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Andrew L. Lieuwen for the degree of Master of Science

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Title: Estimating Streamflow Characteristics for Micro-hydro Sites in Northwestern Oregon

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A methodology for estimating streamflow characteristics on ungaged streams was developed for northwestern Oregon. Basin area and basin area multiplied by the square root of relief were found to be effective independent variables in regression models for estimating the average annual flow, the average daily flood with a two-year recurrence interval, and the seven day average low flow with a two-year recurrence interval. A method for constructing synthetic flow-duration curves from estimates of these three flow characteristics is described. These synthetic flow-duration curves provide important information for assessing hydropower potential for micro-hydro sites in this region.

Estimating Streamflow Characteristics for Micro-hydro Sites in Northwestern Oregon

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ESTIMATING STREAMFLOW CHARACTERISTICS FOR MICRO-HYDRO SITES IN NORTHWESTERN OREGON

I. INTRODUCTION

For centuries, flowing water has been recognized as a renewable energy source. Since the invention of hydroelectric power in 1869, various scales of water powered generators have produced electricity worldwide. Today, the term hydropower is commonly associated with large dams and generating facilities which produce relatively low cost electricity, particularly in the northwestern United States. Natural resource scarcity and consequent escalation in energy costs have rekindled interest in smaller scales of hydropower.

In the United States, this interest enhanced by a 1978 federal law requiring utilities to buy power from people who operate small hydro-electric systems. The term "micro-hydro" refers to systems that generally have outputs less than 100 kilowatts and are used for individual homes, farms, or shops. The principal objective of this study is to develop an efficient methodology for estimating streamflow characteristics for application to micro-hydro site analyses.

One of the fundamental problems associated with micro-hydro development is the assessment of the power and energy potential of the site. The available power, which can be expressed in kilowatts, is basically a product of two hydraulic components, stream discharge and available head. Since the head is fixed by design constraints, the power production (and hence the physical feasibility) of a project is a direct function of flow.

Because discharge varies both seasonally and annually, reliable estimates of the hydrologic characteristics of small, ungaged streams are difficult to obtain in a short time period. Flow-duration curves provide concise pictures of flow variability at a point on a stream, which is essential information for maximizing the power that the site is capable of yielding. Synthetic flow-duration curves can be generated from estimates of low, average, and flood flows. In this study, estimation models for these flow characteristics are developed for northwestern Oregon.

II. LITERATURE REVIEW

Quantitative models applied in hydrologic analyses can be classified as deterministic, parametric, stochastic, or a combination of these. Haan (1977) notes that there are not distinct divisions between these three basic types, rather they are "made up of some combination of components, each of which represents a point on a continuous spectrum of model "types" ranging from completely deterministic on the one hand to completely stochastic on the other." A wide range of model types has been used to estimate streamflow characteristics.

Numerous investigators have developed regional multiple regression models for estimating low, average and flood flows. Thomas and Benson (1970) used multiple regression analysis to estimate streamflow characteristics in four hydrologically dissimilar regions in the United States. Their correlations for the humid Eastern and Southern regions were superior to those for the more arid Central and Western regions. They showed that flows nearest the mean could be estimated more accurately than high flows, which could be estimated more accurately than low flows.

Various climatologic and geomorphic parameters are used as streamflow predictor variables. Rango et al. (1977) demonstrated that snow-covered areas were significantly related to seasonal streamflow in the Indus and Kabul River basins in Pakistan. Basin elevation, slope, and rise were important in predicting water yield from high mountain watersheds in the western United States (Julian et al., 1967). In Finland, Mustonen (1967) found that annual runoff correlated much stronger with seasonal precipitation and mean annual temperature than with soil type or vegetation indexes. In the northeastern United States, Lull and Sopper (1966) determined that average annual and seasonal runoff were most closely related to isohyetal annual precipitation, percentage of forest cover, elevation, latitude, July mean maximum temperature and percentage of swamp. Several authors have cited drainage area as the principal variable for estimating streamflows in relatively homogeneous hydrologic regions (Riggs, 1964; Hudzikiewicz, 1968; Orwig, 1973; Lowham, 1976). For small mountain watersheds in western Oregon, Marston (1978) found significant relationships between drainage density and mean annual runoff; topography and base flow; and stream frequency and mean annual peak flow.

Through applications of dimensional analysis, Strahler (1958) and Orsborn (1974; 1976; 1981) have developed hydrogeologic, output-output methods for predicting ungaged streamflows. In the mid-coast region of Oregon, Orsborn (1981) developed streamflow prediction models incorporating only basin area and relief.

Synthetic flow-duration curves have been developed from estimates of streamflow characteristics. Searcy (1959) showed how base flow could be used to estimate a flow-duration curve. Dingman (1978) made useful estimates of flow-duration curves for ungaged points on unregulated streams in New Hampshire using basin area and mean basin elevation. In Oregon, Klingeman (1979) developed synthetic flow duration curves from generalized flow-duration curves produced from stream gage data. A method for generating flow-duration curves from estimates of low, average, and flood flows is presented by Orsborn

(1980). Broadus (1981) developed a computer package for calculating duration curves from monthly average flow rates. Methods of assessing energy potential from synthetic flow-duration curves are described by Searcy (1959), Klingeman (1979), and Broadus (1981).

III. STUDY AREA

Location and Description of Provincial Divisions

For purposes of this study, northwestern Oregon (Figure 1) is bounded by the Pacific Ocean to the west, the Columbia River to the north, and the Cascade Mountains to the east. The southern boundary is defined by the Calapooya Mountains and the Siuslaw River drainage divide.

Six provinces of assumed hydrologic homogeneity were originally determined for this study. These provinces, selected on the basis of general geomorphic and climatic similarities are shown in Figure 1. These are: 1) the northern division of the west slopes of the Cascades; 2) the southern division of the west slopes of the Cascades; 3A) the southern division of the east slopes of the Coast Range; 3B) the northern division of the east slopes of the Coast Range; 4A) the northern division of the west slopes of the Coast Range; and 4B) the southern division of the west slopes of the Coast Range. The results of the hydrologic analyses indicated that the only north-south division necessary for developing provincial models was in the Cascades. Hence, 3A, 3B, 4A and 4B rather than 3, 4, 5, and 6 are used as reference numbers for the Coast Range provinces. General descriptions of the region's topography, geohydrology and climate follow.

Topography

The major topographic features of this region are from west to

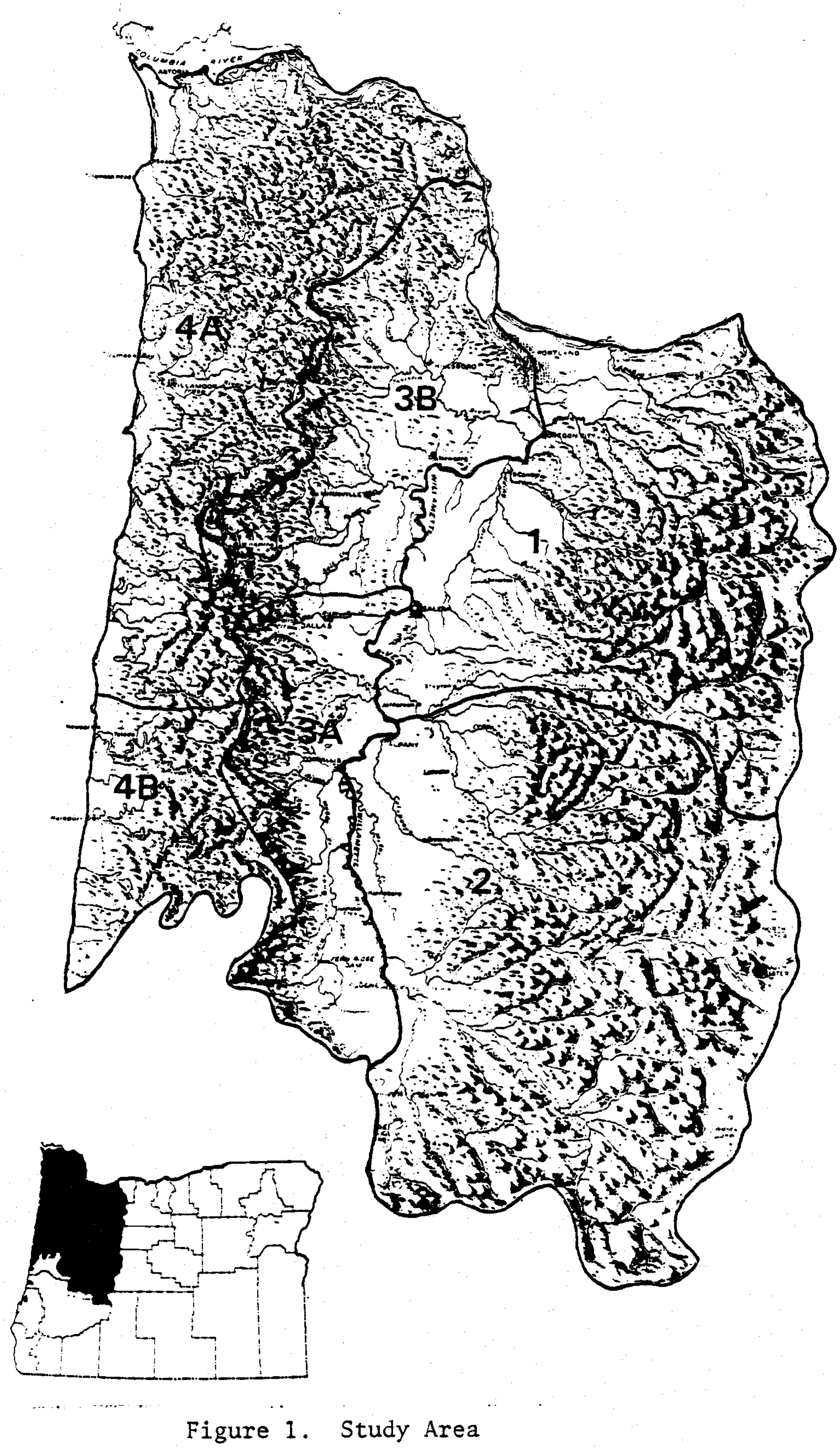


Figure 1. Study Area

east, the Coast Range, the Willamette Valley, and the Cascade Range. From sea level at the coast, the Coast Range rises to between 1,200 and 2,000 feet at the crest, with a few peaks extending from 1,000 to 2,000 feet higher. Eastward, the elevation decreases to less than 500 feet along the Willamette Valley floor, then rises to between 5,000 and 6,000 feet along the crest of the Cascades, with a number of peaks extending several thousand feet higher. The highest of these peaks, Mt. Hood, has an elevation of 11,245 feet.

Geohydrology

Given similar climates, streams in areas underlain by aquifers conducive to high groundwater storage tend to have less extreme low flows and flood peaks than streams in areas underlain by rocks conducive to low groundwater storage. Although there is considerable variation in groundwater storage capacity within each province, predominant geologic influences can be identified for the Coast Range, Cascades, and Willamette Valley. The sedimentary aquifer units that predominate in the Coast Range are largely responsible for comparatively lower groundwater storage capacity than the predominantly volcanic Cascades or the alluvial Willamette Valley (Pacific Northwest River Basins Commission, 1969).

The Coast Range is underlain largely by older volcanic rocks and derived marine sediments. The high density of the rocks permits little infiltration, movement, or storage of groundwater.

Rocks of the Cascade Range are composed almost entirely of lava flows and associated pyroclastics and stream deposits. The older volcanic rocks have moderate to low permeability and are less dense than the rocks in the Coast Range. The younger sequence of volcanic rocks that forms the high Cascades is very porous and permeable. Transmissibility as well as storage and infiltration capacity are high.

The Willamette Valley is basically a broad elongated lowland framed by the resistant volcanic and sedimentary rocks of the Cascade and Coast Ranges. These rocks extend beneath the alluvial gravel and sand deposits and protrude above the valley plain as isolated bedrock hills. Groundwater storage conditions in the valley are extremely variable, but the prevalent alluvial aquifer unit is highly permeable.

Climate

The climate of northwestern Oregon is generally humid and temperate, characterized by relatively wet winters and dry summers. Principal climatic controls are: the geographical location near the center of the middle latitude westerly winds, the Pacific Ocean, and topography.

In winter, predominantly eastward moving air masses are conditioned from one to several days by the relatively warm Pacific Ocean, which also provides a source of unlimited moisture. This moderates temperature extremes and provides intense precipitation for the region. Occurrences of extreme temperatures are usually associated with the occasional invasions of continental air masses (Sternes, 1960).

The dry summers of this region are primarily caused by a dominant high pressure system with descending and stable air that precludes much precipitation. The cool marine air crosses the cold offshore current and is cooled and stabilized further. This stability prevents the moisture laden air from bringing in much rain (Loy, 1976).

In the winter, moisture laden air masses are cooled as they move onto the land both by their passage over the cooler land surface and by their forced ascent as they cross the Coast and Cascade Ranges. This resultant cooling and condensation produces extremely heavy orographic precipitation along the higher west slopes of these ranges and reduces the moisture available for distribution on the leeward slopes.

Between the coast and the crest of the Coast Range, the normal annual precipitation ranges from 60 inches to about 100 inches, with a few points receiving as much as 200 inches. This gradually decreases on the east slopes to less than 40 inches along the Willamette Valley floor, then increases up the west slopes of the Cascades to 60-80 inches, with a few of the highest points receiving up to 100 inches (Pacific Northwest River Basins Commission, 1970). Approximately 70 percent of these totals fall during the winter months, November-March, and only about 5 percent in the three summer months, June-August. Excepting the middle and higher slopes of the Cascades, practically all of this precipitation falls as rain.

IV. METHODOLOGY

Data Compilation

The streamflow and drainage area data for this study were obtained from both published and unpublished (provisional) stream gage records compiled by two gaging agencies; the United States Geological Survey (USGS) and the Oregon Water Resources Department (OWRD). Monthly flow and flow duration data were used for some of the more specific analyses. The 63 stream gages selected for the analyses are listed by province in Table 1. The locations of these stations are shown in Figure 2. These gages were selected according to the following criteria:

1) The gage must have at least five years of good or excellent records (as specified by the gaging agency).
2) There must be no major (as noted by the gaging agency) regulation or diversions above the gage.
3) The drainage basin must have been mapped at a scale of 1:62,500 (or 1:24,000 scale where available).
4) The basin must be less than 200 square miles in area, unless the gage is used as a base station (see Gaging Station Correlations section).

Other data for the flow estimation models were compiled from USGS topographic maps and isohyetal maps produced by the Oregon Water Resources Department and the Pacific Northwest River Basins Commission.

The compiled data were analyzed using the Oregon State University CYBER 70/73 computer and the Statistical Interactive

Table 1. Gaging Stations Selected For Study

Station No.	Station Name	Period of Record, Years
	Province 1. West Slopes of Cascades - Northern Division	
13400	Salmon River near Government Camp	55
13840	Cedar Creek near Sandy	10
13880	Blazed Alder Creek near Rhododendron	17
13887	Fir Creek near Brightwood	05
13970	Cedar Creek near Brightwood	15
13980	South Fork Bull Run River near Bull Run	06
14150*	Little Sandy River near Bull Run	61
17900	Breitenbush River above Canyon Creek near Detroit	48
18250	Little North Santiam River near Mehama	49
19850	Molalla River above Pine Creek near Wilhoit	45
20030	Silver Creek at Silverton	14
21150	Johnson Creek at Sycamore	40
	Province 2. West Slopes of Cascades - Southern Division	
14490	Hills Creek above Hills Creek Lake near Oakridge	22
14650*	Salmon Creek near Oakridge	53
15030	Fall Creek near Lowell	17
15080	Winberry Creek near Lowell	17
15879	Smith River above Smith River Reservior near Belknap Springs	20
15920	South Fork McKenzie River above Cougar Reservior near Rainbow	23
16110	Blue River below Tidbits Creek near Blue River	17
16150	Lookout Creek near Blue River	23
16300	Gate Creek near Vida	20
18590	Quartzville Creek near Cascadia	16
18710	Wiley Creek at Foster	07
	Province 3A. East Slopes of Coast Range - Southern Division	
16650	Long Tom River near Noti	45
16700	Coyote Creek near Crow	40
17100*	Marys River near Philomath	40
18950	Luckiamute River near Hoskins	44
19010	Little Luckiamute River at Falls City	15
19030	Teal Creek near Falls City	05
19035	Grant Creek near Falls City	12
19080	Rickreall Creek at Rickreall	15
	Province 3B. East Slopes of Coast Range - Northern Division	
19250	South Yamhill River near Willamina	46
19300*	Willamina Creek near Willamina	46
19330	Mill Creek near Willamina	15
19430	North Yamhill River near Fairdale	20
20285	Scoggins Creek above Henry Haag Lake near Gaston	08
20400	Gales Creek near Gates Creek	07
20450	Gales Creek near Forest Grove	26
	Province 4A. West Slopes of Coast Range - Northern Division	
24850	Big Creek near Knappa	06
25150	Youngs River near Astoria	31
25200	North Fork Klatskanie near Olney	06
29914	North Fork Elk Creek near Cannon Beach	06
29915	West Fork Elk Creek near Cannon Beach	06
30130	Miami River near Garibaldi	06
30150*	Wilson River near Tillamook	50
30250	Trask River near Tillamook	34
30260	Killam Creek near Tillamook	05
30290	Nestucca River near Fairdale	20
30360	Nestucca River near Beaver	16
30375	Salmon River near Otis	06
30380	Rock Creek near Lincoln City	08
30395	Schooner Creek near Lincoln City	08
30435	Sunshine Creek near Valsetz	08
30485	Big Rock Creek near Valsetz	07
	Province 4B. West Slopes of Coast Range - Southern Division	
30603	Yaquina River near Chitwood	08
30610	North Fork Alsea River at Alsea	23
30640	Five Rivers near Fisher	18
30650*	Alsea River near Tidewater	41
30660	Drift Creek near Salado	08
30670	Needle Branch Creek near Salado	15
30680	Flynn Creek near Salado	15
30681	Deer Creek near Salado	15
30690	Big Creek near Roosevelt Beach	08

* Indicates provincial base station

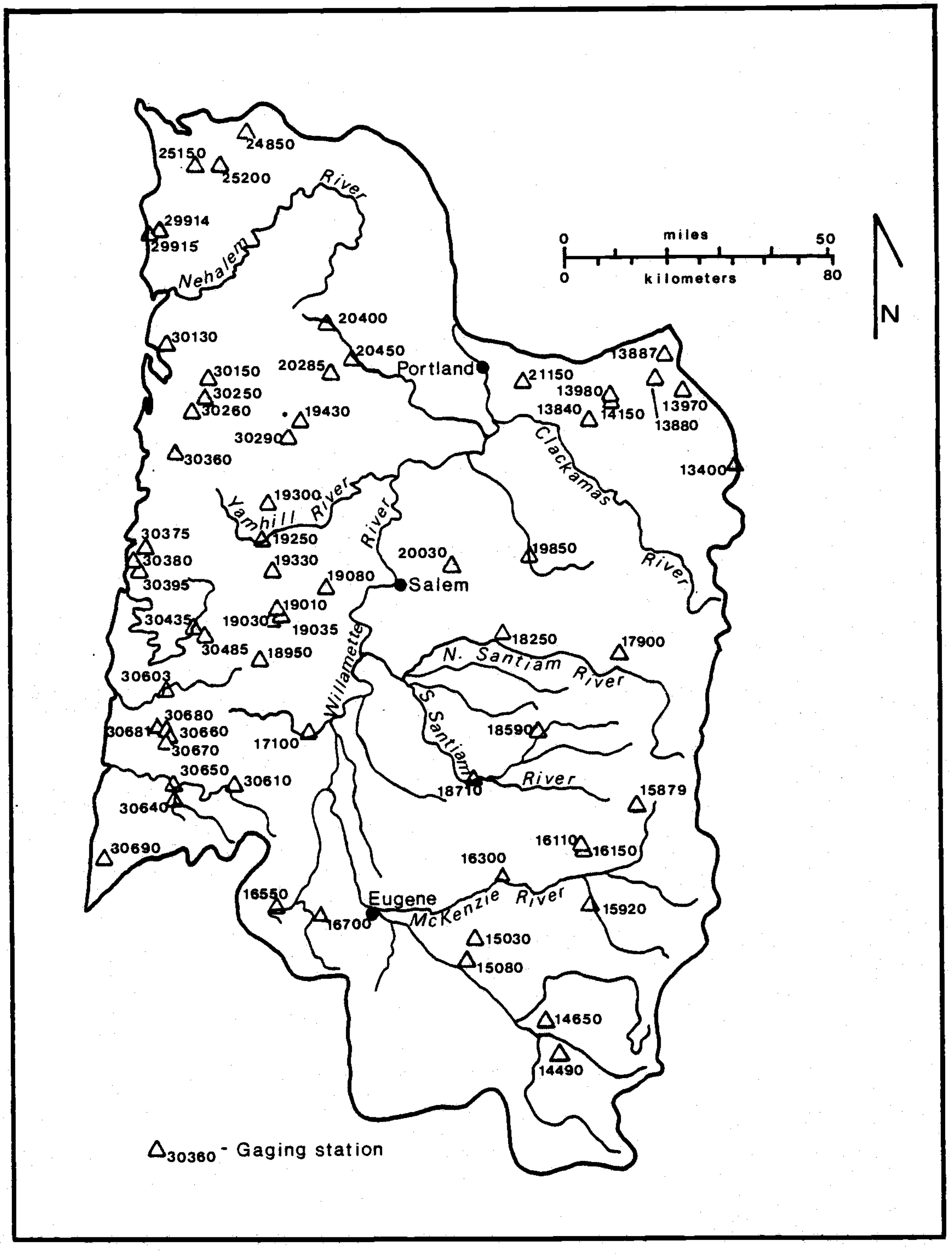


Figure 2. Gaging Stations Selected for Study

Programming System (SIPS).

Gaging Station Correlations

The primary objective of these analyses was to develop a procedure for estimating high, average and low streamflow characteristics. Provincial regression models were developed to estimate three statistical streamflow characteristics. The following abbreviations are used throughout this study to designate the three flows of interest:

1) QAA: The average annual flow; the mean of all annual mean flows for the period of record.
2) QF2D: The average annual maximum daily flow with a two-year recurrence interval.
3) Q7L2: The seven-day average low flow with a two-year recurrence interval.

The recurrence interval is defined as the average time elapsed between occurrences of an event with a certain magnitude or greater. For example, QF2D is a discharge that is equalled or exceeded on the average once every two years over a long period of time. It does not mean that an exceedence occurs every two years, but that the average time between exceedences is two years.

Searcy (1960) notes that the reliability of the streamflow data for estimating future flows at the gaging site depends upon how well the sample represents long-term flow characteristics. Period of record is one important measure of representativeness. The lengths of record for all stations used in this study are listed in Table 1. For stations with twenty or more years of record, the QF2D and the

Q7L2 were calculated from ranked highest and lowest mean values using the following equation:

$$m = (n+1)/RI \quad (1)$$

where:

RI = recurrence interval

n = number of years of record

m = ranking, or order of magnitude

Once m was known, its corresponding flow value could be obtained. When the calculated m value was an average of two distinct ranking numbers, the more extreme of the two numbers was chosen to represent the dependent variable for the stream. This procedure was not used for the majority of the stations because they had less than twenty years of record. Twenty years was selected as the minimum period from which reasonably accurate definitions of streamflow as specific probability levels could be obtained. The problem of short periods of record was also considered for QAA, since short term averages could also be entirely unrepresentative, due to possible dominance of abnormally wet or dry years.

Correlation analysis was used to adjust short-term gaging station records to more representative long-term records. This procedure is widely used in regional hydrologic analyses (Searcy, 1960; Orsborn, 1979). Haan (1977) points out: "by the very concept of a hydrologic region, the hydrologic characteristics are going to be correlated." This is not due to a cause-effect relationship between streamflow changes in the same hydrologic province, rather the changes are caused by the same external factors operating on both watersheds. Searcy (1960) notes that the sampling error in streamflow records of any length

> ...is often large in comparison to the errors that would be introduced by correlation with a longer record. Thus correlation with longer records can serve to reduce the sampling error and provide a more reliable base from which to estimate the characteristics of future flow.

For this study, selected stations with at least 40 years of record were designated as provincial base stations (Table 1). Flow values for the "short-term" stations were correlated against concurrent base station flow values to obtain more representative estimates of the QAA, the QF2D, and the Q7L2. A logarithmic transformation of the data was used because it tends to normalize the streamflow data and linearize the common curvilinear relation that exists between gaging station records.

For all stations that had shorter periods of record than the provincial base station, adjustments of QAA were obtained by correlating QAA values for concurrent years. Estimates of Q7L2 and QF2D were not obtained from these correlations because they would have been extrapolations outside the scope of the model. Problems associated with extrapolation are discussed by Haan (1977).

Estimates of the long-term QF2D were obtained from correlations of concurrent or near concurrent highest daily average flows or daily average flows immediately following these high flows. Values of the selected data points were checked to insure that the calculated base-station QF2D values fell within the range of data point values.

Estimates of the long-term Q7L2 were obtained by correlating averages of concurrent seven-day increments of data recorded during low flow periods. The data were examined carefully to avoid using increments that contained evidence of summer storms.

Because streamflow data were used to estimate streamflow characteristics it is possible that the error terms may be correlated, thus violating an assumption of the true regression model. This prohibited the derivation of precise confidence intervals for the estimates that were obtained. The correlation method was tested by comparing observed values of the three flows for stations with 20 or more years of record to their respective estimates. Synthetic 95 and 99 percent confidence intervals were obtained for the estimates. The ratios of the estimated to the observed values, and the percentage of observed values that fell within the synthetic confidence intervals were considered as indices of the reliability of this method. Assuming that the base station is representative of its hydrologic province, observed values falling outside of the confidence intervals or abnormally high or low ratios revealed that the test station did not exhibit flow characteristics common to its hydrologic province. Conversely, a high percentage of either poor estimates or extreme ratios may indicate that the base station is unrepresentative of its province. In either case, possible reasons for the discrepancy were investigated.

It is recognized that the discrepancies could reflect a myriad of factors known to affect low, average, and flood flows. For purposes of this research, however, the more subtle factors were not investigated. Factors considered were gaging accuracy, diversion, regulation, geology, land use, and orography. These factors were identified from streamflow records and various maps. Although field checking of these factors was not feasible for this study, it would be a necessary part of any specific micro-hydro site analysis.

Gaging accuracy was occasionally cited as a possible reason for discrepant results in the tests. The degree of accuracy is stated in the station description under "REMARKS" (U.S. Geological Survey 1979). "Excellent" means that about 95 percent of the daily discharges are within 5 percent, "good" within 10 percent, "fair" within 15 percent, and "poor" not within 15 percent. Only fair or poor records were considered as sources of discrepancy.

Diversions for irrigation, domestic, or other consumptive uses can significantly reduce the natural streamflow. Because irrigation in this region is commonly practiced in the summer low flow season, many of the streams are affected by this. If there are known diversions above the gaging station, this is stated in the gaging station description, however, water rights diversions are not quantified in the USGS or OWRD records.

Storage of water in snow, lakes, and ponds was another consideration in the model tests. These features tend to have a regulating effect on the streamflow characteristics which results in unusually high base flows and low flood flows. Average annual flows are usually not affected much unless there is an extremely high evaporation rate.

Streamflow characteristics often reflect the overall infiltration capacity and permeability of a watershed. Two important controls of these factors are geology and land use. A list of the range of permeability in several types of rock which notes some important controls is presented by Dunne and Leopold (1978). Land use changes such as urbanization, cultivation, grazing, and clearcutting can cause radical decreases in the infiltration capacity of the soil. Given several watersheds in the same hydrologic province, those with relatively low infiltration capacity and low permeability (i.e. poor groundwater storage) will have proportionately higher flood peaks and lower base flows than those with relatively high infiltration rates and high permeability.

Examination of isohyetal and topographic maps of the study area revealed that considerable variations in precipitation within the hydrologic provinces is related to differential orographic effects. Although these effects are rather complex, relative elevation and aspect are key characteristics which can be identified from topographic maps. Orographic precipitation theory is discussed by Barry and Chorley (1968).

Reasons to assume that the streamflow characteristics are significantly altered by one or more of these factors are noted for the individual test station discrepancies. Because of the complex nature of many of these factors discussion of their comparative degrees of effect on the individual test stations is subject to conjecture. In this study, all flow estimates for test stations which deviated significantly from their observed values were noted.

Development of Streamflow Estimation Models

In order to develop practical models for micro-hydro site analysis, conventional statistical guidelines were considered in the selection of independent variables. A goal of the variable selection process was to include only the more important independent variables in the final estimation equations. Neter and Wasserman

(1974) describe the "best" independent variables as those that: 1) are fundamental to the problem and have stable physical relationships with the dependent variables; 2) can be easily and efficiently quantified; 3) are not subject to large measurement error; 4) do not effectively duplicate other independent variables on the list. The following basin and climatic characteristics were selected for the regression analyses to develop flow estimation models for ungaged potential micro-hydro sites.

The first independent variable considered was drainage basin area (A). This parameter has been effective in many analyses, and can intuitively be considered a logical cause of streamflow variations between sites (Riggs 1964, Thomas and Benson 1970). The basin area can be determined from topographic maps.

As an alternate variable to basin area, basin area multiplied by the square root of relief ($A\sqrt{H}$) was considered in the model development. This term was used because it has a physically sound relationship with streamflow, and has recently proved to be an important predictor variable for flow characteristics in the mid-coast region of Oregon (Orsborn, 1981).

The logic for this hydrogeomorphic "basin energy" term is discussed in detail by Orsborn (1976, 1981). Strahler's (1958) application of dimensional analysis to fluvially eroded landforms demonstrated that various geomorphic characteristics of a basin could be combined with a flow term to develop dimensionless parameters. Expanding on this concept, Orsborn (1976) points out that:

> These dimensionless ratios of forces could then be used to derive physical process equations. For example, the hydrogeologic Froude number expression is
>
> $$F = \frac{Q^2}{Hg}$$
>
> where Q is a flow rate per unit area, H the basin relief and g the gravitational acceleration term. From the continuity equation, Q is a measure of the velocity and thus the inertia of the flow. The basin relief, H (elevation difference between the headwaters and the outlet) is a measure of the potential energy of or driving force due to gravity acting on all flows in a basin. Thus the Froude number Q^2/Hg represents a ratio of inertia to gravity forces in any basin ...

From this relationship, the "basin energy" term can be derived as follows (Orsborn 1981):

Changing Q^2 to Q1 in the above equation yields:

$$\frac{Q1}{\sqrt{Hg}} \qquad (2)$$

If it is assumed that the "unit" discharge in equation (2) is for each square mile of watershed, and the numerator and denominator are both multiplied by area (A) conditions are not changed and

$$\frac{Q1A}{\sqrt{gHA}} = \frac{Q2}{\sqrt{gHA}} \qquad (3)$$

where Q2 is assumed to be the total discharge for a given basin area. Equation (3) can be rearranged so that

$$Q(X) = C\sqrt{g} \;\; A\sqrt{H} \qquad (4)$$

where C is part of a proportionality constant and (X) denotes some unknown characteristic flows such as low, average, or flood flows. Combining the proportionality constant and the $\sqrt{g}$ yields

$$Q(X) = C'A\sqrt{H} \qquad (5)$$

Since A is given in the stream gage descriptions, only measurement of relief was required to calculate $A\sqrt{H}$. Basin relief was determined from topographic maps by subtracting the gage elevation from the elevation of the highest continuous contour in the basin. Variability due to the effects of isolated mountain peaks along the drainage divides is thus minimized. Further discussion on the physical significance of basin relief is discussed in detail by Yang (1971).

Mean annual precipitation (P) was considered because it is a measure of the average, long-term amount of water supplied to a drainage basin and hence the average potential runoff. Several methods of estimating the areal average precipitation are discussed by Dunne and Leopold (1978). Despite these attempts to improve accuracy, quantification of basin precipitation is subject to sources of measurement error such as poor exposure of the gauge, strong winds associated with many storms, and sparse distribution of the gauges in and around most areas. Since the streamflow characteristics data were computed from different base periods than the isohyetal maps available, attempts to improve the estimates by tedious and time consuming methods were avoided in this study. Only general estimates of the normal annual precipitation were obtained from the isohyetal maps.

The last independent variable considered for the analyses was the estimated mean basin elevation (E). Thomas and Benson (1970) point out that:

> Although elevation itself may not directly cause streamflow variations, elevation may serve as an index to other factors that cause interbasin streamflow variation but are difficult to evaluate. Radiation, temperature, wind, vegetation and basin ruggedness, for example may vary with elevation.

Dingman (1978) found mean basin elevation to be useful for estimating average annual flows and 95 percent exceedence flows. The tedious and time-consuming task of constructing area-elevation curves was not feasible for purposes of this study. For all stream basins in this study, the following formula, as presented by Dingman (1978), was employed as an expedient means of obtaining estimates of the mean basin elevation.

$$Y = Ymin + 0.324\ (Ymax - Ymin) \qquad (6)$$

Because orographic precipitation is common in the study region, there was a considerable possibility that P and E would be intercorrelated if their combined effects were incorporated in the regression analyses. Hence, the analyses were more oriented toward comparing their predictive powers separately.

Data used in developing the streamflow estimation models are presented in Table 2. As in the correlation analyses, both the independent and dependent variables were logarithmically transformed to linearize the relations between the variables. The uncorrelated error term violation of the correlation analysis used to estimate flow

Table 2. Tabulated Regression Analysis Data

Province No.	Gage No.	Dependent Variables: QF2D (ft^3/sec)	Dependent Variables: QAA (ft^3/sec)	Dependent Variables: Q7L2 (ft^3/sec)	Independent Variables: A (mi^2)	Independent Variables: $A\sqrt{H}$ ($mi^{2.5}$)	Independent Variables: P (in/yr)	Independent Variables: E (ft)
1	13400	194	45.9	18.0	8.00	5.77	90	4335
	13840	305	52.5	8.0	14.00	9.75	70	1370
	13880	687	57.7	2.6	8.17	3.48	125	2851
	13887	420	34.4	2.8	5.46	3.19	115	2023
	13970	546	66.5	10.6	7.93	4.31	115	2466
	13980	1002	112.7	13.1	15.40	9.98	105	1706
	14150	1490	147.0	15.0	22.30	16.46	85	1622
	17900	4760	583.0	125.0	106.00	92.47	85	2877
	18250	8420	771.0	29.0	112.00	90.16	100	1766
	19850	5500	545.0	31.0	97.00	70.63	100	1702
	21150	972	54.5	0.6	28.20	7.05	45	348
	20030	1945	195.4	8.9	47.90	35.73	75	1172
2	14490	1500	151.0	20.0	52.70	43.85	60	2812
	14650	2740	426.0	125.0	117.00	98.40	60	2673
	15030	2999	404.0	27.2	118.00	85.31	55	1738
	15080	1037	118.0	5.9	43.90	33.38	50	1854
	15879	800	90.8	4.0	16.20	7.83	75	3006
	15920	3810	635.0	207.0	160.00	114.16	75	2582
	16110	3090	251.0	13.3	45.80	29.65	90	2104
	16150	1230	127.0	10.0	24.10	18.24	85	2355
	16300	1930	215.0	18.0	47.60	29.01	85	1400
	18590	7925	670.0	35.2	99.20	74.22	90	2004
	18710	2193	221.0	11.2	62.30	46.99	75	1567
3A	16650	2770	232.0	12.0	89.30	30.40	55	587
	16700	3480	176.0	0.0	95.10	35.20	45	610
	17100	5550	457.0	9.7	159.00	61.00	70	475
	18950	2370	209.0	10.0	34.30	16.60	100	783
	19010	1161	155.0	12.8	22.70	13.30	100	1066
	19030	372	37.3	2.1	7.97	4.50	80	857
	19035	130	10.3	0.1	3.00	1.10	65	530
	19080	2559	200.0	6.0	46.70	29.20	90	853
3B	19250	7480	622.0	14.0	133.00	73.54	85	759
	19300	2890	260.0	13.0	64.70	34.32	65	794
	19330	1644	135.0	3.7	27.40	14.31	80	1023
	19430	441	48.0	3.2	9.03	5.56	85	1202
	20285	679	63.0	1.9	15.90	7.38	70	989
	20400	1122	127.0	3.9	33.20	20.18	75	1081
	20450	2370	228.0	8.4	66.10	42.61	70	914
4A	24850	1040	160.0	22.8	31.90	15.10	90	483
	25150	2100	186.0	5.8	40.10	18.58	95	432
	25200	603	60.8	3.3	14.00	6.91	95	630
	29914	766	71.9	4.0	8.90	5.38	110	695
	29915	689	67.5	5.2	9.25	5.60	110	689
	30130	2965	270.0	18.5	29.50	19.03	105	724
	30150	13213	1202.0	71.9	161.00	106.91	115	826
	30250	9420	966.0	74.0	145.00	99.77	115	869
	30260	386	34.1	2.7	3.40	2.11	120	1021
	30290	369	31.3	1.9	6.18	1.26	95	1849
	30360	10023	1114.0	80.9	180.00	115.08	95	741
	30375	4943	447.0	32.4	60.10	14.11	110	834
	30380	112	17.1	2.2	3.10	1.28	85	392
	30395	733	99.1	10.8	13.70	6.35	90	447
	30435	841	63.1	1.8	6.70	2.34	110	838
	30485	603	48.6	2.2	6.90	2.86	100	1000
4B	30603	2618	275.0	8.0	71.00	37.45	75	505
	30610	3220	279.0	17.0	63.00	30.37	95	670
	30640	7015	566.0	28.0	114.00	52.54	100	493
	30650	17100	1517.0	78.0	334.00	175.19	90	519
	30660	1205	122.0	6.8	20.60	9.99	95	861
	30670	19	1.6	0.4	0.27	0.08	95	573
	30680	41	4.4	0.2	0.78	0.14	95	738
	30681	62	4.7	0.4	1.17	0.39	95	794
	30690	869	102.0	6.6	11.90	4.62	85	409

characteristics (dependent variables) of many of the streams is integrated in the regression analyses. Thus, as in the previous analysis, it was not possible to derive true confidence bands about the regression lines. Therefore, tests nearly identical to those performed for the correlations were applied to the regression analyses. The same factors (i.e. gaging accuracy, diversion, regulation, etc.) were considered in the evaluation of discrepancies in the test results. The basic difference in interpretation of the test results of the two major analyses is that in the regression analyses, the test results are more indicative of the particular test station's representativeness of flow characteristics common to its hydrologic province. The base station data have considerably less effect in the regression analyses because they are not treated as predictor variables.

Flow-Duration Curves

Once provincial estimation models for the QF2D, QAA and Q7L2 were obtained, a synthetic flow-duration curve can be generated for an ungaged site within these provinces. The following step-by-step procedure summarizes a method by which this can be done.

1. Define the provincial characteristic shape of the curve by constructing a calculated flow-duration curve for any gaged stream with a long period of record. It is assumed that this stream is hydrologically similar to the ungaged stream.
2. Assume that the QF2D is equalled or exceeded zero percent of the time and the Q7L2 is equalled or exceeded ninety-five percent of the time.
3. Make these curves dimensionless by calculating ratios of QF2D/QAA

and Q7L2/QAA. The ratio of QAA/QAA is always one on the dimensionless scale. To illustrate this procedure, a flow-duration curve for the Trask River near Tillamook (gaging station no. 30250) is shown in Figure 3. The same curve is constructed on a dimensionless scale directly above the dimensional curve.

4. Compare ratios calculated from the estimated flow characteristics of the ungaged stream to those for the gaged stream to check the hydrologic homogeneity of the two streams.

5. If the ratios are nearly constant, the three points for the ungaged stream can be connected following the shape of the gaged station duration curve as a guide. Slight adjustments in the curve shape may be necessary to connect the three points, but this will not significantly change the area under the curve.

6. Generalized maximum and minimum duration curves can be constructed by plotting the maximum and minimum recorded values of the average daily flood, the average annual flow and the seven-day average low flow above and below the QF2D, QAA and Q7L2 points. Dimensionless ratios of these extreme values to the QAA can be used to construct synthetic maximum and minimum curves for an ungaged stream. Because the variances of flood, average, and low flows are not constant, slight adjustments in the original curve shape are necessary to connect the three maximum and minimum points. These curves nonetheless can provide reasonable estimates of the highest and lowest flow conditions at any given exceedence level.

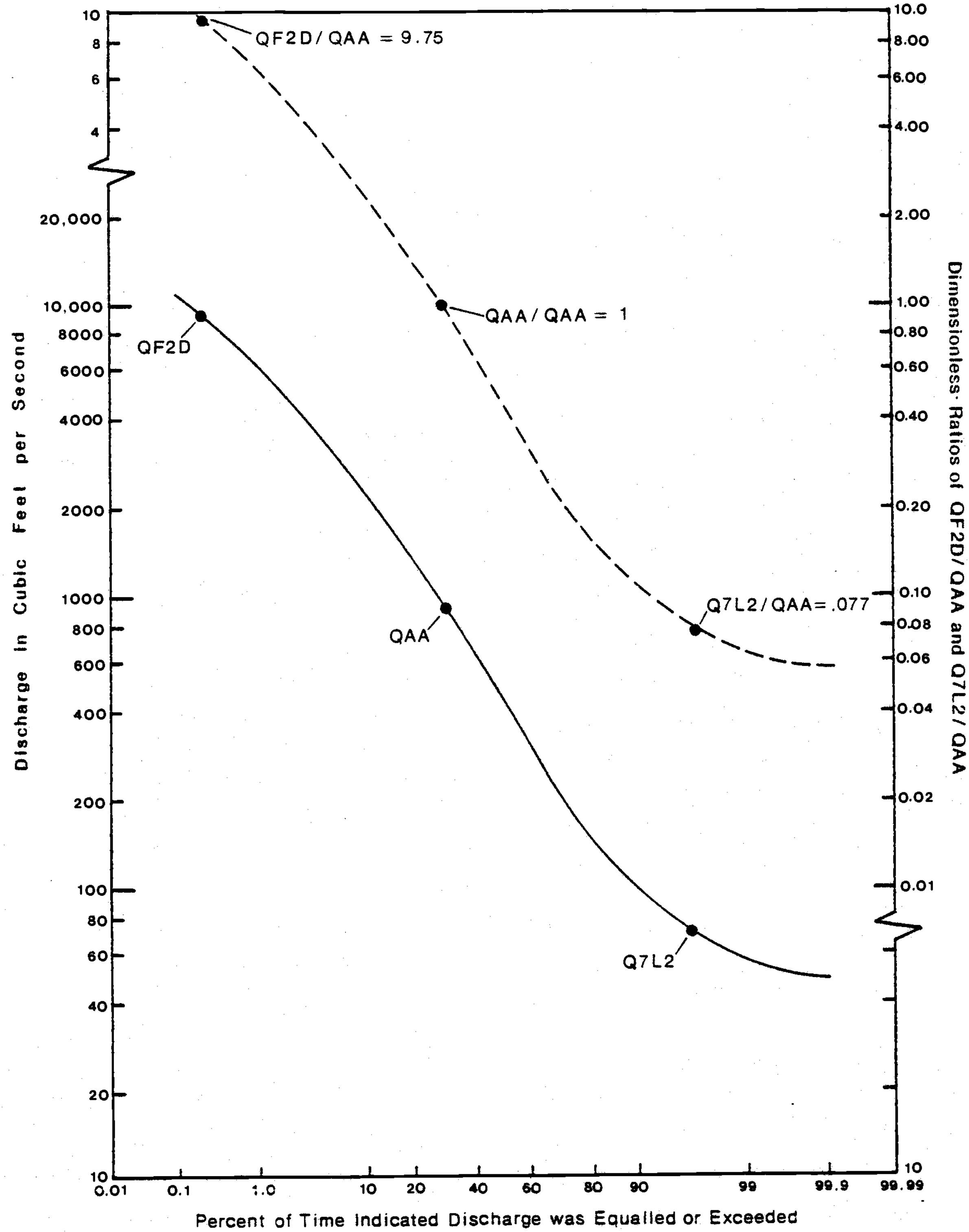


Figure 3. Dimensionless and Dimensional Flow-Duration Curves for Trask River near Tillamook (station no. 30250).

This procedure was tested by comparing the shapes of provincial base station dimensionless duration curves with those of the selected test station curves.

Example of Methodology Application

Application of the developed methodology was exemplified by a preliminary micro-hydro site analysis. Wolf Creek, a third order stream in the Yaquina River basin was selected for this analysis. The synthetic flow-duration curve developed for this site was used to assess the hydropower potential of this site given hypothetical turbine specifications and assumed developable head and minimum flow requirements. The HYDRO-CALC program of the Hydropower Computer Reconnaissance (HCR) Package (Broadus, 1981) and an Apple II computer were used in this hydropower analysis.

V. RESULTS AND DISCUSSION

Introduction

Results of the analyses performed in this study are discussed in four separate sections. These sections are entitled: 1) Gaging Station Correlations; 2) Streamflow Estimation Models; 3) Flow-Duration Curves; and 4) Example of Methodology Application.

In the first two sections, the gaging station correlation methods and the selected streamflow estimation models were tested using the procedures described in the METHODOLOGY chapter of this thesis. Ideally, for purposes of this study, small, natural streams would be selected for testing. Because the natural streamflows of several of the test streams are altered by various natural and artificial factors, many of these stations have provincially aberrant flow characteristics. Because specific field testing and quantification of diversions were not feasible for this study, reasons for these aberrations were only conjectured and noted.

Estimated values of the three streamflow characteristics were compared to their observed values in both the correlation methods and estimation model tests. Since the observed test station data were considered to be superior to the estimated test station data, the observed values were used in the development of the final models. To illustrate the effects of using estimated values of the three streamflow characteristics, test results of models developed using estimated test station flow data were compared to test results of the final models.

In the third section, dimensionless flow-duration curves for two stations in each section were compared to exemplify the variability in flow characteristics within each of the four hydrologic provinces.

Application of the methodology is exemplified in the fourth section of this chapter by a preliminary feasibility analysis for a hypothetical micro-hydro site. In this example, general effects of flow-duration variability and minimum flow requirements on hydropower potential are illustrated.

Gaging Station Correlations

Test results for the QAA, QF2D, and Q7L2 correlation analyses are summarized in Tables 3, 4, and 5. For each of the four major hydrologic provinces and the test stations within them, these three tables show: the observed streamflow characteristics; the estimated mean values of the streamflow characteristics; the ratios of these estimates to the observed flow characteristics (E/O); and estimated 95(CI_1) and 99(CI_2) percent confidence intervals for the estimates. The lower and upper limits of these intervals are denoted on the tables as LCL and UCL. One asterisk denotes those observed values which did not fall within CI_1, whereas two asterisks denote those which did not fall within CI_2. Percentages of the total number of test stations considered that had observed values within these two confidence limits are noted below each table.

These test results are used to identify discrepancies from the hypothesized relations between the base station flows and the test station flows. Results showing extremely high or low E/O ratios, relatively wide confidence intervals, or observed values much higher or lower than the upper and lower confidence limits provide a basis

Table 3. Test Results for QAA Correlations

Province	Station No.	Observed QAA (cfs)	Estimated QAA (cfs)	E/O Ratio	CI_1 LCL (cfs)	CI_1 UCL (cfs)	CI_2 LCL (cfs)	CI_2 UCL (cfs)
1	13400	45.9	44.9	0.978	40.9	49.4	37.9	53.4
	17900	583.0	568.0	0.974	488.0	661.0	431.0	739.0
	18250	771.0	761.0	0.987	629.0	920.0	537.0	1037.0
	19850	545.0	519.0	0.952	422.0	639.0	356.0	758.0
	21150	54.5	55.9	1.026	35.6	87.6	24.6	127.0
2	14490	151.0	145.0	0.960	115.0	184.0	95.3	223.0
	15879	90.8	86.1	0.948	75.1	98.6	67.2	110.0
	15920	635.0	636.0	1.002	610.0	662.0	590.0	685.0
	16150	127.0	119.0	1.496	99.0	143.0	85.1	167.0
	16300	215.0	198.0	0.921	181.0	216.0	169.0	232.0
3	16650	232.0	226.0	0.974	212.0	241.0	202.0	254.0
	16700	176.0	153.0	0.869	122.0	192.0	101.0	231.0
	18950	209.0*	230.0	1.100	214.0	247.0	201.0	263.0
	19250	622.0	619.0	0.995	604.0	635.0	591.0	648.0
	19430	48.0	45.0	0.938	40.8	49.6	37.6	53.8
	20450	228.0	222.0	0.974	202.0	244.0	187.0	264.0
4	25150	178.0	186.0	1.045	175.0	198.0	166.0	208.0
	30250	966.0	969.0	1.003	953.0	986.0	939.0	1000.0
	30290	31.3	30.0	0.958	24.1	37.5	20.1	44.9
	30610	279.0	274.0	0.982	252.0	298.0	235.0	320.0

Percent of observed values within CI_1: 95%
Percent of observed values within CI_2: 100%

* Observed value not within CI_1
** Observed value not within CI_2

Table 4. Test Results for QF2D Correlations

Province	Station No.	Observed QF2D (cfs)	Estimated QF2D (cfs)	E/O Ratio	CI_1 LCL (cfs)	CI_1 UCL (cfs)	CI_2 LCL (cfs)	CI_2 UCL (cfs)
1	13400	194**	128	0.660	98	169	87	188
	17900	4760	4635	0.974	3089	6954	2625	8186
	18250	8420	7370	0.875	5345	10160	4698	11561
	19850	5500	6192	1.126	4020	9539	3379	11349
	21150	972	699	0.719	398	1226	317	1537
2	14490	1500	1380	0.920	1019	1868	902	2110
	15879	800	798	0.998	426	1494	331	1922
	15920	3810	3849	1.010	2877	4230	2663	4571
	16150	1230	880	0.715	672	1154	602	1286
	16300	1930	1602	0.830	1231	2083	1107	2316
3	16650	2770	3004	1.084	2287	3946	2053	4395
	16700	3480*	2202	0.633	1472	3293	1256	3859
	18950	2370*	1820	0.768	1435	2306	1307	2532
	19250	7480	6744	0.902	5877	7739	5561	8179
	19430	441	413	0.937	345	493	321	530
	20450	2370	2364	0.997	1841	3034	1665	3355
4	25150	2100	2191	1.043	1823	2633	1693	2834
	30250	9420	9348	0.992	7702	11347	7124	12266
	30290	369	280	0.759	156	504	123	638
	30610	3220*	2946	0.915	2729	3180	2646	3279

Percent of observed values within CI_1: 80%
Percent of observed values within CI_2: 95%

* Observed value not within CI_1
** Observed value not within CI_2

Table 5. Test Results for Q7L2 Correlations

Province	Station No.	Observed Q7L2 (cfs)	Estimated Q7L2 (cfs)	E/O Ratio	CI_1 LCL (cfs)	CI_1 UCL (cfs)	CI_2 LCL (cfs)	CI_2 UCL (cfs)
1	13400	18.0**	21.8	1.211	19.8	23.9	19.1	24.8
	17900	125.0	121.0	0.968	102.0	144.0	94.5	155.0
	18250	29.0**	38.2	1.317	32.5	44.9	30.4	48.1
	19850	31.0**	59.4	1.916	55.6	63.4	54.1	65.2
	21150	0.60	0.52	0.867	0.41	0.65	0.38	0.71
2	14490	20.0	19.9	0.995	18.1	22.0	17.4	22.9
	15879	4.0	4.8	1.200	3.5	6.6	3.0	7.7
	15920	207.0*	192.0	0.928	183.0	202.0	179.0	207.0
	16150	10.0	9.8	0.980	8.2	11.7	7.6	12.8
	16300	18.0	19.4	1.078	15.4	24.3	13.8	27.1
3	16650	12.0**	2.5	0.208	1.2	5.2	0.92	7.0
	16700	0.0	N.A.	-	-	-	-	-
	18950	10.0**	15.2	1.520	12.4	18.5	11.4	20.1
	19250	14.0*	18.8	1.343	14.6	24.3	13.1	27.1
	19430	3.2*	3.8	1.188	3.6	4.1	3.5	4.2
	20450	8.4	7.1	0.845	6.0	8.4	5.5	9.0
4	25150	5.8	6.2	1.069	5.8	6.7	5.6	6.9
	30250	74.0	74.1	1.001	70.9	77.4	69.5	78.8
	30290	1.9*	2.5	1.316	2.0	3.1	1.8	3.4
	30610	17.0	17.9	1.053	16.8	19.1	16.3	19.6

Percent of observed values within CI_1: 52.6%
Percent of observed values within CI_2: 68.4%

* Observed value not within CI_1
** Observed value not within CI_2

from which possible reasons for the discrepancies can be identified. It should be noted that these tests essentially provide an indication of how closely the correlation methods estimate the QF2D, QAA, and Q7L2 for the test station period of record. Although the test station periods of record were usually shorter than those for the base station, the differences in observed flow characteristics were not significant.

A comparison of the overall test results shows that based on the test criteria, the QAA correlations yielded more reliable estimates than those for the QF2D or Q7L2. Most E/O values were considerably closer to one than those for the extreme flows, the confidence intervals were comparatively narrow, and the percentage of observed flow values falling within CI_1 was highest (95%). The only station that had a discrepant QAA test result was the Luckiamute River near Hoskins

(18950), the estimate of which was slightly higher than the observed value. Because the observed value was only five cfs lower than the lower confidence limit for CI_1 this station was not considered to be a significant discrepancy. The greater reliability of the QAA correlations reflects the tendency for variability in these types of correlations to decrease as the time unit increases. Each of the data points of the QAA correlations represents a mean value of 365 daily mean flows, whereas the low flow data points represent seven-day mean values, and the high flow data points represent one-day mean values.

Although the high flow correlations had higher percentages of positive test results than the low flow correlations, this does not necessarily mean that the QF2D estimates were more reliable. In most cases, the comparative standard deviations were greater for the QF2D estimates which resulted in wider confidence intervals. Thus, the superior QF2D test results are partially explained by relative confidence interval width. Lower fluctuations in streamflow during low flow periods is identified as a major reason for the generally lower standard deviations of the Q7L2 estimates.

Four stations in the QF2D tests were identified as provincial discrepancies: Salmon River near Government Camp (13400), Coyote Creek near Crow (16700), Luckiamute River near Hoskins (18950), and North Fork Alsea River at Alsea (30610). The Salmon River represents a stream which has high flows that are controlled more by snowmelt during the spring and summer months rather than rainfall during the winter months. Since concurrent winter high daily flow values were used in the QF2D base-station correlations, the Salmon River values were not representative of the highest flow values. Hence, the QF2D was underestimated. Coyote Creek, the Luckiamute River and the North Fork of the Alsea River all are believed to represent streams that have geologic and possibly geomorphic characteristics conducive to proportionately higher flood peaks than the base stations with which they were correlated. Hence, the observed QF2D values are considerably higher than their estimates.

The Q7L2 correlations had the highest percentages of provincial discrepancies, but most of these had observed values that were not much higher or lower than the upper or lower confidence limits for CI_1. Salmon River near Government Camp (13400), Little North Santiam River near Mehama (18250), Molalla River above Pine Creek near Wilhoit (19850), South Fork McKenzie River above Cougar Reservior near Rainbow (15920), Long Tom River near Noti (16650), Luckiamute River near Hoskins (18950), South Yamhill River near Willamina (19250), North Yamhill River near Fairdale (19430) and Nestucca River near Fairdale (30290) all had aberrant test results. Only the Molalla River and the Long Tom River, however, had estimated Q7L2 values that were far enough outside of the confidence intervals to be judged significant. Possible reasons identified for the high estimate of Q7L2 for the Molalla River are poor gaging accuracy at the time the low flow values were recorded and comparatively low groundwater storage capacity. Possible reasons for the low Q7L2 estimate for the Long Tom River are poor gaging accuracy, low flow regulation by log ponds, and diversions above the provincial base station.

The test results indicate that in general, concurrent flow correlations with the selected provincial base stations is a reliable means by which reasonable estimates of QF2D, QAA and Q7L2 may be obtained. Because it is likely that the test station streams are altered to a greater degree than most other streams considered in this study, the test results are assumed to be conservative indices of the accuracy of the QF2D, QAA and Q7L2 variables that were used to develop the regression models for estimating these three flow characteristics. Omission of the stations determined to be provincial discrepancies would, of course, greatly increase the percentages of the total number of observed flow values falling within the confidence intervals of their estimated values.

Streamflow Estimation Models

Regression models for estimating QAA, QF2D, and Q7L2 were developed through comparison of the predictive abilities of each of the independent variables examined in the analyses. The final models were tested using the same gaging station and test criteria that were used for the correlation analyses. Criteria considered in the selection of the most important estimation variables included the coefficient of determination (R^2), the error mean square (MSE), and the F statistic.

The selected final models, selection criteria values, and the degrees of freedom (d.f.) are listed in Tables 6a and 6b. Models developed for both the northern and southern divisions of the three major mountain slopes in the study region (the six original provinces) are listed in Table 6a, whereas models in which the data of the northern and southern divisions were combined are listed in Table 6b.

Table 6a. Provincial Estimation Models for QF2D, QAA, and Q7L2

North and South Data Separate

Province	Model	R^2	MSE*	F	d.f.
1	$QF2D=50.38(A)^{1.00}$	.86	.042	59.2	1, 10
	$QAA=13.57(A\sqrt{H})^{0.83}$	.92	.019	122.7	1, 10
	$Q7L2=1.28(A\sqrt{H})^{0.79}$	.52	.192	10.7	1, 10
2	$QF2D=1.07.74(A)^{0.74}$	.62	.034	14.8	1, 9
	$QAA=6.09(A)^{0.90}$	.83	.017	44.6	1, 9
	$Q7L2=0.05(A)^{1.48}$	.75	.074	27.3	1, 9
3A	$QF2D=109.53(A\sqrt{H})^{0.96}$	.98	.007	295.0	1, 6
	$QAA=10.63(A\sqrt{H})^{0.91}$	.95	.016	113.3	1, 6
	$Q7L2=0.25(A\sqrt{H})^{1.10}$	.79	.128	19.6	1, 5
3B	$QF2D=44.42(A)^{1.00}$	.95	.010	93.5	1, 5
	$QAA=5.24(A)^{0.94}$	.97	.005	171.6	1, 5
	$Q7L2=0.38(A\sqrt{H})^{0.92}$	.83	.036	23.7	1, 5
4A	$QF2D=188.96(A\sqrt{H})^{0.85}$	.92	.030	158.2	1, 14
	$QAA=18.63(A\sqrt{H})^{0.85}$	.97	.012	422.0	1, 14
	$Q7L2=1.21(A\sqrt{H})^{0.86}$	.91	.035	141.1	1, 14
4B	$QF2D=60.55(A)^{0.97}$	.99	.008	1124.1	1, 7
	$QAA=5.57(A)^{0.97}$	.99	.008	725.3	1, 7
	$Q7L2=0.25(A)^{0.99}$	.97	.046	202.1	1, 7

* MSE values are from transformed data analyses.

Table 6b. Provincial Estimation Models for QF2D, QAA, and Q7L2

North and South Data Combined

Province	Model	R^2	MSE*	F	d.f.
1 and 2	$QF2D=68.73(A)^{0.87}$	.80	.040	84.6	1, 21
	$QAA=14.80(A\sqrt{H})^{0.77}$	.88	.021	160.7	1, 21
	$Q7L2=1.05(A\sqrt{H})^{0.86}$	.59	.140	30.5	1, 21
3A and 3B	$QF2D=53.46(A)^{0.95}$	.96	.010	288.8	1, 13
	$QAA=10.42(A\sqrt{H})^{0.90}$	.95	.010	245.2	1, 13
	$Q7L2=0.29(A\sqrt{H})^{1.03}$	.80	.071	48.6	1, 12
4A and 4B	$QF2D=186.46(A\sqrt{H})^{0.85}$	.96	.022	621.1	1, 23
	$QAA=17.72(A\sqrt{H})^{0.86}$	.98	.013	1050.6	1, 23
	$Q7L2=0.99(A\sqrt{H})^{0.89}$	.93	.046	325.8	1, 23

*MSE values are from transformed data analyses.

Comparison of the separate data and combined data models revealed that changes in the models caused by combining data from the northern and southern divisions were minor and consistent compared to the changes in the Cascades models. Thus, only in the Coast Range provinces was the increase in degrees of freedom considered to be reasonable justification for combining data. For this reason, the only north-south division deemed necessary was in the Cascades, and four rather than six major provincial divisions were identified.

In all of the regression analyses the most important variables were either basin area (A) or the "basin energy" term ($A\sqrt{H}$). Since inclusion of either normal annual precipitation (P) or average elevation (E) did not substantially change the R^2, MSE, or F values, multivariate regression analysis was not required for development of the final models. The predictive abilities of the simpler models were shown to be equivalent to the more complex models. There is no concrete pattern with regard to flow or provincial characteristics that can explain the relative importance of A and $A\sqrt{H}$. Since $A\sqrt{H}$ is theoretically a more logical predictor variable than A, evaluation errors in the H component are presumed to be the main reason for A being the most important variable in several of the models.

Comparison of the selection criteria values indicates that in terms of flow characteristics, variability in the regression relations is lowest for the QAA and highest for the Q7L2. One reason for this trend is that the QAA estimates were derived from data averaged over considerably longer time units which reduces the error in estimation. Another important reason is the difficulty in low flow estimation caused by geologic diversity within each province. As Riggs (1972) points out:

> The principal roadblock to regionalization of low flow characteristics is our inability to describe quantitatively the effects of various geological formations on low flows - even where detailed geologic maps are available.

One reason that the QF2D models showed less variability than the Q7L2 models is that the high flows are controlled more by precipitation intensity and distribution than they are by geology. In this region, precipitation characteristics and streamflow responses to them are believed to be more uniform than streamflow responses to groundwater storage characteristics.

Examination of provincial differences in the models revealed that variability in the models developed for the Cascades provinces was higher than the variability in the Coast Range models. This was particularly apparent in the QF2D and Q7L2 models.

One reason for the greater variability in the QF2D models is that there is more opportunity for nonuniformity in the distribution of winter precipitation. This is due to the higher variation in relief and the greater distance from the Pacific Ocean, the source area for most of the winter storms. Effects of snow storage at the higher elevations is another possible reason for the generally higher variability.

Reasons for the relatively high variability in the Q7L2 models for the Cascades are assumed to be greater geologic diversity and higher incidence of artificial streamflow alteration caused by comparitively more intensive water and land uses in these provinces.

Only the models developed for the four major provinces were tested. It should be noted that since different test station data were removed from the model for each test, the regression coefficients were slightly altered in each test. Therefore all tested models are slightly different than those listed in Tables 6a and 6b. Removal of test station data was necessary in each of the tests to minimize bias in the test results.

The only QAA models developed and tested were those in which the flow data were adjusted to similar base periods by the correlation methods. The test results of these QAA models are shown in Table 7.

Table 7. Test Results for Selected QAA Estimation Models

Province	Station No.	Observed† QAA (cfs)	Estimated QAA (cfs)	E/O Ratio	CI_1 LCL (cfs)	CI_1 UCL (cfs)	CI_2 LCL (cfs)	CI_2 UCL (cfs)
1	13400	45.9	60.6	1.320	45.9	79.9	40.7	90.3
	17900	583.0	593.0	1.017	370.0	951.0	301.0	1168.0
	18250	771.0*	514.0	0.667	300.0	674.0	273.0	965.0
	19850	545.0	449.0	0.824	331.0	796.0	251.0	805.0
	21150	54.5*	71.4	1.310	55.4	91.9	49.6	102.0
2	14490	151.0**	228.0	1.510	184.0	281.0	168.0	309.0
	15879	90.8	66.3	0.730	36.1	122.0	27.3	161.0
	15920	635.0	583.0	0.918	362.0	939.0	291.0	1165.0
	16150	127.0	104.0	0.819	68.4	158.0	56.5	191.0
	16300	215.0	200.0	0.930	157.0	255.0	140.0	285.0
3	16650	232.0	228.0	0.983	193.0	270.0	180.0	289.0
	16700	176.0**	273.0	1.551	233.0	320.0	218.0	341.0
	18950	209.0**	128.0	0.612	114.0	145.0	108.0	152.0
	19250	622.0	486.0	0.781	376.0	628.0	339.0	697.0
	19430	48.0	49.6	1.033	39.8	61.6	36.5	67.0
	20450	228.0**	325.0	1.425	271.0	389.0	252.0	418.0
4	25150	186.0*	221.0	1.188	195.0	250.0	186.0	262.0
	30250	966.0	926.0	0.959	763.0	1123.0	712.0	1204.0
	30290	31.3**	21.0	0.671	18.1	24.5	17.2	25.8
	30610	279.0	337.0	1.208	293.0	388.0	279.0	408.0

Percent of observed values within CI_1: 60%
Percent of observed values within CI_2: 75%

* Observed value not within CI_1
** Observed value not within CI_2
† Observed values are adjusted by correlation to base periods similar to those for provincial base stations

The results show that 60 percent of all test station observed QAA values fell within CI_1 and 75 percent of the observed values fell within CI_2. Estimated to observed value ratios ranged from 1.551 for overestimates to 0.612 for underestimates.

Since QAA values represent averages over a 365 day period, discrepancies are difficult to evaluate relative to those in the extreme flow models. Overestimates or underestimates of QAA could be reflections of the aforementioned factors that theoretically affect low flows, the factors that theoretically affect high flows, or a combination of these. Stations with observed flow values falling outside of the confidence intervals are evaluated in two basic categories: those believed to be caused primarily by low flow factors and those believed to be caused primarily by high flow factors.

Stations with aberrant test results and overestimates of QAA believed to be caused by low flow factors such as geologic anomalies or diversions included Johnson Creek near Sycamore (21150), Coyote Creek near Crow (16700), Gales Creek near Forest Grove (20450), and Youngs River near Astoria (25150). All of these stations have noted diversions, however, these diversions are not quantified in the streamflow records.

Stations with aberrant test results and underestimates of QAA believed to be caused by relatively extreme flood peaks include the Little North Santiam River near Mehama (18250), the Luckiamute River near Hoskins (18950) and Nestucca River near Fairdale (30290). Relatively low permeability and shallow bedrock are the most discernable reasons for the Little North Santiam results whereas relatively high orographic precipitation is the probable reason for the Luckiamute and Nestucca results.

Stations with overestimates of QAA believed to be a result of high flow factors are Hills Creek above Hills Creek Lake near Oakridge (14490) and Salmon River near Government Camp (13400). The only discernable reason for the Hills Creek result is relatively high permeability and reduced flow peaks. The Salmon River result is believed to be due to relatively low flood peaks as a result of snow storage effects at the time the daily flows were correlated with the base station flows.

Test results for QF2D models developed from estimated test station flow data (Table 8a) are compared to those for models developed from observed test station flow data (Table 8b). Comparisons of these results were used to check the representativeness of the QF2D estimates obtained from the correlation analyses. In most cases, the results were consistent in that the pairs of data were both underestimates or overestimates of the observed values. In these cases, there were slight differences in the two estimates and the widths of their confidence intervals. There were four cases (stations 15879, 16650, 16700, and 19430) of inconsistencies in which the pairs of data contained one underestimate and one overestimate. With these exceptions, the comparisons indicated that estimates of QF2D obtained from the correlation analyses were reasonably accurate and did not cause major changes in these models. In one case (station 30290) the value from the estimated data model was identical to the observed data model, with a slight difference in the confidence interval widths. Discrepancies in the final QF2D models (those developed from observed test station data) are evaluated in the following discussion.

Table 8a. Test Results for Selected QF2D Estimation Models Developed with Estimated Test Station Flow Data

Province	Station No.	Observed QF2D (cfs)	Estimated QF2D (cfs)	E/O Ratio	CI_1 LCL (cfs)	CI_1 UCL (cfs)	CI_2 LCL (cfs)	CI_2 UCL (cfs)
1	13400	194**	460	2.371	293	722	241	879
	17900	4760	5537	1.163	2504	12240	1771	17307
	18250	8420	5094	0.605	2267	11443	1592	16293
	19850	5500	4491	0.817	2134	9455	1541	13087
	21150	972	1340	1.379	908	1976	767	2343
2	14490	1500	1937	1.291	1388	2705	1192	3149
	15879	800	698	0.873	277	1758	182	2677
	15920	3810	5035	1.322	2547	9956	1867	13577
	16150	1230	1059	0.861	570	1963	431	2600
	16300	1930	1748	0.906	1224	2497	1041	2936
3	16650	2770	2433	0.878	2081	2844	1954	3028
	16700	3480*	2920	0.839	2481	3437	2324	3670
	18950	2370**	1393	0.588	1219	1591	1156	1679
	19250	7480*	5392	0.721	4217	6893	3821	7609
	19430	441	529	1.200	433	647	399	701
	20450	2370**	3551	1.498	3002	*4201	2806	4495
4	25150	2100	2213	1.054	1890	2590	1786	2740
	30250	9420	9346	0.992	7345	11894	6736	12969
	30290	369**	217	0.588	179	263	166	282
	30610	3220	3399	1.056	2853	4050	2680	4312

Percent of observed values within CI_1: 70%
Percent of observed values within CI_2: 80%

* Observed value not within CI_1
** Observed value not within CI_2

Table 8b. Test Results for Selected QF2D Estimation Models Developed with Observed Test Station Flow Data

Province	Station No.	Observed QF2D (cfs)	Estimated QF2D (cfs)	E/O Ratio	CI_1 LCL (cfs)	CI_1 UCL (cfs)	CI_2 LCL (cfs)	CI_2 UCL (cfs)
1	13400	194**	469	2.418	306	718	254	865
	17900	4760	5644	1.186	2890	11023	2157	14765
	18250	8420	4928	0.585	2541	9559	1902	12765
	19850	5500	4768	0.867	2526	9001	1914	11879
	21150	972	1386	1.426	991	1940	856	2246
2	14490	1500	2072	1.381	1500	2862	1295	3315
	15879	800	875	1.094	358	2140	238	3214
	15920	3810	4924	1.292	2525	9602	1863	13013
	16150	1230	1096	0.891	608	1996	459	2622
	16300	1930	1858	0.963	1316	2625	1125	3071
3	16650	2770**	3982	1.438	3325	4769	3093	5127
	16700	3480	4134	1.188	3385	5047	3125	5493
	18950	2370**	1488	0.628	1318	1679	1256	1763
	19250	7480**	5235	0.700	4179	6558	3817	7180
	19430	441	431	0.977	340	546	309	601
	20450	2370*	2918	1.231	2474	3441	2315	3678
4	2515	2100	2240	1.067	1903	2637	1795	2796
	3025	9420	9371	0.995	7300	12029	6674	13158
	3029	369**	217	0.588	178	263	167	282
	3061	3220	3409	1.059	2842	4089	2662	4366

Percent of observed values within CI_1: 70%
Percent of observed values within CI_2: 75%

* Observed value not within CI_1
** Observed value not within CI_2

As indicated in Table 8b, 70 percent of the observed values fell within CI_1 and 75 percent of the observed values fell within CI_2. Stations with aberrant results included Salmon River near Government Camp (13400), Long Tom River near Noti (16650), Luckiamute River near Hoskins (18950), Gales Creek near Forest Grove (20450), and Nestucca River near Fairdale (30290).

The most discernable reason for the overestimate of QF2D for the Salmon River is that high flows are regulated by snow storage and are out of phase with the winter high flows of most other stations in this province.

Probable reasons for the overestimate for the Long Tom River are the relatively high permeability of the basin and regulation of peak flows by log ponds.

As in the QAA tests, the underestimates of QF2D for the Luckiamute and Nestucca Rivers are probably caused by extreme orographic effects which cause relatively high precipitation in these basins.

Anomalous geologic formation is the only factor cited as a possible reason for the underestimate for the South Yamhill River and the overestimate for Gales Creek.

Test results for models developed with estimated flow data (Table 9a) and models developed with observed flow data (Table 9b) were also compared for QF2D. In all of these comparisons, results were consistent in that the pairs of data were both underestimates or overestimates. Differences in the degrees of under or overestimation and confidence interval widths were very small. In two cases (stations 19430 and 30290) there was no difference in the values of the estimates. These comparisons imply that there were no marked

Table 9a. Test Results for Selected Q7L2 Estimation Models Developed with Estimated Test Station Flow Data

Province	Station No.	Observed Q7L2 (cfs)	Estimated Q7L2 (cfs)	E/O Ratio	CI_1 LCL (cfs)	CI_1 UCL (cfs)	CI_2 LCL (cfs)	CI_2 UCL (cfs)
1	13400	18.0**	4.1	0.228	1.7	9.8	1.2	14.3
	17900	125.0	40.5	0.324	8.7	187.0	4.5	366.0
	18250	29.0	61.7	2.128	12.9	293.0	6.5	581.0
	19850	31.0	40.0	1.290	10.0	159.0	5.5	290.0
	21150	0.60**	8.3	13.833	4.7	14.5	3.7	18.6
2	14490	20.0	18.1	0.905	11.1	29.5	8.8	36.9
	15879	4.0	2.7	0.675	0.74	9.6	0.41	17.3
	15920	207.0*	63.2	0.305	26.5	150.0	17.9	224.0
	16150	10.0	5.1	0.510	2.2	11.9	1.5	17.6
	16300	18.0	15.5	0.861	9.3	25.7	7.4	32.3
3	16650	12.0	9.1	0.758	5.5	15.1	4.4	18.6
	16700	0.0**	9.2	N.A.	5.3	15.9	4.3	19.3
	18950	10.0**	4.2	0.420	2.7	6.6	2.3	7.8
	19250	14.0	17.8	1.271	7.3	43.8	5.0	63.4
	19430	3.2*	1.5	0.469	0.78	2.9	0.59	3.8
	20450	8.4	11.7	1.393	6.0	22.6	4.6	29.7
4	25150	5.8**	14.1	2.431	11.2	17.6	10.4	19.1
	30250	74.0	58.7	0.793	40.9	84.5	35.9	96.2
	30290	1.9**	1.2	0.632	0.31	1.6	0.11	1.7
	30610	17.0	21.1	1.241	16.2	27.6	14.7	30.3

Percent of observed values within CI_1: 60%
Percent of observed values within CI_2: 70%

* Observed value not within CI_1
** Observed value not within CI_2

Table 9b. Test Results for Selected Q7L2 Estimation Models Developed with Observed Test Station Flow Data

Province	Station No.	Observed Q7L2 (cfs)	Estimated Q7L2 (cfs)	E/O Ratio	CI_1 LCL (cfs)	CI_1 UCL (cfs)	CI_2 LCL (cfs)	CI_2 UCL (cfs)
1	13400	18.0**	4.2	0.233	1.8	9.8	1.3	14.1
	17900	125.0	45.2	0.362	13.7	149.0	8.2	248.0
	18250	29.0	50.0	1.724	11.4	220.0	5.9	420.0
	19850	31.0	38.4	1.239	10.4	143.0	5.8	253.0
	21150	0.60**	7.9	13.167	4.6	13.7	3.6	17.4
2	14490	20.0	17.7	0.885	10.8	28.9	8.7	36.1
	15879	4.0	2.6	0.650	0.71	9.5	0.39	17.2
	15920	207.0*	65.7	0.317	27.8	155.2	18.8	229.5
	16150	10.0	4.6	0.460	2.0	10.6	1.4	15.4
	16300	18.0	15.1	0.839	9.1	25.1	7.2	31.6
3	16650	12.0	9.6	0.800	6.1	15.1	5.0	18.2
	16700	0.0**	11.4	N.A.	7.3	17.6	6.2	21.0
	18950	10.0**	5.0	0.500	3.4	7.2	3.0	8.4
	19250	14.0	22.9	1.636	11.2	46.8	8.4	62.8
	19430	3.2*	1.5	0.469	0.90	2.6	0.72	3.2
	20450	8.4*	14.9	1.774	8.9	25.1	7.1	31.0
4	25150	5.8**	13.9	2.397	11.1	17.4	10.3	18.8
	30250	74.0	58.3	0.788	40.7	83.4	35.8	94.9
	30290	1.9**	1.2	0.632	0.88	1.6	0.80	1.7
	30610	17.0	21.0	1.235	16.1	27.2	14.7	29.9

Percent of observed values within CI_1: 55%
Percent of observed values within CI_2: 70%

* Observed value not within CI_1
** Observed value not within CI_2

changes in the models caused by developing the models with estimates of Q7L2 that were derived from the correlation analyses. Test results of the final Q7L2 models are shown in Table 9b.

Relatively high percentages of aberrant test results were evident in the Q7L2 model tests. As shown in Table 9b, 55 percent of the observed values were within CI_1 and 70 percent of the observed values were within CI_2. Test station discrepancies included Salmon River near Government Camp (13400), Johnson Creek near Sycamore (21150), South Fork McKenzie River above Cougar Reservior near Rainbow (15920), Coyote Creek near Crow (16700), Luckiamute River near Hoskins (18900), North Yamhill River near Fairdale (19430), Gales Creek near Forest Grove (20450), Youngs River near Astoria (25150) and Nestucca River near Fairdale (30290).

In Province 1, the Salmon River and Johnson Creek represent two extreme discrepancies. The underestimate for the Salmon River reflects regulation in low flows caused by snow storage. The extreme overestimate for Johnson Creek reflects combined effects of diversion for irrigation, and low groundwater recharge caused by urbanization. This basin is also at a relatively low elevation and receives less precipitation than most other basins in this province.

The South Fork of the McKenzie River has an underestimate of Q7L2 which reflects extremely high groundwater storage relative to the other gaged basins in Province 2.

The overestimates of Q7L2 for Coyote Creek, Gales Creek, and the Youngs River are believed to be due to diversions for irrigation and domestic use. Relatively low groundwater storage is another probable reason.

The Luckiamute, the North Yamhill, and the Nestucca Rivers all had underestimates of Q7L2. The same reason that was believed to cause the underestimates of QF2D for these stations also applies to Q7L2. Greater orographic effects cause relatively high precipitation in these basins. The relations between antecedent precipitation and low flows are discussed in detail by Riggs and Hanson (1969). Although there are minor diversions on the Luckiamute River, the antecedent precipitation factor seems to be more important in affecting the low flows. In the Nestucca River case, regulation by McGuire Lake is believed to be another reason for the underestimate of Q7L2.

The streamflow estimation models and their test results reflect some basic problems associated with hydrologic modelling. No hydrologic model can simulate perfectly the complex realm of natural processes which occur both on and within a watershed, and the simple models developed in these analyses are indeed no exception. Several salient reasons for the hydrologic nonhomogeneity of the provincially aberrant test stations were conjectured and noted. In practical applications of these models, field checking would be necessary so that provincial aberrations could be identified, and the streamflow estimates could be adjusted accordingly. Despite the simplicity of the estimation models, they are believed to be an effective means by which reasonable estimates of the QF2D, QAA and Q7L2 may be obtained. These estimates are the basic information needed to construct synthetic flow-duration curves for sites on ungaged streams.

Flow-Duration Curves

For each of the four provinces, two representative flow-duration curves are compared on a dimensionless scale. These curves were made dimensionless by the procedure described in the METHODOLOGY and are illustrated in Figure 3. As noted previously, synthetic flow-duration curves can be constructed for ungaged streams, from estimated values of QF2D, QAA, and Q7L2. If dimensionless ratios of QF2D/QAA and Q7L2/QAA for the ungaged site are similar to those for a gaged site in the same hydrologic province, a synthetic flow-duration curve can be constructed using the shape of the long-term station as a guide. Comparisons of the two representative curves for each province (Figures 4-7) illustrate variation in curve shapes typical of each province. It should be apparent that the hydrologic factors that are reflected in the variation of the provincial curve shapes are similar to those that are reflected in the variability of the provincial estimation models. Searcy (1959) notes:

> Except in basins with a highly permeable surface, the distribution of high flows is governed largely by the climate, the physiography, and the plant cover of the basin. The distribution of low flows is controlled chiefly by the geology of the basin.

Since low flow characteristics are of particular importance in hydropower potential assessment, the main focus of the comparisons is on the low flow ends of the curves.

Dimensionless curves for the Little Sandy River near Bull Run (14150) and the Molalla River above Pine Creek near Wilhoit (19850) are shown in Figure 4. There is about a seven percent difference in area under these two curves. Since there is no major regulation or

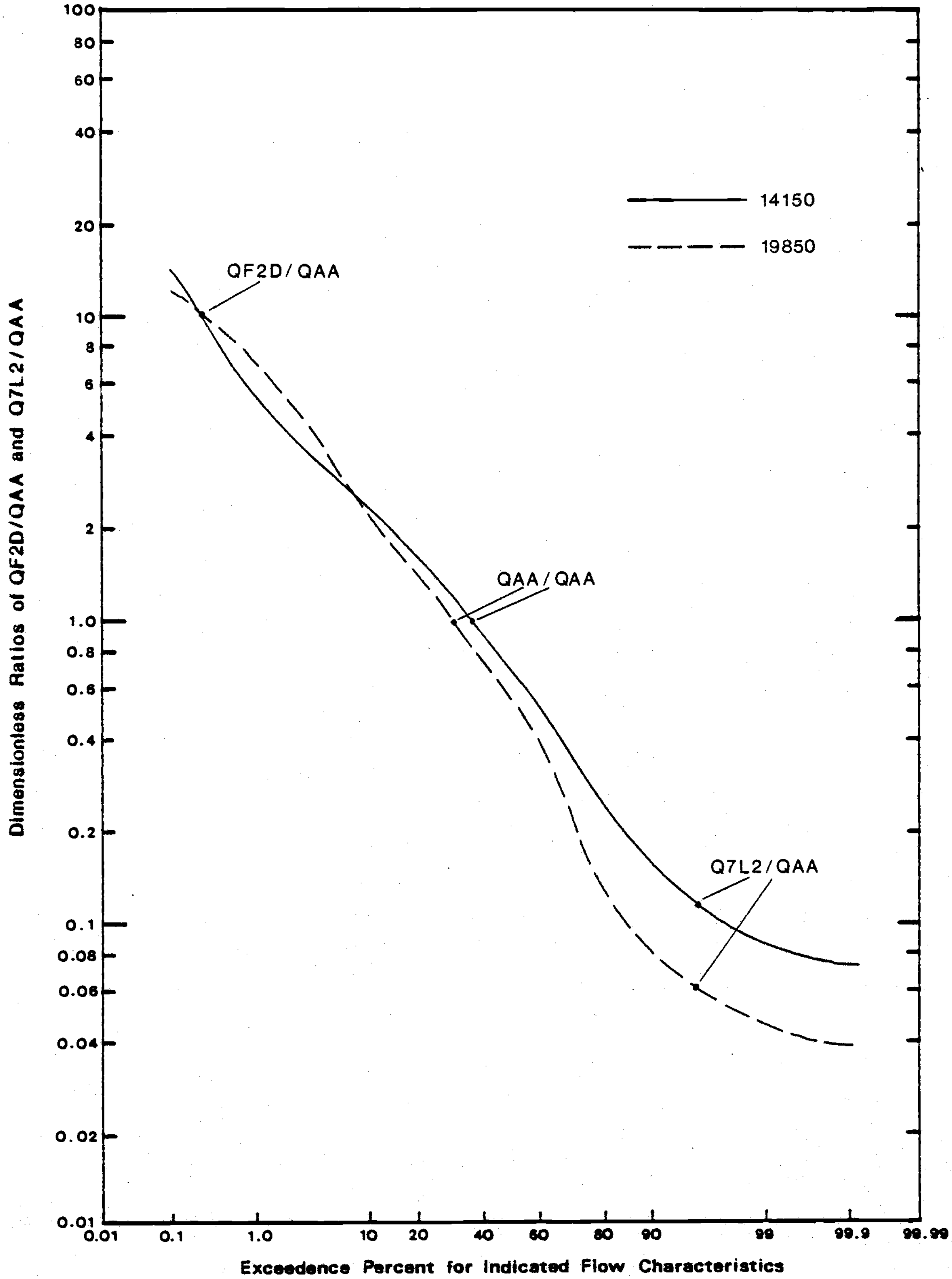


Figure 4. Comparison of Two Province 1 Dimensionless Flow-Duration Curves: Little Sandy River near Bull Run (14150) and Molalla River above Pine Creek near Wilhoit (19850).

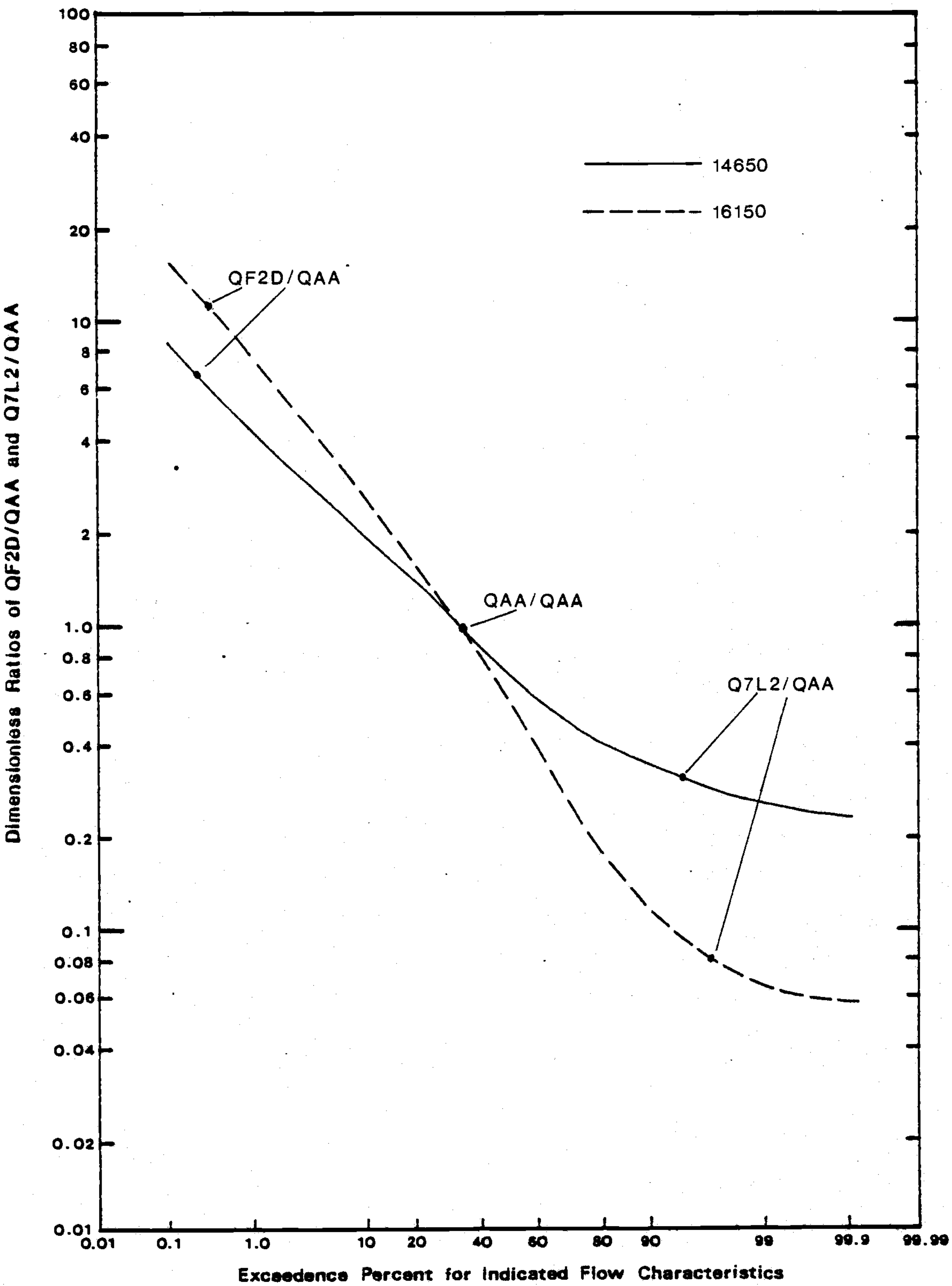


Figure 5. Comparison of Two Province 2 Dimensionless Flow-Duration Curves: Salmon Creek near Oakridge (14650) and Lookout Creek near Blue River (16150).

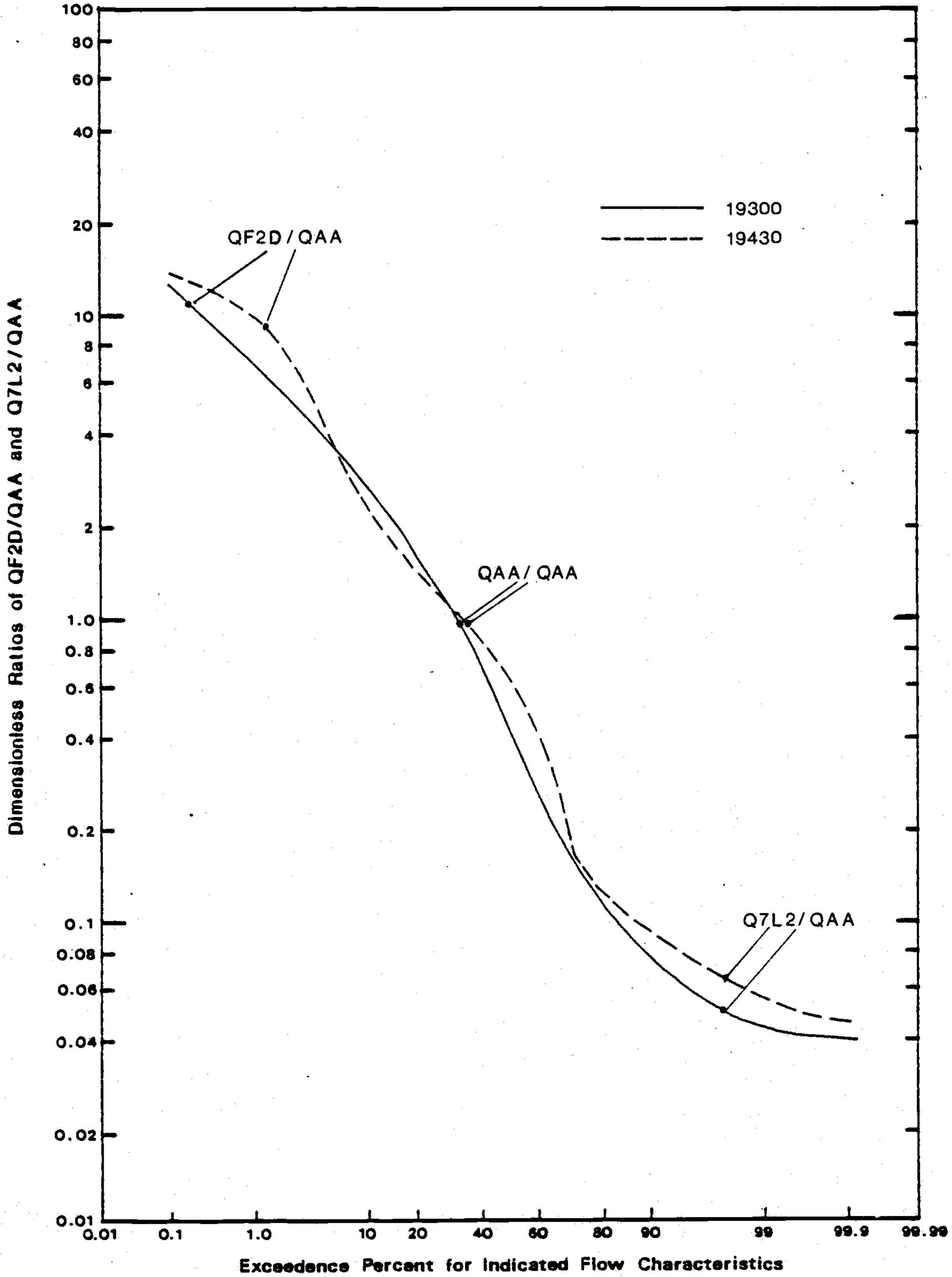


Figure 6. Comparison of Two Province 3 Dimensionless Flow-Duration Curves: Willamina Creek near Willamina (19300) and North Yamhill River near Fairdale (19430).

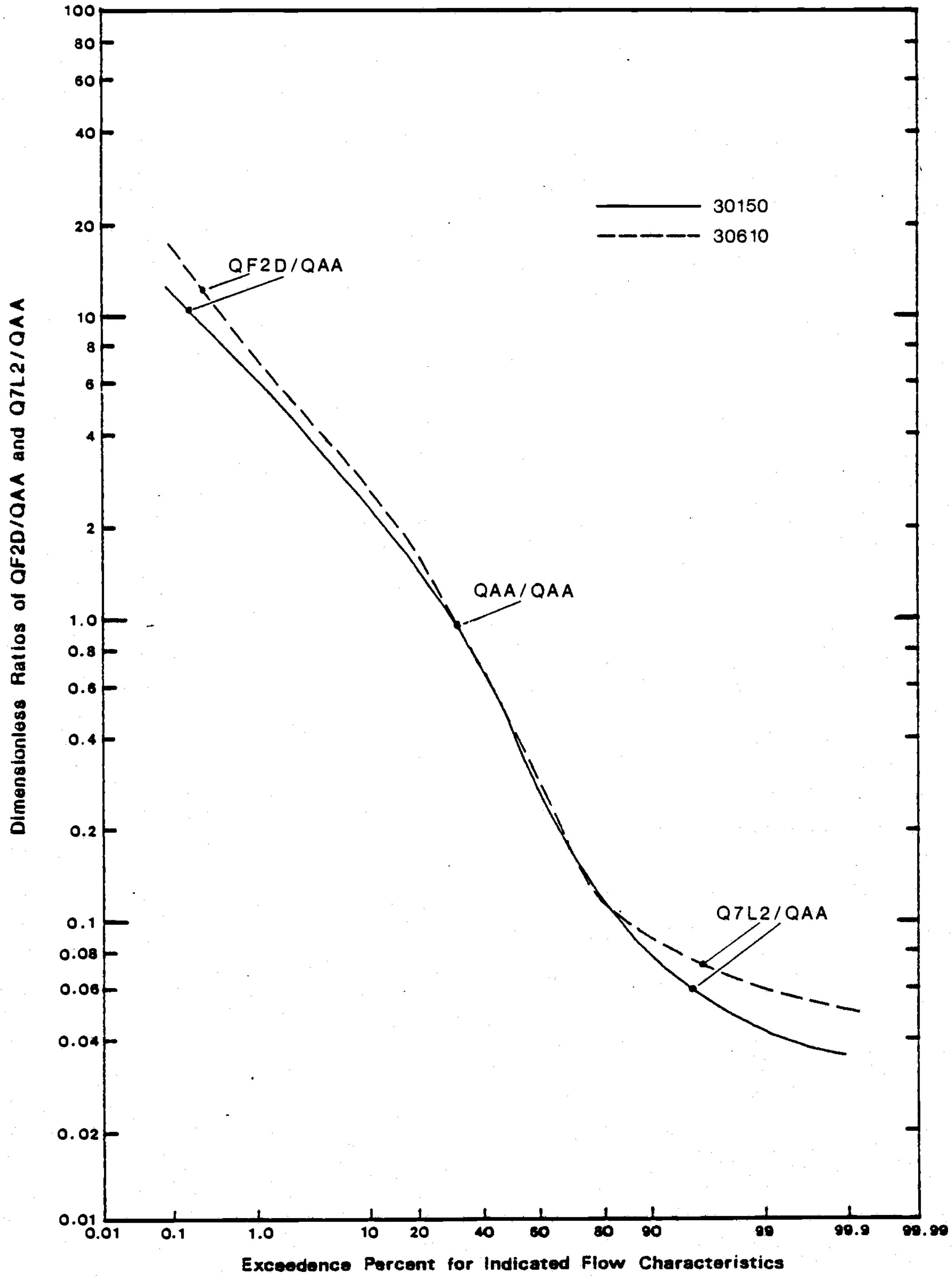


Figure 7. Comparison of Two Province 4 Dimensionless Flow-Duration Curves: Wilson River near Tillamook (30150) and North Fork Alsea River at Alsea (30610).

diversion above these stations the difference in the distribution of low flows in these two streams may reflect different geologic formations in these two basins. Groundwater contributions to low flows appear to be proportionately greater in the Little Sandy basin.

The dimensionless duration curves representative of Province 2 are shown in Figure 5. These curves are drawn for Salmon Creek near Oakridge (14650) and Lookout Creek near Blue River (16150). The difference in the area under these curves is approximately nine percent. The relatively "flat" curve shape for Salmon Creek may reflect proportionately higher surface infiltration and groundwater storage in the Salmon Creek basin. This comparison may also illustrate the generally greater geologic diversity in Province 2.

The comparisons of two dimensionless curves for the Coast Range provinces may reflect considerably less geologic diversity in the Coast Range than that in the Cascades (Figures 6 and 7). There is relatively small variation in the curve shape comparisons for Willamina Creek near Willamina (19300) and the North Yamhill River near Fairdale (19430) and the comparison for the Wilson River near Tillamook (30150) and North Fork Alsea River at Alsea (30610). This is particularly apparent when the lower ends of the Coast Range curves are compared to those for the Cascades. The difference in area under the curves in each of these comparisons is slightly less than four percent. It is likely that there are some basins in the Coast Range with anomalous geologic formations that would be reflected by considerably different curve shapes. These kinds of anomalies, however, are believed to be less frequent than those in the Cascades.

This discussion has been oversimplified to emphasize that when synthetic flow-duration curves are constructed using shapes of long-term duration curves as guides, the general hydrologic homogeneity of the two basins should be checked, particularly in the Cascade provinces. Comparison of dimensionless ratios of QF2D/QAA and Q7L2/QAA is needed before the synthetic curves are drawn for an ungaged site. Because of the critical relation between the low flow distribution and hydropower potential, base flow measurements would be necessary in an actual micro-hydro site analysis. Given micro-hydro plant specifications and minimum flow requirements, the low flow end of the curve can indicate the percent of time when operation of the plant would not be feasible, whereas the high end of the curve can aid in selecting a site where flood hazard would be minimized.

Example of Methodology Application

A preliminary micro-hydro site feasibility analysis was done to illustrate the procedures involved in application of this methodology. The site selected was on Wolf Creek, near its confluence with Elk Creek. A map of the Wolf Creek drainage basin is provided in Figure 8. This site is located in Province 4 in the Yaquina River basin. Because the Alsea River near Tidewater (30650) has dimensionless flow ratios (QF2D/QAA=11.27, Q7L2/QAA=0.51) that are similar to those for Wolf Creek (QF2D/QAA=10.34, Q7L2/QAA=0.57), the shape of the Alsea River curve was used as a guide in drawing the synthetic average, maximum and minimum flow-duration curves for Wolf Creek (Figure 9). The maximum and minimum duration curves were based on

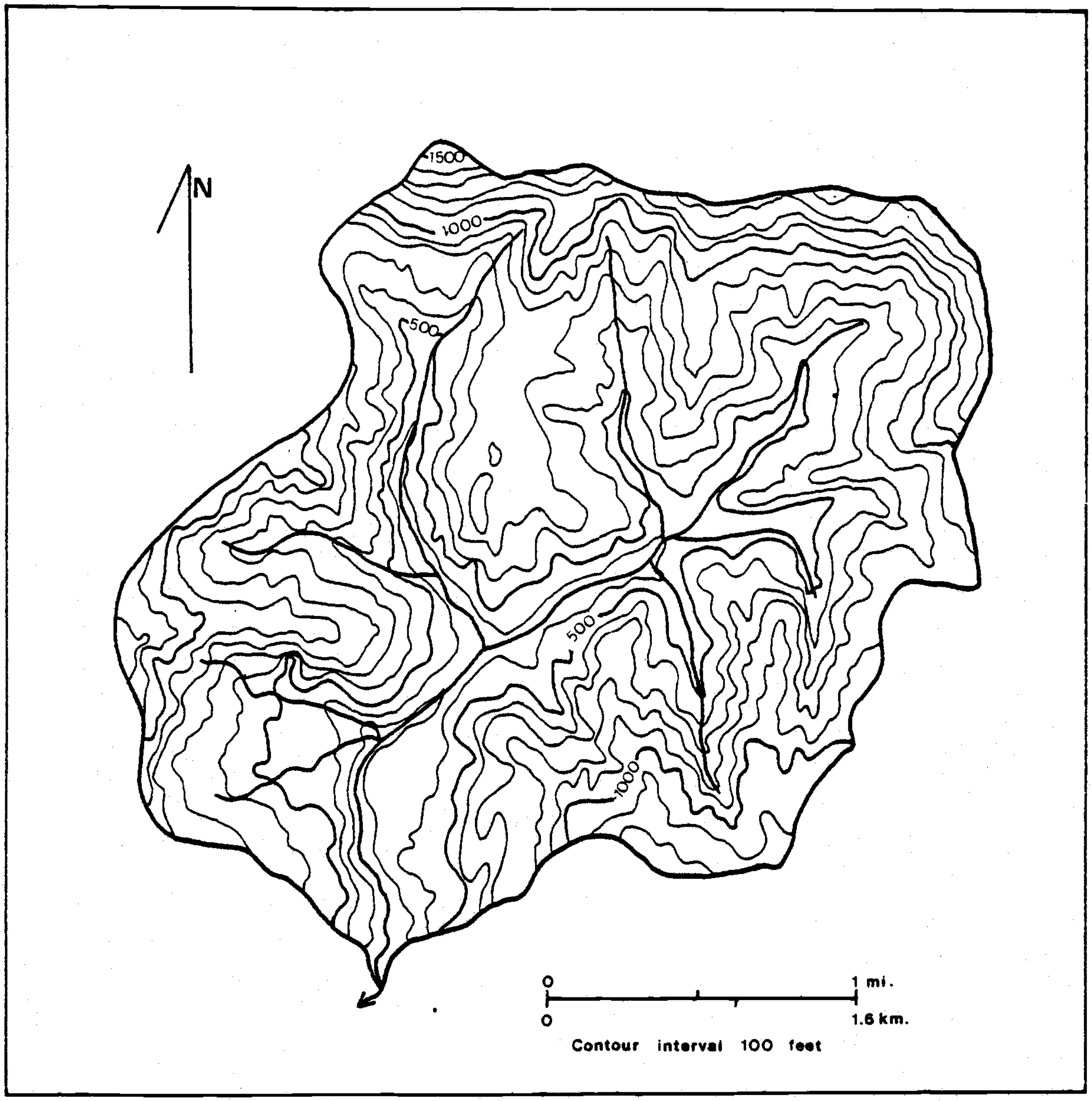


Figure 8. Wolf Creek Drainage Basin

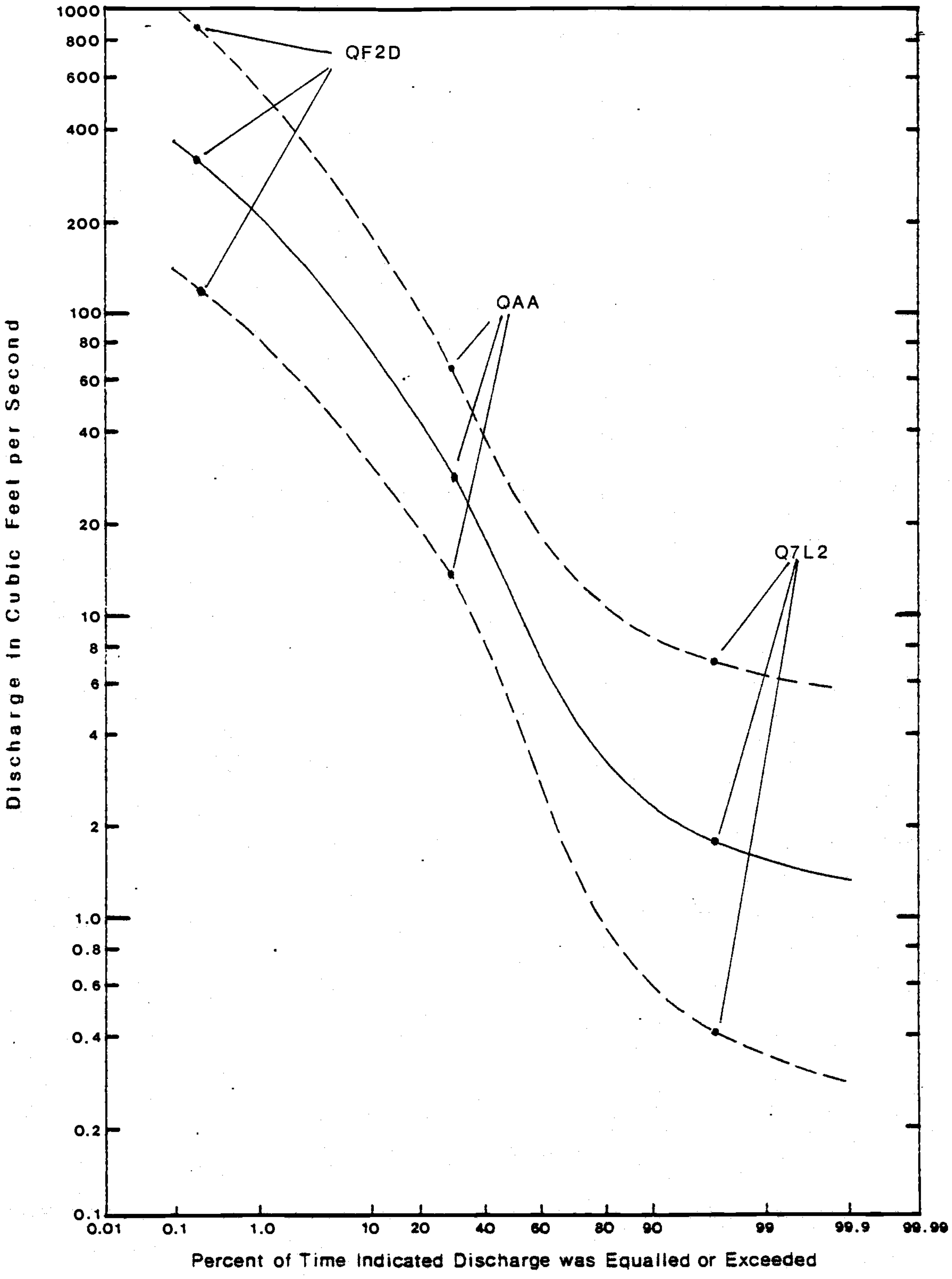


Figure 9. Synthetic Average, Maximum, and Minimum Flow-Duration Curves for Wolf Creek

99 percent prediction limits computed from the model estimates of QF2D, QAA and Q7L2. Because these prediction limits were roughly proportional to the maximum and minimum recorded values for the same Alsea River flow characteristics, the maximum and minimum duration curves provide reasonably accurate representation of the highest and lowest flow conditions for this site.

Assessments of micro-hydro power potential were based on hypothetical turbine specifications, assumed developable head and minimum flow requirements, and specified exceedence flows derived from the average, maximum, and minimum duration curves. These data (Table 10) were analyzed using the HYDRO-CALC program of the Hydropower Computer Reconnaissance (HCR) Package (Broadus, 1981). The plant specifications are based on recommendations given these flow characteristics and 50 feet of developable head. Two separate analyses were done for the average, maximum and minimum flow-duration situations. In the first analysis (Case 1), two cfs is assumed to be the minimum flow requirement which is an approximation of the seven-day average low flow. In the second analysis (Case 2), ten cfs is assumed to be the minimum flow requirement which is considered to represent a minimum flow requirement for providing adequate habitat for migratory fish such as anadromous salmonids. These two flows are only examples of possible recommended or required flows in these two situations. Recommended habitat characteristics for some migratory fish species are discussed by Smith and Lauman (1972) and Bergstrom (1981). The two and ten cfs minimum flow requirements are used to illustrate the tradeoffs between minimum flow requirements and hydropower potential.

Table 10. Wolf Creek Location Description, Basin Characteristics, Measurements and Input Data for HYDRO-CALC Analyses.

Stream: Wolf Creek

Location: Northeast Quarter of Section 1, Township 12 South, Range 9 West.

Basin Parameters:	Area	4.8 $mi.^2$
	Relief	0.174 mi.
	$A\sqrt{H}$	2.00 $mi.^{2.5}$

Estimated Values of Maximum, Average, and Minimum QF2D, QAA, and Q7L2 (cfs).

QF2D max.:	123.0	QF2D avg.:	333.0	QF2D min.:	901.0
QAA max. :	14.9	QAA avg. :	32.2	QAA min. :	69.5
Q7L2 max.:	7.69	Q7L2 avg.:	1.83	Q7L2 min.:	0.44

Selected Exceedence Values Derived from Maximum, Average, and Minimum Duration Curves.

Exceedence(%)	Max. Flow Rate (cfs)	Avg. Flow Rate (cfs)	Min. Flow Rate (cfs)
5	295.0	120.0	48.0
10	190.0	81.0	35.0
30	69.0	32.2	14.0
50	27.0	13.0	5.2
80	12.0	3.5	0.9
95	8.0	2.0	0.5

Hypothetical Site and Plant Specifications.

Available Head (ft.):	50
Turbine Type:	Crossflow
Rated Flow Rate (cfs):	40
Cutoff Flow Rate (cfs):	12-14
Generator Efficiency (%):	90

Minimum Flow Requirements (cfs).

Case 1 - 2.0
Case 2 - 10.0

A typical flow-duration curve defining various HYDRO-CALC terms is shown in Figure 10. The values a-f in this figure apply to all of the flow-duration curves determined in this section. These values are defined by Broadus (1981) as:

a - Rated flow of the turbine. This is the ideal flow rate the turbine is designed to operate at.

b - Rated exceedence corresponding to the rated flow.

c - Cutoff flow rate. This is the flow rate below which the turbine will not operate efficiently and is assumed to be shut down.

d - Cutoff exceedence corresponding to the cutoff flow rate.

e - Minimum or low flow limit. This is the amount of river flow which cannot be used for electric generation. This is the river flow which must bypass the turbine due to legal or environmental considerations.

f - Minimum flow exceedence corresponding to the minimum or low flow.

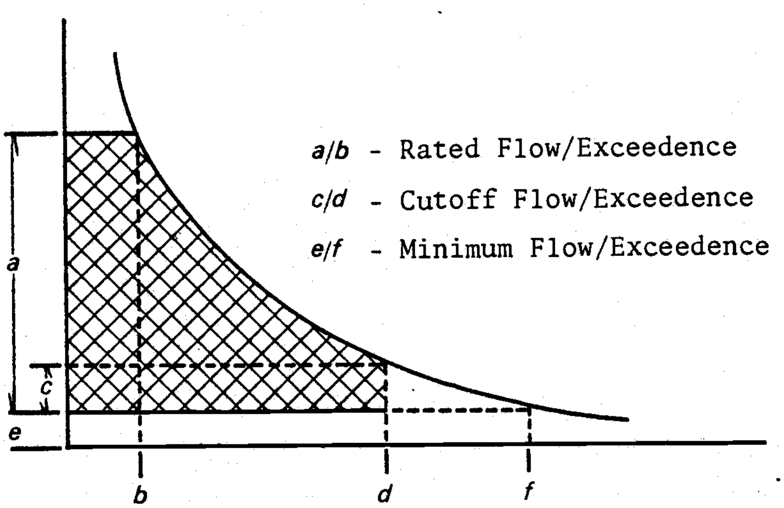


Figure 10. Definition of HYDRO-CALC terms

Values a-f thus define the operating region of the turbine and are integrated by HYDRO-CALC to determine the annual energy as:

$$AE = (EG)(HD)(1\ \text{year}) \int_0^D (TF)(ET)\,dE \qquad (7)$$

where

AE = Annual Energy

EG = Generator efficiency

HD = Effective Head

E = Exceedence

TF = Turbine flow as a function of E

ET = Turbine efficiency as a function of TF

This integration is performed using a modified Simpson's Rule Method (Broadus 1981).

The plant factor is the other notable value calculated by HYDRO-CALC. This is defined as the total annual energy, AE, divided by the maximum energy possible given a constant rated flow.

$$PF = \frac{AE}{(PW)(1\ \text{year})} \qquad (8)$$

where

PF = Plant factor

PW = Rated turbine-generator capacity

AE = Annual Energy

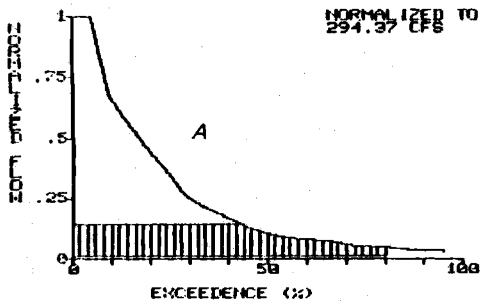
Results for the Case 1 analyses are summarized in Figure 11(A-C) and results for the Case 2 analyses are summarized in Figure 12(A-C).

A

TURBINE #1

CROSSFLOW

AVAILABLE HEAD	50	FT	
	EXC. %	TURB. CFS	RIVER CFS
RATED	42.8	40	42
CUTOFF	80	10.1	12.1
MINIMUM	100	---	2
GENERATOR EFF.	90	%	
RATED POWER	129.44	KW	
ANNUAL ENERGY	694482	KWH	
PLANT FACTOR	61.2	%	

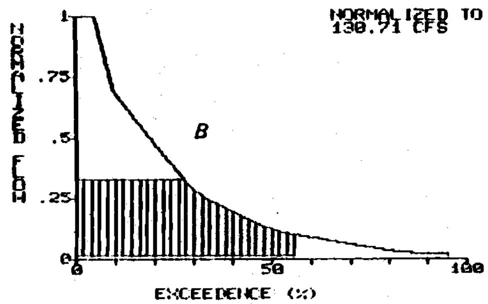


B

TURBINE #1

CROSSFLOW

AVAILABLE HEAD	50	FT	
	EXC. %	TURB. CFS	RIVER CFS
RATED	27.4	40	42
CUTOFF	56	10.1	12.1
MINIMUM	96.6	---	2
GENERATOR EFF.	90	%	
RATED POWER	129.44	KW	
ANNUAL ENERGY	479805	KWH	
PLANT FACTOR	42.3	%	



C

TURBINE #1

CROSSFLOW

AVAILABLE HEAD	50	FT	
	EXC. %	TURB. CFS	RIVER CFS
RATED	9.3	40	42
CUTOFF	37	10.5	12.5
MINIMUM	74.1	---	2
GENERATOR EFF.	90	%	
RATED POWER	129.44	KW	
ANNUAL ENERGY	278940	KWH	
PLANT FACTOR	24.6	%	

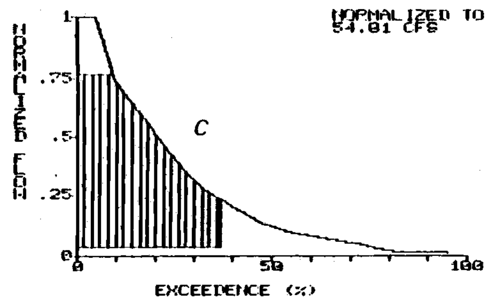


Figure 11(A-C). Wolf Creek Power Potential Assessments for Case 1: 2 cfs Minimum Flow Requirement

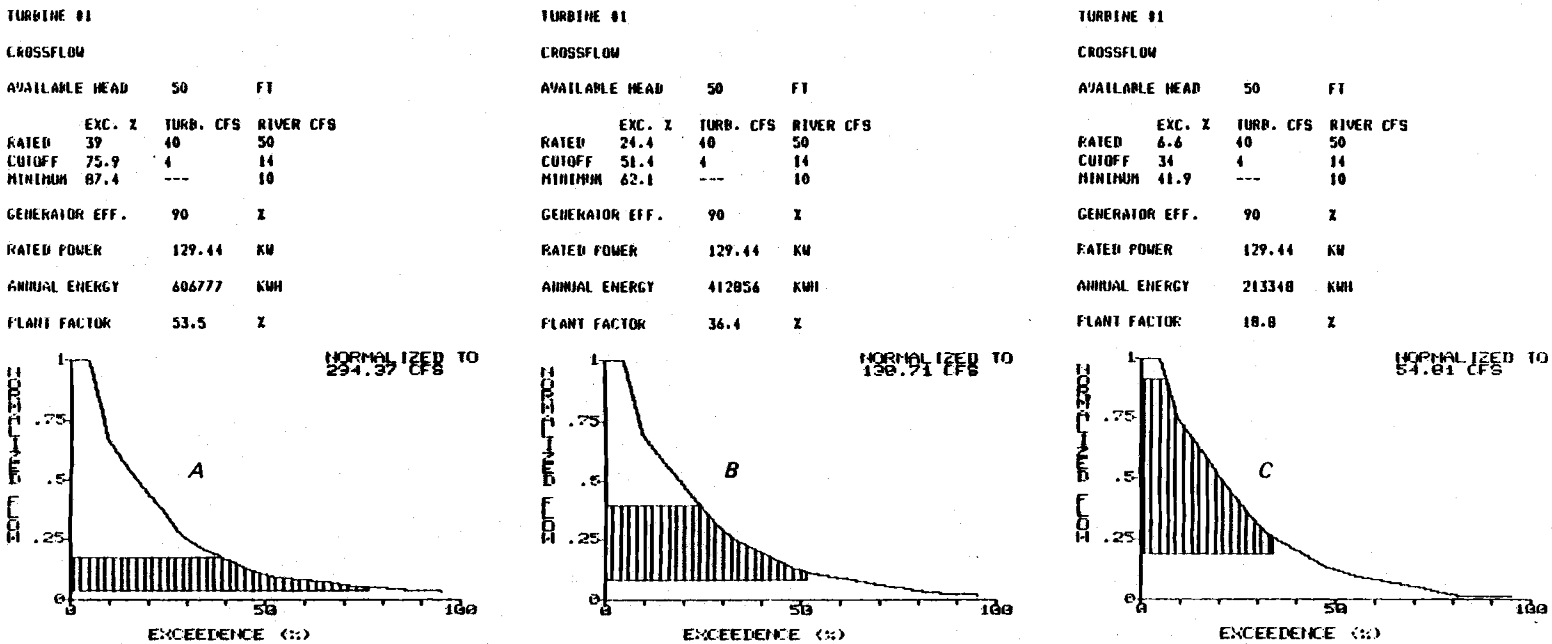


Figure 12(A-C). Wolf Creek Power Potential Assessments for Case 2: 10 cfs Minimum Flow Requirement

In both of these figures, A denotes analysis based on the maximum duration curve, B denotes the average duration curve, and C denotes the minimum duration curve. All of the curves are normalized according to the input flow-duration data.

Figures 11(A-C) and 12(A-C) illustrate the magnitude of changes in power potential caused by extremely wet or dry years and two different minimum flow requirements. When the minimum flow requirement is two cfs, the "best" flow conditions increase the annual energy value for the average flow conditions from 479805 Kilowatt-hours (KWH) to 694482 KWH, an increase of about 31 percent. The plant factor is increased from 42.3 percent to 61.2 percent. Under poorest flow conditions, the annual energy value for average flow conditions is reduced by about 42 percent to 278940 KWH. The plant factor is reduced to 24.6 percent. Comparison of Figures 11B and 12B shows that under average flow conditions, increasing the minimum flow requirement from two to ten cfs results in an annual energy reduction of about 14 percent, and a plant factor reduction to 36.4 percent.

Because power requirements for the site would depend on the needs of the user, they were not specified for this site. Hence it is not possible to evaluate the significance of reductions in power potential caused by drought conditions or high minimum flow requirements. The annual energy values shown in the figures are considered to be overestimates, since reductions in the overall efficiency that would result from penstocks or other sources of friction loss are not included in the calculations. Nonetheless, the values of rated power and annual energy calculated from the inputs assumed are far greater than what would be needed to supply average electricity needs for an individual home.

A synthetic annual hydrograph for Wolf Creek was developed from dimensionless ratios of average monthly flows to QAA for the Alsea River (Figure 13). The shaded area on this hydrograph represents the operating region of the hypothesized turbine. This figure portrays a general illustration of the yearly distribution of power potential for this site. The greatest power potential occurs in the winter months when energy demands would most likely be highest.

Based on these preliminary analyses, the general power potential for this site appears to be more than adequate for micro-hydro purposes. A turbine with a much smaller rated flow could probably supply electricity for an individual home at this site through most of the year.

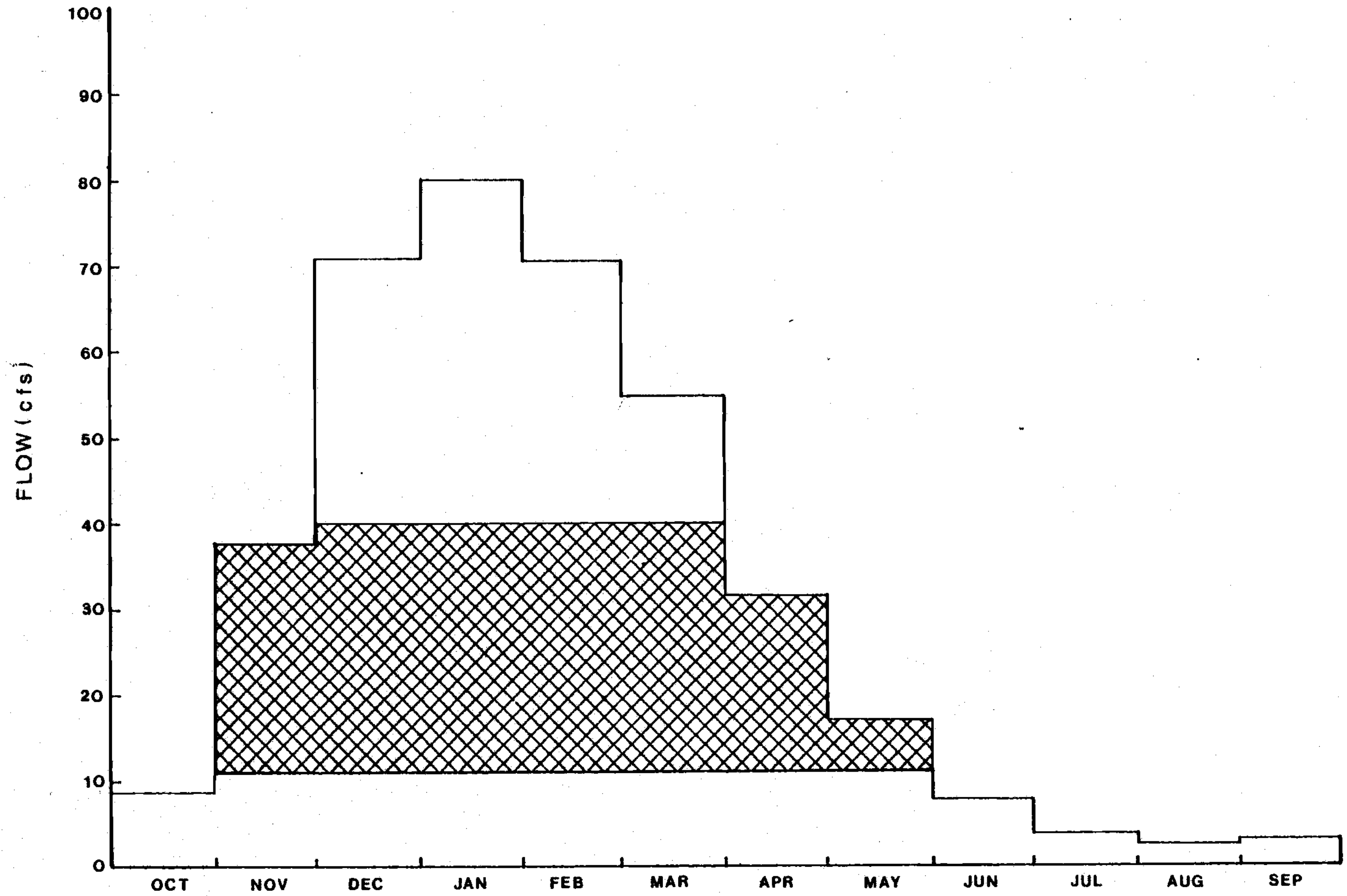


Figure 13. Synthetic Annual Hydrograph for Wolf Creek Showing Operating Range of Hypothesized Turbine.

VI. SUMMARY AND CONCLUSIONS

A methodology for estimating streamflow characteristics on ungaged streams in northwestern Oregon was developed and tested. Streamflow and basin characteristics data from gaged streams were used to develop estimation models for three streamflow characteristics, the QF2D, the QAA, and the Q7L2. A procedure for constructing synthetic flow-duration curves from estimates of the three streamflow characteristics was described. Finally, a preliminary power potential assessment for a hypothetical micro-hydro site was presented to exemplify application of the methodology.

Satisfactory estimates of the three streamflow characteristics can be derived from the provincial estimation models developed in this study. The independent variables, basin area (A) and basin area multiplied by the square root of relief ($A\sqrt{H}$), have sound physical relationships to streamflows and can be easily and accurately measured from topographic maps.

The relative variability in the models was contingent upon the streamflow characteristic and the hydrologic province. Variability tended to be highest in the Q7L2 models and lowest in the QAA models. Variability also tended to be higher in the Cascades provinces than in the Coast Range provinces.

Test results of the models and comparisons of the flow-duration curve shapes in each of the four hydrologic provinces revealed important considerations for practical application of this methodology. If the natural streamflow characteristics of a particular micro-hydro site are altered by factors such as diversion, regulation, anomalous geologic formations, orography or land use, estimates of QF2D, QAA, and Q7L2 can be significantly erroneous. These factors, however, can usually be identified and reasonable adjustments in the estimates can be made.

In this study, an efficient methodology for obtaining pragmatic information for micro-hydro site feasibility analyses was developed. It is emphasized that assessment of potential hydropower derived from the methodology developed in this study would constitute only one part of any micro-hydro site feasibility analysis. Complete micro-hydro feasibility analyses are typically complicated by important elements such as economic feasibility, water rights, and environmental impacts, none of which were addressed in this study. The findings of this study should not be interpreted as either an endorsement or a condemnation of micro-hydro development. The potential for hydroelectric power production on a very small scale is recognized for this study region. It is hoped that any applications of this methodology will be sound and conservative, with minimal impact on lotic and riparian environments.

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