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Quality Assurance Project Plan

Middle Snake Watershed Planning Area Assessment of Gaged Streamflows by Modeling

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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/1203107.html.

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Abstract

The Washington State Department of Ecology (Ecology) is proposing a study during 2012 to evaluate Ecology and U.S. Geological Survey (USGS) streamflow monitoring gages in the Middle Snake watershed planning area in eastern Washington State. This area is also called Water Resource Inventory Area (WRIA) 35.

To predict flows at Ecology stations and at USGS stations funded by Ecology, 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, other agencies, and local stakeholders.

Background

Overview of the Watershed

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

Water Supply and Watershed Planning

In 1998 the Washington legislature passed RCW 90.82, which created a statewide watershed planning program. Watershed planning efforts began in the Middle Snake basin in 2002. Asotin County Public Utility District is Lead Agency for Watershed Planning under RCW 90.82 in WRIA 35. According to the Asotin County Public Utility District's Middle Snake WRIA 35 watershed planning website (www.asotinpud.org/watershedplanning/index.html):

Asotin, Columbia, Garfield, and Whitman Counties, the City of Clarkston, and the Asotin County Public Utility District joined to initiate organization of the WRIA 35 Planning Unit in 2002. The 37-member Middle Snake Watershed Planning Unit is comprised of the initiating governments and the following stakeholder groups:

- *landowners and citizens*
- *tribes*
- *conservation districts*
- *agricultural groups*
- *local governments*
- *environmental groups*
- *state and federal agencies*

The WRIA 35 Middle Snake Watershed Plan was approved by the WRIA 35 Watershed Planning Unit and then adopted by the Asotin, Whitman, Garfield, and Columbia County Boards of Commissioners in August 2007 (Middle Snake Watershed Planning Unit, 2011). A Detailed Implementation Plan was completed in September 2008 and updated in June 2011.

The WRIA 35 Middle Snake Watershed Planning Unit worked with Ecology to develop methodology for setting instream flow levels. A list of streams with instream flow levels and control station locations was presented by the Planning Unit in June 2011 (Johnson, 2011). Ecology is planning to adopt these instream flow levels and control stations into state regulations in the future. However, rule-making will depend on available resources and priorities and will likely not be completed for several years.

A summary of water availability is provided in a recent Ecology Focus Sheet (Ecology, 2011). Adjudications have been completed for Alpowa Creek, Deadman Creek, Meadow Gulch Creek, and Wawawai Creek. Surface Water Source Limitations have been set for Alpowa Creek. In August 2011, there were 12 surface water and 34 groundwater pending water rights applications.

Geography

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

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

Climate

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

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

Hydrology

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

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

More information of flow regimes in the gaged rivers are provided below.

Land Ownership, Land Use, and Water Use

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

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

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

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

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

Streamflow Gages and Models

Streamflow Measurement

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

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

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 stage-height data.

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

Instantaneous streamflow measurements have been collected and gaged flows used for analysis in special studies of streams in WRIA 35. Examples include:

- Asotin Creek Fecal Coliform Study (Ecology, 2010)
- Tucannon River and Pataha Creek Temperature Total Maximum Daily Load (Bilhimer et al., 2010)
- Tucannon River Fish Habitat Analysis Using the Instream Flow Incremental Methodology (Caldwell, 1995)

The USGS has gaged streamflow in WRIA 35 and in neighboring basins at a variety of sites historically and currently (USGS, 2009):

- Three active USGS stations in WRIA 35 and two active gages in neighboring basins are listed in Table 2. Two of the stations have Ecology as a *cooperator* (in other words, the stations are partially funded by Ecology), while other stations have other cooperators.
- Six historical USGS stations in WRIA 35 with continuous flow have no data after 1996 and will not be used for this analysis.
- Two active stations on the Snake River will not be used in this study. Flow data from the Snake River is not expected to be useful for this study, since the river drains an extremely large basin and is highly regulated.

Hydrologic Assessments and Modeling

Hydrologic and hydrogeologic assessments for WRIA 35 are limited. The primary source of information is the watershed planning process (Middle Snake Watershed Planning Unit, 2005).

The University of Washington Climate Impacts group has developed hydrologic models based on the Variable Infiltration Capacity (VIC) hydrologic modeling framework; these models include streamflow forecasts for climate change scenarios. Its forecasts include the USGS gages on the Snake, Tucannon, Grand Ronde, and Palouse Rivers, and on Asotin Creek. Forecast products are available (www.hydro.washington.edu/2860/), based on modeling 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 16 Ecology and USGS continuous and manual stage-height flow monitoring stations during eight complete years: February 2004 through January 2012. (The station codes used in the figures are defined in Tables 1 and 2.)

- Figure 2 shows the range of flows at the Joseph Creek and Tucannon River stations. Flows at these stations are generally the highest in the study area. Joseph Creek has a wider range of flows: median flows and low flows less than the Tucannon River but flows at the 95th percentile greater than the Tucannon River. The ratio of 95th percentile flow to 5th percentile flow is 33.6, indicating a relatively "flashy" system. Flows in the Tucannon River generally increase between the Marengo and Starbuck gages, except for the lowest 5th percentile flow which is lower downstream.
- Figure 3 shows flows for Asotin Creek and its tributary George Creek. Flows generally increase from upstream (George Creek and the upstream "below confluence" station) to downstream. However, George Creek shows a proportionally wide range of flows, with the highest flows about 100 times higher than the lowest flows. George Creek's "flashiness" ratio (the 95th:5th percentile ratio) is 76.8, the highest found in WRIA 35.
- Flows at the two Pataha Creek stations (Figure 4) are similar, although from the upstream to the downstream station high flows tend to increase while low flows tend to decrease. Pataha Creek near its mouth has a high flashiness ratio of 61.1. Since one station is a staff gage station and the other is continuous, the value of comparison is limited.

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

ID	Station Name	Code	Status	Type[1]	Proposed Control Station?	Start	End	No. days	Comment
35K050	Alpowa Creek @ Mouth	Alpowa	Active	T	yes	6-Jun-03	present	3056	
35D100	Asotin Creek abv George Creek	Aso-aGC	Active	T		10-Feb-05	present	2443	
35M100	Deadman Creek nr Gould City	Dead-GC	Active	T	yes	4-Jun-03	present	3064	
35G060	Joseph Creek nr Mouth	Joseph	Active	T	yes	5-Jun-03	present	3079	
35F050	Pataha Creek nr Mouth	Pat-Mth	Active	T	yes	4-Jun-03	present	3024	
35B150	Tucannon River nr Marengo	Tuc-Mar	Active	T	yes	4-Jun-03	present	3139	
35L050	Almota Creek @ Mouth	Almota	Historical	C	yes	5-Jun-03	13-Jul-10	2516	Former telemetry station
35M060	Deadman Creek nr Mouth	Dead-Mth	Historical	C	yes	4-Jun-03	12-Jul-10	2394	Former telemetry station
35H050	Couse Creek @ Mouth	Couse	Active	C	yes	4-Jun-03	present	549	MSH until 8/18/2010
35P050	George Creek @ mouth	George	Active	C	yes	1-Oct-08	present	333	MSH until 8/20/2010
35J050	Tenmile Creek @ Mouth	Tenmile	Active	C	yes	4-Jun-03	present	289	MSH until 8/19/2010
35N050	Meadow Creek @ Mouth	Meadow	Historical	MSH		19-Jun-03	7-Jul-10	225	
35F100	Pataha Creek nr Pataha	Pat-Pat	Historical	MSH	yes	19-Jun-03	7-Jul-10	228	

[1] MSH = Manual Stage Height; C = Continuous; T = Telemetry

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

ID	Station Name	Code	Status	Type[1]	Proposed Control Station?	Start	End	No. days	Cooperator[2]
13344500	Tucannon River near Starbuck, WA	Tuc-Star	Active	RT	yes	1-Oct-1914	present	20205	ECY
13335050	Asotin Creek at Asotin, WA	Aso-Aso	Active	NRT	yes	22-Mar-1991	30-Sep-2010	7133	ECY
13334450	Asotin Creek below Confluence Near Asotin, WA	Aso-Con	Active	RT		1-Jan-2001	Present	4042	
13351000	Palouse River at Hooper, WA	Pal-Hoop	Active	RT		10/1/1897	Present	28300	BPA
13333000	Grande Ronde River at Troy, OR	GRR-Troy	Active	RT		1-Oct-1944	Present	24588	USACE

[1] RT = Real-time (Telemetry)

[2] ECY = Ecology; USBR = U.S. Bureau of Reclamation; USACE = U.S. Army Corps of Engineers

- The flow distributions for the three small creeks draining to the Snake River are shown in Figure 5. Couse and Tenmile Creeks show very “flashy” flow regimes, as shown by the flashiness ratios of 22.2 and 46.3 respectively. By contrast, Alpowa Creek has a very stable flow regime with little variation between low and high flows. It has a flashiness ratio of 3.6, the lowest of all WRIA 35 gages. Possible explanations could be a strong contribution of groundwater inflows and/or a well-vegetated watershed for controlling runoff.
- Figure 6 shows the flow distributions for Meadow, Deadman, and Almota Creeks. Meadow Creek, like Alpowa Creek, shows a narrow range of flows, suggesting a strong groundwater component. Flows in Deadman Creek tend to increase from upstream to downstream for high flows, but decrease in the downstream direction during low flows. Flow patterns for Almota Creek are similar to Deadman Creek, with a moderate range of flows from low to high.

Figures 7 through 11 illustrate seasonal flow patterns at the gaging stations for 8½ years from June 2003 through February 2012. Note that the Y-axis scale is logarithmic, which deemphasizes the difference between high and low flows.

- Flows at the stations in Joseph Creek and the Tucannon River (Figure 7), Asotin and George Creeks (Figure 8), and Pataha Creek (Figure 9) all show “bimodal” flow, with a peak in late spring from snowmelt and peaks at other times from rain events. The wide range of flows from winter to summer can also be observed, especially in Joseph Creek. George and Pataha Creeks show similar peaks but very low summer flows.
- Tenmile, Couse, Alpowa, Meadow, Deadman, and Almota Creeks (Figures 10 and 11) are all relatively low elevation creeks and show less of a spring snowmelt signal. Relatively high flows are scattered throughout the winter and spring months, and flows in the summer months are relatively low.
- The interannual patterns can also be observed in these figures. For example, the 2008-09 water year had relatively high flows. Summer low-flow levels are relatively consistent from year to year, although some differences can be observed.

Instream Flow Rule Development

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

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

Project Description

Goals and Objectives

The goals of this project are to:

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

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

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

Model Development

The first study objective will be met by an analysis of (1) the streamflow records for the gages in the study area and (2) other relevant information such as geographical, geological, or meteorological data. The planned approach is to first select *reference stations*, such as active long-term USGS flow stations and to then predict flow data at Ecology 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 local stakeholders and Ecology.

Simple correlations will be used as the starting point to choose reference stations. Correlations were developed[1] between continuous flow time series from the Ecology and USGS stations (Table 3). This initial analysis shows how some gages appear to correlate well, while others will have much poorer relationships.

Reference stations for this analysis will be selected from 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 active Ecology telemetry 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.

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

Table 3. Correlations between flows from gages in the WRIA 35 Middle Snake watershed planning area.

*Coefficient colors and font size emphasize strongest correlations (***blue*** = greater than or equal to 0.9, ***green*** = between 0.80 and 0.89, ***red*** = between 0.70 and 0.79).*

Station colors and footnotes are explained in the legend (upper right). Station ID defined in Tables 1 and 2.

ECY-Telemetry

ECY-Continuous

ECY-Manual Staff

USGS

Potential Control Station

***** **Historical gage**

+ **Not real time**

	Alpowa	*Aso-aGC*	*Dead-GC*	*Joseph*	*Pat-Mth*	*Tuc-Mar*	*Almota**	*Dead-Mth**	*Couse +*	*George +*	*Tenmile +*	*Meadow**	*Pat-Pat**	*Tuc-Star*	*Aso-Aso +*	*Aso-Con*	*Pal-Hoop*	*GRR-Troy*
Joseph	0.60	**0.74**	0.61															
Pat-Mth	**0.71**	**0.73**	0.68	**0.83**														
Tuc-Mar	0.51	**0.92**	0.57	**0.75**	**0.78**													
Almota*	0.69	0.40	**0.75**	0.62	0.67	0.51												
Dead-Mth*	0.67	0.57	**0.85**	0.57	0.68	0.55	0.69											
Couse +	0.53	0.52	0.57	**0.72**	0.64	0.55	0.59	0.35										
George +	0.64	**0.86**	**0.80**	**0.89**	**0.88**	**0.90**	**0.76**	**0.90**	**0.85**									
Tenmile +	0.51	0.37	0.51	0.68	0.52	0.36	**0.73**	0.52	**0.83**	**0.82**								
Meadow*	0.19	0.04	0.19	0.09	0.02	0.08	0.13	0.18	-0.36	-1.00	0.03							
Pat-Pat*	0.52	**0.79**	0.47	**0.74**	**0.86**	**0.81**	0.47	0.53	0.61	*	0.55	-0.03						
Tuc-Star	0.56	**0.91**	0.63	**0.81**	**0.87**	**0.93**	0.60	0.64	0.59	**0.89**	0.47	0.03	**0.85**					
Aso-Aso +	0.39	**0.95**	0.40	**0.75**	0.69	**0.84**	0.41	0.46	0.32	**0.89**	0.40	0.07	**0.78**	**0.89**				
Aso-Con	0.31	**0.97**	0.39	0.64	0.65	**0.85**	0.32	0.43	0.44	**0.81**	0.28	0.05	**0.74**	**0.86**	**0.94**			
Pal-Hoop	0.60	0.50	0.64	**0.73**	**0.73**	0.60	**0.80**	0.60	**0.76**	**0.81**	**0.81**	0.10	0.65	**0.70**	0.50	0.41		
GRR-Troy	0.37	**0.92**	0.50	**0.76**	0.65	**0.84**	0.39	0.49	0.54	**0.84**	0.43	0.15	0.69	**0.84**	**0.84**	**0.85**	0.53	

* Insufficient data for correlation

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.

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 =

$$\frac{(P_i - O_i) * 2}{(P_i + O_i)}$$

where:

P_i = ith prediction
O_i = ith observation

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[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.

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.

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.

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. Terminology similar to the following will be used to describe model results:

Median %RSD for annual streamflow and summer baseflow	Characterization
Less than 5%	Very Good
Greater than 5% and less than 15%	Good
Greater than 15% and less than 30%	Fair
Greater than 30%	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 with full Ecology support.
- Decommissioning the station and using modeling to assess flows at the site, combined with spot-flow measurements for confirmation of modeled flows.
- Transferring the station to another party.
- Continuing operation of the gage as a telemetry gage with cooperative funding from stakeholders.

This project may also make recommendations regarding Ecology's future funding of USGS flow monitoring stations in WRIA 35.

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 Ecology's Gaging Strategy Workgroup 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 members of the WRIA 35 planning unit and the Snake River Salmon Recovery Board Regional Technical Team. 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

Project objective 5 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 4 are involved in this project. All are employees of the Washington State Department of Ecology.

Table 4. Organization of project staff and responsibilities.

Staff	Role	Responsibilities
Rusty Post SEA Program, ERO Phone: (509) 329-3579	Regional Client	Provides internal review of the QAPP, approves the final QAPP, and reviews the project report. Serves as regional program point of contact.
Bill Zachmann SEA Program Phone: (360) 407-6548	Client, Statewide Watershed Coordinator	Clarifies scopes of the project. Reviews and approves the QAPP. Reviews the project report.
Brad Hopkins Freshwater Monitoring Unit, EAP Phone: (360) 407-6686	Client, Manager of Ecology's 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 Client	Reviews the draft QAPP and approves the final QAPP. Reviews the project report.
Jenifer Parsons Eastern Operations Section, EAP Phone: (509) 454-4244	Acting Section Manager for Study Area	Reviews the draft QAPP and approves the final QAPP. Reviews the project report.
Paul J. Pickett MISU, SCS, EAP Phone: (360) 407-6882	Project Manager/ Principal Investigator	Writes the QAPP and report. Organizes, analyzes, and interprets data. Develops model and analyzes quality of data and model.
Mitch Wallace Eastern Operations Section, EAP Phone: (509) 329-3470	Project Support, Regional EAP staff	Reviews and approves the QAPP. Reviews the project report. Serves as liaison between project manager and ERO staff and local stakeholders.
Karol Erickson MISU, SCS, EAP Phone: (360) 407-6694	Unit Supervisor for the Project Manager	Reviews and approves the QAPP, and reviews and approves the project report. Approves the budget and tracks progress.
Will Kendra SCS, EAP Phone: (360) 407-6698	Section Manager for the Project Manager	Reviews the project scope and budget. Reviews and approves the QAPP. Reviews the project report.
William R. Kammin Phone: (360) 407-6964	Ecology Quality Assurance Officer	Reviews the draft QAPP and approves the final QAPP.

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

As described earlier, 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 5 shows the schedule proposed for completing the reports for this study.

Table 5. Proposed schedule for completing reports.

Final report	
Author lead	Paul Pickett
Schedule	
Draft due to supervisor	September 2012
Draft due to client/peer reviewer	September 2012
Draft due to external reviewer(s)	October 2012
Final report due on web	December 2012

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.

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Figures

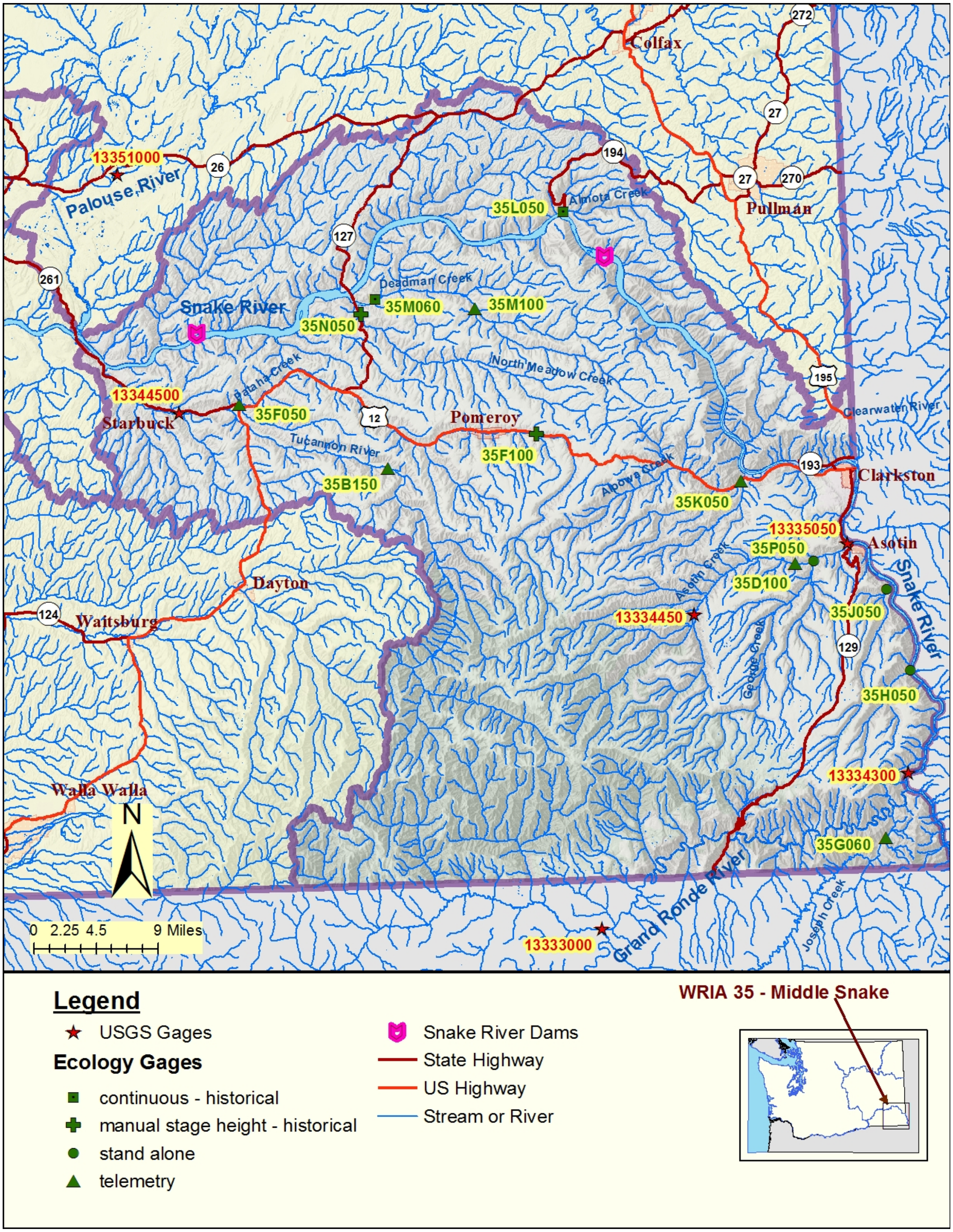

Figure 1. Middle Snake watershed study area.

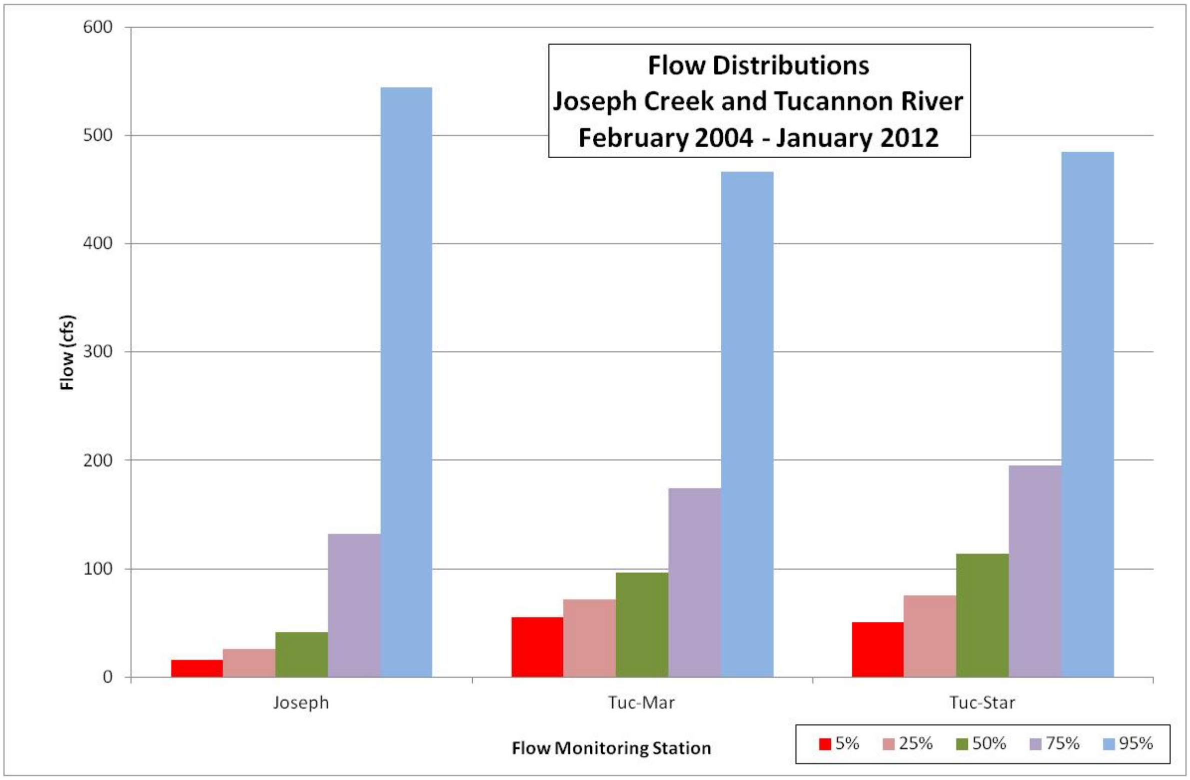

Figure 2. Flow distributions for Joseph Creek and Tucannon River gaging stations.

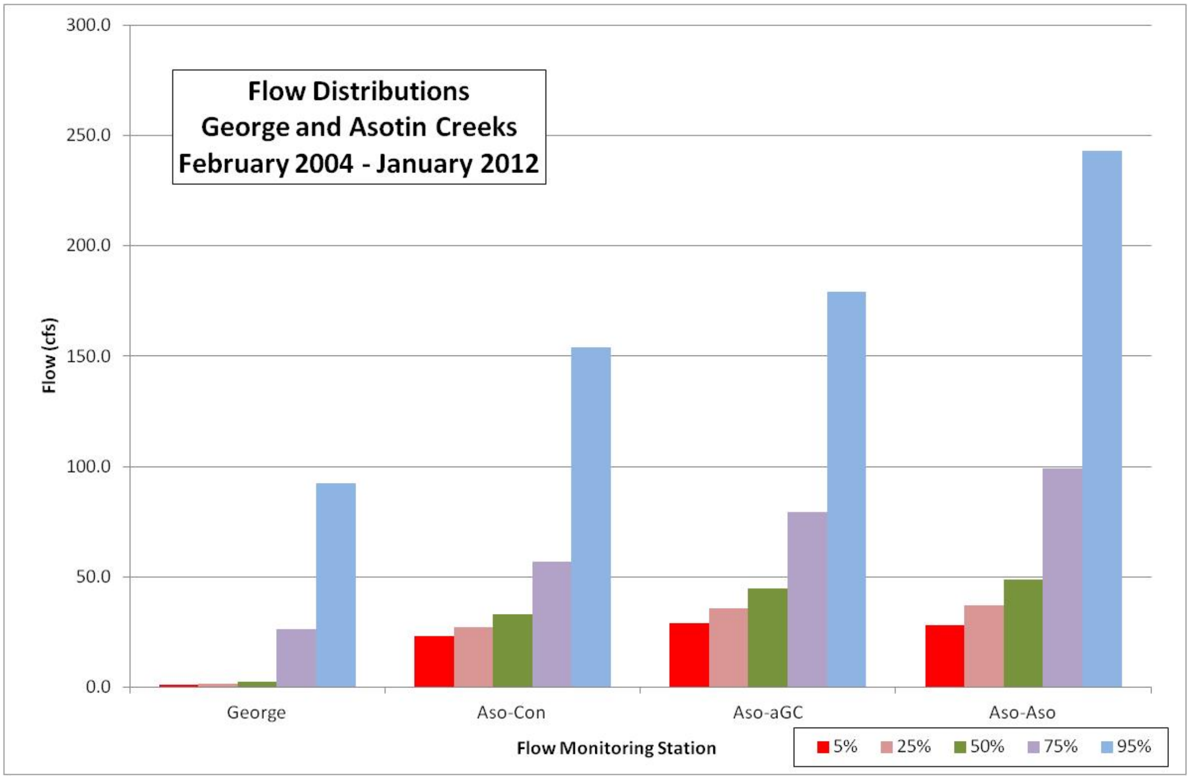

Figure 3. Flow distributions for George Creek and Asotin Creek gaging stations.

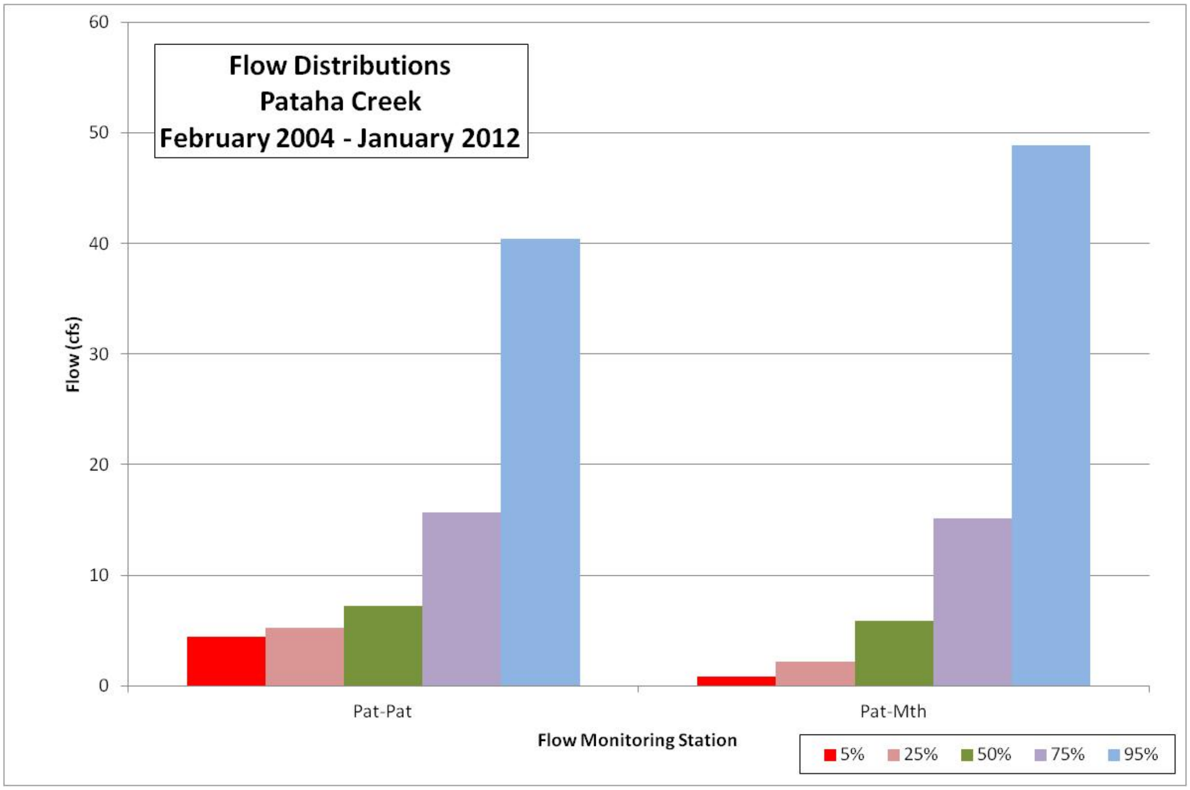

Figure 4. Flow distributions for Pataha Creek gaging stations.

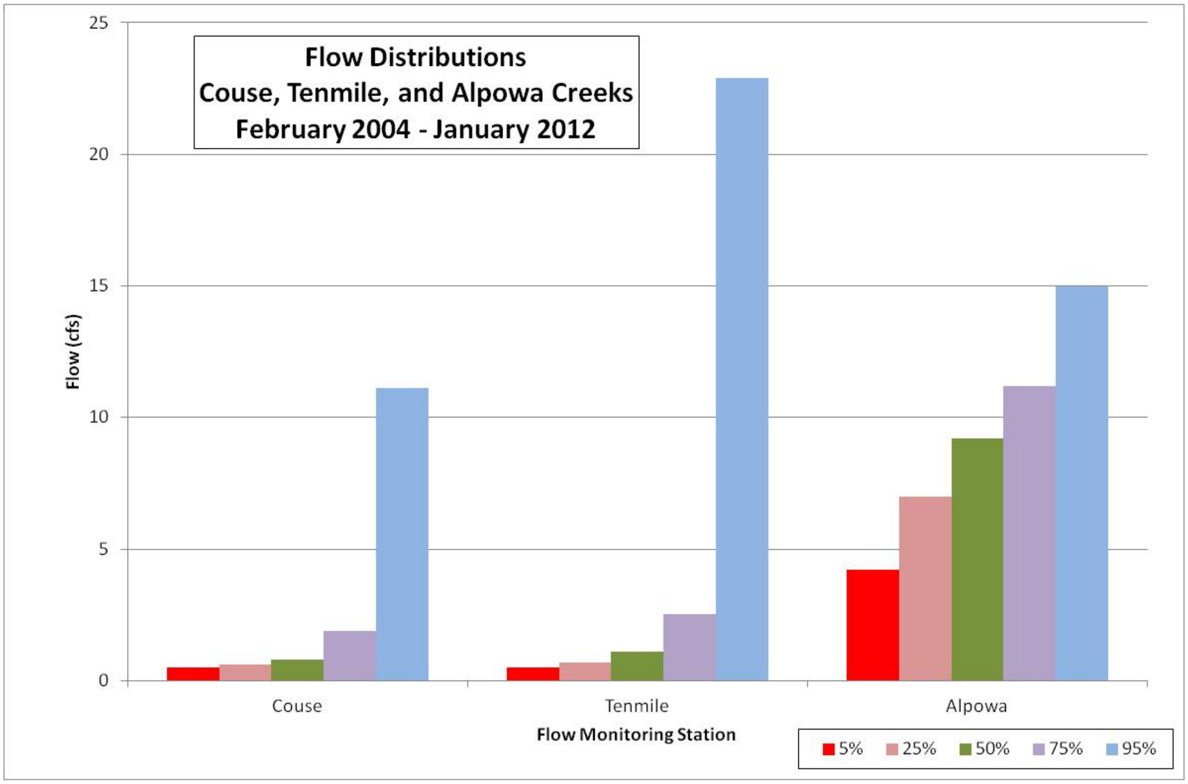

Figure 5. Flow distributions for Couse Creek, Tenmile Creek, and Alpowa Creek gaging stations.

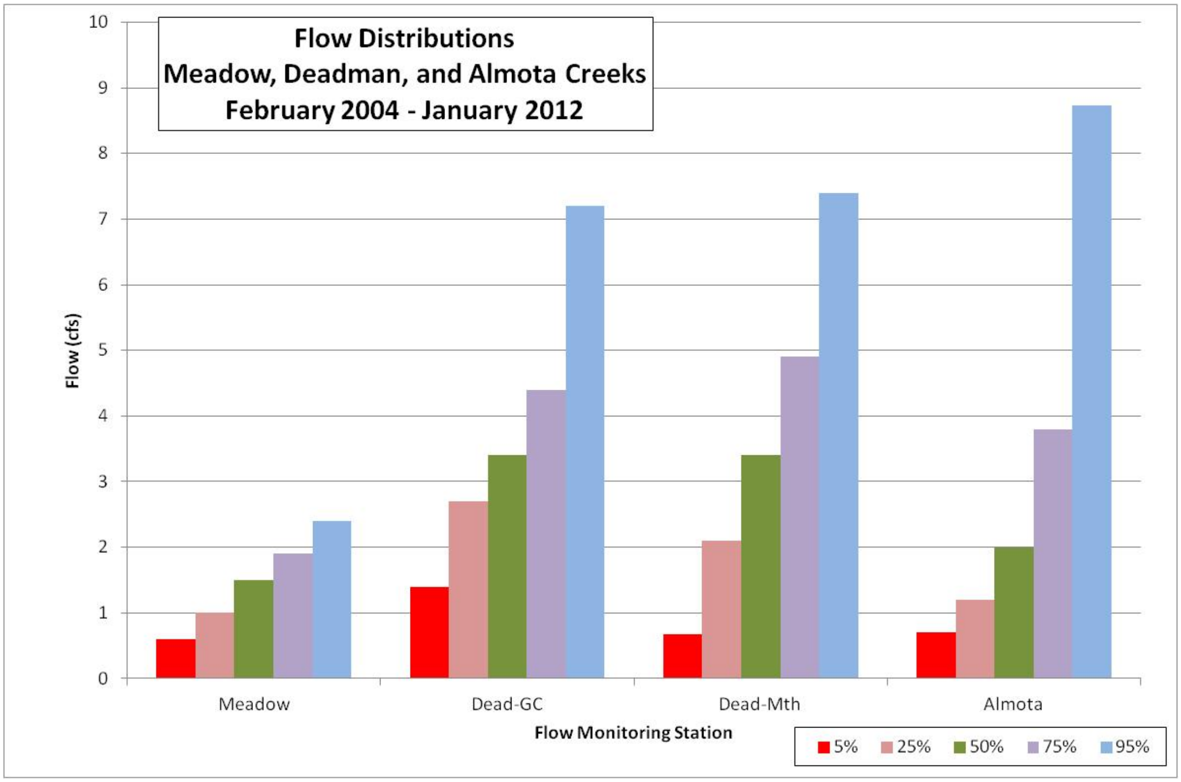

Figure 6. Flow distributions for Meadow Creek, Deadman Creek, and Almota Creek gaging stations.

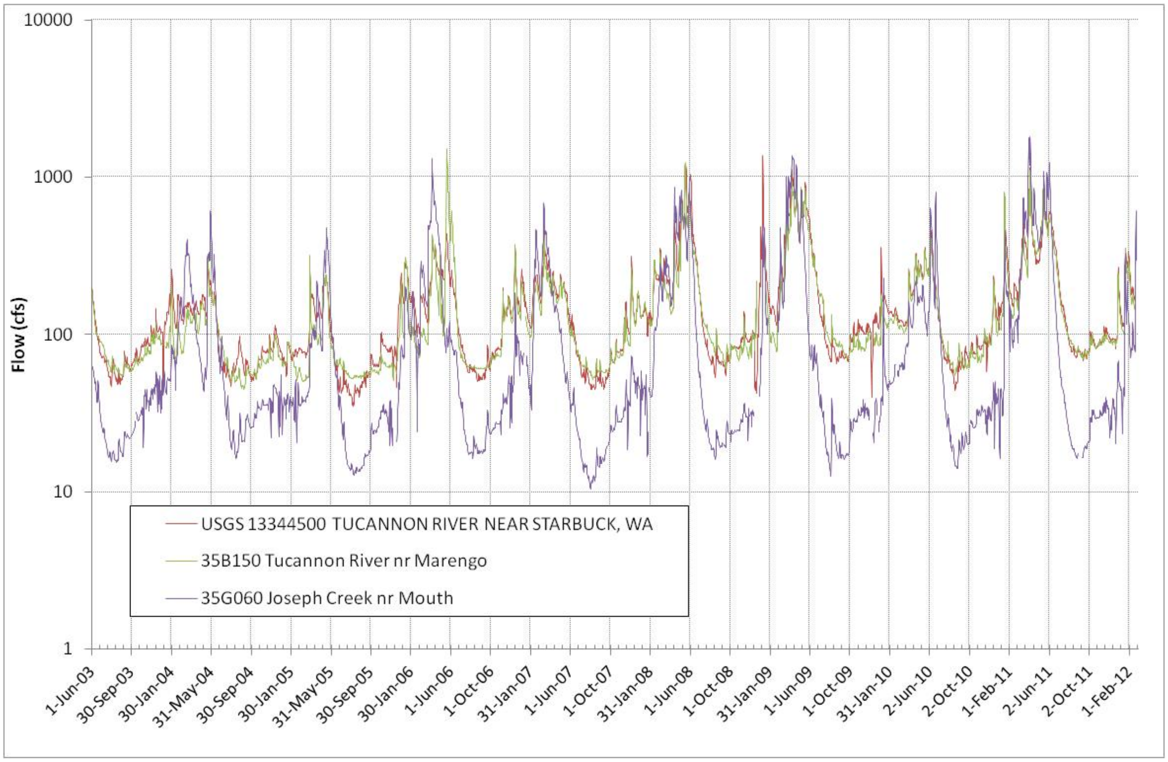

Figure 7. Flow at Joseph Creek and Tucannon River gaging stations, June 2003-February 2012.

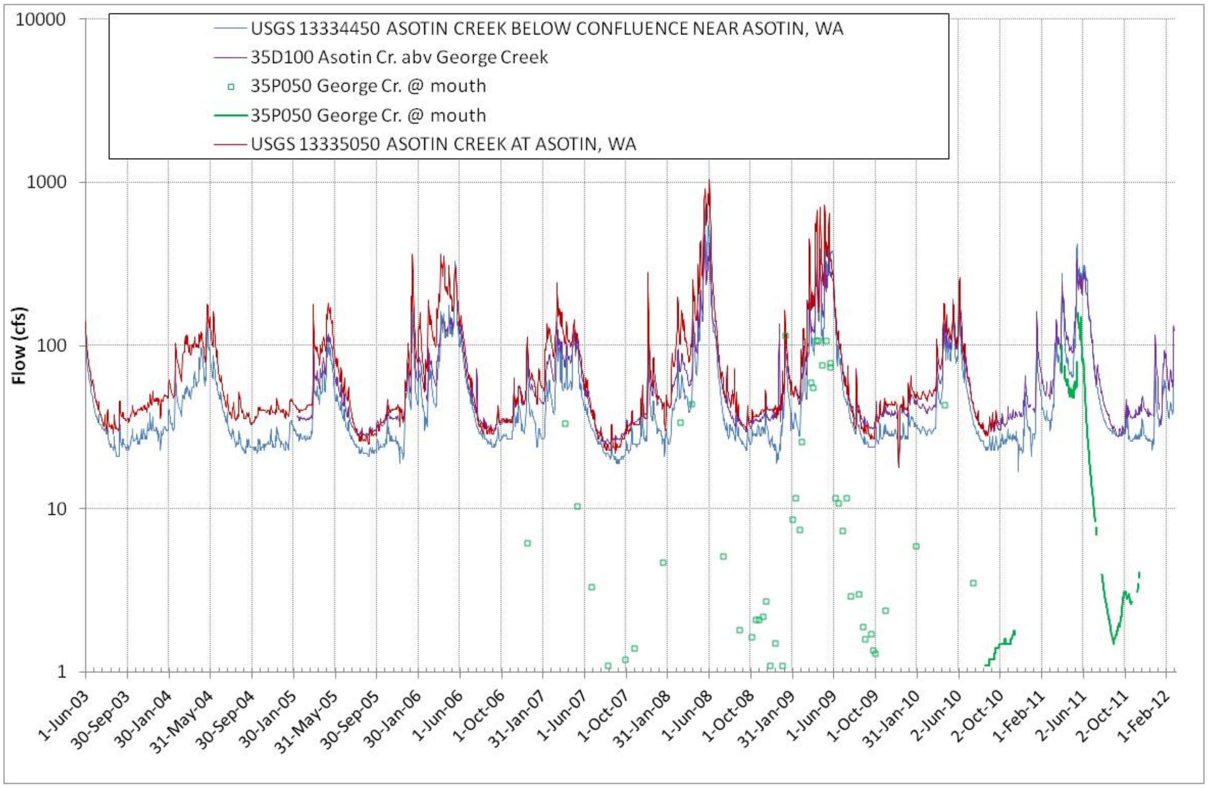

Figure 8. Flow at George Creek and Asotin Creek gaging stations, June 2003-February 2012.

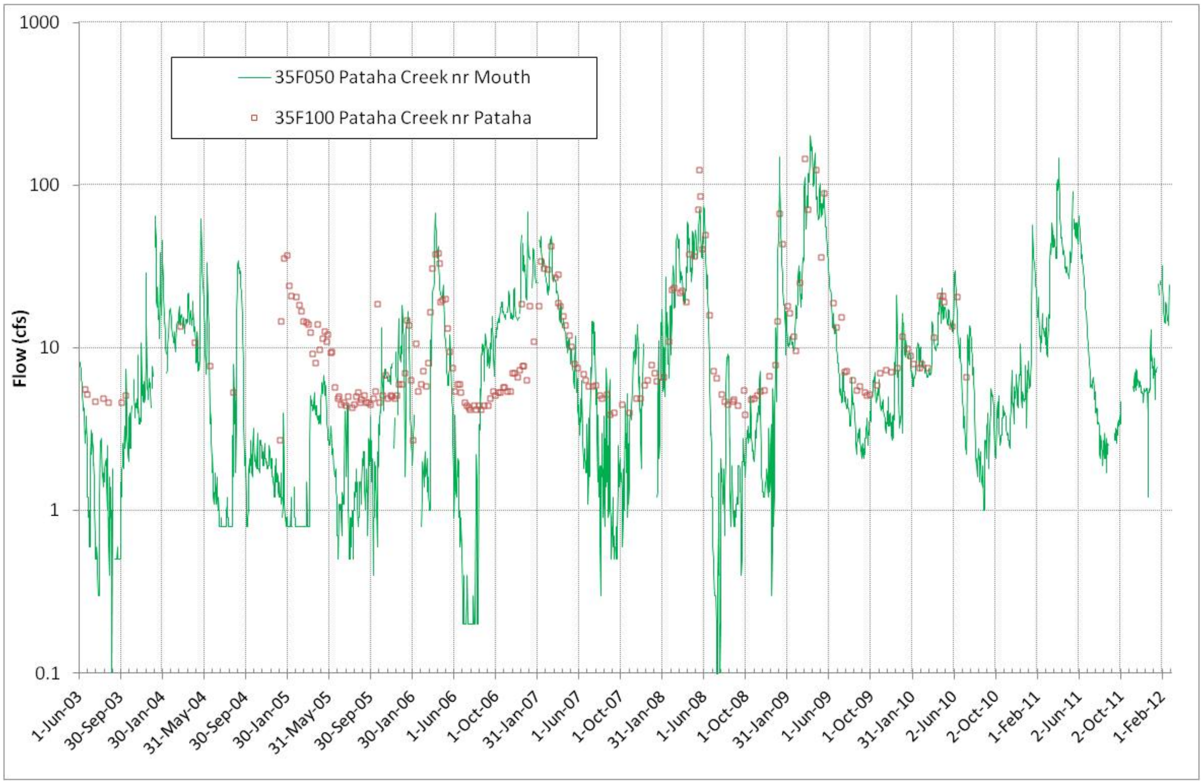

Figure 9. Flow at Pataha Creek gaging stations, June 2003-February 2012.

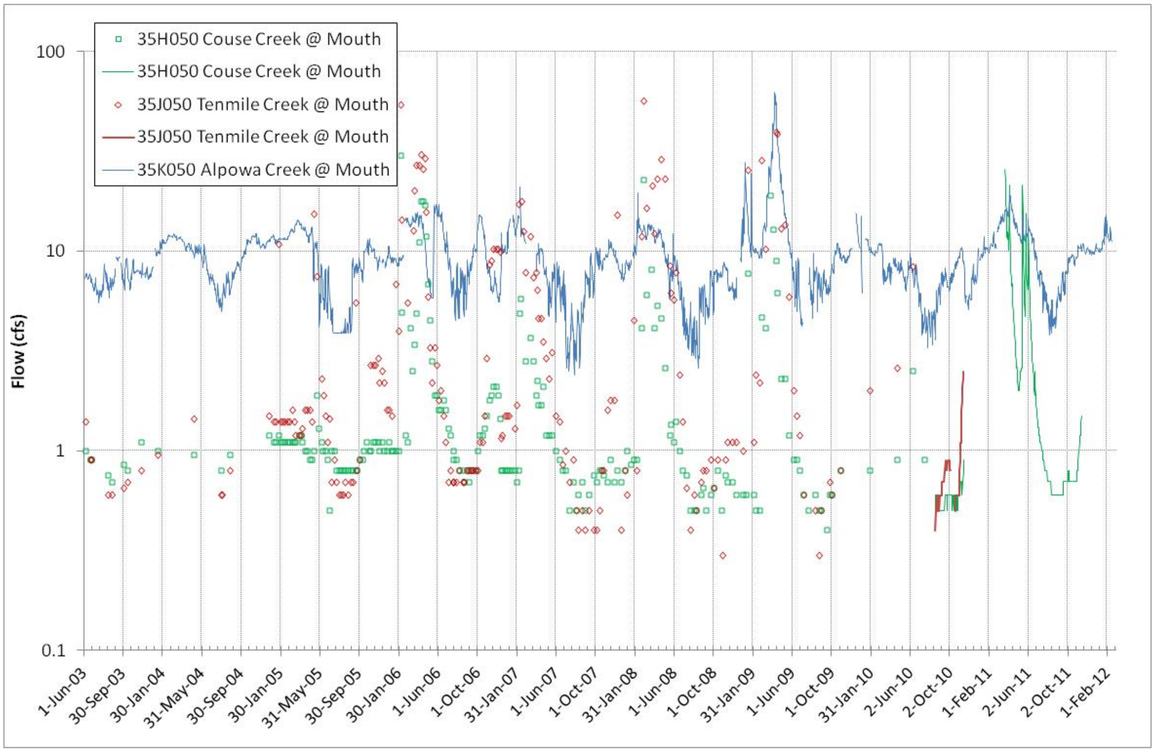

Figure 10. Flow at Tenmile Creek, Couse Creek, and Alpowa Creek gaging stations, June 2003-February 2012.

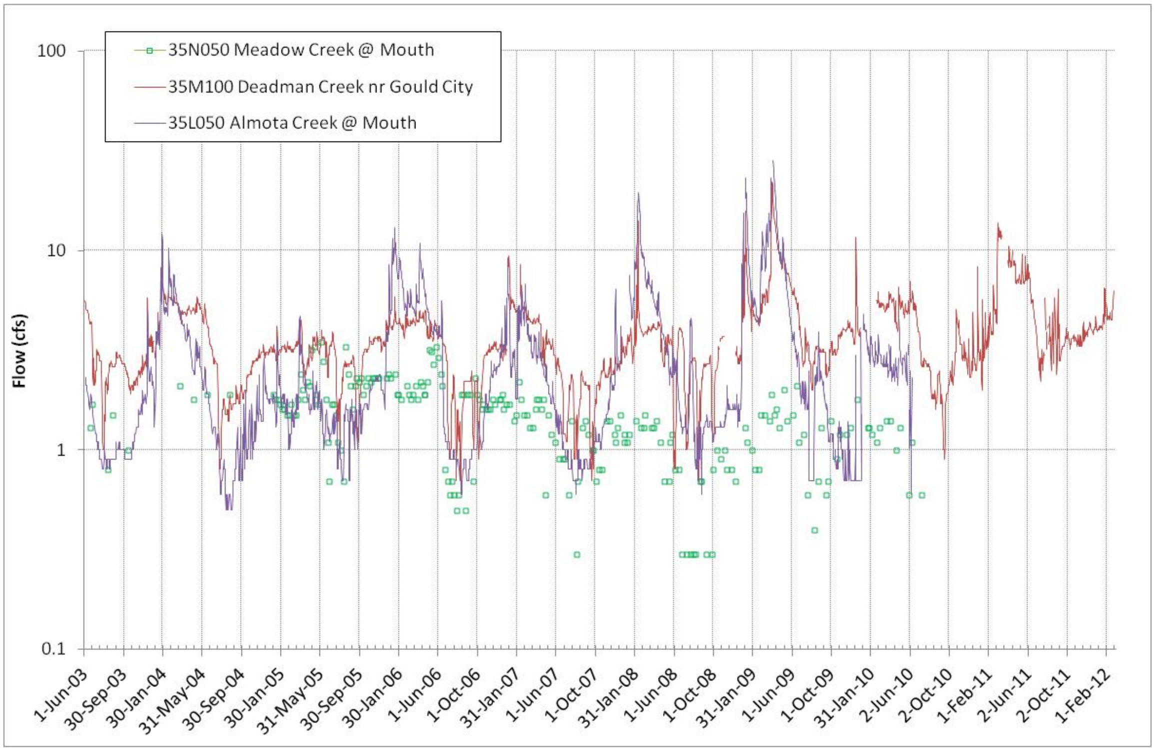

Figure 11. Flow at Meadow Creek, Deadman Creek, and Almota Creek gaging stations, June 2003-February 2012.

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.

Control Station: A location on a stream or river where regulatory instream flows are set by rule in a watershed, with a seniority date set by the date of rule adoption.

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.

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

Reach: A specific portion or segment of a stream.

Stage height: Water surface elevation from a local datum.

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 2010 describes the water year beginning October 1, 2009 and ending September 30, 2010.

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
Ecology	Washington State Department of Ecology
GIS	Geographic Information System software
No.	Number
RCW	Revised Code of Washington
RM	River mile
RPD	Relative percent difference
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
WY	Water Year

Units of Measurement

^{o}C	degrees Centigrade or Celsius
cfs	cubic feet per second, a unit of flow discharge
ft	feet
in/d	inches per day
mm	millimeters