WATER for IDAHO

METHODOLOGIES FOR THE DETERMINATION OF FLOW DURATION CURVES AT SPECIFIC SITES ON UNGAGED REACHES OF STREAMS

A THESIS

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ABSTRACT

This thesis study examines several techniques for synthesizing flow duration curves, at ungaged river sites, for application to hydro-electric energy surveys of entire river systems.

Three techniques are presented which can be utilized on natural flowing rivers. Data requirements consist of existing streamflow records and compilations of area-precipitation products. The procedures are based on regression equations and normalization of existing flow duration curves. The three techniques are applied to the Clearwater River in Idaho and a comparison of their results is made.

A fourth technique is presented for synthesizing flow duration curves for regulated streams using similar data input as for the three natural flow Methods. This procedure is applied to the regulated portions of the Priest and Payette Rivers in Idaho. The Method is also applicable to natural streams and this is illustrated by application to the Clearwater river.

Comparisons of synthetic results to actual discharge and energy values for various exceedance percents along with percent differences is presented to give indications of error magnitudes.

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DEFINITIONS

ap --Sum of the area-precipitation products for an individual reach. The area (a) between each pair of projected isohyetal lines multiplied by the average value of the bordering isohyets (p) and summed over the reach, ie. aipi for i= 1 to n where n = the number of sub-areas, within the reach, created by the overlying isohyetal lines. (cfs-days).

AP--Sum of individual reach area-precipitation products, ie. (ap)i for i = 1 to n, where n = the number of reaches upstream of the summation point. The summation point is usually the downstream boundary of a reach. This term represents the total precipitation input to the drainage area upstream of some particular reach boundary. (cfs-days).

CFS-DAYS--Unit of volume, Discharge in cubic feet per second (cfs) multiplied by the duration in days of that discharge. This unit of measure is used because of the convenience in converting from volumes to discharge.

DURATION CURVE--A plot of discharge versus frequency of occurrence ie. discharge versus the percent of time that a specified flow is equalled or exceeded. (exceedance percent) Refer to Figure 3-1.

IDWR--Abbreviation for Idaho Department of Water Resources.

K-VALUE--Runoff coefficient. Used to reduce the AP product to account for losses from (1) evapo-transpiration, (2) deep percolation, (3) interception (4) depression storage etc. Usually the K-value is between 0 and 1.

NAP--Normal Annual Precipitation.

QAA--Average annual runoff (discharge).

REACH--A section of river or stream. The boundaries of which are usually defined by discontinuities such as major tributary inflow points. Boundaries may also be defined arbitrarily at points of interest.

CHAPTER 1 INTRODUCTION

Recently the Idaho Water Resources Research Institute, in cooperation with the Research Institutes of Oregon, Washington and Montana, has been involved with a study, funded by the Department of Energy, entitled, "A Resource Survey of Low-Head Hydroelectric Potential-Pacific Northwest Region". This study by Heitz (10) has attempted to determine the total theoretical power and energy which might be produced by utilizing the various discharges and elevation differences available in the Pacific Northwest river systems. A restraint imposed by the Department of Energy limited the investigation to those portions of the streams which have flows capable of producing 200 KW of power at least 50% of the time with a maximum operating head of 20 meters. This condition is equivalent to the investigation of only those streams which have a discharge of 36 cfs, 50% of the time.

In performing this study, it was necessary to determine flows and their corresponding durations for many points along a river or stream. These so called "duration curves" show the percentage of time that a specified flow is equalled or exceeded and can be used to calculate the theoretical potential energy available at a specified point on a stream. These curves can readily be constructed from the historical records at gaged points, however the number of stream gages within a river basin is usually limited and it is necessary to estimate the curves for many ungaged points along the streams. This was accomplished by Heitz (10) using methods based on historical data acquired from surrounding stream gages.

The purpose of this presentation is to examine and test the procedures used in estimating flow duration curves at ungaged sites. Specifically, the objectives are (1) to apply three techniques which have been developed for natural flowing streams to a common river basin, (2) to compare the predictions of the above techniques to existing gage records not used in the analyses and (3) to present and test a fourth method of estimating flow duration curves for ungaged points which lie downstream of a flow regulating structure.

A discussion of previous studies related to flow estimation is presented in Chapter 2 illustrating possible alternative procedures to those examined in this paper.

In Chapter 3, three methodologies are described which are applicable to unregulated natural flowing streams. Since these methods were developed by the Research Institutes of the various states involved in the study by Heitz (10), they are are termed (1) Idaho Method, (2) Washington Method and (3) the Montana Method. These techniques are individually applied to the Clearwater River in Idaho (Chapter 4). A comparison is presented between predicted flow duration curves and duration curves constructed from three existing stream gage records.

Differences between energy values calculated from both predicted and actual duration curves is also shown.

Chapter 5 presents the fourth method used for estimating flow duration curves. This method can be used for both natural flowing rivers and for those rivers which are regulated. This procedure is applied in Chapter 6 to three different basins. They are (1) Priest River, (2) Clearwater River and (3) the Payette River. Predicted flow duration curves, for each of the applications, are compared to actual curves computed from existing stream gage data not used in the analyses. Computed energy data from both actual and synthetic flow duration curves is presented along with percent differences.

Chapter 7 consists of a summary of the methods presented and the authors conclusions.

CHAPTER 2 LITERATURE REVIEW

A review of the literature indicated four main types of methods used to estimate streamflow at ungaged sites. By the authors definition these are (1) interpolation-extrapolation methods, (2) methods which use basin characteristics, climatic data and historic streamflow data as input parameters to regression equations, (3) stochastic methods, ie. methods which use historic streamflow data to develop stochastic parameters and synthetically generate streamflows using a random component and (4) methods of direct measurement and correlation with longer gage records.

The first of these appears to be the simplest of the four types and is described to some degree by Torelli (17) and Smith (16). Use is made of ratios of stream length, drainage area etc. to adjust historical flows from a gaged point to an ungaged point. For example, consider a case where an estimate of average monthly flows is desired at an ungaged point between two stream gages. If no major tributary inflows occur between the gages, it may be reasonable to assume that the inflow is uniformly distributed along the stream length. The total inflow between the gages for any particular month is simply the difference between the two gaged values. Thus to determine an estimated flow for that month, a ratio of stream lengths multiplied by the inflow and added to the upstream gage value will yield an estimated flow. Linear interpolation using drainage area may be better than stream length especially where large tributary inflows occur between the gaged points. Once flow estimates for each month are made, an estimated duration curve can be constructed.

Methods utilizing basin characteristics and climatic data input parameters appear to be of two types. (1) An input-output relationship and (2) an output-output relationship.

The input-output method uses such variables as precipitation, drainage area, temperature, soil types, vegetation, evapotranspiration estimates etc. as input to regression equations to predict output or outflows at a particular point. Using these data, prediction of streamflows and construction of a duration curve at an ungaged point is possible. Barton (1) and Pentland (15) describe two different and complicated procedures illustrating this type of method.

The output-output method uses basin characteristics such as drainage density, stream length, drainage area, elevation differences etc. to estimate some specified flow at an ungaged point, for instance the seven day two year return period discharge. This estimated discharge can then be used to predict other selected flows. The initial relationships are of course, based on existing gage records. This particular method is more fully described by Orsborn (12), (13) and (14). Using Orsborn's methods, estimates of the discharges corresponding to the 0 and 100 exceedance percents and an estimate of the plotting position of the average annual discharge can be used to construct a three point duration curve for an ungaged point. Estimation of the average annual discharge in this case is similar to the methods discussed in Chapter 3.

Stochastic generation methods use historical gage records to obtain estimates of parameters such as means, standard deviations, serial correlation coefficients etc. The assumption of some type of probability distribution and the introduction of a random component allows the synthesis of average monthly or daily flows. This type of procedure is more fully discussed by Fuller (8), Torelli (17), Fiering (6) and Beard (2). For ungaged points, initial estimation of means, standard deviations and correlation coefficients are necessary using some type of regional analysis or data transfer (7),(11). These estimates have often been related to physiographic and climatic data such as drainage area, slope, mean monthly precipitation and mean monthly temperatures (8).

The fourth method is usually not practical. The method consists of installing stream gages at points of interest, measuring streamflows for a short time and correlating these flows with corresponding flows of a longer period gage. Using this established relationship, the longer record can be used to reconstruct past flow records at the site of interest.

In general, the method used to estimate ungaged streamflows should be dependent on the use to be made of the data. The data requirements for the above described methods vary from little to intensive. It should be noted that in some basins the simpler methods may give just as good an estimate as the more data intensive methods. This is especially true for basins with few gaging stations. The accuracy of the methods discussed also depends to some degree on the basin to which it is applied. In other words, accurate predictions on one basin does not imply that the method can be used for all basins with the same degree of accuracy.

For a time limited hydroelectric energy survey methods must be simple, the required data input must be kept to a minimum and yet the results must be representative. The following chapters discuss several methods utilized by the study teams of Idaho, Oregon, Washington and Montana in the hydroelectric energy survey of the Pacific Northwest.

CHAPTER 3 NATURAL STREAMS

The previously mentioned contract study of potential hydroelectric energy invloved four slightly different methodologies, three of which will be discussed here. The Oregon method uses the same regression approach as in the Idaho procedure and a similar approach to the estimation of average annual runoff as the Montana method. Hence the Oregon procedure will not be explicitly discussed.

In applying these methods it is most desirable to have a knowledge of the areas of interest so that inaccurate generalities can be kept to a minimum. It also should be noted that these procedures apply only to those streams which are natural, ie. regulation is negligible.

A. IDAHO METHOD

This method consists of a least-squares regression analysis. The logs of the discharges from several stream gages corresponding to a selected exceedance percent, are regressed against the logs of the respective average annual runoff values. The procedure is outlined below.

REGRESSION ANALYSIS

Initially a search should be made to determine the number of stream gages within the basin of interest and their respective locations. It should also be noted which gage records or parts of records reflect natural and which reflect regulated flows. Only those which are natural should be utilized in this analysis.

A duration curve, as shown in Figure 3-1, must be plotted for each gage record. This can be accomplished using data from the U.S. Geological Survey, Water Supply Papers or by using the Hydrologic Information Storage and Retrieval System (HISARS), developed by North Carolina State University, which is available on some computer systems. The gage records from which the duration curves are developed should be as long as possible and if possible reflect a geographic cross section of the basin. After plotting these curves, the discharges corresponding to the exceedance percentages of 10, 30, 50, 80 and 95 can be determined for each gage. These values were selected since they seemed to adequately define the shape of most of the known duration curves. The values are then plotted against the average annual runoff on log-log paper. Regressing discharges against average annual runoff for each exceedance percent results in the family of curves shown in Figure 3-2.

A duration curve for an ungaged point may be determined by entering the family of curves with a known average annual runoff value and graphically picking off the various discharge values associated with the exceedance percentages of 10, 30, 50, 80 and 95 (Q10, Q30, Q50, Q80, Q95).

AVERAGE ANNUAL RUNOFF

The average annual runoff (AAR) for a point on a stream is determined by applying a runoff coefficient to the total normal annual precipitation input at that point.

Initially the drainage basin of interest should be delineated following natural divides, on topographical maps. A map having a scale of 1:250,000 was found to work most effectively. Stream gage locations should also be accurately plotted using location descriptions found in the U.S.G.S. Water Supply Papers. Once the gage locations have been plotted, the basin can be subdivided so that the stream is cut at the gage locations, points of interest and at points of major tributary inflow. The length of stream between divisions will hereafter be referred to as a reach.

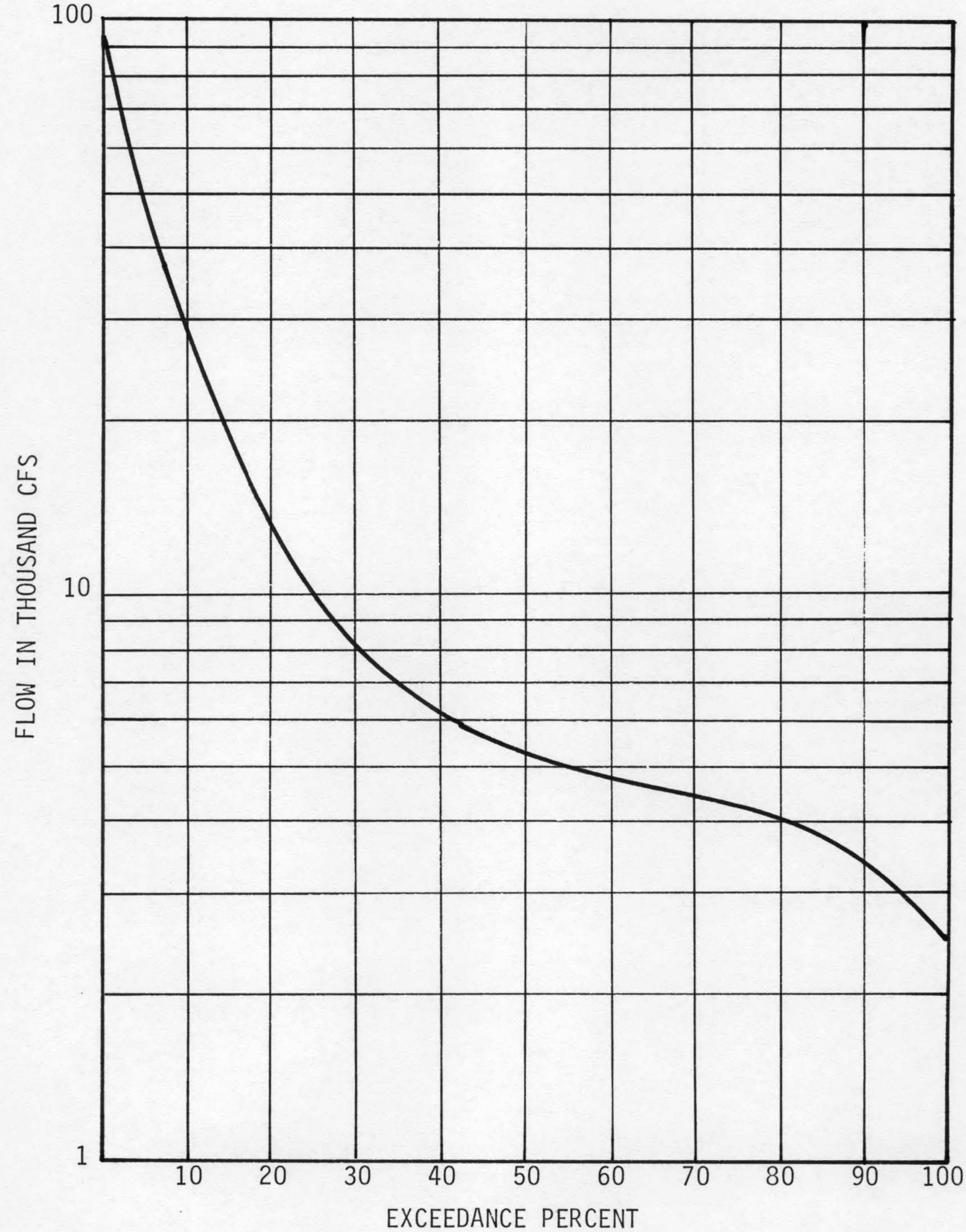

Figure 3-1. Typical Duration Curve

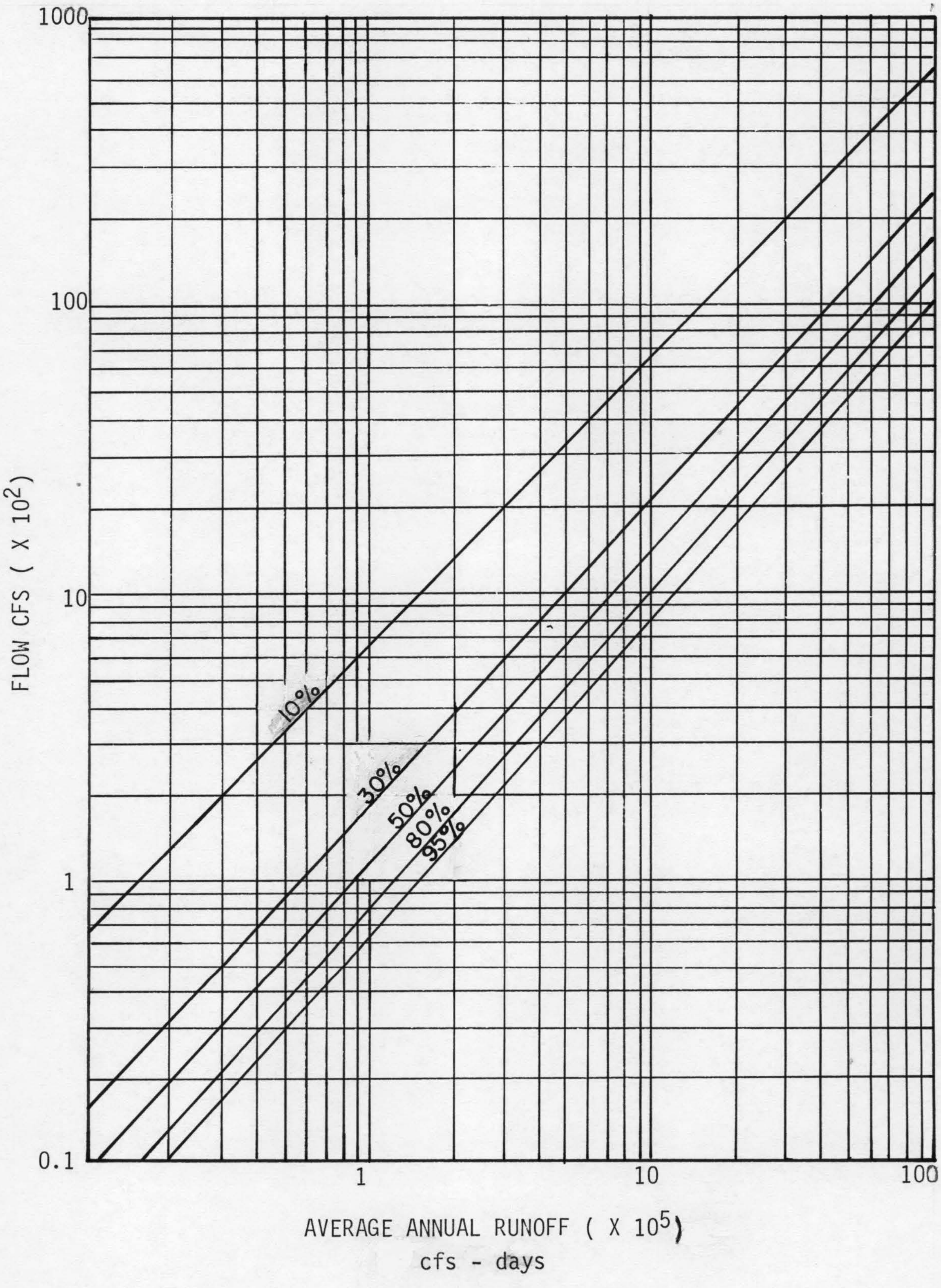

FIGURE 3-2 Parametric Duration Curves

The next step is to superimpose isohyetal lines of normal annual precipitation (NAP) onto the basin. One method which worked well was to obtain transparencies of the isohyetal maps and project and trace the isohyetal lines onto a tracing of the basin outline using an overhead projector. This overcame the problem of having to work with the different map scales. The normal annual precipitation input to the basin was then determined by planimetering the area between the isohyetal lines and then multiplying the area by the average precipitation for the area. This total input is then reduced by a runoff coefficient (K) to arrive at the average annual runoff for each point of interest or reach. These K-values may be determined exactly at the gage locations from the ratio of average annual runoff to normal annual precipitation input. Since periods of record vary with gages and also with the period of record used in developing the isohyetal maps, these known K-values should be adjusted to a common time base. Using a reference gage record, which spans the entire period used by the isohyetal maps, the average annual runoff of the remaining gages within the basin can be adjusted to the time base of the isohyetal maps. The equation used for this purpose is given below as,

$$Ys = Xs(Xro/Xr) \qquad (3-1)$$

where,

Ys = adjusted average annual runoff for station.

Xr = average annual runoff for reference station.

Xs = average annual runoff for station to be adjusted. computed for period which overlaps the period used in calculating the isohyetal averages.

Xro = average annual runoff for reference station using the same period of record as Xs above.

Adjusted K-values can be calculated using the adjusted average annual runoff values. For reaches between gages, K-values must be estimated or interpolated using the known values at the gages as guides. This is a situation where sound judgement is necessary so that resulting runoff values appear reasonable.

B. WASHINGTON METHOD

As in the Idaho Method, a duration curve for each gage record in a basin must be plotted so that discharge values corresponding to exceedance percentages of 10, 30, 50, 80 and 95 can be found. These values are then normalized by dividing each by the average annual runoff from the appropriate gage. Each normalized gage is then assigned an area of influence for which it will be used. To determine a flow duration curve for an ungaged reach, the ordinates of the normalized curve are multiplied by the estimated average annual runoff for that reach. Notice that this requires quite a lot of judgement and that a knowledge of the basin characteristics is most essential for good results.

AVERAGE ANNUAL RUNOFF

The Washington method of estimating average annual runoff is essentially identical to the Idaho Method. It requires delineation of the drainage basin, projection of normal annual precipitation lines, planimetry of the areas and assignment of K-values. The assignment of K-values is the main difference between the two methods. In order to stay away from a judgement type of situation as much as possible, the following rules were followed.

(1) K-values for areas above the farthest upstream gage were taken to be the same as at the gage.

(2) For drainage areas between two U.S.G.S. stations K was calculated by,

$$K = (QAAds - QAAus)/(AP) \qquad (3\text{-}2)$$

where,

QAAds = average annual runoff for the downstream station.

$QAAus$ = average annual runoff for the upstream station, and

AP = The NAP-area product contributing the difference.

(3) For basins where no U.S.G.S. gaging stations exist, a K-value was selected from surrounding basins on the basis of similarity of conditions affecting the precipitation and runoff.

This K-value is not the same as that for the Idaho method. This value is to be applied to that area between the gaged points only, not to the total contributing area as in the Idaho method.

C. MONTANA METHOD

This procedure is somewhat of a combination between the Idaho and Washington methods. The known duration curves are normalized by dividing the discharges, associated with the 10, 30, 50, 80 and 95 exceedance percents, by the 10 percent exceedance value. Refer to Figure 3-3. Each of the normalized curves are assigned an area for which they will be used. If more than one gage exists within an area, the two normalized curves are smoothed by inspection or averaged so that only one curve represents the area.

Since Q10 was used to normalize the duration curves, a relationship between Q10 and average annual runoff is necessary. This is accomplished by plotting the Q10 versus QAA on log-log paper for each gage within the basin. Most often the points fall fairly well in line with with one another, hence a least-squares regression analysis can be performed.

AVERAGE ANNUAL RUNOFF

The determination of average annual runoff for a reach is identical to the previous two methods with the exception of the determination of runoff coefficients, ie. K-values. For each gage, the accumulated normal annual precipitation-area product is tabulated against the corresponding average annual runoff values and a regression analysis is performed regressing QAA against the normal annual precipitation - area product. The resulting equation is expressed as,

$$QAA = b(AP)^c \qquad (3-3)$$

or assuming that QAA can also be expressed as

$$QAA = K(AP)$$

then the K-value is given as,

$$K(AP) = b(AP)^c$$

$$K = b(AP)^{c-1}$$

where b and c are coefficients determined from the regression.

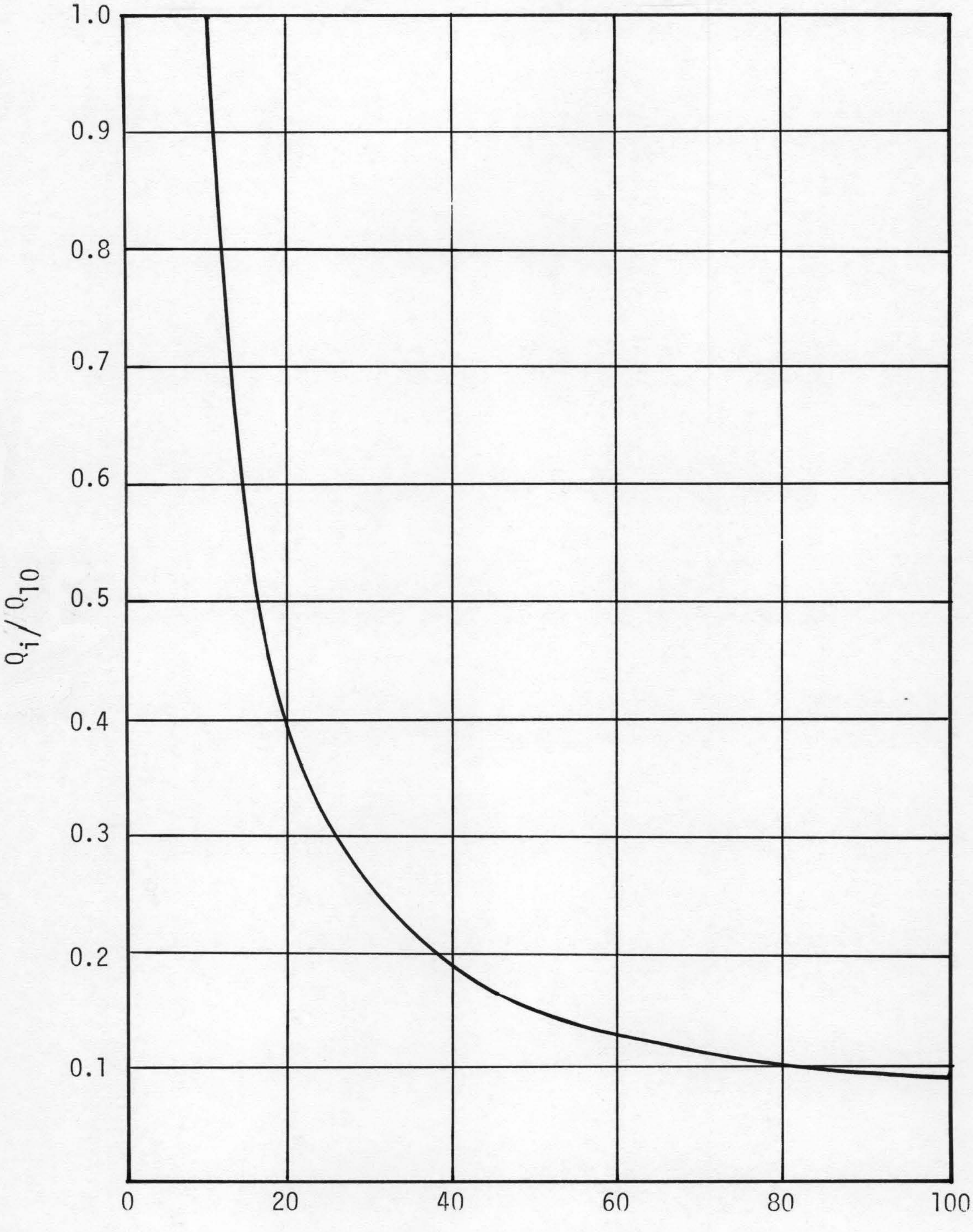

Figure 3-3. Dimensionless Duration Curve, Montana Method.

CHAPTER 4 APPLICATION AND COMPARISON OF TECHNIQUES FOR NATURAL STREAMS

In this chapter, an example application is presented of the various methods. These methods are applied individually to the Clearwater River Basin and their results compared to 3 existing gage records not used in the analyses. The Clearwater River was selected since the only regulation which exists on the stream is Dworshak reservoir located on the North Fork. The methods are applied to the portion of the basin above the influence of Dworshak dam.

BASIN DESCRIPTION

The Clearwater river drains an area of approximately 9,329 square miles. The major tributaries include Potlatch Creek, North Fork, South Fork, the Selway and Lochsa Rivers. Dworshak Reservoir is located at the mouth of the North Fork and inundates some 436 square miles of the basin. Storage began in this reservoir in September of 1971. A schematic diagram of the Clearwater basin is shown in Figure 4-1.

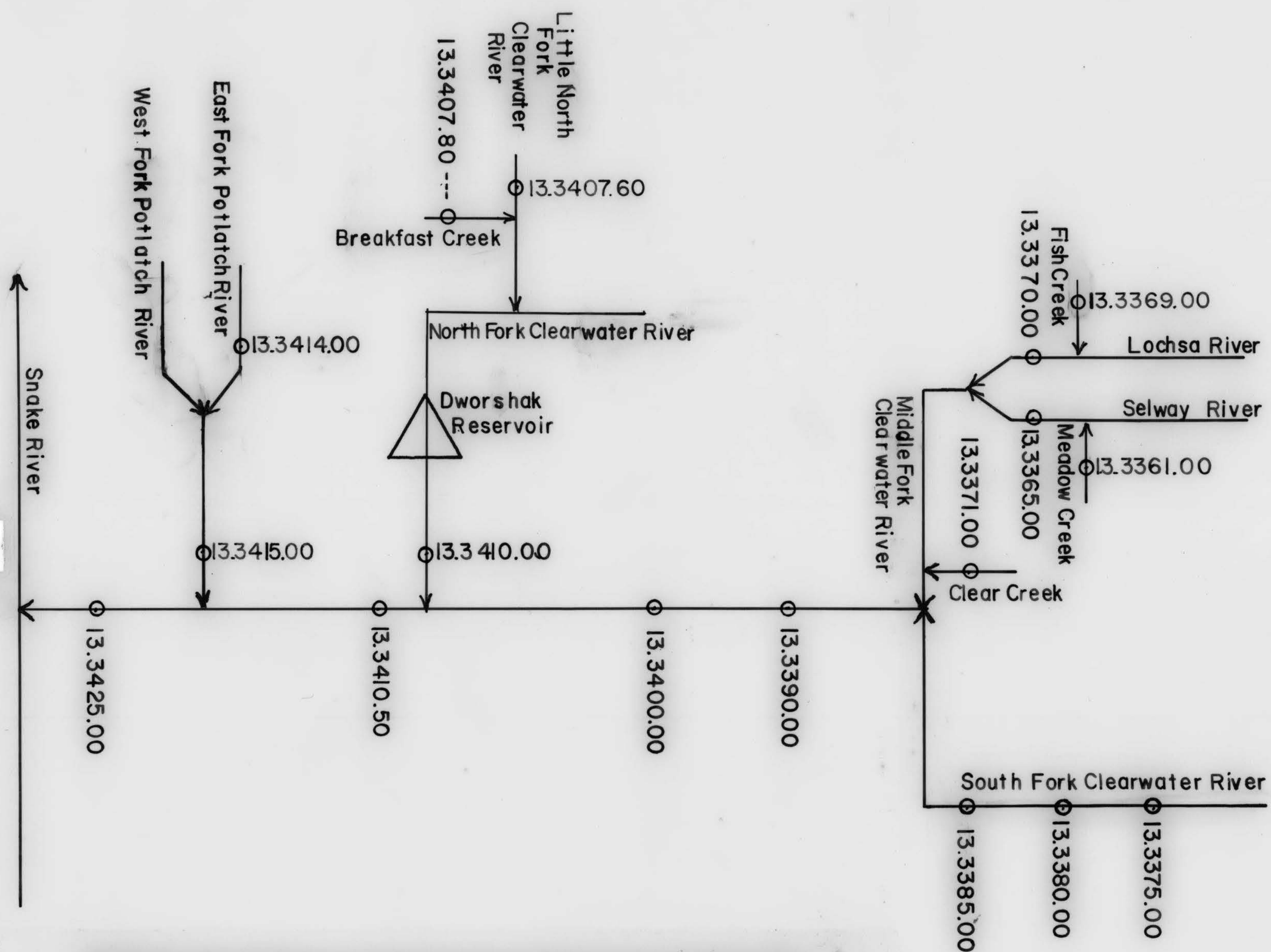

Figure 4-1. Schematic Diagram of the Clearwater River.

DATA

There are a number of stream gages on the Clearwater River. These are listed in Table 4-1 along with their corresponding gage number and respective period of record. The daily flows of each of the gages are recorded in the U.S.G.S. Water Supply Papers and in this case, in the HISARS data bank which is available on the University of Idaho computer system. The relative locations of the gages are shown by the schematic of Figure 4-1. Of these, only eight have sufficiently long periods of record to give confidence to the analysis. The duration curves associated with these eight gages are shown in figures 4-2 thru 4-5. Notice that the Clearwater at Spalding stream gage is located below the North Fork which is presently regulated by Dworshak reservoir. Since Dworshak began storage in September of 1971, only those records prior to this date can be used.

AVERAGE ANNUAL RUNOFF

The Clearwater basin was defined on a 1:250,000 scale topographical map. Divisions were made following natural divides at points of major tributary inflow and at gage locations. Isohyetal lines of normal annual precipitation (NAP) were then projected and traced onto a reach outline of the basin. An example of the type of NAP map used is shown in

Figure 4-6. This map was obtained from the Pacific Northwest River Basins Commission from a study entitled "Columbia-North Pacific Region Comprehensive Framework Study".

After working up the basin outline, each individual reach was planimetered to determine the area lying between each isohyetal line and also to determine the total drainage area for that particular reach. The area between each isohyetal line was multiplied by the average value of the isohyetal lines which make up its boundary. These values were then summed and multiplied by a factor tc convert cubic inches to cfs-days. The total value represents the average yearly precipitation input for that reach. Refer to Table 4-2 for an example calculation for a reach of the South Fork of the Clearwater River. After each reach has been planimetered, a listing is made of the reaches with their respective NAP-AREA products starting with the uppermost reach in the basin. The precipitation area products are summed to determine the total yearly input to the basin. (Refer to Table 4-3 and Figure 4-7). To determine the average annual runoff for a particular reach, the total NAP-AREA product at the upper boundary of the reach is averaged with the total NAP-AREA product at the lower boundary of the reach. This gives an estimate of the average value of the NAP-AREA product for the midpoint of the reach. Now by multiplying this average NAP-AREA product by a K-value, determined by one of the methods of Chapter 3, the average annual runoff for the reach can be found.

A. IDAHO METHOD

Following the discussion presented in Chapter 3 and using the duration curves of Figures 4-2 through 4-5, the log-log plot of Figure 4-8 was developed. The following equations define the curves shown.

(1) $\log(Q10) = -1.9149 + 0.9696\log(QAA)$ (4-1)

(2) $\log(Q30) = -2.9892 + 1.0598\log(QAA)$ (4-2)

(3) $\log(Q50) = -3.3067 + 1.0583\log(QAA)$ (4-3)

(4) $\log(Q80) = -3.4147 + 1.0282\log(QAA)$ (4-4)

(5) $\log(Q95) = -3.6757 + 1.0423\log(QAA)$ (4-5)

Notice in Figure 4-8 that gage 13.3405.00, the North Fork at Bungalow is somewhat out of line from the other gages at the 50, 80 and 95 percent exceedance values. It was felt that part of this discrepancy might be explained by the differing periods of record. Using the overlapping period of 10/1944 to 9/1963, the analysis was repeated.

Significance tests at the 95% level were attempted in order to determine the best fit. These tests revealed no significant difference between the coefficients of determination of each fit. However these tests were not conclusive. In order to properly use the test in question, a data set of greater than 25 observations is required whereas, only 8 were available in this case. For this discussion it was assumed that the tests are valid and the curves described by the longer periods of record were used.

To visualize the goodness of fit, the log-log relationships were transformed and plotted along with 95% confidence bounds as shown in Figures 4-9 through 4-13. The relationship of discharge to average annual runoff is much better at the 10% level than at the other levels. This is evidenced by the widening of the confidence bands with increase in exceedance percent. Note that the portion of the curve greater than 3,500,000 cfs-days is not really needed since this runoff volume occurs at the confluence of the North Fork which is presently regulated. Plots of observed versus predicted values are shown in Figures 4-14 through 4-18.

Table 4-1. Stream Gages in the Clearwater River Basin.

Gage Number	Location	Period of Record
13.3361.00	Meadow Creek near Lowell	10/1963 - 9/1970
13.3365.00	Selway River near Lowell	10/1923 - 9/1974
13.3369.00	Fish Creek near Lowell	10/1957 - 9/1967
13.3370.00	Lochsa River near Lowell	10/1929 - 9/1974
13.3371.00	Clear Creek near Kooskia	7/1971 - 2/1973
13.3375.00	S.F. Clearwater near Elk City	10/1944 - 9/1974
13.3380.00	S.F. Clearwater near Grangeville	4/1923 - 9/1963
13.3385.00	S.F. Clearwater at Stites	10/1964 - 9/1974
13.3388.00	Lawyer Creek near Nez Perce	8/1967 - 9/1974
13.3390.00	Clearwater at Kamiah	9/1910 - 10/1965
13.3400.00	Clearwater at Orofino	10/1964 - 9/1974
13.3405.00	N.F. Clearwater at Bungalow R.S.	10/1944 - 9/1969
13.3406.00	N.F. Clearwater near Canyon R.S.	4/1967 - 9/1974
13.3407.60	Little N.F. Clearwater near Elk R.	10/1970 - 9/1974
13.3407.80	Breakfast Creek	10/1970 - 9/1974
13.3410.00	N.F. Clearwater at Ahsahka	10/1926 - 1/1965
13.3410.50	Clearwater near Peck	10/1964 - 9/1974
13.3413.00	Bloom Creek near Bovill	9/1959 - 10/1971
13.3414.00	East Fork Potlatch River	9/1959 - 10/1971
13.3415.00	Potlatch at Kendrick	10/1945 - 9/1960
13.3425.00	Clearwater at Spalding	10/1925 - 9/1974

Note: Dworshak Reservoir began storage in September, 1971.

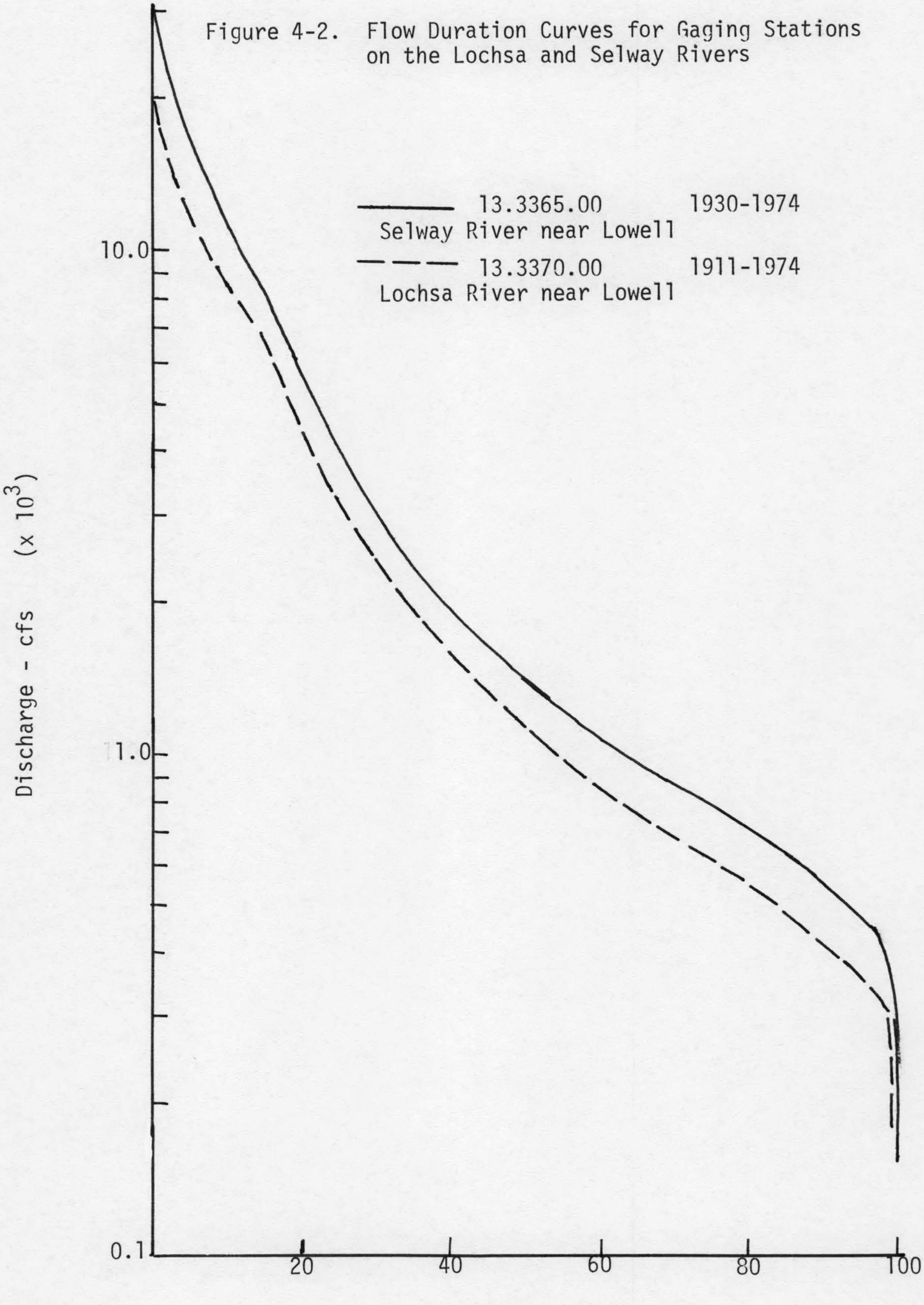
Figure 4-2. Flow Duration Curves for Gaging Stations on the Lochsa and Selway Rivers
13.3365.00 1930-1974
Selway River near Lowell
13.3370.00 1911-1974
Lochsa River near Lowell
10.0
1.0
0.1
20
40
60
80
100
Discharge - cfs (x 10³)
Exceedance Percent

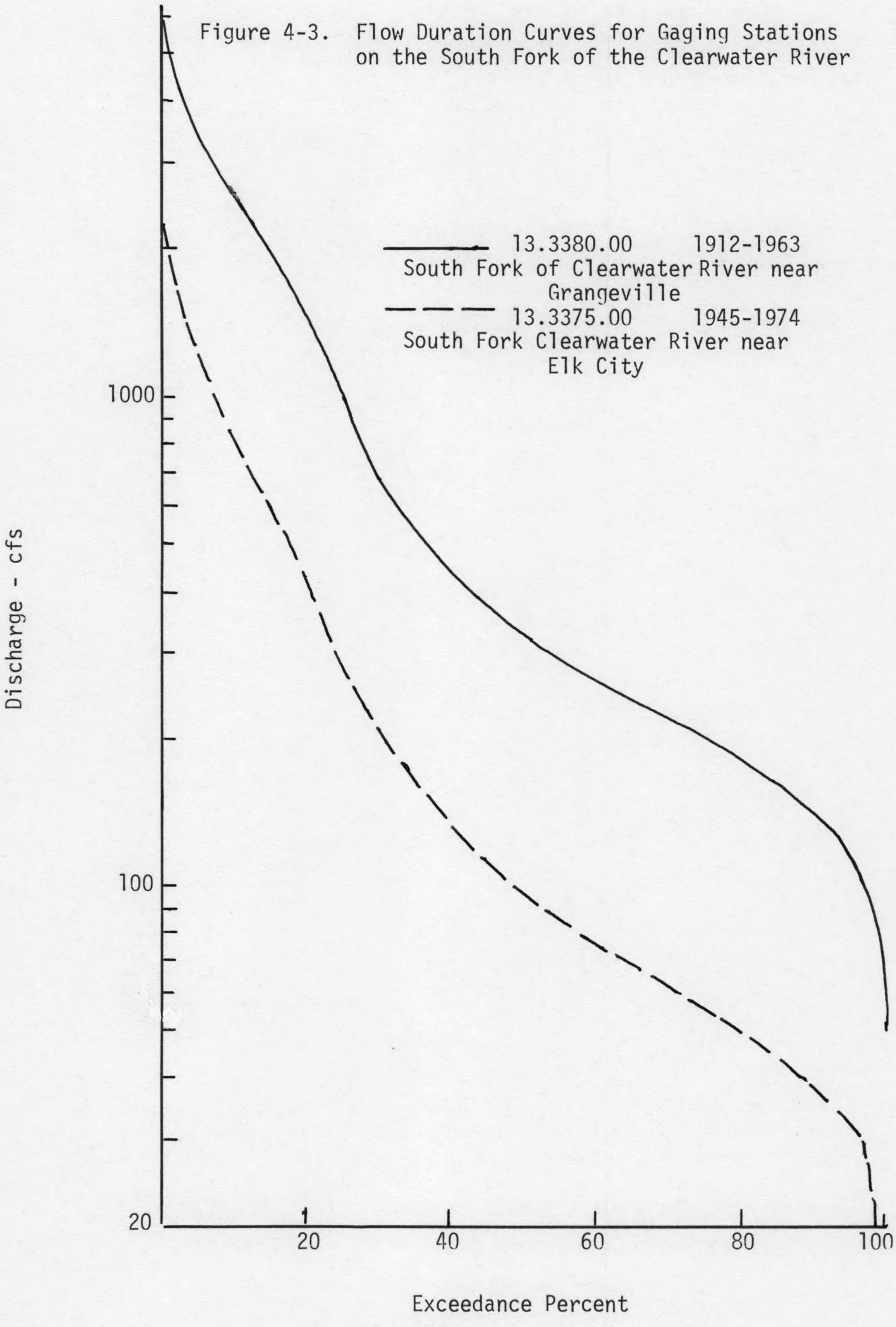
Figure 4-3. Flow Duration Curves for Gaging Stations on the South Fork of the Clearwater River
13.3380.00 1912-1963
South Fork of Clearwater River near Grangeville
13.3375.00 1945-1974
South Fork Clearwater River near Elk City
1000
100
20
Discharge - cfs
20
40
60
80
100
Exceedance Percent

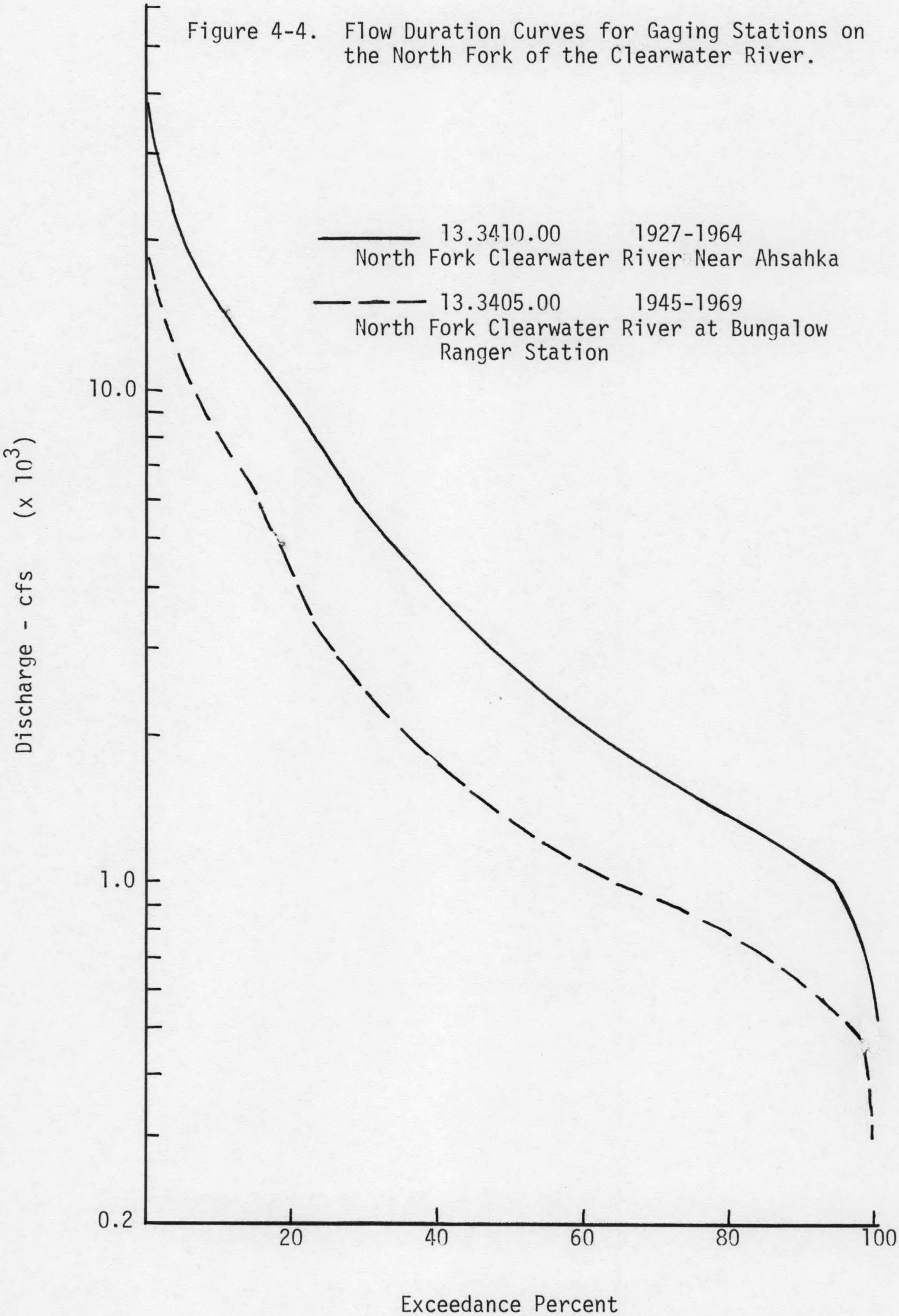
Figure 4-4. Flow Duration Curves for Gaging Stations on the North Fork of the Clearwater River.
13.3410.00 1927-1964
North Fork Clearwater River Near Ahsahka
13.3405.00 1945-1969
North Fork Clearwater River at Bungalow Ranger Station
10.0
1.0
0.2
Discharge - cfs (x 10^3)
20
40
60
80
100
Exceedance Percent

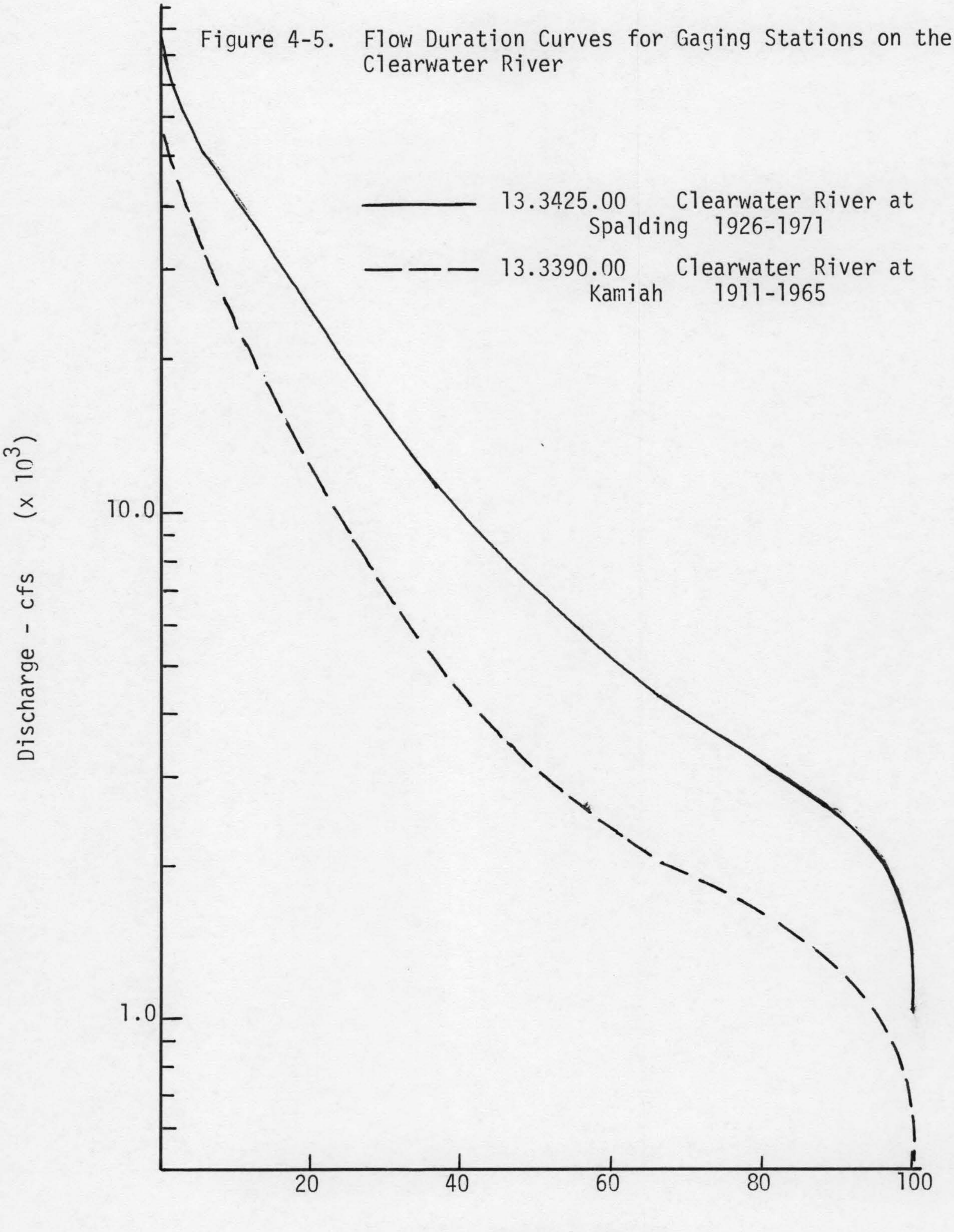

Figure 4-5. Flow Duration Curves for Gaging Stations on the Clearwater River

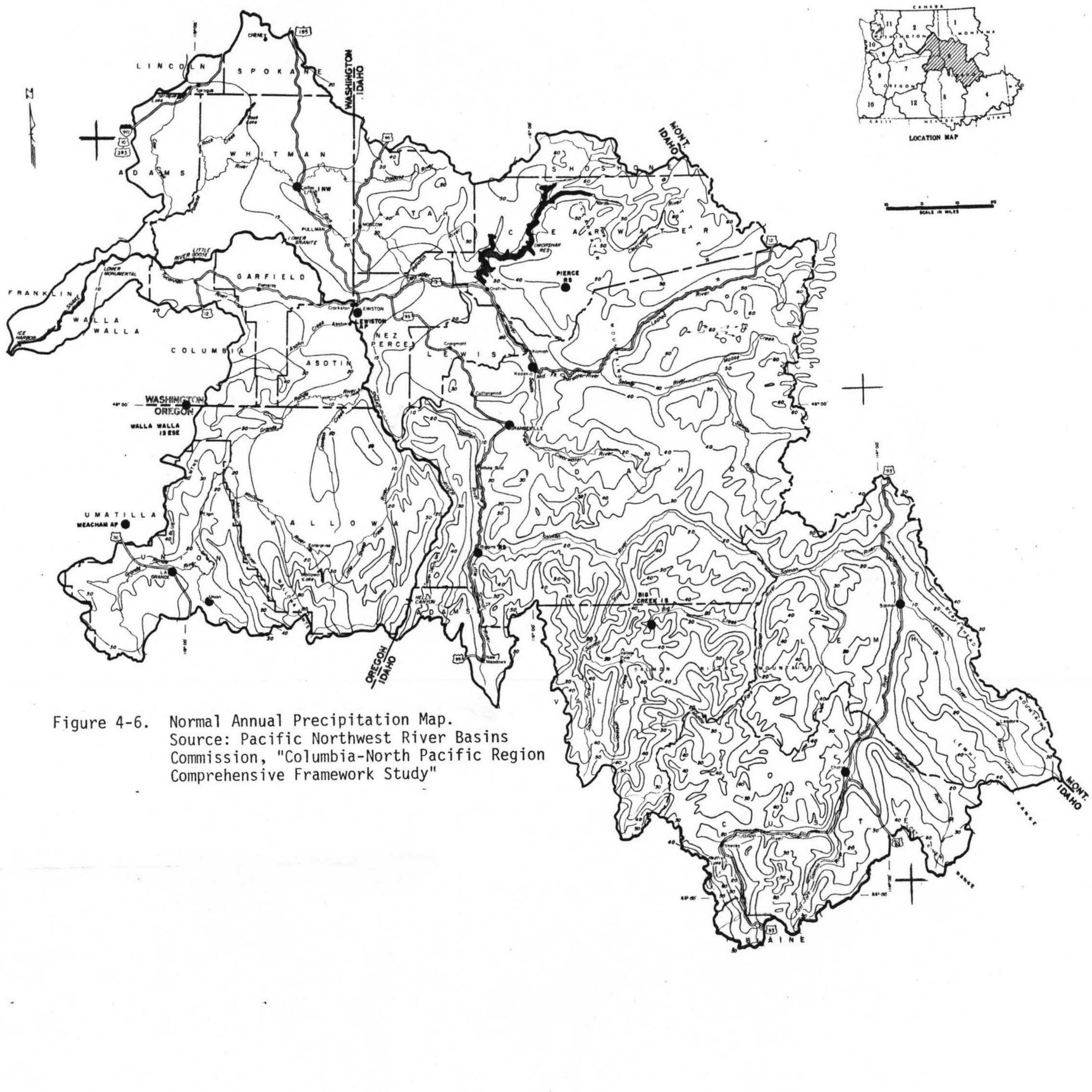

Figure 4-6. Normal Annual Precipitation Map.
Source: Pacific Northwest River Basins Commission, "Columbia-North Pacific Region Comprehensive Framework Study"

Table 4-2. Example Calculations of Reach Area-Precipitation Product.

Basin Clearwater River

Sub Basin South Fork of the Clearwater River

Reach x

Average-NAP (in)	Map Area (in^2)	(Map Area) x (Average - NAP)
20	.5885	11.77
25	.8282	20.71
35	.0999	3.50
Total	1.52	35.98

1) Total Area - Precipitation (ap)

$$(35.98\ in^3) \times (250{,}000)^2 \times (1ft^3)\ (12)^3\ in^3 \times 1\ day/_{86400\ sec}$$

$$= 15060\ cfs\text{-}days$$

2) Area

$$(1.5)^2\ in^2 \times (250{,}000)^2 \times 1ft^2/(12)^2\ in^2 \times (1\ mile)^2/(5280)^2\ ft^2$$

$$= 23.7\ mi^2$$

Table 4-3. Example Summation Sheet of Area - Precipitation Products for the South Fork of the Clearwater River.

Basin Clearwater River

Sub Basin South Fork of the Clearwater River

Reach	Drainage Area Sq. Miles	Total Drainage Area Sq. Miles	Precip-Area Product cfs-days	Total Precip-Area Product cfs-days
I	162.2	-	134071	-
H	92.0	(254.2)	87592	(221663)
W1	9.0	263.2	5473	227136
G	70.0	(333.2)	54459	(281595)
W	14.1	347.3	8724	290319
Y	67.0	(414.3)	60321	(350640)
X	23.7	438.1	15060	365700
V	54.1	(492.2)	48276	(413976)
F	97.5	589.7	77258	491234
E	114.5	(704.2)	99826	(591060)
D	135.0	839.2	95231	686291
C	132.6	971.8	81026	767317
B1	125.9	-	69453	-
B	71.6	(1169.3)	38582	(875352)
A	12.3	1181.6	6643	881995

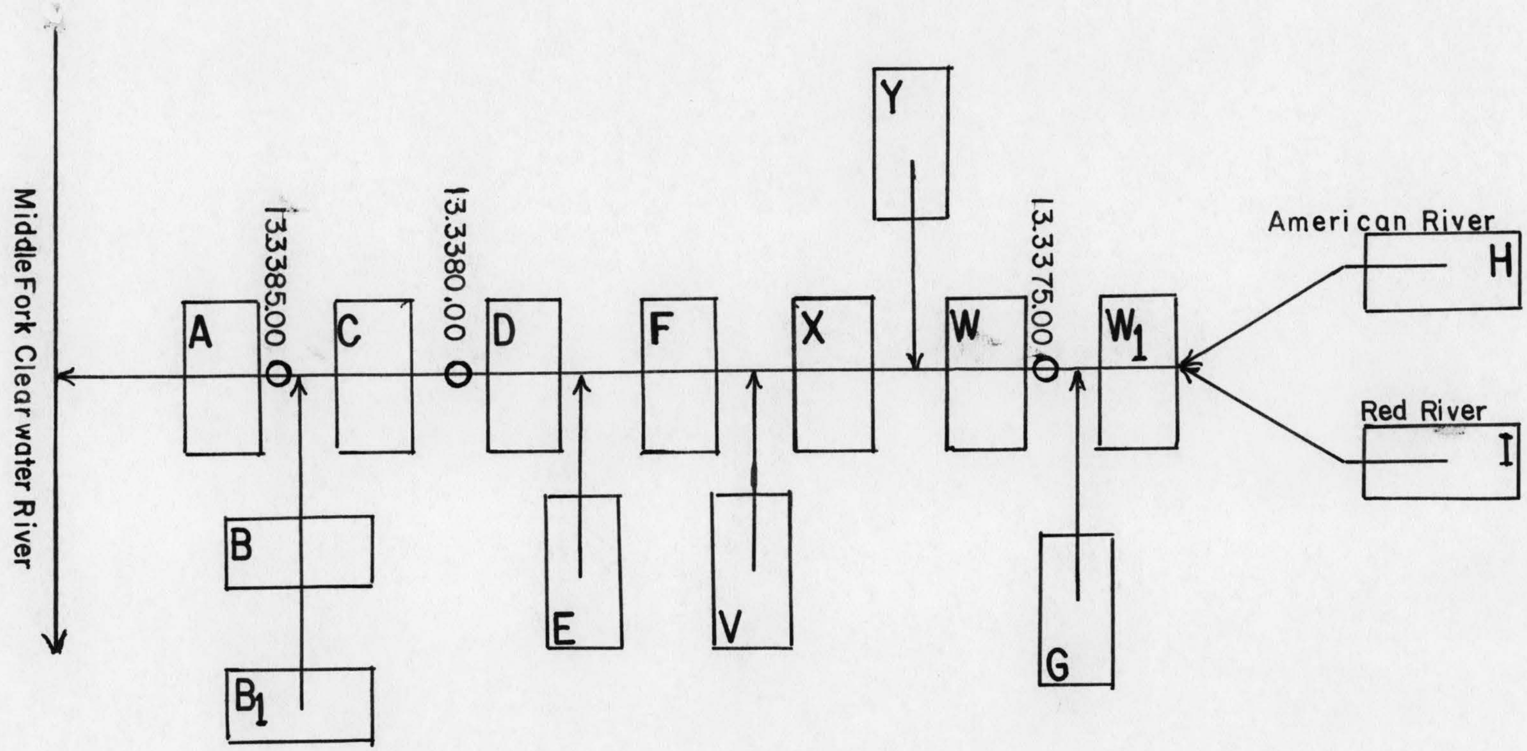

Figure 4-7. Schematic Diagram of River Reaches for the South Fork of the Clearwater River.

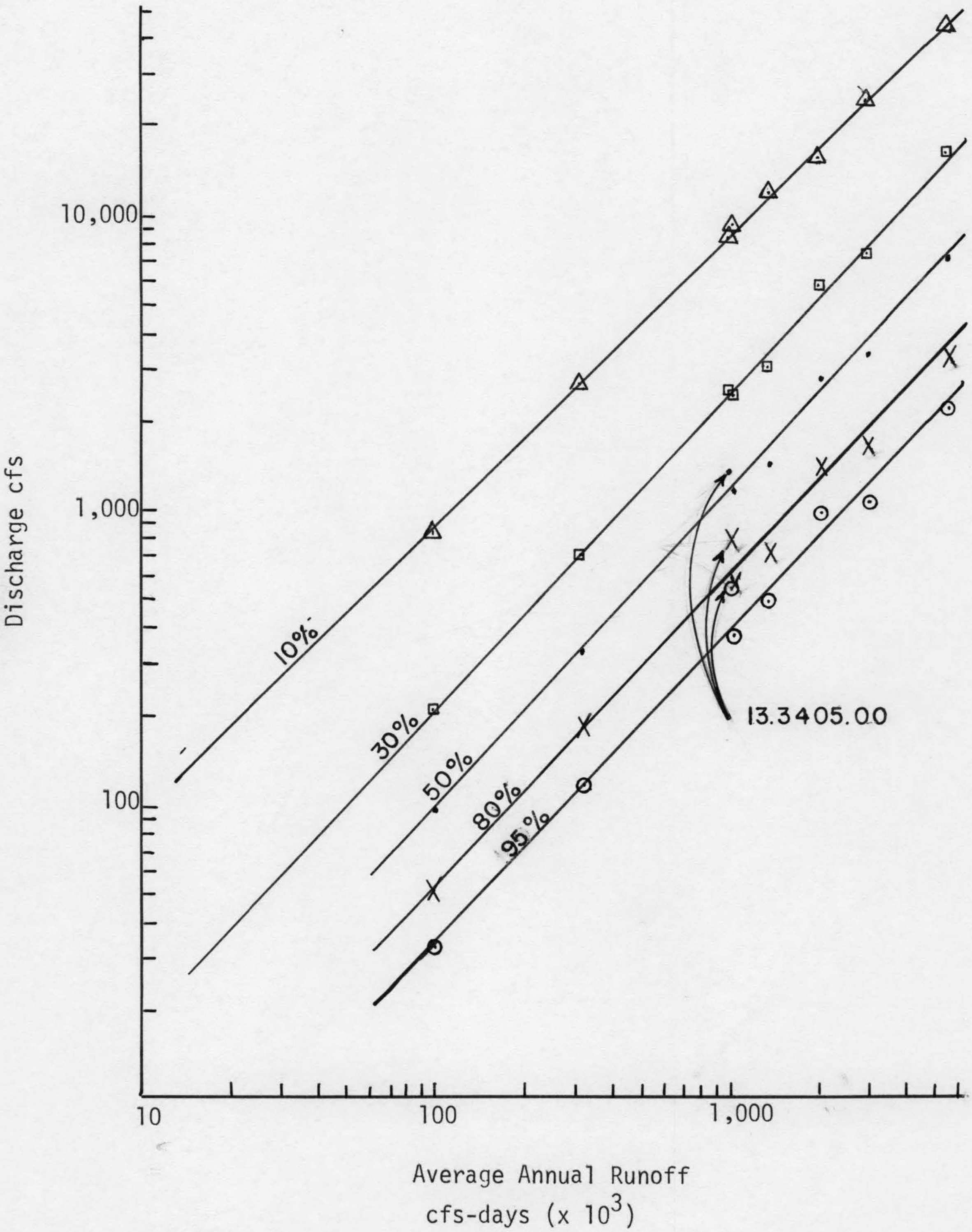

Figure 4-8. Parametric Duration Curves for the Clearwater River.

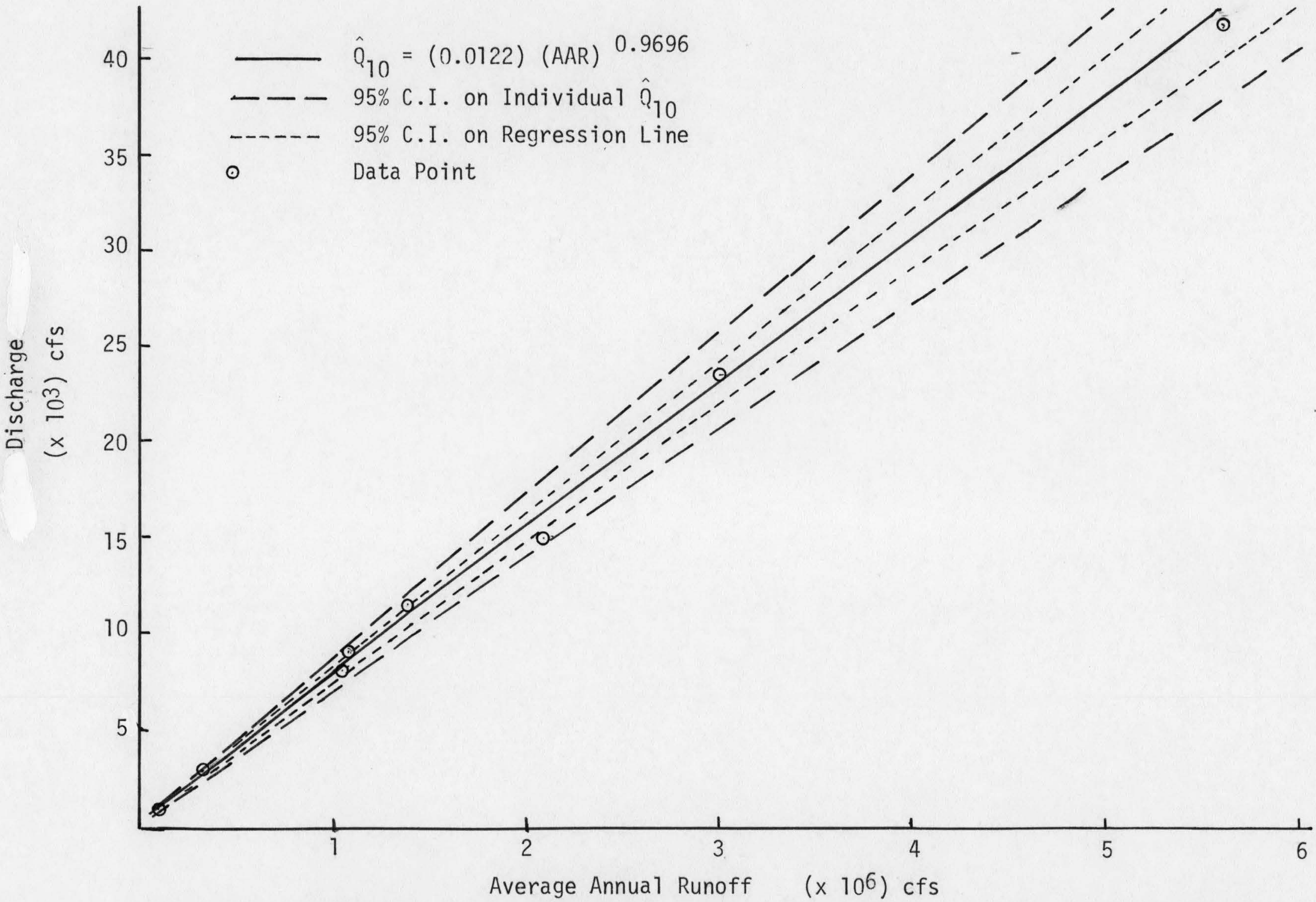

Figure 4-9. Arithmetic Plot of the Regression Equation Relating Discharge (Q_{10}) to Average Annual Runoff, Idaho Method.

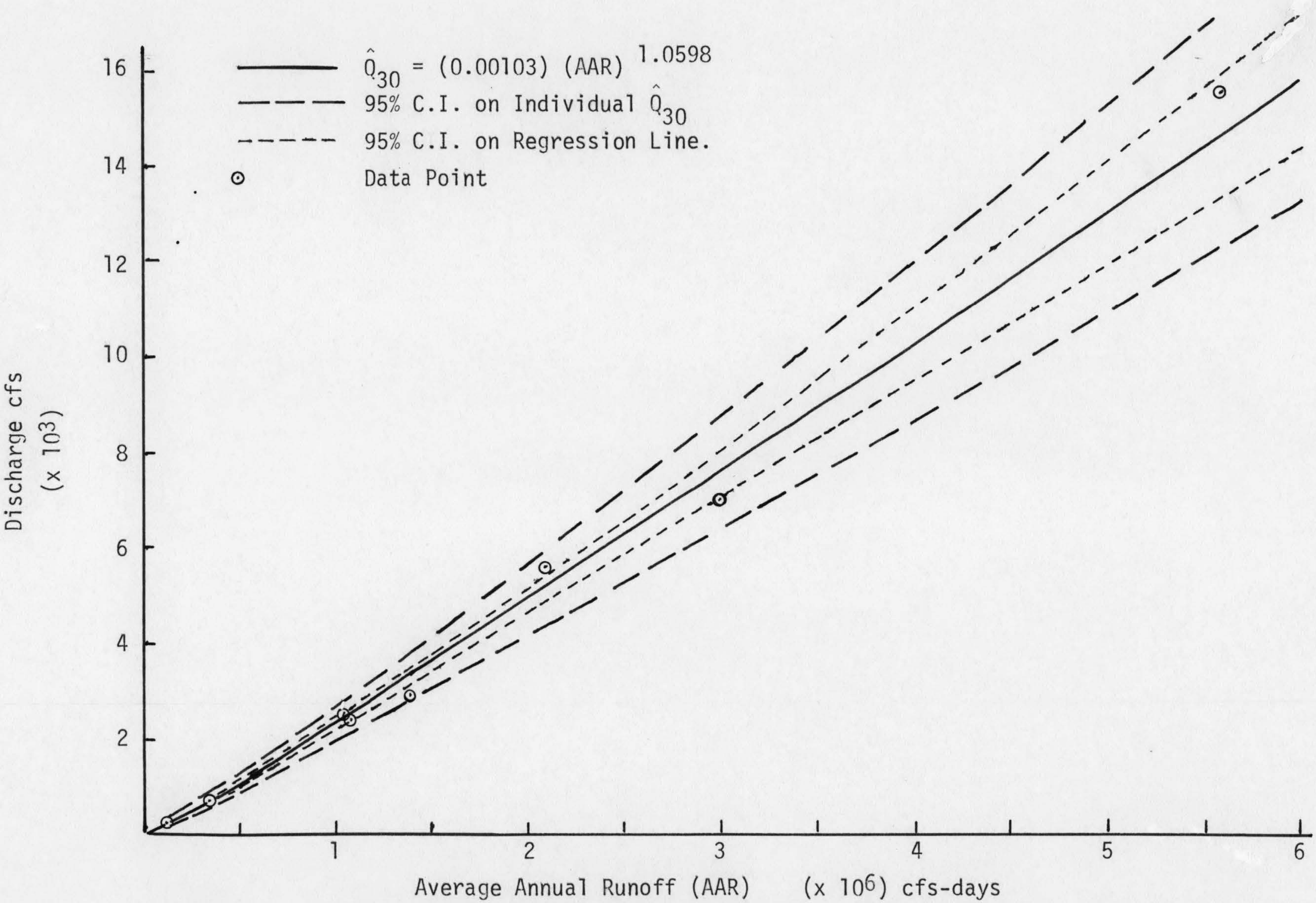

Figure 4-10. Arithmetic Plot of the Regression Equation Relating Discharge (Q_{30}) to Average Annual Runoff, Idaho Method.

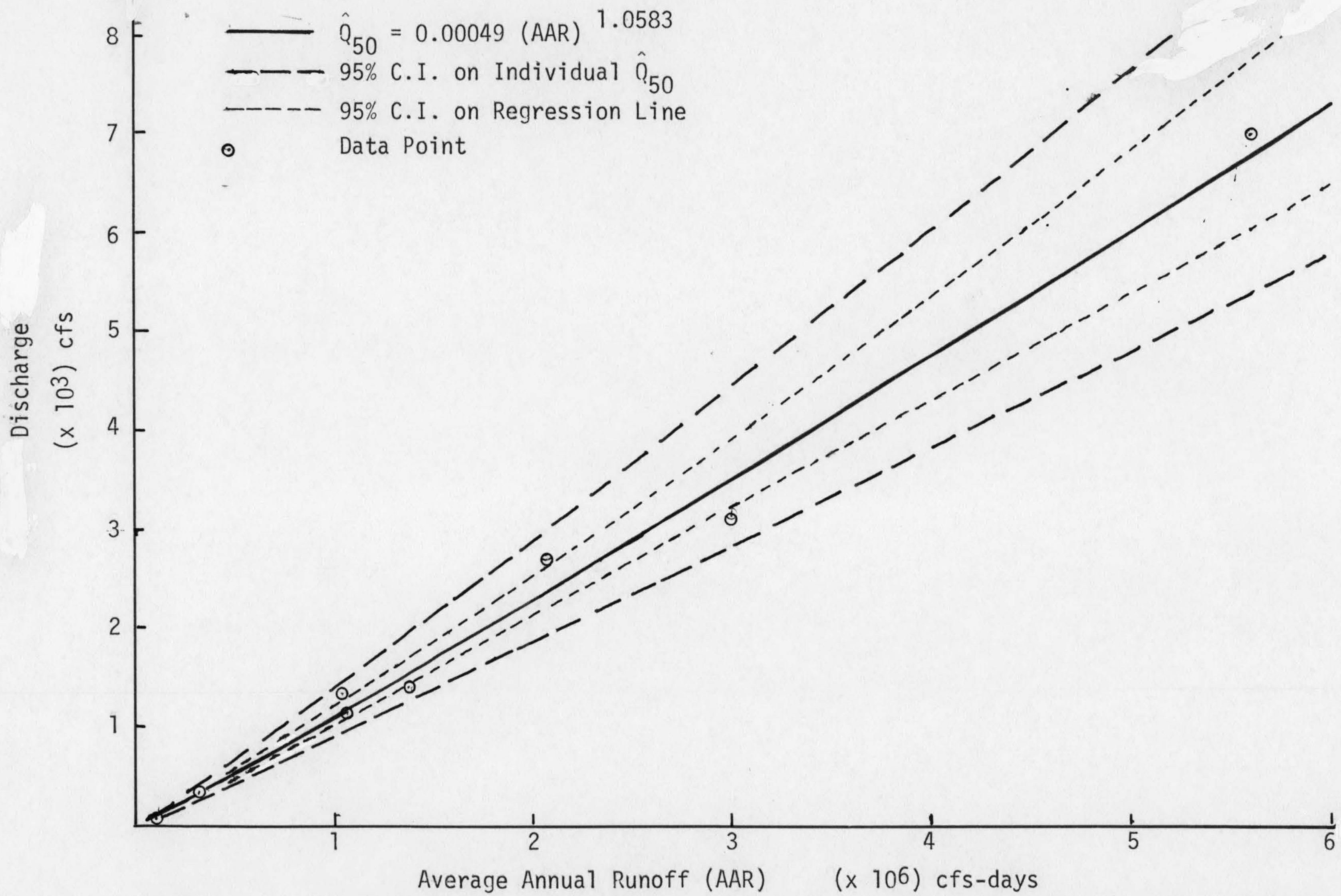

Figure 4-11. Arithmetic Plot of the Regression Equation Relating Discharge (Q_{50}) to Average Annual Runoff, Idaho Method.

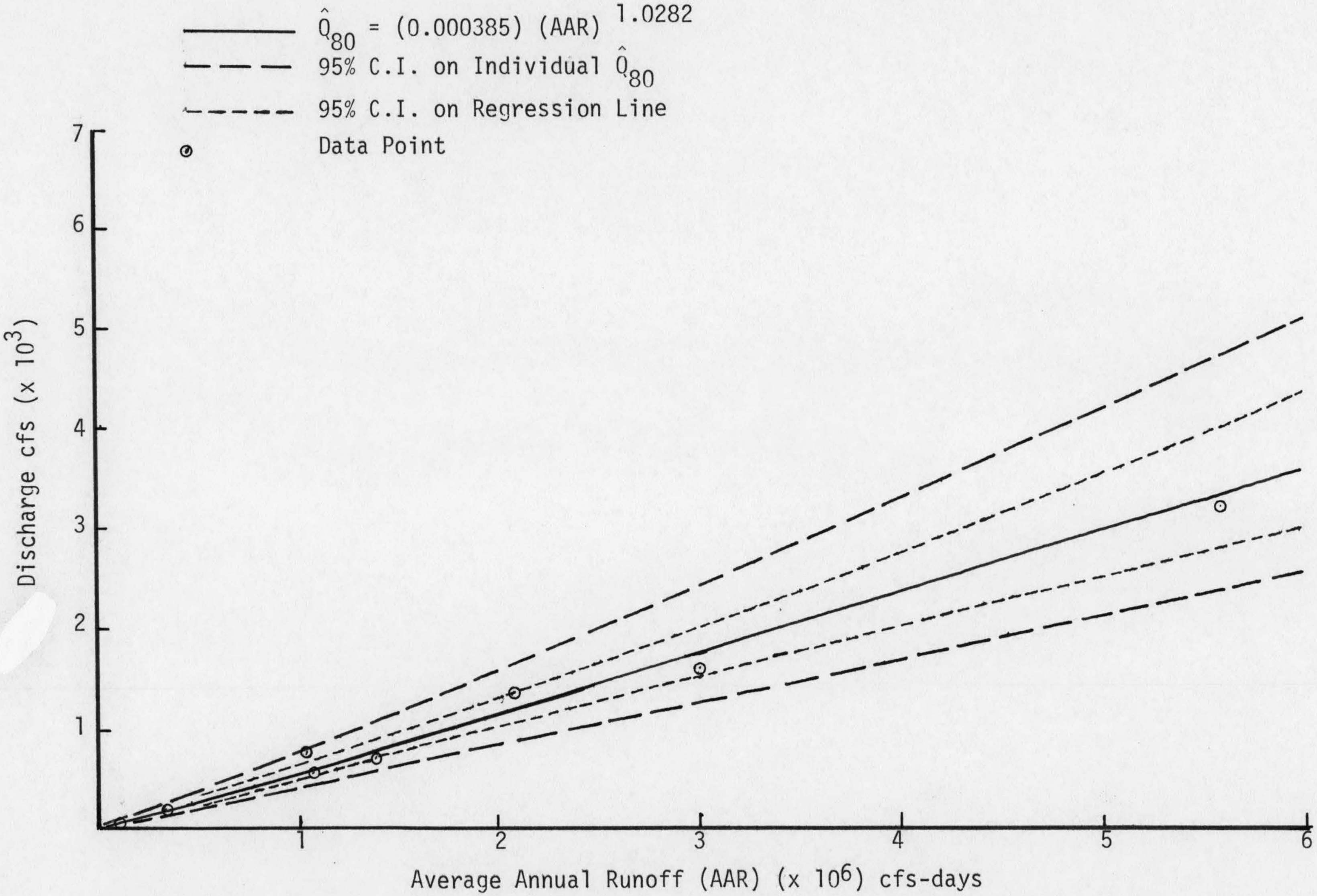

Figure 4-12. Arithmetic Plot of the Regression Equation Relating Discharge (Q_{80}) to Average Annual Runoff, Idaho Method.

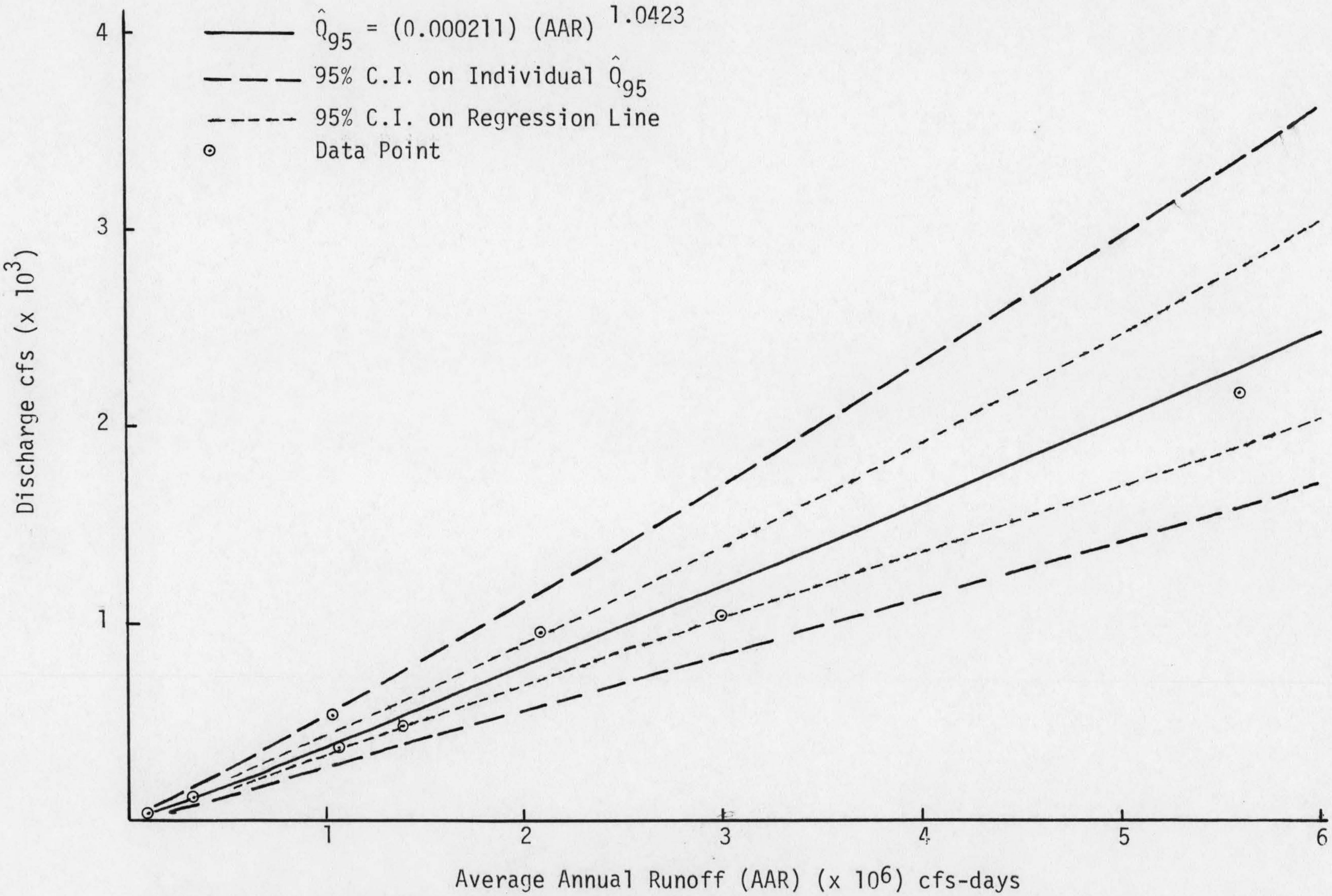

Figure 4-13. Arithmetic Plot of the Regression Equation Relating Discharge (Q_{95}) to Average Annual Runoff, Idaho Method.

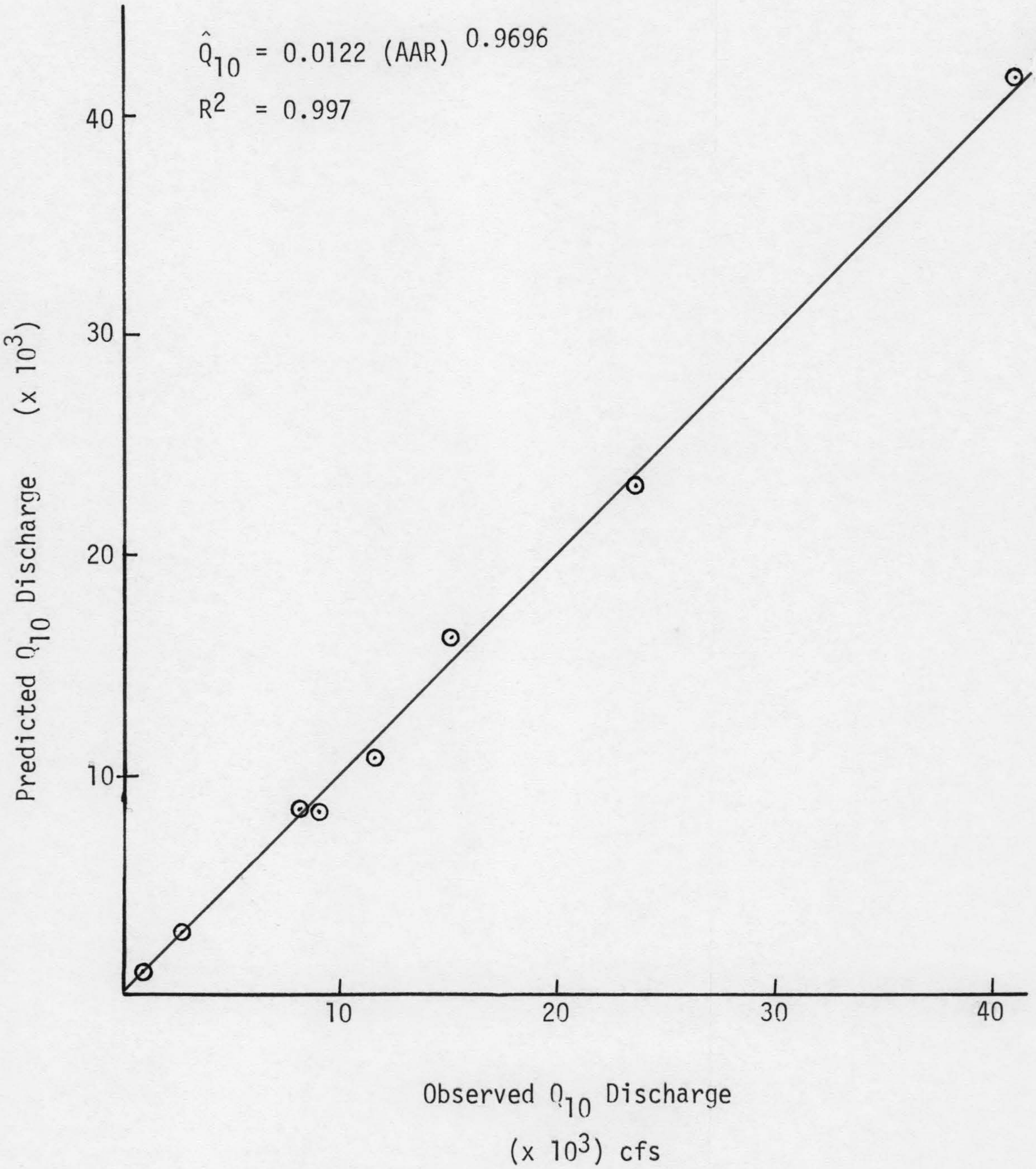

Figure 4-14. Plot of Observed Versus Predicted Discharge at 10% Exceedance, Idaho Method.

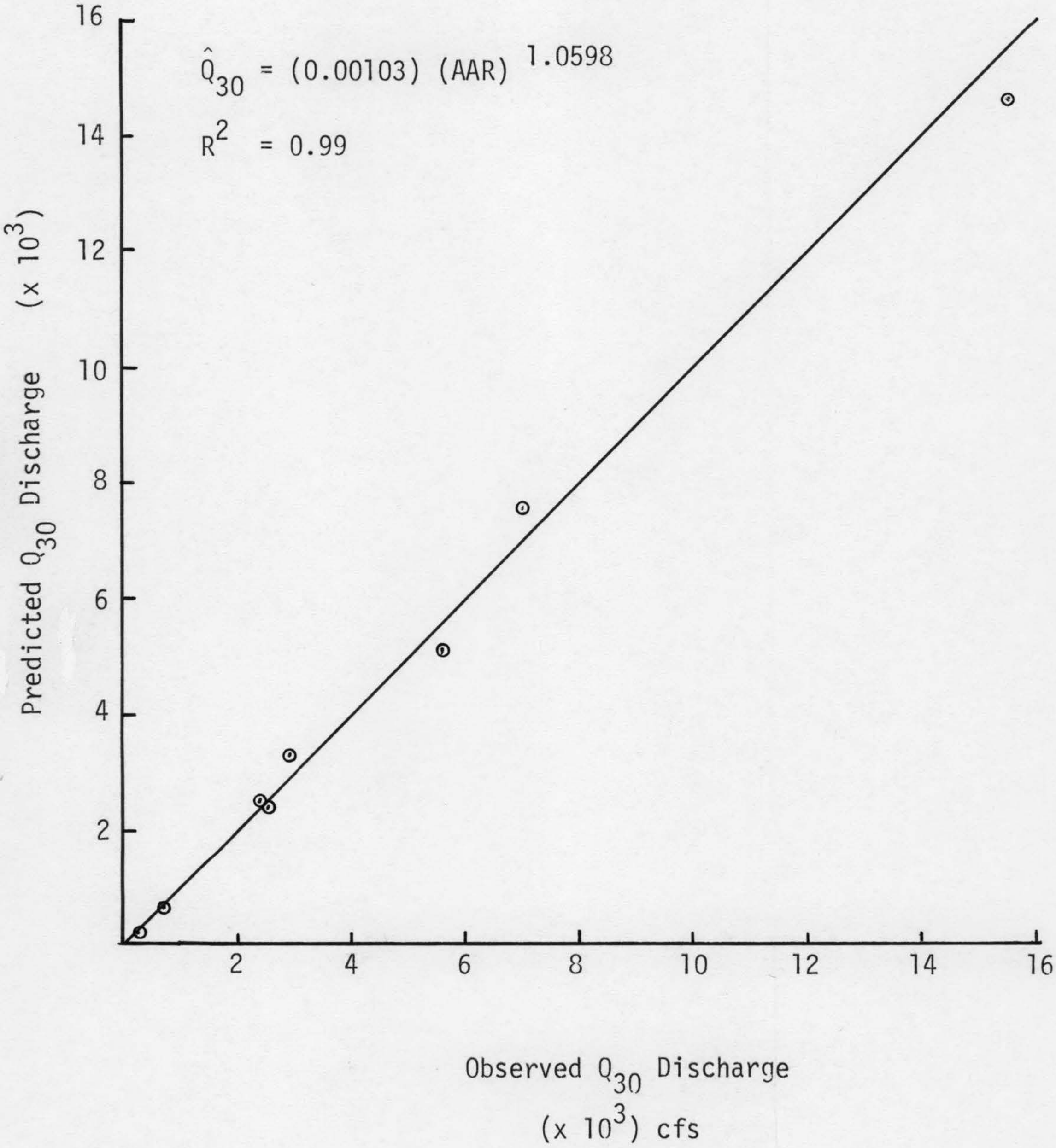

Figure 4-15. Plot of Observed Versus Predicted Discharge at 30% Exceedance, Idaho Method.

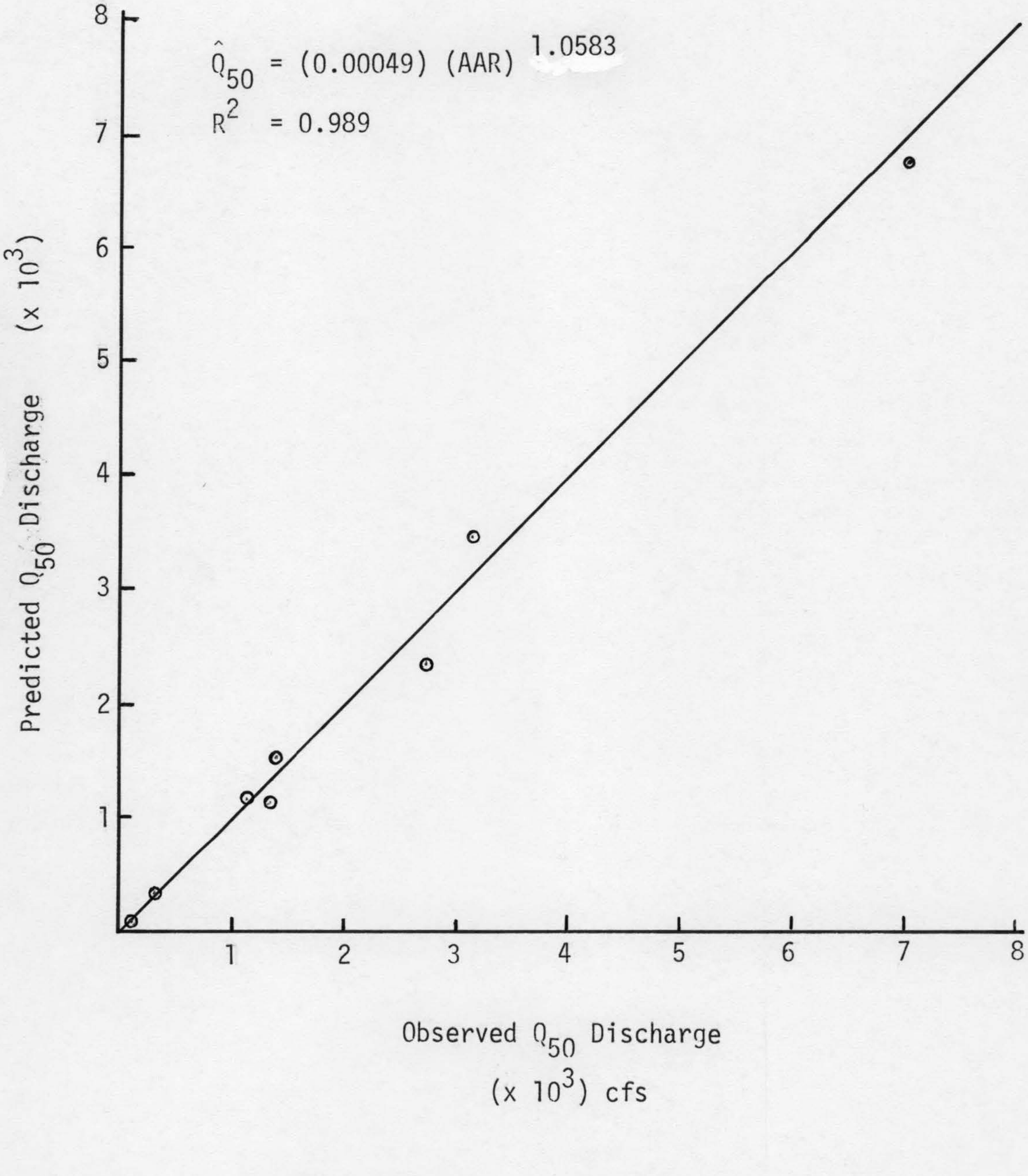

Figure 4-16. Plot of Observed Versus Predicted Discharge at 50% Exceedance, Idaho Method.

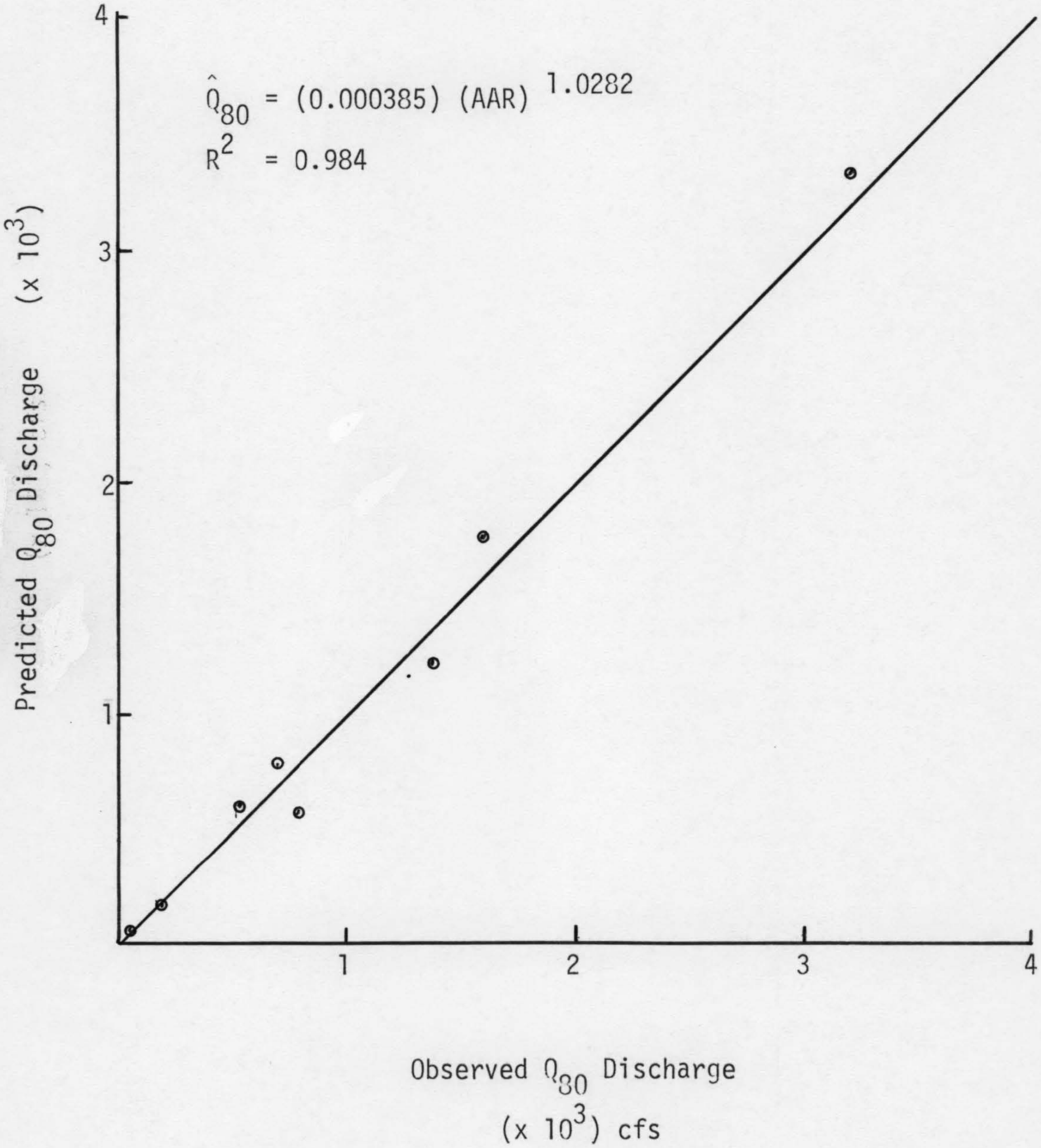

Figure 4-17. Plot of Observed Versus Predicted Discharge at 80% Exceedance, Idaho Method.

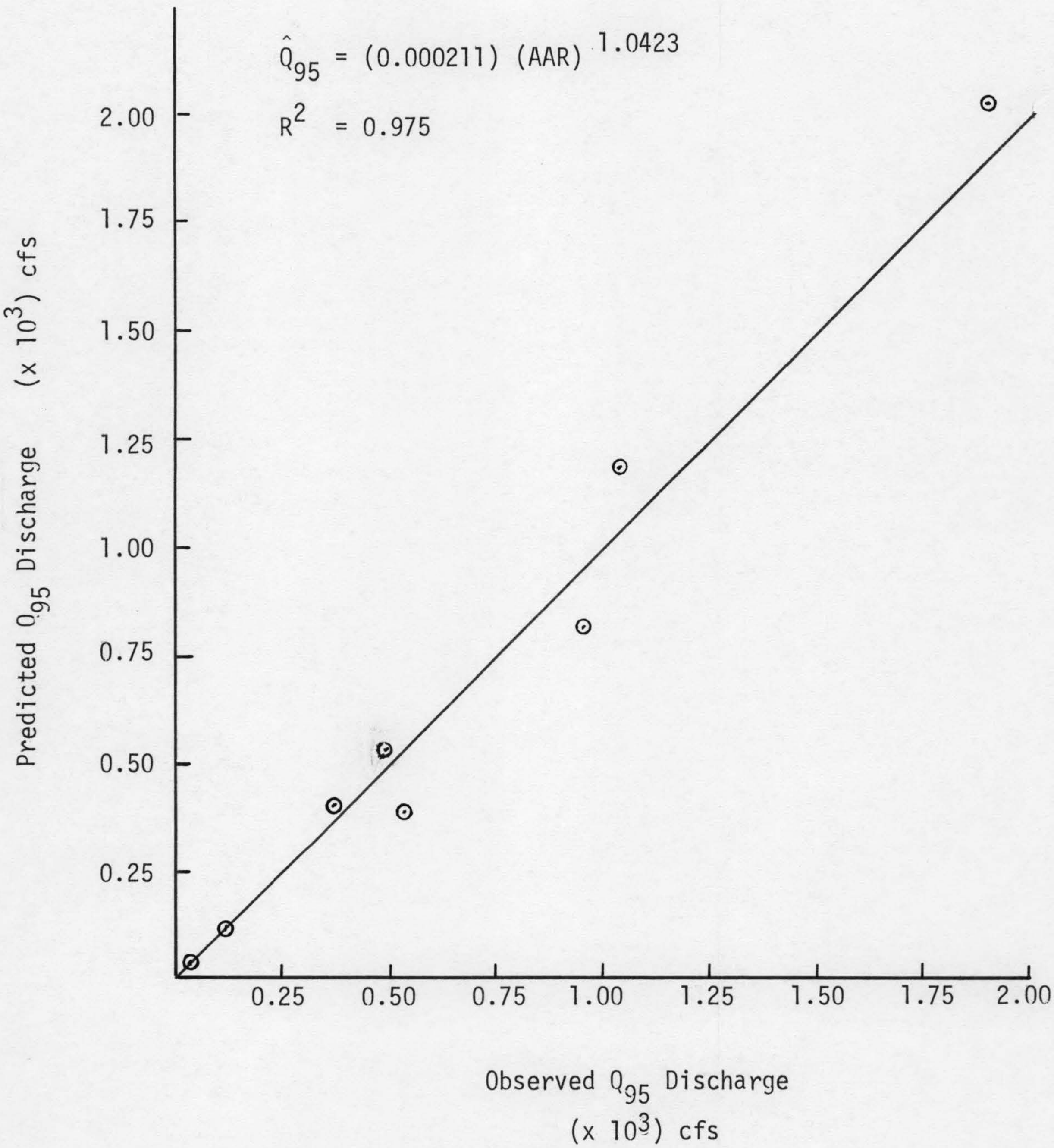

Figure 4-18. Plot of Observed Versus Predicted Discharge at 95% Exceedance, Idaho Method.

K-VALUES

The average annual runoff values for most of the gages in the Clearwater basin were adjusted to coincide with the period of record used by the normal annual precipitation maps. In order to adjust the average annual runoff, the gage must first have a part of its record overlapping the adjustment period. Some of the shorter period gages did not meet this requirement, and therefore, K-values computed from them were used as guides or estimates only.

A plotting of K-value versus the total area-precipitation product (AP) is shown in Figure 4-19. This diagram appears to illustrate the different runoff characteristics of the various streams. The solid lines connect seemingly reliable gages which lie on the main stem of the same river while the dotted lines are based more on judgement and estimates. Points labeled with a "P" indicate that they are the result of weighted averaging. Consider, for instance, the construction of the South Fork curve. There are three stream gages within the basin, two of which have records of at least twenty years with a substantial overlap with the NAP map period. Hence, K-values computed from these two gages appear fairly reliable. Also these two gages lie on the main stem, as shown on the schematic in Figure 4-7. Thus, a solid line was drawn between them. Gage 13.3385.00 did not have a good record nor any overlap with the adjustment period. Therefore a K-value computed from this gage can at best be used as an estimate. The location of the two points labeled as "P" were determined as follows. Referring to the schematic of Figure 4-7, it can be seen that tributary Y flows into the main stem between reaches X and W. The AP-product just above the confluence of reach Y is 290319 cfs-days (From Table 4-3). Entering the partly constructed curve of the South Fork, ie. the solid line drawn between the two main stem gages, the K-value at this point is found to be 0.31. Now the AP product below the confluence is 350640 cfs-days and the associated K equals 0.33. The contribution of tributary Y is 60321 cfs-days and the associated K-value (Ky) can be estimated by weighted averaging, ie.

$$60321Ky + 290319(0.31) = (0.33)350640$$

$$\text{or } Ky = 0.43$$

Overall the K-value interpolations on the main stems of the larger rivers, with no large tributary inflows, appear to be fairly accurate. The normal annual precipitation-area product is large and hence the effect of even a very high or very low K-value tributary with AP (tributary) << AP (main stem) is quite insignificant. For large tributary inflows, an obvious discontinuity occurs in the AP versus K-value curves. This is evidenced by the separation between the main stem and Middle Fork portions of the Clearwater river in Figure 4-19.

This is evidently due to the confluence of the North Fork with the middle fork.

In general "K-values" seem to be related to numerous factors, some of which are; soil type, aspect, vegetation and slope.

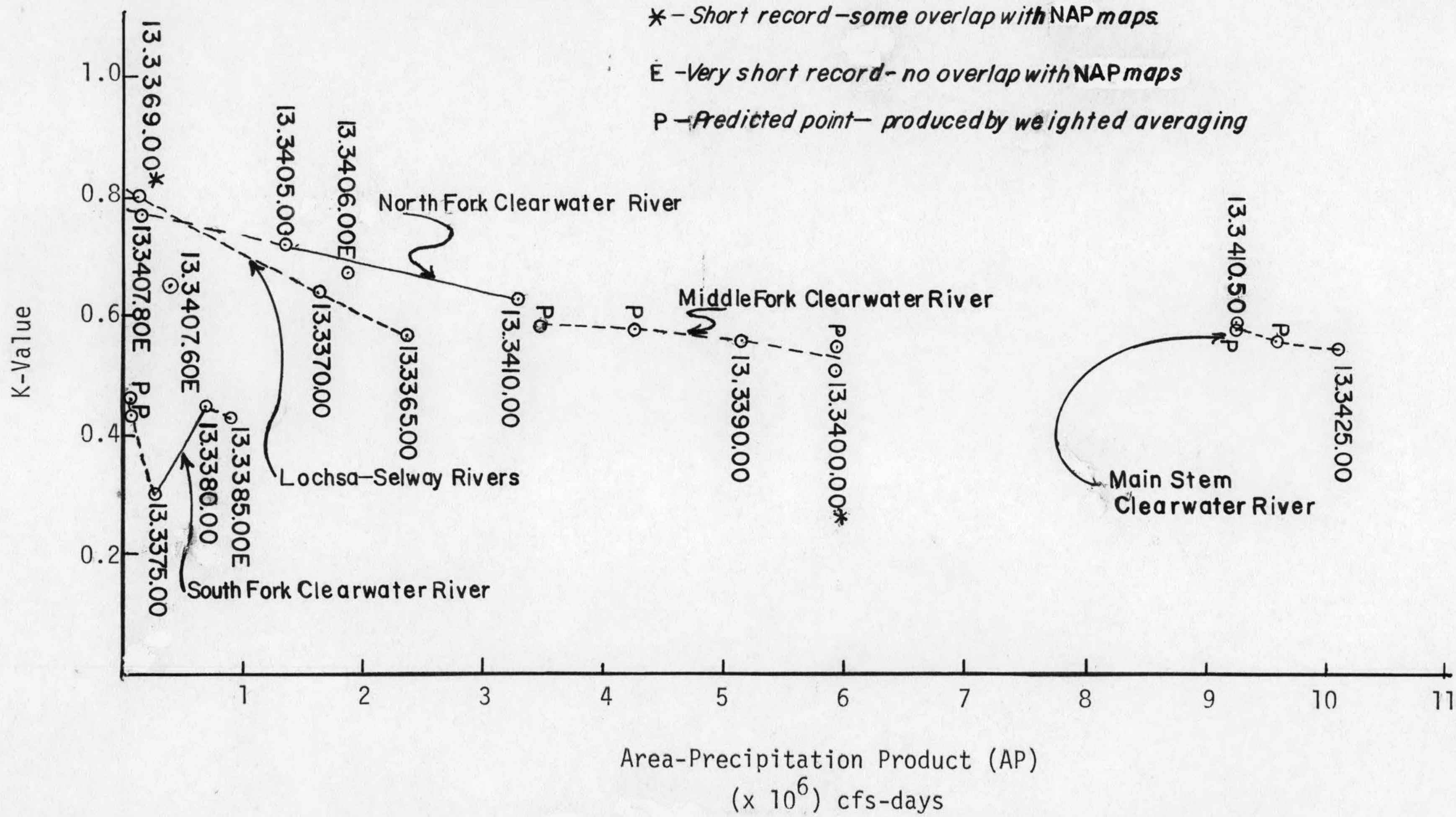

Figure 4-19. Relationship Between K-Values and Area-Precipitation Product for the Clearwater River, Idaho Method.

APPLICATION

Suppose that an estimate of the hydroelectric potential is desired of reach X on the South Fork of the Clearwater River (Figure 4-7). The total NAP-area product is given in the summation (Table 4-3) as 365700 cfs-days at the lower boundary and 350640 cfs-days at the upper boundary. The average value for the midpoint of the reach is 358170 cfs-days.

Entering Figure 4-19, the K-value associated with this reach is given as 0.33. Hence the average annual runoff is 0.33(358170) = 118196 cfs-days. Now entering Figures 4-9 through 4-13, the duration values corresponding to exceedance percents of 10, 30, 50, 80 and 95 may be graphically determined or calculated from the given equations.

Using the calculated discharge values, the 240 ft. elevation difference between the upper and lower reach boundaries as the available power head in the reach, and an efficiency of one, the theoretical energy, power and plant size values can be calculated. Refer to Heitz (10). Since energy calculations involved numerically integrating the area under the duration curve, estimates of discharges at the 0 and 100 percent exceedances were required. This was accomplished by extrapolating the logs of the discharges associated with exceedance percents of 10 and 30 for the 0 percent value and 80 and 95 percent values for 100%. An energy table is shown below for reach X using the Idaho method.

TABLE 4-4. Power and Energy Table for Reach X on the South Fork of the Clearwater River Using a Head of 240 Feet and Efficiency of 100%, Idaho Method.

PERCENT	DISCHARGE CFS	PLANT SIZE MW	ENERGY MWH	LOAD FACTOR
10	1011	20.53	53250	0.30
30	245	4.97	25955	0.59
50	114	2.31	16619	0.82
80	63	1.28	10712	0.95
95	41	0.83	7283	0.99

B. WASHINGTON METHOD

This method assumes that the shape of the duration curve is constant for a given area. As previously stated, the duration curves from gages within a basin are normalized by dividing the discharges, corresponding to the exceedance percentages of 10, 30, 50, 80 and 95 by the respective average annual runoff value. Each normalized curve is then assigned an area for which it will be used.

Applying this method to the Clearwater River, the eight gages were normalized, plotted on log-probability paper (Figures 4-20 and 4-21) and tabulated in table 4-5. The logical area assignments for seven of the gages are shown below.

TABLE 4-6. Assignment of Stream Gages to Area of Influence Washington Method.

GAGE NUMBER	ASSIGNED AREA
13.3370.00	Lochsa River and tributaries
13.3365.00	Selway River and tributaries
13.3380.00	South Fork and tributaries
13.3375.00	South Fork and tributaries
13.3405.00	North Fork and tributaries
13.3410.00	North Fork and tributaries
13.3390.00	Middle Fork and Main Stem to North Fork confluence

Notice that two gages were assigned to the South Fork. The normalized values are not extremely different for these two gages and hence the average of the two will be used to represent the South Fork. This was also done for the two stream gages on the North Fork of the Clearwater. (see table 4-7)

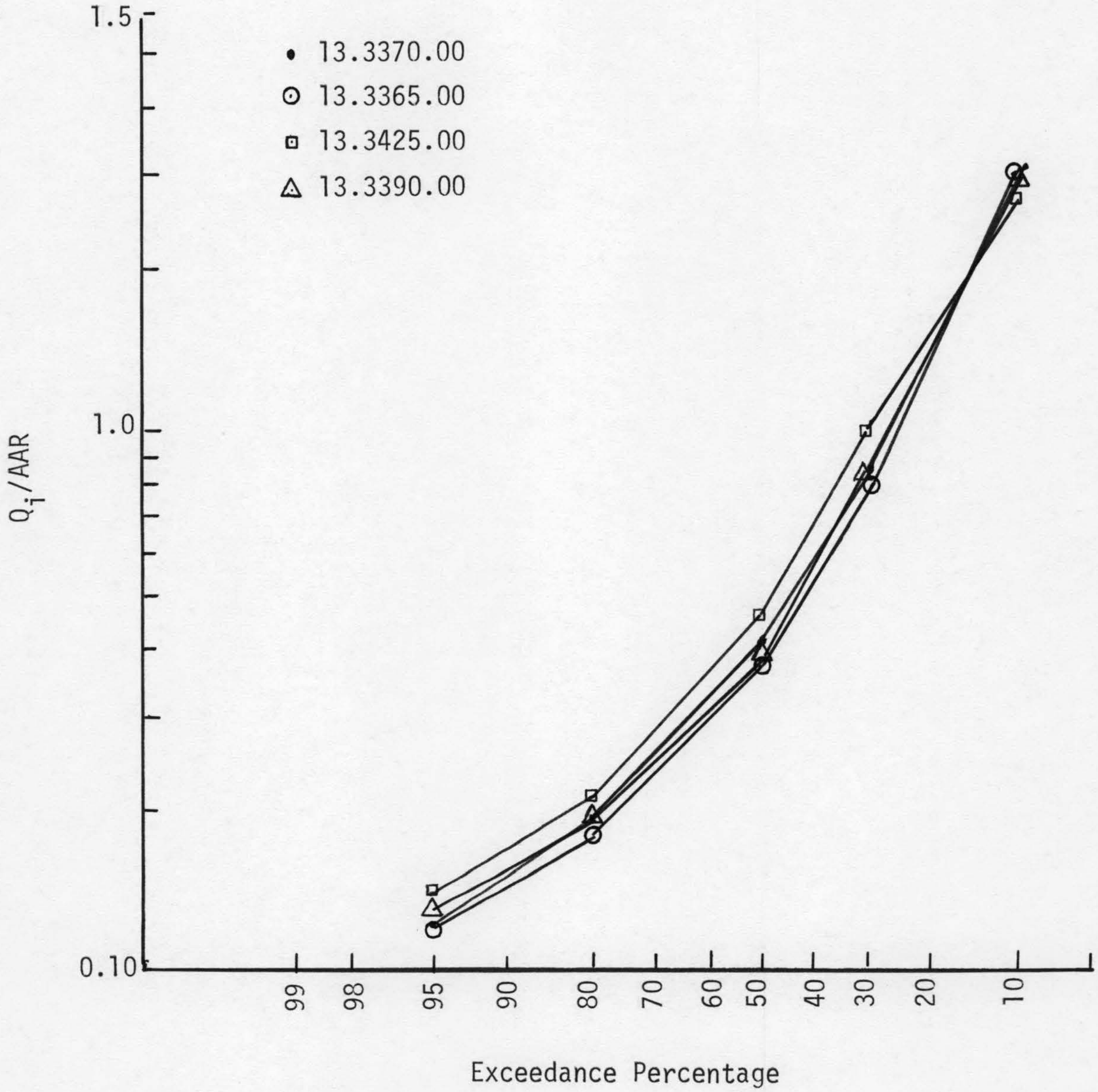

Figure 4-20. Dimensionless Duration Curves for Selected Clearwater River Gages, Washington Method.

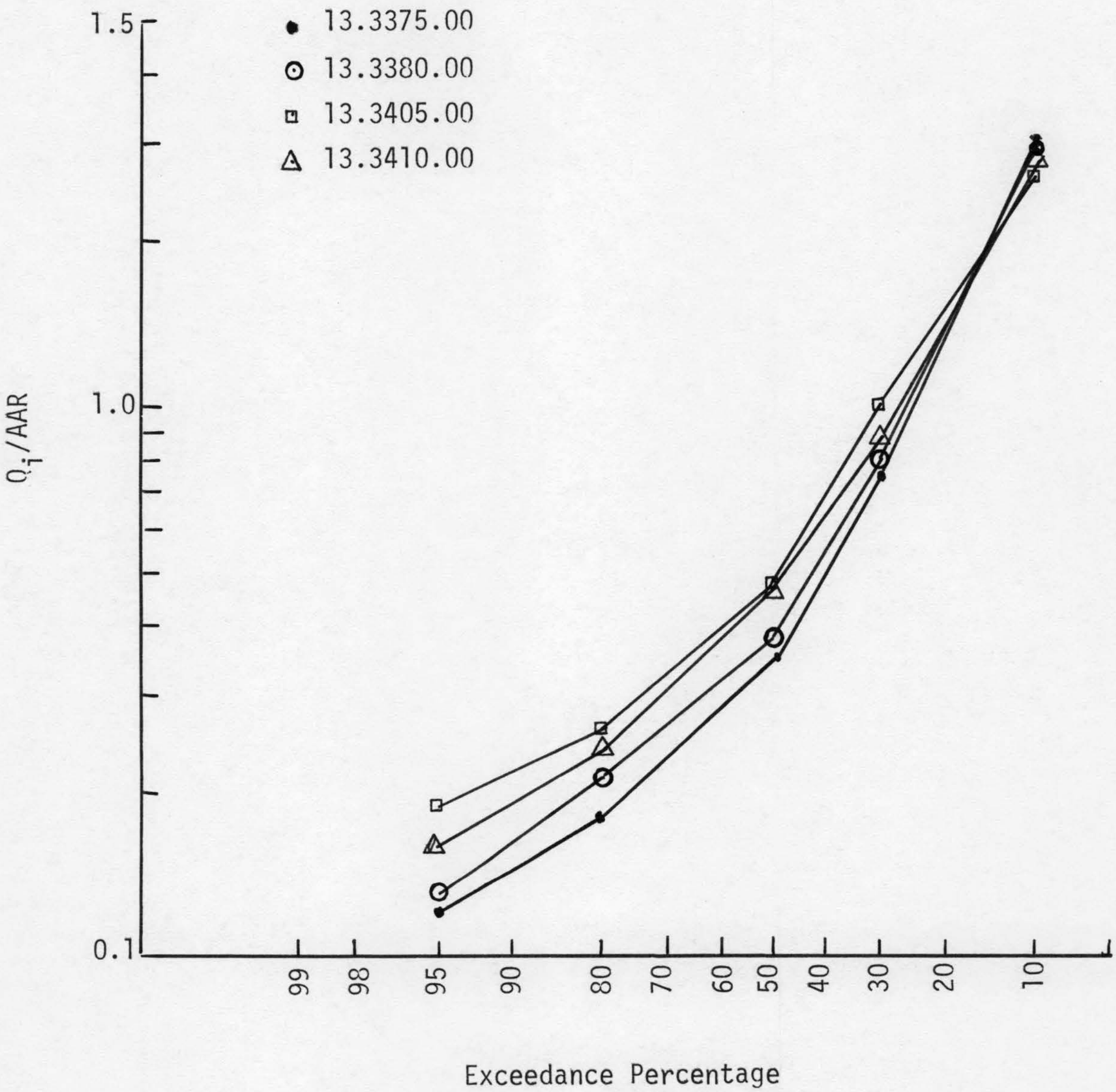

Figure 4-21. Dimensionless Duration Curves for Selected Clearwater River Gages, Washington Method.

Table 4-5. Normalized Duration Curve Values for Stream gages in the Clearwater Basin, Washington Method.

Gage	Q_{10}/QAA	Q_{30}/QAA	Q_{50}/QAA	Q_{80}/QAA	Q_{95}/QAA
13.3370.00	2.90	0.83	0.40	0.19	0.12
13.3365.00	3.04	0.78	0.37	0.18	0.12
13.3375.00	3.07	0.75	0.35	0.18	0.12
13.3380.00	2.97	0.79	0.38	0.21	0.13
13.3405.00	2.89	0.88	0.47	0.26	0.19
13.3410.00	2.72	01.02	0.47	0.24	0.16
13.3390.00	2.99	0.83	0.38	0.19	0.13

Table 4-7. Average Values of Normalized Duration Curves for use on the North and South Forks of the Clearwater River, Washington Method.

Area	Q_{10}/QAA	Q_{30}/QAA	Q_{50}/QAA	Q_{80}/QAA	Q_{95}/QAA
S. Fork Ave	3.02	0.77	0.37	0.20	0.13
N. Fork Ave	2.81	0.95	0.47	0.25	0.18

K-VALUES

With reference to Chapter 3, K-value assignments to the Clearwater, using the Washington method, will be demonstrated by application.

Refer to Figures 4-7 and Table 4-3. The K-value associated with the uppermost gage (13.3375.00) on the South Fork is calculated as follows.

$$K = Runoff/(AP)$$

$$85702/281595 = 0.30$$

According to chapter 3, this value will be used for all reaches upstream of this gage. For the reaches lying between gages 13.3375.00 and 13.3380.00, K is calculated as shown below.

the AP product at gages 13.3375.00 and 13.3380.00 is 281595 cfs-days and 686291 cfs-days respectively and the corresponding runoff values are 85702 cfs-days and 309162 cfs-days. The fraction of the (AP) input between the gages which contributes to the runoff is,

$$K(686291-281595) = (309162-85702)$$

$$K = (309162-85702)/(686291-281595) = 0.55$$

For a particular reach between the gages say reach X, the average (AP) for the midpoint of the reach is 358170 cfs-days. The average annual runoff is, AAR = (0.55)(358170-281595) + 85702 = 127818 cfs-days.

Notice that the K of 0.55 is constant for all reaches between the gages. This assumption is probably not too good if one is interested in the energy from one particular tributary to the main stem. Following this procedure may give a grossly over or underestimated runoff value.

APPLICATION

The application of the Washington Method is fairly straight forward. All that is required is (1) estimation of the average annual runoff value for the reach of interest and (2) multiplication of the average annual runoff by the normalized values which describe the appropriate curve. For energy calculations, values corresponding to 0 and 100 exceedance percents are required. These can be estimated by extrapolation of the logs of the Q10 and Q30 and the logs of Q80 and Q95 for 0 and 100 percent values respectively. On the other hand, the 0 and 100 percent values could be assumed to be identical with Q10 and Q95 respectively. The difference in the area under the curve is usually not large.

For reach X on the South Fork of the Clearwater River, the estimated discharge, power and energy values are shown below using a head of 240 ft. and efficiency of one.

TABLE 4-8. Power and Energy Table for Reach X on the South Fork of the Clearwater River Using a Head of 240 Feet and an Efficiency of 100%, Washington Method.

PERCENT	DISCHARGE (CFS)	PLANT SIZE (MW)	ENERGY (MWH)	LOAD FACTOR
10	1058	21.52	56916	0.30
30	270	5.49	28837	0.60
50	130	2.64	18859	0.81
80	70	1.42	11911	0.95
95	46	0.94	8169	0.99

C. MONTANA METHOD

This method combines the use of normalized duration curves and a regression analysis.

As previously described, the known duration curves are normalized by dividing the discharges of various exceedance percents by the 10 percent discharge. Refer to figures 4-22 and 4-23 for the normalized Clearwater Basin curves. Each of these curves was assigned an area to represent which was, of course, identical to the Washingtion Method assignments. Likewise, the averaging or smoothing process was done on the curves representing the North and South Forks. (see Figure 4-24)

REGRESSIONS

Following the Montana procedure two regression analyses were performed. One regressing Q10 against AAR and the other regressing AAR against (AP). The arithmetic scaled plots along with 95% confidence intervals are shown in Figures 4-9 and 4-25. In order to apply the method, it is only necessary to obtain the average (AP) value for the reach of interest, enter the (AP) versus AAR curve to find AAR and then enter the AAR versus Q10 curve to determine the Q10 value. Multiplication by the various normalized points of the representative duration curve yields the estimated curve for the reach.

A slightly different approach consists of one regression only. For the Clearwater data, a regression of log Q10 versus log (AP) yields the arithmetic scale plot shown in Figure 4-26.

In order to compare the results, the equations from the separate regressions were combined to relate Q10 to AP. Tests at the 95% level of significance show no significant difference between the coefficients from the two regression approaches. Plots of observed versus predicted for the two approaches are shown in Figures 4-27 and 4-28.

One reason however for using two regression equations would be the need for the average annual runoff value. However, this could be determined from the single equation approach by integrating the area under the final duration curve.

With regard to the confidence limits on the regressions, it should be noted that the curve is not needed beyond a precipitation-area product of about 6000000 cfs-days. Above this value, the river is influenced by Dworshak reservoir and this method is not applicable. However even at the value of 6000000 cfs-days, the confidence bounds are very wide which implies a great amount of uncertainty.

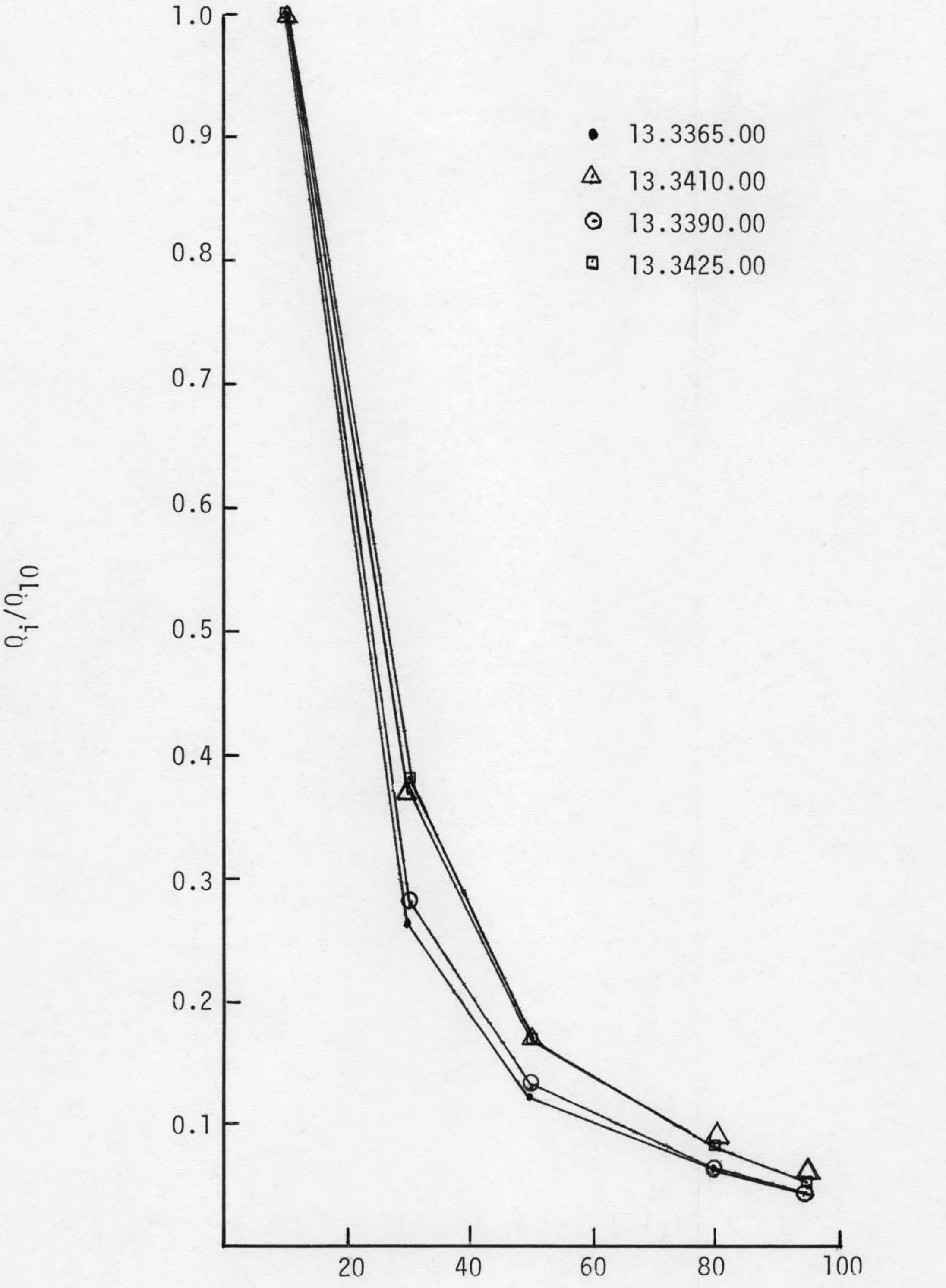

Figure 4-22. Dimensionless Duration Curves for Selected Clearwater River Gages, Montana Method.

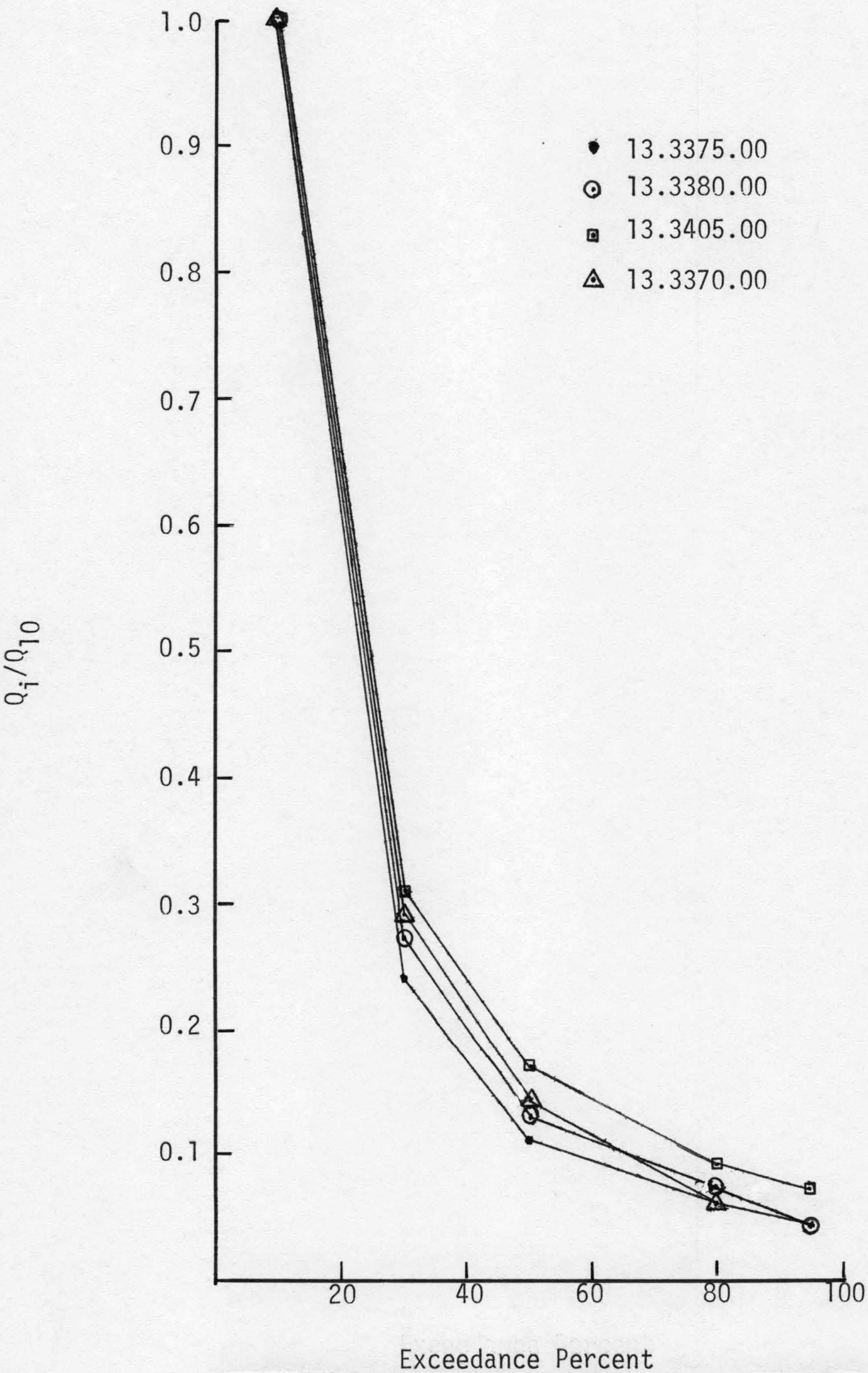

Figure 4-23. Dimensionless Duration Curves for Selected Clearwater River Gages, Montana Method.

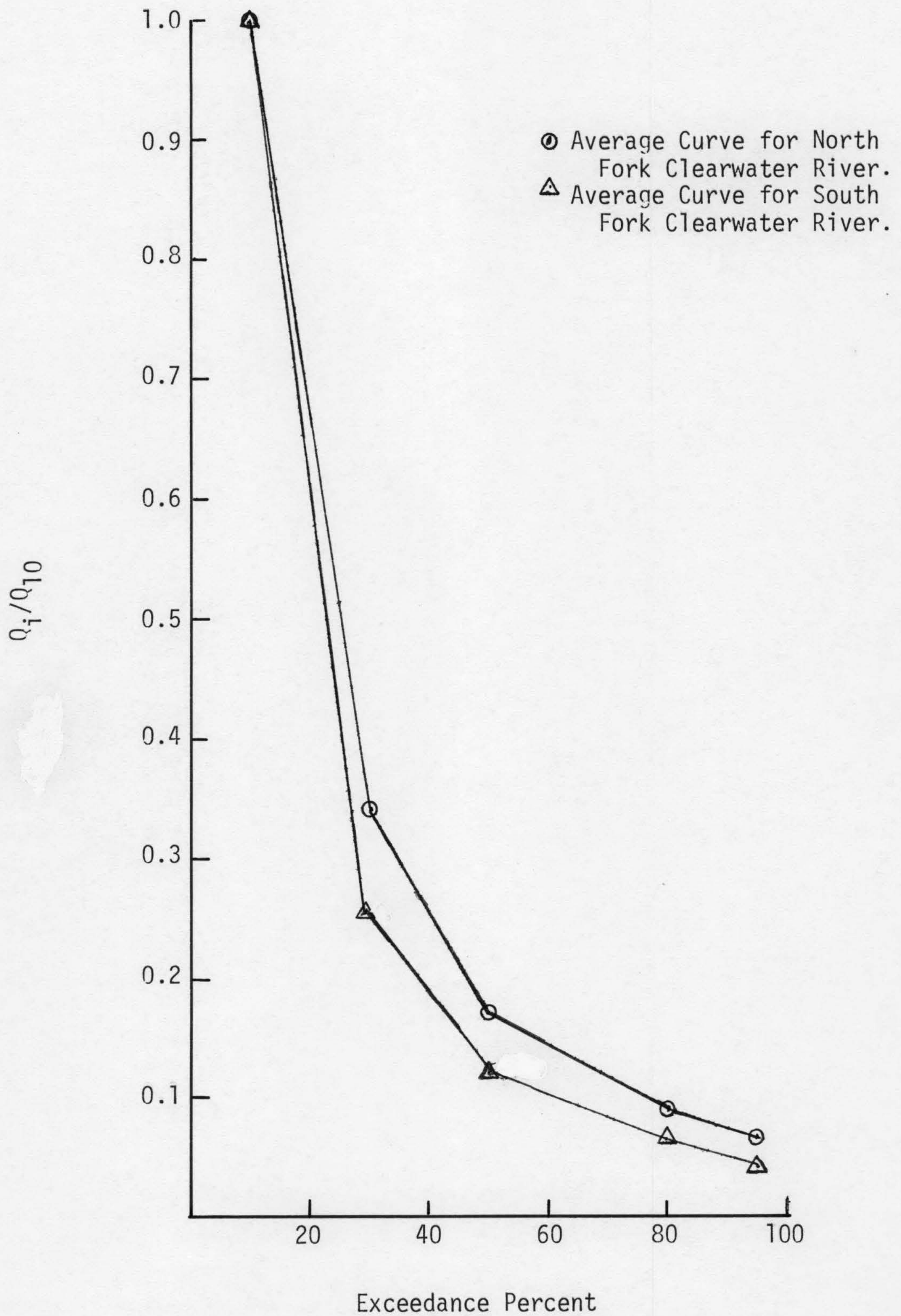

Figure 4-24. Averaged Dimensionless Duration Curves for use on the North and South Forks of the Clearwater River, Montana Method.

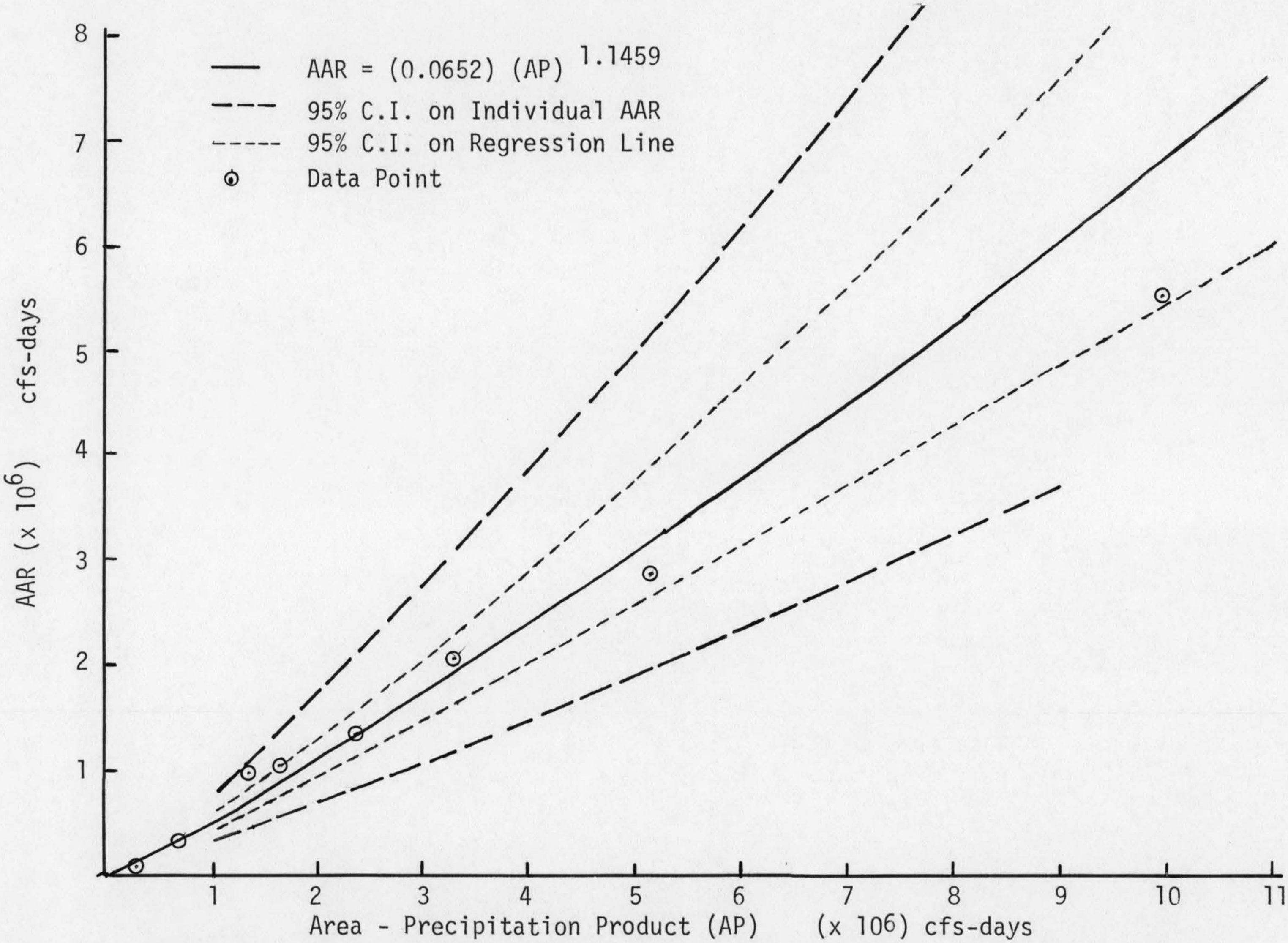

Figure 4-25. Regression Relationship Between AAR and Area - Precipitation Product, Montana Method.

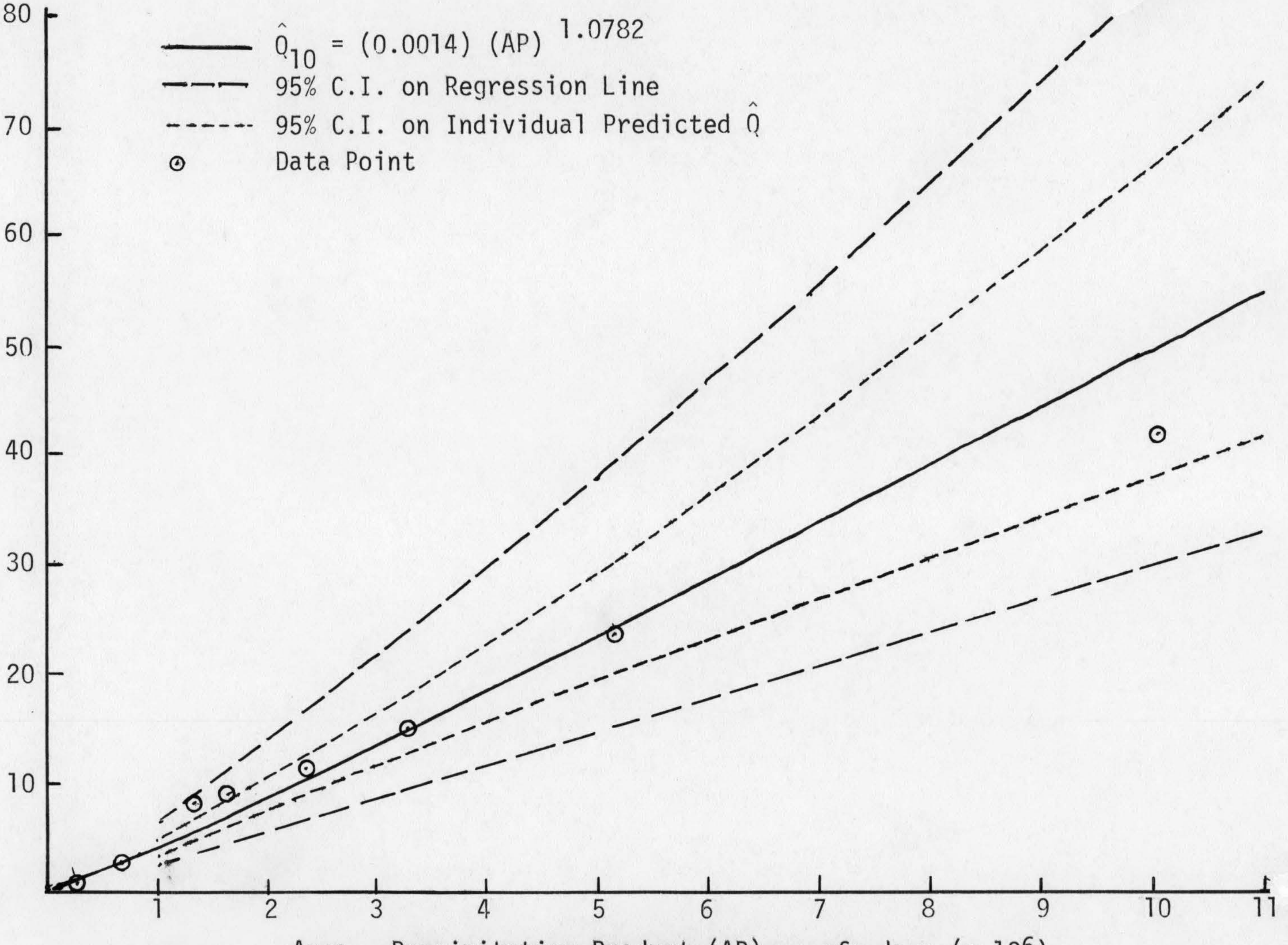

Figure 4-26. Regression Relationship Between the Q_{10} Discharge and Area-Precipitation Product, Montana Method.

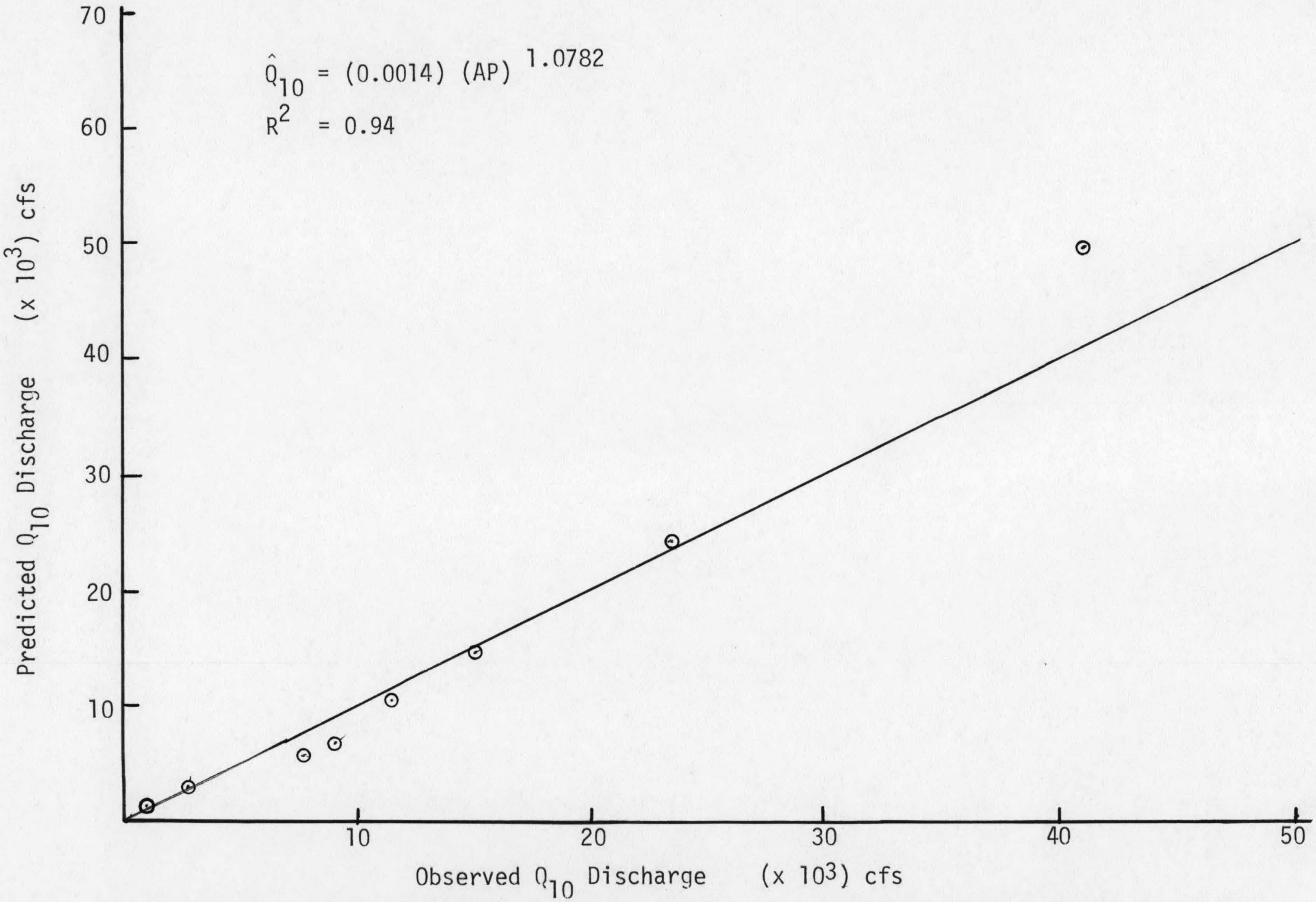

Figure 4-27. Observed Versus Predicted Discharge (Q_{10}) Using Direct Regression Equation, Montana Method.

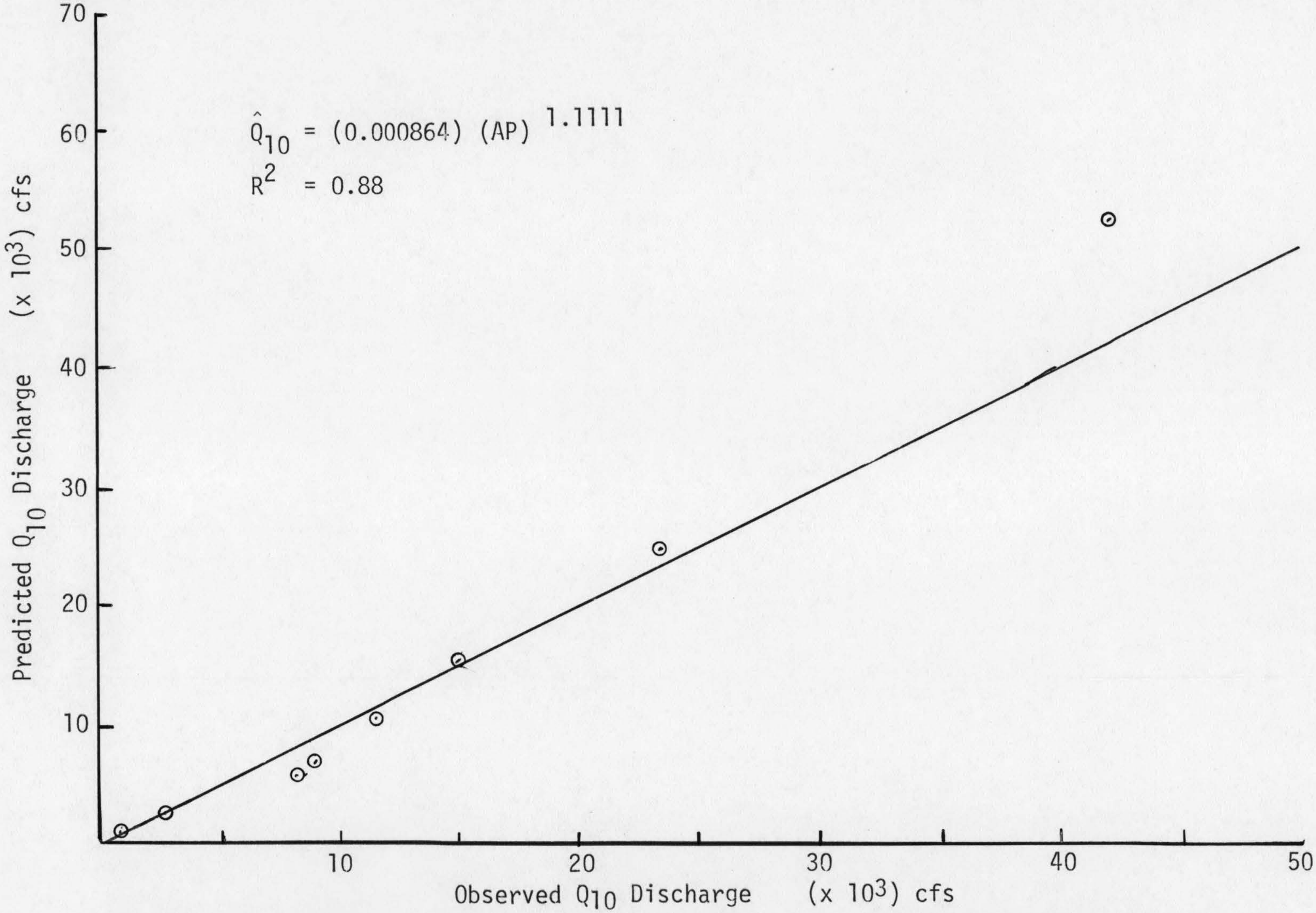

Figure 4-28. Observed Versus Predicted Discharge (Q_{10}) Using Combined Equation, Montana Method.

APPLICATION

Applying the Montana method to reach X on the South Fork of the Clearwater, an estimated average annual runoff value of 150896 cfs-days was found from Figure 4-25. The associated Q10 discharge from Figure 4-9 is 1363 cfs. Using the average normalized curve in Figure 4-24, the discharge and energy for each exceedance percent were calculated and the results are shown in Table 4-9.

TABLE 4-9. Power and Energy Table for Reach X on the South Fork of the Clearwater River Using a Head of 240 Feet and an Efficiency of 100%, Montana Method.

PERCENT	DISCHARGE CFS	PLANT SIZE MW	ENERGY MWH	LOAD FACTOR
10	1363	27.72	73032	0.30
30	348	7.08	36863	0.59
50	164	3.34	23750	0.81
80	89	1.81	15064	0.95
95	55	1.12	9764	0.99

A comparison of estimated duration curves for reach X on the South Fork of the Clearwater River for the three methods is shown in Figure 4-29.

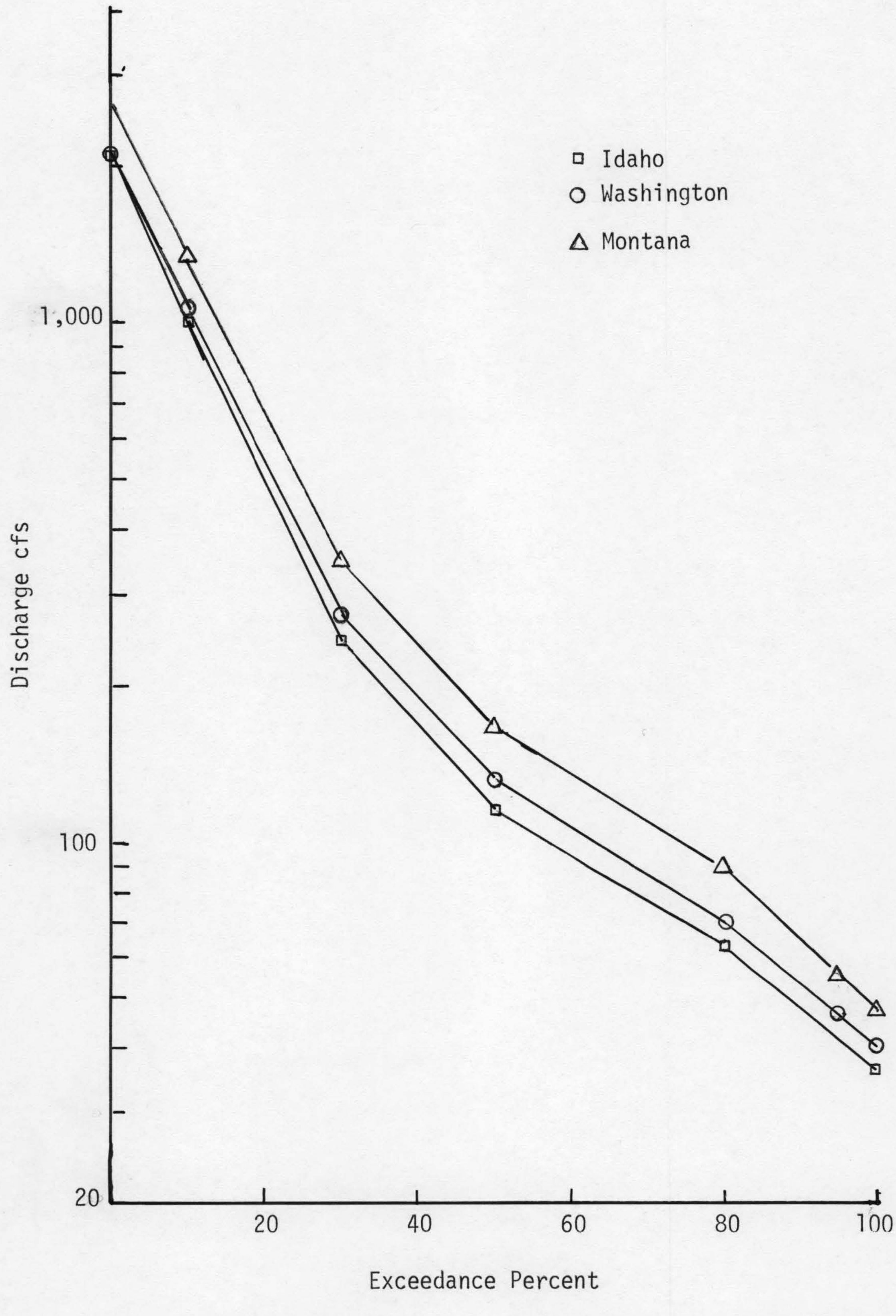

Figure 4-29. Predicted Flow Duration Curves for Reach x on the South Fork of the Clearwater River using Idaho, Washington and Montana Methods.

D. COMPARISONS

The previous development utilized eight of twenty-one gage records in the Clearwater basin. These eight gages have records of twenty years or greater. There are also seven other gages with records of ten to fifteen years. Of these seven, three are on Potlatch creek and tributaries and one on the main stem of the Clearwater just below the confluence of the North Fork. The gages lying on Potlatch Creek could not be used to compare with the techniques since the Montana and Washington methods would necessarily use them in their development. Also, the gage on the main stem cannot be used since it reflects some natural flows and some regulated flows due to Dworshak reservoir. This leaves three gages against which the methods may be compared. Hence the following comparisons assume that the ten-year records accurately reflect the shape and magnitudes which would occur in a duration curve from a longer period of record.

The three gages to be used, along with observed and predicted average annual runoff and discharge values are listed in Table 4-10.

Using these values, the theoretical energy, in megawatt-hours, plant size in kilowatts and load factors were calculated assuming unity for the head and efficiency (refer to Tables 4-11 through 4-14).

A visual comparison of duration curves is shown in Figures 4-30, 4-31 and 4-32. The percent differences between the observed and predicted theoretical energy values are shown in Tables 4-15, 4-16 and 4-17. It should be remembered that the objective of these procedures is to estimate the total theoretical energy and power within a basin. Hence the error at individual points is not as critical as the error in the computation of the total energy or power for the basin. In order to observe this, assume that a basin is comprised of three reaches represented by the predicted duration curves for the three stream gages. The observed and predicted totals and percent differences are shown in Table 4-18.

Table 4-10. Comparison of Discharge and AAR Values for Observed and Predicted Duration Curves Using the Idaho, Washington and Montana Methods.

Gage	Average Annual Runoff cfs-days	Q_{10} cfs	Q_{30} cfs	Q_{50} cfs	Q_{80} cfs	Q_{95} cfs
13.3369.00	92,684	760	240	102	45	30
Idaho	89,136	769	182	85	47	30
Washington	89,136	708	203	98	46	29
Montana	39,588	387	112	54	23	15
13.3385.00	390,714	3,000	1,000	490	250	165
Idaho	376,401	3,108	835	390	208	137
Washington	376,401	3,114	794	382	206	134
Montana	420,141	3,573	911	429	232	143
13.3400.00	3,222,078	26,000	8,000	3,000	1,600	1,000
Idaho	3,142,055	24,325	7,917	3,683	1,845	1,248
Washington	3,142,055	25,739	7,145	3,271	1,636	1,119
Montana	3,761,466	28,100	7,868	3,653	1,686	1,124

Table 4-11. Power and Energy Data Using Observed Data from Three Stream Gages in the Clearwater Basin.

Gage Number	Exceedance Percent	Discharge cfs	Theoretical Plant Size kw	Theoretical Energy mwh	Load Factor
13.3369.00					
	10	760	64.3	177	0.31
	30	240	20.3	100	0.56
	50	102	8.6	59	0.78
	80	45	3.8	32	0.95
	95	30	2.5	22	0.98
13.3385.00					
	10	3,000	253.8	741	0.33
	30	1,000	84.6	444	0.60
	50	490	41.5	292	0.80
	80	250	21.2	176	0.95
	95	165	14.0	121	0.99
13.3400.00					
	10	26,000	2,199.7	6,067	0.31
	30	8,000	676.8	3,395	0.57
	50	3,600	304.6	2,088	0.78
	80	1,600	135.4	1,123	0.95
	95	1,000	84.0	733	0.99

Table 4-12. Predicted Power and Energy Data for Three Stream gages in the Clearwater Basin Using the Idaho Method.

Gage Number	Exceedance Percent	Discharge cfs	Theoretical Plant Size kw	Theoretical Energy mwh	Load Factor
13.3369.00					
	10	769	65.0	168	0.29
	30	182	15.4	80	0.59
	50	85	7.2	52	0.82
	80	47	4.0	33	0.95
	95	30	2.5	22	0.99
13.3385.00					
	10	3,108	262.9	705	0.31
	30	835	70.6	367	0.59
	50	390	33.0	235	0.81
	80	208	17.6	147	0.96
	95	137	11.6	101	0.99
13.3400.00					
	10	24,325	2,057.9	5,892	0.33
	30	7,917	669.8	3,456	0.59
	50	3,683	311.6	2,198	0.80
	80	1,845	156.1	1,311	0.96
	95	1,248	105.6	924	0.99

Table 4-13. Predicted Power and Energy Data for Three Stream gages in the Clearwater Basin Using the Washington Method.

Gage Number	Exceedance Percent	Discharge cfs	Theoretical Plant Size kw	Theoretical Energy mwh	Load Factor
13.3369.00					
	10	708	59.9	164	0.31
	30	203	17.2	89	0.59
	50	98	8.3	58	0.79
	80	46	3.9	32	0.95
	95	29	2.5	21	0.99
13.3385.00					
	10	3,114	263.5	698	0.30
	30	794	67.2	353	0.60
	50	382	32.3	231	0.81
	80	206	17.4	146	0.95
	95	134	11.3	99	0.99
13.3400.00					
	10	25,739	2,177.6	5,864	0.31
	30	7,145	604.5	3,103	0.59
	50	3,271	276.7	1,953	0.80
	80	1,636	138.4	1,164	0.96
	95	1,119	94.7	828	0.99

Table 4-14. Predicted Power and Energy Data for Three Stream gages in the Clearwater Basin Using the Montana Method.

Gage Number	Exceedance Percent	Discharge cfs	Theoretical Plant Size kw	Theoretical Energy mwh	Load Factor
13.3369.00					
	10	387	32.7	89	0.31
	30	112	9.5	48	0.58
	50	54	4.6	31	0.78
	80	23	1.9	16	0.95
	95	15	1.3	11	0.99
13.3385.00					
	10	3,573	302.3	797	0.30
	30	911	77.1	402	0.59
	50	429	36.3	259	0.81
	80	232	19.6	164	0.95
	95	143	12.1	106	0.99
13.3400.00					
	10	28,100	2,377.3	6,402	0.31
	30	7,868	665.7	3,398	0.58
	50	3,653	309.1	2.146	0.79
	80	1,686	142.6	1,197	0.96
	95	1,124	95.1	832	0.99

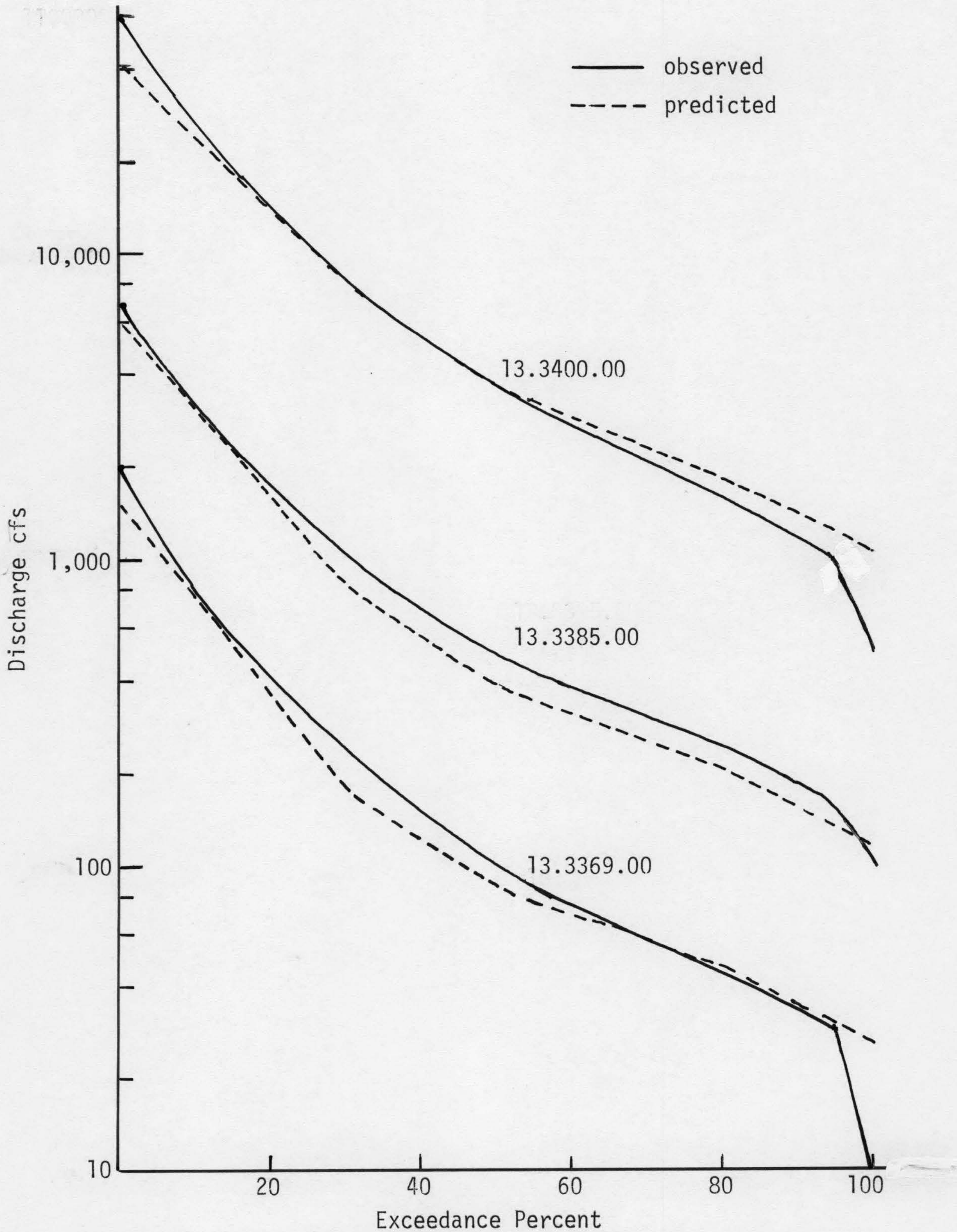

Figure 4-30. Predicted Versus Observed Flow Duration Curves Using the Idaho Method.

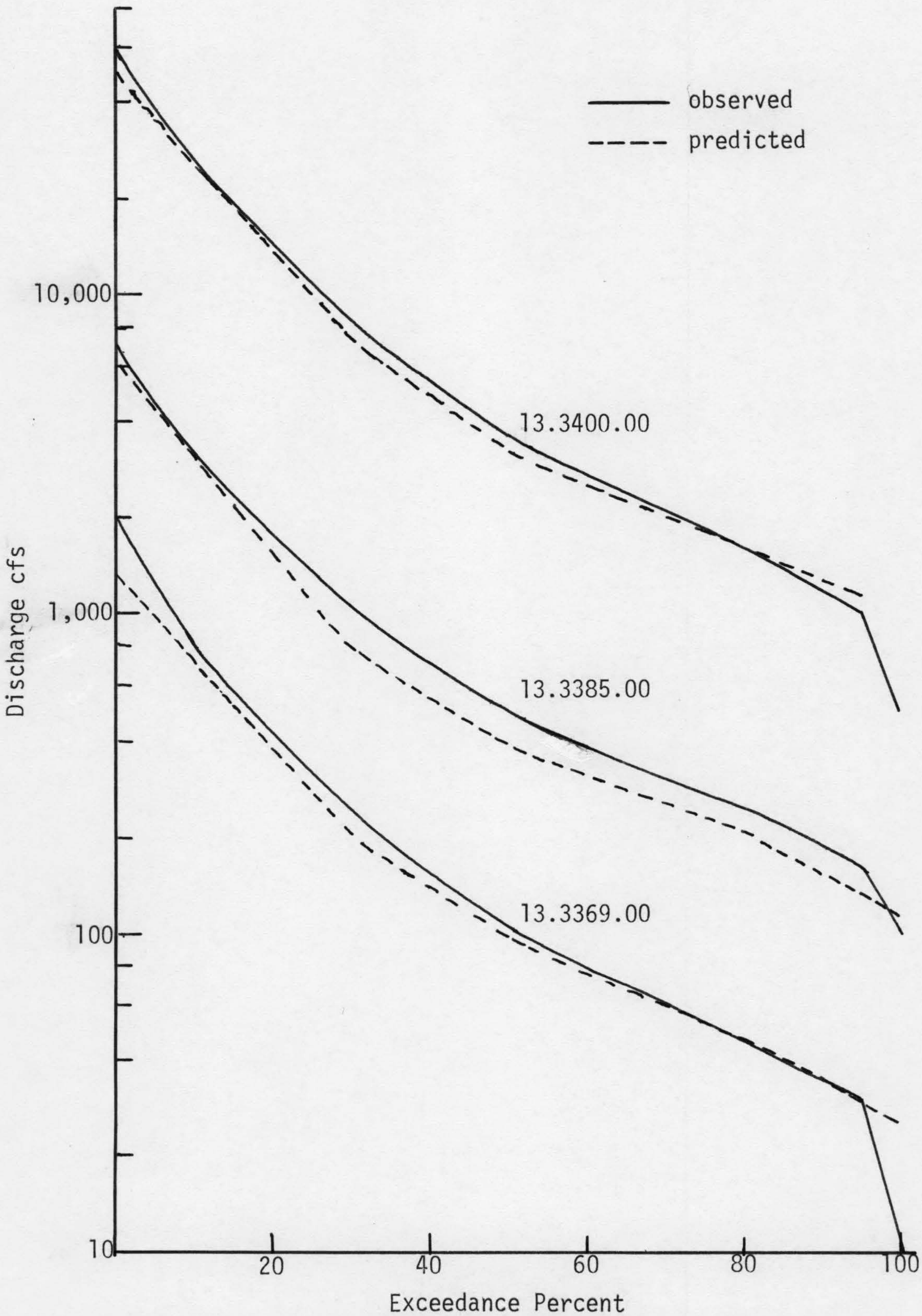

Figure 4-31. Predicted Versus Observed Flow Duration Curves Using the Washington Method.

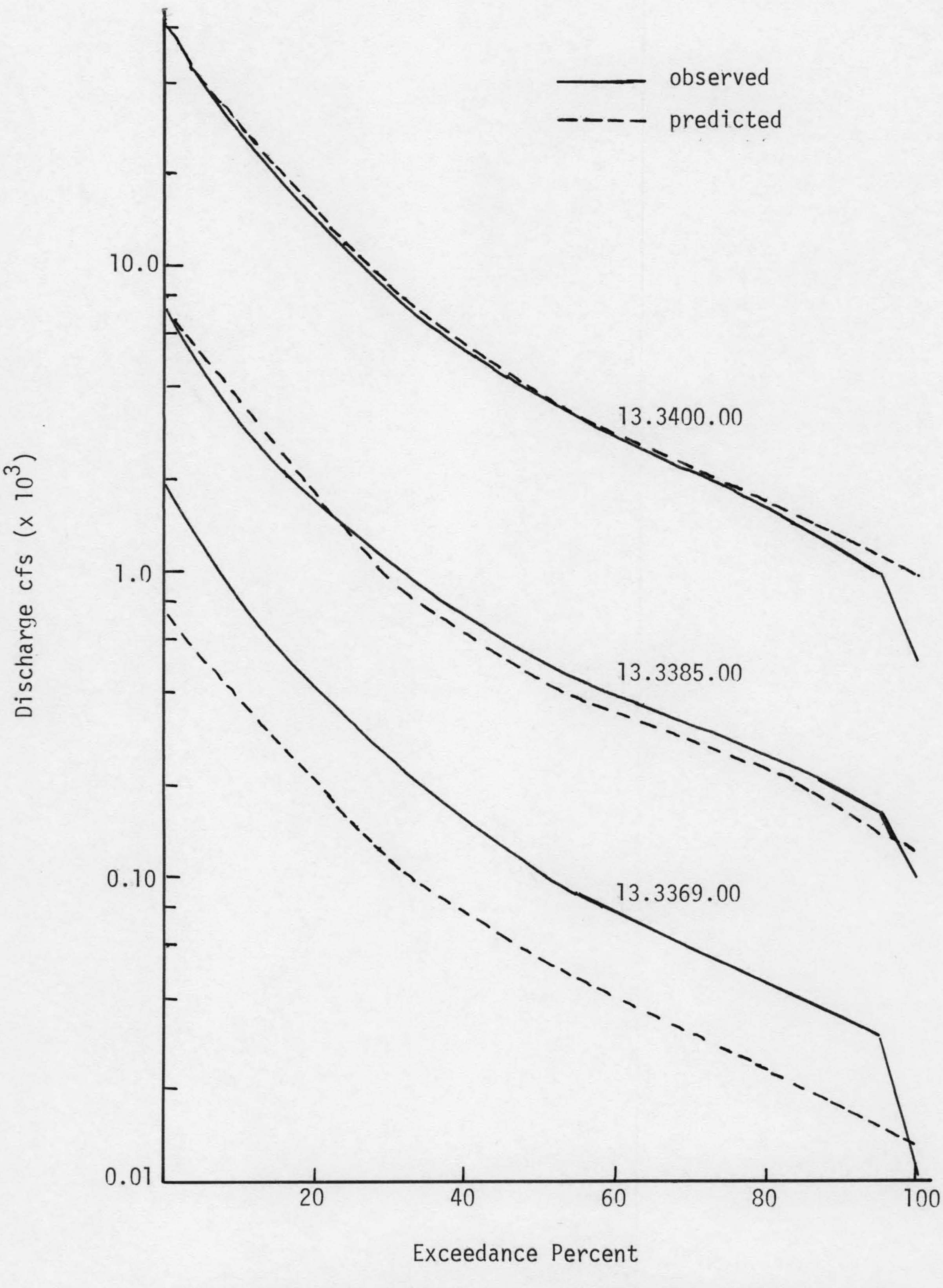

Figure 4-32. Predicted Versus Observed Flow Duration Curves Using the Montana Method.

Table 4-15. Differences Between Observed and Predicted Theoretical Energy Values (mwh) for Three Stream Gages in the Clearwater Basin, Idaho Method.

Gage	E10	E30	E50	E80	E95
13.3369.00	177	100	59	32	22
Predicted	168	80	52	33	22
% Difference	5.1	20	11.9	3.1	0
13.3385.00	741	444	292	176	121
Predicted	705	367	235	147	101
% Difference	4.9	17.3	19.5	16.5	16.5
13.3400.00	6,067	3,395	2,088	1,123	733
Predicted	5,892	3,456	2,198	1,311	924
% Difference	2.9	1.8	5.3	16.7	26.1

Table 4-16. Differences Between Observed and Predicted Theoretical Energy Values (mwh) for Three Stream Gages in the Clearwater Basin, Washington Method.

Gage	E10	E30	E50	E80	E95
13.3369.00	177	100	59	32	22
Predicted	164	89	58	32	21
% Difference	7.3	11	1.7	0	4.5
13.3385.00	741	444	292	176	121
Predicted	698	353	231	146	99
% Difference	5.8	20.5	20.9	17.0	18.2
13.3400.00	6,067	3,395	2,088	1,123	733
Predicted	5,864	3,103	1,953	1,164	828
% Difference	3.3	8.6	6.5	3.7	13.0

Table 4-17. Differences Between Observed and Predicted Theoretical Energy Values (mwh) for Three Stream Gages in the Clearwater Basin, Montana Method.

Gage	E10	E30	E50	E80	E95
13.3369.00	177	100	59	32	22
Predicted	89	48	31	16	11
% Difference	49.7	52.0	47.5	50.0	50.0
13.3385.00	741	444	292	176	121
Predicted	797	402	259	164	106
% Difference	7.6	9.5	11.3	6.8	12.4
13.3400.00	6,067	3,395	2,088	1,123	733
Predicted	6,402	3,398	2,146	1,197	832
% Difference	5.5	0.10	2.8	6.6	13.5

Table 4-18. Energy Totals: Differences Between Observed and Predicted Values for Idaho, Washington and Montana Methods. (mwh)

	E10	E30	E50	E80	E95
Observed	6,985	3,939	2,439	1,331	876
Idaho	6,765	3,903	2,485	1,491	1,047
% Difference	3.1	0.9	1.9	12.0	19.5
Washington	6,726	3,545	2,242	1,342	948
% Difference	3.7	10.0	8.1	0.8	8.2
Montana	7,288	3,848	2,436	1,377	949
% Difference	4.3	2.3	0.1	3.5	8.3

CHAPTER 5 REGULATED STREAMS

Chapters 3 and 4 are primarily concerned with the prediction of duration curves for reaches of ungaged natural flowing streams. Immediately a problem arises in predicting duration curves for reaches downstream of a regulating structure. This chapter considers this specific problem and a simple method is presented as one solution.

Following this method, duration curves are constructed from average monthly flows rather than average daily flows. Hence, a discussion is in order as to the error introduced in estimating daily flow duration curves using average monthly values.

In order to illustrate some of these differences, a curve of each type was constructed and compared for each of five stream gages in the Clearwater River Basin. The curves are shown in Figures 5-1 through 5-5 and representative points with percent differences are tabulated in Table 5-1.

Since energy values are the main interest, energy tables were computed using each type of curve for the five stream gage records. A comparative head of one foot and an efficiency of 100% were used. These values are tabulated along with the percent differences in Table 5-2.

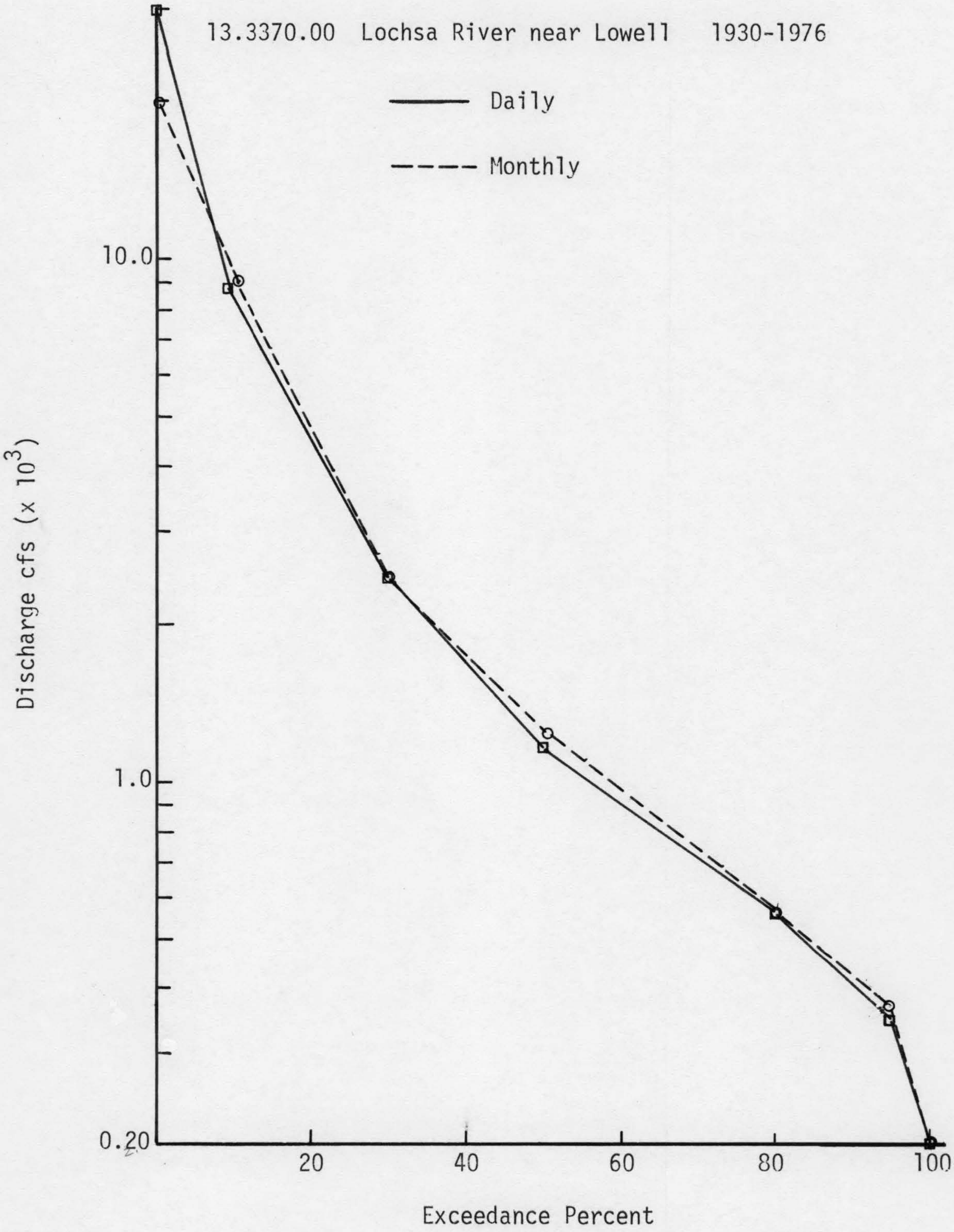

Figure 5-1. Comparison of Duration Curves Constructed Using Average Monthly Versus Average Daily Data for Stream Gage 13.3370.00, Lochsa River near Lowell.

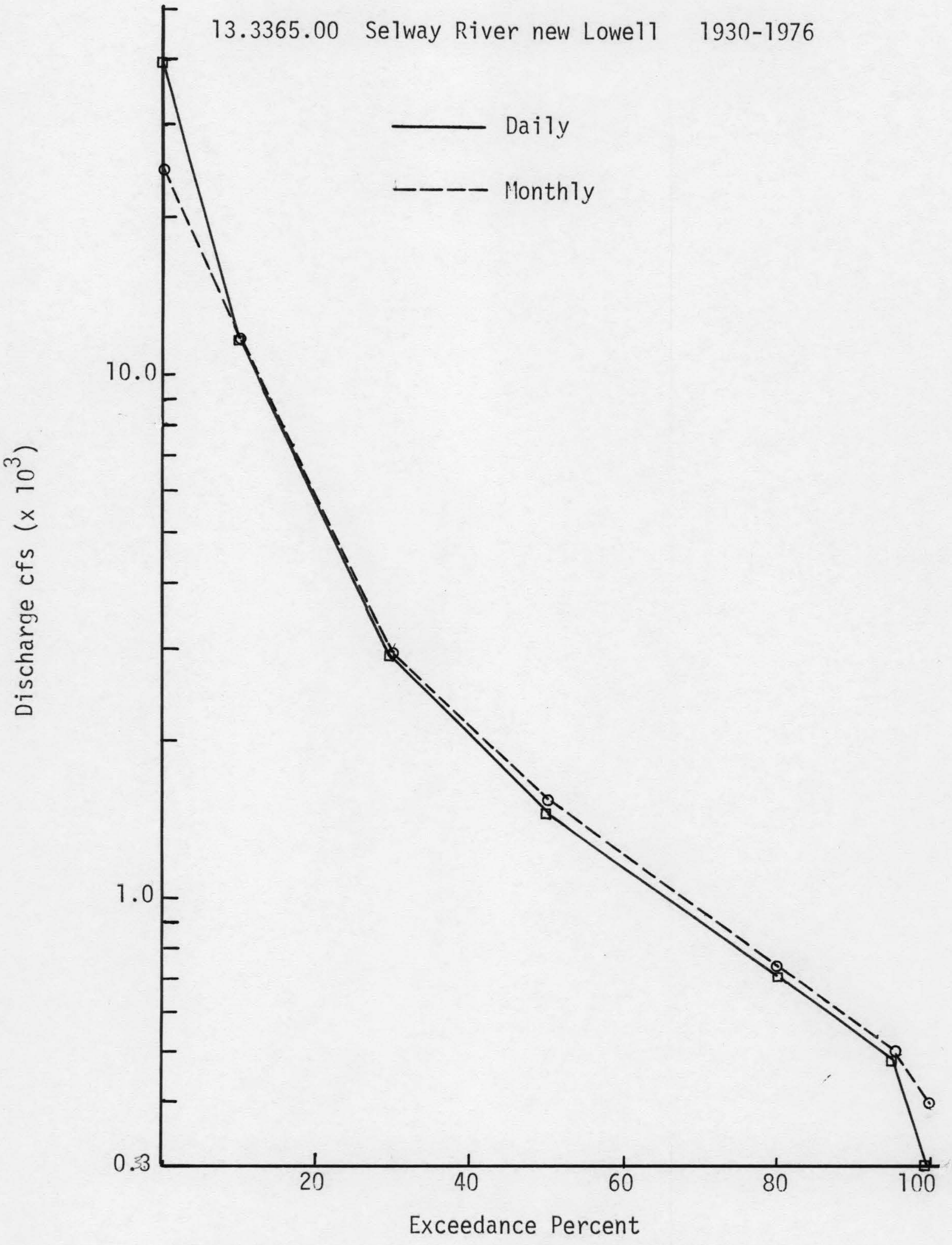

Figure 5-2. Comparison of Duration Curves Constructed Using Average Monthly Versus Daily Data for Stream Gage 13.3365.00, Selway River near Lowell.

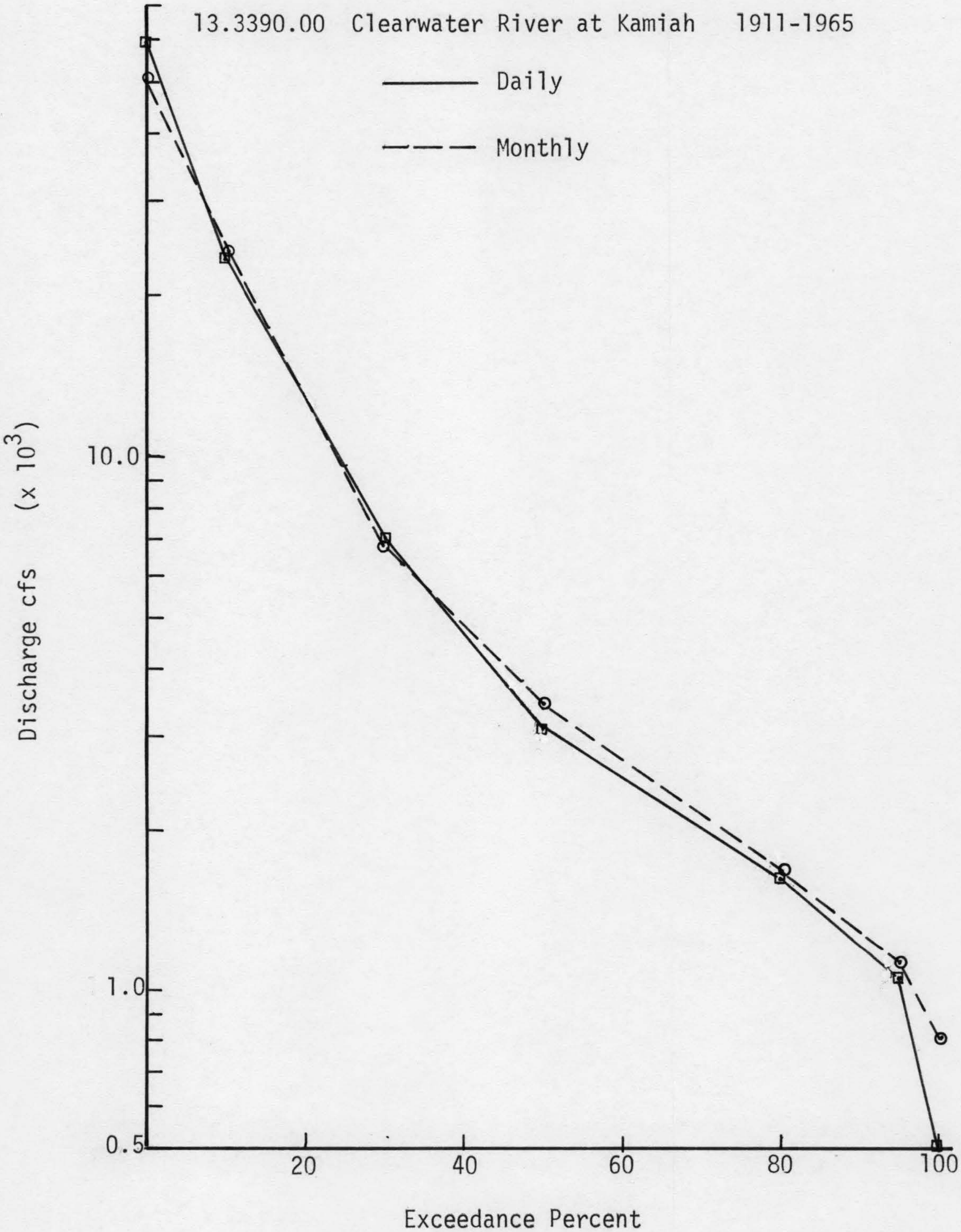

Figure 5-3. Comparison of Duration Curves Constructed Using Average Monthly Versus Daily Data for Stream Gages 13.3390.00, Clearwater River at Kamiah

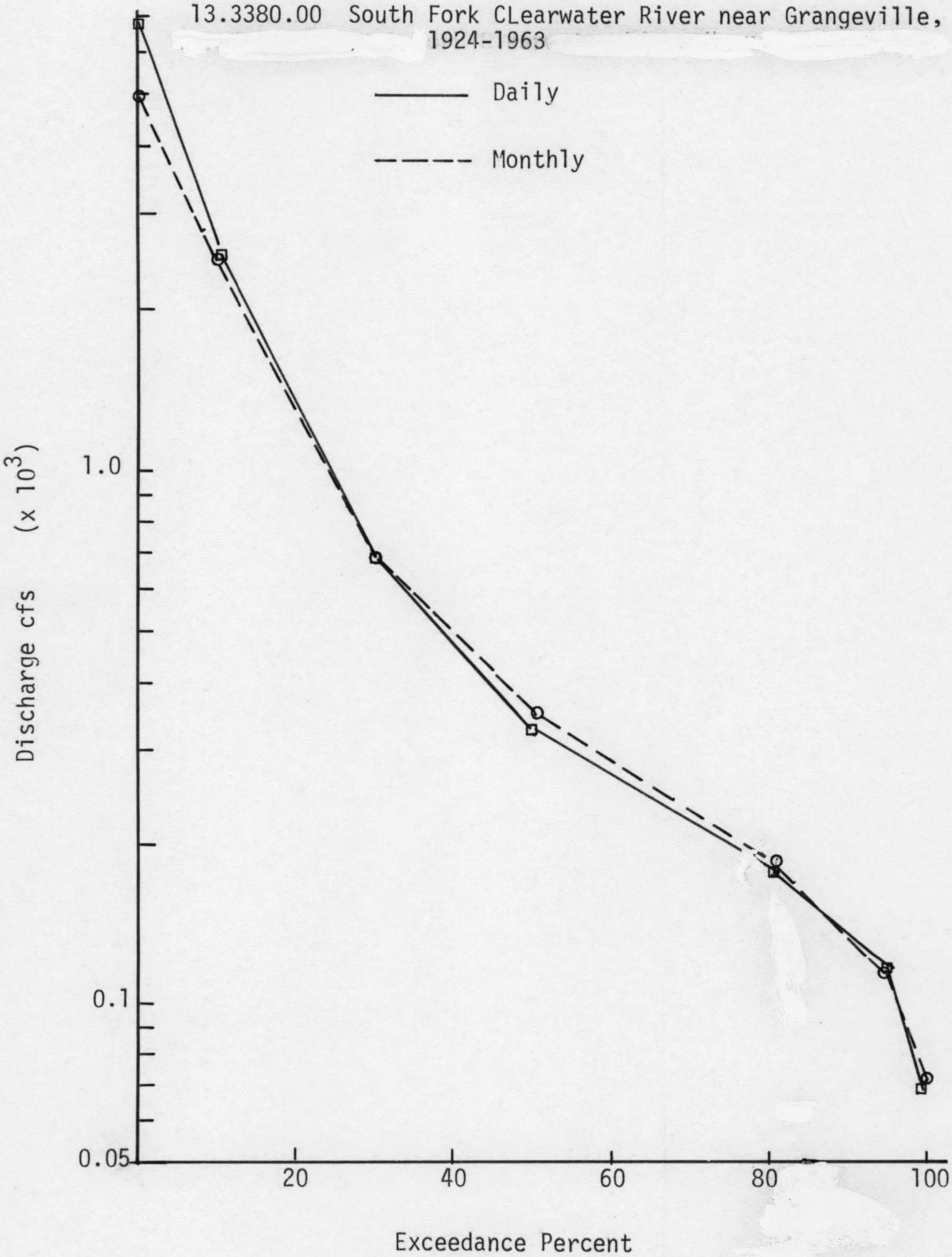

Figure 5-4. Comparison of Duration Curves Constructed Using Average Monthly Versus Daily Data for Stream Gage 13.3380.00, South Fork Clearwater River near Grangeville.

Figure 5-5. Comparison of Duration Curves Constructed Using Average Monthly Versus Daily Data for Stream Gage 13.3375.00, South Fork Clearwater River near Elk City.

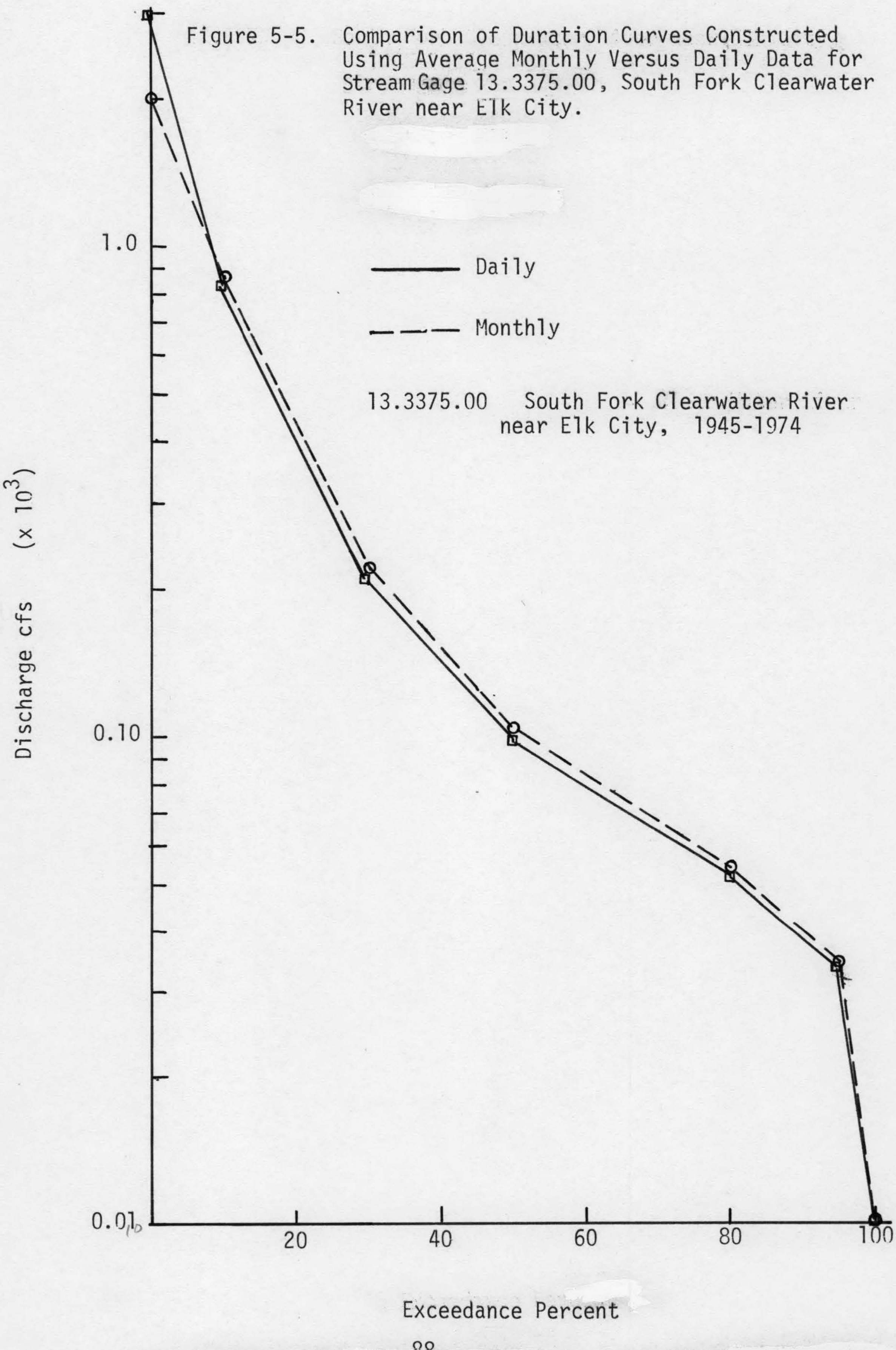

Table 5-1. Percent Differences Between Duration Curve Flow Values (cfs) Computed From Average Monthly and Daily Data, Clearwater River Gages.

	Q_0	Q_{10}	Q_{30}	Q_{50}	Q_{80}	Q_{95}	Q_{100}
Gage 13.3370.00				Period of Record 1930-1976			
Daily	30,000	8,600	2,500	1,150	560	350	200
Montly	20,000	8,881	2,418	1,257	563	368	200
% Diff.	33.3	3.3	3.28	9.3	.5	5.1	0
Gage 13.3365.00				Period of Record 1930-1976			
Daily	40,000	11,500	3,000	1,450	710	490	300
Monthly	25,000	11,980	2,942	1,544	739	508	400
% Diff.	37.5	4.2	1.9	6.5	4.1	3.7	33.3
Gage 13.3375.00				Period of Record 1945-1974			
Daily	3,000	840	210	98	52	33	10
Monthly	2,000	857	224	103	54	34	10
% Diff.	33.3	2.0	6.7	5.1	3.8	3.0	0
Gage 13.3390.00				Period of Record 1911-1965			
Daily	60,000	23,500	7,000	3,125	1,600	1,035	500
Monthly	50,000	24,283	6,943	3,444	1,661	1,108	800
% Diff.	16.7	3.3	.8	10.2	3.8	7.1	60
Gage 13.3380.00				Period of Record 1924-1963			
Daily	7,000	2,600	680	330	180	120	70
Monthly	5,000	2,500	689	350	183	119	70
% Diff.	28.6	3.8	1.3	6.1	1.7	.8	0

Table 5-2. Percent Differences Between Energy Values (mwh) Computed from Duration Curves Constructed from Average Monthly and Daily Data, Clearwater River Gages.

	E10	E30	E50	E80	E95
13.3370.00					
Daily	1,985	1,079	678	393	257
Monthly	2,036	1,076	732	397	270
% Diff.	2.6	0.3	8.0	1.0	5.1
13.3365.00					
Daily	2,583	1,320	860	503	360
Monthly	2,671	1,329	914	525	375
% Diff.	3.4	0.7	6.3	4.4	4.2
13.3375.00					
Daily	185	92	59	36	24
Monthly	191	97	61	38	25
% Diff.	3.2	5.4	3.4	5.6	4.2
13.3390.00					
Daily	5,462	3,012	1,861	1,125	758
Monthly	5,650	3,075	2,036	1,176	817
% Diff.	3.4	2.1	9.4	4.5	7.8
13.3380.00					
Daily	589	303	200	127	88
Monthly	579	310	210	129	87
% Diff.	1.7	2.3	5.0	1.6	1.1

Although these comparisons are by no means conclusive, the differences in energy values do not appear to be great. For the method presented below, it is assumed that the error introduced by using duration curves constructed with monthly averages is small.

A. METHOD DESCRIPTION

The initial data required for this method is almost identical to that required for the Idaho natural stream analysis. The method requires that the reaches of interest be delineated following natural divides. Superposition and planimetry of normal annual precipitation lines is necessary to estimate the total yearly precipitation input to the basin. A summation table as shown in Table 4-3 is also required. Runoff coefficients (K-values) should be estimated as if the basin were natural. Historical records of stream gages prior to and downstream of the regulating structure should be used to estimate these K-values. In other words, the data preparation should be accomplished as if the reservoir or other structure were not present.

In order to apply this method, average monthly outflows from the reservoir(s) must initially be known. These outflows can often be obtained from (1) the agencies which regulate the dams or (2) stream gages immediately downstream of the reservoir. Use of the latter assumes that no changes in regulation have occurred over the period of record used. The reasons for using average monthly flows are twofold. (1) Reservoir releases are often given in terms of average monthly discharges and (2) The use of average monthly flows allows lag-time to be ignored. There also must exist a stream gage within the immediate area which reflects only natural flows and has a reasonably long record. This historical record of natural streamflows is used as an indicator to the response of natural tributary basins below the regulatory structure.

PROCEDURE

In general, the procedure consists of starting with the known reservoir outflows, and adding increments of flow to these as you proceed downstream. These increments of flow can be determined in two ways. One consists of using the NAP-volumes as previously determined and the second uses actual gage records if they are available. For instance, if a tributary is gaged at its mouth, then these gaged flows are added to the estimated main stream flows at the point of confluence. Ungaged natural inflows are determined as follows.

1. Select a gaging station (representative gage) within the basin of interest, the record of which you feel would substantially reflect or be indicative of the response of

natural tributaries to the regulated stream.

2. Using this record, determine the total volume of flow which has passed the gage during the entire period of record. Also determine the portion of the total flow which occurred in each month of the record. Generate a record of ratios of monthly flow volume to total flow volume. Note that this is simply a normalization of the gage record.

3. Assume that the inflow due to tributaries within a reach is distributed in the same fashion as the record of ratios (comparison gage). The total natural inflow for a particular reach can be found by superposition of average precipitation lines and planimetry, ie.

$$\text{TOTAL INFLOW} = N(K1AP1-K2AP2) \qquad (5\text{-}1)$$

where,

N = number of years of record of the comparison gage.

K1(AP1) = (cfs-days) Average annual runoff at the downstream boundary of the reach.

K2(AP2) = (cfs-days) Average annual runoff at the upstream boundary of the reach.

The distribution of this flow volume is accomplished by multiplying the ratios from step 2 by this total inflow.

4. The distributed flows are then added to the regulated monthly flows to obtain a combined flow record at the point for which the total inflow was determined. Using this combined record, a duration curve can be constructed for the

point.

5. Continue to the next downstream reach adding incremental flows to the previous combined flow record. It is best to continue downstream and check the resulting duration curves against the actual curve of some gage record which reflects the historical combination of natural and regulated flows.

It should be kept in mind that the objective is in predicting the shape and magnitude of the constructed duration curves not in predicting monthly flows. If volumes of the predicted and actual curves are not close, some adjustment may be necessary in the K-values. These adjustments must be kept within reason and might require logical justification. It is possible for K-values to exceed unity. This could happen for example in areas where ground water is entering the basin from another area, ie. the precipitation input is not the only input to the basin. The shape of the curve may be adjusted by using a different comparison gage or even a weighted average of several representative gages. This is somewhat of a regionalization approach. Once the adjustments have been made so that the predicted curve is similar to the curve from the downstream gage, it is assumed that all intermediate curves are representative of what is actually occurring.

Note that this procedure combines the shape of a natural curve with a regulated curve and as you proceed downstream with sufficient natural inflows, the effect of the regulated curve should be dampened and a more natural shape should take precedence.

It also should be noted that the comparison gage and outflows from the reservoirs must have a substantial overlap in time period. It is also desirable to use only the portion of the records which overlap the period from which the NAP maps have been generated. This however, is sometimes difficult to do and one must assume that the input reasonably reflects other periods of time as well.

In applying this method, it is most convenient to use a computer program consisting only of subroutines. In this way the program is general and can be set up for various circumstances without a large number of changes. A listing of this program and a users manual can be obtained from the Idaho Water Resources Research Institute at the University of Idaho.

CHAPTER 6 APPLICATION OF REGULATED STREAM TECHNIQUE

In order to illustrate the use of the procedure outlined in Chapter 5, the method was applied to three different basins. First the method was applied to a simple case, that of generating curves for reaches lying below regulated Priest Lake in the Priest River Basin. Second, to illustrate its use in a natural flowing basin, the method was applied to the portion of the Clearwater River Basin above the influence of Dworshak dam. Finally the method was applied to the Payette River where more than one reservoir has an effect on the flow.

A. PRIEST RIVER

Following the procedure outlined in Chapter 5, the river was subdivided into reaches as displayed in Figure 6-1. Normal annual precipitation lines were superimposed on the basin and the area planimetered to obtain the average annual input to each reach. Runoff coefficients (K-values) were assigned to each reach as if Priest Lake dam were not present, ie. as if no regulation existed. Such values can be determined at the gaged points by using the period of record prior to the development of the regulating structure. If no prior record exists, estimates of K-values might be assigned to the reaches by using known K-values from another basin with similar characteristics affecting the precipitation and runoff. For those reaches which have natural flows, the duration curves are estimated from an analysis similar to those presented in Chapter 3.

Using the assigned K-values, average annual contribution to the main stem discharge for each reach, was determined as shown in the following table.

TABLE 6-1. Determination of Average Annual Reach Contribution for the Priest River Below Priest Lake.

REACH	AP CFS-DAYS	K	(K)X(AP) CFS-DAYS	CONTRIBUTION CFS-DAYS
USB-G	667823	0.65	434085	--
DSB-G	711898	0.63	448496	14411
DSB-D	824790	0.60	494874	46378
DSB-B	959843	0.58	556709	61835
DSB-A	1054376	0.55	579907	23198

Note: USB = Upstream Reach Boundary
DSB = Downstream Reach Boundary

Referring to the schematic in Figure 6-1, three stream gages exist on the river below Priest Lake. They are (1) 12.3930.00, Priest Lake at Outlet, (2) 12.3940.00, Priest

River near Coolin and (3) 12.3950.00, Priest River near Priest River. Adjusted average monthly flows (1974 Level of Development) for each of these gaged points was supplied by the Idaho Department of Water Resources (IDWR). The unadjusted historical record of gage 12.3950.00 prior to the development of Priest Lake Dam (August 1950), period 1930 to 1950, was used to indicate the response of the natural flows from the contributing reaches. This period of record also overlaps the period of 1930 to 1957, used in developing the NAP map for the area.

PROCEDURE

STEP 1. The period 1930 to 1950 is a twenty one year span, hence "N" in equation 5-1 is 21 and the values given in Table 6-1, column 5 were multiplied by 21 to estimate the total runoff volume to be distributed in the same way that the distribution of historical flows occurred in the representative gage record.

STEP 2. The synthetic record for the downstream boundary of reach G was determined by adding the distributed volume of contribution for the reach to the outflows from Priest Lake. These outflows were obtained from the Idaho Department of Water Resources (IDWR). This record was then used to compute the synthetic duration curve shown in Figure 6-2. This synthetic curve should be approximately the same as that for gage 12.3940.00.

STEP 3. The distributed flows from reach D were summed to the synthetic record of reach G to obtain a synthetic record and duration curve for a point at the downstream boundary of reach D.

STEP 4. This same procedure of distributing flows and summing to the upstream record was continued for reaches B and A. The curve developed for the downstream boundary of reach B should be comparable to that from gage 12.3950.00.

RESULTS

The synthetic duration curves for each reach are plotted in Figure 6-2. Visual and tabulated comparisons of Observed versus predicted values for reach G vs. gage 12.3940.00 and reach B vs. gage 12.3950.00 are shown in Figures 6-3, 6-4 and Table 6-2. Adjustments in the predicted curves can be made by changing predicted K-values and/or in changing the representative gage record selection. It should be kept in mind that the use of these curves is for the computation of the potential energy. Table 6-3 shows the percent difference in energy values for the predicted and observed points. A comparative head of one foot and efficiency of 100% were used in these calculations.

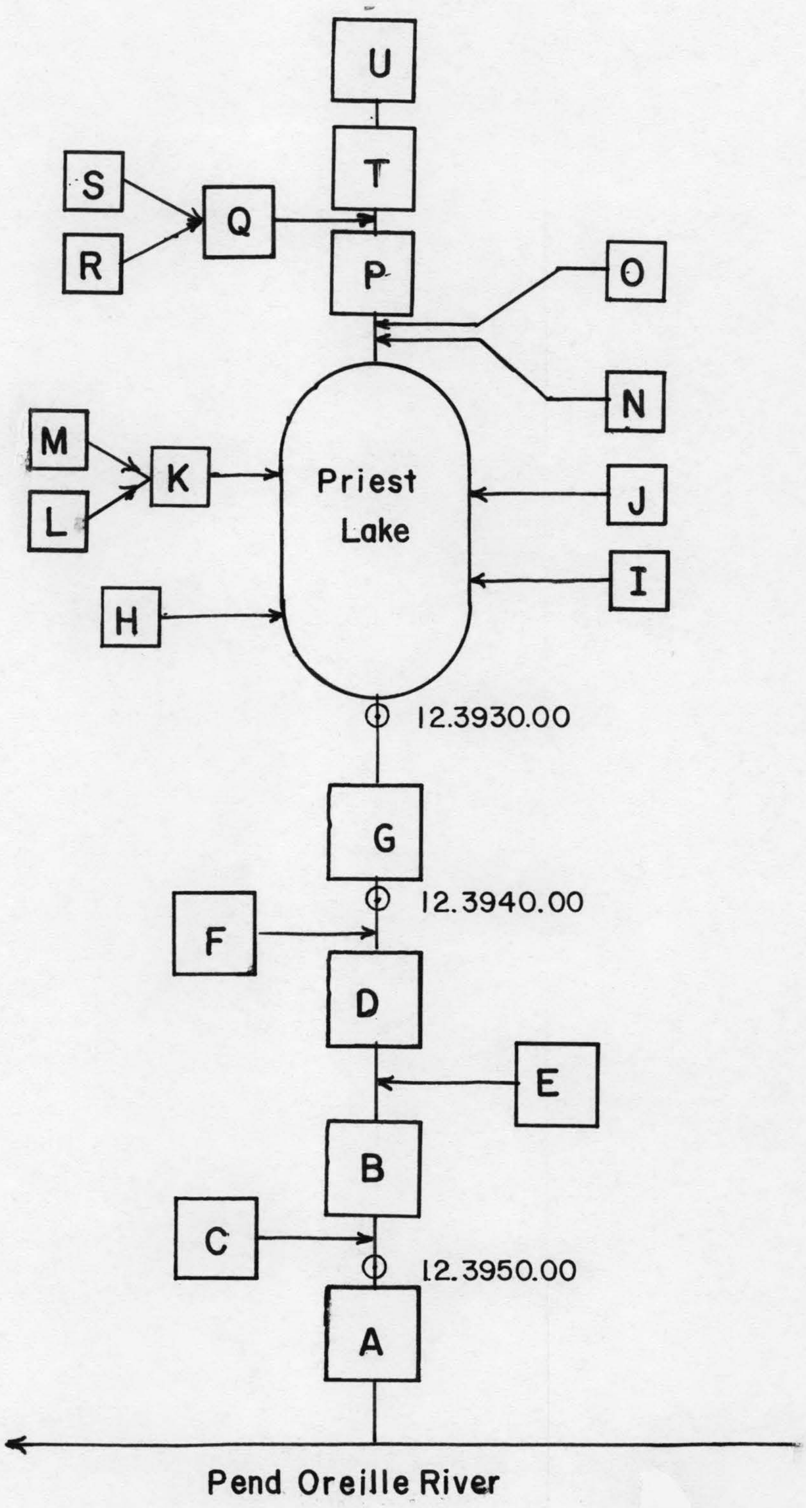

Figure 6-1. Schematic Diagram of Priest River Reaches.

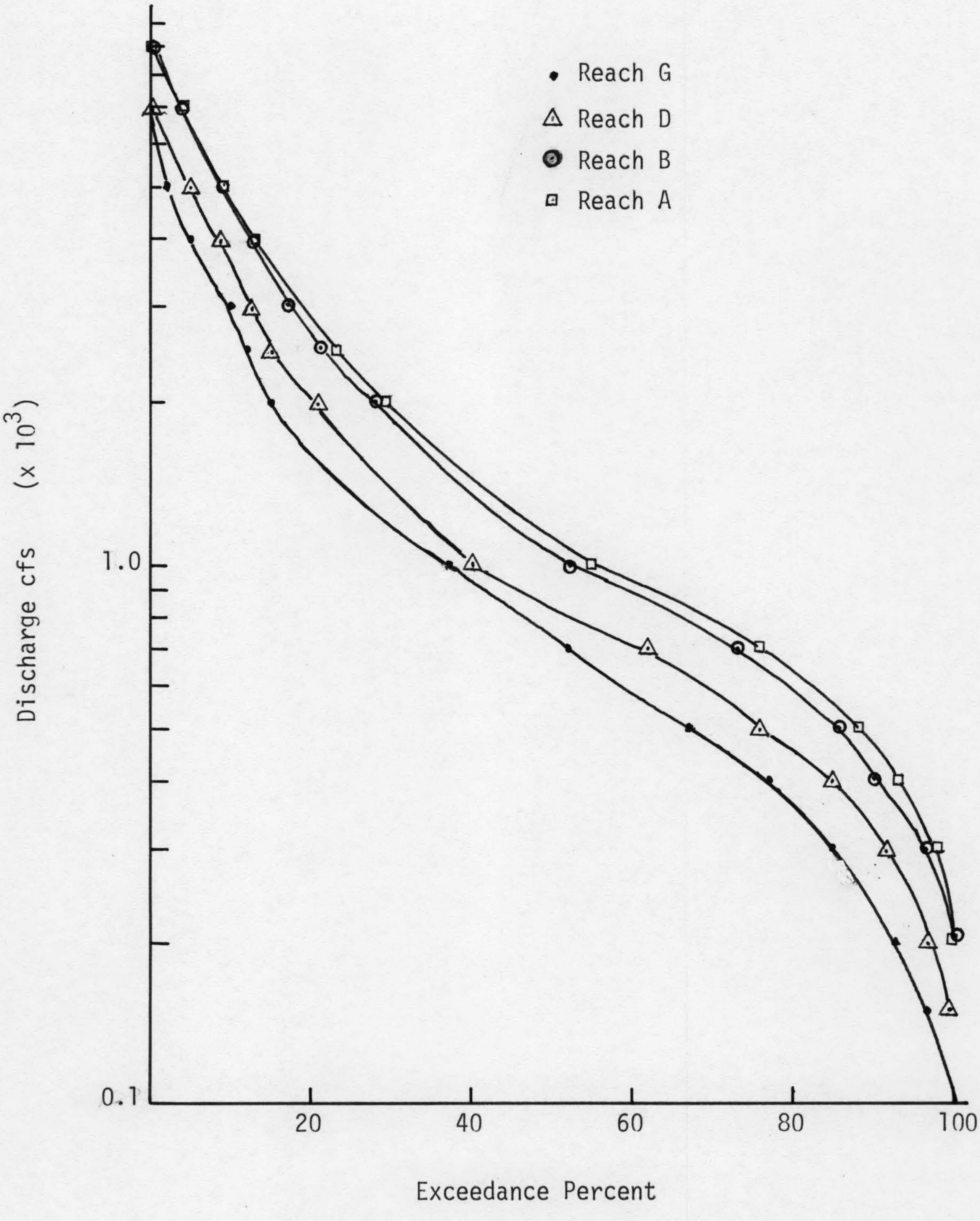

Figure 6-2. Synthetic Duration Curves Generated for Reaches Below Priest Lake

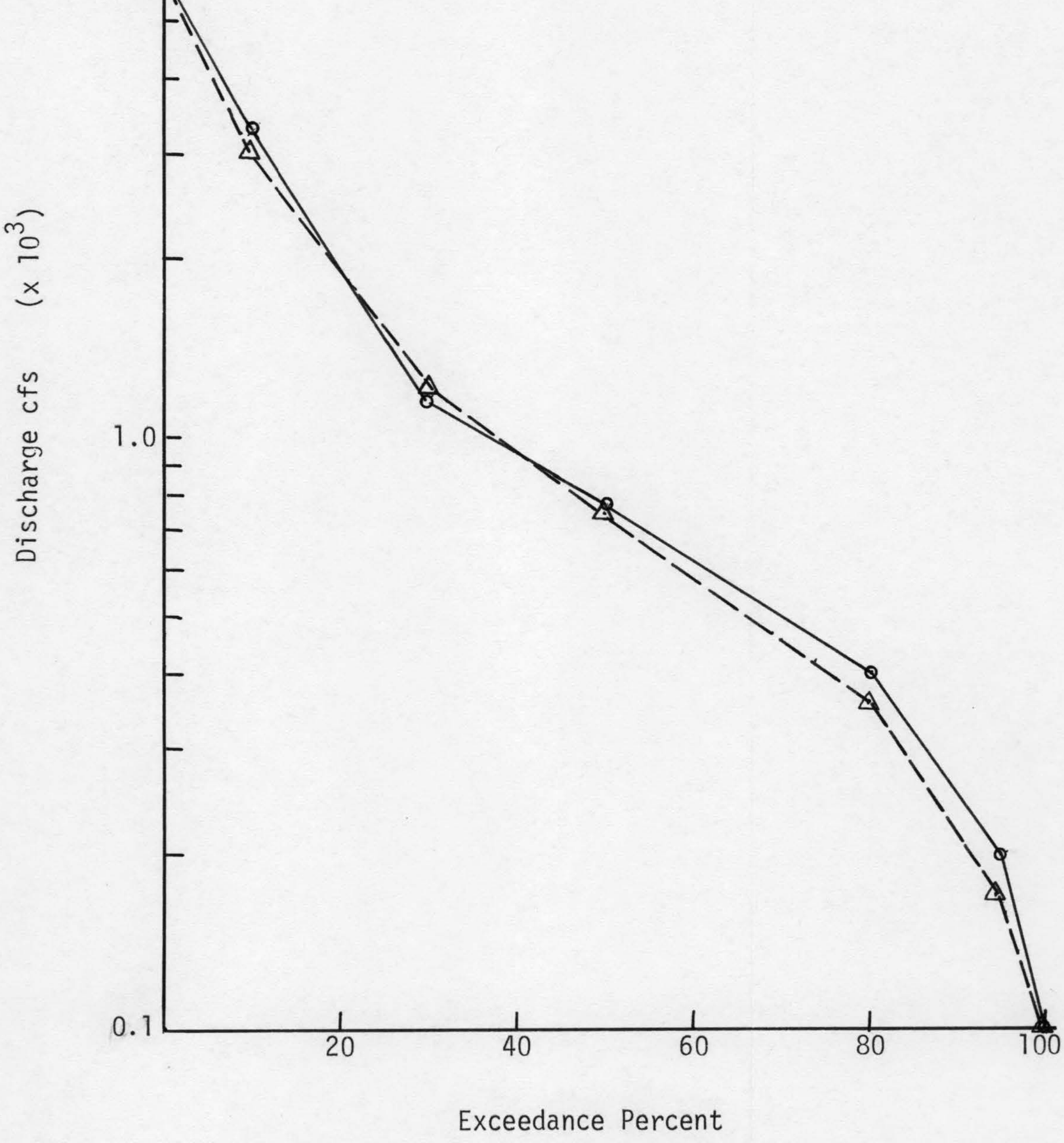

Figure 6-3. Comparison of Synthetic and Actual Duration Curves for the Priest River at Coolin Stream Gage, 12.3940.00

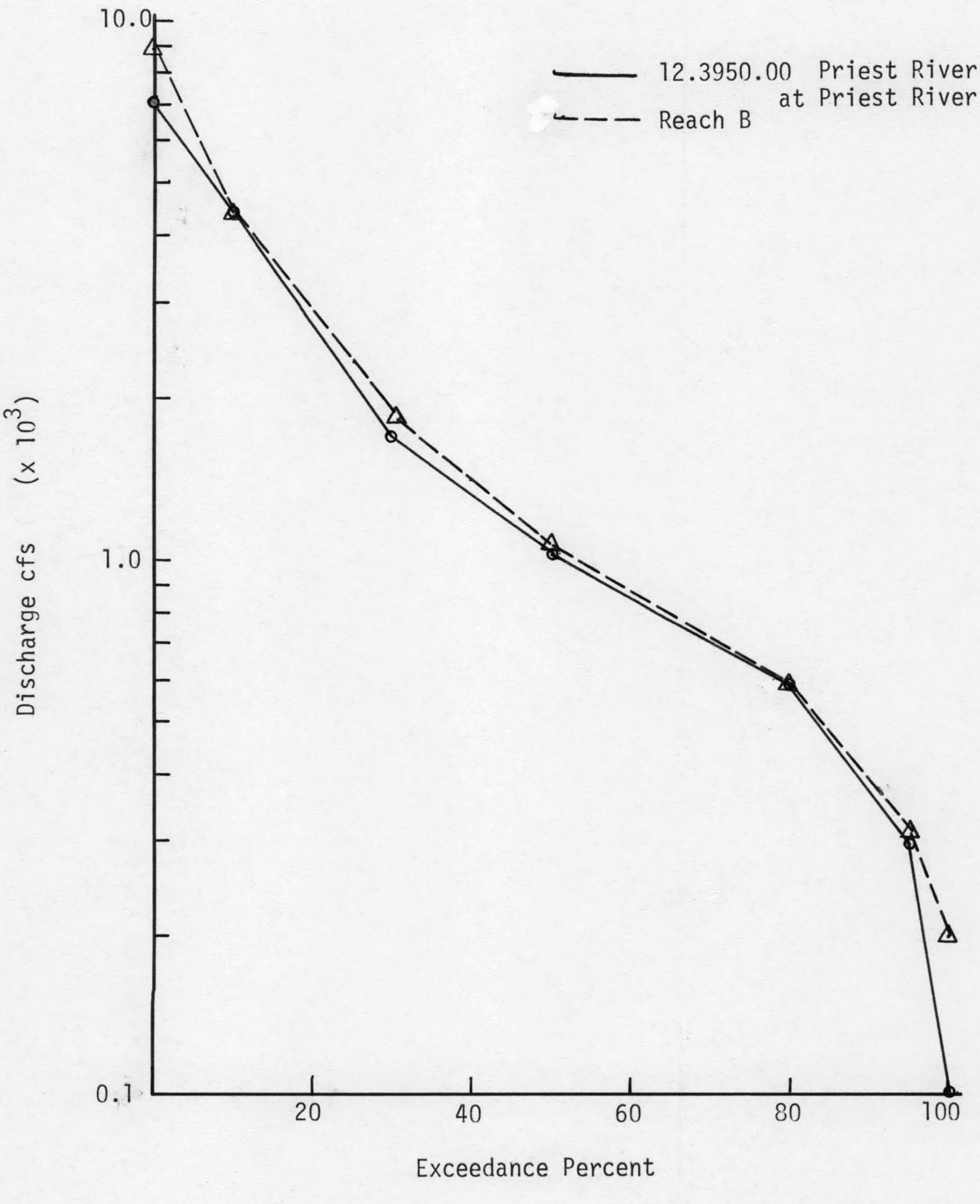

Figure 6-4. Comparison of Synthetic and Actual Duration Curves for the Priest River at Priest River Stream Gage 12.3950.00.

Table 6-2. Discharge (cfs) and Corresponding Differences Calculated from Observed and Synthetic Duration Curves for Priest River.

Gage	Q_{10}	Q_{30}	Q_{50}	Q_{80}	Q_{95}
Priest River	4,400	1,700	1,010	580	300
Reach B	4,500	1,850	1,050	580	320
% Diff.	2.3	8.8	4.0	0	6.7
Coolin	3,300	1,150	760	400	200
Reach G	3,000	1,200	740	360	170
% Diff.	9.1	4.3	2.6	10.0	15.0

Table 6-3. Energy Values (mwh) and Corresponding Differences Calculated from Observed and Synthetic Duration Curves for Priest River.

Gage	E_{10}	E_{30}	E_{50}	E_{80}	E_{95}
Priest River	1,214	813	608	401	219
Reach B	1,262	869	631	404	235
% Diff.	3.95	6.89	3.78	0.75	7.31
Coolin	885	566	450	277	147
Reach G	836	568	432	248	125
% Diff.	5.54	0.35	4.0	10.5	15.0

B. CLEARWATER RIVER

Application of the method of Chapter 5 to an unregulated stream such as the Clearwater is essentially identical to the Washington Method except that normalization is applied to the record rather than to selected points of the duration curve. The method maintains the shape of the duration curve which is characteristic of the representative or distributive stream gage record.

The previously described method requires initial starting points. These are shown on the flow diagram of Figure 6-5, as the gages 13.3370.00, 13.3365.00 and 13.3375.00. This diagram illustrates the reaches for which flows were generated by the program in the application process. These steps are described below.

STEP 1. Starting with the stream flow record of gage 13.3375.00, average monthly flows were generated for nine reaches downstream of gage 13.3375.00 on the South Fork. The inflow volumes were distributed in the same manner as the recorded distribution of gage 13.3375.00. Using these synthetic records a flow duration curve was computed for each generation point. Note: Since the period of record of gage 13.3375.00 is 1945 to 1974, the generated records were for the same period.

STEP 2. Starting with the streamflow record of gage 13.3365.00, average monthly streamflows and a corresponding flow duration curve were generated for one reach downstream of gage 13.3365.00, ie. for the mouth of the Selway River. The period of record was 1930 to 1976. The inflow volumes were distributed as the recorded distribution of gage 13.3365.00.

STEP 3. The average monthly flows from gage 13.3370.00 (Lochsa River at mouth) were added to the previously generated flows at the mouth of the Selway River (from step 2). The overlapping period of record was 1930 to 1976.

STEP 4. The distributive ratios from gages 13.3370.00 and 13.3365.00 were averaged and the inflow volumes from reaches E and D were distributed over these averages. The flows were then summed to the record of step 3 and flow duration curves were computed based on the synthetic generations. The overlapping period of record was 1930 to 1976.

STEP 5. The generated flows from the mouth of the South Fork (step 1) were combined with the generated flows from the Middle Fork at a point just above the South Fork confluence (step 4). The overlapping period of record was 1945 to 1974. Flows for two points downstream of the South Fork confluence were generated based on an average of ratios from gages 13.3370.00, 13.3375.00 and 13.3365.00. Flow duration curves were then computed from these average monthly generated flows.

Two stream gages were left out of the analysis so that the method could be checked. These gages are 13.3380.00 and

13.3390.00. Their locations can be seen on the flow diagram in Figure 6-5. In order to check for accuracy and to see whether or not any adjustments must be made, the predicted flow duration curves (monthly averages) were compared against the daily flow duration curves of gages 13.3380.00 and 13.3390.00 for the same period of record. The discharge values corresponding to the 0, 10, 30, 50, 80, 95 and 100 exceedance percents are plotted in Figures 6-6 and 6-7. These specific discharge and calculated energy values with percent differences are displayed in Tables 6-4 and 6-5 respectively.

TABLE 6-4. Discharge Values (cfs) and Corresponding Differences Calculated from Actual and Synthetic Duration Curves for the Clearwater River.

GAGE	Q10	Q30	Q50	Q80	Q95
13.3380.00	2650	700	325	180	115
predicted	2648	651	318	163	106
% diff	0.075	4.1	2.2	9.4	7.8
13.3390.00	23500	7000	3125	1600	1035
predicted	27614	7081	3798	1775	1277
% diff	17.5	1.2	21.5	10.9	23.4

TABLE 6-5. Energy Values (mwh) and Corresponding Differences Calculated from Actual and Synthetic Duration Curves for the Clearwater River.

GAGE	E10	E30	E50	E80	E95
13.3380.00	597	308	196	126	84
predicted	588	295	190	115	78
% diff	1.5	4.2	3.1	8.7	7.1
13.3390.00	5462	3012	1861	1125	758
predicted	6262	3214	2239	1263	939
% diff	14.6	6.7	20.3	12.3	23.9

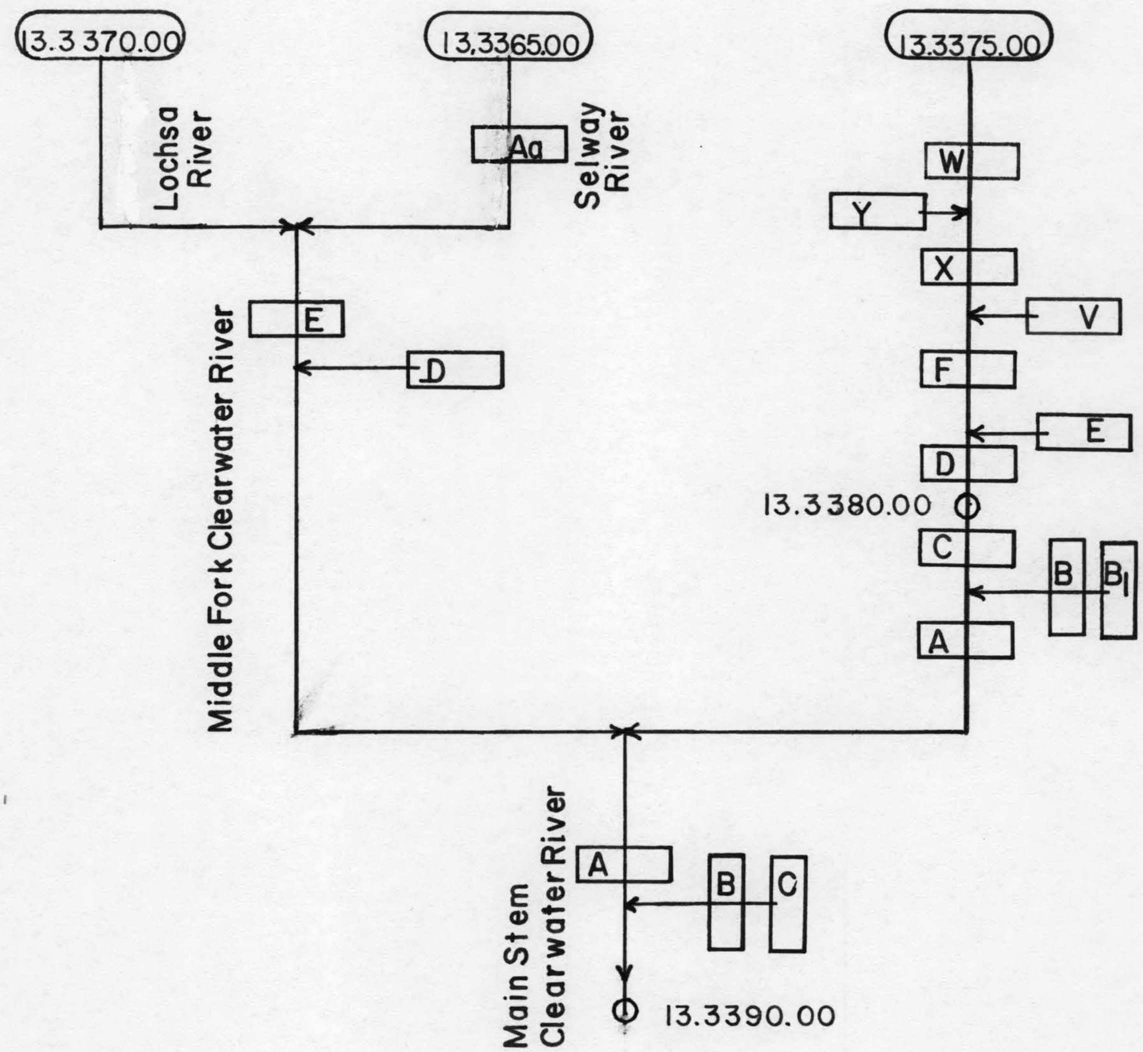

Figure 6-5. Schematic diagram of Reaches of the Clearwater River.

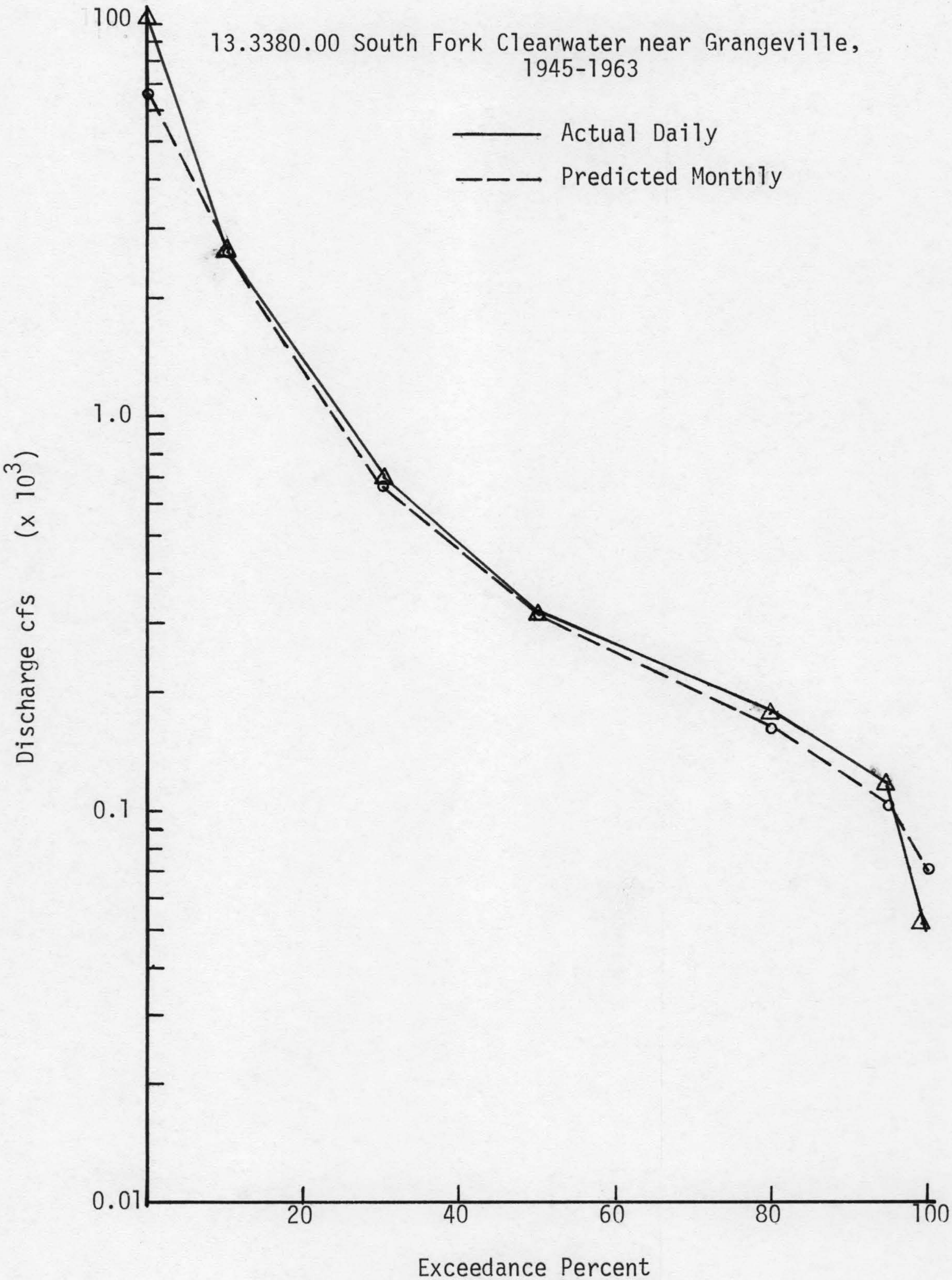

Figure 6-6. Comparison of Synthetic to Actual Duration Curves for the South Fork Clearwater near Grangeville Stream Gage, 13.3380.00

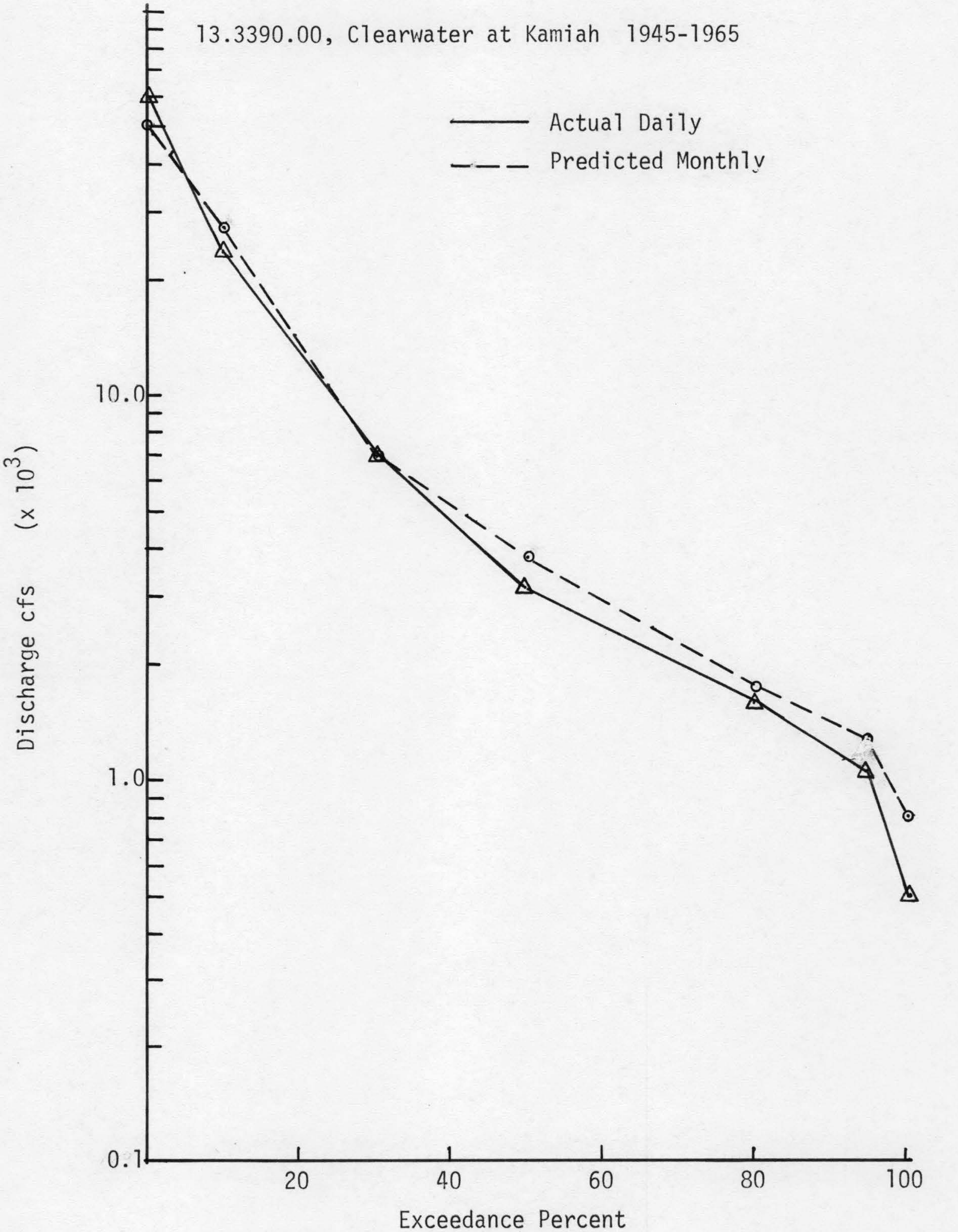

Figure 6-7. Comparison of Synthetic to Actual Duration Curves for the Clearwater at Kamiah Stream Gage, 13.3390.00

C. PAYETTE RIVER

The determination of duration curves for reaches of the Payette River required both of the previously described methods. The natural reaches such as those of the Middle Fork and South Fork above the Deadwood River confluence were analyzed using methods presented in Chapter 3. For reaches below the influence of Deadwood and Cascade Reservoirs the method of Chapter 5 was applied. A description of the method of Chapter 5 as applied to the Payette River is presented below.

DATA AND ASSUMPTIONS

The usable data available for analysis of the regulated portion of the Payette River consists of the following.

(1) Average monthly outflows from Cascade and Deadwood Reservoirs. Data were obtained from the Idaho Department of Water Resources. The period of record was from 1928 to 1975.

(2) U.S. Geological Survey-stream gage records.

- (a) Gage 13.2350.00, South Fork of the Payette River at Lowman, 1941 to 1974.
- (b) Gage 13.2380.00, Payette River near Banks, 1921 to 1973.
- (c) Gage 13.2475.00, Payette River at Horseshoe Bend, 1919 to 1974.

(3) Storage began in Deadwood Reservoir in November 1930 and Cascade Reservoir in November 1947.

(4) The period of record used in the development of the isohyetal map used in the analysis was 1930 to 1957.

The assumptions used in the following analysis are (1) that the level of development has not changed significantly since storage began in the above listed reservoirs, ie. the operations have not changed. (2) That the average precipitation values from the isohyetal map of the period 1930 to 1957 are the same as the averages for periods 1942 to 1974 and 1942 to 1960. (3) That the shape and magnitude of a duration curve constructed from the record of gage 13.2380.00 for the period of 1942 to 1973 is identical to one constructed for the period 1942 to 1974.

PROCEDURE

Refer to the schematic diagram in Figure 6-8 as the following steps of the analysis are discussed.

STEP 1. The stream gage 13.2350.00 located on the South Fork of the Payette River reflects natural flows for the period of 1942 to 1974. Hence it was selected to be the representative gage for the distribution of inflow volumes for reaches 2, 4, 6, 7, 8 and 9.

Beginning with the average monthly flows from gage 13.2350.00, the inflow volume from reach 4 was distributed and summed to these monthly averages to obtain a synthetic monthly average record for a point just above the confluence of Deadwood River. This synthetic record was used to compute a duration curve for that point.

STEP 2. The inflow volume from reach 2 for the 33 year period of 1942 to 1974 was distributed in the same manner as the record of gage 13.2350.00 and added to the corresponding outflows from Deadwood Reservoir. This created a synthetic record for a point at the mouth of the Deadwood River.

STEP 3. The two synthetic records of steps 1 and 2 were summed to obtain a synthetic record for a point just downstream of the confluence of the Deadwood River and the South Fork of the Payette River . (The hexagonal symbols shown in the schematic 5 and 15, imply a summing point while the squares represent reaches where inflow volumes occur.)

STEP 4. Using gage 13.2350.00 as the distributive or representative gage, the inflow volumes of reaches 6, 7, 8 and 9 were distributed and consecutively added to the synthetic record of step 3. For instance, the synthetic record at the downstream boundary of reach 7 would be the sum of the synthetic record from step 3, the distributed flows of reach 6 and the distributed flows of reach 7. Note that reach 8 is really a point of major tributary inflow, the Middle Fork of the Payette River.

STEP 5. This step is an example of data transfer from one basin to another. Since the South Fork of the Salmon River is similar to the North Fork of the Payette, it was felt that the natural stream flow record of gage 13.3105.00, the South Fork of the Salmon River at Knox might reasonably represent or be indicative of the distribution of the natural inflow volumes from reaches 11, 12, 13 and 14. The period of record of this gage is 1929 to 1960. Distributing these inflows and summing consecutively to the average monthly outflows from Cascade Reservoir created synthetic records and corresponding duration curves for each of the above listed reaches.

STEP 6. The sum of the synthetic record of reach 14 and reach 9 created the synthetic record to which the distributed inflows from reaches 16 and 20 were added. The period of record of these synthetic records is 1942 to 1960.

COMPARISON

As previously stated, it is best to check the method against some actual duration curve to determine if any adjustment in K-values or choice of representative gage record is necessary. In this case the synthetic duration curve for the downstream boundary of reach 9 (period 1942 to 1974) is approximately the same as the actual daily curve constructed from gage 13.2380.00 for the period 1942 to 1973 and no adjustment was attempted.

The values corresponding to the exceedance percents of 10, 30, 50, 80 and 95 are tabulated in Table 6-6 and plotted in Figure 6-9. Also the synthetic curve representing the downstream boundary of reach 16, period 1942 to 1960 should be comparable to the actual daily curve of gage 13.2475.00 for the same period. The values are tabulated in Table 6-6 along with the percent differences and plotted in Figure 6-10.

Once the curves are matched (within limits) it is assumed that all intermediate curves are representative. Since the concern here is with potential energy, the predicted and actual values along with percent differences are tabulated in Table 6-7.

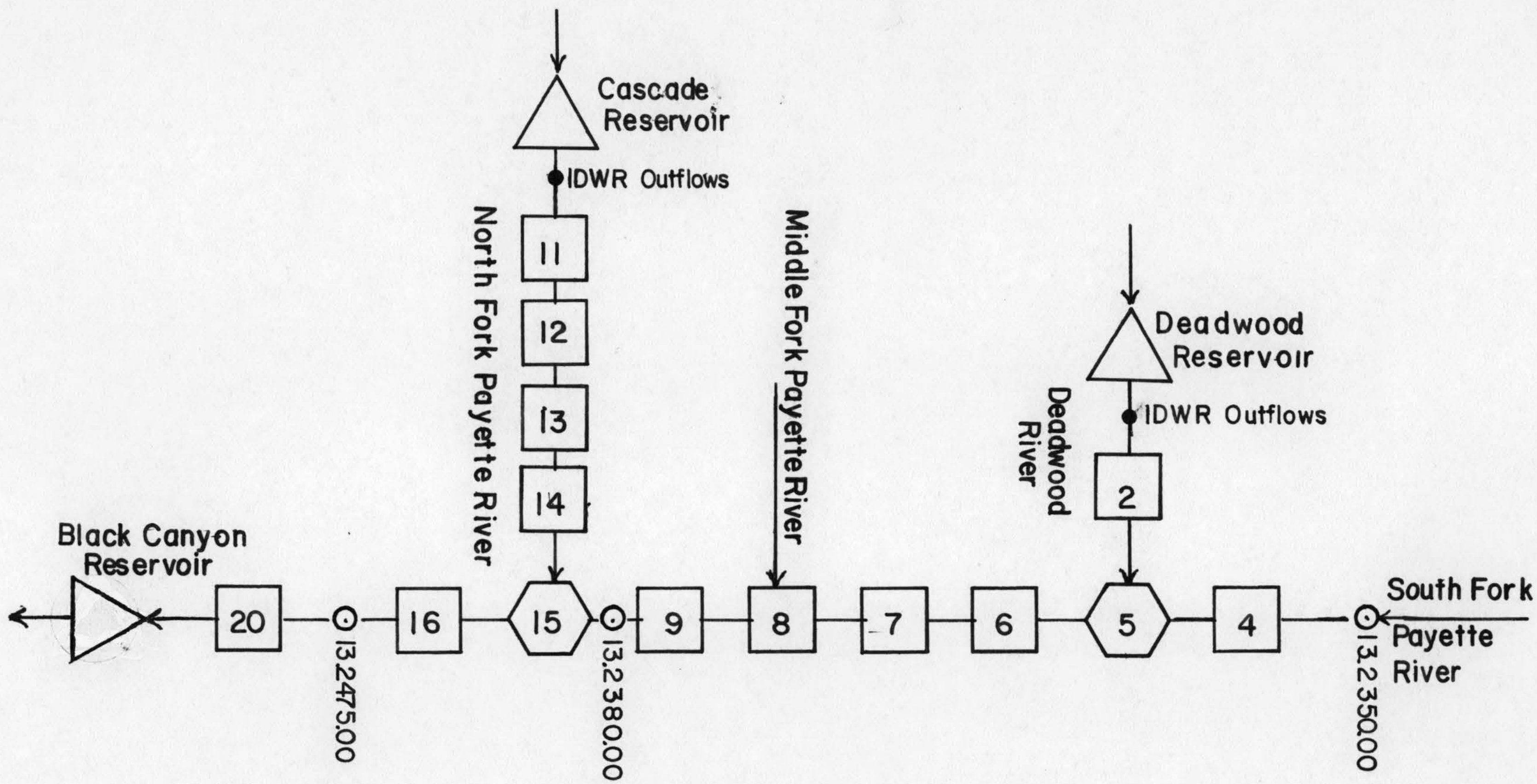

Figure 6-8. Schematic Diagram of Payette River Reaches.

Table 6-6. Predicted Versus Actual Discharge Values (cfs) for Gages on the Payette River.

Gage	Q_0	Q_{10}	Q_{30}	Q_{50}	Q_{80}	Q_{95}	Q_{100}
Actual[1]	10,000	4,800	2,000	1,200	640	520	400
Predicted	9,000	4,500	1,800	900	560	500	400
% Diff.	10	6.3	10.0	25.0	12.5	3.8	0
Actual[2]	20,000	8,800	3,600	2,300	1,200	780	500
Predicted	15,000	7,500	3,900	2,800	1,300	980	800
% Diff.	25.0	14.8	8.3	21.7	8.3	25.6	60

[1] Gage 13.2380.00, 1942 to 1974
[2] Gage 13.2475.00, 1942 to 1960

Table 6-7. Predicted Versus Actual Energy Values (mwh) for Gages on the Payette River.

Gage	E_{10}	E_{30}	E_{50}	E_{80}	E_{95}
Actual[1]	1,385	970	732	462	384
Predicted	1,241	840	572	408	369
% Diff.	10.4	13.4	21.9	11.7	3.9
Actual[2]	2,536	1,764	1,377	847	574
Predicted	2,517	1,983	1,656	932	724
% Diff.	0.70	12.4	20.3	10.0	26.1

[1] Gage 13.2380.00, 1942 to 1974
[2] Gage 13.2475.00, 1942-1960

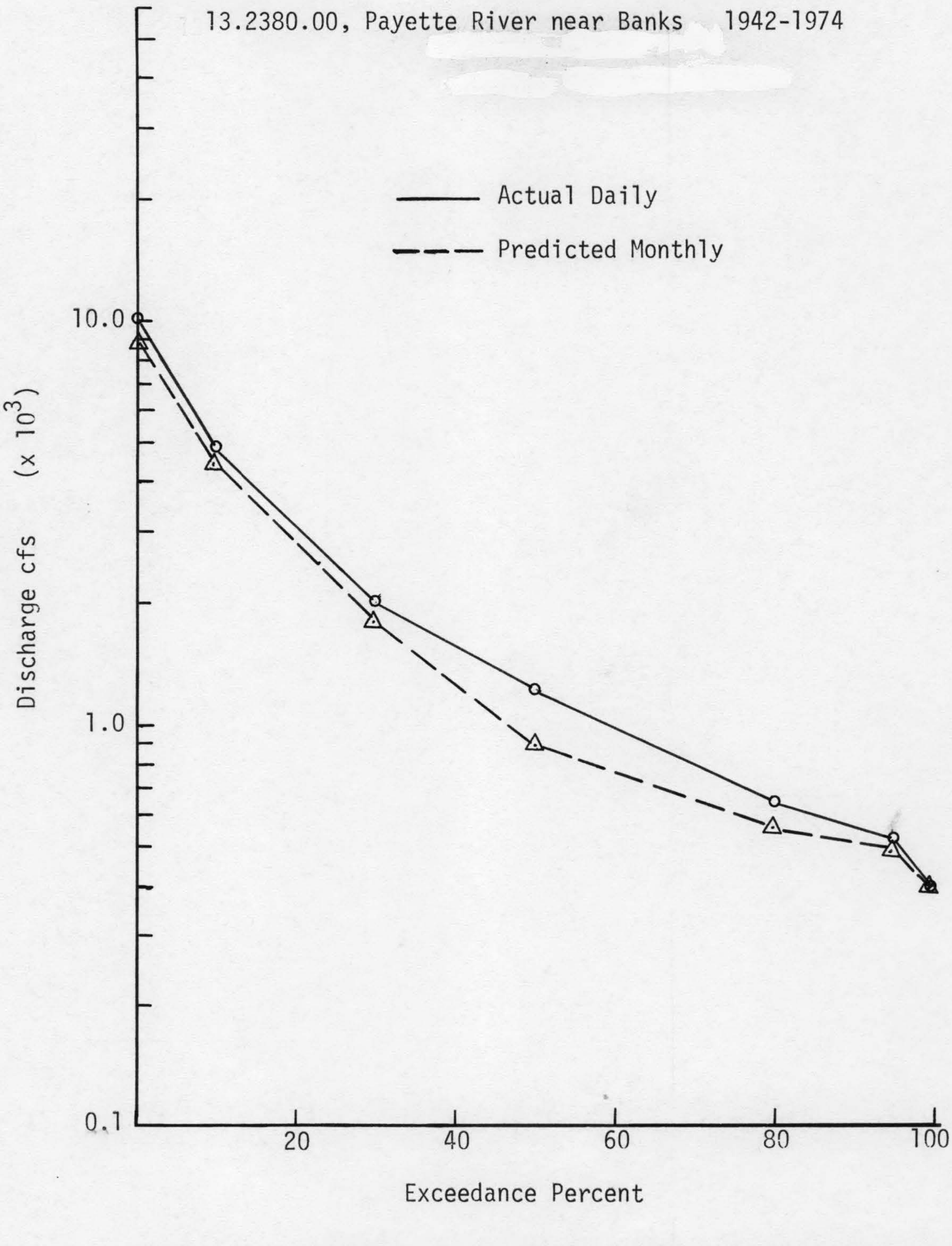

Figure 6-9. Comparison of Synthetic to Actual Duration Curves for the Payette River near Banks Stream gage, 13.2380.00

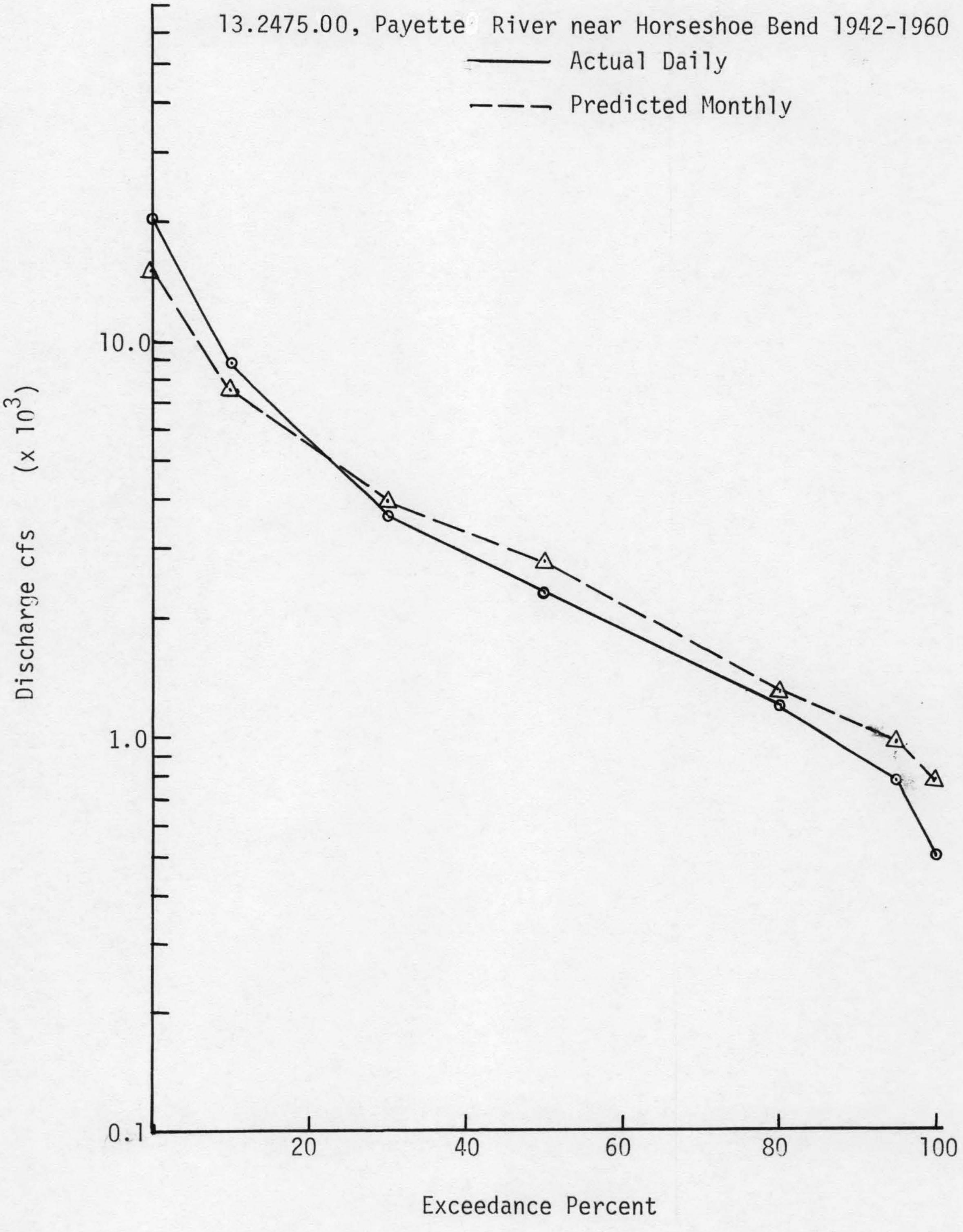

Figure 6-10. Comparison of Synthetic to Actual Duration Curves for the Payette River at Horseshoe Bend Stream gage, 13.2475.00

CHAPTER 7. SUMMARY AND CONCLUSIONS

With reference to the literature review of Chapter 2, not many references were found which directly related to the contract study methods by Heitz(10). The literature did indicate several methods which could be used in a similar manner, however most require a large and varied amount of data input. For a time limited hydroelectric energy survey, the data requirements must be minimal and yet the results must be representative. The method used to estimate ungaged streamflows should be dependent on the use to be made of the results.

The application and comparison of the results of the methods presented in Chapter 3 to the Clearwater River indicated that for point predictions the Idaho and Washington methods give better results than the Montana method. This is evidenced by Figures 4-30 through 4-32 and Tables 4-15 through 4-17. For the comparisons shown, the errors for point predictions using the Idaho and Washington methods appear to be somewhat less than the error using the Montana method. It should be noted, however, that part of the error shown may be due to the 10 year records of the gages against which the predictions are compared. The predictions are based upon gages with much longer records. Part of the error may also be due to the fact that the methods use adjusted K-values in the computation of the average annual runoff values whereas the gages reflect observed runoff for their particular period of record. The normal annual precipitation maps used, although they are some of the best available, may also be the source of some error in the results.

For the total energy prediction of an entire river basin (Table 4-18), no conclusions can readily be drawn as to the better method since the errors are roughly of the same magnitude.

With regard to the selection of K-values, the author supports the construction of a diagram as shown in Figure 4-19. This illustrates the variability of K-values in different areas of a basin. K-values as determined by the Washington method could give grossly over or underestimated power and energy values, especially for small tributaries to the main stream. K-values are not really determined by the Montana method, however, by regressing AAR against the AP product, the method suggests an increase in K-value with increase in AP product. This assumption certainly does not seem consistent with the K-values calculated at some of the gaged points (See Figure 4-19). The selection of K-values or the prediction of average annual runoff needs to be studied further. Perhaps the K-values can be related to such variables as drainage density, elevation, slope, aspect etc. to remove some of the judgement necessary in assignment of the values. This could be done with much more input data and a multiple correlation approach.

The method described in Chapter 5 and applied in Chapter 6, for estimating duration curves below regulating structures, appears to work well for the situations described. However, the method does not work well on rivers where significant diversions occur and no diversion data are available. Also point sources of large ground water inflows can induce large errors in some reaches if knowledge of them is not known and K-values adjusted accordingly. In general the method should only be applied in situations where a reliable downstream gage exists so that checks and adjustments can be made. The method is quite sensitive to changes in K-values and hence selection and adjustment of these must be done with much care. One possible adjustment not considered in this presentation is a procedure for adjusting the values computed from monthly averages, toward those computed from daily values. One way this might be accomplished would be to compare the actual curves constucted with daily values to the predicted curves constructed with monthly values. For selected points on the curves, a set of ratios of values from the observed to the predicted could be calculated. These ratios could be multiplied by the corresponding values of the other predicted curves in the basin. The result would be a duration curve constructed from average monthly values adjusted toward the shape of a curve constructed from daily values.

In applying the method of Chapters 5 and 6 to basins where diversion data is available, a possible adjustment in the method might include more direct accounting for some of the return flows. This is already done to some degree by the adjustment of the K-values, however the separation of return flow from natural flow might result in less error differences between observed and predicted duration curve and corresponding energy values.

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