U.S. Department of the Interior
U.S. Geological Survey

Equations for Estimating Fish Passage Design Flows at Ungaged Streams in Eastern Washington

Water-Resources Investigations Report 99-4186

Prepared in cooperation with
Washington State Department of Natural Resources

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Multiply	By	To obtain
inch (in)	25.4	millimeter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
square mile (mi^2)	2.590	square kilometer

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ABSTRACT

Washington Administrative Code (WAC) 220-110-070 requires that all bridges and culverts on fish bearing streams be designed to facilitate fish passage. Existing culverts may be assessed to determine whether they are barriers to fish passage. Assessment of the barrier status of some culverts requires that a hydraulic analysis be conducted. The streamflow discharge used to conduct the hydraulic analysis is the high fish passage design flow, which is defined in the WAC as "the flow that is not exceeded more than 10 percent of the time during the months of adult fish migration". The Washington State Department of Natural Resources, which maintains culverts at more than 6,500 stream channel road crossings in eastern Washington, needs a way to estimate the design flow at each of these culverts that requires a hydraulic analysis.

Equations for estimating fish passage design flows at ungaged streams in six eastern Washington regions were developed using data for 79 continuous-record gaging stations and 88 crest-stage gage (annual instantaneous peak discharge) partial-record stations located on unregulated streams in eastern Washington. The equations for three of the regions were developed by ordinary least squares regression analysis between the 10-percent flows during the months of adult fish migration and the basin characteristics drainage area and mean annual precipitation using the base-10 logarithmic transformations of all values. Drainage area was the only basin characteristic used in the development of the regression equations for the other three regions. The standard errors of estimate of the regression equations range from 43 to 112 percent.

Crest-stage gage stations were included in the analyses because nearly all of them are located in small basins (67 percent of them are less than 5 square miles) similar to the ones for which the equations will be used to estimate flows (culverts are normally installed in only relatively small basins), but nearly all the continuous-record stations are located in medium to large basins (87 percent of them are over 50 square miles). The 10-percent flows at the crest-stage gage stations were estimated from ordinary least squares regression equations derived between the 2-year peak discharges and the 10-percent flows at the continuous-record stations. The standard errors of estimate of these equations range from 13 to 41 percent.

INTRODUCTION

Washington Administrative Code (WAC) 220-110-070 Water Crossing Structures (1994) requires that all bridge and culvert structures on fish bearing streams be designed to facilitate fish passage. Existing culverts may be assessed to determine whether they are barriers to fish passage using Washington State Department of Fish and Wildlife guidelines (1998). If the barrier status of a culvert is unknown after completing a Level A preliminary analysis, then a Level B hydraulic analysis must be conducted to determine whether it is a barrier to fish passage. The high fish passage design flow must be known to conduct a Level B hydraulic analysis. This flow, hereafter sometimes referred to as simply the design flow, is defined in the WAC as "the flow that is not exceeded more than 10 percent of the time during the months of adult fish migration". The flow statistic that the design flow is based on, the 10-percent exceedance probability flow during the months of adult fish migration, is hereafter referred to as simply the 10-percent flow. A culvert is considered to be a barrier to fish passage if the flow velocity through it, determined using the design flow, exceeds the maximum allowable velocity established by the WAC.

The Washington State Department of Natural Resources is assessing the barrier status of more than 6,500 culvert road crossings that they maintain on eastern Washington streams. Because it is likely that at least some of these assessments will require a Level B hydraulic analysis, they need a way to estimate design flows.

WAC 220-110-070 allows the use of the 2-year recurrence interval (0.5 exceedance probability) instantaneous peak discharge, a flow statistic for which estimating equations were derived by Sumioka and others (1998), for use in the determination of design flows in place of the 10-percent flow if equations for estimating the latter values are not available. However, because 2-year peak discharges are frequently several times greater than 10-percent flows, use of 2-year peak discharge equations for estimating design flows would likely produce higher discharges than if 10-percent flow equations were used. This could result in the costly overdesign of some culverts. Overdesigned culverts could result in reduced flow depths that, in turn, could adversely affect fish passage during low-flow periods. Therefore, to more accurately determine design flows consistent with the intentions of the WAC, the U.S. Geological Survey (USGS), in cooperation with the Washington State Department of Natural Resources, used 10-percent flows to derive equations for estimating design flows at ungaged streams in eastern Washington. This report describes the development of the equations and presents the data used to develop them.

Because of the diversity of fish species in eastern Washington streams and the different periods during the year when individual runs occur, adult fish migration takes place during most, if not every, month of the year. Therefore, to ensure that maximum allowable flow velocities will not be exceeded during any month of the year, development of the design flow equations was based on discharges during just the months of highest flows.

The Washington State Department of Fish and Wildlife derived equations for determining design flows for streams in western Washington (Powers and Saunders, 1998). These equations were based solely on data for continuous-record gaging stations on streams with less than 50 square miles of drainage because (1) the authors were primarily concerned with flow at culverts and (2) culverts normally are installed only in relatively small drainage basins. However, this approach was not successful for eastern Washington streams because of the lack of a sufficient number of continuous-record gaging stations on watersheds of less than 50 square miles.

The USGS, in cooperation with the Washington State Departments of Transportation and Ecology, conducted a study of the magnitude and frequency of floods in Washington (Sumioka and others, 1998) in which the State was divided into nine geographical regions. In that study regression equations were developed for estimating 2-year peak discharges for ungaged streams in each of the nine regions. The independent variables drainage area and mean annual precipitation were used for six of the regions, but only drainage area was used for the other three regions.

APPROACH

Equations for estimating design flows at ungaged streams in eastern Washington were derived using ordinary least squares regression analyses for six geographical regions (fig. 1) using discharge data and basin characteristics for gaging stations with 10 or more years of record on unregulated streams in eastern Washington. Weighted least squares and generalized least squares regression analyses were considered but were not used because of limitations of the data.

The USGS operates two principal types of streamflow discharge gaging stations—continuous-record stations and crest-stage gage (CSG) partial-record stations. Continuous-record station records typically contain discharge values at 15-minute or 1-hour intervals, from which daily-, monthly-, or annual-mean discharges can be calculated, as well as annual instantaneous peak discharges. The 10-percent flow for a continuous-record station can easily be determined from its record of daily-mean discharges. CSG station records, on the other hand, contain only annual instantaneous peak discharges from which 10-percent flows cannot be directly determined. Discharge records for 79 continuous-record stations and 88 CSG stations on unregulated streams in eastern Washington were available for use.

Although there are a sufficient number of continuous-record stations on eastern Washington streams to adequately define design flow equations, it is questionable whether such equations would accurately estimate flows at culverts. This is because while nearly all of the continuous-record gaging stations are located on streams with medium to large drainage basins (87 percent of them are more than 50 square miles), the basins upstream from culverts, for which the equations will be used to estimate flows, are typically quite small. The Washington State Department of Natural Resources estimates that the average size of the drainage basins upstream of the more than 6,500 culvert road crossings that they maintain on eastern Washington streams is about 2 square miles and that the largest of the basins is only about 10 square miles.

The drainage basins upstream from many of the 88 CSG stations in eastern Washington (67 percent of them are less than 5 square miles) are similar in size to those typically found upstream from culverts, so the discharge records at these stations were included in the development of the design flow equations. In order to incorporate the CSG station records into the analyses, it was first necessary to estimate the 10-percent flow for each station. These estimates were made from the 2-year peak discharge for each of the CSG stations using regression equations developed for the continuous-record stations that relate 10-percent flows with 2-year peak flows. The 2-year peak discharges used for both the CSG and continuous-record gaging stations were obtained from Sumioka and others, 1998.

ESTIMATION OF 10-PERCENT FLOWS AT CREST-STAGE GAGE STATIONS

Daily-mean and 2-year peak discharges for 79 continuous-record stations, with basins ranging in size from 17 to 2,500 square miles, were used to develop equations for estimating 10-percent flows at CSG stations. The station numbers, station names, and period of record for each of the continuous-record stations used are given in table 1. The 2-year peak discharge (from Sumioka and others, 1998, table 2) and the 10-percent flow determined for each of these stations are given in table 2.

The mean-monthly discharges for the continuous-record stations were analyzed to determine which months typically had the highest flows. The high-flow period at most of the stations was found to last for about 3 months and to occur sometime during the 6-month period January through June. The 6-month period was divided into two 3-month periods, January through March and April through June, and the 10-percent flow for each station was determined for whichever one of these 3-month periods best represented the high-flow period at that station.

The 10-percent flow for each continuous-record station was calculated from the daily-mean discharges for the 3-month period of high flow (table 2) using flow duration analysis as described by Searcy (1959). In flow duration analysis, all of the daily-mean discharges for the period of interest are placed in 20 to 30 well-distributed class intervals according to their magnitudes. The total number of values in each class is determined and then accumulated for all classes, starting with the highest class. The percentage of time that the values in each class are equalled or exceeded is determined by dividing the accumulated number of values by the total number of values in all classes. An automated procedure in the USGS Automated Data Processing System (ADAPS) of the USGS National Water Information System (NWIS) was used to calculate the 10-percent flow for each one of the continuous-record stations.

The continuous-record stations were divided into six geographic regions (fig. 1) with similar high flow characteristics. The boundaries of the regions, which are based on USGS hydrologic-unit drainage-area boundaries, are the same as those used by Sumioka and others, 1998. A separate ordinary least squares regression equation was developed for each region except for region 4 by regressing the 10-percent flows with the 2-year peak discharges using the base-10 logarithmic transformations of all values. The equations thus developed are given in table 3. The standard errors of estimate of the regression equations are given in units of both $\log_{10}$ and percent. The percent standard errors, which range from 13 percent for region 2 to 41 percent for region 6, were derived from the formula by Tasker (1978):

$$\text{Standard error in percent} = 100(e^{\sigma^2} - 1)^{1/2} \quad ,$$

where σ is the standard error of estimate expressed in natural (ln) log units. Standard errors in $\log_{10}$ units are converted to ln units by multiplying them by $ln 10$ or 2.3026.

Not enough station records were available in region 4 to define a separate regression equation for that region. Because of this it was decided that one of the equations for the other five regions would be used to estimate 10-percent flows for the CSG stations in region 4. Furthermore, as a factor of safety, it was decided that the equation used should be whichever one predicted the largest 10-percent flows for the smallest basins because the equations will be used primarily, if not completely, to estimate 10-percent flows for small basins. Comparison of the equations for the other five regions indicated that the equation for region 3 best met this criterion. Therefore, that equation was used to determine 10-percent flows for the CSG stations in region 4.

The station number, station name, and period of record for 88 CSG stations for which the 10-percent flow was estimated are given in table 4. Although the total range in drainage basin sizes for these stations is large (0.38 to 523 square miles), more than 67 percent of them are less than 5 square miles and only 2 of them are over 100 square miles. The 2-year peak discharge (from Sumioka and others, 1998, table 2), and the 10-percent flow estimated for each one of the CSG stations using the equations in table 3 are given in table 5.

The accuracy of the 10-percent flows estimated for the CSG stations may be considered somewhat questionable because most of the CSG's are in drainage basins considerably smaller than the range of basin sizes associated with the continuous-record stations used to define the estimating equations. However, the fact that the standard errors of the estimating equations are relatively small increases the likelihood that the estimated flows are of reasonable accuracy.

Note that the 10-percent flow calculated for some of the continuous-record stations was nearly equal to or greater than the 2-year peak discharge (station 12409000, for example) - an occurrence that without further examination may seem impossible. The explanation for this occurrence relates to the differences in the manner in which the two flow statistics are determined. A 2-year peak discharge, which is determined by statistical analysis of the set of instantaneous annual-peak discharges for a station, is said to have a 50-percent chance of being equalled or exceeded each year. On the other hand, because a 10-percent flow is determined by flow-duration analysis of the daily-mean flows for an entire period of record without regard to which year they occur in, the flow thus determined can only be said to have some probability of occurrence for the entire period of record —not for each year of record, as was the case for a 2-year peak flow. Most of the daily-mean discharges that make up the highest 10-percent of the flows at some stations may occur during just a few of the years of record—frequently during the years of the highest annual-peak discharges. Many of the daily-mean discharges during an extreme high-flow period may be considerably higher than the 2-year peak discharge, especially for those eastern Washington streams whose high-flow periods occur in the spring as a result of snowmelt. Snowmelt runoff frequently lasts for several days or weeks, and because runoff during such periods is related only to temperature fluctuations and not to storm events, the instantaneous peak discharge is frequently not significantly higher than the daily-mean discharges on the days immediately before and after the peak.

DEVELOPMENT AND APPLICATION OF REGIONAL REGRESSION EQUATIONS

The only basin characteristics found by Sumioka and others (1998) to be statistically significant in developing peak discharge equations were drainage area and mean annual precipitation. Therefore, because this study also involves the development of equations for a high-flow streamflow statistic, only these two basin characteristics were used as independent variables in the regression analyses. The drainage area and mean annual precipitation (from Sumioka and others, 1998) for each gaging station used in the development of the design flow equations is given in tables 2 and 5. The maximum and minimum basin characteristics values for the gaging stations in each region are given in table 6.

The drainage area and mean annual precipitation (from Sumioka and others, 1998) for each gaging station was determined using geographic information system (GIS) techniques. The drainage areas were determined by digitizing basin boundaries delineated on topographic maps and then using GIS techniques to determine the area within the boundaries. The mean annual precipitation over each basin was determined by averaging the mean annual precipitation grid points that fell within the digitized basin boundary. The grid of mean annual precipitation points was created by GIS procedures from a digitized version of a U.S. Weather Bureau map of mean annual precipitation in Washington (1965)

Equations for estimating the design flow at ungaged streams within regions 1, 3, and 6 were derived by ordinary least squares regression of the 10-percent flows from all available gaging-station records (both those calculated for the continuous-record stations and those estimated for the CSG stations) with the basin characteristics drainage area and mean annual precipitation using the base-10 logarithmic transformations of all values. Drainage area was the only basin characteristic used in the development of the regression equations for regions 2, 4, and 5 because it was the only one that was found to be statistically significant in those regions by Sumioka and others (1998). The equations thus developed for each region are given in table 7. The standard errors of estimate of the regression equations, given in units of both $\log_{10}$ and percent in table 7, indicate how well the regression equations predict 10-percent flows from the data used in the analyses; a higher degree of uncertainty is associated with a higher standard error. The standard errors in percent range from 43 percent for region 6 to 112 percent for region 4.

The design flow for an ungaged stream in eastern Washington can be estimated by (1) determining which region the stream is located in, (2) determining the value(s) of the basin characteristic(s) needed for the regional equation, and (3) entering the value(s) into the equation and calculating the flow. If and how the standard errors of estimate of the regression equations should be applied to the calculated flows is left to the discretion of the user. Application of the equations should be limited to unregulated streams in eastern Washington for which the basin characteristics values are within the range of those used in their development (table 6).

As mentioned previously, 88 percent of the 79 continuous-record gaging stations in eastern Washington are on streams with drainage basins of less than 50 square miles, and even the smallest of these (station 14013500) has a drainage basin of 17 square miles. Installation and operation of several continuous-record gaging stations on small eastern Washington streams should greatly improve the reliability of future analyses involving the need for continuous-record stream discharges for small eastern Washington streams. This would be especially true for the development of updated design flow equations because these equations are applied primarily to drainage basins of less than 10 square miles.

SUMMARY

Washington Administrative Code (WAC) 220-110-070 requires that all bridges and culverts on fish bearing streams be designed to facilitate fish passage. Existing culverts may be assessed to determine whether they are barriers to fish passage. Assessment of the barrier status of some culverts requires that a hydraulic analysis be conducted. The streamflow discharge used to conduct the hydraulic analysis is the high fish passage design flow, which is defined in the WAC as "the flow that is not exceeded more than 10 percent of the time during the months of adult fish migration". The Washington State Department of Natural Resources, which maintains culverts at more than 6,500 road crossings in eastern Washington, needs a way to estimate the design flow at each of these culverts that requires a hydraulic analysis.

Seventy-nine continuous-record gaging stations located on unregulated streams in eastern Washington were available for use in determining the design flow equations. However, the flow equations were not developed solely on the basis of these stations because although the purpose of the design flow equations is to estimate flows at culverts, which normally are installed only in relatively small basins, nearly all of the continuous-record gages are located on streams with medium to large drainage basins. Therefore, the records for 88 crest-stage gage (CSG) stations, which are located primarily in small basins, were also included in the analyses.

The records for the CSG stations were included by estimating the 10-percent flow from the 2-year peak discharge for each station. These estimates were made from ordinary least squares regression equations developed between the 10-percent flows and the 2-year peak flows for the continuous-record stations. The 10-percent flow calculated for each continuous-record gage was for the 3-month period of highest flow (January through March or April through June). The standard errors of estimate of the equations range from 13 to 41 percent.

Equations for estimating the design flow at ungaged streams in eastern Washington were developed for six geographic regions. Equations for three of the regions were developed by ordinary least squares regression analysis between the 10-percent flows from all available gaging-station records (both those calculated for the continuous-record stations and those estimated for the CSG stations) and the basin characteristics drainage area and mean annual precipitation using base-10 logarithmic transformations of all values. Drainage area was the only basin characteristic used in the development of the regression equations for the other three regions. The standard errors of estimate of the regression equations range from 43 to 112 percent.

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FIGURE 1

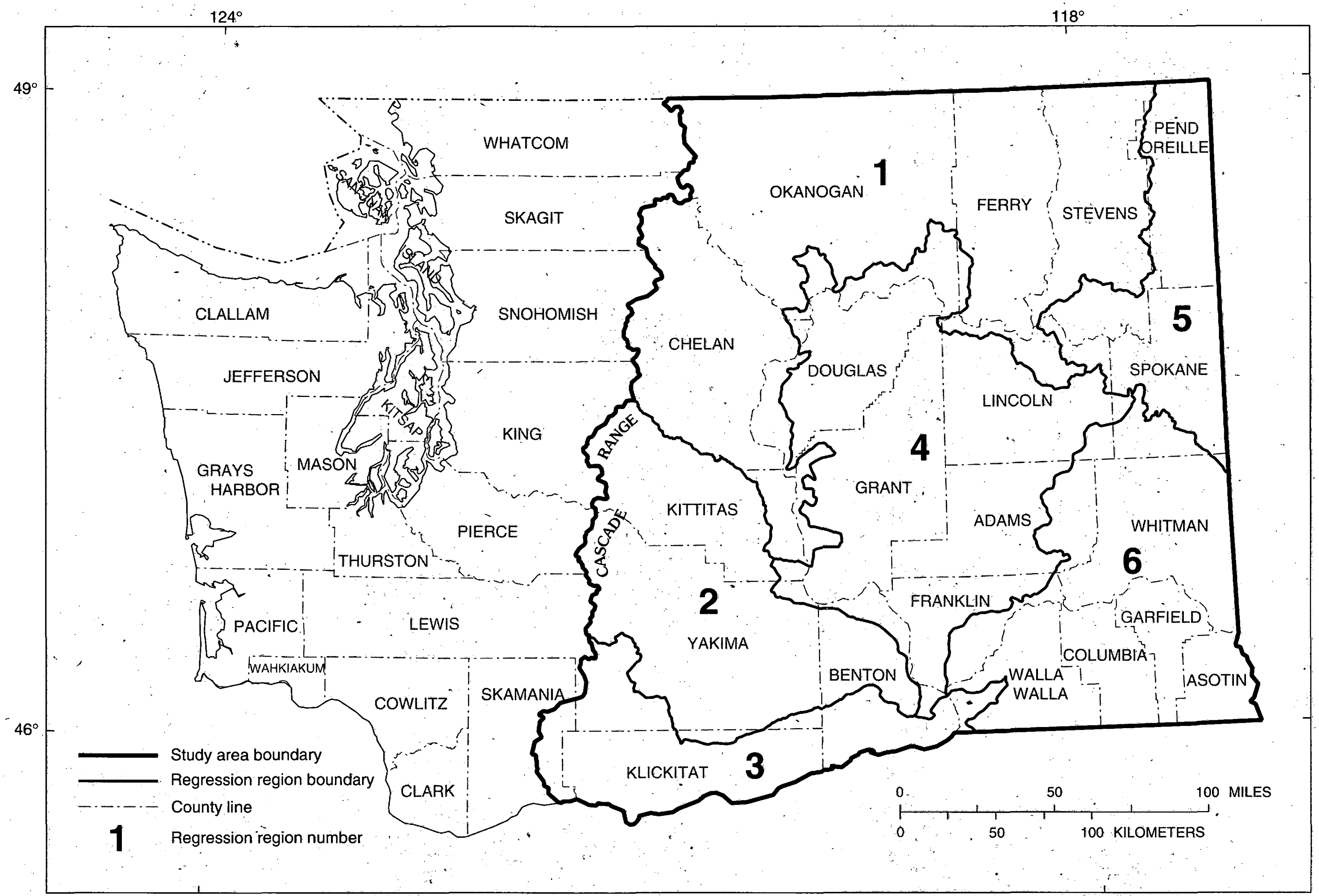

Figure 1. Regions used in the development of regression equations for estimating fish passage design flows at ungaged streams in eastern Washington.

TABLES 1–7

Table 1. Continuous-record gaging stations with at least 10 years of record at unregulated streams in eastern Washington

Station number	Station name	Period of record (Water years)
12396000	Calispell Creek near Dalkena, Wash.	(1951–73)
12396900	Sullivan Creek above Outlet Creek near Metaline Falls, Wash.	(1959–72, 1995–97)
12397500	Sullivan Creek near Metaline Falls, Wash.	(1914–24)
12398000	Sullivan Creek at Metaline Falls, Wash.	(1954–68, 1995–97)
12400500	Sheep Creek near Northport, Wash.	(1930–42, 1948)
12401500	Kettle River near Ferry, Wash.	(1929–96)
12407500	Sheep Creek at Springdale, Wash.	(1953–72)
12407520	Deer Creek near Valley, Wash.	(1960–72)
12407700	Chewelah Creek at Chewelah, Wash.	(1957–74)
12408300	Little Pend Oreille River near Colville, Wash.	(1958–75)
12408420	Haller Creek near Arden, Wash.	(1960–70)
12408500	Mill Creek near Colville, Wash.	(1940–72, 1978–86)
12409000	Colville River at Kettle Falls, Wash.	(1923–96)
12409500	Hall Creek at Inchelium, Wash.	(1913–29, 1948, 1972–73)
12431000	Little Spokane River at Dartford, Wash.	(1929–32, 1947–96)
12433200	Chamokane Creek below falls near Long Lake, Wash.	(1971–79, 1988–96)
12439300	Tonasket Creek at Oroville, Wash.	(1950, 1967–91)
12442000	Toats Coulee Creek near Loomis, Wash.	(1920–26, 1948, 1957–70)
12447390	Andrews Creek near Mazama, Wash.	(1969–96)
12448998	Twisp River near Twisp	(1948, 1975–79, 1990–96)
12449500	Methow River at Twisp, Wash.	(1920–29, 1934–62, 1991–96)
12449600	Beaver Creek below South Fork, near Twisp, Wash.	(1960–78)
12449950	Methow River near Pateros, Wash.	(1948, 1959–96)
12451000	Stehekin River at Stehekin, Wash.	(1911–15, 1927–96)
12451500	Railroad Creek at Lucerne, Wash.	(1911–13, 1927–57)
12452800	Entiat River near Ardenvoir, Wash.	(1958–96)
12453000	Entiat River at Entiat, Wash.	(1911–25, 1948, 1952–58)
12454000	White River near Plain, Wash.	(1955–83)
12455000	Wenatchee River below Wenatchee Lake, Wash.	(1932–58)
12456500	Chiwawa River near Plain, Wash.	(1914, 1937–49, 1955–57, 1991–96)
12457000	Wenatchee River at Plain, Wash.	(1911–29, 1932–79, 1990–96)
12458000	Icicle Creek above Snow Creek near Leavenworth, Wash.	(1912–14, 1937–77, 1994–96)
12459000	Wenatchee River at Peshastin, Wash.	(1929–96)
12461000	Wenatchee River at Dryden, Wash.	(1905–06, 1910–18, 1948)
12461400	Mission Creek above Sand Creek near Cashmere, Wash.	(1959–71)
12462500	Wenatchee River at Monitor, Wash.	(1963–96)
12463000	Douglas Creek near Alstown, Wash.	(1948, 1950–55, 1963–68)
12465000	Crab Creek at Irby, Wash.	(1943–96)
12483800	Naneum Creek near Ellensburg, Wash.	(1957–72, 1974–78))
12488500	American River near Nile, Wash.	(1940–96)
12489500	Naches River at Oak Flat near Nile, Wash.	(1905–17)

Table 1. Continuous–record gaging stations with at least 10 years of record at unregulated streams in eastern Washington—Continued

Station number	Station name	Period of record (Water years)
12492500	Tieton River at Canal Headworks near Naches, Wash.	[1](1908–78)
12500500	North Fork Ahtanum Creek near Tampico, Wash.	(1908, 1910–21, 1932–79)
112501000	South Fork Ahtanum Creek at Conrad Ranch near Tampico, Wash.	(1915–24, 1931–78)
12502000	Ahtanum Creek at The Narrows near Tampico, Wash.	(1909–13, 1960–68)
12502500	Ahtanum Creek at Union Gap, Wash.	(1908, 1910, 1912–14, 1952, 1960–96)
12506000	Toppenish Creek near Fort Simcoe, Wash.	[2](1910–24)
12506500	Simcoe Creek below Spring Creek near Fort Simcoe, Wash.	(1909–23)
13334500	Asotin Creek near Asotin, Wash.	(1904, 1929–59)
13334700	Asotin Creek below Kearney Gulch near Asotin, Wash.	(1960–82, 1990–96)
13344500	Tucannon River near Starbuck, Wash.	(1915–17, 1929–31, 1959–90, 1995–96)
13348000	South Fork Palouse River at Pullman, Wash.	(1934–42, 1948, 1959–81, 1996)
13348500	Missouri Flat Creek at Pullman, Wash.	(1935–40, 1948, 1960–79, 1996)
13349210	Palouse River below South Fork at Colfax, Wash.	(1963–96)
13349400	Pine Creek at Pine City, Wash.	(1962–75)
13350500	Union Flat Creek near Colfax, Wash.	(1954–71)
13351000	Palouse River at Hooper, Wash.	(1898–99, 1901–07, 1909–16, 1948, 1951–96)
14013000	Mill Creek near Walla Walla, Wash.	(1914-17, 1931, 1940-96)
14013500	Blue Creek near Walla Walla, Wash.	(1940-42, 1944-71)
14016000	Dry Creek near Walla Walla, Wash.	(1949-53, 1955-67)
14016500	East Fork Touchet River near Dayton, Wash.	(1944-51, 1956-68)
14017000	Touchet River at Bolles, Wash.	(1925-29, 1952-89, 1996)
14017500	Touchet River near Touchet, Wash.	(1942, 1944, 1946-53, 1955)
14018500	Walla Walla River near Touchet, Wash.	(1949, 1952-96)
14107000	Klickitat River above West Fork near Glenwood, Wash.	(1945-78, 1992-96)
14110000	Klickitat River near Glenwood, Wash.	(1910-56, 1958-71)
14112000	Little Klickitat River near Goldendale, Wash.	(1911-12, 1947-50, 1958-70)
14112500	Little Klickitat River near Wahkiacus, Wash	(1945-49, 1951-81)
14113000	Klickitat River near Pitt, Wash.	(1910-12, 1929-96)
14121300	White Salmon River below Cascades Creek near Trout Lake, Wash.	(1958-78)
14121500	Trout Lake Creek near Trout Lake, Wash.	(1910-11, 1960-69)
14122000	White Salmon River near Trout Lake, Wash.	(1929-31, 1958-67)
14123000	White Salmon River at Husum, Wash.	(1910-18, 1930-41, 1958-62)
14123500	White Salmon River near Underwood, Wash.	(1916-30, 1936-96)
14124500	Little White Salmon River at Willard, Wash.	(1945-61)
14125000	Little White Salmon River above Lapham Creek, Willard, Wash.	(1950-63)
14125500	Little White Salmon River near Cook, Wash.	(1957-77)
14127000	Wind River above Trout Creek near Carson, Wash.	(1945-69)
14128500	Wind River near Carson, Wash.	(1935-77)

[1] Used only the period of record 1908-24 because flow regulated by Rimrock Lake beginning in 1925.

[2] Used only the period of record 1909-19 because of significant diversions to Toppenish feeder canal beginning in 1920.

Table 2. Basin characteristics, 2-year peak discharge, and 10-percent flow at continuous-record gaging stations used in development of regression equations for estimating fish passage design flows at ungaged streams in eastern Washington

[ft^3/s, cubic feet per second; A, 10-percent flow calculated for the months of April through June; B, 10-percent flow calculated for the months of January through March]

Station number	Regression region	Contributing drainage area[1] (square miles)	Mean annual precipitation[1] (inches)	2-year peak discharge[1] (ft^3/s)	10-percent flow (ft^3/s)	3-month high-flow period
12396000	5	68.3	38	525	349	A
12396900	5	70.2	45	1,010	738	A
12397500	5	122	37	989	827	A
12398000	5	142	37	1,260	1,120	A
12400500	1	225	25	1,720	1,340	A
12401500	1	2,220	27	12,300	9,380	A
12407500	1	48.2	18	44	24	A
12407520	1	36	20	119	84	A
12407700	1	94.1	22	165	158	A
12408300	1	132	29	301	293	A
12408420	1	37	20	41	45	A
12408500	1	83	26	298	241	A
12409000	1	1,007	21	1,140	1,240	A
12409500	1	160	20	390	402	A
12431000	5	665	25	1,300	831	A
12433200	5	179	20	373	207	A
12439300	1	60.1	15	54	18	A
12442000	1	130	29	523	340	A
12447390	1	22.1	35	368	236	A
12448998	1	245	40	1,910	1,400	A
12449500	1	1,301	35	11,200	8,060	A
12449600	1	62	24	133	137	A
12449950	1	1,772	32	11,800	8,770	A
12451000	1	321	99	9,600	5,690	A
12451500	1	64.8	52	1,270	850	A
12452800	1	203	59	2,680	1,940	A
12453000	1	419	45	3,380	2,600	A
12454000	1	150	108	4,640	3,150	A
12455000	1	273	100	7,040	5,080	A
12456500	1	172	78	3,140	2,410	A
12457000	1	591	69	11,600	8,950	A
12458000	1	193	88	4,420	2,800	A

Table 2. Basin characteristics, 2-year peak discharge, and 10-percent flow at continuous-record gaging stations used in development of regression equations for estimating fish passage design flows at ungaged streams in eastern Washington—Continued

Station number	Regression region	Contributing drainage area[1] (square miles)	Mean annual precipitation[1] (inches)	2-year peak discharge[1] (ft^3/s)	10-percent flow (ft^3/s)	3-month high-flow period
12459000	1	1,000	67	16,100	12,400	A
12461000	1	1,160	62	17,400	13,300	A
12461400	1	39.8	25	181	54	A
12462500	1	1,301	60	17,500	13,000	A
12463000	4	99.9	11	490	27	B
12465000	4	1,042	13	814	433	B
12483800	2	69.5	25	412	279	A
12488500	2	78.9	74	1,460	975	A
12489500	2	638	45	5,930	4,810	A
12492500	2	239	57	2,390	1,540	A
12500500	2	68.9	53	380	298	A
12501000	2	24.8	54	96	74	A
12502000	2	119	49	538	306	A
12502500	2	173	38	421	294	A
12506000	2	122	29	696	424	A
12506500	2	81.5	39	241	142	B
13334500	6	156	22	338	227	A
13334700	6	170	24	413	204	A
13344500	6	431	23	1,510	442	A
13348000	6	132	22	1,060	243	B
13348500	6	27.1	21	398	65	B
13349210	6	796	25	5,950	1,960	B
13349400	6	302	18	1,970	402	B
13350500	6	189	18	889	216	B
13351000	6	2,500	18	7,930	3,490	B
14013000	6	59.6	40	878	292	B
14013500	6	17	36	324	68	B
14016000	6	48.4	29	548	89	B
14016500	6	102	30	862	289	A
14017000	6	361	25	2,700	836	B
14017500	6	733	20	3,520	926	B
14018500	6	1,657	22	6,110	2,320	B
14107000	3	151	58	1,840	1,310	A

Table 2. Basin characteristics, 2-year peak discharge, and 10-percent flow at continuous-record gaging stations used in development of regression equations for estimating fish passage design flows at ungaged streams in eastern Washington—Continued

Station number	Regres-sion region	Contri-buting drainage area[1] (square miles)	Mean annual precipi-tation[1] (inches)	2-year peak discharge[1] (ft^3/s)	10-percent flow (ft^3/s)	3-month high-flow period
14110000	3	360	56	3,180	2,530	A
14112000	3	83.5	25	1,070	296	B
14112500	3	280	25	3,260	766	B
14113000	3	1,297	36	7,840	3,930	B
14121300	3	32.4	106	699	342	A
14121500	3	69.3	82	1,590	709	A
14122000	3	185	82	1,979	971	A
14123000	3	294	71	2,760	1,820	A
14123500	3	386	66	4,600	2,410	B
14124500	3	114	70	2,780	1,200	B
14125000	3	117	70	2,520	1,400	B
14125500	3	134	70	3,300	1,590	B
14127000	3	108	103	5,240	1,660	B
14128500	3	225	99	13,800	3,800	B

[1]From Sumioka and others, 1998.

Table 3. Regression equations for estimating 10-percent flows during the months of adult fish migration at crest-stage gage stations in eastern Washington

[Q, 10-percent flow, in cubic feet per second; X, 2-year peak discharge, in cubic feet per second; a, regression constant; b, regression coefficient]

Region	Number of stations used in analysis	Regression equation	Constant a	Coefficient b	Standard error or estimate, log 10	Standard error of estimate, percent
1	30	$Q = aX^b$	0.646	1.02	.125	29
2	10	$Q = aX^b$	.624	1.01	.056	13
3	15	$Q = aX^b$	.953	.907	.159	38
[1]4						
5	6	$Q = aX^b$	.143	1.24	.062	14
6	16	$Q = aX^b$	.189	1.06	.173	41

[1]Use equation derived for region 3.

Table 4. Crest-stage gage stations with at least 10 years of record at unregulated streams in eastern Washington

Station number	Station name	Period of record (Water years)
12395800	Deer Creek near Dalkena, Wash.	(1954–73)
12395900	Davis Creek near Dalkena, Wash.	(1954–73)
12396100	Winchester Creek near Cusick, Wash.	(1954–88)
12396450	Little Muddy Creek at Ione, Wash.	(1954–73)
12403700	Third Creek near Curlew, Wash.	(1954–73)
12405400	Nancy Creek near Kettle Falls, Wash.	(1952, 1954–72)
12407600	Thomason Creek near Chewelah, Wash.	(1954–73)
12408200	Patchen (Bighorn) Creek near Tiger, Wash.	(1954–73)
12408400	Narcisse Creek near Colville, Wash.	(1954–73)
12410600	South Fork Harvey Creek near Cedonia, Wash.	(1954–73)
12410650	North Fork Harvey Creek near Cedonia, Wash.	(1954–73)
12423550	Hangman Creek Tributary near Latah, Wash.	(1961–76)
12423700	South Fork Rock Creek Tributary near Fairfield, Wash.	(1962–76)
12423900	Stevens Creek Tributary near Moran, Wash.	(1954–73)
12429200	Bear Creek near Milan, Wash.	(1963–75)
12429600	Deer Creek near Chattaroy, Wash.	(1962–75)
12429800	Mud Creek near Deer Park, Wash.	(1954–73)
12430370	Bigelow Gulch near Spokane, Wash.	(1950, 1962–75)
12431100	Little Creek at Dartford, Wash.	(1963–77)
12433300	Spring Creek Tributary near Reardan, Wash.	(1954–73)
12433580	Cottonwood (Hawk) Creek at Davenport, Wash.	(1957, 1959, 1963–77)
12433800	Granite Creek near Republic, Wash.	(1954–73)
12437930	East Fork Foster Creek at Leahy, Wash.	(1959, 1963–77)
12437950	East Fork Foster Creek Tributary near Bridgeport, Wash.	(1957–77)
12437960	West Fork Foster Creek near Bridgeport, Wash.	(1957, 1963–77)
12441700	Middle Fork Toats Coulee Creek near Loomis, Wash.	(1965–70, 1972–75)
12445800	Omak Creek Tributary near Disautel, Wash.	(1955–75)
12447380	Pine Creek near Mazama, Wash.	(1966–88)
12447400	Doe Creek near Winthrop, Wash.	(1957–75)
12447430	Ortell Creek near Winthrop, Wash.	(1965–75)
12448700	Williams Creek near Twisp, Wash.	(1965–75)
12448900	Little Bridge Creek near Twisp, Wash.	(1965–75)
12449790	Rainy Creek near Methow, Wash.	(1965–75)
12452880	Tillicum Creek near Ardenvoir, Wash.	(1965–75)
12454290	Little Wenatchee River Tributary near Telma, Wash.	(1965–75)
12456300	Brush Creek near Telma, Wash.	(1965–75)
12457300	Skinney Creek at Winton, Wash.	(1954–73)
12457900	Chatter Creek near Leavenworth, Wash.	(1966–75)
12458900	Posey Canyon near Leavenworth, Wash.	(1954–73)
12459400	Tronsen Creek near Peshastin, Wash.	(1960–75)
12461100	East Branch Mission Creek near Cashmere, Wash.	(1955–74)

Table 4. Crest-stage gage stations with at least 10 years of record at unregulated streams in eastern Washington—Continued

Station number	Station name	Period of record (Water years)
12461200	East Branch Mission Creek Tributary near Cashmere, Wash.	(1955–88)
12461500	Sand Creek near Cashmere, Wash.	(1954–73)
12462000	Mission Creek at Cashmere, Wash.	(1948,1954–73)
12463600	Rattlesnake Creek Tributary near Soap Lake, Wash.	(1959, 1961–77)
12463700	McCarteney Creek Tributary near Farmer, Wash.	(1960, 1962–76)
12464600	Schnebly Coulee Tributary near Vantage, Wash.	(1955–74)
12464650	South Fork Crab Creek Tributary at Waukon, Wash.	(1954–73)
12465300	Broadax Draw Tributary near Wilbur, Wash.	(1955–74)
12465400	Wilson Creek below Corbett Draw near Almira, Wash.	(1969–79, 1992–94)
12467400	Haynes Canyon near Coulee City, Wash.	(1959–76)
12470300	Iron Springs Creek near Winchester, Wash.	(1959–76)
12471100	Paha Coulee Tributary near Ritzville, Wash.	(1962–76)
12474700	Mosquito Creek near Easton, Wash.	(1968–77)
12480700	Hovey Creek near Cle Elum, Wash.	(1955–74)
12483300	South Fork Manastash Creek Tributary near Ellensburg, Wash.	(1955–74)
12485900	Pine Canyon near Naches, Wash.	(1961–76)
12487400	Deep Creek near Goose Prairie, Wash.	(1966–75)
12488300	American River Tributary near Nile, Wash.	(1955–74)
12491700	Hause Creek near Rimrock, Wash.	(1955–88)
12507600	Shinando Creek Tributary near Goldendale, Wash.	(1955–74)
12512600	Hatton Coulee Tributary No.2 near Cunningham, Wash.	(1961–76)
12512700	Hatton Coulee Tributary near Hatton, Wash.	(1956 –75))
13335200	Critchfield Draw near Clarkston, Wash.	(1959–76)
13343450	Dry Creek at mouth near Clarkston, Wash.	(1963–77)
13343520	Clayton Gulch near Alpowa, Wash.	(1961–76)
13343620	South Fork Deadman Creek Tributary near Pataha, Wash.	(1961–76)
13343660	Smith Gulch Tributary near Pataha, Wash.	(1955–74)
13348400	Missouri Flat Creek Tributary near Pullman, Wash.	(1955–74)
13349300	Palouse River Tributary at Colfax, Wash.	(1955–88)
13349350	Hardman Draw Tributary at Plaza, Wash.	(1955–74)
13349500	Rock Creek near Ewan, Wash.	(1904–05, 1915–17, 1959, 1963, 1965–75)
13349800	Imbler Creek Tributary near Lamont, Wash.	(1967–77)
13352200	Cow Creek Tributary near Ritzville, Wash.	(1951, 1955–73)
13352550	Stewart Canyon Tributary near Riparia, Wash.	(1958–75)
14015900	Spring Creek Tributary near Walla Walla, Wash.	(1955–74)
14016600	Hatley Creek near Dayton, Wash.	(1955–74)
14017040	Thorn Hollow near Dayton, Wash.	(1962–76)
14017070	East Fork McKay Creek near Huntsville, Wash.	(1963–77)
14017200	Badger Hollow near Clyde, Wash.	(1955–74)
14034250	Glade Creek Tributary near Bickleton, Wash.	(1961–76)
14034325	Alder Creek near Bickleton, Wash.	(1963–77)

Table 4. Crest-stage gage stations with at least 10 years of record at unregulated streams in eastern Washington—Continued

Station number	Station name	Period of record (Water years)
14111800	West Prong Little Klickitat River near Goldendale, Wash.	(1961–75)
14112200	Little Klickitat River Tributary near Goldendale, Wash.	(1960–88)
14112400	Mill Creek near Blockhouse, Wash.	(1965–78)
14125200	Rock Creek near Willard, Wash.	(1949–68)
14126300	Columbia River Tributary at Home Valley, Wash.	(1950–70)
14127200	Layout Creek near Carson, Wash.	(1966–75)

Table 5. Basin characteristics, 2-year peak discharge, and estimated 10-percent flow at crest-stage gage stations used in development of regression equations for estimating fish passage design flows at ungaged streams in eastern Washington

[ft³/s, cubic feet per second]

Station number	Regression region	Contributing drainage area[1] (square miles)	Mean annual precipitation[1] (inches)	2-year peak discharge[1] (ft³/s)	10-percent flow[2] (ft³/s)
12395800	5	4.75	36	45	35
12395900	5	16.8	36	88	67
12396100	5	16.8	37	80	61
12396450	5	11.3	29	92	70
12403700	1	1.18	24	9.5	6.4
12405400	1	11.9	20	54	38
12407600	1	4.08	20	6.0	4.0
12408200	1	1.65	34	9.3	6.3
12408400	1	11.1	25	28	19
12410600	1	18.1	21	22	15
12410650	1	6.96	22	5.7	3.8
12423550	5	2.18	20	55	43
12423700	5	.59	22	25	20
12423900	5	2.02	22	18	14
12429200	5	10.5	22	50	39
12429600	5	31.9	28	138	105
12429800	5	1.83	18	12	9.6
12430370	5	2.07	18	23	18
12431100	5	11.9	20	39	30
12433300	5	1.14	15	48	37
12433580	1	23.2	15	176	126
12433800	1	4.25	19	12	8.1
12437930	4	35.4	12	73	47
12437950	4	4.75	12	24	17
12437960	4	28	12	60	39
12441700	1	17.1	32	206	148
12445800	1	4.12	18	6.2	4.2
12447380	1	4.63	80	158	113
12447400	1	3.8	19	24	17
12447430	1	4.05	22	54	38
12448700	1	3.15	30	59	41
12448900	1	16.6	35	132	94
12449790	1	8.51	30	55	38

Table 5. Basin characteristics, 2-year peak discharge, and estimated 10-percent flow at crest-stage gage stations used in development of regression equations for estimating fish passage design flows at ungaged streams in eastern Washington—Continued

Station number	Regression region	Contributing drainage area[1] (square miles)	Mean annual precipitation[1] (inches)	2-year peak discharge[1] (ft^3/s)	10-percent flow[2] (ft^3/s)
12452880	1	7.15	40	32	22
12454290	1	1.02	35	96	68
12456300	1	3.34	40	66	46
12457300	1	2.55	41	28	19
12457900	1	2.25	80	54	38
12458900	1	1.36	23	2.3	1.5
12459400	1	3.44	27	27	19
12461100	1	15.4	25	22	15
12461200	1	2.49	22	6.8	4.6
12461500	1	18.6	24	64	45
12462000	1	81.2	21	182	130
12463600	4	2.22	10	9.0	7.0
12463700	4	.4	10	5.3	4.3
12464600	1	.82	12	6.6	4.4
12464650	4	.68	17	18	13
12465300	4	1.12	13	23	16
12465400	4	327	12	1,040	519
12467400	4	2.7	10	5.8	4.7
12470300	4	1.57	10	17	12
12471100	4	8.52	12	114	70
12474700	2	1.07	85	82	53
12480700	2	2.65	30	31	20
12483300	2	2.12	18	33	21
12485900	2	2.26	13	12	7.7
12487400	2	12.7	55	464	308
12488300	2	1.1	48	17	11
12491700	2	3.91	25	26	17
12507600	2	.38	24	3.5	2.2
12512600	4	2.44	10	3.0	2.6
12512700	4	3.71	10	4.1	3.4
13335200	6	1.8	14	17	3.8
13343450	6	6.83	14	78	19
13343520	6	5.6	15	100	25
13343620	6	.54	17	26	6.0

Table 5. Basin characteristics, 2-year peak discharge, and estimated 10-percent flow at crest-stage gage stations used in development of regression equations for estimating fish passage design flows at ungaged streams in eastern Washington—Continued

Station number	Regression region	Contributing drainage area[1] (square miles)	Mean annual precipitation[1] (inches)	2-year peak discharge[1] (ft^3/s)	10-percent flow[2] (ft^3/s)
13343660	6	1.85	16	50	12
13348400	6	.88	21	36	8.4
13349300	6	2.1	20	29	6.7
13349350	6	1.64	18	32	7.4
13349500	6	523	17	1,140	329
13349800	6	1.33	13.5	59	14
13352200	6	1.51	13	22	5.0
13352550	6	1.27	12	21	4.8
14015900	6	1.94	20	22	5.0
14016600	6	4.12	23	77	19
14017040	6	2.68	19	35	8.2
14017070	6	4.92	18	59	14
14017200	6	4.16	16	47	11
14034250	3	.5	13	7.3	5.8
14034325	3	8.35	10	207	120
14111800	3	10.4	25	105	65
14112200	3	.71	20	25	18
14112400	3	26.9	21	113	69
14125200	3	4.1	55	192	112
14126300	3	.54	70	44	29
14127200	3	1.8	116	342	189

[1]From Sumioka and others, 1998.

[2]Estimated using the equations in table 3.

Table 6. Maximum and minimum values of basin characteristics used in the regression analyses to develop equations for estimating fish passage design flows at ungaged streams in eastern Washington

[--, basin characteristic not used in regression equation]

Region[1]	Contributing drainage area (square miles)	Mean annual precipitation (inches)
Region 1		
Maximum	2,220	108
Minimum	.82	12.0
Region 2		
Maximum	638	--
Minimum	.38	--
Region 3		
Maximum	1,297	116
Minimum	.5	10.0
Region 4		
Maximum	1,042	--
Minimum	.40	--
Region 5		
Maximum	665	--
Minimum	.59	--
Region 6		
Maximum	2,500	40.0
Minimum	.54	12.0

[1]See figure 1 for location.

Table 7. Regression equations for estimating fish passage design flows at ungaged streams in eastern Washington

[Q, fish passage design flow, in cubic feet per second; A, total drainage area, in square miles; P, mean annual precipitation, in inches; a, regression constant; b and c, regression coefficients; --, regression coefficient not determined]

Region	Number of stations used in analysis	Regression equation	Constant a	Coefficients b	Coefficients c	Standard error of estimate, log 10	Standard error of estimate, percent
1	59	$Q = aA^bP^c$	0.0178	0.900	1.68	.319	84
2	18	$Q = aA^b$	9.45	.836	--	.353	97
3	23	$Q = aA^bP^c$	1.64	.657	.799	.195	47
4	15	$Q = aA^b$	5.97	.589	--	.391	112
5	19	$Q = aA^b$	4.89	.690	--	.362	100
6	33	$Q = aA^bP^c$	.772	.764	.663	.179	43

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