Culvert Design Flows For Fish Passage And Structural Safety In East Cascade And Blue Mountain Streams

WA-RD 545.2

Research Report
August 2002

Washington State
Department of Transportation

Washington State Transportation Commission
Planning and Capital Program Management
in cooperation with:
U.S. DOT - Federal Highway Administration

Research Report

Research Project T1804, Task Order 4

CULVERT DESIGN FLOWS FOR FISH PASSAGE AND STRUCTURAL SAFETY IN EAST CASCADE AND BLUE MOUNTAIN STREAMS

by

John F. Orsborn PE
Mack T. Orsborn
31 Forester Lane
Port Ludlow WA 98365

Washington State Transportation Center (TRAC)
Washington State University
Department of Civil and Environmental Engineering
P. O. Box 642910
Pullman, WA 99164-2910

Washington State Department of Transportation

Matt Witecki
Technical Monitor

Jim Toohey
Research Program Manager
Olympia, WA 98504

Prepared for

Washington State Transportation Commission
Department of Transportation

and in cooperation with

U.S. Department of Transportation
Federal Highway Administration

October 2002

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NUMBER	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 545.2		

4. TITLE AND SUBTITLE	5. REPORT DATE
CULVERT DESIGN FLOWS FOR FISH PASSAGE AND STRUCTURAL SAFETY IN EAST CASCADE AND BLUE MOUNTAIN STREAMS	October 2002
	6. PERFORMING ORGANIZATION CODE
7. AUTHORS John F. Orsborn, PE and Mack T. Orsborn, MD	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State Transportation Center (TRAC) Washington State University, Department of Civil and Environmental Engineering, P.O. Box 642910, Pullman, WA 99164-2910	10 WORK UNIT NO.
	11. CONTRACT OR GRANT NO. T1804, Task Order 4
12. SPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation Transportation Building, Olympia, WA 98504	13. TYPE OF REPORT AND PERIOD COVERED Research Project 10/00 - 10/02
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was complementary to a study conducted at Washington State University titled "MODELING HYDROLOGY FOR DESIGN OF FISH PASSAGE" (Rowland, Hotchkiss and Barber 2002)

16. ABSTRACT

The pervasive problem of restoring fish runs to their natal streams is characterized in many regions of Washington by improperly placed culverts. The replacement of these fish migration barriers requires knowledge of design flows: floods for structural safety and migration season high and low flows. High flows block fish passage with velocities that exceed their swimming capabilities. During low flows, the migration barrier is caused by a lack of enough water depth to support the bodies of the fish. The estimation of these fish passage and safety flows in ungaged streams is impeded in eastern Washington due to: the wide range of climatic conditions (5 to 110 inches per year of precipitation); diverse geology and soils; a lack of stream-gaging stations with long-term records; changes in land use; and the seasonal impacts of irrigation diversions and well pumpage on the remnant instream flows. Past efforts to estimate these flows have not been successful.

Therefore, the WSU project was undertaken to model the high migration season flow in all of eastern Washington. In addition, WSU established 20 stream-gaging stations on salmon streams along the east side of the Cascade Mountains plus the Blue Mountains. Our complementary project was developed to estimate other design flows in the Water Resource Inventory Areas (WRIA) 29, 30, 32, 35, 38, 40, 45, 48 and 49, in which the WSU gage sites are located. United States Geological Survey (USGS) gage records in those WRIAs (and in WRIAs 39, 46 and 47) were used to develop our models that estimate the following statistical flows: 100-year, 25-year and 2-year daily and peak floods; the average annual flow and its variability; ranges of mean monthly flows (maximum, average and low); the 7-day average, 2-year, 10-year, 20-year low flow; and the 30- and 60-day average low flows. The model results are, for the most part, very good. The standard error of estimate ranges are: for floods, 2 - 37%; average annual flow, 10 - 37%; maximum annual flow, 6 -14%; minimum annual flow, 13 - 23%; and low flows, 3 - 22%. Monthly average flows reflected the strong influences of seasonal variability and irrigation withdrawals: 3-242%, due to winter frozen low flows (3%) in the Entiat-Wenatchee Region, and August low flows (242%) in the Blue Mountains due to irrigation. All flow estimation equations were based on USGS stream-gaging data from continuous gages located in the WRIAs.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
culverts, fish passage, structural safety, design flows, hydrologic models	None

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None		

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Department of Transportation. This report does not constitute a standard, specification or regulation.

(No text on this page)

TABLE OF CONTENTS

Table of Contents (continued)

Section **Page**

LIST OF FIGURES

Figure **Page**

List of Figures (continued)

Figure **Page**

LIST OF TABLES

Table **Page**

List of Tables (continued)

Table **Page**

List of Tables (continued)

Table **Page**

EXECUTIVE SUMMARY

Improperly placed culverts impeding fish runs create severe problems in many regions of Washington. The replacement of these fish migration barriers requires knowledge of design flows: floods for structural safety, and migration season high and low flows. High flows block fish with velocities that exceed their swimming capabilities. During low flows, the migration barrier is caused by a lack of enough water depth for fish to breathe and support their bodies. The estimation of these fish passage and safety flows in ungaged streams is impeded in eastern Washington due to: the wide range of climatic conditions; diverse geology and soils; a lack of stream-gaging stations with long-term records and gages not affected by storage and diversions; changes in land use; and the seasonal impacts of irrigation diversions and well pumpage on the remnant instream flows. Past efforts to estimate these design flows have not been very successful, partly because of a lack of data, partly because hydrologic regions were too large and diverse and because of model complexities.

The hydraulic design of new or replacement culverts requires three design flows (two for fish passage and one for culvert capacity): (1) the 10% exceedence high flow (Q10 MS) during the Migration Season; (2) the 7-day average low flow (Q7L2) for fish passage during summer and fall; and (3) the 100-year peak flood for maximum culvert flow passage and road safety.

WSU's research project had the primary objective of developing a method to estimate Q10MS. In another part of their project, WSU installed stream gages on twenty smaller, salmon-bearing streams. Our complementary project provided methods to estimate other migration season and culvert design flows.

Procedures developed were for a total of fifty (50) flows including floods, monthly and low flows, so that the flow regime for an ungaged stream can be estimated. These models apply to the six regions (combinations of Water Resource Inventory Areas, WRIA) of eastern Washington where the twenty stream gages have been installed by WSU. The models can be used to estimate streamflows for numerous other streamflow problems besides culvert design.

The WSU project was undertaken to: (1) model the migration season high flow in all of eastern Washington; and (2) install the new stream-gaging stations on salmon streams along the east side of the Cascade Mountains and the Blue Mountains to improve the data base. This complementary project was developed to estimate other design flows in Water Resource Inventory Areas (WRIA) 29, 30, 32, 35, 38-40 and 45-48. The WSU gages were located in WRIAs 29, 30, 32, 35, 38, 40, 45, 48 and 49. No USGS gages were included from WRIA 49 due to large diversions and a lack of hydrologic similitude. WRIAs 39, 46 and 47 were included to add more U.S. Geological Survey (USGS) stream gaging stations to the database. The WRIAs are the planning units for the current Washington watershed restoration programs and were developed for the state water resources planning program in the 1970's. The WRIA names are: Wind-White Salmon (#29); Klickitat (#30); Walla Walla (#32); Middle Snake (#35); Naches (#38); Upper Yakima (#39); Wenatchee (#45); Entiat (#46); Chelan (#47); Methow (#48); and Okanogan (#49). If you wish to refer to a map of the WRIAs, see Figure 3 on page 14.

The computerized mathematical models estimate these statistical flows: 100-year, 25-year and 2-year daily and peak floods; the average annual flow and its variability; ranges of mean monthly flows (maximum, average and low); the 7-day average, 2-year, 10-year, 20-year low flows; and the 30- and 60-day average low flows. The standard error of estimate ranges are daily and peak floods, 2 - 37%; average annual flow, 10 - 37%; maximum annual flow, 6 -14%; minimum annual flow, 13 - 23%; and low flows, 3 - 22%. Monthly average flow records reflected the strong influences of natural seasonal variability and unnatural irrigation withdrawals: 3-242%. All flow estimation equations were based on USGS stream-gaging data for continuous gages located in the WRIAs.

The only comparative model results available are for flood estimates. In eastern Washington earlier studies had standard errors of estimate for peak floods that ranged from 52-128%. Our peak flood estimates ranged from 4-29% for the same recurrence intervals (2 to 100 years). Our regions (WRIAs) were smaller than the regions used by the United States Geological Survey (USGS). The simple and lower error models that were developed for East Cascade and Blue Mountain streams should be recalibrated for application to Western Washington streams to reduce the standard errors of estimate in existing models.

This report covers the details of hydrologic model development and application of this complementary project. A tutorial CD-ROM has been prepared to assist persons applying these models. Detailed background information for both projects is presented in the WSU report "Modeling Hydrology for Design of Fish Passage" by Rowland, Hotchkiss and Barber (2002) and in Rowland (2001).

INTRODUCTION

PROBLEM STATEMENT

Probably the most extensive problem associated with fish being denied access to their natal streams is blockage by impassable culverts. These, and other migration barriers, are classified as: (1) Total – impassable to all fish all the time; (2) Partial – impassable to some fish all the time; and (3) Temporary – impassable to all fish some of the time (Powers and Orsborn, 1985). The hydraulic analysis of the depth and velocity conditions inside a culvert is straight forward. But that analysis does not tell what the high and low flows will be during the migration seasons .

The State laws (WAC-220-110, State of Washington, 2000) governing the installation of permanent culverts call for the following flows using the hydraulic design option:

"(A) The low flow design, to be used to determine the minimum depth of flow in the culvert, is the two-year, seven-day low flow discharge for the subject basin or ninety-five percent exceedence flow for migration months of the fish species of concern. Where flow information is unavailable for the drainage in which the project will be conducted, calibrated flows from comparable gauged drainages may be used or the depth may be determined using the installed no-flow condition *(water surface elevation in the pool downstream at no flow; berm elevation)*;

"(B) The high flow design discharge, used to determine maximum velocity in the culvert, is the flow that is not exceeded more than ten percent of the time during the months of adult fish migration;"

Later sections of the Hydraulic Code Rules state:

"(E) Appropriate statistical or hydraulic methods must be applied for the determination of flows in (b) (ii) (A) and (B) of this subsection."

"(c) ...culverts shall be installed according to an approved design to maintain structural integrity to the 100-year peak flow with consideration of the debris loading likely to be encountered. (State of Washington, Current RCW).

For a more detailed discussion of culvert design see WDFW (1998, 1999).

This project has been undertaken to demonstrate new methods for generating estimates of culvert design flows in ungaged streams. And this is the basic problem; most streams are ungaged. As one moves upstream from the uppermost gaging station in a basin and approaches a tributary, all the streams above this point are ungaged.

For its part of the project, WSU focused on the development of a model to estimate the high migration season flow (Q10) and on the generation of more streamflow data for smaller salmon-bearing streams in eastern Washington. For our part we developed the other two legally required design flows: (1) Q7L2 (paragraph (A) of the WAC) for fish passage; and (2) QPF100, the 100-year peak flood to provide for structural safety. Our other models will estimate: 36 monthly maximum, mean and minimum average monthly flows; 5 other flood flows; the average annual flow and its expected high and low values (3 flows); and 4 other statistical low flows, for a total of 50 flows.

AVAILABLE STUDIES

A literature search into streamflow models which relate one type of statistical streamflow to basin characteristics and to other statistical streamflows, began in 1964 at the University of Wisconsin (Orsborn, 1964). It has progressed to include portions of the states of: Washington, (Orsborn, 1966; Orsborn and Sood, 1973 and 1975); Oregon (Orsborn, 1980b; Orsborn, 1981; Orsborn and Arce, 1975; Idaho (Orsborn and Arce, 1975); and Alaska (Orsborn 1980a; 1983; Orsborn and Storm, 1991). A comprehensive analysis of the use of drainage basin characteristics for hydraulic design and water resources management was presented at the SUNY Symposium on Geomorphology and Engineering in Binghamton, NY (Orsborn, 1976). Recent regionalized and computerized studies have included regions in Washington State such as the Olympic Peninsula (Amerman and Orsborn, 1987) and the Colville Indian Reservation in northeastern Washington (Orsborn and Orsborn, 1997). A study for the Washington Timber, Fish and Wildlife Program related basin to channel characteristics using hydrologic modeling of streamflows to link the basin and channel characteristics (Orsborn, 1990).

One can readily ask the question, "What about the influences of land-use changes on basin and streamflow characteristics?" There are two basic approaches to this question: (1) monitor all, or a sample of, the watersheds of interest; or (2) evaluate changes in precipitation and streamflow in the region. Using the first method, we are chasing a moving target (streamflow) while traveling on a moving platform (cumulative effects of land used changes in the basin). By evaluating changes in precipitation against changes in the low, average and high streamflows it is possible to examine the relative influences of changes in all three components (precipitation, land use and streamflow) (Orsborn, 1990).

In our modeling we relate statistical flows to basin characteristics and to other flows by correlation. The basin characteristics are: average annual precipitation, P (U. S. Weather Bureau, 1965; Sumioka et al, 1998); basin area A, and basin differential elevation (relief), H. Details about the development of these models are discussed in the report on the hydrology of the Colville Indian Reservation (Orsborn and Orsborn, 1997) and they are explained briefly in this report under Procedures.

Two other questions which might be asked are: (1) "What other types of hydrologic models are available?" and (2) "Why are the proposed models better than the alternatives?" Two other types of hydrologic models: the process-related models and regression models. An example of the so-called process model is the HSPF (Hydrologic Simulation Program-Fortran) model developed by Dinicola (1990) of the USGS, and adopted and adapted later by numerous agencies and consulting firms along the east side of Puget Sound.

The reason this is described as a "so-called" process model is that the modelers try to simulate the precipitation-runoff process using seventeen indices to represent ground- and surface-water components of the hydrologic cycle. The benefits of these types of models are that they can: estimate the effects of land use changes; simulate runoff processes; be fine-tuned once they are calibrated; and estimate continuous hydrographs. On the contrary, these models require extensive calibration, data and assumptions.

Multiple regression models became popular just after time-saving computers became available. The USGS developed a nationwide procedure for testing the length of record needed for reliable statistical flow estimates at gaging stations. (Thomas and Benson, 1970; Riggs, 1973). USGS offices in Washington and other states developed similar procedures (Moss and Hauschild, 1978; Williams and Pearson, 1985a; 1985b).

Floods in Washington have received a lot of attention in the last forty years from: Bodhaine and Thomas (1960, 1964), Haushild (1974) , Cummans et. al. (1975) and Sumioka et al (1998). Most of these USGS studies used a multiple regression approach involving watershed parameters (indices) which are assumed to represent components of the hydrologic cycle. The watershed indices used by the USGS in their multiple regression analyses of Washington streams is listed in Table 1 and are published in Williams and Pearson (1985a, 1985b). The hydrologic factors, which the watershed indices are assumed to represent, are listed also in Table 1. We used the watershed areas and average annual precipitation values for our modeling gages from Williams and Pearson (1985a, 1985b) and checked those against Sumioka et al (1998).

Watershed area usually explains 80 to 90 percent of the variability in these relationships. The percent of forest cover has certainly been a part of the "moving platform" of baseline conditions for the past fifty years or so, and is not an appropriate parameter to use in many watersheds in the Pacific Northwest. Sumioka et al (1998) still listed forest cover in their table of basin characteristics. But, forest cover did not appear in any of their final regional flood equations. Powers and Sanders (1998) used the same USGS regions of the State as Sumioka et al (1998) to develop their fish passage flows (Figure 1). They stratified their

Table 1. Watershed Indices Used in USGS Hydrologic Multiple Regression Models in Washington.

Watershed Index	Represents
Area	Ability to catch precipitation
Channel Slope	Flood timing and size
Stream Length	Interface between groundwater and streamflow
Mean Elevation	Orographic effect on precipitation
Percent Storage and Lake Area	Influence of storage on the reduction in flood size
Percent Forest	Transpiration from plants and reduction in runoff
Average Annual Precipitation	Average input of water to the watershed
Precipitation Intensity	Storm input to the watershed
Snowfall	Input to the watershed with delayed runoff
January Minimum Temperature	Delay in snowmelt runoff

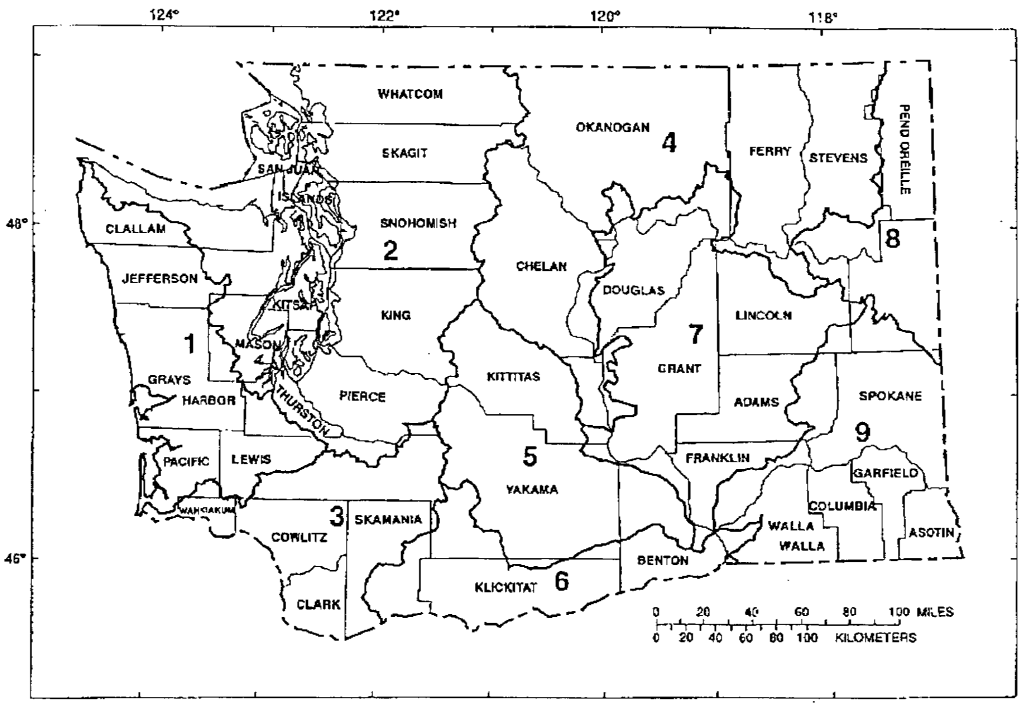


Figure 1. USGS hydrologic regions for Washington used by Sumioka et al (1998), Powers and Sanders (1998).

flows by dividing the basins between gages above or below 1000 feet in elevation.

The regions used by the USGS (Sumioka et al, 1998) and Powers and Sanders (1998) are too large to expect climatic and streamflow similitude to be present. For example, Sumioka et al (1998) in Region 2 (Figure 1) used basin areas of 0.08 to 3020 square miles and average annual precipitation values of 23-170 inches. We decided to use the Department of Ecology Water Resource Inventory Areas (WRIA) as basic regions, and use hydrologic uniformity to define "regions" (more as hydrologic provinces).

The value of P in **inches** raises the fundamental issues of units, dimensions and basic hydrologic principles. All nine USGS regional equations and five of the six equations developed by Powers and Sanders (1998) are in the form of

$$Q = a\, A^{b}\, P^{c} \qquad \text{(Equation 1)}$$

where Q is a high flow (cfs) of some probability, A is the basin area (sq. mi.), P is the average annual precipitation (**inches**); a is a constant, and b and c are coefficients determined by the regression analysis. In reality a is a coefficient, b and c are exponents, and all are variables. The given units in Equation (1) are

$$ft^3/sec = \text{(sq. mi.) (inches)}$$

But, P is the average **annual** precipitation and must have the units of **inches per year**. Now Equation (1) is dimensionally correct (in F - L - T terms) and

$$L^3/T = L^2(L/T) = L^3/T.$$

Another reality check has to do with the fact that the right side of Equation (1), (AP), represents the average annual INPUT to the watershed. Therefore, the lefthand side should be the average annual flow (OUTPUT), (QAA), not an extreme high flow, if strong relationships are to be developed.

It follows that average annual flow increases as precipitation increases, and there is no reason to do a multiple regression analysis on both A and P. Rearranging terms in Equation (1) gives

$$QAA = C\ (PA) \qquad \text{(Equation 2)}$$

The maximum value of C in Equation 2 is 0.0737 cfs per 1 in. of precipitation on 1 sq. mi. per year from unit conversions. The coefficient, c, is a power function of P so

$$QAA = C\ (P)^{n}\ A \qquad \text{(Equation 3)}$$

For the Olympic Peninsula (Amerman and Orsborn, 1987)

$$QAA = 0.0034\ (P)^{1.60}\ A \qquad \text{(Equation 4)}$$

and for northeastern of Washington (Orsborn and Orsborn, 1997)

$$QAA = 0.0025\ (P)^{1.64}\ A \qquad \text{(Equation 5)}$$

In the range of application, Equations (4) and (5) give almost identical answers and very similar models have been developed for other regions of the State (Orsborn, Johnson and Orsborn, 2001).

It has been shown that the regression equations for estimating high flows are by definition associated with the average annual flow. Following the section on previous work, the regional models for estimating QAA in terms of PA will be developed from the database. Then it will be demonstrated that all the other 49 flows at an ungaged site can be estimated from its average annual flow (QAA).

OBJECTIVE

The objective of this project was to develop improved methods for estimating flows for fish passage and flood safety design at culverts and other migration barriers in cooperation with the WSU research efforts. Tasks to be performed to achieve this objective were: 1) prepare a handbook and computer disk for use by persons needing to know fish passage, flood and monthly and low flows; and 2) conduct a workshop on the use of the handbook and computer programs. The WRIA flow estimation equations may be used to assess many types of water resources problems including: flood plain management; land-use effects on channel size; seasonal fish habitat studies; seasonal instream flow requirements; year-to-year low flow stability; and the variability in average annual flow.

REVIEW OF PREVIOUS WORK

The WDFW commonly refers to three reports when estimating design flows at culverts: Kresch (1999); Sumioka, Kresch and Kasnick (1998); and Powers and Saunders (1998). The report by Kresch (1999) deals with methods for estimating migration season high fish passage design flows for ungaged streams in eastern Washington. The methods used United States Geological Survey (USGS) records for unregulated streams with at least 10 years of streamflow data to develop equations for estimating: (1) the 2-year peak flood (QPF2); and (2) the 10-percent flows for April through June, or January through March, whichever months had the higher Q10 flows.

Sumioka, Kresch and Kasnick (1998) updated earlier studies of the USGS on the magnitude and frequency of floods for the whole state of Washington (Cummans et al 1975; Haushild 1974; and Williams and Pearson 1985 a,b). The reference by Williams and Pearson (1985 b) for eastern Washington provided a considerable amount of the data for our complementary study, because of the 41 USGS gaging stations used in our original database, 26 were discontinued during or prior to 1979. This was the last water year in which these USGS statistical summary reports were published. The gaging station peak floods, drainage areas and average annual precipitation values developed by Sumioka, Kresch and Kasnick (1998) were used by Kresch (1999) to estimate Q10 values at regular gaging stations. Kresch (1999) developed additional relationships between Q10 values and the 2-year peak discharges to estimate the Q10 values from the crest-stage gage data for eastern Washington streams.

The report by Powers and Saunders (1998) used the same six (6) large diverse regions in Figure 2 that the USGS did (Kresch 1998) to cover all of eastern Washington but "no correlation was found amongst the small, unrepresentative data pool gathered within this large, diverse region" (Powers and Saunders 1998)

Our report uses models for which the fundamental work was completed over the years in: Amerman and Orsborn (1987), Hardison and Moss (1972), Moss and Haushild (1978), Orsborn and Sood (1973), Orsborn (1978), Orsborn and Orsborn (2000), Riggs (1968a, 1968b), Searcy (1960), Thomas and Benson (1970) and the US Geological Survey (1967). We selected smaller regions than Powers and Saunders (1998), Sumioka et. al. (1998) and Kresch (1999) based on combinations of Water Resource Inventory Areas (WRIA) in Figure 3. Our regions encompass the twenty WSU stream gaging sites, which are listed in Table 2 along with the WRIAs where the WSU sites are located. Also included in Table 2 are: the DeLorme Washington Gazeteer map page numbers for WSU Sites; the WRIAs from which USGS gages were added to the database; the USGS gage map index numbers for the USGS gages in the reports at the top of Table 2 (Williams and Pearson 1985a, 1985b); and the USGS gage numbers and stream names used to establish the database for this project.

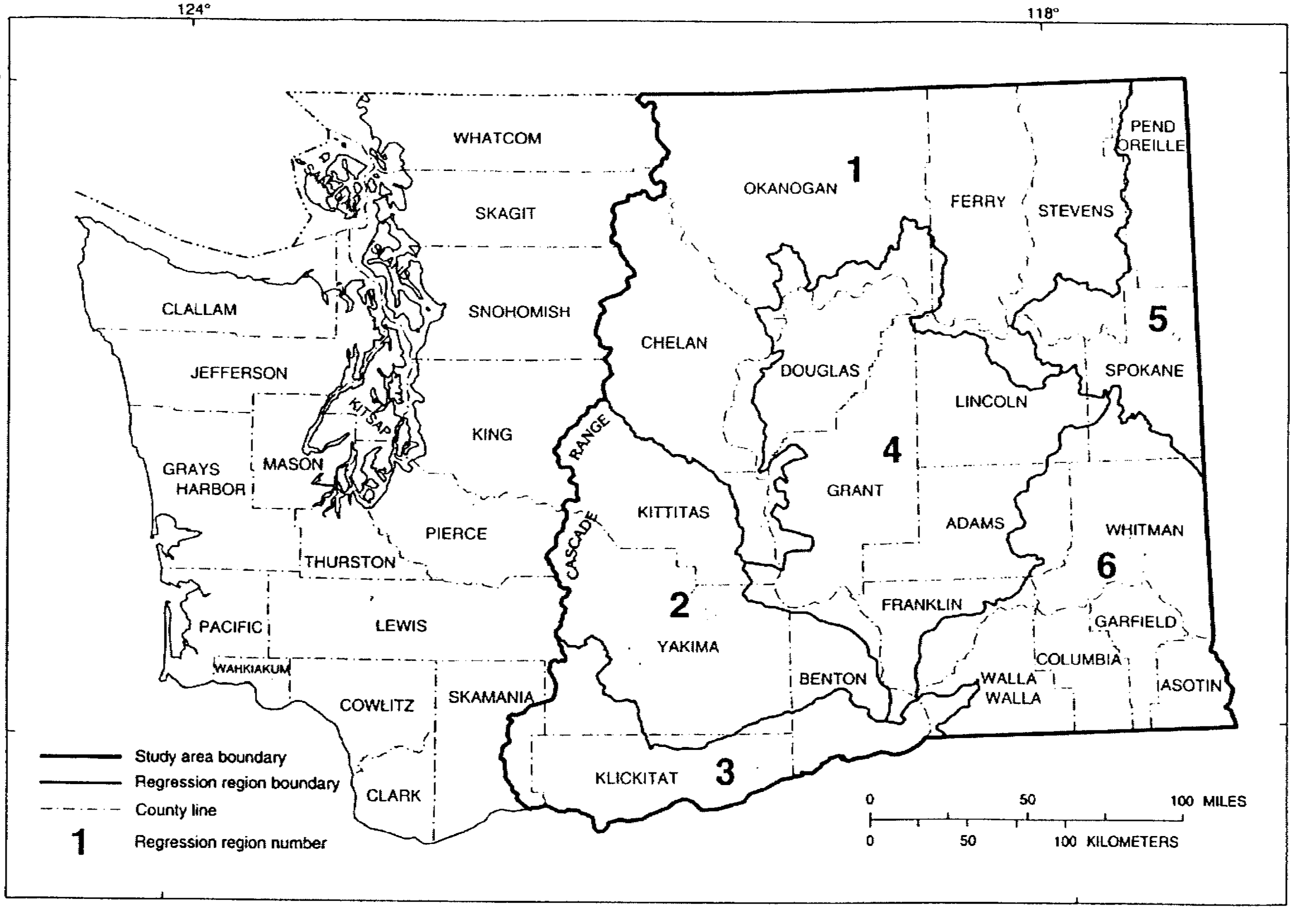


Figure 2. Regions used in the development of regression equations for estimating fish passage design flows at ungaged streams in eastern Washington (Kresch, 1999).

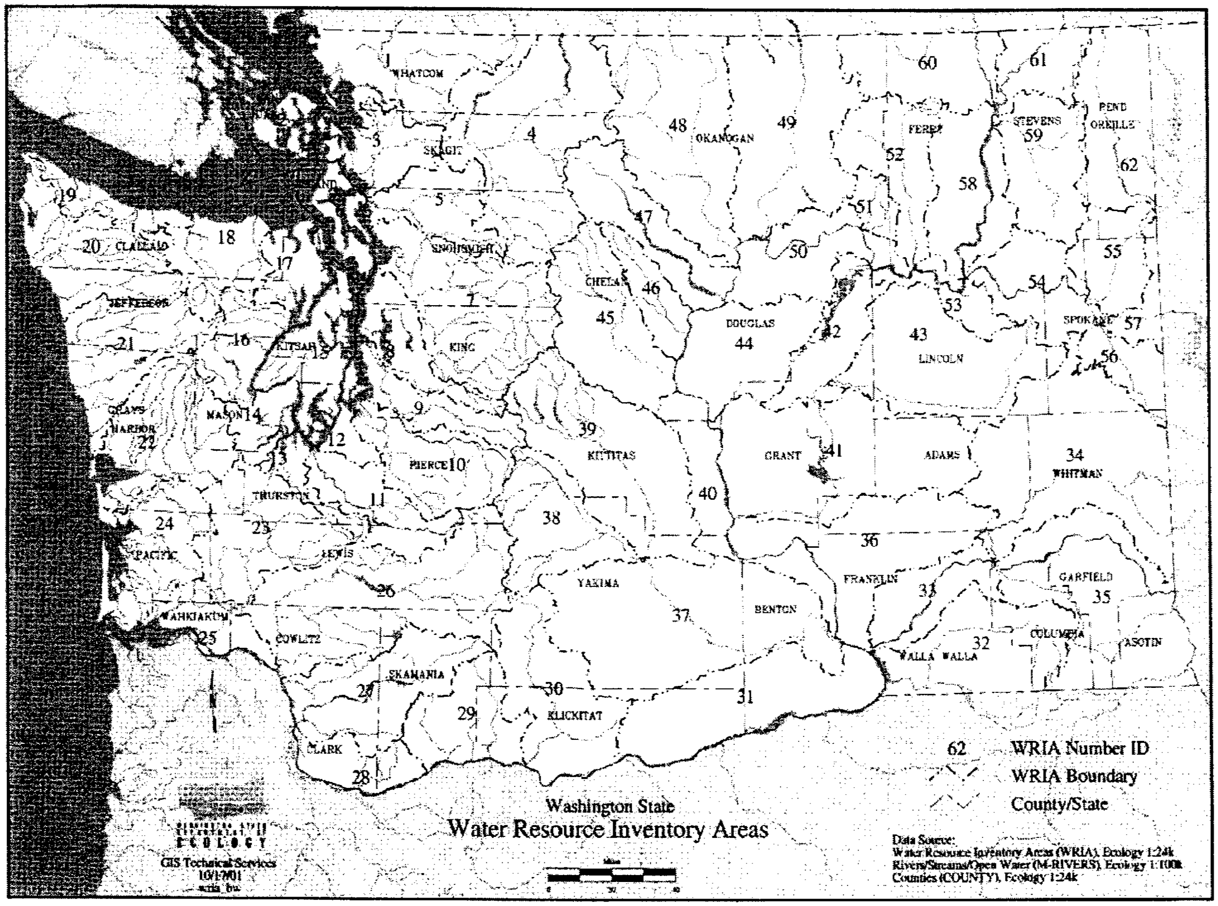


Figure 3. Water Resource Inventory Areas used in this report include 29, 30, 32, 35, 38-40, and 45-49.

Table 2. Regional USGS and WSU Gaging Station Information

References: **(1)** USGS Open-File Report (Williams & Pearson,1985a): 84-145-A, Vol. I, SW WA
(2) USGS Open-File Report (Williams & Pearson,1985b): 84-145-B, Vol. II, East. WA

Notes: **a** In Yakima Basin

REGION	WRIA	WRIA Name	WSU Sites No.	WSU Sites Name	DeLorme Map No.	USGS Map Site No.	USGS Gage No.	Stream Name
METHOW-CHELAN	48	Methow	6	Loup Loup	100	85	12442000	Toats Coulee Cr.
			7	L. Bridge	99	103	12447390	Andrews Cr.
			8	Libby	99	109	12449500	Methow R.
			9	Black Canyon	99	110	12449600	Beaver Cr.
						115	12449950	Methow R.
	47	Chelan				118	12451000	Stehekin R.
						119	12451500	Railroad Cr.
ENTIAT-WENATCHEE	46	Entiat				124	12452800	Entiat R.
						126	12453000	Entiat R.
	45	Wenatchee	10	Colockum	66	129	12454000	White R.
			11	Stemilt	67	134	12456500	Chiwawa R.
			12	Mission	83	138	12458000	Icicle Cr.
			13	Upper Peshastin	66	145	12461400	Mission Cr.
			14	Lower Peshastin	66	197 [a]	12483800	Naneum
NACHES-YAKIMA	38	Naches	15	Nile	50	197 [a]	12483800	Naneum
			16	Rock	50	206	12488500	American
						210	12492500	Tieton
						211	12494000	Naches
	39	Yakima [a]				215	12500500	NF Ahtanum
						216	12501000	SF Ahtanum
						219	12502500	Ahtanum
						222	12506000	Toppenish
						223	12506500	Simcoe
BLUE MOUNTAINS	35	Middle Snake	1	SF Asotin	43	246	13334500	Asotin Cr.
			2	Pataha	42	247	13334700	Asotin Cr.
			3	Tumalum	42	258	13343800	Meadow
			4	Patit	42	260	13344500	Tucannon R.
	32	Walla Walla	5	SF Coppei	41	288	14013000	Mill Cr.
						289	14013500	Blue Cr.
						294	14016000	Dry Cr.
						295	14016500	E.F. Touchet
						298	14017000	Touchet R.
						301	14017500	Touchet R.
						302	14018500	Walla Walla
KLICKITAT	30	Klickitat	17	Butler	26	222 [a]	12506000	Toppenish
			18	Bowman	26	223 [a]	12506500	Simcoe
			19	Mill	26	314	14107000	Klickitat
						317	14110000	Klickitat
						321	14112000	L. Klickitat
						326	14113000	Klickitat
WIND-WHITE SALMON	29	Wind-White Salmon	20	Buck	24	1	14121300	White Salmon
						2	14121400	White Salmon
						3	14121500	Trout L. Cr.
						8	14123000	White Salmon
						9	14123500	White Salmon
						10	14124500	L. Wh. Salmon
						16	14127000	Wind R.

PROCEDURES

DATABASE

The research approach used to reach our objective involved the following tasks:

1) Assess the USGS statistical streamflow records and basin characteristics that were available in the selected WRIAs through 1979 in the two reports by Williams and Pearson (1985a and 1985b);
2) Determine the relief (H) in the basins above the USGS gages from USGS 1:24,000 topographic maps; relief is the uppermost contour elevation that lies within the basin minus the elevation of the gage; it represents the potential energy available in the watershed; it is a basin characteristic not available in the USGS publications mentioned above.
3) Tabulate the basin characteristics and model parameters for the selected USGS gaging stations through 1979 (Table 2). The nomenclature for the flows used in this analysis are listed in Table 3. The parts of Table 3 in bold print should be carefully reviewed. Note especially the functions of the **three characteristic key flows Q1F2, QAA and Q7L2**, which are the average (2-year RI) daily flood, the average annual flow and the 7-day average (2-year RI) low flow. They are discussed in more detail in the section on modeling.

Table 3. Nomenclature and Uses for Characteristic Statistical Streamflows

(1a) Peak Flood Flows for Culvert and Roadway Safety

QPF 100	Instantaneous peak flood with a 100-year Recurrence Interval **(RI)**
QPF25	Instantaneous peak flood with a 25-year RI
QPF2	Instantaneous peak flood with 2-year RI

(1b) Average Daily Flood Flows With the Same RI's as the peak floods. Q1F2 is Used in relation to QPF2 at Continuous Gages to estimate Q1F2 (and all other flows) from QPF2 at Crest-Stage Gages on Smaller Streams; Q1F2 is the characteristic flow used to estimate all other flood flows.

Q1F100	Average daily flood with a 100-year RI
Q1F25	Average daily flood with a 25-year RI
Q1F2	Average daily flood with a 2-year RI; **(nominal bankfull flow in channel). A Key Flow.**

(2) Average Annual Flow (The Arithmetic Mean of All Average Daily Flows for Period of Record including all daily floods and low flows).

QA Max	ADF for the wettest year of record (POR)
QAA	Average annual flow for a POR. **THE KEY FLOW.**
QA	Average daily flow (ADF) for a particular year
QA Min	ADF for the driest year in the POR
	QAA is used in regional models to estimate Q1F2, monthly flows and Q7L2.

(3) Average Monthly Flows Used to Evaluate Seasonal Fish Passage Flows During the Migration Seasons and for Habitat Evaluation in Conjunction with Channel Geometry.

Max QM(#)	Maximum Mean Monthly flow for month number (#) (10-12, and 1-9 in a water year of Oct – Sept)
Mean QM (#)	Mean Monthly flow for month (#) in water year
Min QM (#)	Minimum Mean Monthly flow for month #. **For low flow months in Fall Min QM(#) compares with Q30L2 (below).**

(4) Low Flows

Q7L2	Seven-day average low flow with a two-year **RI**; **low passage design flow; Q7L2 is the characteristic flow used to estimate all other statistical low flows; A Key Flow.**
Q7L10	Seven-day average low flow with a ten-year RI; **Water quality flow.**
Q7L20	Seven-day average low flow with a twenty-year RI; **Ratio Q7L2/Q7L20 measures low flow stability year to year**
Q30L2	Thirty-day average low flow with a two-year RI, a measure of Q7L2 extended to 30 days; **like Min QM in fall.**
Q60L2	Sixty-day average low flow with a two-year RI; **used as a "habitat" flow by WDFW (1998)**

The nomenclature in this table was developed in the 1970s for the basin study areas (WRIAs) as part of the State Water Program.

Example from Table 3:

Q	1	F	2	Q1F2
Flow	No. of Days for which Flow is Averaged	Flood-Type of Flow	Recurrence Interval, Years (RI)	

Notes:

- Q7L2 is flow, averaged over 7 days, low type, with a 2-year recurrence interval (or Q1L2 for one day).
- RI = 1/probability; RI = 2; p = 0.50

---

4) Tabulate the periods of record and basin characteristics for the USGS stations (Table 4). The basin characteristics for the WSU gage sites are in Table 5.

5) Check the USGS gages (Table 6) for extreme flows, dates of occurrence, regulation, diversions and quality of records. This information is contained in USGS annual reports (U.S. Geological Survey, 1999). For each discontinued gage the USGS annual report for the last year of operation was examined.

The Methow-Chelan Region will be used as the example region throughout the rest of this report.

NOTE: The USGS assigns a QUALITY FACTOR to its stream gaging measurements as shown in the footnotes of Table 6 and Appendix A. NO MENTION of this gaging accuracy has been found in any of the reviewed current literature or reports on such important topics as instream flow needs assessments. Only three of the forty-one USGS gages in our database are rated excellent (± 5%) and the rest are either good (± 10%) or worse. For the complete definition of these data quality terms see any recent USGS annual data book (USGS, 1999). This factor must be considered in evaluating the accuracy of any hydrologic model used to estimate ungaged streamflows or to set flows.

Table 4. Period of Record Information and Basin Characteristics for Selected USGS Stations by Region
USGS map gage site reference numbers in Williams and Pearson, 1985a and 1985b.

STATION NO	STATION NAME	MAPSITE NO	PERIODS OF RECORD	WYS TOTAL	PRECIP (in/yr)	AREA BASIN (sq. mi.)	UPPER ELEV (feet)	GAGE ELEV (feet)	H RELIEF (mi.)
1. METHOW-CHELAN									
12442000	Toats Coulee Creek Near Loomis, Wash.	85	1958-1969	12	29	130.0	2200	1880	0.061
12447390	Andrews Creek Near Mazama, Wash.	103	1969-2000	32	35	22.1	6600	4270	0.441
12449500	Methow River At Twisp, Wa	109	1920-1929; 1934-1962; 1992-2000	48	35	1301.0	6500	1580	0.932
12449600	Beaver Creek Below South Fork, Near Twisp, Wash.	110	1961-1978	18	24	62.0	6200	2800	0.644
12449950	Methow River Nr Pateros, Wash.	115	1960-2000	41	32	1772.0	6500	900	1.061
12451000	Stehekin River At Stehekin, Wash.	118	1912-1915; 1928-2000	77	99	321.0	6800	1099	1.080
12451500	Railroad Creek At Lucerne, Wash.	119	1912; 1928-1957	31	52	64.8	6600	1250	1.013
2. ENTIAT-WENATCHEE									
12452800	Entiat River Near Ardenvoir, Wash.	124	1958-2000	43	59	203.0	7600	1561	1.144
12453000	Entiat River At Entiat, Wash.	126	1912-1925; 1952-1958	21	45	419.0	7600	690	1.309
12454000	White River Near Plain, Wash.	129	1955-1983	29	108	150.0	6400	1882	0.856
12456500	Chiwawa River Near Plain, Wash.	134	1914; 1937-1949; 1955-1957; 1992-2000	26	78	170.0	7000	2100	0.928
12458000	Icicle Creek Abv Snow Cr Nr Leavenworth, Wash.	138	1937-1971; 1994-2000	42	88	193.0	5200	1450	0.710
12461400	Mission Creek Above Sand Cr Near Cashmere, Wash.	145	1960-1971	12	25	40.0	5600	1750	0.729
12483800	Naneum Creek Near Ellensburg, Wash.	197	1958-1971; 1973-1978	20	25	70.0	5800	2480	0.629
3. NACHES-YAKIMA									
12483800	Naneum Creek Near Ellensburg, Wash.	197	1958-1971; 1973-1978	20	25	70.0	5800	2480	0.629
12488500	American River Near Nile, Wash.	206	1940-2000	61	74	79.0	5400	2700	0.511
12494000	Naches River Below Tieton River Nr Naches, Wash.	211	1910-1912; 1917-1979	66	60	941.0	5400	1550	0.729
12500500	North Fork Ahtanum Creek Near Tampico, Wash.	215	1911-1915; 1932-1978	52	53	69.0	6400	2450	0.748
12501000	So Fk Ahtanum Cr At Conrad Rnch N Tampico, Wash.	216	1932-1978	47	54	25.0	6400	2400	0.758
12502500	Ahtanum Creek At Union Gap, Wash.	219	1912-1914; 1952; 1961-2000	44	38	173.0	6400	940	1.034
12506000	Toppenish Creek Near Fort Simcoe, Wash.	222	1910-1923	14	29	122.0	4800	1310	0.661
12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.	223	1910-1923	14	39	82.0	4500	1150	0.634

Table 4. Period of Record Information and Basin Characteristics for Selected USGS Stations by Region (continued)

STATION NO	STATION NAME	MAPSITE NO	PERIODS OF RECORD	WYS TOTAL	PRECIP (in/yr)	AREA BASIN (sq. mi.)	UPPER ELEV (feet)	GAGE ELEV (feet)	H RELIEF (mi.)
4. BLUE MOUNTAINS									
13334500	Asotin Creek Near Asotin, Wash.	246	1929-1959	31	22	156.0	6000	1380	0.875
13334700	Asotin Cr Blw Kearney Gulch Nr Asotin, Wash.	247	1960-1982; 1990-1995	29	24	170.0	6000	1090	0.930
13344500	Tucannon River Near Starbuck, Wash.	260	1915-1917; 1929-1931; 1959-1990; 1995-2000	44	23	431.0	5800	730	0.960
14013000	Mill Creek Near Walla Walla, Wash.	288	1914-1917; 1940-1976; 1980-2000	62	40	60.0	5400	2000	0.644
14013500	Blue Creek Near Walla Walla, Wash.	289	1940-1971	32	36	17.0	4600	1700	0.549
14016000	Dry Creek Near Walla Walla, Wash.	294	1950-1967	18	29	48.0	4400	1200	0.606
14016500	East Fk Touchet R Nr Dayton, Wash.	295	1942-1951; 1957-1968	22	30	102.0	4900	1868	0.574
14017000	Touchet River At Bolles, Wash.	298	1925-1929; 1952-1989	43	25	361.0	5000	1150	0.729
14017500	Touchet R Nr Touchet, Wash.	301	1942-1955	14	20	733.0	5000	530	0.847
14018500	Walla Walla River Near Touchet, Wash.	302	1952-2000	49	22	1657.0	4800	405	0.832
5. KLICKITAT									
12506000	Toppenish Creek Near Fort Simcoe, Wash.	222	1910-1923	14	29	122.0	4800	1310	0.661
12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.	223	1910-1923	14	39	82.0	4500	1150	0.634
14107000	Klickitat R Abv West Fk Nr Glenwood, Wash.	314	1945-1977; 1992-2000	42	58	151.0	5800	2720	0.583
14110000	Klickitat River Near Glenwood, Wash.	317	1911-1956; 1958-1971	60	56	360.0	5800	1703	0.776
14112000	Little Klickitat R Nr Goldendale, Wash.	321	1911; 1947-1951; 1958-1970	19	25	84.0	5200	1690	0.665
14113000	Klickitat River Near Pitt, Wash.	326	1910-1911; 1929-2000	74	36	1297.0	5800	289	1.044
6. WIND-WHITE SALMON									
14121300	White Salmon R Blw Cascades Cr Nr Trout L, Wash.	1	1958-1978	21	106	32.4	6000	3080	0.553
14121400	White Salmon R Ab Tr Lk Cr Nr Trout Lk, Wash.	2	1960-1968	9	97	65.0	6000	2050	0.748
14121500	Trout Lake Creek Nr Trout Lake, Wash.	3	1910-1911; 1960-1968	11	82	69.3	4200	2000	0.417
14123500	White Salmon R Nr Underwood, Wash.	9	1916-1930; 1936-2000	80	66	386.0	6000	113	1.115
14124500	Little White Salmon River At Willard, Wash.	10	1946-1961	16	70	114.0	3600	1230	0.449
14127000	Wind R Ab Trout Creek Nr Carson, Wash.	16	1945-1969	25	103	108.0	4000	890	0.589

Table 5. Washington State University Site and Basin Characteristics
(Data provided by WSU, 2001)

REGION	WSU ID No.	Stream/Site Name	WRIA No.	Precipitation P (in/yr)	Area A (mi2)	P•A (mi2-in/yr)	Gage Elevation (ft)	Upper Elevation (ft)
METHOW-CHELAN	6	Loup Loup Creek	49	2.0	44.17	87	2153	4267
	7	Little Bridge Creek	48	1.9	24.27	47	2170	6133
	8	Libby Creek	48	1.9	41.68	80	1413	7767
	9	Black Canyon Creek	48	1.9	11.33	22	2013	5267
ENTIAT-WENATCHEE	10	Colockum Creek	40	1.6	35.05	56	1353	5200
	11	Stemilt Creek	40	1.6	24.61	39	1767	5933
	12	Mission Creek	45	1.8	80.78	145	890	4700
	13	Upper Peshastin Creek	45	1.8	19.37	35	2620	5567
	14	Lower Peshastin Creek	45	1.8	36.36	65	2627	5567
NACHES-YAKIMA	15	Nile Creek	38	1.5	31.67	48	2053	5900
	16	Rock Creek	38	1.5	17.41	26	2203	5667
BLUE MOUNTAINS	1	S. Fork Asotin Creek	35	1.4	36.58	51	2383	5433
	2	Pataha Creek	35	1.4	9.35	13	4023	5600
	3	Tumalum Creek	35	1.4	15.83	22	2007	5133
	4	Patit Creek	32	1.3	50.08	64	1907	4367
	5	S. Fork Coppei Creek	32	1.3	12.45	16	1820	3833
KLICKITAT	17	Butler Creek	30	1.2	11.62	14	2200	5667
	18	Bowman Creek	30	1.2	13.38	16	2357	5633
	19	Mill Creek	30	1.2	28.6	34	1640	5400
WIND-WHITE SALMON	20	Buck Creek	29	1.2	13.83	16	370	3367

Table 6. Extreme Flows for Periods of Record, Regulation, Diversions and Record Quality for USGS Gages (Methow-Chelan example). Data for all WRIAs in Appendix A, Table A-1.

REGION	USGS Map Site No.	USGS Gage No.	Stream Name	Ab Basin Area (sq. mi.)	Date of Peak Flow	Peak Flow (cfs)	Regulation Notes	Date of Minimum Flow	Minimum Flow (cfs)	Diversion Notes	Record Quality
METHOW-CHELAN	85	12442000	Toats Coulee Cr.	130	5/28/1948	6010	NR	11/2/1961	1.0 FU	ND	F, P
	103	12447390	Andrews Cr.	22	6/10/1972	1120	NR	11/4/1968	1.2	ND	P
	109	12449500	Methow R.	1301	5/29/1948	40800	NR	9/4/1926	134	D	G, F
	110	12449600	Beaver Cr.	62	5/29/1972	535	NR	11/13/1968	0.75	ND	G, PW
	115	12449950	Methow R.	1772	5/29/1948	46700	NR	1/8/1974	150 FU	11,000 AC. BOR	G, F
	118	12451000	Stehekin R.	321	11/29/1995	20900	NR	1/12/1930	56	ND	F
	119	12451500	Railroad Cr.	65	5/28/1948	3900	NR	1/15/1930	9 FU	ND	G, P

USGS Notes:

NR = No Regulation
R = Regulation

ND = No Diversion
D = Diversion
MD = Many Diversions
MSD = Many Small Diversions
SD = Several Diversions

FU = Freeze Up
E = Excellent ± 5%
G = Good ± 10%
F = Fair ± 15%
P = Poor > ± 15%
PW = Poor in Winter
AC = Acres
BOR = Bureau of Reclamation

6) Check Table 4 for the USGS gages in operation after 1979; 23 of the 41 gages were discontinued in or before 1979, and one each was discontinued in 1983, 1989 and 1995. Thus 18 gages needed to have their statistics rerun to include records through Water Year (WY) 2000 using data from the Internet (U.S. Geological Survey, 1997).

7) Summarize the 50 statistical flows for the 41 USGS gages. An example is in Table 7 for the Methow-Chelan region. **Data for all of the regions is in each appendix where a particular model is documented.**

Table 7. Example of Characteristic (Key) Flows for the Methow-Chelan Region.

Station No.	**Station Name**	**Q1F2** (cfs)	**QAA** (cfs)	**Q7L2** (cfs)
12442000	Toats Coulee Cr.	508	47	6.3
12447390	Andrews Cr.	304	32	4.1
12449500	Methow R.	10786	1378	226
12449600	Beaver Cr.	125	20	5.2
12449950	Methow R.	11271	1577	339
12451000	Stehekin R.	8195	1413	305
12451500	Railroad Cr.	1192	204	45

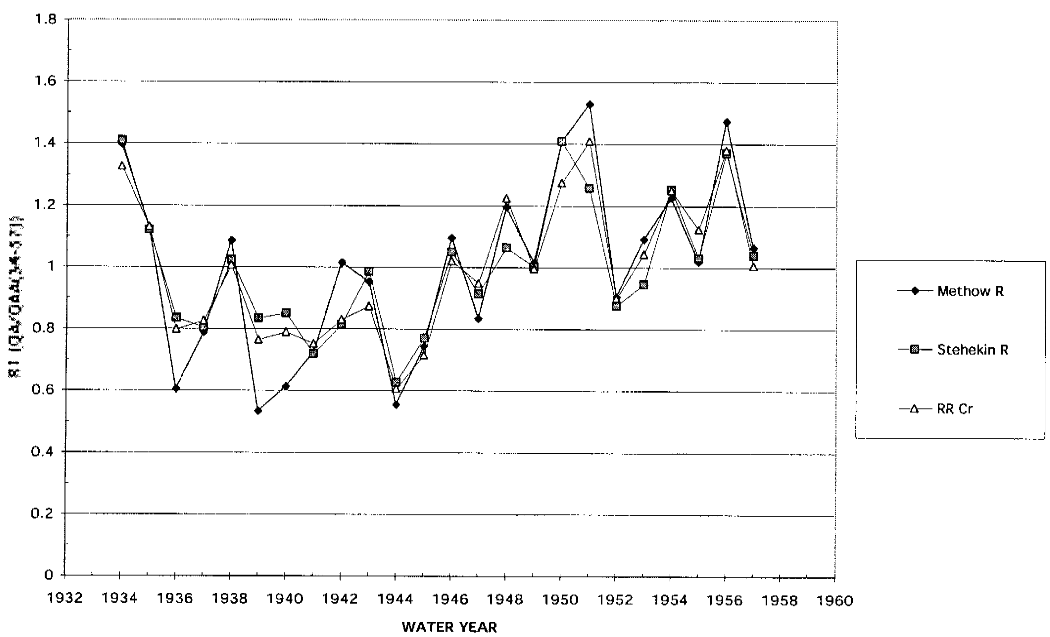
8) Test for regional annual flow hydrologic uniformity of the gages by comparing the annual flows (QA) divided by (QAA) for common periods of record (Ratio: R1 = QA/QAA). A sample of this analysis is in Table 8 and Figure 4 for the Methow-Chelan region. The same analyses for all six regions are in Appendix B.

Table 8. Test for Hydrologic Uniformity; 1934 to 1957 Common POR for Methow-Chelan Region, USGS Gages.

WY	Methow R qa_wy 12449500	Stehekin R qa_wy 12451000	RR Cr qa_wy 12451500	
1934	2036.1	2007.2	279.2	(cfs)
1935	1645.5	1596.4	238.1	(cfs)
1936	882.7	1188.4	167.9	(cfs)
1937	1148.0	1144.7	173.6	(cfs)
1938	1582.9	1457.9	211.9	(cfs)
1939	779.0	1186.5	161.1	(cfs)
1940	894.6	1209.8	166.5	(cfs)
1941	1054.5	1024.8	158.4	(cfs)
1942	1480.3	1159.1	174.7	(cfs)
1943	1388.4	1402.6	184.0	(cfs)
1944	808.0	894.7	127.7	(cfs)
1945	1084.3	1097.6	150.6	(cfs)
1946	1597.1	1496.4	215.0	(cfs)
1947	1216.2	1302.2	199.7	(cfs)
1948	1743.3	1515.9	257.8	(cfs)
1949	1480.0	1427.4	209.8	(cfs)
1950	2055.7	2007.5	268.4	(cfs)
1951	2230.7	1792.4	296.8	(cfs)
1952	1316.8	1247.0	189.7	(cfs)
1953	1592.4	1348.0	219.7	(cfs)
1954	1787.9	1786.4	263.0	(cfs)
1955	1483.9	1468.9	236.7	(cfs)
1956	2149.3	1953.5	290.8	(cfs)
1957	1553.0	1479.3	212.0	(cfs)
QAA(34-57):	1457.9	1424.8	210.5	(cfs)
QAA(Long-term):	*1378.2*	*1412.9*	*203.9*	(cfs)
Count of WY's:	*48*	*77*	*31*	

WY	Methow R R1 12449500	Stehekin R R1 12451000	RR Cr R1 12451500
1934	1.397	1.409	1.326
1935	1.129	1.120	1.131
1936	0.605	0.834	0.797
1937	0.787	0.803	0.825
1938	1.086	1.023	1.006
1939	0.534	0.833	0.765
1940	0.614	0.849	0.791
1941	0.723	0.719	0.752
1942	1.015	0.814	0.830
1943	0.952	0.984	0.874
1944	0.554	0.628	0.607
1945	0.744	0.770	0.715
1946	1.095	1.050	1.021
1947	0.834	0.914	0.948
1948	1.196	1.064	1.224
1949	1.015	1.002	0.996
1950	1.410	1.409	1.275
1951	1.530	1.258	1.410
1952	0.903	0.875	0.901
1953	1.092	0.946	1.043
1954	1.226	1.254	1.249
1955	1.018	1.031	1.124
1956	1.474	1.371	1.381
1957	1.065	1.038	1.007
WRIA	48	48	47

Figure 4. Methow-Chelan R1 for Common POR 1934-57; R1 = QA/QAA('34-'57)



9) Develop the Preliminary List of Models in Table 9.

Table 9. Preliminary List of Models.

MODELS BY REGION	Notes
1. Average Annual Flows; Monthly Flows	
1a. QAA = C (PA) 1b. QAA = C $(P)^n$ (A)	The Key Flow
1c. QAmax = C $(QAA)^E$ 1d. QAmin = C $(QAA)^E$; or	C = coefficient; E = exponent
1e. QM#(10-9) = f(QAA)	Max, Mean and Min monthly models

2. Daily Flood Flows, 2-yr RI	Which equation is better in **each region** by R^2, SE? Select best model of three.
2a. Q1F2 = C $(QAA)^E$	
2b. Q1F2 = C $(BE)^E$ = C $(AH^{0.50})^E$	BE = Basin Energy, $AH^{0.50}$
2c. Q1F2 = C $(PBE)^E$	PBE = Precipitation x BE

3. Other Daily Floods related to Q1F2	Statistical Flood Model (Q1F)
3a. Q1F25 = C $(Q1F2)^E$	(from Log Pearson III)
3b. Q1F100 = C $(Q1F2)^E$	

4. Other Peak Floods related to Q1F2	Regional Relation from USGS Continuous Gages. Q1F2 is a Key Flow.
4a. QPF2 = C $(Q1F2)^E$	Assumed to apply at crest-stage gages
4b. QPF25 = C $(Q1F2)^E$	STAT. PEAK FLOOD MODEL (QPF)
4c. QPF100 = C $(Q1F2)^E$	Values of QP from Sumioka et. al. (1998)

5. For Crest Gages, smaller watersheds	Use Daily Flood Equations
Q1F2 = C $(QPF2)^E$, etc.	Values of QP from Sumioka et. al. (1998)

6. 7-Day Average FALL Low Flows	Select better model of two.
6a. Q7L2 = C $(QAA)^E$	
6b. Q7L2 = C $(PBE)^E$	

7. Other FALL Low Flow related to Q7L2	QL Statistical Model
7a. Q7L10 = C $(Q7L2)^E$	Q7L2 is a Key Flow
7b. Q7L20 = C $(Q7L2)^E$	
7c. Q30L2 = C $(Q7L2)^E$	
7d. Q60L2 = C $(Q7L2)^E$	

10) Test the preliminary models to determine which models are the best (largest correlation coefficient squared (R^2) and the smallest standard error (SE) in percent). SE % = $100(e^{MSE}-1)^{0.50}$; e is 2.302, the base of natural logarithms; and MSE is the mean square error of the square of the sum of the differences between the measured and estimated discharges (Powers and Saunders, 1998).

Referring to the models in Table 9, there are two types. **Type (1)** relates one of the three key characteristic flows (Q1F2, QAA and Q7L2) to basin characteristics; (Models 1a, 1b, 2b, 2c, and 6b.). **Type (2)** relates one type of flow to another flow like Models 1c, 1d, 1e, 2a and 6a. Note in Table 9 that Models #3 and #4 are called STATISTICAL flood models in which all the daily and peak flood flows of different RIs are related to the one-day, 2-year (statistical average) flood flow (Q1F2). Also, the low flow STATISTICAL models (Model #7 in Table 9) relate statistical (RI) low flows to the 7-day, 2-year (statistical RI) low flow (Q7L2).

TESTING THE ALTERNATIVE MODELS FOR THE KEY FLOWS

The testing procedure deals only with the models used to find the three **key** (characteristic) flows: QAA, Q1F2 and Q7L2, all "average" flows (Table 3 and Table 9). The average annual flow (QAA) is the average daily flow for the entire record at a gage. The average daily flood (Q1F2) is the statistical average flood (RI = 2-years, probability, p = 0.50, the arithmetic mean). The 7-day average low flow (Q7L2) is the minimum annual flow, averaged over seven consecutive days, that has occurred once every 2 years (RI = 2, p = 0.50, the arithmetic mean). At a gage Q7L2 rarely differs from Q1L2 or even Q14L2. But Q7L2 is a basic standard low flow which, on the average, is equaled or exceeded about 95% of the time on the annual duration curve.

Models for QAA (Models #1a and #1b in Table 9)

In many WRIAs of the State with uniform climates, the average annual flow (QAA, the average OUTFLOW from a watershed) is a direct percentage of the average INFLOW as was shown in Equation 2:

$$QAA = C\ (PA). \qquad \text{(Equation 2)}$$

which is the same as Model 1a in Table 9. In some WRIAs with more climatic variation, then the relationship is like Equation 3:

$$QAA = C\ (P)^n\ A \qquad \text{(Equation 3)}$$

where C is a coefficient that varies directly as P (Amerman and Orsborn, 1987) (Model 1b in Table 9).

All models used in this report are of the power type (log : log) where one variable is related to another variable in the form $y = C\ (x)^E$, where y and x are the vertical and horizontal axes of the graphical relation. The coefficient C and the exponent E are determined by the regression analysis, which also measures the goodness of fit (R^2, correlation coefficient squared) and the standard error (SE) as defined earlier.

The improvement is the estimation of QAA by using Model #1b instead of Model #1a in Table 9 is demonstrated in Tables 10 and 11. By solving for the coefficient C as a function of P both the R^2 and SE values were improved for the Methow-Chelan and Naches-Yakima regions. The graphical solutions for the equations in Tables 10 and 11 for all the regions are in Appendix C, and Figure 5 shows an example for the Methow-Chelan region.

Testing Models #2a, 2b and 2c for Q1F2 (Table 9)

In doing a comparative analysis of these three models we selected Model #2a not only for its slightly better R^2 and SE values, but also because of the simplicity of the input data required for its application.

$$\text{Model 2a: } Q1F2 = C(QAA)^E \qquad \text{(Equation 6)}$$

$$\text{Model 2b: } Q1F2 = C(A(H)^{0.50})^E \qquad \text{(Equation 7)}$$

where $(A(H)^{0.50})$ is called Basin Energy (BE)

$$\text{Model 2c: } Q1F2 = C(PBE)^E \qquad \text{(Equation 8)}$$

The determination of the relief term (H) from topographic maps could be difficult for some persons. The slight improvement in R^2 and SE did not warrant the additional effort especially when gaging accuracy is considered. **The only basin characteristics necessary to run all 50 flow models will be P and A (average annual precipitation and basin area).**

To estimate Q1F2 at an ungaged site, find QAA from Model #1 then

$$\text{Model 2a: } Q1F2 = 13.21(QAA)^{0.90} \qquad \text{(Equation 9)}$$

for the Methow-Chelan region as shown in Figure 6. The tables of data, coefficients and exponents, and the graphs for all the regions are in Appendix D.

Table 10. Summary of Equations, Model #1a, QAA versus Preciptation times Basin Area, All WRIAs

AVERAGE EQUATION: $QAA = C(PA)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	*0.018*	*1.05*	*0.91*	*53*
ENTIAT-WENATCHEE	0.024	1.04	0.95	18
NACHES-YAKIMA	*0.014*	*1.04*	*0.85*	*46*
BLUE MOUNTAINS	0.062	0.88	0.91	29
KLICKITAT	0.014	1.10	0.99	10
WIND-WHITE SALMON	0.035	1.03	0.96	12

Table 11. Summary of Equations, Model #1b, QAA versus $(\text{Preciptation})^n$ times Basin Area for the Methow-Chelan and Naches-Yakima Regions

AVERAGE EQUATION: $QAA = C(P)^n A$

REGION	C	n	R^2	SE%
METHOW-CHELAN	0.0011	1.89	0.95	37
ENTIAT-WENATCHEE	*(No Improvement from Table 10)*			
NACHES-YAKIMA	0.000017	2.77	0.99	14
BLUE MOUNTAINS	*(No Improvement from Table 10)*			
KLICKITAT	*(No Improvement from Table 10)*			
WIND-WHITE SALMON	*(No Improvement from Table 10)*			

Figure 5. Model #1b, QAA related to P^nA, Methow-Chelan Region

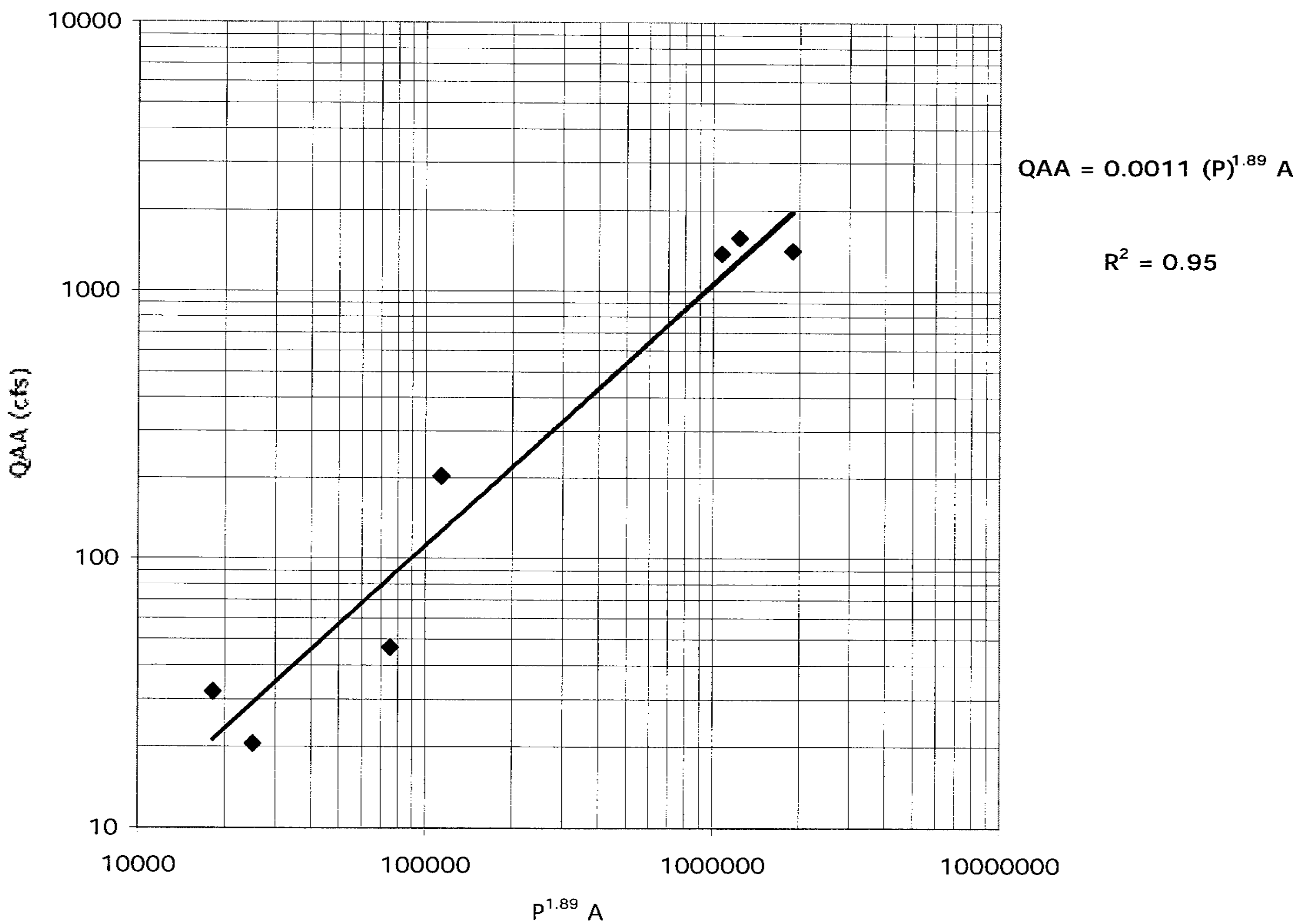
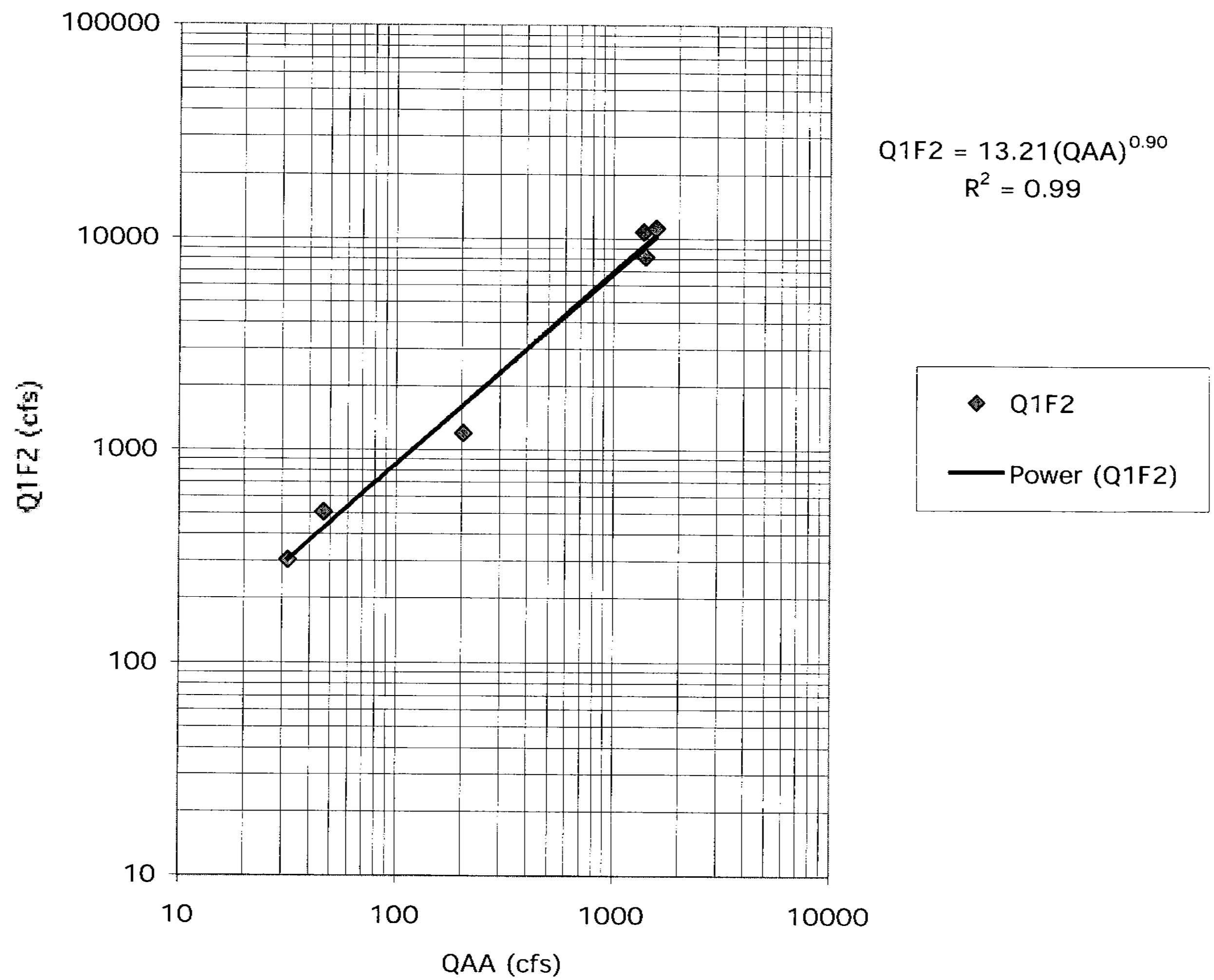


Figure 6. 1-Day Average 2-Year Flood Flow, Model #2a, Methow-Chelan Region



Testing Models #6a and #6b for Q7L2 (Table 9)

Following the same comparative tests of the other models using R^2 and SE, and for ease of data acquisition, we selected Model #6a for estimating the FALL migration season Q7L2 flows:

Model #6a for the Methow-Chelan region is

$$Q7L2 = 0.15(QAA)^{1.04} \qquad \text{(Equation 10)}$$

as shown in Figure 7. The data, coefficients and exponents and graphs for all the regions are in Appendix E along with some notes on low flow model limitations.

MODELS OF OTHER FLOWS RELATED TO QAA

In Table 9 there are no more models to test and select, but there are other flows related to QAA in Model set #1. These are the maximum and minimum annual flows of record and the maximum, mean and minimum average monthly flows.

Models for #1c and #1d for QA Max and QA Min (Table 9)

Using the Methow-Chelan region as an example, the data for the maximum, minimum and long-term average annual flows are in Table 12.

Figure 7. 7-Day Average 2-Year Fall Low Flow Related to QAA, Model #6a, Methow-Chelan Region

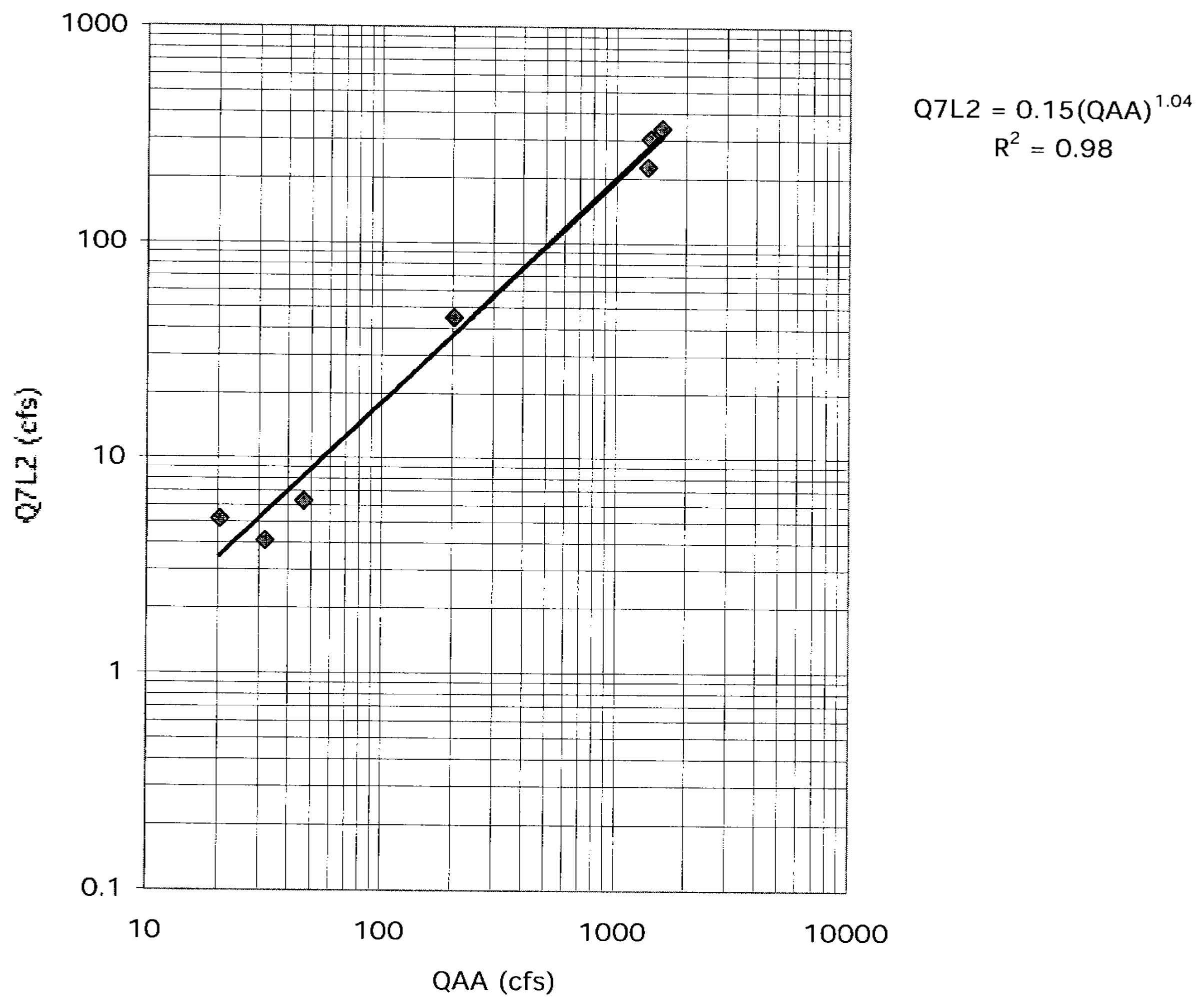


Table 12. Data for Methow-Chelan Region Example of Max and Min Average Annual Flow Analysis; Models #1c and #1d (Table 9)

Station No.	Station Name	QAmin (cfs)	QAA (cfs)	QAmax (cfs)
12442000	Toats Coulee Creek	24.2	46.6	66.1
12447390	Andrews Creek	12.9	32.0	59.1
12449500	Methow River	468	1378	2231
12449600	Beaver Creek	7.5	20.5	46.4
12449950	Methow River	565	1577	2963
12451000	Stehekin River	872	1413	2008
12451500	Railroad Creek	128	204	297

The regression models for this data are in Figure 8 and show excellent relationships for average annual flows ranging from less than 10 to almost 3000 cfs. The data, model coefficients, exponents, and R^2 and SE values for all the regions are in Appendix F.

Model #1e for Monthly Flows Related to QAA (Table 9)

For monthly flow estimates we used:

$$\text{Model 1e: } QM\#(10\text{-}9) = C(QAA)^E \qquad \text{(Equation 11)}$$

is the number of the month in a Water Year (Oct-Sept), for example 10 is October.

Because of the huge mass of data involved we did not print the data, nor the graphs. We went directly from the computer database to the regression solutions as shown in the example Table 13 for the Methow-Chelan region. The rest of the monthly values of C, E, R^2 and SE are in Appendix G. If graphs had been made for all of the monthly flow equations for the six (6) regions there would be 216 more figures in this report.

STATISTICAL MODELS #3, #4 AND #7 (TABLE 9)

Introduction

Once the **three key characteristic flows** (Q1F2, QAA and Q7L2) have been determined then other flows of a similar type can be estimated based on their flow to flow relationships. We have seen in Models #1c and #1d, for example, how QA Max and QA Min (extreme annual flows) are related to the long-term average annual flow, QAA. The statistical models relate daily floods and peak floods of selected RI's to the characteristic **key flood, Q1F2**. Similarly, certain statistical low flows (Model #7: Q7L10, Q7L20, Q30L2 and Q60L2) are all modeled in terms of **the key low flow Q7L2**, the fish passage design low flow.

Daily Flood Models #3a and #3b (Table 9)

Models #3a and #3b are used to estimate the Q1F25 and Q1F100. These models use recurrence interval (RI, frequency) analyses, which have been run by the USGS on their stream gage data. The accuracy of their models will depend on the period of record (POR) and the quality of the data measurements.

Data for Models #3a and 3b are in Table 14 for the Methow-Chelan region.

Figure 8. Maximum & Minimum Annual Flows Related to QAA, Models #1c and #1d, Methow-Chelan Region

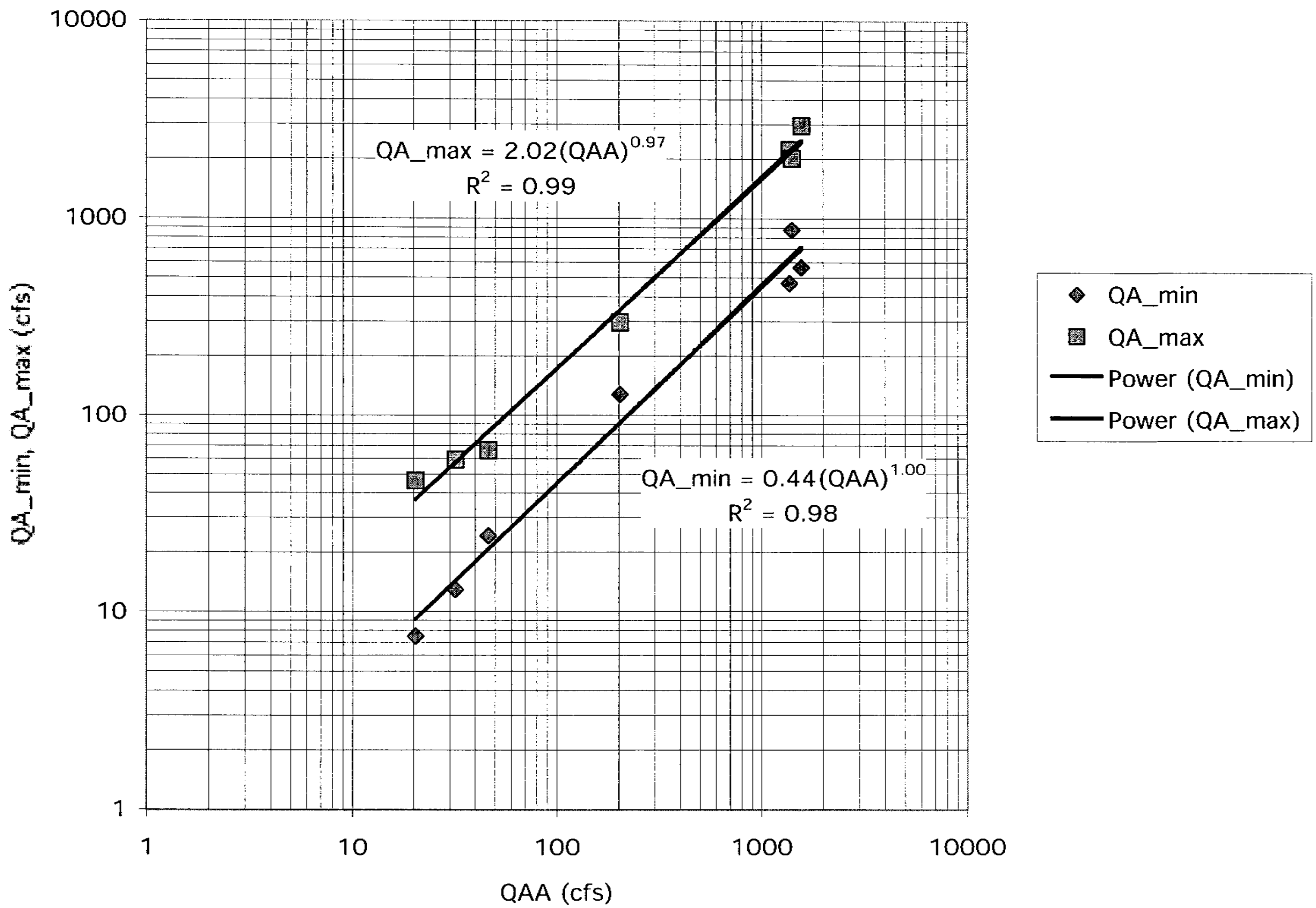


Table 13. Summary of Equation Coefficients and Exponents, METHOW-CHELAN Region, Model #1e (Table 9)

$QM\#(10\text{-}9) = C(QAA)^E$

QM Maximum

MONTH	#	C	E	R^2	SE%
Oct	10	0.40	1.13	0.99	14%
Nov	11	0.38	1.15	0.95	45%
Dec	12	0.26	1.18	0.97	36%
Jan	1	0.29	1.12	0.97	31%
Feb	2	0.15	1.21	0.97	33%
Mar	3	0.23	1.21	0.95	47%
Apr	4	0.75	1.21	0.96	44%
May	5	12.72	0.88	0.97	27%
Jun	6	16.28	0.88	0.98	22%
Jul	7	2.20	1.06	0.99	20%
Aug	8	0.70	1.09	0.97	31%
Sep	9	0.88	0.98	0.97	26%

QM Mean

MONTH	#	C	E	R^2	SE%
Oct	10	0.25	1.05	0.98	22%
Nov	11	0.20	1.09	0.98	25%
Dec	12	0.17	1.09	0.98	25%
Jan	1	0.17	1.05	0.98	25%
Feb	2	0.16	1.06	0.98	28%
Mar	3	0.15	1.11	0.97	32%
Apr	4	0.40	1.13	0.99	15%
May	5	3.34	0.97	0.99	19%
Jun	6	2.98	1.01	0.97	28%
Jul	7	0.70	1.10	0.96	38%
Aug	8	0.38	1.06	0.96	35%
Sep	9	0.30	1.01	0.96	34%

QM Minimum

MONTH	#	C	E	R^2	SE%
Oct	10	0.14	1.02	0.97	29%
Nov	11	0.13	1.01	0.96	32%
Dec	12	0.12	1.01	0.96	35%
Jan	1	0.11	0.99	0.93	46%
Feb	2	0.13	0.98	0.94	41%
Mar	3	0.12	1.02	0.96	37%
Apr	4	0.17	1.04	0.94	44%
May	5	0.68	1.06	0.98	23%
Jun	6	0.52	1.09	0.93	53%
Jul	7	0.25	1.08	0.91	59%
Aug	8	0.16	1.06	0.91	57%
Sep	9	0.12	1.06	0.94	47%

Table 14. Data for Models #3a and #3b, Q1F25 and Q1F100 in the Methow-Chelan Region

Station No.	Station Name	Q1F2 (cfs)	Model #3a Q1F25 (cfs)	Model #3b Q1F100 (cfs)
12442000	Toats Coulee Creek	---	---	---
12447390	Andrews Creek	304	649	864
12449500	Methow River	10786	21149	25304
12449600	Beaver Creek	---	---	---
12449950	Methow River	11271	22519	27725
12451000	Stehekin River	8195	14209	16898
12451500	Railroad Creek	1192	2365	2988

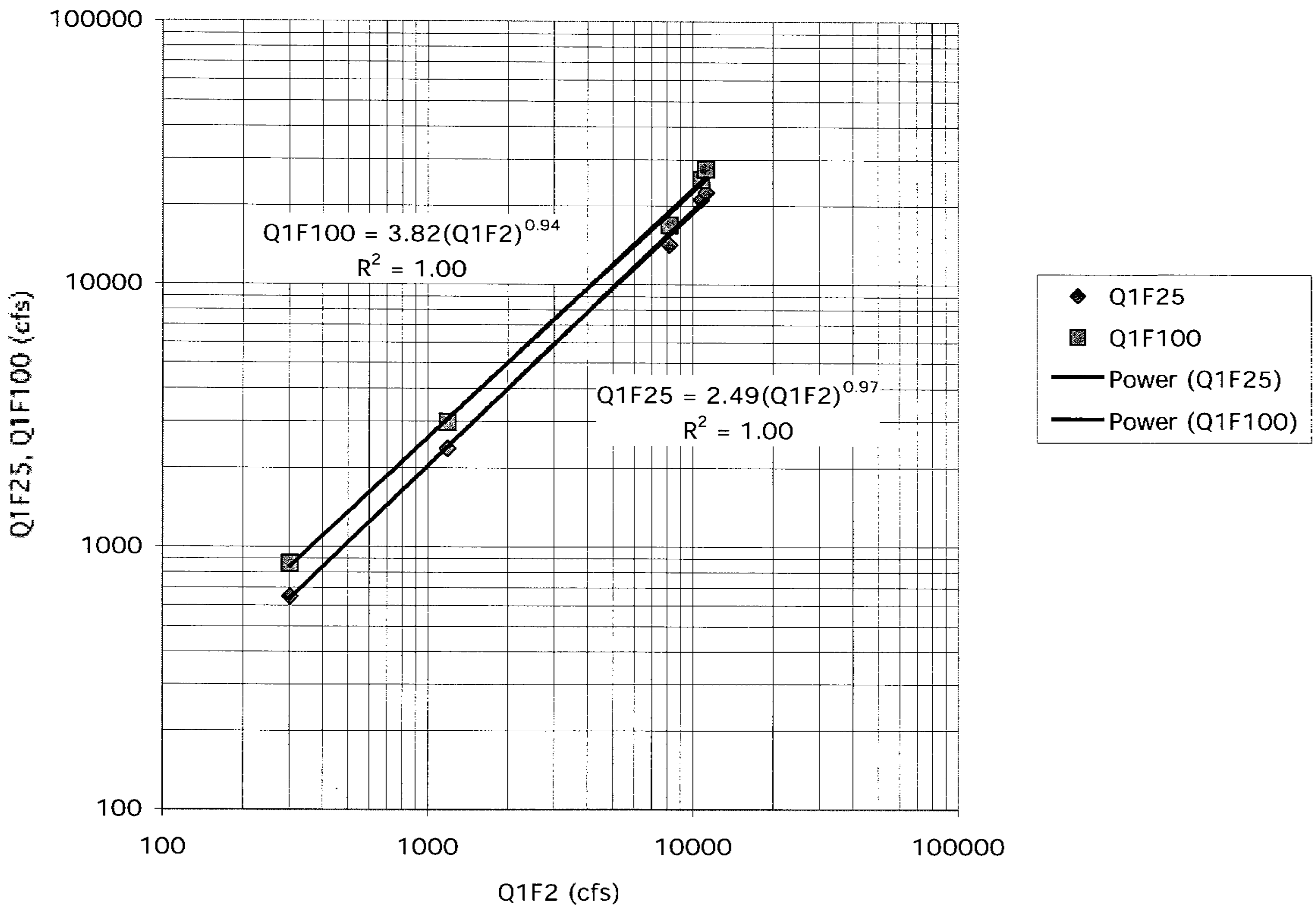
The equations derived from the data in Table 14 are displayed in Figure 9. The data and graphs for all the regions are in Appendix H, along with the table of coefficients and exponents, R^2 and SE. As mentioned earlier, unneeded graphs are not included in the appendices after Appendix E for Q7L2 (Model #6a). The solutions for the Methow-Chelan region are listed in Table 15.

Table 15. Solutions for Models #3a and #3b for Daily Floods in the Methow-Chelan Region.

Daily Flood	**Model #**	**Coeff. C**	**Exponent E**	**Correl. Coeff. R^2**	**Stnd. Error SE%**	**From Table**
Q1F25	3a	2.49	0.97	1.00	5	H-2
Q1F100	3b	3.82	0.94	1.00	6	H-3

The largest standard error for the 25-year flood was 34% in the Klickitat region, and 25% for the 100-year flood in the SW subregion of the Blue Mountains (WRIA 32).

Figure 9. Statistical Model #3a and #3b, Example for the Methow-Chelan Region



Peak Flood Models #4a, #4b and 4c (Table 9)

The average daily flood (Q1F2), one of the three key flows (Q1F2, QAA and Q7L2), is used again in the Model #4 series to estimate peak floods based on their statistical relationships to Q1F2. The relationships are very strong, especially between the 2-year (average) peak and daily floods.

Example graphs for the relationships of QPF2, QPF25 and QPF100 to Q1F2 in the Methow-Chelan are combined in Figure 10. The data for these graphs is given in Table 16.

Table 16. Data for Models #4a, #4b and #4c of Peak Floods QPF2, QPF25 and QPF100 in the Methow-Chelan Region.

Station No.	Station Name	Q1F2 (cfs)	QPF2 (cfs)	QPF25 (cfs)	QPF100 (cfs)
12442000	Toats Coulee Creek	508	524	1690	2570
12447390	Andrews Creek	304	362	784	1060
12449500	Methow River	10786	11100	21500	25700
12449600	Beaver Creek	125	135	539	814
12449950	Methow River	11271	11700	25000	31900
12451000	Stehekin River	8195	9600	16800	19900
12451500	Railroad Creek	1192	1260	2630	3430

The data and solutions for all the regional peak flood models are in Appendix H. The solutions for the Methow-Chelan region are listed in Table 17.

Figure 10. Models #4a, #4b and #4c Peak Flood Flows Related to Q1F2 in the Methow-Chelan Region

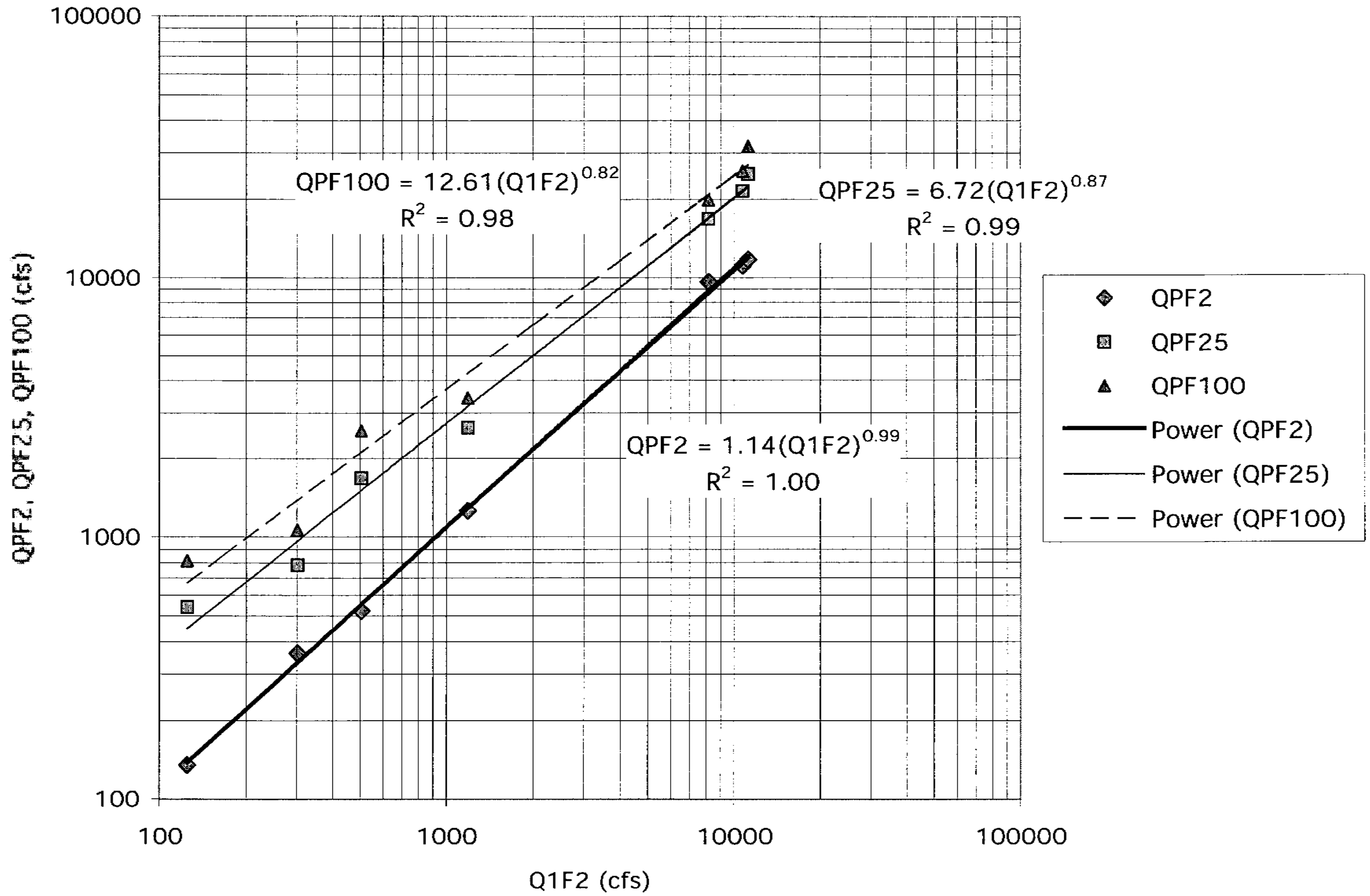


Table 17. Solutions for Peak Flood Statistical Models #4a, #4b and #4c in the Methow-Chelan Region.

Daily Flood	Model #	Coeff. C	Exponent E	Correl. Coeff. R^2	Stnd. Error SE%	From Table
QPF2	4a	1.14	0.99	1.00	5	H-5
QPF25	4b	6.72	0.87	0.99	13	H-6
QPF100	4c	12.61	0.82	0.98	16	H-7

Example: QPF2 = $1.14(Q1F2{=}100)^{0.99}$ = 109 cfs (Spring Snowmelt Peaks only 9% larger than Q1F2)

Low Flow Statistical Models #7a, #7b, #7c and #7d (Table 9)

The example data for these models are given in Table 18.

Table 18. Low Flow Data for Model #7 in the Methow-Chelan Region. All Values are for Fall Low Flows (i.e. Q7L2FALL, Q30L2FALL).

Station No.	Station Name	Q7L2 (cfs)	Q7L10 (cfs)	Q7L20 (cfs)	Q30L2 (cfs)	Q60L2 (cfs)
	Model # :	All	#7a	#7b	#7c	#7d
12442000	Toats Coulee Creek	6.3	4.0	---	7.6	8.0
12447390	Andrews Creek	4.1	2.9	2.5	4.4	4.5
12449500	Methow River	225.7	165.2	150.9	257.5	278.5
12449600	Beaver Creek	5.2	3.6	---	5.9	6.2
12449950	Methow River	339.3	237.2	227.0	369.4	484.2
12451000	Stehekin River	305.3	191.4	144.6	361.0	409.7
12451500	Railroad Creek	44.9	25.8	21.0	55.7	64.6

The data for all the regions are in Appendix I as are the solution tables for the four low flow models. Examples of the solutions are in Table 19. Examples of the correlation graphs for the Methow-Chelan region are given in Figure 11.

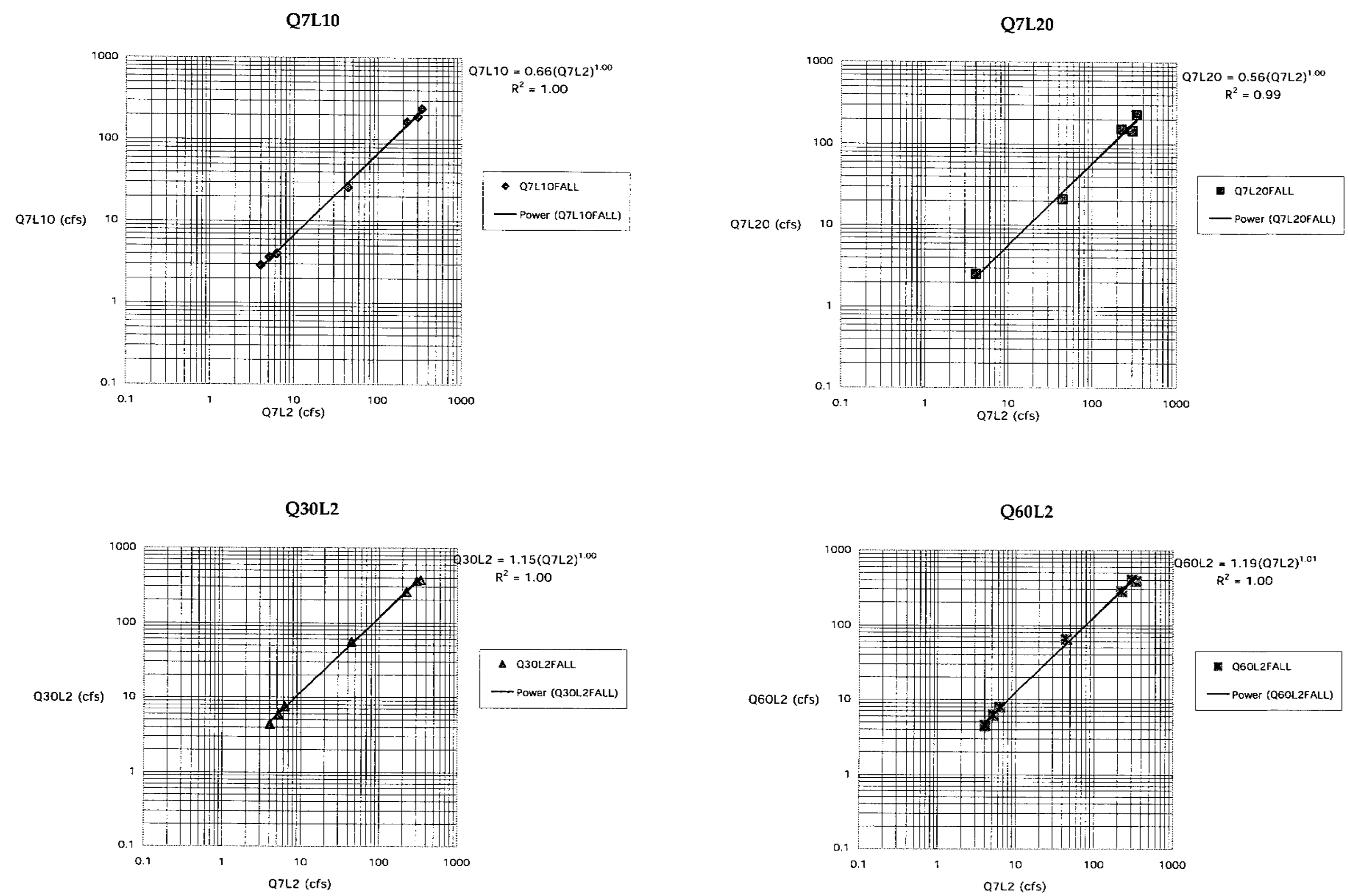
Table 19. Solutions for Low Flow Models #7a, #7b, #7 c and #7c in the Methow-Chelan Region.

Low Flow	Model #	Coeff. C	Exponent E	Correl. Coeff. R^2	Stnd. Error SE%	From Table
Q7L10	7a	0.66	1.00	1.00	7	I-2
Q7L20	7b	0.56	1.00	0.99	15	I-3
Q30L2	7c	1.15	1.00	1.00	4	I-4
Q60L2	7d	1.19	1.01	1.00	8	I-5

Example: $Q60L2 = 1.19(Q1F2=10)^{1.01} = 12.2$ cfs
(an increase of about 22% in a 60-day period)

The standard error is small for these low flows ranging from a low of 1% (Klickitat, Q7L20) to a high of 15% (Methow-Chelan, Q7L2). The high may be due to irrigation diversions.

Figure 11. Low Flow Models, Models #7a, #7b, #7c and #7d for Q7L10, Q7L20, Q30L2 and Q60L2 Related to Q7L2 in the Methow-Chelan Region.



DISCUSSION

SYNOPSIS

Our project objective was to develop improved hydrologic models for estimating low and flood streamflows for culvert design at ungaged sites in eastern Washington. WSU conducted a companion project to provide a better hydrologic model for estimating the high migration season flow that is equaled or exceeded 10% of the time. In addition WSU established 20 stream-gaging sites on salmon streams along the east side of the Cascades and in the Blue Mountains to improve the streamflow database.

The two culvert design flows addressed in our project were: (1) Q7L2, the minimum fall low flow for fish passage; and (2) QPF100, the 100-year peak flood required for culvert and roadway safety to avoid overtopping and washout. In addition to these two fish passage and safety design flows, our project has developed improved hydrologic models to estimate a complete regime of flows. These flows can be of assistance with many water resources problem at any ungaged site within the regions (WRIAs) included, namely the East Cascades and Blue Mountains.

SUMMARY OF MODEL DEVELOPMENT

The general steps in the model development for this project were:

1. Select the WRIAs in which the WSU stream gaging sites are located;
2. Locate USGS gaging stations within those and adjacent WRIAs.

3. Set up a database for USGS gages to include statistical flows and basin characteristics (P, average annual precipitation; A, basin area; and H, basin relief).
4. Check the regions for hydrologic uniformity.
5. Test different models of three key flows related to combinations of basin characteristics, using the standard error of estimate as the primary test.
6. Select the best model for each of the three key flows in each region.
7. Develop models for the desired statistical flows (flood, monthly, annual and low flows) based on their relationships to one of the three key flows.
8. Summarize the models by region in a format that can be applied by anyone desiring to estimate the flow regime at an ungaged site in any of these WRIAs:

WRIA No.	WRIA Name	Project Region
29	Wind-White Salmon	Wind-White Salmon
30	Klickitat	Klickitat
32	Walla Walla	Blue Mountains SW
35	Middle Snake	Blue Mountains NE
38	Naches	Naches-Yakima
39	Upper Yakima	Naches-Yakima
45	Wenatchee	Entiat-Wenatchee
46	Entiat	Entiat-Wenatchee
47	Chelan	Methow-Chelan
48	Methow	Methow-Chelan

The three key flows are all average flows of the type they represent. Floods are represented by Q1F2, the **key** one-day average daily **high flow** which, can be expected (statistically) to occur once every two years. **The key flow, QAA**, is the arithmetic mean of all the average daily flows including the daily and peak floods and low flows. The **key low flow, Q7L2**, is the legally required minimum fish passage flow for culverts.

The average annual flow (QAA) is THE KEY FLOW, because the other key flows (Q1F2 and Q7L2) are modeled by correlation with QAA. Because Q1F2 and Q7L2 are parts of QAA, the interrelationships of these three flows can be used to compare basins which have about the same QAAs, but having different Q1F2 and Q7L2 values, primarily due to geologic differences. Higher values of Q1F2 will be associated with lower values of Q7L2 and vice versa, unless the natural flow regime has been significantly altered by storage, land-use changes and/or diversions.

The three key flows were used individually to develop regional relationships (computerized, hydrologic relationships) between one of the key flows and other statistical flows of the same type. The preliminary list of models in Table 9 has been finalized in Table 20.

SUMMARY OF FINDINGS

Examples of the findings for this project were demonstrated with graphs and tables for the Methow-Chelan region (WRIA 47 and 48) under Procedures. The calibrated equations for all regions are listed in Table 21 except for the 216 monthly equations. The coefficients and exponents for the monthly flow

Table 20. Final General Sequence Models (Reduced from Table 9).

MODELS SPECIFIC TO EACH REGION ARE CALIBRATED WITH USGS STREAMFLOW RECORDS AND ARE LISTED IN **TABLE 21**.

A. Average Annual Flows and Flows Related to QAA (The Key Flow)

1. Average Annual Flows; Monthly Flows

1a. QAA = C (PA)	THE KEY FLOW
1b. QAA = C $(P)^n$ A	Used only in Methow-Chelan and Naches-Yakima Regions
1c. QAmax = C $(QAA)^E$	Extreme annual flow for POR
1d. QAmin = C $(QAA)^E$	Extreme annual flow for POR
1e. QM#(10-9) = C $(QAA)^E$	All QM#s are part of QAA; Max, Mean and Min flows for each month

Model #1e has 36 versions in each of 6 Regions for a total of 216.

2. Daily Flood Flow, Q1F2

2a. Q1F2 = C $(QAA)^E$	Key Flow for larger floods of longer RIs.

6. 7-Day Average FALL Low Flows

6a. Q7L2 = C $(QAA)^E$	Key flow for low flows of same and longer RIs.

B. Floods Related to Key Flow Q1F2 by Recurrence Interval (RI) Analysis

3. Other Daily Floods

	Statistical Flood Model (RI)
3a. Q1F25 = C $(Q1F2)^E$	
3b. Q1F100 = C $(Q1F2)^E$	

4. Peak Floods Related to Q1F2

4a. QPF2 = C $(Q1F2)^E$	
4b. QPF25 = C $(Q1F2)^E$	Related to Q10MS by Kresch (1999). Model #5 for crest stage gages not used.
4c. QPF100 = C $(Q1F2)^E$	

C. Low Flows Related to Key Flow Q7L2 by Recurrence Interval (RI) Analysis

7. Other FALL Low Flows

7a. Q7L10 = C $(Q7L2)^E$	Water Quality Index
7b. Q7L20 = C $(Q7L2)^E$	Q7L2/Q7L20 measure of low flow stability from year to year
7c. Q30L2 = C $(Q7L2)^E$	Extends Q7L to 1-month
7d. Q60L2 = C $(Q7L2)^E$	WDFW (1998) habitat flow.

Table 21. Final Equations for Models by Region

Note: Preliminary Model #5 in Table 9 for crest-stage gages was not used.

	MODELS	REGIONS: METHOW-CHELAN WRIA 48 & 47	ENTIAT-WENATCHEE WRIA 46 & 45	NACHES-YAKIMA WRIA 38 & 39	BLUE MOUNTAINS WRIA 35	BLUE MOUNTAINS WRIA 32	KLICKIAT WRIA 30	WIND-WHITE SALMON WRIA 29
1a. & b.	Average Annual Flow, QAA =	$0.0011(P)^{1.89}$ A	$0.024(PA)^{1.04}$	$0.000017(P)^{2.77}$ A	$0.062(PA)^{0.88}$	$0.062(PA)^{0.88}$	$0.014(PA)^{1.10}$	$0.035(PA)^{1.03}$
1c.	Max Annual Flow, QAmax =	$2.02(QAA)^{0.97}$	$1.60(QAA)^{0.99}$	$2.14(QAA)^{0.98}$	$1.42(QAA)^{1.05}$	$1.42(QAA)^{1.05}$	$2.67(QAA)^{0.93}$	$0.74(QAA)^{1.10}$
1d.	Min Annual Flow, QAmin =	$0.44(QAA)^{1.00}$	$0.43(QAA)^{1.03}$	$0.26(QAA)^{1.03}$	$1.03(QAA)^{0.84}$	$1.03(QAA)^{0.84}$	$0.43(QAA)^{1.01}$	$1.61(QAA)^{0.86}$
1e.	Note: Monthly Flows Require 216 Equations; see Appendix G for Coefficients and Exponents: QM# = C $(QAA)^{E}$							
2	Daily Flood Flows, Q1F2 =	$13.21(QAA)^{0.90}$	$7.55(QAA)^{0.97}$	$7.92(QAA)^{0.94}$	$1.69(QAA)^{1.21}$	$18.81(QAA)^{0.86}$	$14.87(QAA)^{0.81}$	$24.70(QAA)^{.75}$
3a.	Daily Flood Flow, Q1F25 =	$2.49(Q1F2)^{0.97}$	$3.07(Q1F2)^{0.94}$	$8.85(Q1F2)^{0.85}$	$18.85(Q1F2)^{0.79}$	$2.53(Q1F2)^{1.02}$	$9.85(Q1F2)^{0.83}$	$3.84(Q1F2)^{0.89}$
3b.	Daily Flood Flow, Q1F100 =	$3.82(Q1F2)^{0.94}$	$4.40(Q1F2)^{0.92}$	$20.39(Q1F2)^{0.79}$	$91.80(Q1F2)^{0.65}$	$3.72(Q1F2)^{1.01}$	$13.15(Q1F2)^{0.91}$	$5.99(Q1F2)^{0.85}$
4a.	Peak Flow, QPF2 =	$1.14(Q1F2)^{0.99}$	$1.15(Q1F2)^{0.99}$	$1.03(Q1F2)^{1.01}$	$2.05(Q1F2)^{0.95}$	$2.05(Q1F2)^{0.95}$	$1.31(Q1F2)^{0.89}$	$2.01(Q1F2)^{0.94}$
4b.	Peak Flow, QPF25 =	$6.72(Q1F2)^{0.87}$	$4.15(Q1F2)^{0.91}$	$8.74(Q1F2)^{0.84}$	$17.93(Q1F2)^{0.82}$	$17.93(Q1F2)^{0.82}$	$13.85(Q1F2)^{0.82}$	$4.63(Q1F2)^{0.91}$
4c.	Peak Flow, QPF100 =	$12.61(Q1F2)^{0.82}$	$6.49(Q1F2)^{0.89}$	$8.96(Q1F2)^{0.87}$	$10.38(Q1F2)^{0.95}$	$10.38(Q1F2)^{0.95}$	$26.47(Q1F2)^{0.78}$	$6.46(Q1F2)^{0.89}$
6	Low Flow, Q7L2 =	$0.15(QAA)^{1.04}$	$0.16(QAA)^{1.03}$	$0.63(QAA)^{0.72}$	$0.32(QAA)^{1.00}$	$0.32(QAA)^{1.00}$	$0.015(QAA)^{1.48}$	$0.80(QAA)^{0.93}$
7a.	Low Flow, Q7L10 =	$0.66(Q7L2)^{1.00}$	$0.75(Q7L2)^{1.01}$	$0.58(Q7L2)^{1.06}$	$0.55(Q7L2)^{1.10}$	$0.55(Q7L2)^{1.10}$	$0.51(Q7L2)^{1.08}$	$0.89(Q7L2)^{1.00}$
7b.	Low Flow, Q7L20 =	$0.56(Q7L2)^{1.00}$	$0.70(Q7L2)^{1.00}$	$0.42(Q7L2)^{1.11}$	$0.53(Q7L2)^{1.08}$	$0.53(Q7L2)^{1.08}$	$0.42(Q7L2)^{1.09}$	$1.01(Q7L2)^{0.95}$
7c.	Low Flow, Q30L2 =	$1.15(Q7L2)^{1.00}$	$1.14(Q7L2)^{1.00}$	$0.99(Q7L2)^{1.06}$	$1.21(Q7L2)^{0.97}$	$1.21(Q7L2)^{0.97}$	$1.11(Q7L2)^{0.99}$	$1.27(Q7L2)^{0.97}$
7d.	Low Flow, Q60L2 =	$1.19(Q7L2)^{1.01}$	$1.23(Q7L2)^{1.02}$	$1.12(Q7L2)^{1.06}$	$1.44(Q7L2)^{0.94}$	$1.44(Q7L2)^{0.94}$	$1.36(Q7L2)^{0.96}$	$1.71(Q7L2)^{0.92}$

equations (Model #1e in Table 20) are in Appendix G. Examples of data, graphs and tables that lead to the equations in Table 21 are in the appendices. To apply these models, all that one has to do is:

1. Locate the project site and its WRIA # on a map;
2. Determine the area (A) of the basin above the site and the average annual precipitation (P) on the basin;
3. Enter the WRIA, A and P in the designated places on the computer screen (driven by the Appendix J program on CD-ROM) and 50 flows will appear on the screen based on the equations for that WRIA/Region.

Alternatively, one can develop the information in the first two steps and, using the models in Table 21, calculate any of the flows for the site. A complete computerized example for one of the WSU gaging sites (Little Bridge Creek in the Methow basin, WRIA 48) is in Table 22.

In the WDFW (1998) manual a method is provided to estimate potential summer habitat using the "60-Day Low Flow Methodology". In that study the State was divided into four large regions and Q60L2 was plotted against drainage area. The R^2 values for these equations were: Olympic/Coastal, $R^2 = 0.36$; Cascade/East Puget Sound, $R^2 = 0.28$; Columbia/Eastern Washington, $R^2 = 0.22$; and Northern/NE Mountains, $R^2 = 0.22$. By comparison, the R^2 values for all the regions used in our project were either 0.99 or 1.00, using Model #7d: $Q60L2 = C(Q7L2)^E$ as solved in Appendix I.

Table 22. Example Solution for Flow Regime Estimate at WSU Site #7, Methow-Chelan Region; Culvert Design Flows for Fish Passage and Structural Safety

REGION	WRIA	BASIN PARAMETERS	
		Precipitation	Basin Area
METHOW-CHELAN	48	P (in/yr)	A (sq mi)
Stream Name	Site No.		
Little Bridge Creek	WSU 7	30.2	24.3

		Equation	C	E	FLOWS (cfs)	SE (%)
1	Average Annual Flow, QAA =	$0.0011(P)^{1.89}$ A	0.0011	1.89	16.8	*37%*
1c.	Max Annual Flow, QAmax =	$2.02(QAA)^{0.97}$	2.02	0.97	31.1	*14%*
1d.	Min Annual Flow, QAmin =	$0.44(QAA)^{1.00}$	0.44	1.00	7.4	*23%*
2	Daily Flood Flows, Q1F2 =	$13.21(QAA)^{0.90}$	13.21	0.90	167.0	*16%*
3a.	Daily Flood Flow, Q1F25 =	$2.49(Q1F2)^{0.97}$	2.49	0.97	356.6	*5%*
3b.	Daily Flood Flow, Q1F100 =	$3.82(Q1F2)^{0.94}$	3.82	0.94	469.2	*6%*
4a.	Peak Flow, QPF2 =	$1.14(Q1F2)^{0.99}$	1.14	0.99	180.9	*5%*
4b.	Peak Flow, QPF25 =	$6.72(Q1F2)^{0.87}$	6.72	0.87	576.9	*13%*
4c.	Peak Flow, QPF100 =	$12.61(Q1F2)^{0.82}$	12.61	0.82	838.2	*16%*
6a.	Low Flow, Q7L2 =	$0.153(QAA)^{1.04}$	0.153	1.04	2.9	*22%*
7a.	Low Flow, Q7L10 =	$0.66(Q7L2)^{1.00}$	0.66	1.00	1.9	*7%*
7b.	Low Flow, Q7L20 =	$0.56(Q7L2)^{1.00}$	0.56	1.00	1.6	*15%*
	Low Flow Ratio Q7L2/Q7L20 =				*1.8*	
7c.	Low Flow, Q30L2 =	$1.15(Q7L2)^{1.00}$	1.15	1.00	3.3	*4%*
7d.	Low Flow, Q60L2 =	$1.19(Q7L2)^{1.01}$	1.19	1.01	3.5	*8%*

MONTHLY AVERAGE FLOWS: MODEL #1e.

	MONTH	C	E	FLOWS (cfs)	SE (%)
QM Max	Oct	0.40	1.13	9.8	*14%*
	Nov	0.38	1.15	9.9	*45%*
	Dec	0.26	1.18	7.4	*36%*
	Jan	0.29	1.12	6.8	*31%*
	Feb	0.15	1.21	4.6	*33%*
	Mar	0.23	1.21	7.0	*47%*
	Apr	0.75	1.21	22.8	*44%*
	May	12.72	0.88	150.5	*27%*
	Jun	16.28	0.88	192.7	*22%*
	Jul	2.20	1.06	44.0	*20%*
	Aug	0.70	1.09	15.0	*31%*
	Sep	0.88	0.98	13.8	*26%*
QM Mean	Oct	0.25	1.05	4.8	*22%*
	Nov	0.20	1.09	4.4	*25%*
	Dec	0.17	1.09	3.7	*25%*
	Jan	0.17	1.05	3.3	*25%*
	Feb	0.16	1.06	3.2	*28%*
	Mar	0.15	1.11	3.4	*32%*
	Apr	0.40	1.13	9.8	*15%*
	May	3.34	0.97	51.2	*19%*
	Jun	2.98	1.01	51.1	*28%*
	Jul	0.70	1.10	15.6	*38%*
	Aug	0.38	1.06	7.4	*35%*
	Sep	0.30	1.01	5.1	*34%*
QM Minimum	Oct	0.14	1.02	2.5	*29%*
	Nov	0.13	1.01	2.3	*32%*
	Dec	0.12	1.01	2.1	*35%*
	Jan	0.11	0.99	1.8	*46%*
	Feb	0.13	0.98	2.1	*41%*
	Mar	0.12	1.02	2.0	*37%*
	Apr	0.17	1.04	3.2	*44%*
	May	0.68	1.06	13.7	*23%*
	Jun	0.52	1.09	11.4	*53%*
	Jul	0.25	1.08	5.1	*59%*
	Aug	0.16	1.06	3.2	*57%*
	Sep	0.12	1.06	2.4	*47%*

CONCLUSIONS

The objective of providing improved hydrologic models for estimating culvert fish passage and safety design flows has been attained in both parts of this project. The WSU part reduced the standard error of estimate (SE%) for the high migration season flow compared with Kresch (1999). Our part reduced the SE% of floods when compared with Sumioka et al (1998). There were no current literature models of eastern Washington to compare with our Q7L2 models. But a major improvement was made in the current WDFW model used to estimate Q60L2, the "habitat flow" (WDFW 1998).

The ranges of standard errors (SE%) of our models for each type of flow are: peak floods, 4 – 29% (Sumioka et al 1998, 52 - 128%); daily floods, 2 – 37%; average annual flow, 10 – 37%; maximum annual flow, 6 – 14%; minimum annual flow, 13 – 23%; low flows, 3 – 22%; and monthly flows, 3 - 242%, in February and August due to winter freezing and summer irrigation withdrawals.

In some regions the low flow data is distorted by irrigation diversions which are usually not quantifiable. Under these conditions any low flow model based on regional USGS records would tend to underestimate the natural Q7L2 (WAC fish passage low flow). But, the probability of Q7L2 occurring just when fish are migrating is very low because Q7L2 is an average flow condition.

In WAC-220-110 paragraph (A) it states: "The low flow design …is the two-year, seven-day low flow …**or (the) ninety-five percent exceedence flow for migration months** of the fish species of concern." For most streams, Q7L2 is about the 95% exceedence flow for the annual (12-month) duration curve, not for a 3-month migration season duration curve. The 95% exceedence flow for a migration season of May-July would be quite a bit higher than the annual Q7L2. If the migration season was August through October, then the annual Q7L2 would be larger than 95% exceedence flow for those three low-flow months.

We have developed equations for estimating the annual Q7L2 based on average annual minimum flow events which occur in the summer-fall (August – October) migration season. In reality, in many areas in the State, there are fish migrating during almost any month of the year. Use of any low flow, other than the annual summer-fall Q7L2, would have to be examined on a season by season, species by species basis. Use of the fall Q7L2 as estimated in this study would mean that the 7-day average low flow, on the average, would be less than Q7L2 only for about 18 days out of the nominal 3-month migration season of August through October.

RECOMMENDATIONS

Based on the significant improvements in the standard errors of estimate for culvert design flow models associated with fish passage and safety for eastern Washington streams, it is recommended that:

1. these same types of equations should be recalibrated for other WRIAs in the State with salmonid-bearing streams;
2. the hydrologic modeling described in this report would be of great assistance to the Watershed Planning Units operating in most of the WRIAs in the State; and
3. the results of the expensive, but limited, stream-gaging programs underway in the WRIAs would be greatly enhanced by the use of these much-less expensive hydrologic modeling methods; and
4. also, the solutions to water resources planning problems in the WRIAs would be improved with these types of hydrologic models which can produce 50 flows that describe the stream regime at any point on a stream in a matter of seconds; applications include water rights, diversion impacts, hydraulic connectivity, regulation effects on natural flows and instream flow needs assessment.

ACKNOWLEDGEMENT

Funding for this project was provided by the Washington State Department of Transportation. The United States Geological Survey assisted by furnishing the data. We appreciate the guidance provided by Pat Powers of the Washington Department of Fish and Wildlife. Coordination of this project with WSU was managed by Rollin H. Hotchkiss, Director of the Albrook Hydraulics Laboratory. Information about the WSU project was provided by Erik Rowland and Eric Nordstrum.

REFERENCES

Amerman, K.S. and J. F. Orsborn, 1987. "An analysis of streamflows on the Olympic Peninsula in Washington State," Dept. of Civil and Environmental Engineering, Washington State University, Pullman, WA, (Two Volumes).

Bodhaine, G. L. and D. M. Thomas, 1960. "Floods in Washington, magnitude and frequency," U. S. Geological Survey Open-File Report, Tacoma, WA.

Bodhaine, G. L. and D. M. Thomas, 1964. "Magnitude and frequency of floods in the United States, part 12, Pacific Slope basins in Washington and upper Columbia River basin," Geological Survey Water-Supply Paper, 1687.

Cummans, J. E., M. R. Collings and E. G. Nassar, 1975. "Magnitude and frequency of floods in Washington," U. S. Geological Survey Open-file Report 74-336.

Dinicola, R. S. 1990. "Characterization and simulation of rainfall-runoff relations for headwater basins in western King and Snohomish Counties, Washington," USGS Water Resources Investigations Report 89-4052, Tacoma, WA.

Hardison, C. H. and M. E. Moss, 1972. "Accuracy of low-flow characteristics estimated by correlation of base-flow measurements," USGS Manual of Hydrology, Part 2, Low-Flow Techniques, WSP 1542-B, Washington, DC.

Haushild, W. L., 1974. "Estimation of floods of various frequencies for the small ephemeral streams in Eastern Washington," USGS Open-file Report 79-81, Tacoma, WA.

Kresch, D. L., 1999. "Equations for estimating fish passage design flows at ungaged streams in eastern Washington," USGS Water Resources Investigations Report 99-4186 in cooperation with WDNR, Tacoma, WA.

Moss, M. E. and W. L Haushild, 1978. "Evaluation and design of a streamflow data network in Washington," USGS Open-file Report 78-167, Tacoma, WA.

Orsborn, J. F., 1964. "Drainage basin influences on hydrologic parameters," Ph.D. Dissertation, Department of Civil Engineering, University of Wisconsin, Madison, WI.

Orsborn, J. F., 1966. "The distribution of precipitation, runoff and floods in the State of Washington," Pacific NW Scientific Association Meeting, April, Portland, OR.

Orsborn, J. F. and M. N. Sood, 1973. "Hydrographic atlas and technical supplement -- Okanogan- Methow River Basin Study Area -- State Water Program," for the Washington Department of Ecology, Department of Civil and Environmental Engineering, Washington State University, Pullman, WA.

Orsborn, J. F. and M. N. Sood, 1975. "Hydrographic atlas and technical supplement -- Spokane River Basin Study Area -- State Water Program," for the Washington Department of Ecology, Department of Civil and Environmental Engineering, Washington State University, Pullman, WA.

Orsborn, J. F. and M. Th. Arce, 1975. "Relationships of low, average, and flood flows in the Pacific Northwest," OWRT Allotment Project A-WASH, State of Washington Water Research Center, Pullman, WA.

Orsborn, J. F., 1976. "Drainage basin characteristics applied to hydraulic design and water-resources management," Proceedings of the Geomorphology and Engineering Symposium, Sept. 24-25, SUNY at Binghamton, NY.

Orsborn, J. F., 1978. "Determining design flows for culverts and bridges on ungauged streams," Transportation Research Record 685, NRC, NAS, Washington, D. C.

Orsborn, J. F., 1980a. "Summary notes on the hydrology of Alaska," Course on Hydraulics and Hydrology for Fishery Biologists for the USFWS and ADF&G, Anchorage, AK.

Orsborn, J. F., 1980b. "Estimating streamflow characteristics at spawning sites in Oregon," USEPA, Environmental Research Laboratory, Corvallis, OR.

Orsborn, J. F., 1981. "SIUSLOGIC - notes on the development of new methods for hydrologic analysis on the Siuslaw National Forest in the mid-coast of Oregon," Corvallis, OR.

Orsborn, J. F., 1983. "A regional hydrologic model for southeast Alaska," American Fisheries Society, Alaska Chapter Meeting, November 14-17, Soldatna, AK.

Orsborn, J. F., 1990. "Quantitative modeling of the relationships among basin, channel and habitat characteristics for classification and impact assessment," Program Report TFW - AM3 - 90 – 010, Two Vols., Text and Appendices I-IX, Department of Civil and Environmental Engineering, Washington State University, Pullman, WA.

Orsborn, J. F. and M. C. Storm, 1991. "R-10 Flowmod: hydrologic models of southeast and south-central Alaska," For the USDA Forest Service, Region 10, Juneau, AK.

Orsborn, J. F. and M. T. Orsborn, 1997. "An operational hydrologic system for the Colville Indian Reservation," Colville Confederated Tribes, Nespelem, WA.

Orsborn, J. F. and M. T. Orsborn, 2000. "Streamflow characteristics of the Big and Little Quilcene Rivers," Prepared for the City of Port Townsend, WA.

Orsborn, J. F., A. W. Johnson and M. T. Orsborn, 2001. "The integration of basin streamflow and channel characteristics for channel condition analyses," EPA Region 10, Seattle, WA.

Powers, P. D. and J. F. Orsborn, 1985. "Analysis of barriers to upstream fish migration- -an investigation of the physical and biological conditions affecting fish passage success at culverts and waterfalls," Part 4 of four final projects reports for the development of new concepts in fish ladder design (BPA Project 82-14, August, 1985. (Note: Dated 1984 on cover).

Powers, P. D. and C. S. Sanders, 1998. "Fish passage design flows for ungaged catchments in Washington," Washington State Department of Fish and Wildlife in cooperation with the Washington State Department of Transportation.

Riggs, H. C., 1968a. "Low-flow investigations," USGS Techniques of Water-Resources Investigations, Washington, DC.

Riggs, H. C., 1968b. "Techniques of water-resources investigations of the United States Geological Survey, Chapter A 1, Some statistical tools in hydrology," Book 4., Washington, DC.

Riggs, H. C., 1973. "Regional analysis of streamflow characteristics," USGS Techniques of Water-Resources Investigations, Book 4, Chapter B3, Washington, DC.

Rowland, E. R., 2001. "Predicting fish passage design flows at ungaged streams in Washington," MS Thesis, Department of Civil and Environmental Engineering, Washington State University, Pullman, WA.

Rowland, E. R., R. H. Hotchkiss and M. E. Barber, 2002. "Modeling hydrology for design of fish passage," WSDOT Research Report, Department of Civil and Environmental Engineering, Washington State University, Pullman, WA.

Searcy, J. K., 1960. "Graphical correlation of gaging-station records," USGS Manual of Hydrology: Part 1. General Surface-Water Techniques," WSP. 1541-C, GPO, Washington, DC.

State of Washington, 2000. Revised Code Titles 75 and 77, Current. Administrative Code: Hydraulic Code Rules - WAC-220-110, Parts 3A and 3B. "Fisheries flows for permanent culvert installation," Olympia, WA.

Sumioka, S. S., D. L. Kresch and K. D. Kasnick, 1998. "Magnitude and frequency of floods in Washington," USGS Water Resources Investigations Report 97-4277, Tacoma, WA.

Thomas, D. M. and M. A. Benson, 1970. "Generalization of streamflow characteristics from drainage-basin characteristics," USGS Water-Supply Paper 1975, GPO, Washington, DC.

U. S. Geological Survey, 1967. "Extending streamflow records in time," Hydrologic Analysis and Interpretation, Book 4, Section B, Washington, DC.

U. S. Geological Survey, 1999. "Water-resources data for Washington," Tacoma, WA.

U. S. Geological Survey, 1997. "Water resources applications software for Internet users," Tacoma, WA.

U. S. Weather Bureau, 1965. "State of Washington, mean annual precipitation map, 1930-1957," Portland, OR, Soil Conservation Service, map M-4430, 1 sheet, (no scale). (See Plate 1 in Sumioka, et al, 1998, for enlarged version).

Washington Department of Fish and Wildlife (WDFW), 1998. "Fish passage barrier assessment and prioritization manual," Habitat and Land Services Program, Olympia, WA.

Washington Department of Fish and Wildlife (WDFW), 1999. "Fish passage design at road culverts,; a design manual for fish passage at road crossings," Habitat and Land Services Program, Olympia, WA. <http://www.wa.gov/wdfw/hab/engineer/om/toc.htm>

Williams, J. R. and H. E. Pearson, 1985a. "Streamflow statistics and drainage-basin characteristics for the southwestern and eastern regions, Washington," Volume I, Southwestern Washington: U. S. Geological Survey Open-File Report 84-145-A.

Williams, J. R. and H. E. Pearson, 1985b. "Streamflow statistics and drainage basin characteristics for the southwestern and eastern regions, Washington," Volume II, Eastern Washington, US Geological Survey Open-file Report 84-145-B, Tacoma, WA.

APPENDIX A. DATABASE INFORMATION ON USGS GAGING STATIONS; EXTREME FLOWS, PERIODS OF RECORD, REGULATION, DIVERSIONS AND QUALITY OF RECORDS

APPENDIX A.

DATABASE INFORMATION ON USGS GAGING STATIONS; EXTREME FLOWS, PERIODS OF RECORD, REGULATION, DIVERSIONS AND QUALITY OF RECORDS

NOTES:

1) Before setting up the database of statistical streamflows and basin characteristics, it was essential to check on the relative influences of regulation (storage), diversions and the USGS accuracy rating of their flow measurements.

2) The quality scale of their records is described in the USGS annual data books (U.S. Geological Survey, 1999). Also included in these annual books are notes on basin area, extreme flows of record and (usually) unquantified effects of regulation and diversion.

3) This lack of information on diversions leads to a serious problem when trying to quantify natural low flows between July and November. **Until water right uses are quantified by both rate and time to determine volume, the true natural low flows cannot be accurately assessed.**

USGS Notes for Table A-1:

NR =	No Regulation	FU =	Freeze Up	
R =	Regulation	E =	Excellent	± 5%
		G =	Good	± 10%
ND =	No Diversion	F =	Fair	± 15%
D =	Diversion	P =	Poor	> ± 15%
MD =	Many Diversions	PW =	Poor in Winter	
MSD =	Many Small Diversions	AC =	Acres	
SD =	Several Diversions	BOR =	Bureau of Reclamation	

Table A-1. Extreme Flows for Periods of Record, Regulation, Diversions and Record Quality for USGS Gaging Stations
Notes on page A-2.
Map site numbers on Plate 1 in Williams and Pearson, 1985a and 1985b.

REGION	USGS Map Site No.	USGS Gage No.	Stream Name	Ab Basin Area (sq. mi.)	Date of Peak Flow	Peak Flow (cfs)	Regulation Notes	Date of Minimum Flow	Minimum Flow (cfs)	Diversion Notes	Record Quality
METHOW-CHELAN	85	12442000	Toats Coulee Cr.	130	5/28/1948	6010	NR	11/2/1961	1.0 FU	ND	F, P
	103	12447390	Andrews Cr.	22	6/10/1972	1120	NR	11/4/1968	1.2	ND	P
	109	12449500	Methow R.	1301	5/29/1948	40800	NR	9/4/1926	134	D	G, F
	110	12449600	Beaver Cr.	62	5/29/1972	535	NR	11/13/1968	0.75	ND	G, PW
	115	12449950	Methow R.	1772	5/29/1948	46700	NR	1/8/1974	150 FU	11,000 AC. BOR	G, F
	118	12451000	Stehekin R.	321	11/29/1995	20900	NR	1/12/1930	56	ND	F
	119	12451500	Railroad Cr.	65	5/28/1948	3900	NR	1/15/1930	9 FU	ND	G, P
ENTIAT-WENATCHEE	124	12452800	Entiat R.	203	6/10/1972	6430	NR	11/25/1993	20	ND	G, F
	126	12453000	Entiat R.	419	5/28/1948	10800	R- Mill Pond	1/26/1956	29 FU	D; 2500 Ac.	G, F
	129	12454000	White R.	150	12/26/1980	19100	NR	11/27/1979	47 FU	ND	G
	134	12456500	Chiwawa R.	172	11/30/1995	7030	NR	3/2/1993	45	ND	G, F
	138	12458000	Icicle Cr.	193	11/29/1995	19800	Reg. Due to natural Lakes?	11/30/1936	44	ND	F
	145	12461400	Mission Cr.	40	1/16/1974	2090	NR	9/9/1996	0.9	ND	G, PW
	197 [2]	12483800	Naneum	70	6/9/1964	968	NR	8/12/1977	3.8	MSD	G, PW

Table A-1. Extreme Flows for Periods of Record, Regulation, Diversions and Record Quality for USGS Gaging Stations (continued)

REGION	USGS Map Site No.	USGS Gage No.	Stream Name	Ab Basin Area (sq. mi.)	Date of Peak Flow	Peak Flow (cfs)	Regulation Notes	Date of Minimum Flow	Minimum Flow (cfs)	Diversion Notes	Record Quality
NACHES-YAKIMA	197 [2]	12483800	Naneum	70	6/9/1964	968	NR	8/17/1977	3.8	MSD	G, P
	206	12488500	American	79	12/26/1980	4230	NR	11/22/1940	20	ND	G, F
	210	12492500	Tieton	239	12/22/1933	8910	R, Rimrock Lake	Many Times	0	Tieton Canal	Not Available
	211	12494000	Naches	941	12/22/1933	32200	R, Bumping Lake	11/7/1942 Many Days	1	MSD	G, P
	215	12500500	NF Ahtanum	69	1/15/1974	1580	NR	11/21/1977	3.0 FU	MD	G, FW
	216	12501000	SF Ahtanum	25	1/15/1974	1230	NR	11/21/1977	2.0 FU	MD, 55 Ac.	F
	219	12502500	Ahtanum	173	1/16/1974	3100	NR	9/1904	0	D, 9000 Ac.	G
	222	12506000	Toppenish	122	5/4/1916	1650	NR	8/25/1922	2.6	D, but flow corrected	G
	223	12506500	Simcoe	82	2/10/1916	731	NR	9/30/1923	0	D, but flow corrected	P

Table A-1. Extreme Flows for Periods of Record, Regulation, Diversions and Record Quality for USGS Gaging Stations (continued)

REGION	USGS Map Site No.	USGS Gage No.	Stream Name	Ab Basin Area (sq. mi.)	Date of Peak Flow	Peak Flow (cfs)	Regulation Notes	Date of Minimum Flow	Minimum Flow (cfs)	Diversion Notes	Record Quality
BLUE MOUNTAINS	246	13334500	Asotin Cr.	156	4/15/1904	1180	NR	1/5/1937	16 FU	SD	F, P
	247	13334700	Asotin Cr.	170	12/23/1964	2720	NR	1/11/1963	13 FU	D, 30 cfs Municipal Clarkston	F, P
	258	13343800	Meadow Cr.	66	9/13/1966	2380	NR	9/1/1967	0	MSD	G
	260	13344500	Tucannon R.	431	12/22/1964	7980	NR	7/12/1930	15	MSD	G
	288	14013000	Mill Cr.	60	12/23/1964	3420	NR	10/11/1939	16	D, Walla Walla Munic. 22 cfs	G
	289	14013500	Blue Cr.	17	12/28/1945	725	NR	10/1/39	0	ND	F
	294	14016000	Dry Cr.	48	2/22/1949	3340	NR	8/13/1981	0	D	G
	295	14016500	E.F. Touchet R.	102	12/23/1964	5450	NR	1/9/1960	16 FU	MSD	G
	298	14017000	Touchet R.	361	12/23/1964	9350	Reg. Flourmill	7/30/1926	1.4	MSD	F, P.
	301	14017500	Touchet R.	733	2/10/1949	13300	R, Unknown Source	9/11/1951	6	MD, 3500 Ac.	F, P
	302	14018500	Walla Walla R.	1657	12/22/1964	33400	NR	8/1968	0	MSD	F

Table A-1. Extreme Flows for Periods of Record, Regulation, Diversions and Record Quality for USGS Gaging Stations (continued)

REGION	USGS Map Site No.	USGS Gage No.	Stream Name	Ab Basin Area (sq. mi.)	Date of Peak Flow	Peak Flow (cfs)	Regulation Notes	Date of Minimum Flow	Minimum Flow (cfs)	Diversion Notes	Record Quality
KLICKITAT	222 [2]	12506000	Toppenish Cr.	122	5/4/1916	1650	NR	8/25/1922	2.6	D, but flow corrected	G
	223 [2]	12506500	Simcoe Cr.	82	2/10/1916	731	NR	9/30/1923	0	D, but flow corrected	P
	314	14107000	Klickitat R.	151	5/27/1948	3280	NR	2/1/1957	4.4 FU	ND	G
	317	14110000	Klickitat R.	360	12/22/1933	9870	NR		204	D, Hell Cr. 7000 Ac.	E
	321	14112000	L. Klickitat R.	84	12/24/1964	1760	NR	8/1967	0	D, 35 Ac.	E
	326	14113000	Klickitat R.	1297	2/8/1996	51000	NR	1/16/1997	412	D, 7500 Ac.	E
WIND-WHITE SALMON	1	14121300	White Salmon R.	32	12/2/1977	1510	NR	3/24/1964	48	MSD	F
	2	14121400	White Salmon R.	65	12/23/1964	1080	NR	3/4/1966	98	ND	G
	3	14121500	Trout L. Cr.	69	12/23/1964	2900	NR	9/12/1963	26	ND	G
	8	14123000	White Salmon R.	294	12/22/1933	10800	NR	12/30/1930	340	D, 4500 Ac.	G
	9	14123500	White Salmon R.	386	1/15/1974	15300	R, Power PPL	1/17/1950	158, 0	D, 4500 Ac.	G
	10	14124500	L. Wh. Salmon R.	114	12/15/1946	4140	R, Log Pond	11/7/1957	1.5	MD, Hatchery, Irrigation, Water Supply	E
	16	14127000	Wind R.	108	2/8/1945	8880	NR, Fish Hatchery	10/27/1945	52	D, Returns above station	G

APPENDIX B. TESTS OF USGS STREAM GAGE RECORDS FOR REGIONAL HYDROLOGIC UNIFORMITY

APPENDIX B.

TESTS OF USGS STREAM GAGE RECORDS FOR REGIONAL HYDROLOGIC UNIFORMITY

NOTES

1. For common periods of record (POR) at a sample of USGS stream gages in each region, comparisons are made by calculating single-year ratio values (R1) of QA/QAA.
2. QA/QAA is the ratio of the average flow in each year divided by the average annual flow for a common POR at several gages in each region.
3. The results are shown in Tables and Figures B-1 through B-6.
4. Some of the graphs show a high degree of consistency among the R1 values (B-4, B-5 and B-6).
5. Some graphs show consistently higher or lower R1 values for one station in the region (Beaver Creek in B1; Mission Creek in B-2; and the Little Klickitat River in B-5); these gages were dropped from some of the models.
6. The Little Klickitat is located in lower lying and drier hills than the Klickitat River which has its headwaters on the southeast side of Mt. Adams.
7. The Blue Mountain gaging stations show only one erratic R1 for the E. F. Touchet in 1949 when its R1 value increased while those of the other gages decreased (Table and Figure B-4).
8. Graph B-6 shows a very consistent and low range of R1 values indicating a stable and uniform hydrologic region from year to year for the Wind-White Salmon Region.

Table B-1.
Annual Flow Ratios from 1961 to 1978 Common POR for Sample of the Methow-Chelan Region USGS Gages.

WY	Beaver Cr QA_wy 12449600	Methow R QA_wy 12449950	Stehekin R QA_wy 12451000	
1961	22.1	1685.8	1606.7	(cfs)
1962	10.1	1066.0	1279.5	(cfs)
1963	18.1	1544.0	1323.3	(cfs)
1964	11.6	1566.8	1527.5	(cfs)
1965	12.1	1336.3	1376.8	(cfs)
1966	10.1	1092.7	1199.5	(cfs)
1967	24.8	1938.5	1657.5	(cfs)
1968	14.9	1747.7	1737.5	(cfs)
1969	25.5	1647.7	1528.6	(cfs)
1970	12.2	1037.4	1106.8	(cfs)
1971	25.9	2053.6	1743.7	(cfs)
1972	46.1	2963.2	1952.9	(cfs)
1973	11.4	945.6	928.8	(cfs)
1974	46.4	2509.5	1926.3	(cfs)
1975	20.8	1566.7	1436.0	(cfs)
1976	21.0	2026.5	1835.9	(cfs)
1977	7.5	565.4	871.5	(cfs)
1978	28.8	1806.6	1492.1	(cfs)
QAA(61-78):	20.5	1616.7	1473.9	(cfs)
QAA(Long-term):	*20.5*	*1577.0*	*1412.9*	(cfs)
Count of WY's:	*18*	*41*	*77*	

WY	R1 Beaver 12449600	R1 Methow 12449950	R1 Stehekin 12451000
1961	1.077	1.043	1.090
1962	0.492	0.659	0.868
1963	0.882	0.955	0.898
1964	0.565	0.969	1.036
1965	0.590	0.827	0.934
1966	0.492	0.676	0.814
1967	1.208	1.199	1.125
1968	0.726	1.081	1.179
1969	1.243	1.019	1.037
1970	0.594	0.642	0.751
1971	1.262	1.270	1.183
1972	2.246	1.833	1.325
1973	0.555	0.585	0.630
1974	2.261	1.552	1.307
1975	1.014	0.969	0.974
1976	1.023	1.254	1.246
1977	0.365	0.350	0.591
1978	1.403	1.117	1.012
WRIA	48	48	47

Figure B-1. Graphs of Methow-Chelan R1 Values for Common POR 1961-78

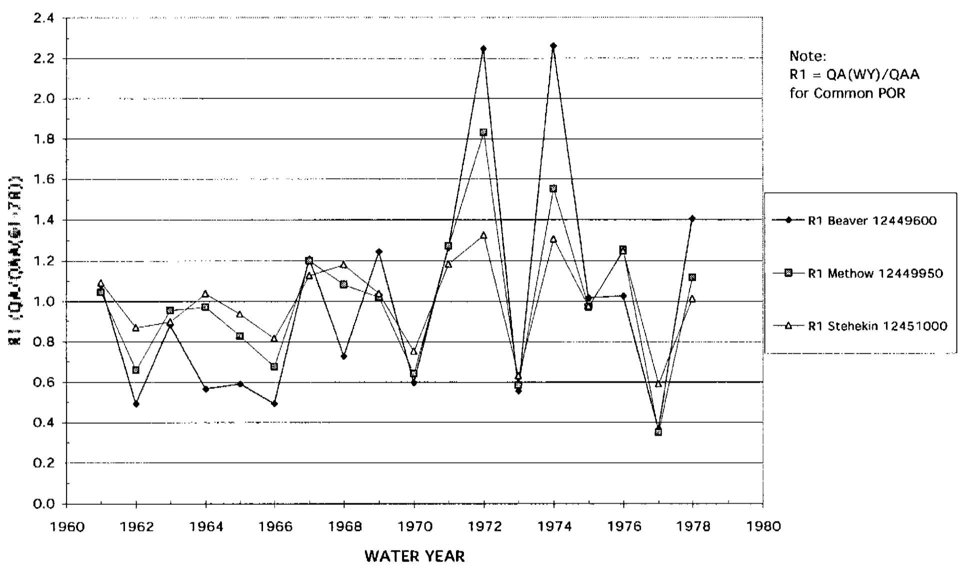


Table B-2.
Annual Flow Ratos from 1960 to 1971 Common POR for Sample of the Entiat-Wenatchee Region USGS Gages.

WY	Entiat QA_wy 12452800	White QA_wy 12454000	Icicle QA_wy 12458000	Mission QA_wy 12461400	Naneum [a] QA_wy 12483800	
QAA(60-71):	362.8	800.1	626.1	13.2	54.6	(cfs)
QAA(Long-term):	*382.6*	*815.8*	*628.6*	*13.2*	*54.3*	(cfs)
Count of WY's:	*43*	*29*	*42*	*12*	*21*	

WY	R1 Entiat 12452800	R1 White 12454000	R1 Icicle 12458000	R1 Mission 12461400	R1 Naneum 12483800
1960	1.201	1.095	1.139	1.440	1.217
1961	1.125	1.091	1.093	1.251	1.270
1962	0.744	0.847	0.931	0.773	0.932
1963	0.846	0.885	0.844	0.879	1.014
1964	0.951	1.059	1.007	0.644	0.829
1965	0.969	0.964	0.979	0.887	0.976
1966	0.793	0.842	0.806	0.652	0.652
1967	1.047	1.006	0.988	1.039	0.990
1968	1.158	1.150	1.154	1.061	0.956
1969	1.137	1.060	1.088	1.425	1.100
1970	0.715	0.828	0.814	0.796	0.807
1971	1.314	1.173	1.157	1.152	1.256
WRIA	46	45	45	45	39

Note: [a] Naneum in Upper Yakima WRIA 39

Figure B-2. Graphs of Entiat-Wenatchee Region R1 Values for Common POR 1960-71

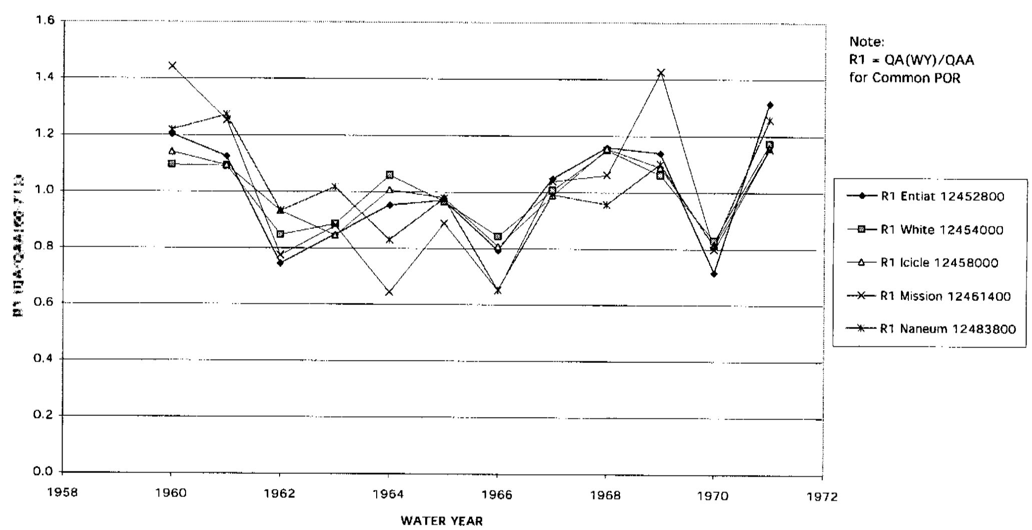


Table B-3.
Annual Flow Ratios from 1940 to 1978 Common POR for Sample of the Naches-Yakima Region USGS Gages.

WY	American QA_wy 12488500	Tieton QA_wy 12491500	Tieton QA_wy 12492500	Naches QA_wy 12494000	NF Ahtanum QA_wy 12500500	SF Ahtanum QA_wy 12501000	
QAA(40-78):	241.9	525.2	441.7	1164.1	71.0	20.6	(cfs)
QAA(Long-term):	*236.4*	*507.2*	*437.9*	*1260.3*	*70.3*	*20.3*	(cfs)
Count of WY's:	*61*	*58*	*63*	*66*	*52*	*47*	

WY	R1 American 12488500	R1 Tieton 12491500	R1 Tieton 12492500	R1 Naches 12494000	R1 NF Ahtanum 12500500	R1 SF Ahtanum 12501000
1940	0.839	0.725	0.594	0.498	0.673	0.617
1941	0.609	0.759	0.666	0.337	0.568	0.486
1942	0.728	0.592	0.438	0.384	0.725	0.733
1943	1.038	0.843	0.870	1.017	1.056	1.175
1944	0.522	0.789	0.654	0.293	0.396	0.403
1945	0.739	0.532	0.384	0.438	0.523	0.490
1946	1.092	0.932	0.926	0.936	0.796	0.767
1947	0.980	1.076	1.113	0.978	0.942	0.971
1948	1.177	1.149	1.222	1.240	1.319	1.384
1949	1.078	1.105	1.132	1.179	1.161	1.209
1950	1.261	1.314	1.415	1.471	1.196	1.151
1951	1.301	1.442	1.508	1.552	1.583	1.573
1952	0.853	0.962	0.928	0.720	0.917	0.864
1953	0.919	0.833	0.730	0.830	1.004	0.966
1954	1.236	1.075	1.053	1.204	1.159	1.093
1955	0.887	0.973	0.915	0.817	0.735	0.660
1956	1.547	1.520	1.738	1.957	1.796	1.806
1957	0.888	1.152	1.170	1.000	0.911	0.874
1958	0.935	0.933	0.907	0.860	1.118	1.175
1959	1.149	0.985	0.993	1.133	1.003	0.995
1960	0.982	1.223	1.226	1.063	0.821	0.816
1961	1.155	1.045	1.094	1.174	1.162	1.190
1962	0.814	0.715	0.656	0.658	0.842	0.791
1963	0.913	1.079	1.127	0.891	1.058	1.088
1964	0.933	0.692	0.620	0.748	0.697	0.665
1965	1.013	1.193	1.300	1.198	1.014	1.073
1966	0.778	0.731	0.680	0.639	0.773	0.723
1967	0.986	0.908	0.883	0.907	1.072	1.044
1968	1.045	0.978	0.981	0.988	0.955	0.913
1969	1.055	1.106	1.162	1.163	1.144	1.131
1970	0.912	0.882	0.824	0.834	0.890	0.879
1971	1.255	0.990	0.996	1.256	1.297	1.248
1972	1.396	1.521	1.768	1.986	1.619	1.699
1973	0.691	1.031	0.921	0.563	0.537	0.568
1974	1.566	1.173	1.325	1.712	1.792	1.971
1975	1.090	1.105	1.188	1.255	1.104	1.156
1976	1.227	1.398	1.525	1.675	1.134	1.185
1977	0.389	0.665	0.489	0.310	0.248	0.311
1978	1.022	0.876	0.881	1.136	1.257	1.156
WRIA	38	38	38	38	38	38

Figure B-3. Graphs of Naches-Yakima Region R1 Values for Common POR 1940-78

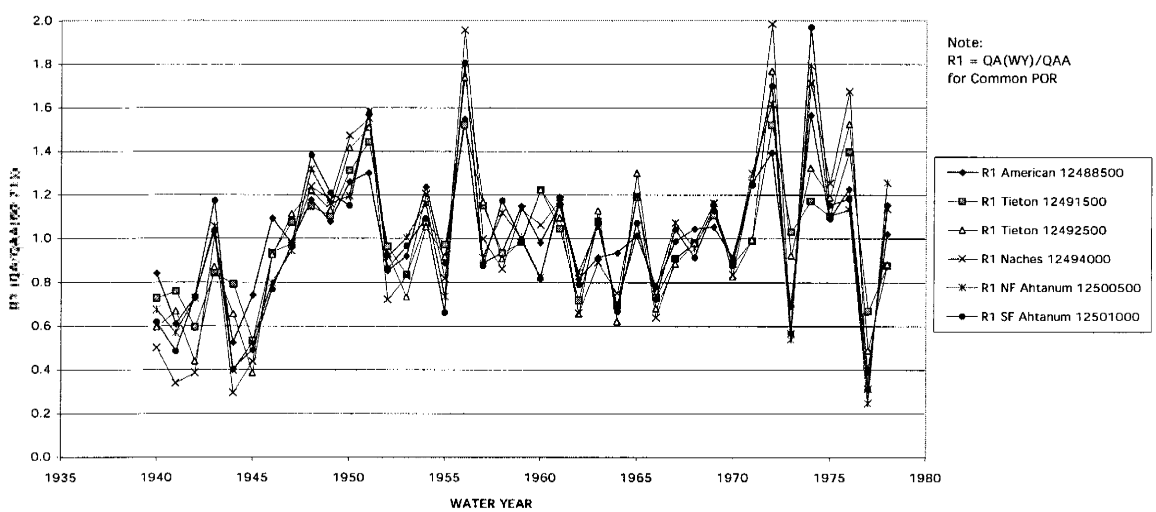


Table B-4.
Annual Flow Ratios from 1942 to 1951 Common POR for Sample of the Blue Mountain Region USGS Gages

	Asotin	Mill	Blue	EF Touchet	Touchet	
WY	QA_wy 13334500	QA_wy 14013000	QA_wy 14013500	QA_wy 14016500	QA_wy 14017500	
QAA(42-51):	73.8	104.4	17.2	124.5	254.9	(cfs)
QAA(Long-term):	*68.4*	*96.4*	*15.6*	*119.8*	*242.5*	(cfs)
Count of WY's:	*31*	*62*	*32*	*22*	*14*	

WY	R1 Asotin 13334500	R1 Mill 14013000	R1 Blue 14013500	R1 EF Touchet 14016500	R1 Touchet 14017500
1942	0.902	0.724	0.772	0.727	0.729
1943	1.126	1.027	1.179	1.086	0.909
1944	0.517	0.596	0.523	0.541	0.433
1945	0.629	0.795	0.610	0.664	0.583
1946	0.943	1.067	1.080	1.001	1.001
1947	0.981	1.007	0.935	0.903	0.911
1948	1.345	1.276	1.498	1.389	1.437
1949	1.107	1.102	1.086	1.128	1.526
1950	1.160	1.270	1.190	1.280	1.248
1951	1.291	1.137	1.127	1.282	1.224
WRIA	35	32	32	32	32

Figure B-4. Graphs of Blue Mountain Region R1 Values for Common POR 1942-51

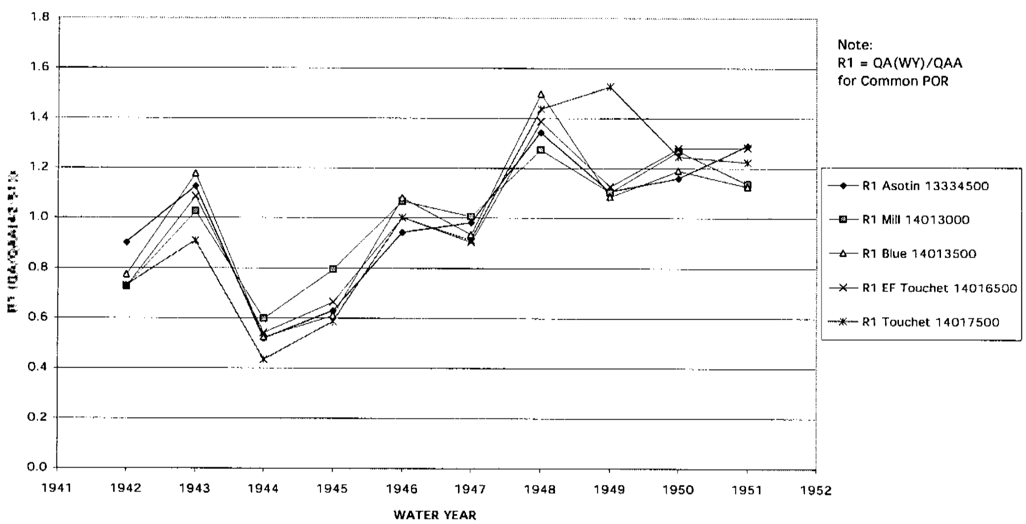


Table B-5.
Annual Flow Ratios from 1958 to 1970 Common POR for Sample of the Klickitat Region USGS Gages

	Klickitat	Klickitat	L. Klickitat	Klickitat	
WY	QA_wy 14107000	QA_wy 14110000	QA_wy 14112000	QA_wy 14113000	
QAA(58-70):	300.0	800.5	54.9	1561.2	(cfs)
QAA(Long-term):	*331.7*	*836.5*	*60.0*	*1599.9*	(cfs)
Count of WY's:	*42*	*60*	*19*	*74*	

WY	R1 Klickitat 14107000	R1 Klickitat 14110000	R1 L. Klickitat 14112000	R1 Klickitat 14113000
1958	0.986	1.051	1.266	1.119
1959	1.127	1.079	0.902	1.010
1960	1.044	1.034	0.609	0.921
1961	1.175	1.166	1.722	1.329
1962	0.953	0.886	0.845	0.865
1963	1.002	0.995	0.800	0.958
1964	0.855	0.831	0.691	0.776
1965	1.100	1.033	1.589	1.102
1966	0.780	0.818	0.858	0.873
1967	0.954	0.984	0.687	0.880
1968	0.942	0.995	0.793	0.932
1969	1.110	1.111	1.168	1.160
1970	0.972	1.017	1.071	1.077
WRIA	30	30	30	30

Figure B-5. Graphs of Klickitat Region R1 Values for Common POR 1958-70

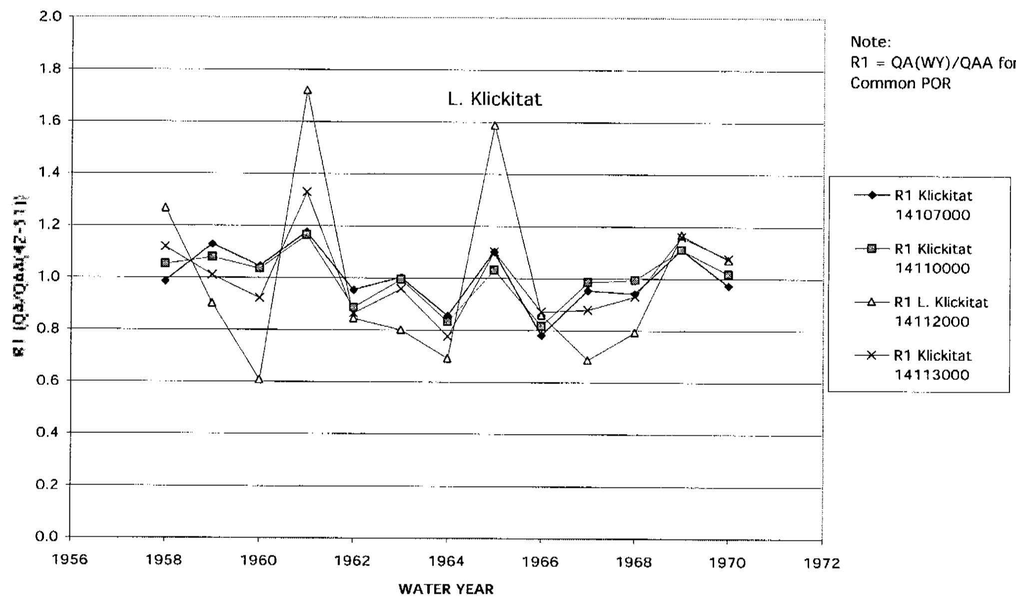
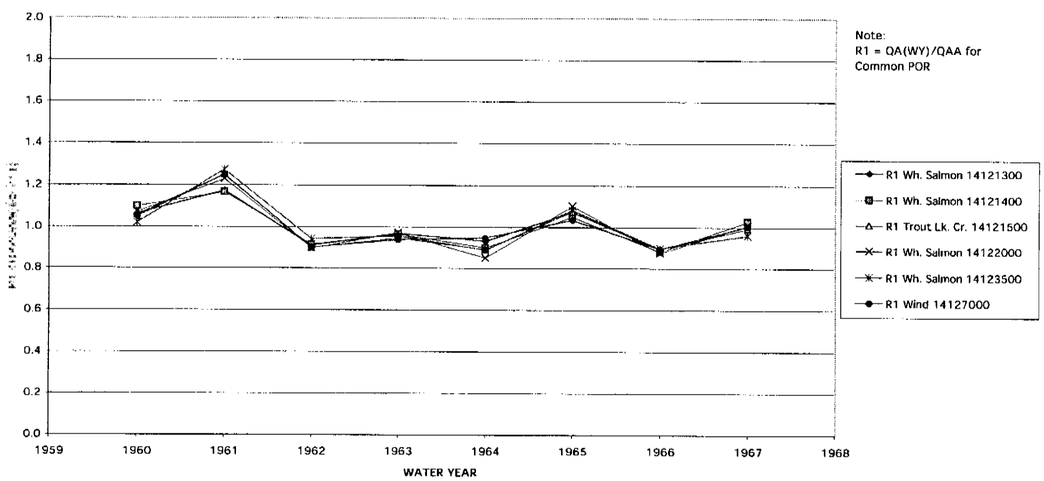


Table B-6.
Annual Flow Ratios from 1960 to 1967 Common POR for Sample of the Wind-White Salmon Region USGS Gages

	Wh. Salmon	Wh. Salmon	Trout Lk. Cr.	Wh. Salmon	Wh. Salmon	Wind	
WY	QA_wy 14121300	QA_wy 14121400	QA_wy 14121500	QA_wy 14122000	QA_wy 14123500	QA_wy 14127000	
1960	152.6	258.3	266.0	443.0	1133.6	576.2	(cfs)
1961	168.8	274.2	314.0	508.1	1414.4	683.9	(cfs)
1962	131.0	215.6	226.6	371.4	1047.4	494.0	(cfs)
1963	139.3	227.4	238.0	401.6	1064.1	515.1	(cfs)
1964	133.8	211.9	224.2	352.7	990.2	520.1	(cfs)
1965	153.8	247.1	270.1	455.4	1203.6	566.9	(cfs)
1966	128.5	207.8	224.8	362.8	1000.2	491.8	(cfs)
1967	144.1	242.0	249.4	417.7	1068.1	551.3	(cfs)
QAA(60-67):	144.0	235.5	251.6	414.1	1115.2	549.9	(cfs)
QAA(Long-term):	*151.9*	*237.1*	*263.8*	*389.7*	*1127.8*	*579.0*	(cfs)
Count of WY's:	*21*	*9*	*11*	*12*	*80*	*25*	

WY	R1 Wh. Salmon 14121300	R1 Wh. Salmon 14121400	R1 Trout Lk. Cr. 14121500	R1 Wh. Salmon 14122000	R1 Wh. Salmon 14123500	R1 Wind 14127000
1960	1.060	1.097	1.057	1.070	1.016	1.048
1961	1.172	1.164	1.248	1.227	1.268	1.244
1962	0.910	0.915	0.901	0.897	0.939	0.898
1963	0.967	0.965	0.946	0.970	0.954	0.937
1964	0.929	0.900	0.891	0.852	0.888	0.946
1965	1.068	1.049	1.073	1.100	1.079	1.031
1966	0.892	0.882	0.893	0.876	0.897	0.894
1967	1.001	1.027	0.991	1.009	0.958	1.003

Figure B-6. Graphs for Wind-White Salmon Region R1 Values for Common POR 1960-67



APPENDIX C. DATA AND SOLUTIONS FOR MODELS #1a AND #1 b RELATING AVERAGE ANNUAL FLOW TO PRECIPITATION AND BASIN AREA

APPENDIX C.

DATA AND SOLUTIONS FOR MODELS #1a AND #1 b RELATING AVERAGE ANNUAL FLOW TO PRECIPITATION AND BASIN AREA

NOTES

1. Previous research in other regions of Washington (Amerman and Orsborn 1987) has shown that the average annual flow from a basin is best described by an equation like Equation 4 where

   $$QAA = 0.0034\ (P)^{1.60}\ A \qquad \text{(Equation 4)}$$

   This type of equation accounts for the fact that average streamflow varies as a power function of precipitation P, and as a function of area A to the first power.

2. In some regions with more uniform precipitation, the relationship is like Equation 2 where

   $$QAA = C(PA) \qquad \text{(Equation 2)}$$

   where C is a regional constant and the average annual flow records are all of long period.

3. The data for the six regions used in these models are in Table C-1; only a few of the stations had to be discarded due to short records.
4. The solutions to the equations are recorded in Table C-2 and C-3.
5. The Methow-Chelan and Naches-Yakima Standard Errors (SE) in Table C-3 are 53 and 46%; by using Model #1b (like Equation 4) the same SE values were reduced to 37 and 14%.

Table C-1. Data Summary for Model #1a & #1b for QAA Related to Precipitation and Basin Area.

	STATION NO	STATION NAME	NO WYS	PRECIP (in/yr)	AREA (sq mi)	P•A	P^nA	QAA (cfs)
1. METHOW-CHELAN								
	12442000	Toats Coulee Creek Near Loomis, Wash.	13	29	130.0	3770	75488	47
	12447390	Andrews Creek Near Mazama, Wash.	32	35	22.1	774	18310	32
	12449500	Methow River At Twisp, Wa	48	35	1301.0	45535	1077869	1378
	12449600	Beaver Creek Below South Fork, Near Twisp, Wash.	18	24	62.0	1488	25176	21
	12449950	Methow River Nr Pateros, Wash.	41	32	1772.0	56704	1239359	1577
	12451000	Stehekin River At Stehekin, Wash.	77	99	321.0	31779	1897822	1413
	12451500	Railroad Creek At Lucerne, Wash.	31	52	64.8	3370	113454	204
2. ENTIAT-WENATCHEE								
	12452800	Entiat River Near Ardenvoir, Wash.	43	59	203.0	11977		383
	12453000	Entiat River At Entiat, Wash.	21	45	419.0	18855		509
	12454000	White River Near Plain, Wash.	29	108	150.0	16200		816
	12456500	Chiwawa River Near Plain, Wash.	26	78	170.0	13260		516
	12458000	Icicle Creek Abv Snow Cr Nr Leavenworth, Wash.	42	88	193.0	16984		629
	12461400	Mission Creek Above Sand Cr Near Cashmere, Wash.	12	25	40.0			
	12483800	Naneum Creek Near Ellensburg, Wash.	20	25	70.0	1750		57
3. NACHES-YAKIMA								
	12483800	Naneum Creek Near Ellensburg, Wash.	20	25	70.0	1750		57
	12488500	American River Near Nile, Wash.	61	74	79.0	5846	11895945	236
	12494000	Naches River Below Tieton River Nr Naches, Wash.	66	60	941.0	56460	79262650	1260
	12500500	North Fork Ahtanum Creek Near Tampico, Wash.	52	53	69.0	3657	4121860	70
	12501000	So Fk Ahtanum Cr At Conrad Rnch N Tampico, Wash.	47	54	25.0	1350	1572790	20
	12502500	Ahtanum Creek At Union Gap, Wash.	44	38	173.0	6574	4111939	79
	12506000	Toppenish Creek Near Fort Simcoe, Wash.	14	29	122.0	3538		98
	12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.	14	39	82.0	3198		29
4. BLUE MOUNTAINS								
	13334500	Asotin Creek Near Asotin, Wash.	31	22	156.0	3432		68
	13334700	Asotin Cr Blw Kearney Gulch Nr Asotin, Wash.	29	24	170.0	4080		73
	13344500	Tucannon River Near Starbuck, Wash.	44	23	431.0	9913		173
	14013000	Mill Creek Near Walla Walla, Wash.	62	40	60.0	2400		96
	14013500	Blue Creek Near Walla Walla, Wash.	32	36	17.0	612		16
	14016000	Dry Creek Near Walla Walla, Wash.	18	29	48.0	1392		22
	14016500	East Fk Touchet R Nr Dayton, Wash.	22	30	102.0	3060		120
	14017000	Touchet River At Bolles, Wash.	43	25	361.0	9025		226
	14017500	Touchet R Nr Touchet, Wash.	14	20	733.0	14660		243
	14018500	Walla Walla River Near Touchet, Wash.	49	22	1657.0	36454		576
5. KLICKITAT								
	12506000	Toppenish Creek Near Fort Simcoe, Wash.	14	29	122.0	3538		98
	12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.	14	39	82.0			
	14107000	Klickitat R Abv West Fk Nr Glenwood, Wash.	42	58	151.0	8758		332
	14110000	Klickitat River Near Glenwood, Wash.	60	56	360.0	20160		837
	14112000	Little Klickitat R Nr Goldendale, Wash.	19	25	84.0	2100		60
	14113000	Klickitat River Near Pitt, Wash.	74	36	1297.0	46692		1600
6. WIND-WHITE SALMON								
	14121300	White Salmon R Blw Cascades Cr Nr Trout L, Wash.	21	106	32.4	3434		152
	14121400	White Salmon R Ab Tr Lk Cr Nr Trout Lk, Wash.	9	97	65.0	6305		237
	14121500	Trout Lake Creek Nr Trout Lake, Wash.	11	82	69.3	5683		264
	14123500	White Salmon R Nr Underwood, Wash.	80	66	386.0	25476		1128
	14124500	Little White Salmon River At Willard, Wash.	16	70	114.0	7980		450
	14127000	Wind R Ab Trout Creek Nr Carson, Wash.	25	103	108.0	11124		579

Table C-2. Solutions of Equations, Model #1a, QAA versus Preciptation times Basin Area, All WRIAs

AVERAGE EQUATION: $QAA = C(PA)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	*0.018*	*1.05*	*0.91*	*53*
ENTIAT-WENATCHEE	0.024	1.04	0.95	18
NACHES-YAKIMA	*0.014*	*1.04*	*0.85*	*46*
BLUE MOUNTAINS	0.062	0.88	0.91	29
KLICKITAT	0.014	1.10	0.99	10
WIND-WHITE SALMON	0.035	1.03	0.96	12

Table C-3. Solutions of Equations, Model #1b, QAA versus $(\text{Preciptation})^n$ times Basin Area for the Methow-Chelan and Naches-Yakima Regions

AVERAGE EQUATION: $QAA = C(P)^n A$

REGION	C	n	R^2	SE%
METHOW-CHELAN	0.0011	1.89	0.95	37
ENTIAT-WENATCHEE	*(No Improvement from Table 10)*			
NACHES-YAKIMA	0.000017	2.77	0.99	14
BLUE MOUNTAINS	*(No Improvement from Table 10)*			
KLICKITAT	*(No Improvement from Table 10)*			
WIND-WHITE SALMON	*(No Improvement from Table 10)*			

APPENDIX D. MODEL #2a FOR AVERAGE DAILY FLOOD Q1F2 RELATED TO QAA

APPENDIX D.

MODEL #2a FOR AVERAGE DAILY FLOOD Q1F2 RELATED TO QAA

NOTES

1. This average daily flood flow is one of the "key" flows in this modeling project.
2. It is also a "characteristic" flow of a stream when used in conjunction with QAA and Q7L2. Q1F2 is equaled or exceeded nearly 0% of the time; QAA 25-35% of the time; and Q7L2 around 95% of the time. These three flows can be used to estimate the average annual duration curve of an ungaged stream. Estimation of Q7L20 will complete the duration curve out to 100% of the time.
3. Characteristic flows can be used to hydrologically describe a region by calculating these ratios: Q1F2/QAA; Q1F2/Q7L2; and Q1F2/Q7L20.
4. There are gaps in the data where certain streams did not fit the regional trends for $Q1F2 = C(QAA)^{E}$ either due to a short record or poor records of greater than ± 15% error. With floods, a short wet or dry record can seriously distort "average" values.
5. The summary of the equations shows a relatively small standard error ranging from 3 to 21%.
6. Referring to Tables D-1 and D-2 and Figure D-4 on page D-8, notice that there are two separate solutions for the Blue Mountains: one for WRIA 32 in the SW and one for WRIA 35 in the NE. There are only 3 data points for WRIA 35, but these basins lie in the lee of the Blue Mountains crest and have different flooding characteristics than those in WRIA 32.

Table D-1. Data Summary for Model 2a, Q1F2 related to QAA by Region.

	STATION NO	STATION NAME	QAA (cfs)	Q1F2 (cfs)
1.	**METHOW-CHELAN**			
	12442000	Toats Coulee Creek Near Loomis, Wash.	47	508
	12447390	Andrews Creek Near Mazama, Wash.	32	304
	12449500	Methow River At Twisp, Wa	1378	10786
	12449600	Beaver Creek Below South Fork, Near Twisp, Wash.		
	12449950	Methow River Nr Pateros, Wash.	1577	11271
	12451000	Stehekin River At Stehekin, Wash.	1413	8195
	12451500	Railroad Creek At Lucerne, Wash.	204	1192
2.	**ENTIAT-WENATCHEE**			
	12452800	Entiat River Near Ardenvoir, Wash.	383	2558
	12453000	Entiat River At Entiat, Wash.	509	3469
	12454000	White River Near Plain, Wash.	816	4165
	12456500	Chiwawa River Near Plain, Wash.	516	3066
	12458000	Icicle Creek Abv Snow Cr Nr Leavenworth, Wash.	629	3834
	12461400	Mission Creek Above Sand Cr Near Cashmere, Wash.	13	89
	12483800	Naneum Creek Near Ellensburg, Wash.	57	375
3.	**NACHES-YAKIMA**			
	12483800	Naneum Creek Near Ellensburg, Wash.	57	375
	12488500	American River Near Nile, Wash.	236	1359
	12494000	Naches River Below Tieton River Nr Naches, Wash.	1260	6582
	12500500	North Fork Ahtanum Creek Near Tampico, Wash.	70	364
	12501000	So Fk Ahtanum Cr At Conrad Rnch N Tampico, Wash.		
	12502500	Ahtanum Creek At Union Gap, Wash.	79	382
	12506000	Toppenish Creek Near Fort Simcoe, Wash.	98	671
	12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.	29	213
4.	**BLUE MOUNTAINS- WRIA 35 (NE)**			
	13334500	Asotin Creek Near Asotin, Wash.	68	310
	13334700	Asotin Cr Blw Kearney Gulch Nr Asotin, Wash.		
	13344500	Tucannon River Near Starbuck, Wash.	173	812
	14016500	East Fk Touchet R Nr Dayton, Wash.	120	593
4.	**BLUE MOUNTAINS- WRIA 32 (SW)**			
	14013000	Mill Creek Near Walla Walla, Wash.		
	14013500	Blue Creek Near Walla Walla, Wash.	16	197
	14016000	Dry Creek Near Walla Walla, Wash.	22	281
	14017000	Touchet River At Bolles, Wash.	226	1886
	14017500	Touchet R Nr Touchet, Wash.	243	1970
	14018500	Walla Walla River Near Touchet, Wash.	576	4813
5.	**KLICKITAT**			
	12506000	Toppenish Creek Near Fort Simcoe, Wash.	98	671
	12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.	29	213
	14107000	Klickitat R Abv West Fk Nr Glenwood, Wash.	332	1747
	14110000	Klickitat River Near Glenwood, Wash.	837	2847
	14112000	Little Klickitat R Nr Goldendale, Wash.		
	14113000	Klickitat River Near Pitt, Wash.	1600	6334
6.	**WIND-WHITE SALMON**			
	14121300	White Salmon R Blw Cascades Cr Nr Trout L, Wash.		
	14121500	Trout Lake Creek Nr Trout Lake, Wash.	264	1367
	14123500	White Salmon R Nr Underwood, Wash.	1128	3892
	14124500	Little White Salmon River At Willard, Wash.	450	2311
	14127000	Wind R Ab Trout Creek Nr Carson, Wash.	579	4220

Table D-2. Solutions for Model #2a, Q1F2 related to QAA by Region.

AVERAGE EQUATION: $Q1F2 = C(QAA)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	13.21	0.90	0.99	16
ENTIAT-WENATCHEE	7.55	0.97	1.00	7
NACHES-YAKIMA	7.92	0.94	0.99	12
BLUE MOUNTAINS- WRIA 35 (NE)	3.76	1.05	0.99	3
BLUE MOUNTAINS- WRIA 32 (SW)	18.81	0.86	1.00	5
KLICKITAT	14.87	0.81	0.99	10
WIND-WHITE SALMON	24.70	0.75	0.74	21

Figure D-1. 1-Day Average 2-Year Flood Flow, Model #2a, Methow-Chelan Region

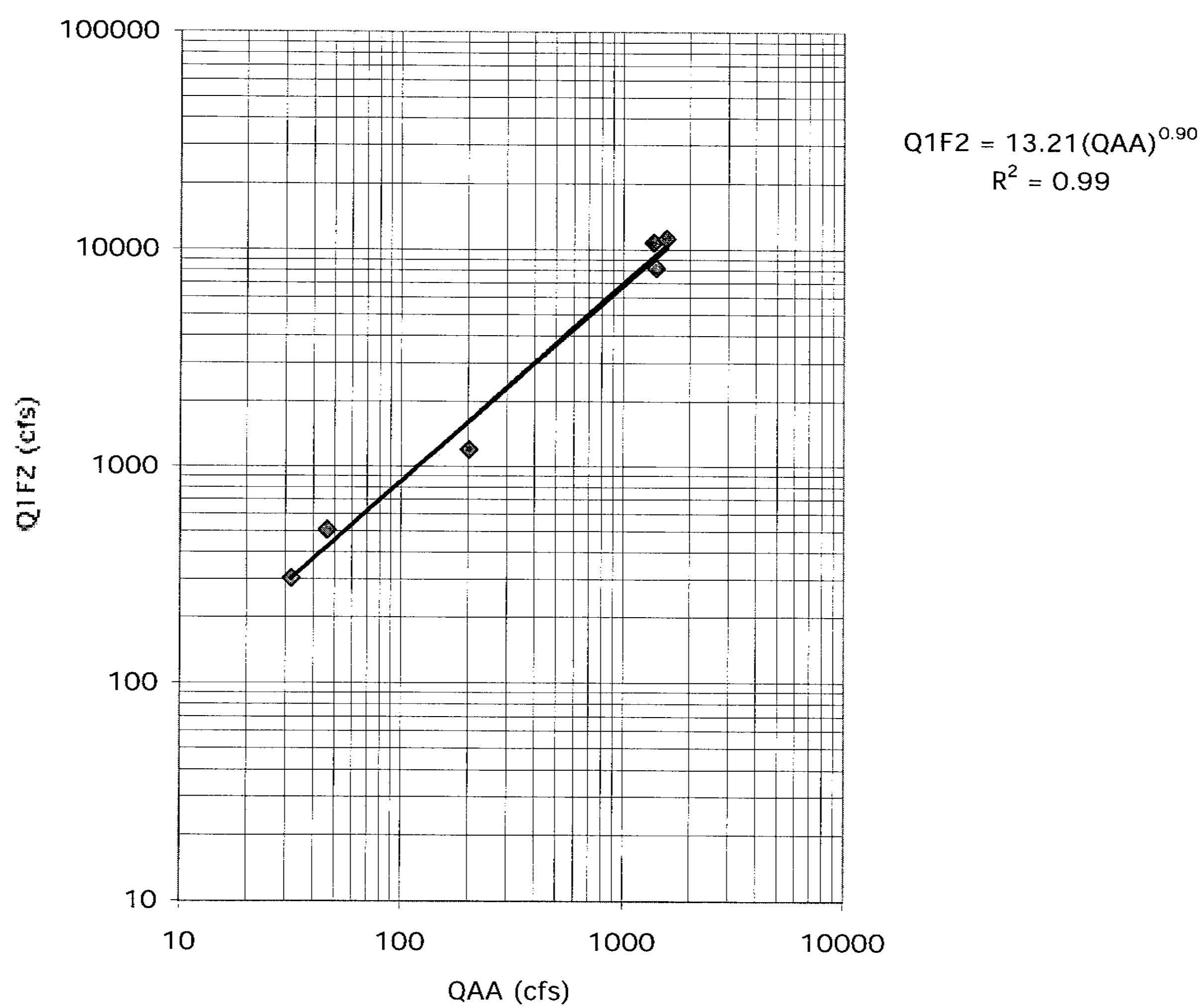


Figure D-2. 1-Day Average 2-Year Flood Flow, Model #2a, Entiat-Wenatchee Region

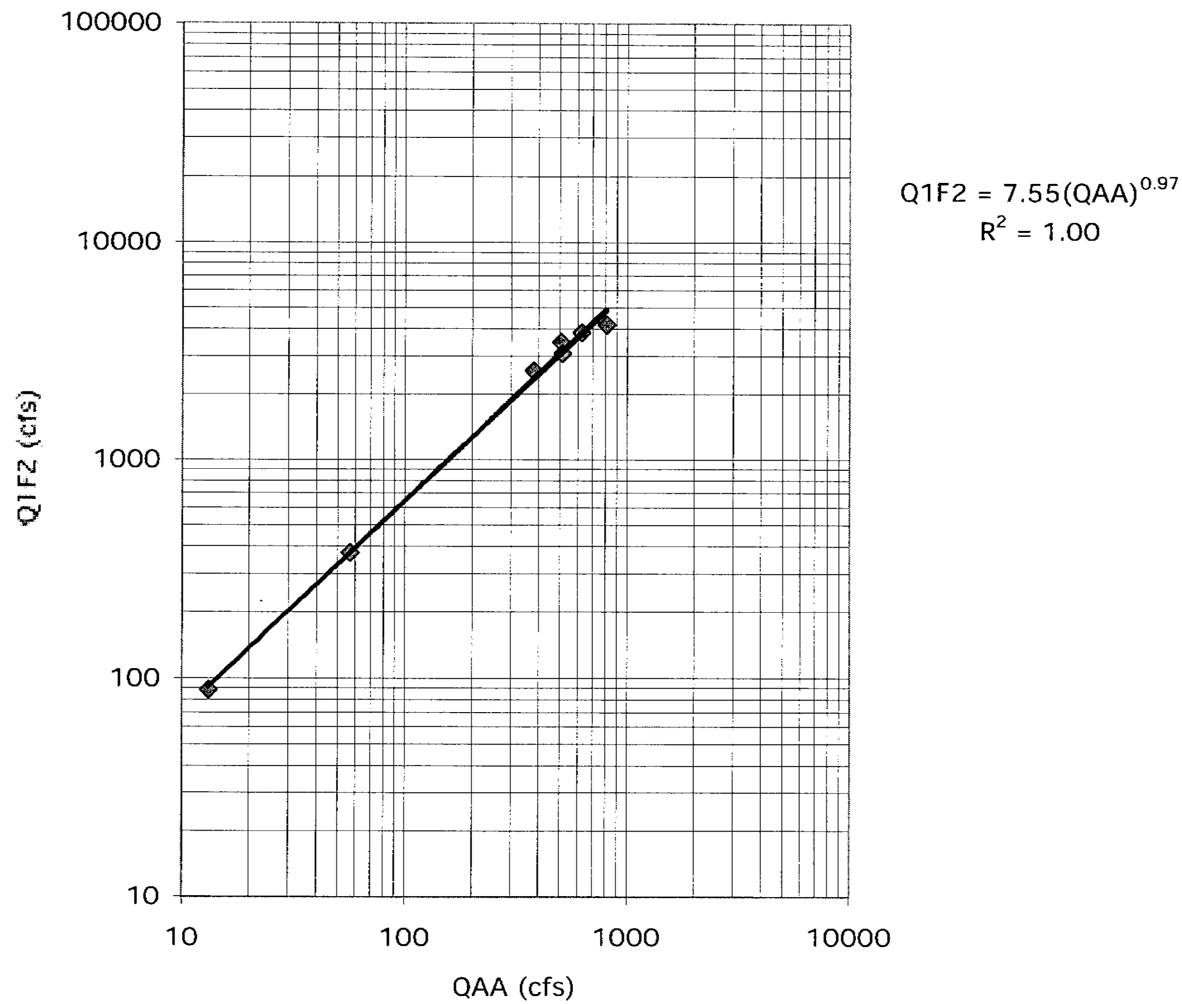


Figure D-3. 1-Day Average 2-Year Flood Flow, Model #2a, Naches-Yakima Region

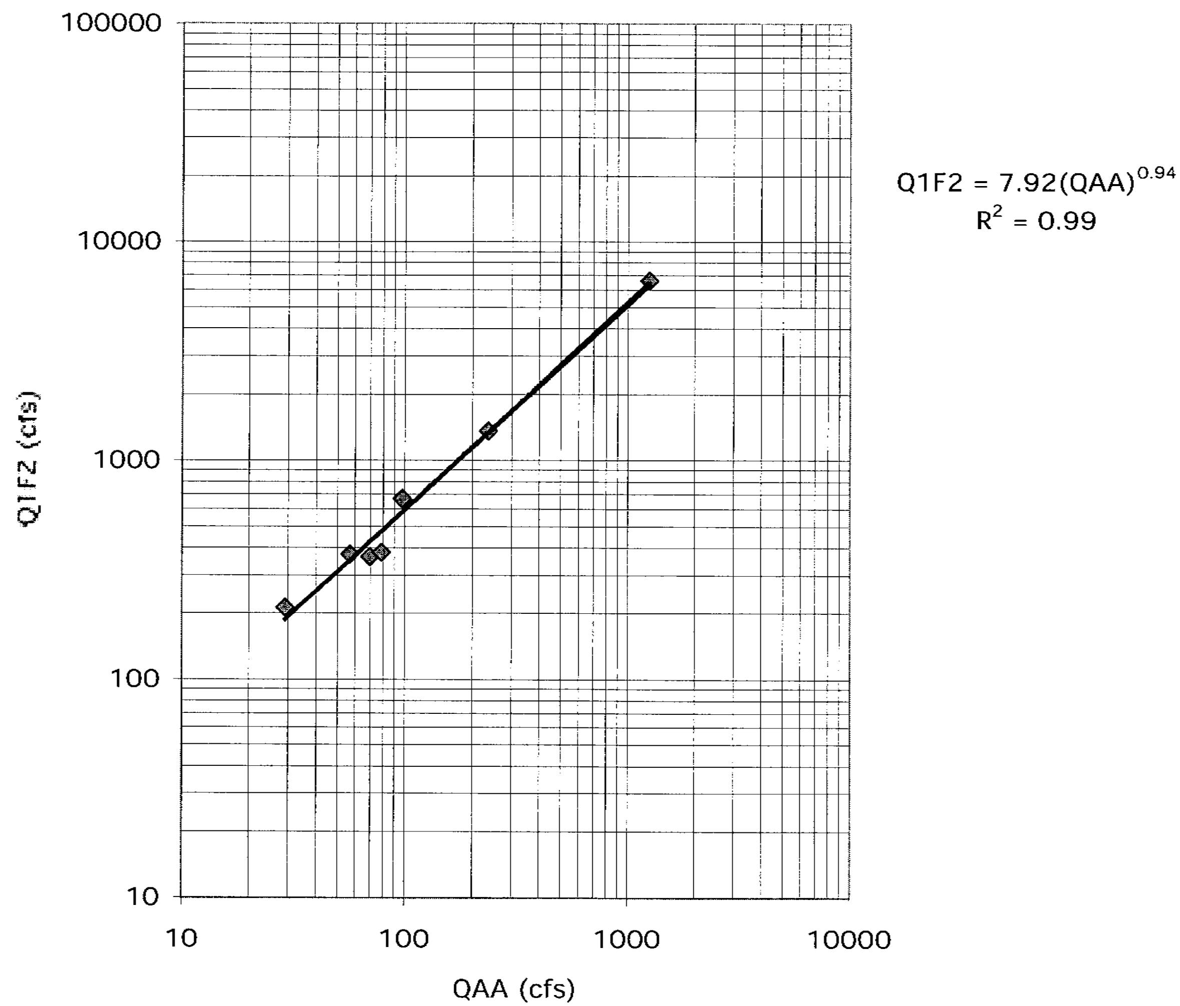


Figure D-4. 1-Day Average 2-Year Flood Flow, Model #2a,
Blue Mountains Region

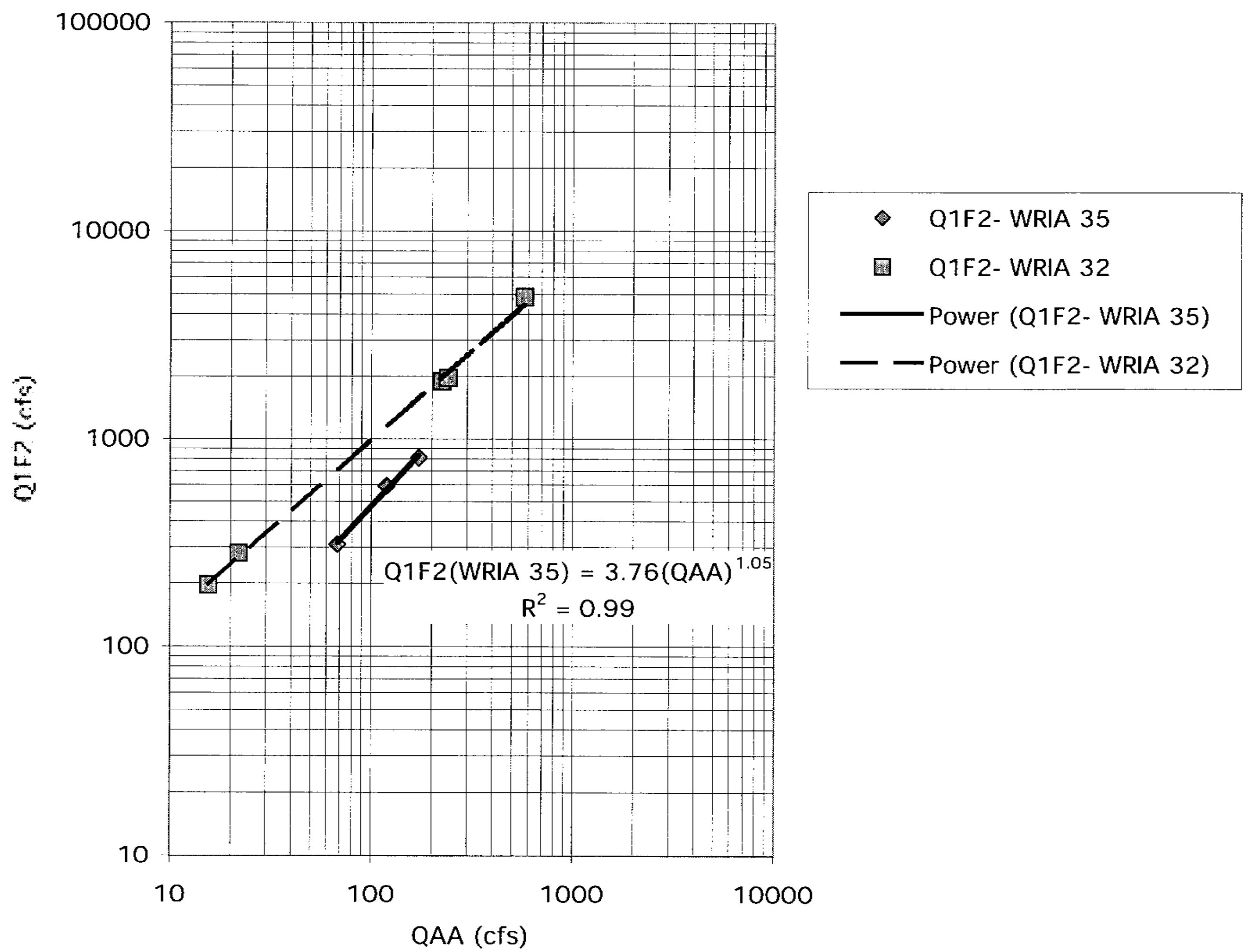


Figure D-5. 1-Day Average 2-Year Flood Flow, Model #2a, Klickitat Region

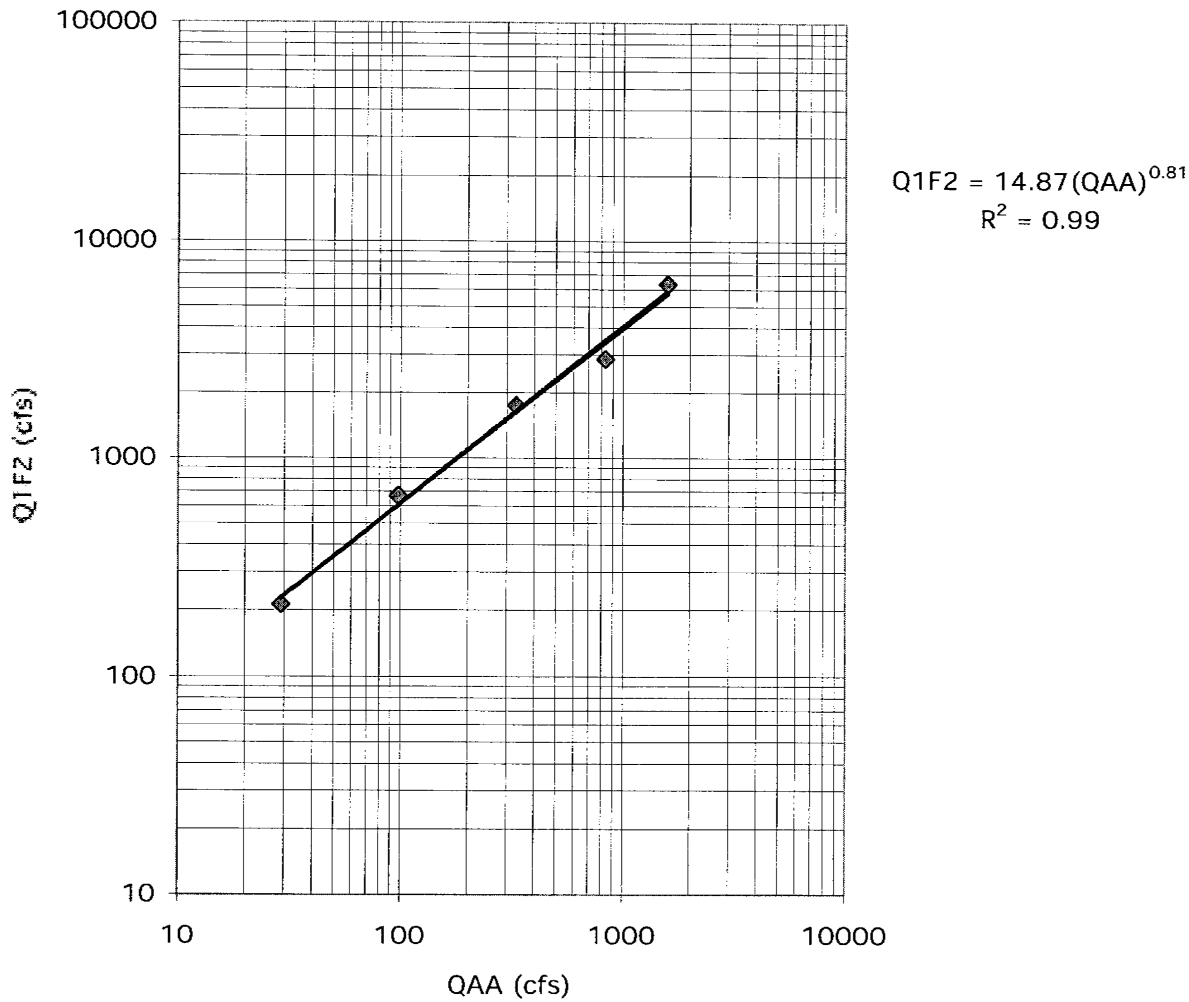
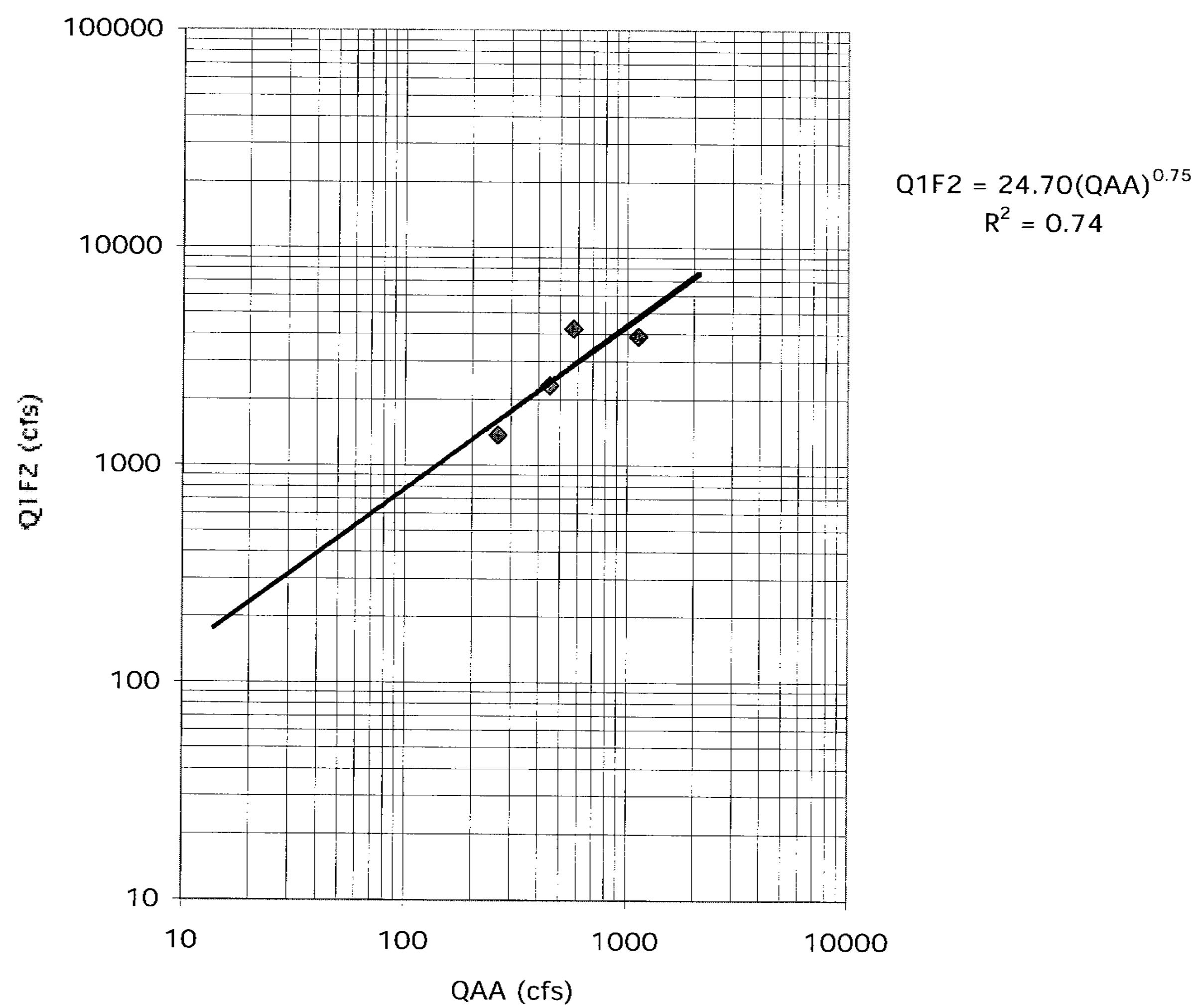


Figure D-6. 1-Day Average 2-Year Flood Flow, Model #2a, Wind-White Salmon Region



APPENDIX E. MODEL #6a: FALL Q7L2 RELATED TO QAA

APPENDIX E.

MODEL #6a: FALL Q7L2
RELATED TO QAA

<u>NOTES</u>

The **FALL Q7L2** values are used because:

1. This is the low design flow for fish passage designated in the WAC;
2. Fish do not migrate during the winter when the other low flow season occurs;
3. In the summaries of flow statistics at USGS gages (Williams and Pearson, 1985a, 1985b) the low flow statistics were based on annual (water year) occurrences which included both winter and fall (Aug-Nov) events; thus the low flows had to be separated into an annual fall series for all of the gages;
4. Some of the low flow data had to be eliminated from the data base (Table E-1) because of short periods of record, large diversions and/or unknown factors which yielded unreasonable relationships;
5. We tried to develop average models with the best (least influenced by diversions) data available;
6. **Historically, diversion water rights have not been documented, nor monitored in such a way that they can be quantified; exceptions to this observation exist for some municipal, irrigation and industrial supplies;**
7. **The numerous smaller and more remote irrigation diversions which are not monitored cause the greatest error in the models (for example, SE = 242% in the Blue Mountains in the month of August);** and

8. The selected Model #6a, Q7L2 = $C(QAA)^E$ was not quite as good as Model # 6b, Q7L2 = $C(PBE)^E$ in a couple of regions, but due to low flow gaging accuracy and model simplicity, Model #6a was selected.

Table E-1. Data Summary for Model 6a, Fall Q7L2 related to QAA by Region.

	STATION NO	STATION NAME	QAA (cfs)	Q7L2 (cfs) FALL
1.	**METHOW-CHELAN**			
	12442000	Toats Coulee Creek Near Loomis, Wash.	46.6	6.3
	12447390	Andrews Creek Near Mazama, Wash.	32.0	4.1
	12449500	Methow River At Twisp, Wa	1378.2	225.7
	12449600	Beaver Creek Below South Fork, Near Twisp, Wash.	20.5	5.2
	12449950	Methow River Nr Pateros, Wash.	1577.0	339.3
	12451000	Stehekin River At Stehekin, Wash.	1412.9	305.3
	12451500	Railroad Creek At Lucerne, Wash.	203.9	44.9
2.	**ENTIAT-WENATCHEE**			
	12452800	Entiat River Near Ardenvoir, Wash.	382.6	70.5
	12453000	Entiat River At Entiat, Wash.	508.8	103.4
	12454000	White River Near Plain, Wash.	815.8	158.9
	12456500	Chiwawa River Near Plain, Wash.	515.9	90.8
	12458000	Icicle Creek Abv Snow Cr Nr Leavenworth, Wash.	628.6	107.0
	12461400	Mission Creek Above Sand Cr Near Cashmere, Wash.	13.2	1.9
	12483800	Naneum Creek Near Ellensburg, Wash.	57.1	13.7
3.	**NACHES-YAKIMA**			
	12483800	Naneum Creek Near Ellensburg, Wash.	57.1	13.7
	12488500	American River Near Nile, Wash.	236.4	42.0
	12494000	Naches River Below Tieton River Nr Naches, Wash.	1260.3	111.3
	12500500	North Fork Ahtanum Creek Near Tampico, Wash.	70.3	16.0
	12501000	So Fk Ahtanum Cr At Conrad Rnch N Tampico, Wash.	20.3	6.3
	12502500	Ahtanum Creek At Union Gap, Wash.	79.1	10.7
	12506000	Toppenish Creek Near Fort Simcoe, Wash.	97.9	11.9
	12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.		
4.	**BLUE MOUNTAINS**			
	13334500	Asotin Creek Near Asotin, Wash.	68.4	28.0
	13334700	Asotin Cr Blw Kearney Gulch Nr Asotin, Wash.	72.6	31.5
	13344500	Tucannon River Near Starbuck, Wash.	173.2	53.3
	14013000	Mill Creek Near Walla Walla, Wash.	96.4	27.6
	14013500	Blue Creek Near Walla Walla, Wash.		
	14016000	Dry Creek Near Walla Walla, Wash.		
	14016500	East Fk Touchet R Nr Dayton, Wash.	119.8	38.7
	14017000	Touchet River At Bolles, Wash.		
	14017500	Touchet R Nr Touchet, Wash.		
	14018500	Walla Walla River Near Touchet, Wash.		
5.	**KLICKITAT**			
	12506000	Toppenish Creek Near Fort Simcoe, Wash.	97.9	11.9
	12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.		
	14107000	Klickitat R Abv West Fk Nr Glenwood, Wash.	331.7	89.5
	14110000	Klickitat River Near Glenwood, Wash.	836.5	378.6
	14112000	Little Klickitat R Nr Goldendale, Wash.		
	14113000	Klickitat River Near Pitt, Wash.	1599.9	680.7
6.	**WIND-WHITE SALMON**			
	14121300	White Salmon R Blw Cascades Cr Nr Trout L, Wash.	151.9	79.2
	14121400	White Salmon R Ab Tr Lk Cr Nr Trout Lk, Wash.	237.1	142.9
	14121500	Trout Lake Creek Nr Trout Lake, Wash.		
	14123500	White Salmon R Nr Underwood, Wash.	1127.8	539.8
	14124500	Little White Salmon River At Willard, Wash.		
	14127000	Wind R Ab Trout Creek Nr Carson, Wash.		

Table E-2. Solutions for Model #6a, Fall Q7L2 related to QAA by Region.

AVERAGE EQUATION: $Q7L2 = C(QAA)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	0.153	1.04	0.98	22
ENTIAT-WENATCHEE	0.161	1.03	0.99	13
NACHES-YAKIMA	0.634	0.72	0.93	21
BLUE MOUNTAINS*	0.320	1.00	(n/a)	17
KLICKITAT	0.015	1.48	0.99	14
WIND-WHITE SALMON	0.801	0.93	0.99	7

Notes:

* Equation based on other graphs for Q7L2 in other regions

Figure E-1. 7-Day Average 2-Year Fall Low Flow Related to QAA, Model #6a, Methow-Chelan Region

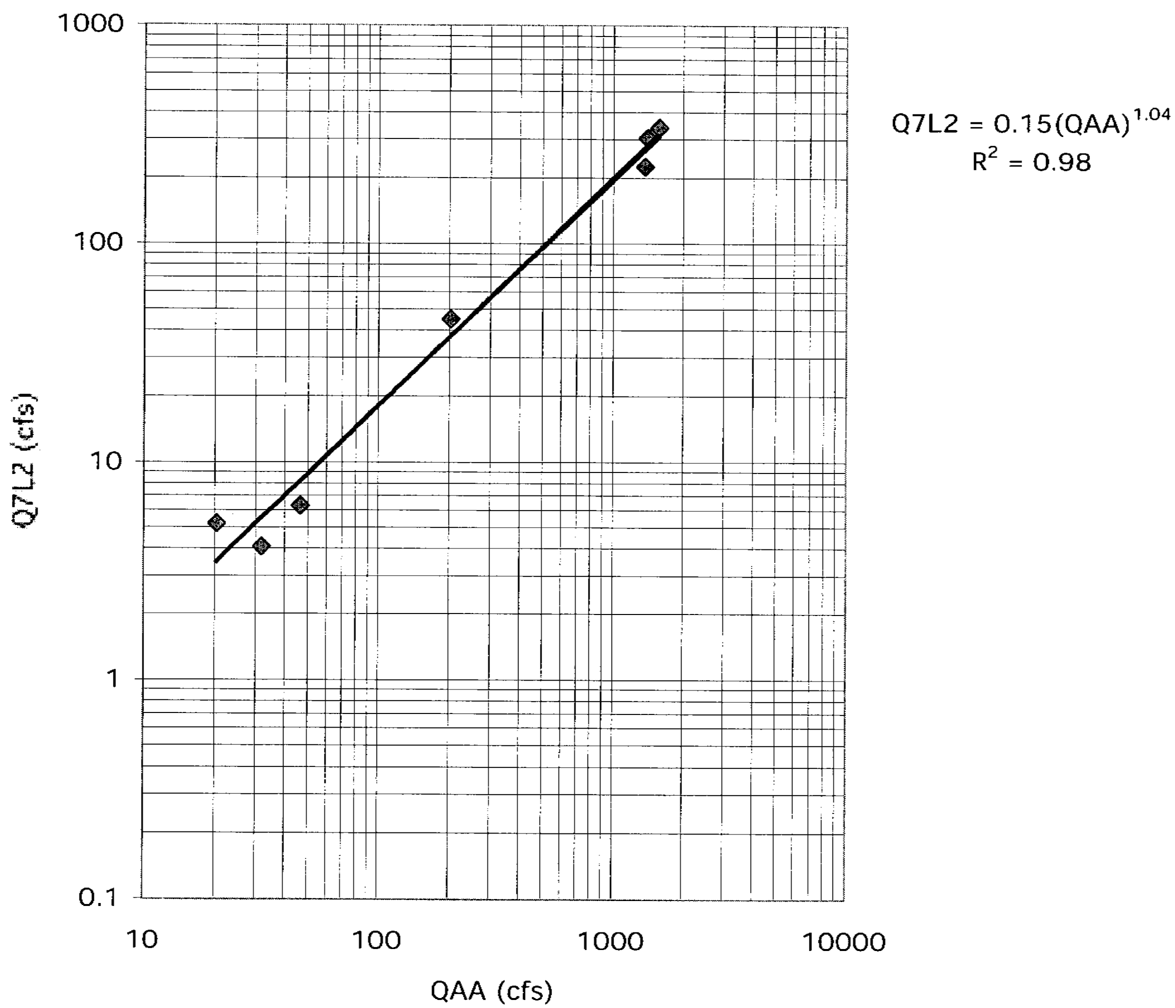


Figure E-2. 7-Day Average 2-Year Fall Low Flow Related to QAA, Model #6a, Entiat-Wenatchee Region

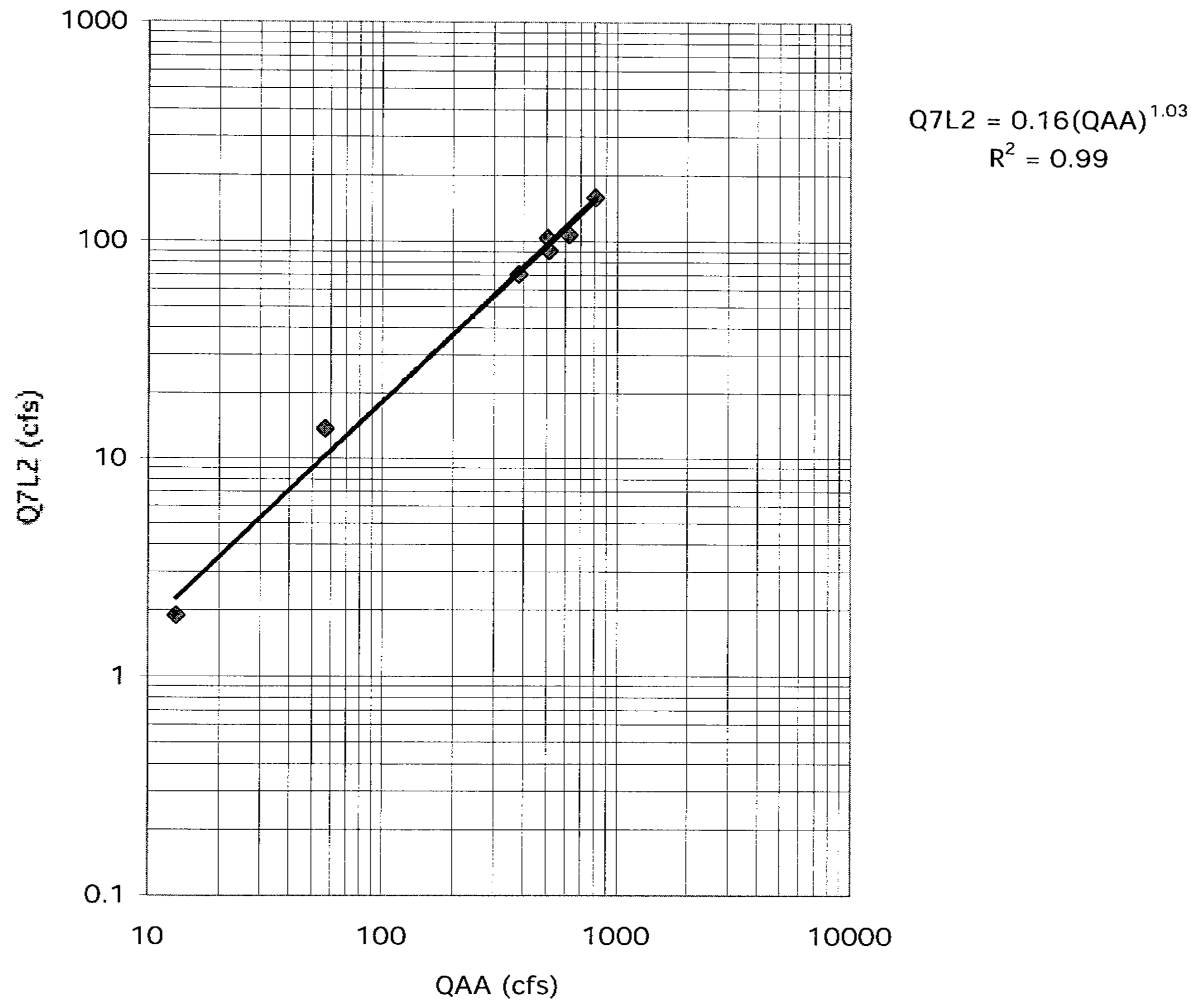


Figure E-3. 7-Day Average 2-Year Fall Low Flow Related to QAA, Model #6a, Naches-Yakima Region

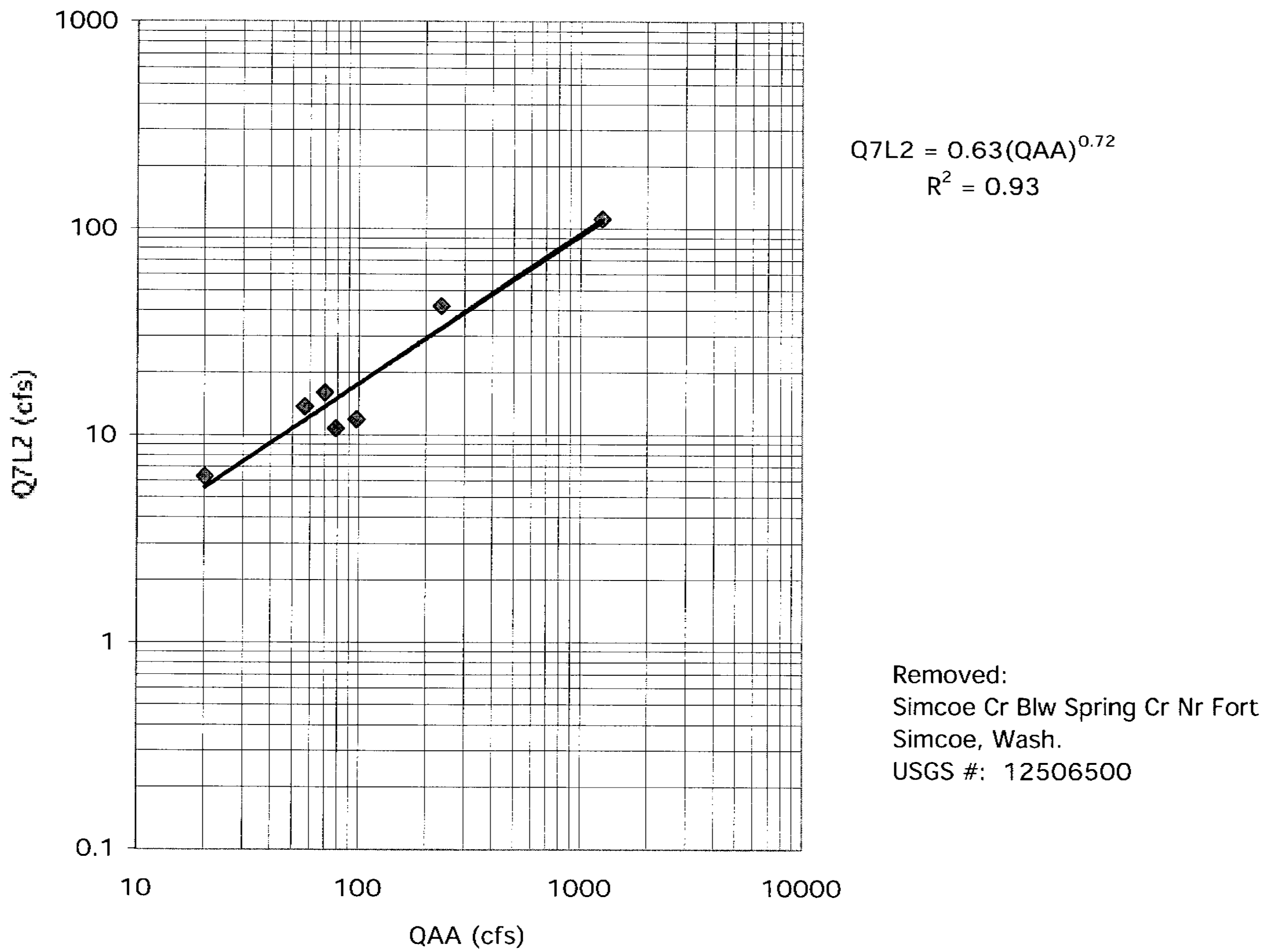
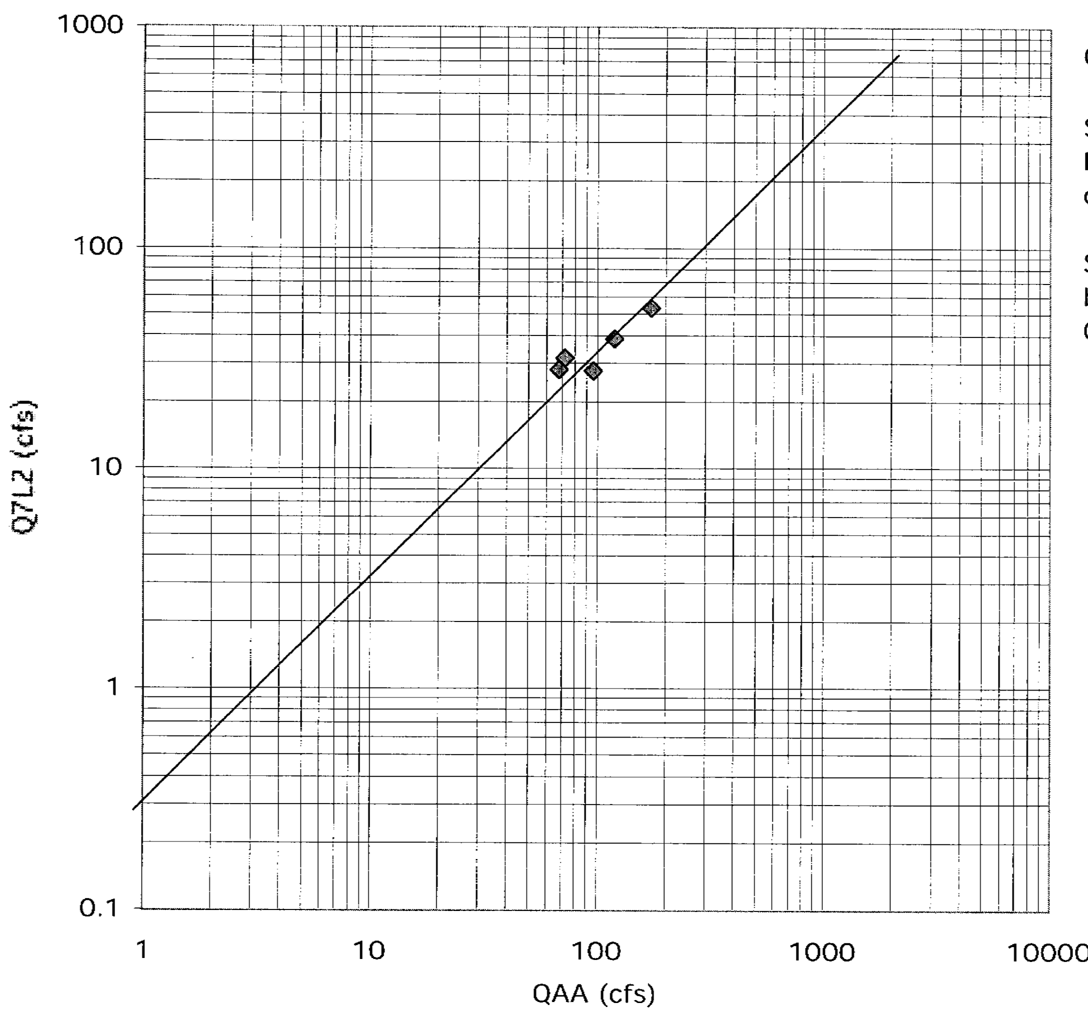


Figure E-4. 7-Day Average 2-Year Fall Low Flow Related to QAA, Model #6a, Blue Mountains Region



$Q7L2 = 0.32(QAA)^{1.00}$

Solid Line 1:1 slope (E = 1.00) Based on other graphs for Q7L2 in other regions.

Some low flows strongly influenced by irrigation and municipal (Asotin Creek) diversions.

Figure E-5. 7-Day Average 2-Year Fall Low Flow Related to QAA, Model #6a, Klickitat Region

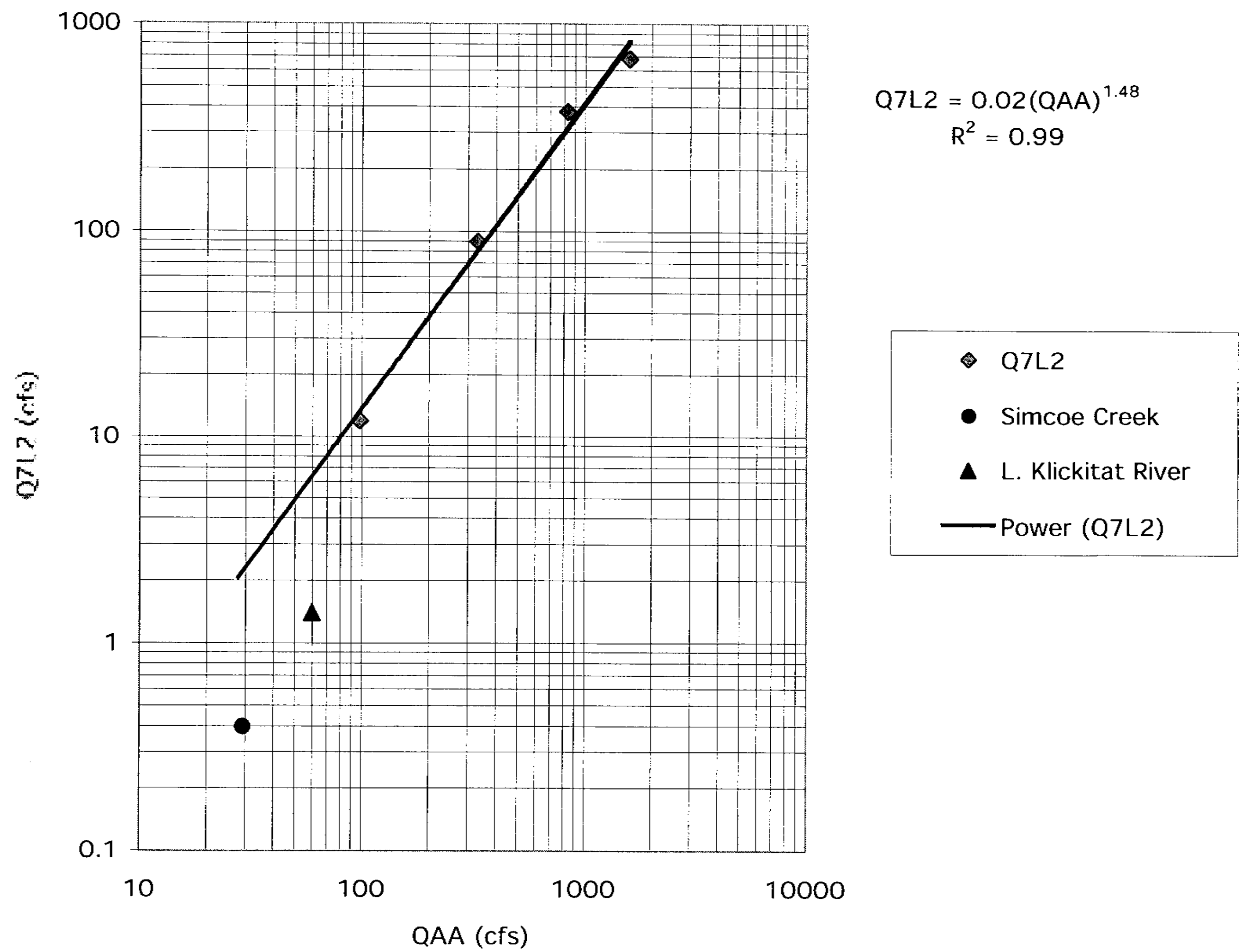
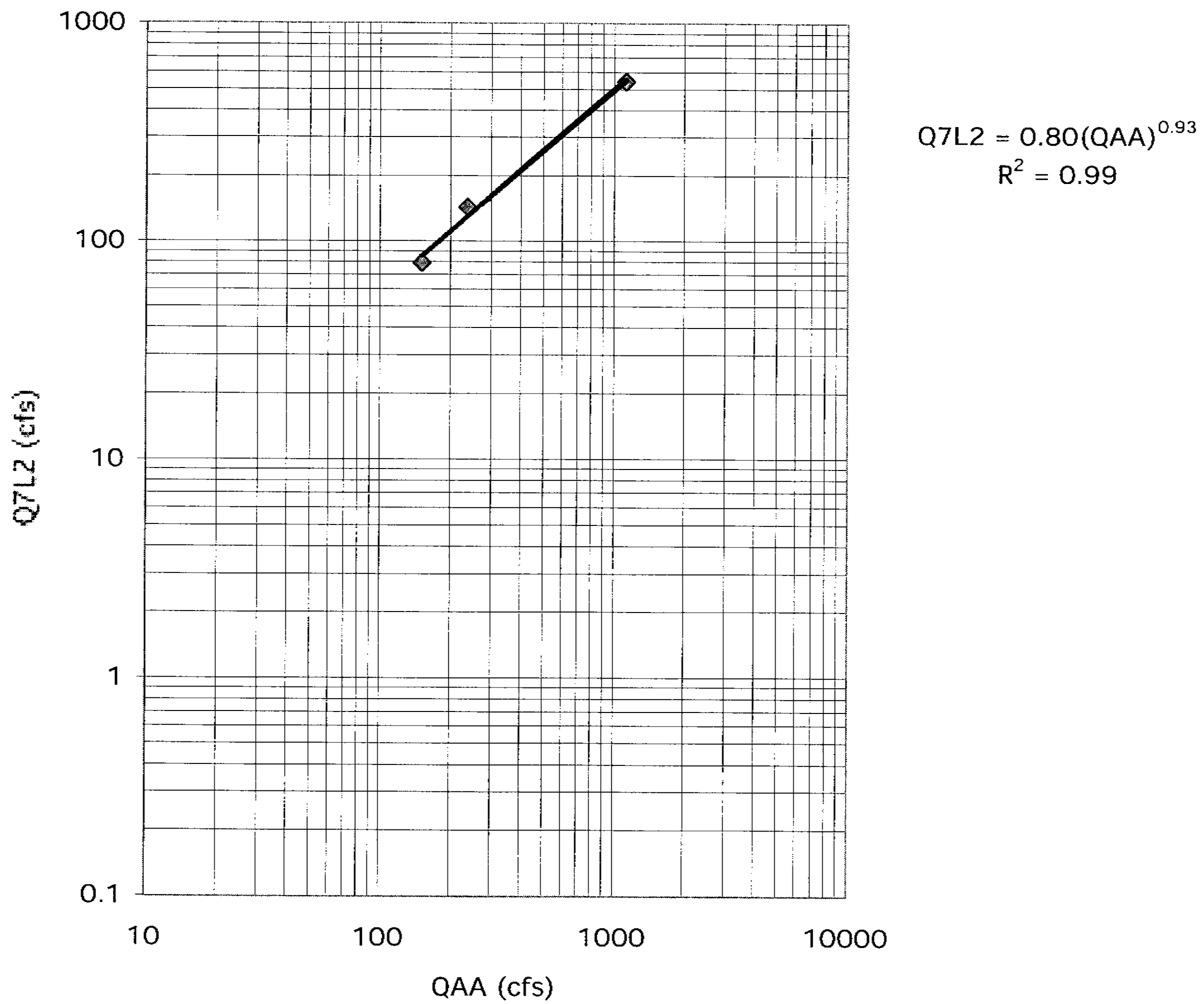


Figure E-6. 7-Day Average 2-Year Fall Low Flow Related to QAA, Model #6a, Wind-White Salmon Region



APPENDIX F. DATA AND SOLUTIONS FOR MODELS #1c AND #1d FOR MAXIMUM AND MINIMUM AVERAGE ANNUAL FLOW RELATED TO LONG-TERM AVERAGE ANNUAL FLOW

APPENDIX F.

DATA AND SOLUTIONS FOR MODELS #1c AND #1d FOR MAXIMUM AND MINIMUM AVERAGE ANNUAL FLOW RELATED TO LONG-TERM AVERAGE ANNUAL FLOW

NOTES

1. The Models for QAMax and QAMin related to QAA are surprisingly good.
2. The average SE for QAMax is under 10% for all the regions, and 18% for QAMin.
3. The ranges of SE values are 6-14% for QAMax and 13-23% for QAMin.
4. In Table F-1, only one gaging station record (Simcoe Creek, actually in the upper Yakima WRIA) was dropped from the database for this analysis.
5. The maximum and minimum annual flows at any ungaged site provide valuable information for water resources planning.
6. Further examination of the daily flow distributions during those extreme flow years may provide additional useful modeling information.
7. The last column in Table F-1 represents the flow range from QAMax to QA Min divided by QAA, for the period of record (POR) (No WYS in Col. 3 stands for "number of water years").
8. This **"Annual Flow Variability Index"** is a dimensionless measure of the hydrologic variability at each gage based on water delivery to the basin.

Table F-1. Data Summary for Model #1c- QAA, Qamin and QAmax by Region.

STATION NO	STATION NAME	NO. WYS	QAA (cfs)	QA_MIN (cfs)	QA_MAX (cfs)	(QAmax-QAmin)/QAA (--)
1. METHOW-CHELAN						
12442000	Toats Coulee Creek Near Loomis, Wash.	13	47	24	66	0.90
12447390	Andrews Creek Near Mazama, Wash.	32	32	13	59	1.44
12449500	Methow River At Twisp, Wa	48	1378	468	2231	1.28
12449600	Beaver Creek Below South Fork, Near Twisp, Wash.	18	21	7.5	46	1.90
12449950	Methow River Nr Pateros, Wash.	41	1577	565	2963	1.52
12451000	Stehekin River At Stehekin, Wash.	77	1413	872	2008	0.80
12451500	Railroad Creek At Lucerne, Wash.	31	204	128	297	0.83
2. ENTIAT-WENATCHEE						
12452800	Entiat River Near Ardenvoir, Wash.	43	383	175	621	1.17
12453000	Entiat River At Entiat, Wash.	21	509	275	804	1.04
12454000	White River Near Plain, Wash.	29	816	488	1079	0.73
12456500	Chiwawa River Near Plain, Wash.	26	516	264	783	1.01
12458000	Icicle Creek Abv Snow Cr Nr Leavenworth, Wash.	42	629	368	905	0.85
12461400	Mission Creek Above Sand Cr Near Cashmere, Wash.	12	13	8.5	19	0.80
12483800	Naneum Creek Near Ellensburg, Wash.	20	57	17	96	1.38
3. NACHES-YAKIMA						
12483800	Naneum Creek Near Ellensburg, Wash.	20	57	17	96	1.38
12488500	American River Near Nile, Wash.	61	236	94	379	1.20
12494000	Naches River Below Tieton River Nr Naches, Wash.	66	1260	341	2556	1.76
12500500	North Fork Ahtanum Creek Near Tampico, Wash.	52	70	18	128	1.56
12501000	So Fk Ahtanum Cr At Conrad Rnch N Tampico, Wash.	47	20	6.4	41	1.68
12502500	Ahtanum Creek At Union Gap, Wash.	44	79	20	171	1.91
12506000	Toppenish Creek Near Fort Simcoe, Wash.	14	98	38	214	1.79
12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.	14	29	6.7	67	2.07
4. BLUE MOUNTAINS						
13334500	Asotin Creek Near Asotin, Wash.	31	68	38	110	1.05
13334700	Asotin Cr Blw Kearney Gulch Nr Asotin, Wash.	29	73	38	152	1.58
13344500	Tucannon River Near Starbuck, Wash.	44	173	90	327	1.37
14013000	Mill Creek Near Walla Walla, Wash.	62	96	54	180	1.31
14013500	Blue Creek Near Walla Walla, Wash.	32	16	8.8	26	1.09
14016000	Dry Creek Near Walla Walla, Wash.	18	22	13	37	1.10
14016500	East Fk Touchet R Nr Dayton, Wash.	22	120	67	192	1.04
14017000	Touchet River At Bolles, Wash.	43	226	79	478	1.76
14017500	Touchet R Nr Touchet, Wash.	14	243	110	389	1.15
14018500	Walla Walla River Near Touchet, Wash.	49	576	166	1212	1.81
5. KLICKITAT						
12506000	Toppenish Creek Near Fort Simcoe, Wash.	14	98	38	214	1.79
12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.					
14107000	Klickitat R Abv West Fk Nr Glenwood, Wash.	42	332	126	539	1.24
14110000	Klickitat River Near Glenwood, Wash.	60	837	475	1231	0.90
14112000	Little Klickitat R Nr Goldendale, Wash.	19	60	33	116	1.37
14113000	Klickitat River Near Pitt, Wash.	74	1600	751	2876	1.33
6. WIND-WHITE SALMON						
14121300	White Salmon R Blw Cascades Cr Nr Trout L, Wash.	21	152	91	203	0.74
14121400	White Salmon R Ab Tr Lk Cr Nr Trout Lk, Wash.	9	237	208	274	0.28
14121500	Trout Lake Creek Nr Trout Lake, Wash.	11	264	224	362	0.52
14123500	White Salmon R Nr Underwood, Wash.	80	1128	554	1766	1.07
14124500	Little White Salmon River At Willard, Wash.	16	450	325	635	0.69
14127000	Wind R Ab Trout Creek Nr Carson, Wash.	25	579	458	825	0.63

Table F-2. Model #1c, QAmax versus QAA (Table 9).

EQUATION: $QAmax = C(QAA)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	2.02	0.97	0.99	14
ENTIAT-WENATCHEE	1.60	0.99	1.00	7
NACHES-YAKIMA	2.14	0.98	0.99	11
BLUE MOUNTAINS	1.42	1.05	0.99	9
KLICKITAT	2.67	0.93	0.99	10
WIND-WHITE SALMON	0.74	1.10	0.99	6

Table F-3. Model #1d, QAmax versus QAA.

EQUATION: $QAmin = C(QAA)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	0.44	1.00	0.98	23
ENTIAT-WENATCHEE	0.43	1.03	0.97	22
NACHES-YAKIMA	0.26	1.03	0.98	17
BLUE MOUNTAINS	1.03	0.84	0.97	13
KLICKITAT	0.43	1.01	0.98	15
WIND-WHITE SALMON	1.61	0.86	0.90	17

APPENDIX G. DATA AND SOLUTIONS FOR MODEL #1e MONTHLY FLOWS

APPENDIX G.

DATA AND SOLUTIONS FOR MODEL #1e
MONTHLY FLOWS

NOTES

1. The maximum, mean and minimum average monthly flow models relate those flows to the average annual flows at each USGS gage in a region using the typical power model of

   Model #1e: $QM\#(10\text{-}9) = C\,(QAA)^{E}$ (Equation G-1)

2. Comparing the Standard Errors (SE%) in Tables G-1 through G-6 for the best and worst models months are:

	BEST			WORST		
REGION	Max	Mean	Min	Max	Mean	Min
1. Methow-Chelan	Oct	Apr	May	Mar	Jun	Jul
2. Entiat-Wenatchee	May	Jul	Feb[1]	Feb	Feb	May
3. Naches-Yakima	May	Dec	May	Aug[2]	Sep[2]	Oct[2]
4. Blue Mountains	Apr	Mar	Jan[1]	Aug[2]	Aug[2]	Aug[2]
5. Klickitat	Oct	Apr	Jan[1]	Feb[1]	Feb[1]	Oct[2]
6. Wind-Wh. Salmon	Mar	Mar	Mar	Aug[2]	Aug[2]	Nov

[1] Probably due to winter freeze up; [2] Probably due to irrigation influence

3. The best monthly model (SE = 3 %, Table G-2) was for the minimum monthly flow in February in the Entiat-Wenatchee region; the worst monthly model (SE = 242%, Table G-4) was for the minimum flow in August in the Blue Mountains. The low SE was probably due to ice, and the high SE was due to irrigation diversions under low flow conditions in a region that has small low flow yields per square mile.

4. The monthly flow models can be used at any ungaged site to estimate habitat conditions, monthly and seasonal water budgets, and the WDFW "habitat flow" (Q60L2, WDFW, 1998). The habitat flow is described in DISSCUSSION. See also Appendix I, Model #7d.

Table G-1. Summary of Monthly Equation Coefficients and Exponents, METHOW-CHELAN Region, Model #1e (Table 9).

$$QM\#(10\text{-}9) = C(QAA)^E$$

QM Maximum

MONTH	C	E	R^2	SE%
Oct	0.40	1.13	0.99	14%
Nov	0.38	1.15	0.95	45%
Dec	0.26	1.18	0.97	36%
Jan	0.29	1.12	0.97	31%
Feb	0.15	1.21	0.97	33%
Mar	0.23	1.21	0.95	47%
Apr	0.75	1.21	0.96	44%
May	12.72	0.88	0.97	27%
Jun	16.28	0.88	0.98	22%
Jul	2.20	1.06	0.99	20%
Aug	0.70	1.09	0.97	31%
Sep	0.88	0.98	0.97	26%

QM Mean

MONTH	C	E	R^2	SE%
Oct	0.25	1.05	0.98	22%
Nov	0.20	1.09	0.98	25%
Dec	0.17	1.09	0.98	25%
Jan	0.17	1.05	0.98	25%
Feb	0.16	1.06	0.98	28%
Mar	0.15	1.11	0.97	32%
Apr	0.40	1.13	0.99	15%
May	3.34	0.97	0.99	19%
Jun	2.98	1.01	0.97	28%
Jul	0.70	1.10	0.96	38%
Aug	0.38	1.06	0.96	35%
Sep	0.30	1.01	0.96	34%

QM Minimum

MONTH	C	E	R^2	SE%
Oct	0.14	1.02	0.97	29%
Nov	0.13	1.01	0.96	32%
Dec	0.12	1.01	0.96	35%
Jan	0.11	0.99	0.93	46%
Feb	0.13	0.98	0.94	41%
Mar	0.12	1.02	0.96	37%
Apr	0.17	1.04	0.94	44%
May	0.68	1.06	0.98	23%
Jun	0.52	1.09	0.93	53%
Jul	0.25	1.08	0.91	59%
Aug	0.16	1.06	0.91	57%
Sep	0.12	1.06	0.94	47%

Table G-2 Summary of Monthly Equation Coefficients and Exponents, ENTIAT-WENATCHEE Region, Model #1e (Table 9).

$$QM\#(10\text{-}9) = C(QAA)^E$$

QM Maximum

MONTH	C	E	R^2	SE%
Oct	0.22	1.22	0.99	20%
Nov	0.49	1.18	0.95	37%
Dec	0.83	1.09	0.97	25%
Jan	2.31	0.85	0.97	21%
Feb	5.04	0.73	0.84	43%
Mar	4.41	0.77	0.97	17%
Apr	7.08	0.79	0.99	13%
May	6.22	0.95	0.99	10%
Jun	1.82	1.18	0.97	26%
Jul	0.42	1.35	0.99	15%
Aug	0.18	1.33	0.99	16%
Sep	0.20	1.18	1.00	10%

QM Mean

MONTH	C	E	R^2	SE%
Oct	0.21	1.08	0.99	12%
Nov	0.40	1.02	0.98	19%
Dec	0.49	0.98	0.98	20%
Jan	1.65	0.75	0.95	24%
Feb	2.69	0.68	0.88	33%
Mar	2.36	0.72	0.98	12%
Apr	3.67	0.80	0.98	16%
May	3.37	0.98	0.99	15%
Jun	1.09	1.17	0.99	12%
Jul	0.31	1.26	1.00	10%
Aug	0.16	1.20	0.99	15%
Sep	0.16	1.11	0.99	17%

QM Minimum

MONTH	C	E	R^2	SE%
Oct	0.16	0.98	0.99	13%
Nov	0.30	0.88	0.98	16%
Dec	0.30	0.89	0.98	14%
Jan	0.39	0.83	0.98	17%
Feb	0.96	0.67	1.00	3%
Mar	0.87	0.75	0.99	9%
Apr	1.64	0.75	0.94	25%
May	0.64	1.10	0.95	33%
Jun	0.28	1.24	0.97	29%
Jul	0.17	1.17	0.98	20%
Aug	0.08	1.17	0.98	19%
Sep	0.08	1.12	0.99	16%

Table G-3. Summary of Monthly Equation Coefficients and Exponents, NACHES-YAKIMA Region, Model #1e (Table 9).

$$QM\#(10\text{-}9) = C(QAA)^E$$

QM Maximum

MONTH	C	E	R^2	SE%
Oct	0.15	1.25	0.95	33%
Nov	0.29	1.35	0.97	25%
Dec	1.47	1.13	0.95	30%
Jan	3.85	0.94	0.83	51%
Feb	4.07	0.92	0.82	50%
Mar	7.74	0.86	0.75	60%
Apr	5.32	0.94	0.92	30%
May	3.96	1.05	0.99	14%
Jun	2.37	1.12	0.86	53%
Jul	0.41	1.33	0.89	56%
Aug	0.15	1.30	0.86	65%
Sep	0.07	1.39	0.88	61%

QM Mean

MONTH	C	E	R^2	SE%
Oct	0.13	1.12	0.84	57%
Nov	0.18	1.16	0.94	33%
Dec	0.45	1.07	0.99	10%
Jan	1.17	0.91	0.89	36%
Feb	1.70	0.85	0.89	34%
Mar	3.21	0.78	0.79	47%
Apr	2.75	0.91	0.95	24%
May	2.07	1.05	0.98	16%
Jun	0.67	1.20	0.85	60%
Jul	0.15	1.29	0.85	65%
Aug	0.07	1.28	0.84	69%
Sep	0.06	1.26	0.82	72%

QM Minimum

MONTH	C	E	R^2	SE%
Oct	0.18	0.75	0.30	194%
Nov	0.62	0.54	0.24	142%
Dec	1.68	0.38	0.29	73%
Jan	15.74	-0.15	0.04	95%
Feb	4.98	0.20	0.11	68%
Mar	3.72	0.34	0.37	52%
Apr	0.87	0.83	0.85	40%
May	0.52	0.97	0.91	35%
Jun	0.08	1.27	0.91	46%
Jul	0.05	1.19	0.75	87%
Aug	0.03	1.22	0.61	148%
Sep	0.23	0.80	0.74	55%

Table G-4. Summary of Monthly Equation Coefficients and Exponents, BLUE MOUNTAINS Region, Model #1e (Table 9).

$$QM\#(10\text{-}9) = C(QAA)^E$$

QM Maximum

MONTH	C	E	R^2	SE%
Oct	0.99	0.92	0.96	19%
Nov	1.41	1.03	0.93	27%
Dec	3.87	0.99	0.91	31%
Jan	5.92	0.91	0.89	32%
Feb	3.38	1.08	0.92	30%
Mar	2.65	1.08	0.95	24%
Apr	4.68	0.95	0.97	16%
May	3.57	1.00	0.89	34%
Jun	1.44	1.09	0.90	35%
Jul	0.33	1.10	0.76	65%
Aug	0.13	1.19	0.74	75%
Sep	0.23	1.10	0.87	43%

QM Mean

MONTH	C	E	R^2	SE%
Oct	0.29	1.01	0.85	43%
Nov	0.65	0.99	0.99	10%
Dec	1.22	0.99	0.97	17%
Jan	1.54	0.97	0.93	25%
Feb	1.87	0.98	0.92	28%
Mar	1.86	0.97	0.95	21%
Apr	2.22	0.97	0.99	9%
May	1.22	1.05	0.93	27%
Jun	0.64	1.04	0.85	44%
Jul	0.21	1.04	0.65	83%
Aug	0.17	0.99	0.54	105%
Sep	0.15	1.07	0.69	77%

QM Minimum

MONTH	C	E	R^2	SE%
Oct	0.15	0.97	0.51	113%
Nov	0.12	1.12	0.78	60%
Dec	0.12	1.19	0.93	32%
Jan	0.16	1.15	0.97	20%
Feb	0.65	0.94	0.94	22%
Mar	0.44	1.07	0.96	22%
Apr	0.75	0.97	0.87	37%
May	0.59	0.92	0.71	61%
Jun	0.30	0.92	0.57	88%
Jul	0.18	0.87	0.37	147%
Aug	0.05	1.05	0.34	242%
Sep	0.14	0.90	0.33	185%

Table G-5. Summary of Monthly Equation Coefficients and Exponents, KLICKITAT Region, Model #1e (Table 9).

$$QM\#(10\text{-}9) = C(QAA)^E$$

QM Maximum

MONTH	C	E	R^2	SE%
Oct	0.07	1.38	0.99	22%
Nov	0.64	1.16	0.98	24%
Dec	3.32	0.99	0.94	34%
Jan	4.54	0.93	0.94	32%
Feb	8.26	0.87	0.88	44%
Mar	29.70	0.65	0.85	38%
Apr	9.28	0.83	0.95	26%
May	2.79	1.05	0.95	31%
Jun	0.54	1.27	0.96	35%
Jul	0.10	1.44	0.96	40%
Aug	0.01	1.61	0.97	42%
Sep	0.01	1.63	0.98	31%

QM Mean

MONTH	C	E	R^2	SE%
Oct	0.01	1.58	0.98	27%
Nov	0.07	1.32	0.98	27%
Dec	0.63	1.04	0.98	21%
Jan	2.66	0.83	0.94	29%
Feb	3.71	0.80	0.87	43%
Mar	5.01	0.76	0.88	38%
Apr	4.69	0.82	0.97	20%
May	1.55	1.03	0.98	20%
Jun	0.15	1.34	0.97	29%
Jul	0.02	1.54	0.98	29%
Aug	0.005	1.70	0.98	32%
Sep	0.003	1.73	0.98	31%

QM Minimum

MONTH	C	E	R^2	SE%
Oct	0.001	1.93	0.91	90%
Nov	0.003	1.69	0.93	68%
Dec	0.02	1.40	0.98	28%
Jan	0.04	1.28	0.99	16%
Feb	0.32	1.01	0.95	31%
Mar	0.37	1.02	0.97	25%
Apr	0.65	0.98	0.97	22%
May	0.29	1.14	0.95	35%
Jun	0.02	1.47	0.98	28%
Jul	0.001	1.90	0.98	33%
Aug	0.0001	2.17	0.97	55%
Sep	0.001	1.93	0.97	42%

Table G-6. Summary of Monthly Equation Coefficients and Exponents, WIND-WHITE SALMON Region, Model #1e (Table 9).

$$QM\#(10\text{-}9) = C(QAA)^E$$

QM Maximum

MONTH	C	E	R^2	SE%
Oct	0.87	1.01	0.83	28%
Nov	0.86	1.11	0.84	30%
Dec	0.58	1.23	0.91	23%
Jan	0.09	1.54	0.91	30%
Feb	0.28	1.38	0.97	16%
Mar	0.45	1.27	0.96	15%
Apr	0.42	1.26	0.96	16%
May	3.78	0.92	0.92	16%
Jun	4.44	0.86	0.87	20%
Jul	1.36	0.97	0.71	39%
Aug	1.52	0.86	0.47	60%
Sep	0.87	0.93	0.65	42%

QM Mean

MONTH	C	E	R^2	SE%
Oct	1.24	0.83	0.64	39%
Nov	1.33	0.93	0.90	19%
Dec	0.68	1.09	0.93	17%
Jan	0.22	1.27	0.92	23%
Feb	0.16	1.34	0.93	22%
Mar	0.16	1.32	0.98	11%
Apr	0.49	1.16	0.97	12%
May	4.18	0.83	0.86	20%
Jun	7.07	0.70	0.86	17%
Jul	3.50	0.72	0.55	40%
Aug	2.09	0.74	0.39	59%
Sep	2.17	0.70	0.39	56%

QM Minimum

MONTH	C	E	R^2	SE%
Oct	3.53	0.52	0.10	113%
Nov	13.15	0.31	0.03	155%
Dec	1.64	0.75	0.53	45%
Jan	1.00	0.87	0.96	10%
Feb	0.28	1.10	0.87	26%
Mar	0.37	1.08	0.95	15%
Apr	0.61	1.03	0.94	16%
May	8.88	0.59	0.70	24%
Jun	5.18	0.63	0.65	28%
Jul	2.07	0.71	0.50	44%
Aug	2.68	0.61	0.26	69%
Sep	3.03	0.55	0.13	100%

APPENDIX H. DATA AND SOLUTIONS FOR STATISTICAL PEAK AND DAILY FLOOD MODELS #3 AND #4

APPENDIX H.

DATA AND SOLUTIONS FOR STATISTICAL PEAK AND DAILY FLOOD MODELS #3 AND #4

NOTES

1. Data for the statistical flood models are in Tables H-1 and H-4.
2. Regression solutions for determining the daily and peak flood flows in terms of the daily average flood (key flow Q1F2) are in Tables H-2, H-3 and H-5 through H-7.
3. Index to Data and Solutions for Statistical Flood Models #3 and #4.

Model #	Data Table	Solutions Table	Solutions for:				
			QPF2	QPF25	QPF100	Q1F25	Q1F100
3a	H-1	H-2				X	
3b	H-1	H-3					X
4a	H-4	H-5	X				
4b	H-4	H-6		X			
4c	H-4	H-7			X		

4. For daily flood Models #3a and #3b (for Q1F25 and Q1F100) the standard errors (SE) range from 2 to 34 percent (Tables H-2 and H-3).
5. For peak flood Models #4a, #4b and #4c (for QPF2, QPF25 and QPF100) the standard errors range from 4 to 37 percent (Tables H-5, H-6 and H-7).
6. Some of the data in Tables H-1 and H-4 were eliminated from the models due to short periods of record, extreme events that distorted the RI analysis or a lack of regional hydrologic uniformity.

Table H-1. Model #3, Q1F25 and Q1F100 Related to Q1F2 by Region.

STATION NO.	STATION NAME	Q1F2 (cfs)	Q1F25 (cfs)	Q1F100 (cfs)
1. METHOW-CHELAN				
12442000	Toats Coulee Creek Near Loomis, Wash.			
12447390	Andrews Creek Near Mazama, Wash.	304	649	864
12449500	Methow River At Twisp, Wa	10786	21149	25304
12449600	Beaver Creek Below South Fork, Near Twisp, Wash.			
12449950	Methow River Nr Pateros, Wash.	11271	22519	27725
12451000	Stehekin River At Stehekin, Wash.	8195	14209	16898
12451500	Railroad Creek At Lucerne, Wash.	1192	2365	2988
2. ENTIAT-WENATCHEE				
12452800	Entiat River Near Ardenvoir, Wash.	2558	4569	5416
12453000	Entiat River At Entiat, Wash.	3469	4839	5003
12454000	White River Near Plain, Wash.	4165	7946	10627
12456500	Chiwawa River Near Plain, Wash.	3066	5763	6945
12458000	Icicle Creek Abv Snow Cr Nr Leavenworth, Wash.	3834	8510	11770
12461400	Mission Creek Above Sand Cr Near Cashmere, Wash.	89	206	275
12483800	Naneum Creek Near Ellensburg, Wash.			
3. NACHES-YAKIMA				
12483800	Naneum Creek Near Ellensburg, Wash.			
12488500	American River Near Nile, Wash.			
12494000	Naches River Below Tieton River Nr Naches, Wash.	6582	15483	19632
12500500	North Fork Ahtanum Creek Near Tampico, Wash.			
12501000	So Fk Ahtanum Cr At Conrad Rnch N Tampico, Wash.	91	363	601
12502500	Ahtanum Creek At Union Gap, Wash.	382	1474	2304
12506000	Toppenish Creek Near Fort Simcoe, Wash.	671	1740	
12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.	213	1012	1651
4. BLUE MOUNTAINS- Subregion 1NE WRIA 35				
13334500	Asotin Creek Near Asotin, Wash.			
13334700	Asotin Cr Blw Kearney Gulch Nr Asotin, Wash.	253	1469	3368
13344500	Tucannon River Near Starbuck, Wash.	812	3984	7450
14017500	Touchet R Nr Touchet, Wash.	1970	7386	12799
4. BLUE MOUNTAINS- Subregion 2SW WRIA 32				
14013000	Mill Creek Near Walla Walla, Wash.	665	1938	2981
14013500	Blue Creek Near Walla Walla, Wash.	197	570	843
14016000	Dry Creek Near Walla Walla, Wash.	281	610	724
14016500	East Fk Touchet R Nr Dayton, Wash.	593	2117	3623
14017000	Touchet River At Bolles, Wash.	1886	4728	6056
14018500	Walla Walla River Near Touchet, Wash.	4813	13981	19776
5. KLICKITAT				
12506000	Toppenish Creek Near Fort Simcoe, Wash.	671	1740	
12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.	213	1012	1651
14107000	Klickitat R Abv West Fk Nr Glenwood, Wash.	1747	3058	
14110000	Klickitat River Near Glenwood, Wash.	2847	5099	
14112000	Little Klickitat R Nr Goldendale, Wash.	647	2914	5462
14113000	Klickitat River Near Pitt, Wash.	6334	23490	38171
6. WIND-WHITE SALMON				
14121300	White Salmon R Blw Cascades Cr Nr Trout L, Wash.	503	974	1197
14121500	Trout Lake Creek Nr Trout Lake, Wash.	1367	2368	2814
14123500	White Salmon R Nr Underwood, Wash.			
14124500	Little White Salmon River At Willard, Wash.	2311	3470	3947
14127000	Wind R Ab Trout Creek Nr Carson, Wash.	4220	6636	7577

Table H-2. Solutions to Model #3a, Q1F25 related to Q1F2

Q1F25 = f(Q1F2)

Model #3a: $Q1F25 = C(Q1F2)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	2.49	0.97	1.00	5
ENTIAT-WENATCHEE	3.07	0.94	0.99	13
NACHES-YAKIMA	8.85	0.85	0.99	14
BLUE MTS- Subregion 1NE WRIA 35	18.85	0.79	1.00	3
BLUE MTS- Subregion 2SW WRIA 32	2.53	1.02	0.98	14
KLICKITAT	9.85	0.83	0.87	34
WIND-WHITE SALMON	3.84	0.89	1.00	4

Table H-3. Solutions to Model #3b, Q1F100 related to Q1F2

Q1F100 = f(Q1F2)

Model #3b: $Q1F100 = C(Q1F2)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	3.82	0.94	1.00	6
ENTIAT-WENATCHEE	4.40	0.92	0.97	22
NACHES-YAKIMA	20.39	0.79	0.99	12
BLUE MTS- Subregion 1NE WRIA 35	91.80	0.65	1.00	2
BLUE MTS- Subregion 2SW WRIA 32	3.72	1.01	0.94	25
KLICKITAT	13.15	0.91	1.00	7
WIND-WHITE SALMON	5.99	0.85	0.99	5

Table H-4. Peak Flood Flows for Model #4, Related to Q1F2

Station No.	Station Name	Q1F2 (cfs)	PEAK FLOODS QPF2 (cfs)	QPF25 (cfs)	QPF100 (cfs)
1. METHOW-CHELAN					
12442000	TOATS COULEE CREEK NEAR LOOMIS, WASH.	508	524	1690	2570
12447390	ANDREWS CREEK NEAR MAZAMA, WASH.	304	362	784	1060
12449500	METHOW RIVER AT TWISP, WA	10786	11100	21500	25700
12449600	BEAVER CREEK BELOW SOUTH FORK, NEAR TWISP, WASH.	125	135	539	814
12449950	METHOW RIVER NR PATEROS, WASH.	11271	11700	25000	31900
12451000	STEHEKIN RIVER AT STEHEKIN, WASH.	8195	9600	16800	19900
12451500	RAILROAD CREEK AT LUCERNE, WASH.	1192	1260	2630	3430
2. ENTIAT-WENATCHEE					
12452800	ENTIAT RIVER NEAR ARDENVOIR, WASH.	2558	2680	5230	6520
12453000	ENTIAT RIVER AT ENTIAT, WASH.	3469	3380	5740	6860
12454000	WHITE RIVER NEAR PLAIN, WASH.	4165	4650	8260	10500
12456500	CHIWAWA RIVER NEAR PLAIN, WASH.	3066	3150	6720	8640
12458000	ICICLE CREEK ABV SNOW CR NR LEAVENWORTH, WASH.	3834	4420	9990	13700
12461400	MISSION CREEK ABOVE SAND CR NEAR CASHMERE, WASH.				
12483800	NANEUM CREEK NEAR ELLENSBURG, WASH.	375	413	951	1290
3. NACHES-YAKIMA					
12483800	NANEUM CREEK NEAR ELLENSBURG, WASH.	375	413	951	1290
12488500	AMERICAN RIVER NEAR NILE, WASH.	1359	1450	2960	3750
12492500	TIETON RIVER AT CANAL HEADWORKS NR NACHES, WASH.	1751	2370	5210	6800
12494000	NACHES RIVER BELOW TIETON RIVER NR NACHES, WASH.	6582	7040	17430	22707
12500500	NORTH FORK AHTANUM CREEK NEAR TAMPICO, WASH.	364	381	892	1210
12501000	SO FK AHTANUM CR AT CONRAD RNCH N TAMPICO, WASH.	91	97	381	621
12502500	AHTANUM CREEK AT UNION GAP, WASH.				
12506000	TOPPENISH CREEK NEAR FORT SIMCOE, WASH.	671	697	1950	2760
12506500	SIMCOE CR BLW SPRING CR NR FORT SIMCOE, WASH.				
4. BLUE MOUNTAINS					
13334500	ASOTIN CREEK NEAR ASOTIN, WASH.	310	351	1170	1830
13334700	ASOTIN CR BLW KEARNEY GULCH NR ASOTIN, WASH.				
13344500	TUCANNON RIVER NEAR STARBUCK, WASH.	812	1520	6880	10900
14013000	MILL CREEK NEAR WALLA WALLA, WASH.	665	880	3420	5830
14013500	BLUE CREEK NEAR WALLA WALLA, WASH.	197	324	981	1400
14016000	DRY CREEK NEAR WALLA WALLA, WASH.				
14016500	EAST FK TOUCHET R NR DAYTON, WASH.	593	864	2940	4550
14017000	TOUCHET RIVER AT BOLLES, WASH.	1886	2670	7460	10500
14017500	TOUCHET R NR TOUCHET, WASH.	1970	3400	6820	14000
14018500	WALLA WALLA RIVER NEAR TOUCHET, WASH.	4813	6060	20000	29600
5. KLICKITAT					
12506000	TOPPENISH CREEK NEAR FORT SIMCOE, WASH.	671	697	1950	2760
14107000	KLICKITAT R ABV WEST FK NR GLENWOOD, WASH.	1747	1850	3950	5250
14110000	KLICKITAT RIVER NEAR GLENWOOD, WASH.	2847	3190	6900	9130
12506500	SIMCOE CR BLW SPRING CR NR FORT SIMCOE, WASH.	213	247	1360	2270
14112000	LITTLE KLICKITAT R NR GOLDENDALE, WASH.	647	1050	4330	6990
14113000	KLICKITAT RIVER NEAR PITT, WASH.	6334	7840	29500	46600
6. WIND-WHITE SALMON					
14121300	WHITE SALMON R BLW CASCADES CR NR TROUT L, WASH.	503	709	1420	1800
14121500	TROUT LAKE CREEK NR TROUT LAKE, WASH.	1367	1600	3200	4060
14123500	WHITE SALMON R NR UNDERWOOD, WASH.	3892	4610	10600	13900
14124500	LITTLE WHITE SALMON RIVER AT WILLARD, WASH.	2311	2760	4270	4940
14127000	WIND R AB TROUT CREEK NR CARSON, WASH.	4220	5190	8810	10400

Table H-5. Solutions to Model #4a, QPF2 related to Q1F2 by Region.

AVERAGE EQUATION: QPF2 = C(Q1F2)^E

REGION	C	E	R^2	SE%
METHOW-CHELAN	1.14	0.99	1.00	5
ENTIAT-WENATCHEE	1.15	0.99	1.00	5
NACHES-YAKIMA	1.03	1.01	1.00	7
BLUE MOUNTAINS	2.05	0.95	0.97	15
KLICKITAT	1.31	0.99	0.98	14
WIND-WHITE SALMON	2.01	0.94	1.00	4

Table H-6. Solutions to Model #4b, QPF25 related to Q1F2 by Region.

AVERAGE EQUATION: $QPF25 = C(Q1F2)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	6.72	0.87	0.99	13
ENTIAT-WENATCHEE	4.15	0.91	0.97	13
NACHES-YAKIMA	8.74	0.84	0.93	26
BLUE MOUNTAINS	17.93	0.82	0.87	29
KLICKITAT	13.85	0.82	0.84	37
WIND-WHITE SALMON	4.63	0.91	0.96	13

Table H-7. Solutions to Model #4c, QPF100 related to Q1F2 by Region.

AVERAGE EQUATION: QPF100 = C(Q1F2)^E

REGION	C	E	R^2	SE%
METHOW-CHELAN	12.61	0.82	0.98	16
ENTIAT-WENATCHEE	6.49	0.89	0.95	16
NACHES-YAKIMA	8.96	0.87	0.97	19
BLUE MOUNTAINS	10.38	0.95	0.93	24
KLICKITAT	26.47	0.78	0.77	46
WIND-WHITE SALMON	6.46	0.89	0.93	17

APPENDIX I. DATA AND SOLUTIONS FOR STATISTICAL LOW FLOW MODELS #7a, #7b, #7c AND #7d FOR Q7L10, Q7L20, Q30L2 AND Q60L2 CORRELATED TO KEY FLOW Q7L2

APPENDIX I.

DATA AND SOLUTIONS FOR STATISTICAL LOW FLOW MODELS #7a, #7b, #7c AND #7d FOR Q7L10, Q7L20, Q30L2 AND Q60L2 CORRELATED TO KEY FLOW Q7L2

NOTES

1. Data for the low flow statistical models are in Table I-1. A few RI values were not calculated due to records of less than 20 years.
2. The solution tables for C, E, R^2 and SE values are as listed below:

Model #	Low Flow	Table No.	Range of SE%
7a	Q7L10	I-2	6 - 11
7b	Q7L20	I-3	1 - 15
7c	Q30L2	I-4	3 - 7
7d	Q60L2	I-5	7 - 14

3. The low flow models were much better in terms of SE % values than all other models, and all the R^2 values for low flow relationships were either 0.99 or 1.00.
4. Graphical displays of the twenty-four computerized low flow solutions are not included, because the tables of C and E values are all that are required to solve the models. See Figure 11 on page 44 for examples of low flow graphical models.
5. All of the models are contained on the disk that accompanies this report.

Table I-1. Data Summary for Model #7; Q7L10, Q7L20, Q30L2 and Q60L2 Related to Q7L2 by Region.

STATION NO.	STATION NAME	Q7L2 FALL (cfs)	Q7L10 FALL (cfs)	Q7L20 FALL (cfs)	Q30L2 FALL (cfs)	Q60L2 FALL (cfs)
1. METHOW-CHELAN						
12442000	Toats Coulee Creek Near Loomis, Wash.	6.3	4.0		7.6	8.0
12447390	Andrews Creek Near Mazama, Wash.	4.1	2.9	2.5	4.4	4.5
12449500	Methow River At Twisp, Wa	225.7	165.2	150.9	257.5	278.5
12449600	Beaver Creek Below South Fork, Near Twisp, Wash.	5.2	3.6		5.9	6.2
12449950	Methow River Nr Pateros, Wash.	339.3	237.2	227.0	369.4	384.2
12451000	Stehekin River At Stehekin, Wash.	305.3	191.4	144.6	361.0	409.7
12451500	Railroad Creek At Lucerne, Wash.	44.9	25.8	21.0	55.7	64.6
2. ENTIAT-WENATCHEE						
12452800	Entiat River Near Ardenvoir, Wash.	70.5	48.0	43.2	78.5	85.0
12453000	Entiat River At Entiat, Wash.	103.4	82.4	81.0	118.1	127.3
12454000	White River Near Plain, Wash.	158.9	98.4	76.3	194.0	243.3
12456500	Chiwawa River Near Plain, Wash.	90.8	68.4	59.4	102.0	116.8
12458000	Icicle Creek Abv Snow Cr Nr Leavenworth, Wash.	107.0	73.8	52.7	121.4	147.9
12461400	Mission Creek Above Sand Cr Near Cashmere, Wash.	1.9	1.3		2.2	2.5
12483800	Naneum Creek Near Ellensburg, Wash.	13.7	9.2		15.5	16.4
3. NACHES-YAKIMA						
12483800	Naneum Creek Near Ellensburg, Wash.	13.7	9.2		15.5	16.4
12488500	American River Near Nile, Wash.	42.0	28.9	27.7	49.1	54.6
12494000	Naches River Below Tieton River Nr Naches, Wash.	111.3	10.4		168.6	220.6
12500500	North Fork Ahtanum Creek Near Tampico, Wash.	16.0	10.3	8.1	18.7	19.4
12501000	So Fk Ahtanum Cr At Conrad Rnch N Tampico, Wash.	6.3	4.1	3.4	6.7	7.0
12502500	Ahtanum Creek At Union Gap, Wash.	10.7	5.9	5.7	12.9	15.4
12506000	Toppenish Creek Near Fort Simcoe, Wash.	11.9	3.5		12.4	13.2
12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.	0.4			0.4	0.5
4. BLUE MOUNTAINS						
13334500	Asotin Creek Near Asotin, Wash.	28.0	22.8	21.5	29.0	29.6
13334700	Asotin Cr Blw Kearney Gulch Nr Asotin, Wash.	31.5	23.6	22.4	32.6	35.3
13344500	Tucannon River Near Starbuck, Wash.	53.3	38.0	32.2	58.6	62.0
14013000	Mill Creek Near Walla Walla, Wash.	27.6	21.4	19.0	28.7	29.6
14013500	Blue Creek Near Walla Walla, Wash.	0.6	0.3	0.3	0.7	0.8
14016000	Dry Creek Near Walla Walla, Wash.	1.0	0.5		1.2	1.4
14016500	East Fk Touchet R Nr Dayton, Wash.	38.7	31.5	30.4	40.9	41.9
14017000	Touchet River At Bolles, Wash.	29.7	18.1	8.1	33.3	37.8
14017500	Touchet R Nr Touchet, Wash.	20.3	11.0		21.4	27.4
14018500	Walla Walla River Near Touchet, Wash.	8.1	2.6	2.0	11.4	15.0
5. KLICKITAT						
12506000	Toppenish Creek Near Fort Simcoe, Wash.	11.9	3.5		12.4	13.2
12506500	Simcoe Cr Blw Spring Cr Nr Fort Simcoe, Wash.	0.4	0.2		0.4	0.5
14107000	Klickitat R Abv West Fk Nr Glenwood, Wash.	89.5	63.4	55.3	98.3	106.2
14110000	Klickitat River Near Glenwood, Wash.	378.6	296.0	272.3	399.2	410.7
14112000	Little Klickitat R Nr Goldendale, Wash.	1.4	0.6		1.8	2.3
14113000	Klickitat River Near Pitt, Wash.	680.7	523.6	497.0	703.6	731.7
6. WIND-WHITE SALMON						
14121300	White Salmon R Blw Cascades Cr Nr Trout L, Wash.	79.2	70.3	65.1	87.0	90.5
14121400	White Salmon R Ab Tr Lk Cr Nr Trout Lk, Wash.	142.9	133.7		151.4	156.7
14121500	Trout Lake Creek Nr Trout Lake, Wash.	39.4	28.5		42.1	46.2
14123500	White Salmon R Nr Underwood, Wash.	539.8	407.0	392.0	572.3	593.1
14124500	Little White Salmon River At Willard, Wash.	37.7			46.6	57.5
14127000	Wind R Ab Trout Creek Nr Carson, Wash.	78.1	62.9	61.5	84.6	93.7

Table I-2. Solution of Equations, Model #7a, Q7L10 related to Q7L2 by Region.

AVERAGE EQUATION: $Q7L10 = C(Q7L2)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	0.66	1.00	1.00	7
ENTIAT-WENATCHEE	0.75	1.01	1.00	7
NACHES-YAKIMA	0.58	1.06	0.99	6
BLUE MOUNTAINS	0.55	1.10	1.00	11
KLICKITAT	0.51	1.08	1.00	8
WIND-WHITE SALMON	0.89	1.00	0.99	10

Table I-3. Solution of Equations, Model #7b, Q7L20 related to Q7L2 by Region.

AVERAGE EQUATION: $Q7L20 = C(Q7L2)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	0.56	1.00	0.99	15
ENTIAT-WENATCHEE*	0.70	1.00	(n/a)	(n/a)
NACHES-YAKIMA	0.42	1.11	0.99	6
BLUE MOUNTAINS	0.53	1.08	1.00	9
KLICKITAT	0.42	1.09	1.00	1
WIND-WHITE SALMON	1.01	0.95	1.00	1

Notes:

* Equation based on other graphs for Q7L20 & Q7L2 in other regions

Table I-4. Solution of Equations, Model #7c, Q30L2 related to Q7L2 by Region.

AVERAGE EQUATION: $Q30L2 = C(Q7L2)^E$

REGION	C	E	R^2	SE%
METHOW-CHELAN	1.15	1.00	1.00	4
ENTIAT-WENATCHEE	1.14	1.00	1.00	3
NACHES-YAKIMA	0.99	1.06	1.00	7
BLUE MOUNTAINS	1.21	0.97	1.00	7
KLICKITAT	1.11	0.99	1.00	7
WIND-WHITE SALMON	1.27	0.97	1.00	4

Table I-5. Solution of Equations, Model #7d, Q60L2 related to Q7L2 by Region.

AVERAGE EQUATION: $Q60L2^{*} = C(Q7L2)^{E}$

REGION	C	E	R^2	SE%
METHOW-CHELAN	1.19	1.01	1.00	8
ENTIAT-WENATCHEE	1.23	1.02	1.00	7
NACHES-YAKIMA	1.12	1.06	0.99	14
BLUE MOUNTAINS	1.44	0.94	0.99	13
KLICKITAT	1.36	0.96	1.00	10
WIND-WHITE SALMON	1.71	0.92	0.99	9

APPENDIX J. LOGIC FOR USING THE MODELS TO DEVELOP PROJECT SITE HYDROLOGY FOR LOCATIONS ON EAST CASCADE AND BLUE MOUNTAIN STREAMS IN WASHINGTON

APPENDIX J

LOGIC FOR USING THE MODELS TO DEVELOP PROJECT SITE HYDROLOGY FOR LOCATIONS ON EAST CASCADE AND BLUE MOUNTAIN STREAMS IN WASHINGTON

NOTE: The logic in this Appendix describes **what** information is needed to drive the models, **not how** that information is to be generated. The options are either manual (hard-copy) or computerized (GIS), or some combination of the two. The results are applicable to most any water resources problems, not just fish passage at culverts.

INFORMATION NEEDED:

1. Site location in WRIA No. _______, Name______________________
2. Watershed Drainage Area: A__________ sq. mi.
3. Average Annual Precipitation: P___________ inches per year.

Table J-1. Applicable WRIAs for Streamflow Models in this Report.

WRIA No.	**WRIA Name**	**Project Region**
29	Wind-White Salmon	**Wind-White Salmon**
30	Klickitat	**Klickitat**
32	Walla Walla	**Blue Mountains SW**
35	Middle Snake	**Blue Mountains NE**
38	Naches	**Naches-Yakima**
39	Upper Yakima	**Naches-Yakima**
45	Wenatchee	**Entiat-Wenatchee**
46	Entiat	**Entiat-Wenatchee**
47	Chelan	**Methow-Chelan**
48	Methow	**Methow-Chelan**

INFORMATION SUGGESTED:

1. **Stream Name** (or no name).
2. **Tributary** to (named stream).
3. **Map(s)** used: Example: Name and scale (1:24000 if available) of USGS topographic map(s).
4. **Site** Location: Latitude, Longitude; 1/4 Section, Section, Township and Range; County; Miles (direction) from (town or other geographic feature).
5. **Site** Land **Ownership**
6. **Watershed** Land **Ownership**.
7. Dominant Current **Land-Use** Type(s) in Watershed: Forest, Meadow, Agriculture, Urbanizing, Urbanized; Percent Mixture
8. **Upstream conditions** that could affect streamflow at the site: e.g. lakes, ponds, wetlands, reservoirs (regulated or unregulated outflow); diversions (purpose, amount, season, return flow, quality) springs.
9. **Watershed Condition**: stable, unstable; exposed soils; slides; logging debris; mineral debris.
10. Streamflow and Fish **Observations** at Site: miscellaneous flow measurements; washouts; replacement of culvert or bridge; large floods due to bedrock basin; reduced flood peaks due to natural storage; extremely low, low flows; stable low flows year-to-year; fish migration seasons, species, passage success and barrier problems **(See WDFW 1998, 1999 for protocol and procedures)**.

COMPTERIZED SOLUTION:

Once the needed information has been developed (WRIA, Watershed Area, Precipitation) then:

1) Open the Excel workbook "O2FISH_Q.XLS" (or copy the file from the CD-ROM to the hard drive and open in that location).
2) Select the Excel worksheet TAB at the bottom of the window for your project's WRIA.
3) Enter the Site Name, Watershed Drainage Area and Average Annual Precipitation in the appropriate cells of the selected worksheet. No flow values will appear on the selected worksheet unless both the Area and Precipitation values are entered.
4) Print out the selected worksheet or use the "Save As" command to rename and save the workbook to your hard drive.

MANUAL SOLUTION:

Once the needed information has been developed (WRIA, Watershed Area, Precipitation) then:

complete the manual calculations to determine the desired flows using the equations in Table 21 (page 49 of report body) and Appendix G (monthly flows).