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Quality Assurance Project Plan

Nooksack Basin
Prediction of Gaged Flows by Modeling

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Author and Contact Information

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

For more information contact: Carol Norsen, Communications Consultant
Phone: 360-407-7486

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

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Approved by:

Signature: ____________________ Date: __________
Doug Allen, Client, Bellingham Field Office

Signature: ____________________ Date: __________
Richard Grout, Client's Manager, Bellingham Field Office

Signature: ____________________ Date: __________
Bill Zachmann, Client, SEA Program

Signature: ____________________ Date: __________
Brad Hopkins, Client, Freshwater Monitoring Unit, EAP

Signature: ____________________ Date: __________
Robert F. Cusimano, Client's and Study Area Section Manager, EAP

Signature: ____________________ Date: __________
Paul J. Pickett, Author/Project Manager/Principal Investigator, EAP

Signature: ____________________ Date: __________
Karol Erickson, Author's Unit Supervisor, EAP

Signature: ____________________ Date: __________
Will Kendra, Author's Section Manager, EAP

Signature: ____________________ Date: __________
Bill Kammin, Ecology Quality Assurance Officer

Signatures are not available on the Internet version.
SEA – Shorelands and Environmental Assistance Program
EAP – Environmental Assessment Program

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Abstract

The Washington State Department of Ecology (Ecology) is proposing a study to evaluate Ecology streamflow monitoring gages in the Water Resource Inventory Area (WRIA) 1 watershed. This watershed is also referred to as the Nooksack watershed planning area. It is located in the northwest corner of Washington State.

To predict flows at those stations, simple regression-based models will be developed and applied. In addition, regulatory flow control stations will be evaluated to determine the feasibility of applying simple models to estimate flow at the control stations where current or historic flow data are available. The existing TOPNET hydrologic model will also be evaluated for possible use to predict flows at Ecology flow monitoring and control stations.

The quality of all models applied will be evaluated, and recommendations will be made for use of the models for water management by Ecology and the WRIA 1 Planning Unit. The Planning Unit is comprised of representatives of local tribes, governments, and citizens.

Each study conducted by 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 completion of the study, a final report describing the study results will be posted to the Internet.

Background

Overview of the Watershed

The focus of this study is Water Resource Inventory Area No. 1 (WRIA 1), which is also referred to as the Nooksack watershed planning area. This area is bordered on the north by the international border with Canada, on the east by the Cascade crest (the divide between the Puget Sound and Columbia basins), on the south by the Skagit River basin, and on the west by Puget Sound (Figure 1). Detailed information on the WRIA can be found at the website for the WRIA 1 Watershed Management Project (http://wria1project.whatcomcounty.org/About-The-Watershed/10.aspx).

Hydrologically, WRIA 1 is a complex region. The range of landscape elevations extend from Mount Baker at 10,778 feet (3,285 m) to the Puget Sound shoreline. Upper elevation watershed areas are dominated by glacier and snow melt, while lower elevations are more likely rainfall-dominated. Total land area is about 1,628 square miles (4,217 square kilometers).

WRIA 1 can be divided into three basin categories:

- **The Nooksack River basin.** The watershed for the Nooksack River and all its tributaries lies in WRIA 1.
- **Coastal basins.** Several small watersheds in WRIA 1 drain directly into Drayton Harbor, Birch Bay, Lummi Bay, Bellingham Bay (including Lake Whatcom), and the northeastern side of Samish Bay.
- **Fraser River tributaries.** The upstream portion of the Sumas River and Saar Creek drains north into Canada from WRIA 1. Several headwater tributaries of the Fraser River lie in the northeast corner of WRIA 1, including the Chilliwack River and Silesia Creek.

Mean annual rainfall in WRIA 1 varies from 40 inches around Bellingham to over 100 inches in the highest elevations. Evapotranspiration rates in low-lying areas are approximately 30 inches per year, mostly occurring in May through August at rates of 4 and 5 inches per month.

Groundwater levels are relatively shallow in the river valleys and other low-lying areas of northwestern Whatcom County, suggesting that connectivity between surface water and groundwater in these areas is high.

Snowpack is a significant source of seasonally stored water, with April 1 (seasonal maximum) snow depths on Mount Baker averaging about 170 inches and ranging from 70 to 310 inches over the last 80 years. Seasonal maximum Snow Water Equivalent (SWE) data over the last 13 years at Natural Resource Conservation Service Snowpack Telemetry (SNOTEL) stations in the basin ranged from 9 to 74 inches.

Flows can vary widely in WRIA 1 streams. Those draining the higher elevations are dominated by snow and glacier melt, while those at low elevations are rain-dominated. Intermediate elevations are characterized by a mixed snow-rain regime.

Water use in Whatcom County in 1995 was estimated by U.S. Geological Survey (USGS) at 87 million gallons per day (mgd) of groundwater, and 74 mgd of surface water. About 49% of groundwater use was for public supply and about 43% for irrigation. Surface water use was about 67% for public supply, 21% for irrigation, and 9% for industrial use.

Political jurisdictions in WRIA 1 include Whatcom County, Lummi Nation, Nooksack Tribe, City of Bellingham, and smaller cities and towns: Ferndale, Blaine, Lynden, Everson, Nooksack, and Sumas. Whatcom Public Utility District also plays a key role in water management.

Whatcom County has experienced rapid population growth, doubling from 82,606 to 166,814 persons between 1970 and 2000. This has resulted in growth in urban and rural residential uses, especially around Bellingham and in the Drayton Harbor watershed. The economy has traditionally been dependent on timber, farming, and fishing, and many industries related to those sectors were established in Whatcom County, such as food processors and lumber and paper mills. Whatcom County is also home to large oil refining and aluminum smelting plants.

About 20% of WRIA 1 is zoned for forestry, 11% for rural development, 8% for agriculture, and 7% for urban and commercial/industrial development. The eastern one-third of WRIA 1 is mostly forested lands managed by the U.S. Forest Service and the National Park Service. Of the western two-thirds, about 60% is either undeveloped, timber lands, or managed as open space. Agriculture dominates the low-lying areas around Lynden, the Sumas River, the Lower Nooksack River, Barrett Lake, and Drayton Harbor. Agricultural water use includes irrigation, stock watering, and facility washdown.

Watershed Planning

Over the past 11 years, the WRIA 1 Planning Unit has been developing and implementing the WRIA 1 Watershed Management Project (WMP). The following, borrowed from the WRIA 1 WMP website (http://wria1project.whatcomcounty.org/About-The-Project/History/15.aspx), describes the history of this project:

> *In 1998, the Washington State Watershed Management Act (Act) legislation was passed and codified as Chapter 90.82 RCW. This law allows citizens and local governments to develop a plan specifically related to local water-related circumstances and needs. The state designated the Nooksack watershed as Water Resource Inventory Area No. 1 (WRIA 1). The Watershed Management Act requires all participating local governments to address water quantity, and also gives them the option of addressing water quality, instream flows, and fish habitat. The WRIA 1 Watershed Management Plan addresses all three.*
>
> *In October of 1998, a Memorandum of Agreement (MOA) initiated the planning process. This MOA was signed by four of the five Initiating Governments. Later, the Nooksack Tribe submitted a Letter of Agreement. In the case of WRIA 1, the Initiating Governments are:*
>
> - *City of Bellingham*
> - *Lummi Nation*
> - *Nooksack Tribe*

- *Public Utility District No. 1*
- *Whatcom County*

The Initiating Governments established the Planning Unit to ensure representation of a broad range of water resource interests. In 1999, an Interlocal Agreement (ILA) created the Joint Board, which is comprised of representatives of the Lummi Nation, Nooksack Indian Tribe, City of Bellingham, Whatcom County, and the Public Utility District No. 1.

In March 2000, a general Scope of Work (SOW) for the WRIA 1 Watershed Management Project was developed by project participants and approved by the Planning Unit and the Joint Board. The March 2000 SOW identifies project goals, the technical elements to be addressed (water quantity, water quality, instream flow, and fish habitat), the approach for defining solutions, and elements to be considered for Watershed Management Plan (WMP) implementation including governance structure, funding, long-term monitoring, and adaptive management. The Watershed Plan was approved by the Planning Unit in March 2005 and by the Whatcom County Council in June 2005.

In June 2007, the WRIA 1 Planning Unit approved the WRIA 1 Detailed Implementation Plan (DIP). The DIP was prepared for WRIA 1 Watershed Management Project participants and is a tool intended to facilitate implementation of actions and strategies in the June 2005 WRIA 1 WMP.

Several efforts related to the WRIA 1 WMP are relevant to this study:

- The USGS conducted a hydrologic assessment for WRIA 1, which compiled and assessed hydrologic data (USGS, 2001).

- Utah State University (USU), as part of its technical support for the WRIA 1 WMP:
  - Reviewed existing models.
  - Made recommendations for hydrologic modeling.
  - Conducted surveys of the basin in support of modeling.
  - Developed a hydrologic model of streams in WRIA 1 (called *TOPNET*).
  - Developed a Decision Support System for watershed planning in WRIA 1.

Flow Gages

The Washington State Department of Ecology (Ecology) has 14 current and historical flow monitoring stations (www.ecy.wa.gov/programs/eap/flow/shu_main.html, Table 1 and Figure 2):

- Seven stations are *telemetry* stations that provide real-time gage height and flow measurement. One station was discontinued in 2008. Also, Bar Creek was discontinued due to damage from a landslide, while Maple Creek was discontinued due to excessive beaver activity near the gage.

- Two stations are *stand-alone* stations that collect continuous gage height for periodic download and conversion to discharge measurements. These stations were *manual stage* stations until 2007, but were upgraded for the Drayton Harbor Total Maximum Daily Load study (Mathieu and Sargeant, 2008).

- Five are stations where *manual stage* readings are collected infrequently (at least once per month). The Middle Fork Nooksack River station was stand-alone, but vandalism forced a downgrade.

Table 1. Ecology WRIA 1 flow monitoring stations.

Station ID	Station Name	Type
01N060	Bertrand Creek near mouth	Real-time
01C070	Hutchinson Creek near Acme	Real-time
01A140	Nooksack River above the Middle Fork	Real-time
01F070	South Fork Nooksack River at Potter Road	Real-time
01P080	Tenmile Creek above Barrett Lake	Real-time
01J060	Bar Creek at mouth	Historical continuous
01K050	Maple Creek at mouth	Historical continuous
01R090	California Creek at Valley View Road	Stand-alone (previously Manual Stage)
01Q070	Dakota Creek at Giles Road	Stand-alone (previously Manual Stage)
01G100	Middle Fork Nooksack River above Clearwater Creek	Manual Stage (previously Stand-alone)
01L050	Anderson Creek at mouth	Manual Stage
01M090	Kamm Slough at Northwood Road	Manual Stage
01S070	Squalicum Creek at West Street	Manual Stage

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

The USGS has gaged flow throughout WRIA 1 at a variety of sites historically and currently (USGS, 2001):

- Continuous streamflow data have been collected at 56 stations, of which 14 are currently active. The active stations are listed in Table 2 and shown in Figure 2. Of the active stations, 6 are *real-time* telemetry stations, while 8 are *non-real-time*, stand-alone stations. Of the 8 stand-alone stations, 6 are operated through funding from the Lummi Tribe with 90.82 watershed planning grant funds and other funds.
- A total of 2,537 miscellaneous flow measurements have been collected at 134 sites over the last 100 years (Figure 3).

Table 2. USGS active flow monitoring stations.

Site Number	Site Name	Start date	Type
12205000	North Fork Nooksack River below Cascade Creek near Glacier	1-Oct-1937	Real-time
12206900	Racehorse Creek at North Fork Road near Kendall	1-Oct-1998	Stand-alone[1]
12207750	Warm Creek near Welcome	1-Oct-1998	Stand-alone[1]
12207850	Clearwater Creek near Welcome	1-Oct-1998	Stand-alone[1]
12208000	Middle Fork Nooksack River near Deming	28-Aug-1920	Real-time
12209000	South Fork Nooksack River near Wickersham	1-May-1935	Stand-alone
12209490	Skookum Creek above diversion near Wickersham	1-Oct-1998	Stand-alone[1]
12210000	South Fork Nooksack River at Saxon Bridge	1-Oct-2008	Real-time
12210700	Nooksack River at North Cedarville	15-Oct-2004	Real-time
12210900	Anderson Creek at Smith Road Near Goshen	1-Oct-1998	Stand-alone[1]
12212050	Fishtrap Creek at Front Street at Lynden	1-Oct-1998	Stand-alone[1]
12212390	Bertrand Creek at International Boundary	5-May-2007	Stand-alone
12212430	Unnamed tributary to Bertrand Creek near H Street near Lynden (Jackman Ditch)	6-Jan-2007	Real-time
12213100	Nooksack River at Ferndale	1-Oct-1966	Real-time

[1]Funded by Lummi Tribe

To provide a comparison of the flows at the Ecology and USGS gages, the annual mean flows for Water Year 2006 (October 2005-September 2006) are shown in Figure 4. The coastal streams and most of the Nooksack River tributaries averaged less than 100 cfs. The larger Nooksack tributaries and forks averaged from 100 to just over 1000 cfs, while the mainstem Nooksack River averaged from 1,700 up to almost 4,000 cfs in 2006.

Flows can vary widely between years as well. Between Water Years 1967 and 2008, annual mean flows in the Nooksack River at Ferndale ranged from 2,536 cfs (2001) to 5,152 cfs (1991). The maximum flow on record was 57,000 cfs (November 10, 1990), while the minimum flow on record is 463 cfs (October 26, November 9, 10, 1987).

Instream Flow Rule

In December 1985, Ecology set minimum instream flows under the Nooksack Instream Resources Protection Program (IRPP) for WRIA 1 (Ecology, 1985). Flows must be met at specified *control stations* in each designated stream. Those flows are senior in right to any water rights established after the date of the rule implementing the IRPP (Chapter 173-501 WAC).

Regulatory flow control stations established by the IRPP and rule are shown in Table 3. The Ecology gages identified for some of the control stations were apparently never physically established, but their approximate locations are shown in Figure 4. The periods of record for the USGS gages are shown in Table 3.

Table 3. Ecology flow control stations from WAC 173-501-030.

Stream Management Unit Name	Agency	ID	River Mile	Town-ship	Range	Section	Stream Management Reach
Anderson Creek	WDOE	2109-00	1.4	39 N.	4 E.	19	From confluence with Nooksack River to headwaters, including all tributaries.
Bells Creek	WDOE	2073-00	0.5	39 N.	5 E.	21	From confluence with Nooksack River to headwaters, including all tributaries.
Bertrand Creek	WDOE	2124-00	1	40 N.	2 E.	26	From U.S./Canada border to confluence with Nooksack River, including all tributaries.
California Creek	WDOE	2134-00	3	40 N.	1 E.	21	From influence of mean annual high tide at low instream flow levels to headwaters, including all tributaries.
Canyon Creek	WDOE	2045-00	0.2	40 N.	6 E.	35	From confluence with North Fork Nooksack River to headwaters, including all tributaries.
Cornell Creek	WDOE	2057-00	0.6	39 N.	6 E.	1	From confluence with North Fork Nooksack River to headwaters, including all tributaries.
Deer Creek	WDOE	2130-50	0.2	39 N.	2 E.	28	From the confluence with Tenmile Creek to headwaters, including all tributaries.
Gallop Creek	WDOE	2056-00	0.3	39 N.	7 E.	6	From confluence with North Fork Nooksack River to headwaters, including all tributaries.
Hutchinson Creek	WDOE	2101-00	1.8	38 N.	5 E.	36	From confluence with South Fork Nooksack River to headwaters, including all tributaries.
Johnson Creek	WDOE	2149-00	0.5	41 N.	4 E.	35	From U.S./Canada border to headwaters, including all tributaries.
Maple Creek	WDOE	2059-00	0.8	40 N.	6 E.	30	From confluence with North Fork Nooksack River to headwaters, including all tributaries.
Porter Creek	WDOE	2084-00	0.7	38 N.	5 E.	11	From confluence with Middle Fork Nooksack River to headwaters, including all tributaries.
Racehorse Creek	WDOE	2071-00	1.5	39 N.	5 E.	11	From confluence with North Fork Nooksack River to headwaters, including all tributaries.
Silver Creek	WDOE	2132-00	2	38 N.	2 E.	4	From confluence with Nooksack River to headwaters, including all tributaries.
Smith Creek	WDOE	2111-00	0.8	39 N.	4 E.	22	From confluence with Nooksack River to headwaters, including all tributaries.
Terrell Creek	WDOE	2133-00	2.2	40 N.	1 E.	31	From influence of mean annual high tide at low instream flow levels to headwaters, including all tributaries.
Wiser Lake Creek	WDOE	2126-00	0.7	39 N.	2 E.	3	From confluence with Nooksack River to headwaters, including all tributaries.

Table 3, continued. Ecology flow control stations from WAC 173-501-030.

Stream Management Unit Name	Agency	ID	Period of Record	River Mile	Town-ship	Range	Section	Stream Management Reach
Canyon Creek at Kulshan	USGS	12-2085-00	7-1948 to 9-1954	0.2	39 N.	5 E.	27	From confluence with North Fork Nooksack River to headwaters, including all tributaries.
Dakota Creek near Blaine	USGS	12-2140-00	7-1948 to 10-1954	3.5	40 N.	1 E.	9	From influence of mean annual high tide at low instream flow levels to headwaters, including all tributaries.
Fishtrap Creek at Lynden	USGS	12-2120-00	7-1948 to 10-1971	6.9	40 N.	3 E.	16	From U.S./Canada border to confluence with Nooksack River, including all tributaries.
Kendall Creek	USGS	12-2065-00	8-1955 to 8-1981 (n=15)	0.1	39 N.	5 E.	3	From confluence with North Fork Nooksack River to headwaters, including all tributaries.
Nooksack River (at Deming)	USGS	12-2105-00	7-1935 to 9-2005	36.6	39 N.	5 E.	31	From confluence with Smith Creek to confluence of North Fork and Middle Fork Nooksack Rivers.
Nooksack River (at Ferndale)	USGS	12-2131-00	10-1966 to present	5.8	39 N.	2 E.	29	From influence of mean annual high tide at low instream flow levels to confluence with, and including, Smith Creek.
Nooksack River (Middle Fork)	USGS	12-2080-00	8-1920 to present	5	38 N.	5 E.	13	From confluence with North Fork to headwaters.
Nooksack River (North Fork)	USGS	12-2072-00	9-1964 to 12-1975	44.1	39 N.	5 E.	15	From confluence with Middle Fork to headwaters.
Nooksack River (South Fork)	USGS	12-2090-00	5-1934 to 9/2008	5	38 N.	5 E.	19	From confluence with Nooksack River (mainstem) to headwaters.
Saar Creek	USGS	12-2155-00	11-1954 to 8-1959 (n=8)	0.2	41 N.	5 E.	31	From U.S./Canada border to headwaters, including all tributaries.
Skookum Creek near Wickersham	USGS	12-2095-00	7-1948 to 9-1969	0.1	37 N.	5 E.	27	From confluence with South Fork Nooksack River to headwaters, including all tributaries.
Sumas River near Sumas	USGS	12-2145-00	7-1948 to 9-1955	2.1	41 N.	4 E.	2	From U.S./Canada border to headwaters including all tributaries.
Tenmile Creek at Laurel	USGS	12-2129-00	5-1968 to 9-1972	4.4	39 N.	2 E.	13	From confluence with Nooksack River to headwaters, including all tributaries.

WDOE – Washington State Department of Ecology (Ecology).

Project Description

Goals and Objectives

The goals of this project are to:

- Develop computer modeling tools that can determine streamflows in WRIA 1 for Ecology flow monitoring sites and regulatory control stations.
- Determine the quality of the modeling tools.
- Assess their ability to support Ecology and the WRIA 1 Planning Unit in their water management activities in the basin.
- Identify data gaps in flow measurement or modeling.
- Support Ecology in making decisions about use of its flow gaging resources statewide.

To meet this goal, this project has the following objectives:

1. Develop statistical and simple hydrologic models that can predict streamflows at Ecology flow monitoring stations in WRIA 1 based on relationships with long-term USGS flow stations or other Ecology flow stations.
2. Evaluate whether sufficient flow information is available to develop simple modeling tools that predict flows at regulatory control stations, and develop models for those stations.
3. Evaluate the USU hydrologic model for WRIA 1, and determine whether it can be applied to predict flows at Ecology flow monitoring stations and regulatory control stations at a level of effort within the schedule designated for this project, and if so, develop those applications.
4. Assess the quality of the results of the modeling tools developed for Objectives 1 through 3.
5. Provide support in determining a long-term approach to flow discharge assessment that combines direct monitoring of gage height with modeling approaches, thus reducing the total number of flow monitoring stations using continuous stream gage measurements.
6. 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.
7. Recommend any flow measurement needs to allow flows to be estimated or measured for regulatory control stations.
8. 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 1 basin and (2) other relevant information such as geographical, geological, or meteorological data. The planned approach is to select *index stations*, such as the long-term USGS flow stations, and then predict Ecology flow data from one or more of those stations. Based on this analysis, one or more Ecology flow stations may also be selected as index stations.

A number of 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 and other non-hydrologic data to adjust predictive equations.
- Other tools identified by USGS (Curran and Olsen, 2009), such as Maintenance of Variance Extension (Hirsch, 1982).

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

- The adequacy of the quality of the results from the simpler approach.
- Whether the available data supports a more complex approach.
- The time available in the project schedule to pursue a more complex approach.
- The potential use of the modeling approach.
- The priority of the station to the WRIA 1 Planning Unit and Ecology.

An example of the simplest kind of correlation is provided in Table 4. Real-time flow data from the Ecology and USGS stations were correlated using *Hydstra*, the data management software used by Ecology for analyzing its flow monitoring network. This initial analysis shows how some gages will correlate well, while others will have much poorer relationships.

To evaluate regulatory control stations (the second study objective), the sites identified in state regulations will be evaluated in the field and compared to active and historic flow records. The modeling approaches described above will then be applied to control points with historic flow records that are adequate for model development. The age and representativeness of the gaging data will be taken into account in deciding the validity and quality of a modeling approach. Potential alternate flow measurement sites may also be suggested for control stations.

To meet the third study objective, the USU hydrologic model will be evaluated to determine whether it can be extended or modified to predict flows at Ecology gages and at control stations. Development of an application of the model to meet study objectives will be pursued if the application can be developed within the schedule and level of effort planned.

Table 4. Summary of simple correlation r values (Hopkins, 2009).

Name	Type*	Type:	RT	RT	RT	SA	CH	RT	RT	SA	SA	MS	MS	MS	MS
		Station ID	01A140	01C070	01F070	01G100	01K050	01N060	01P080	01Q070	01R090	01D100	01L050	01M090	01S070
Nooksack R above M.F.	RT	01A140	NA												
Hutchinson Cr	RT	01C070	0.428	NA											
S.F. Nooksack R	RT	01F070	0.655	0.761	NA										
M.F. Nooksack R	SA	01G100	0.761	0.851	0.607	NA									
Maple Cr	CH	01K050	0.402	0.459	0.747	0.240	NA								
Bertrand Cr	RT	01N060	0.260	0.890	0.773	0.175	0.792	NA							
Tenmile Cr	RT	01P080	0.240	0.841	0.707	0.142	0.842	0.899	NA						
Dakota Cr	SA	01Q070	-0.257	0.756	0.509	NA	0.617	0.903	0.819	NA					
California Cr	SA	01R090	-0.446	0.762	0.351	NA	0.776	0.928	0.869	0.950	NA				
Sumas R	MS	01D100	0.38	0.958	0.900	NA	NA	0.941	0.956	NA	NA	NA			
Anderson Cr	MS	01L050	0.286	0.938	0.872	NA	NA	0.938	0.911	NA	NA	NA	NA		
Kamm Slough	MS	01M090	0.241	0.892	0.739	NA	NA	0.898	0.882	NA	NA	NA	NA	NA	
Squalicum Cr	MS	01S070	0.291	0.921	0.833	NA	NA	0.931	0.923	NA	NA	NA	NA	NA	NA
Nooksack R at N Cedarville	USGS	12210700	0.822	0.654	0.892	0.777	0.613	0.53	0.479	0.687	0.036	0.761	0.610	0.578	0.618
Nooksack R at Deming	USGS	12210500	0.853	0.763	0.875	0.712	0.601	0.562	0.539	0.857	0.689	0.866	0.741	0.960	0.835
Nooksack R at Ferndale	USGS	12213100	0.754	0.752	0.900	0.657	0.706	0.642	0.610	0.706	0.272	0.818	0.682	0.607	0.687
NF Nooksack R below Cascade Cr	USGS	12205000	0.487	-0.053	0.205	0.435	-0.048	-0.148	-0.184	0.119	-0.599	0.068	-0.109	-0.020	0.000
MF Nooksack R near Deming	USGS	12208000	0.822	0.404	0.700	0.898	0.300	0.258	0.192	0.535	-0.394	0.562	0.441	0.307	0.488
SF Nooksack R near Wickersham	USGS	12209000	0.676	0.788	0.974	0.633	0.682	0.687	0.604	0.740	-0.394	0.869	0.819	0.615	0.785

* RT = Real-time; SA = Stand Alone; MS = Manual Staff.
Correlations greater than 0.8 are shaded.

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.

Items 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). 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 mean of RPD values for all pairs of results.

$$RPD = (| P_i - O_i | * 2) / (O_i + P_i)$$, where
P_i = i^{th} prediction
O_i = i^{th} observation

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 and observed 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 provides a measure of the importance of an input factor in generating output variation. While it 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.

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
Does not meet criteria above	Poor

Flow Gaging Assessment

Objectives 5 through 7 will be accomplished by evaluating the results of the model assessments described above for each gaging station. Each Ecology flow monitoring station will have a preferred modeling approach identified and an evaluation of the quality of the model. This information will be provided to Ecology staff and local stakeholders to support decisions about allocation of resources for flow gaging.

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.

Control stations will be categorized by the:

- Presence of an active flow monitoring station.
- Availability and quality of modeling tools to estimate flows at the station.
- Need for additional flow monitoring.
- Potential for moving the flow station to a location better suited for flow monitoring.

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 those models as 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. Public input during the project will be through the WRIA 1 Planning Unit. The form and timing of public input will be determined by the project, regional, and client leads in consultation with the GSW and the Bellingham Field Office and Regional Water Resource Management Team.

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 will be determined through consultation with project clients and responsible staff and groups.

Organization and Schedule

Table 5 lists the people involved in this project with their contact information, roles, and responsibilities. All are employees of the Washington State Department of Ecology.

Table 5. Organization of project staff and responsibilities.

Staff (all EAP unless noted otherwise)	Role	Responsibilities
Paul J. Pickett MISU Statewide Coordination Section 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 Statewide Coordination Section Phone: (360) 407-6694	Unit Supervisor for the Project Manager	Provides internal review of the QAPP. Approves the budget and approves the final QAPP.
Will Kendra Statewide Coordination Section Phone: (360) 407-6698	Section Manager for the Project Manager	Reviews the project scope and budget. Tracks progress. Reviews the draft QAPP and approves the final QAPP.
Bob Cusimano Western Operations Section Phone: (360) 407-6596	Section Manager for the Study Area	Reviews the project scope and budget. Tracks progress. Reviews the draft QAPP and approves the final QAPP.
Doug Allen Bellingham Field Office (360) 715-5217	Client, Ecology WRIA 1 Watershed Lead	Clarifies scopes of the project. Provides internal review of the QAPP and approves the final QAPP. Serves as Ecology liaison between the Project Manager and the WRIA 1 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. Serves as liaison with Ecology WAG and SEA Program.
Brad Hopkins Freshwater Monitoring Unit Western Operations Section 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.
William R. Kammin Phone: (360) 407-6964	Ecology Quality Assurance Officer	Reviews the draft QAPP and approves the final QAPP.

EAP - Environmental Assessment Program.
MISU - Modeling and Information Support Unit.
QAPP - Quality Assurance Project Plan.
SEA - Shorelands and Environmental Assistance Program.
WAG - Watershed Advancement Group.

As described above, updates to the WRIA 1 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 completing the reports for this study.

Table 6. Author lead and proposed schedule for completing reports.

Final report	
Author lead	Paul Pickett
Schedule	
Draft due to supervisor	November 2009
Draft due to client/peer reviewer	November 2009
Draft due to external reviewer(s)	January 2010
Final report due on web	April 2010

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

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Figures

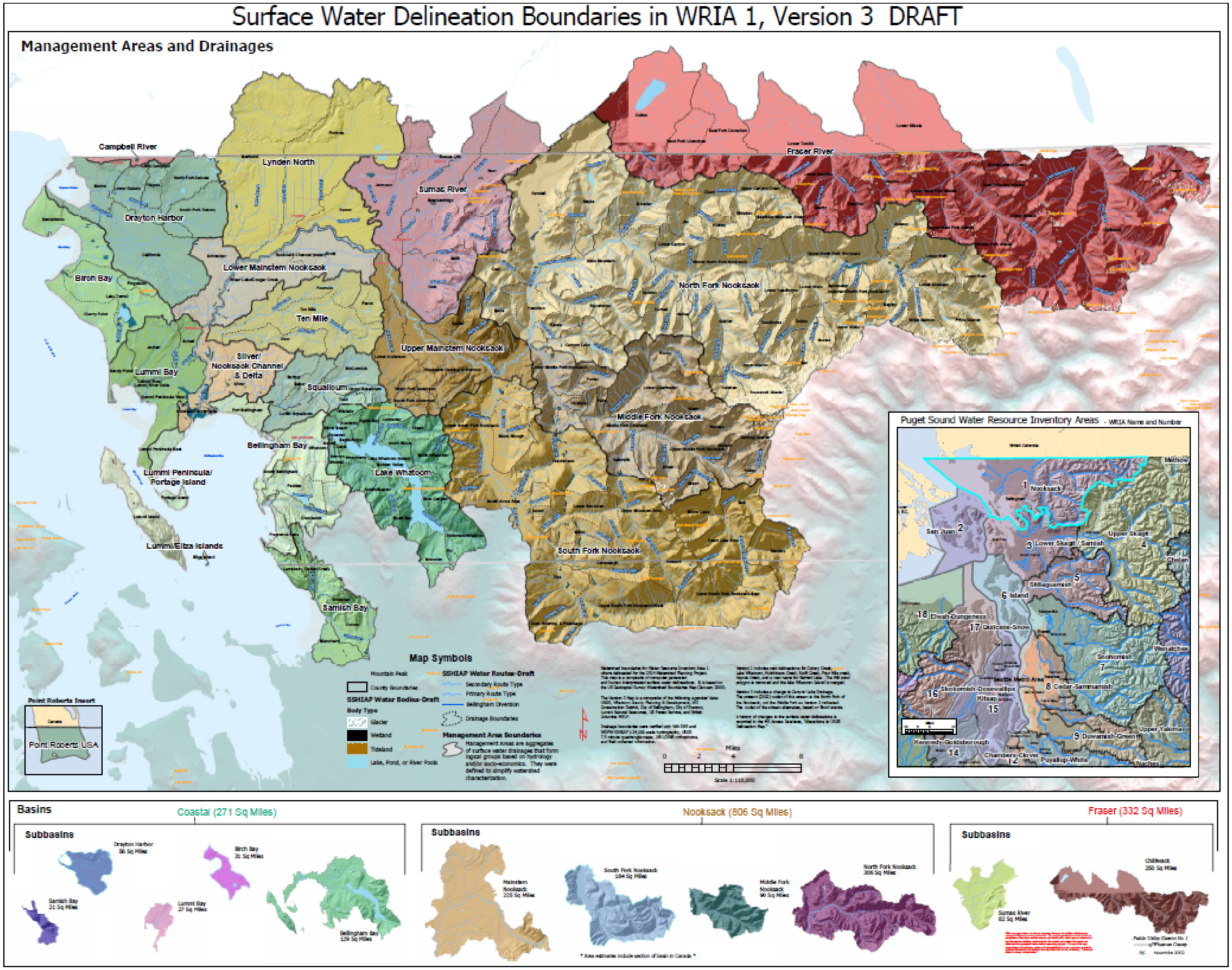

Figure 1. WRIA 1 basin boundaries (from: http://wria1project.whatcomcounty.org/ResourceLibrary/Maps/38.aspx).

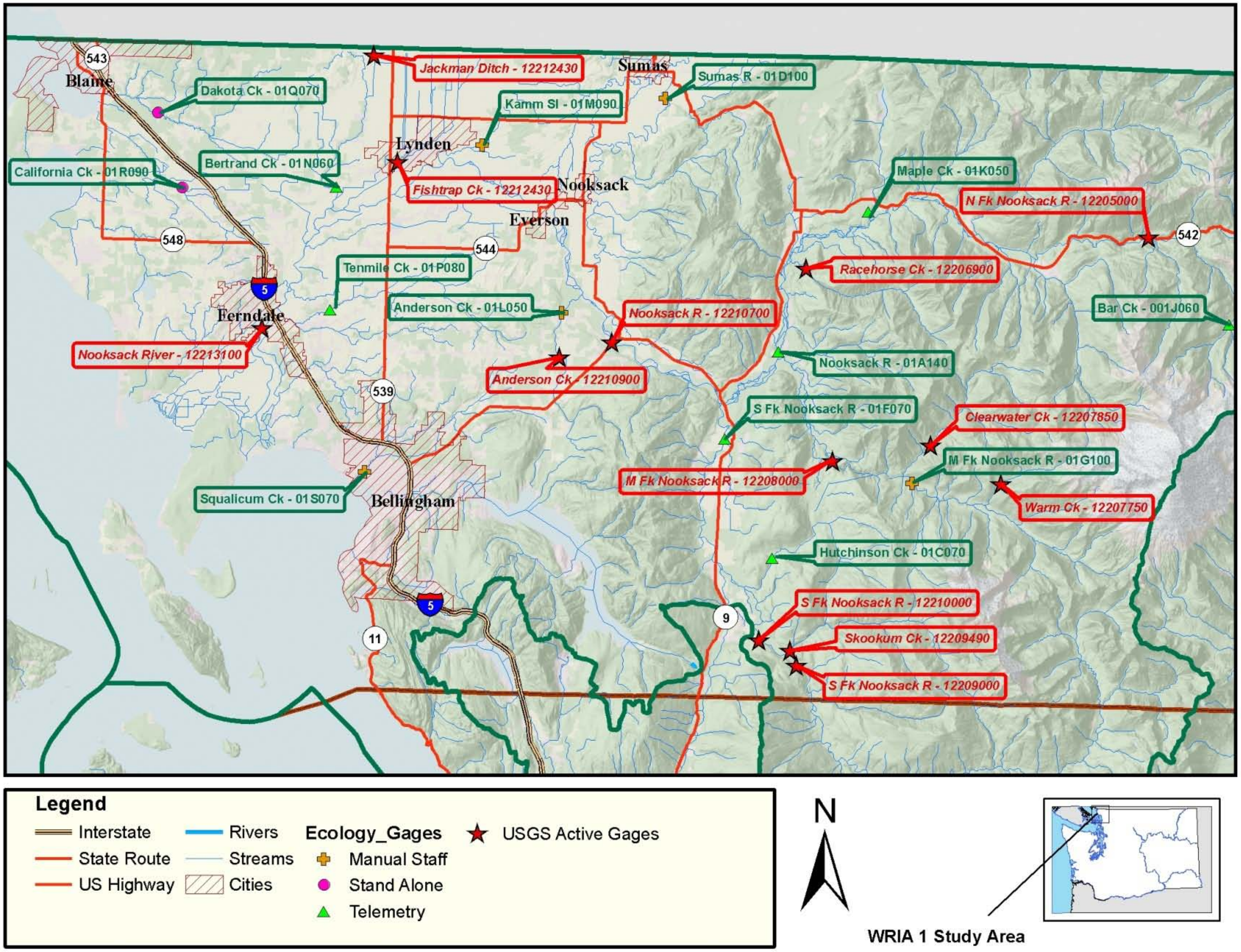

Figure 2. WRIA 1 flow monitoring stations (Ecology active and historical, USGS active, 24 total).

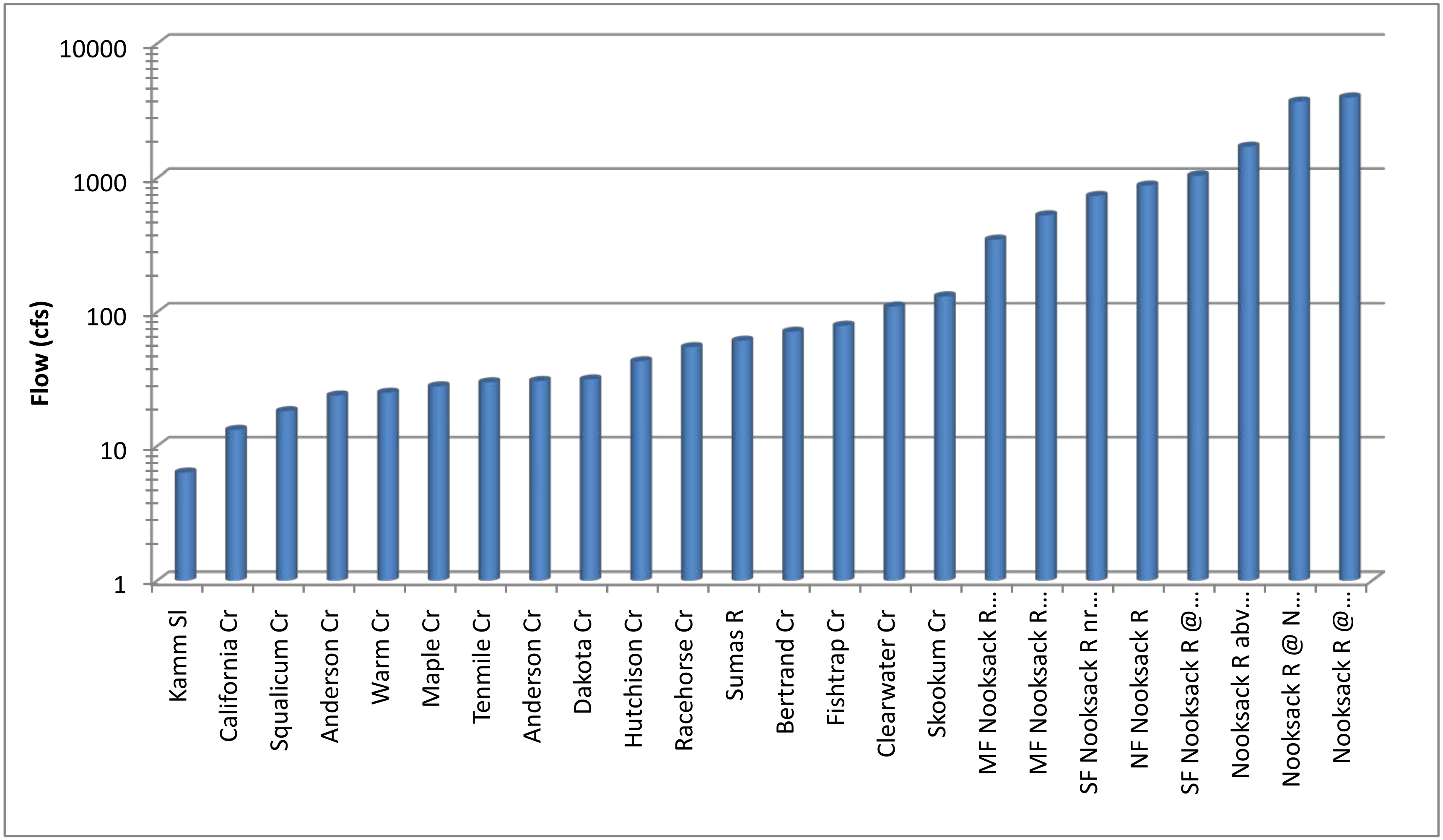

Figure 3. Comparison of Water Year 2006 mean streamflows for WRIA 1 flow monitoring stations (Ecology active and historical, USGS active, 24 total).

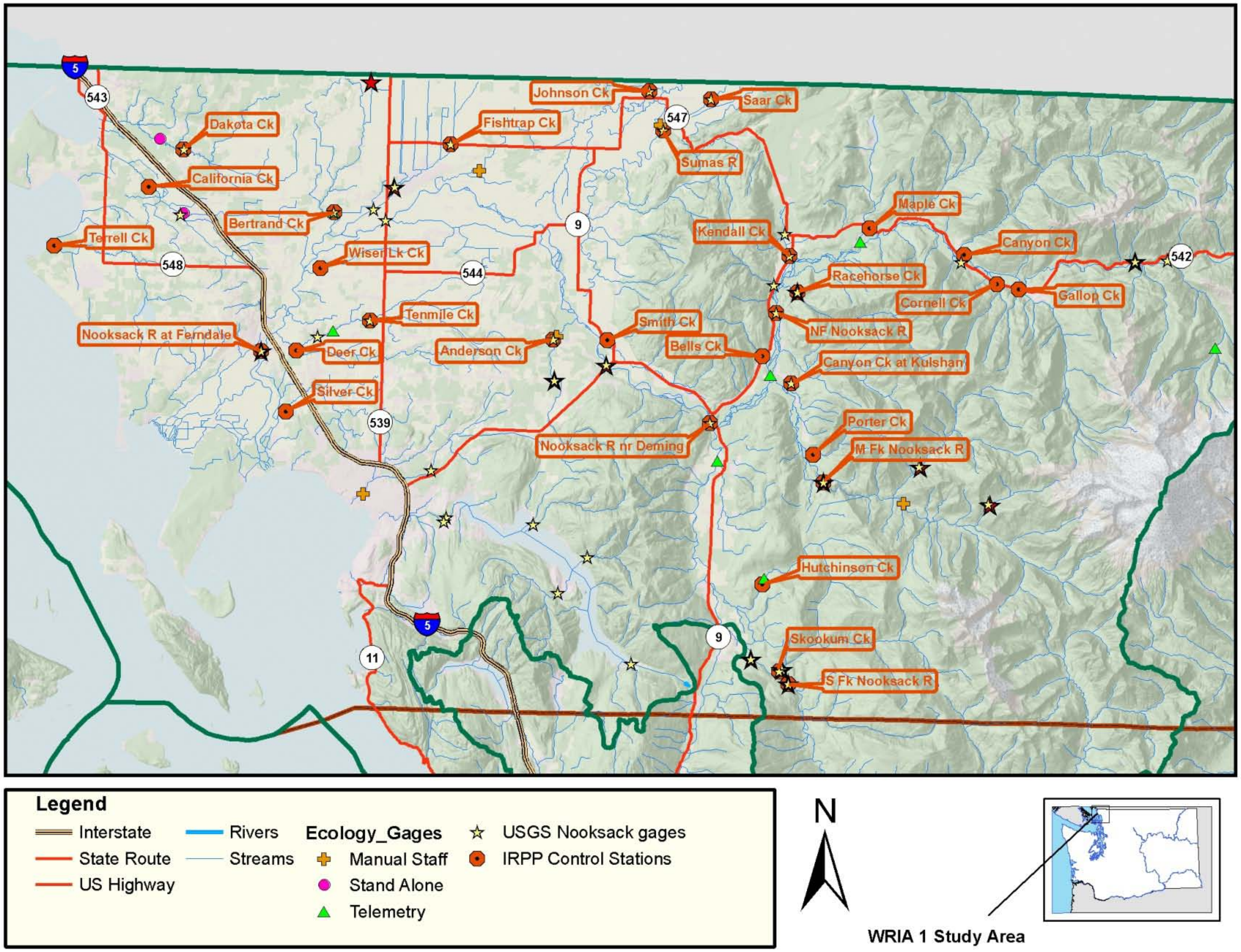

Figure 4. WRIA 1 regulatory flow control stations (30 total).

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.
Parameter:	A physical chemical or biological property whose values determine environmental characteristics or behavior.
Streamflow:	Discharge of water in a surface stream (river or creek).

Acronyms and Abbreviations

Acronyms and abbreviations used frequently in this report:

EAP	Environmental Assessment Program.
Ecology	Washington State Department of Ecology
GIS	Geographic Information System software
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
USGS	U.S. Geological Survey
USU	Utah State University
WAC	Washington Administrative Code
WMP	Watershed Management Project
WRIA	Water Resources Inventory Area

Units of measurement:

cfs	cubic feet per second, a unit of flow discharge
cms	cubic meters per second, a unit of flow discharge
ft	feet
g	gram, a unit of mass
kcfs	1000 cubic feet per second
kg	kilograms, a unit of mass equal to 1,000 grams
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters
l/s	liters per second (0.03531 cubic foot per second)
m	meter
mg	million gallons
mgd	million gallons per day
mg/d	milligrams per day
mg/Kg	milligrams per kilogram (parts per million)
mL	milliliters