. Quality Assurance Monitoring Plan: Streamflow Gaging Network. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-204. www.ecy.wa.gov/biblio/0503204.html.

Lombard, S. and C. Kirchmer, 2004. Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-030. www.ecy.wa.gov/biblio/0403030.html.

Schneider, D. and R. Anderson, 2007. Wenatchee River Watershed Temperature Total Maximum Daily Load Water Quality Improvement Report. Publication No. 07-10-045. Washington State Department of Ecology, Yakima, WA. www.ecy.wa.gov/biblio/0710045.html.

Springer, C., 2005. Flow Summary for Gaging Stations on the Wenatchee River and Selected Tributaries. Publication No. 05-03-015. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/biblio/0503015.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.

USEPA, 2002. Quality Assurance Project Plans for Modeling. U.S. Environmental Protection Agency, Washington DC. Publication No. EPA QA/G-5M.

Whiley, A.J. and B. Cleland, 2003. Wenatchee National Forest Water Temperature Total Maximum Daily Load Technical Report. Publication No. 03-10-063. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/biblio/0310063.html.

Figures

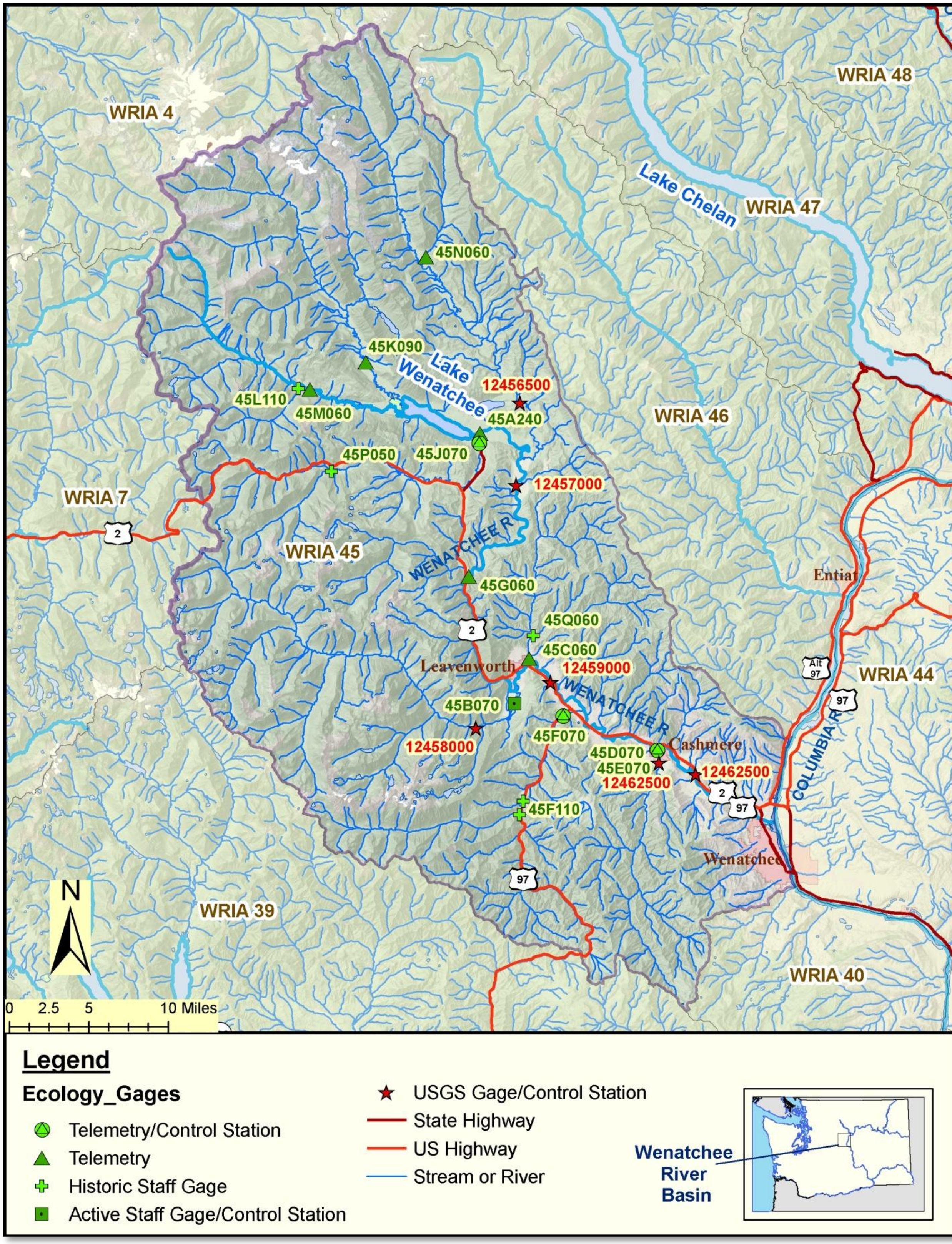

Figure 1. Wenatchee watershed study area (Water Resource Inventory Area 45).

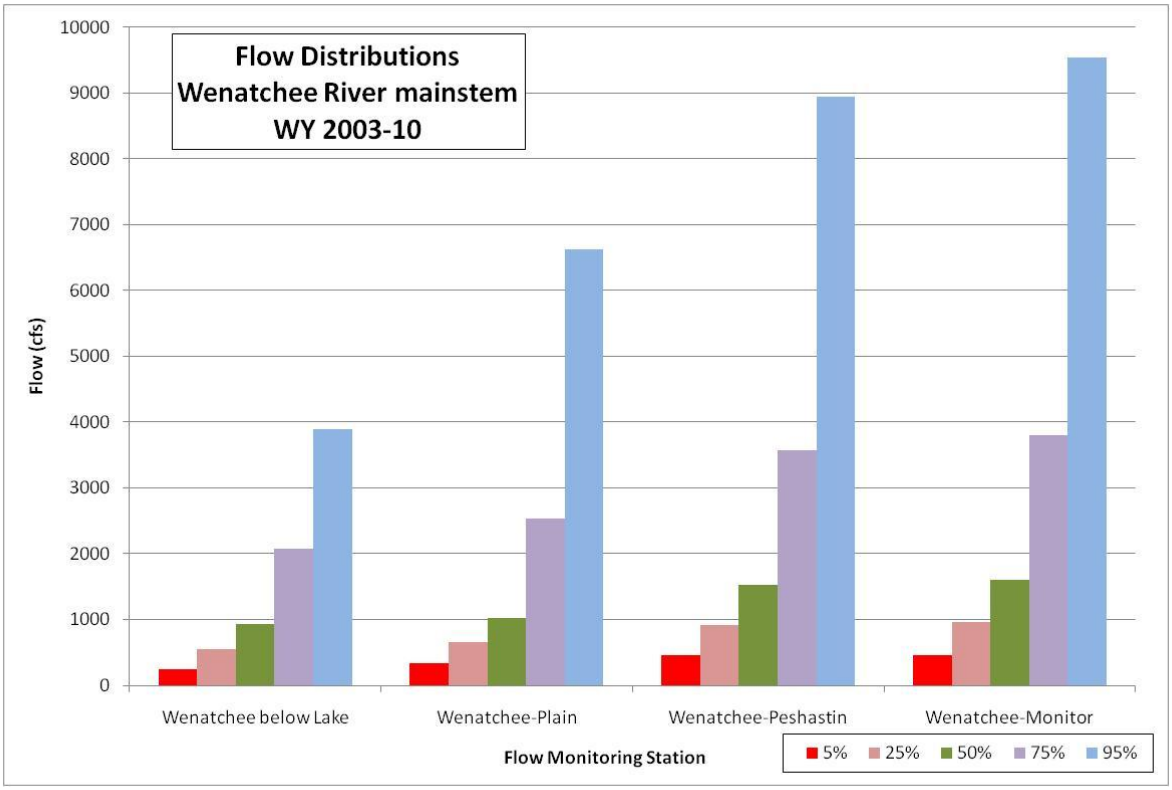

Figure 2. Flow distributions for Wenatchee River gaging stations.

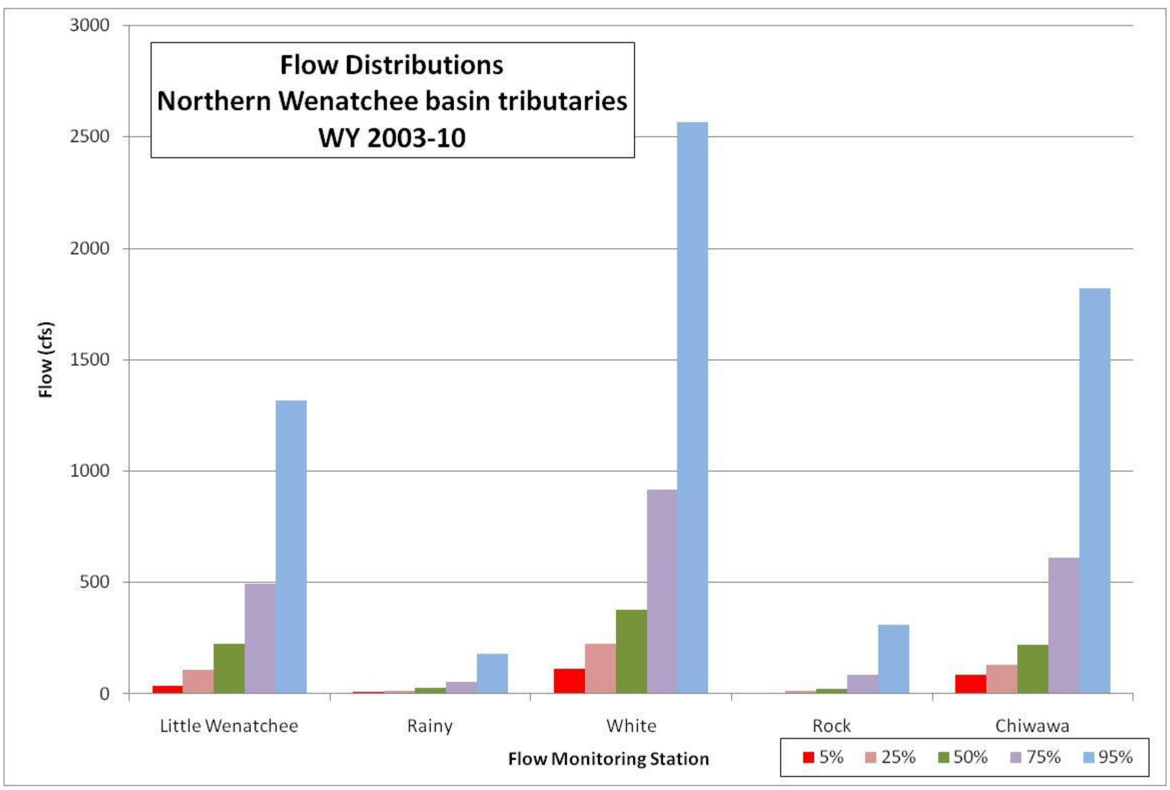

Figure 3. Flow distributions for northern Wenatchee basin tributary gaging stations.

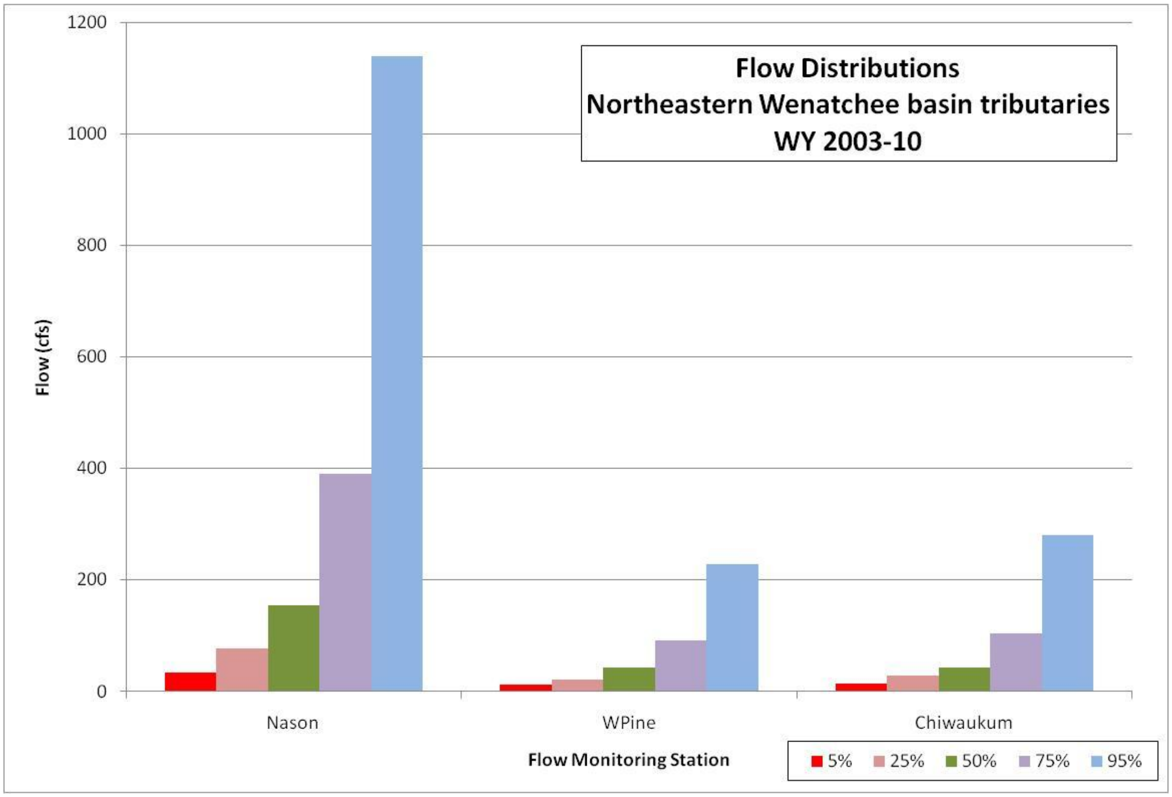

Figure 4. Flow distributions for northeastern Wenatchee basin tributary gaging stations.

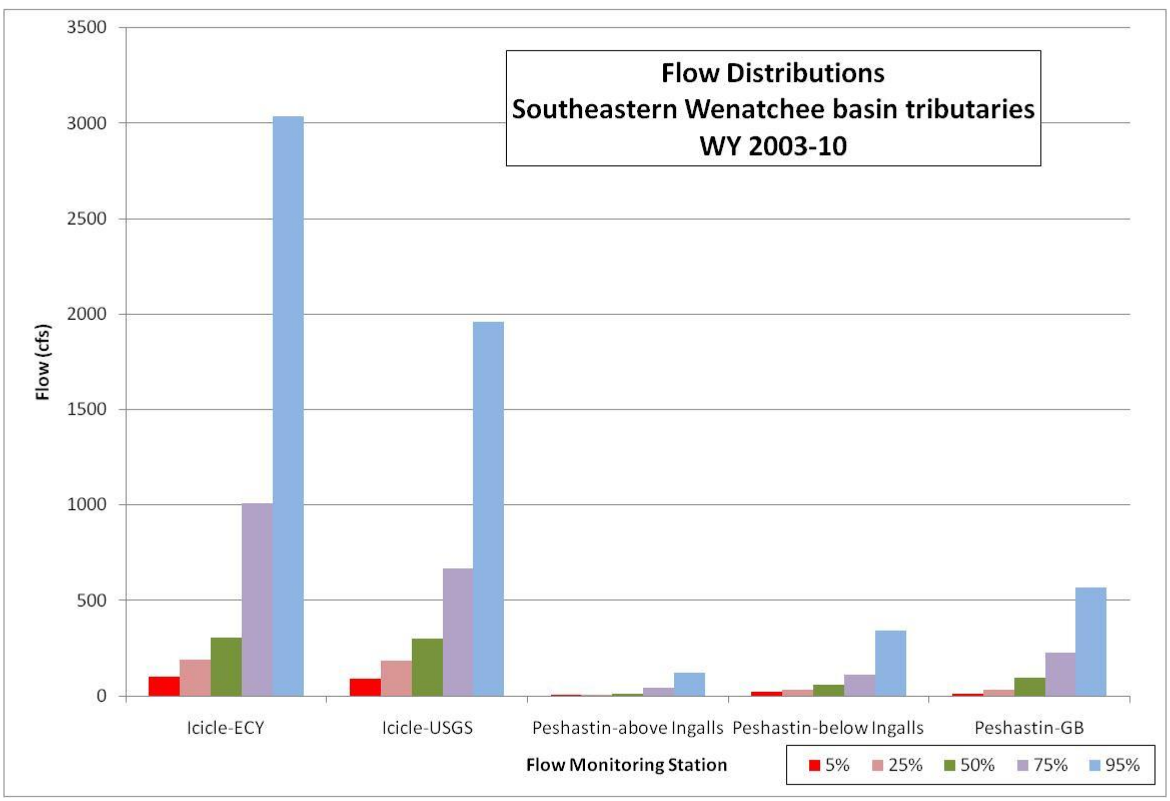

Figure 5. Flow distributions for southeastern Wenatchee basin tributary gaging stations.

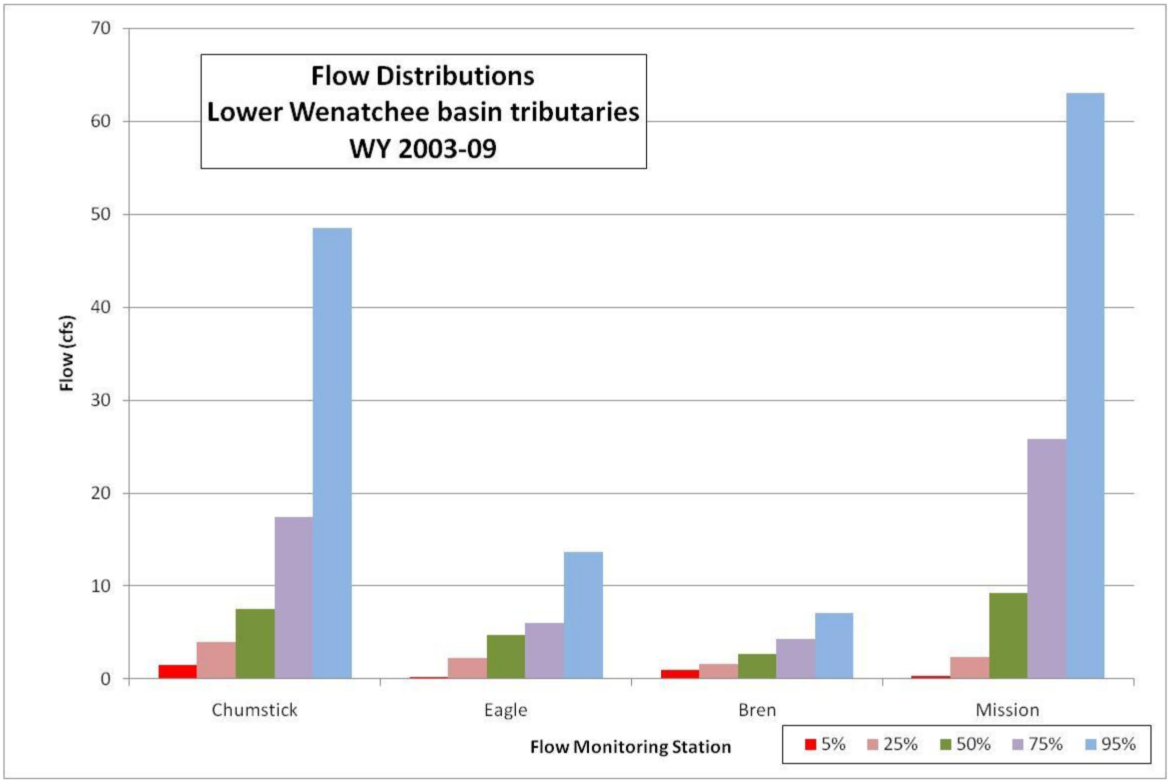

Figure 6. Flow distributions for lower Wenatchee basin tributary gaging stations.

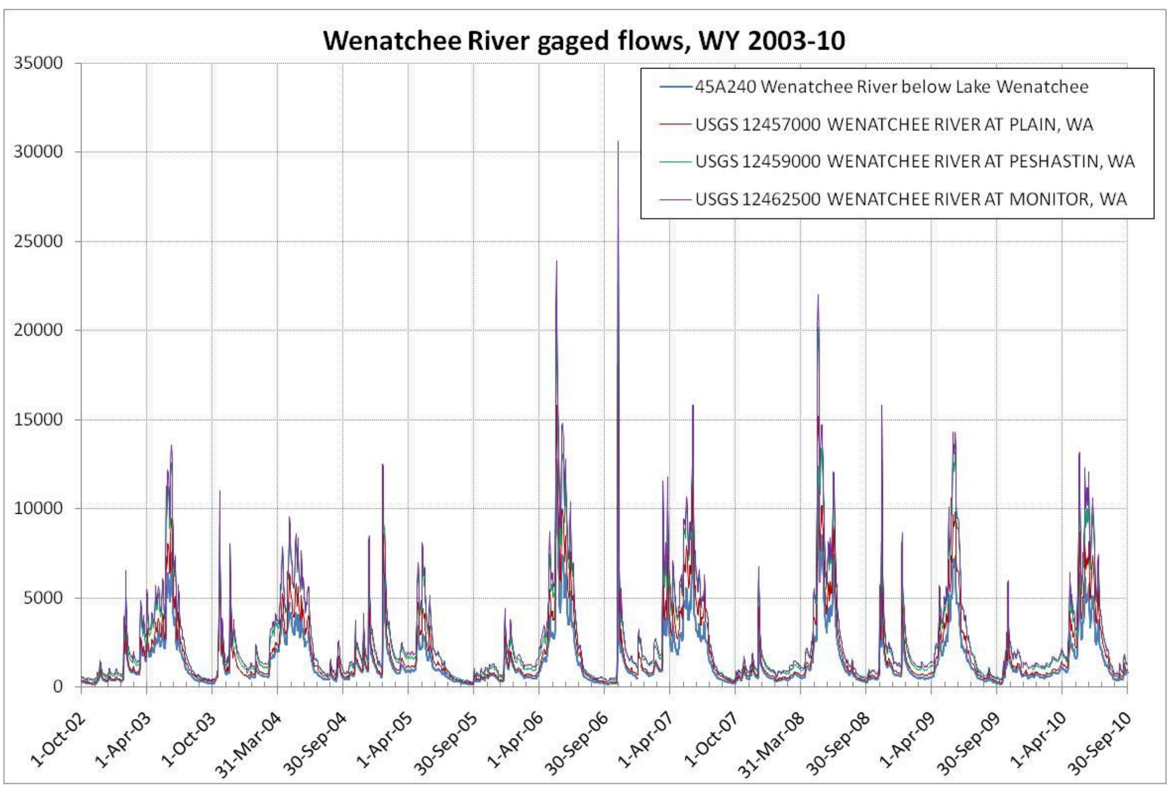

Figure 7. Flow at Wenatchee River gaging stations, water years 2003-2010.

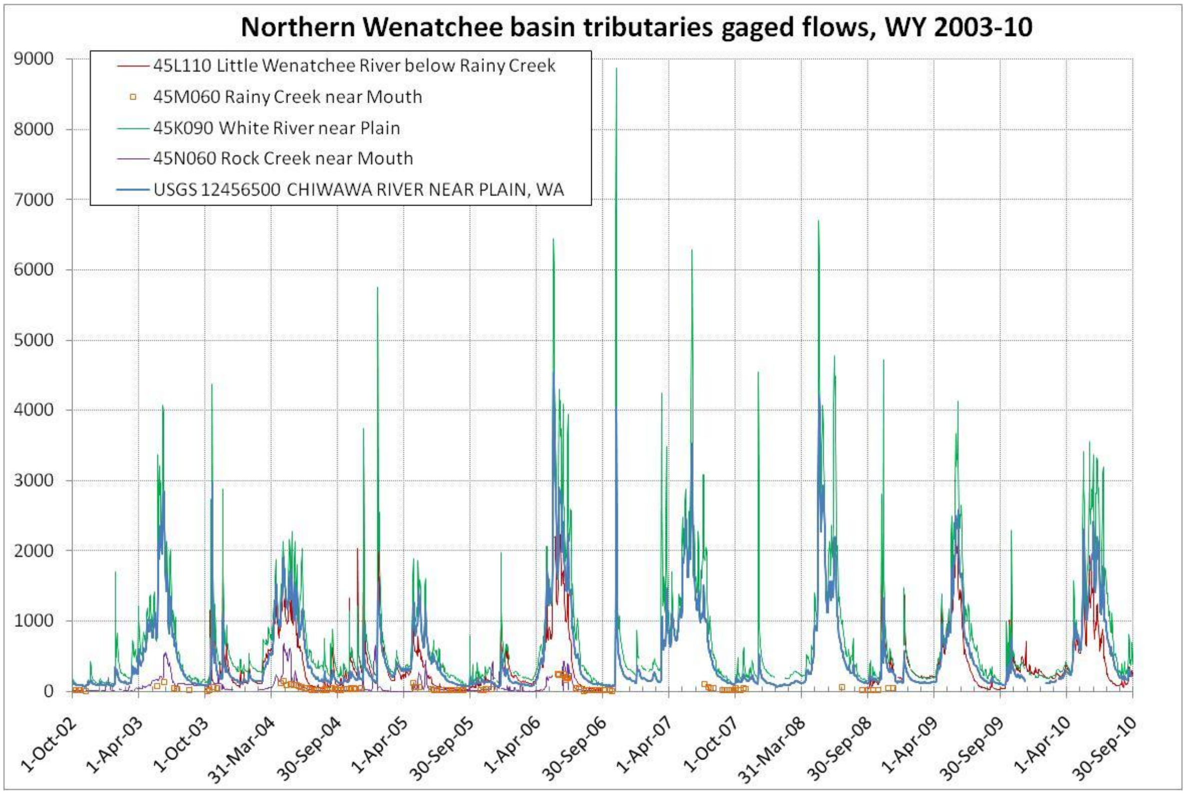

Figure 8. Flow at northern Wenatchee basin gaging stations, water years 2003-2010.

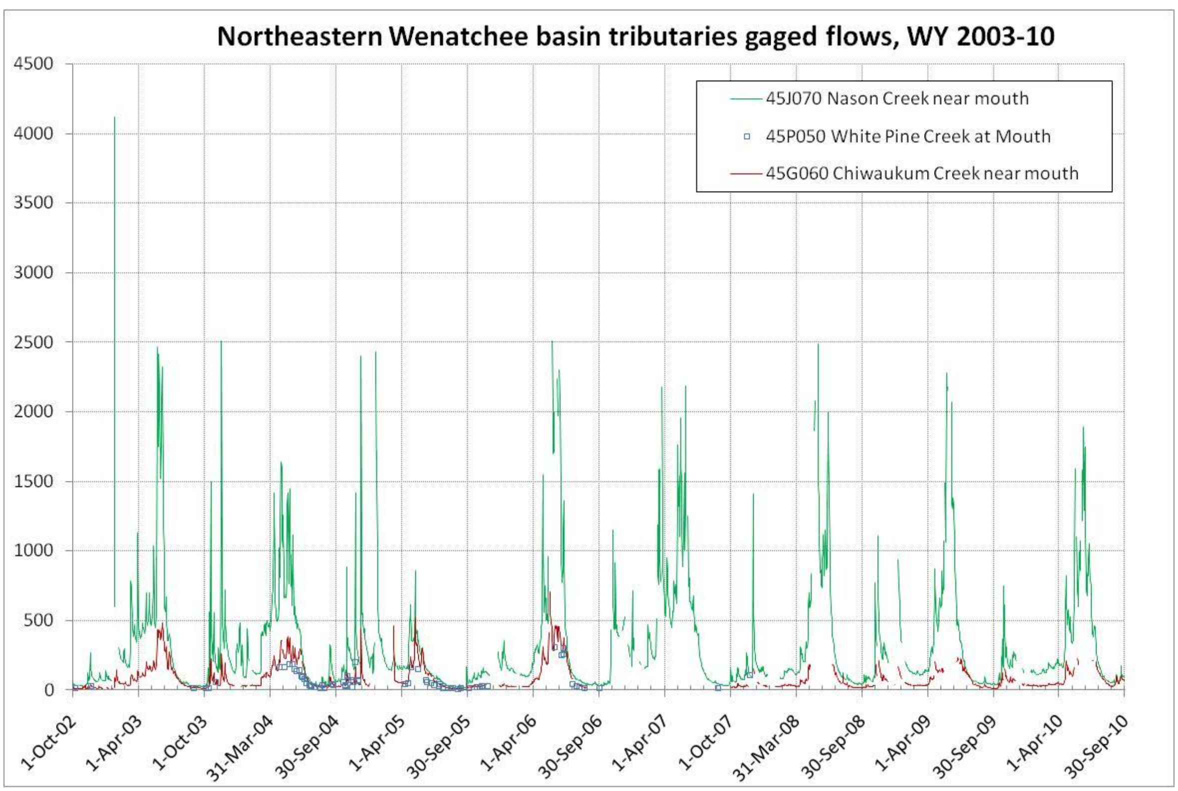

Figure 9. Flow at northeastern Wenatchee basin gaging stations, water years 2003-2010.

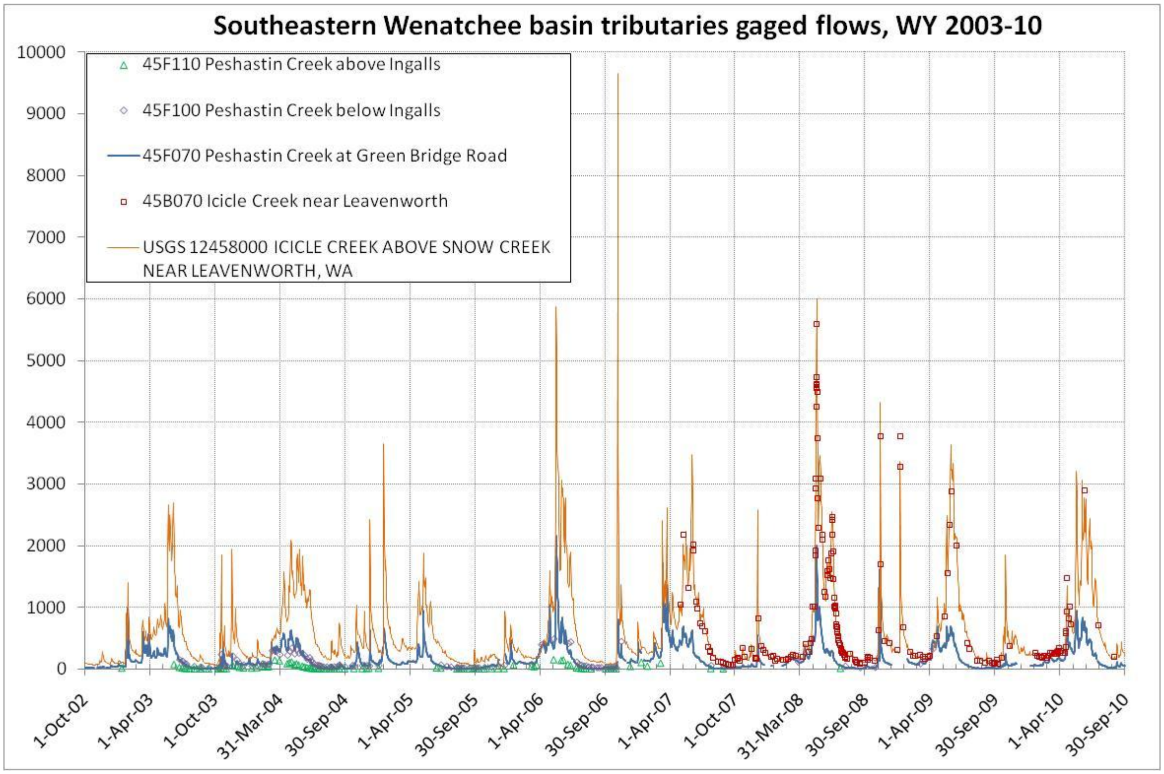

Figure 10. Flow at southeastern Wenatchee basin gaging stations, water years 2003-2010.

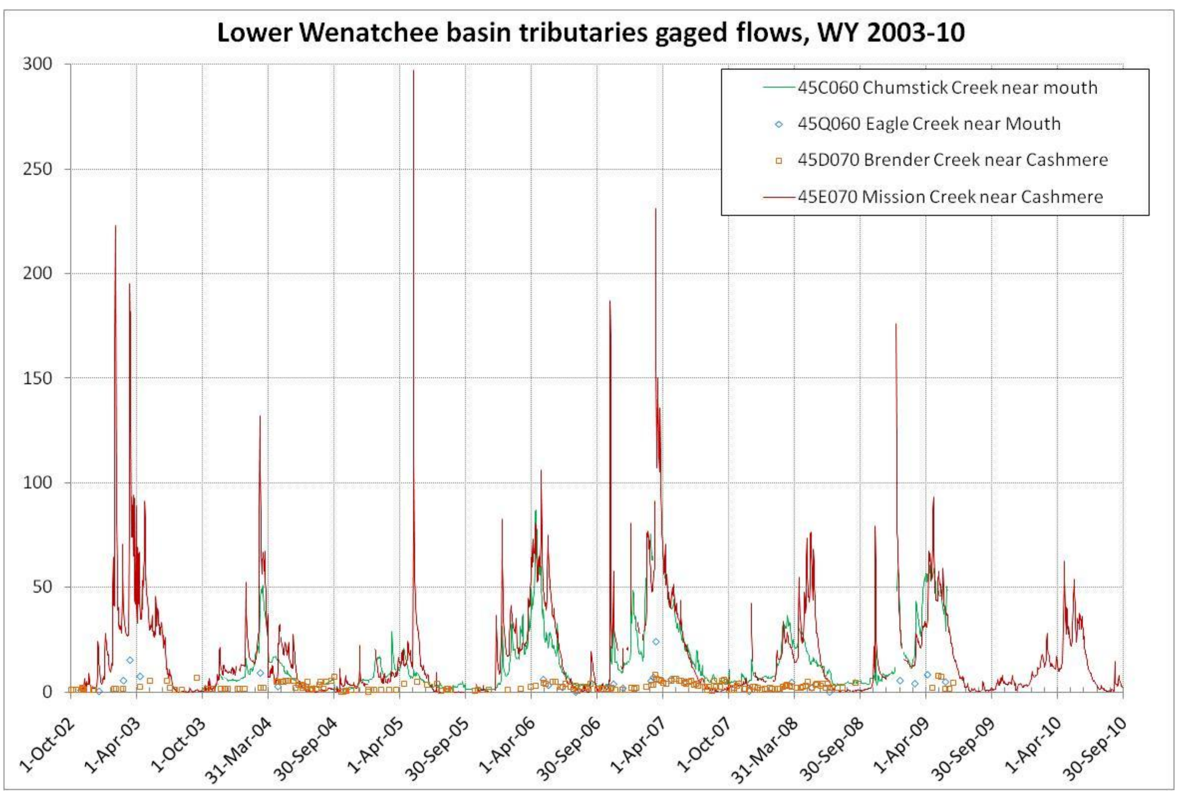

Figure 11. Flow at lower Wenatchee basin gaging stations, water years 2003-2010.

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.

Planning Unit: The Wenatchee Watershed Planning Unit, a local organization founded under Chapter 90.82 RCW in order to develop and implement a watershed plan.

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.

Usual and Accustomed fishing areas: Terminology from the treaties between the United States Government and Columbia River Native American Tribes, referring to areas where off-reservation Tribal fishing rights are reserved and shared “in common” with non-Tribal fishing.

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.

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, a unit of flow discharge
Ecology	Washington State Department of Ecology
GIS	Geographic Information System software
No.	Number
NOAA	National Oceanic and Atmospheric Administration
RCW	Revised Code of Washington
RM	River mile
RPD	Relative percent difference
USGS	U.S. Geological Survey
VIC	Variable Infiltration Capacity hydrologic model, developed by the University of Washington (http://www.hydro.washington.edu/Lettenmaier/Models/VIC/)
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
WY	(See Glossary above)