Research Technical Completion Report Project A-068-IDA

Assessment of the Usefulness of Hydrologic Data for Hydropower Feasibility Analysis

by

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Idaho Water and Energy Resources Research Institute
University of Idaho
Moscow, Idaho
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FOREWORD

The Idaho Water and Energy Resources Research Institute has provided administrative coordination for this study and organized the team that conducted the research. It is the Institute policy to make available the results of significant research related to the water and energy resources within Idaho and for possible application in a national and international realm. The Institute neither endorses nor rejects the findings of the authors. In this study a strong effort has been made to utilize earlier findings of research in the field of hydropower engineering and to determine limitations that must be accounted for in using data drawn from hydrologic measurements that are frequently very limited in geographic coverage and often of limited historical length. The Institute does encourage careful consideration of techniques recently developed for extending the usefulness of limited hydrologic measurements.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the Office of Water Research and Technology of the U.S. Department of Interior through the allotment program under Project A-068, short-titled WR-Hydrologic Data. The project was initiated under the supervision of Dr. John S. Gladwell as Director of the Institute and completed under the direction of D.W. Fitzsimmons as Acting Associate Director of the Institute. Bruce Prud'homme assisted in organizing and collecting portions of the hydrologic data. The staff of the Intermountain Forest and Range Experiment Station of the U.S. Forest assisted in providing some of the hydrologic data for small watershed analysis made in the study.

Portions of the work done in the study were efforts of L.F. Heitz and resulted in a separate Ph.D. dissertation. Students who assisted in the study were Duane Truitt, Kojo Kpordze, and Don Schutt.

Special thanks must go to the administrative and secretarial staff of Linda Fulton, Gloria Hall, Judy Kidd and Lorraine Frazier for their strong supportive role during the entire progress of the research.

ABSTRACT

This report has defined methods of extrapolating hydrologic data for use in hydropower feasibility studies. Two large drainage basins in Idaho were studied and the measured flow data from various streams in those basins were used to develop parametric duration curves similar to those developed by Heitz at the University of Idaho in earlier studies.

Comparison studies made in the report defined the general limits of curve extrapolation and indicated the required flow data input for making acceptable flow duration analysis. In addition, the economic consequences of using different predicted values of flow duration were demonstrated.

INTRODUCTION

Recent interest in developing hydropower to meet energy needs has come about due to the rising cost of fuel for conventional stream power plants. The fact that hydropower is a renewable energy source and requires no depletion of the natural resource has made it attractive to look at the feasibility of many hydropower sites that were previously uneconomical to develop. On a previous project, OWRT Project A-057-IDA, the authors studied undeveloped hydropower as a potential energy source in Idaho (Warnick and Heitz, 1979 and Emmert, 1979). Extension of that project to a study of hydropower potential of the Pacific Northwest was sponsored by the U.S. Department of Energy, Gladwell, Heitz, Warnick et al. 1979, Heitz, Warnick and Gladwell, 1980 and Heitz (1981). These revealed a considerable hydropower potential was available for possible development. The work of those projects developed several new techniques for analysing the hydrologic aspects of hydropower. Most important was the development of a method of calculating the magnitude of the flow duration at ungaged locations along the stream using parametric flow duration curves relating flow in the stream at a particular excedance percentage to the average flow of the stream.

A parallel study by U.S. Army Corps fo Engineers known as the National Hydroelectric Power Study (U.S. Army Corps of Engineers, 1979) carried out a complete inventory of the undeveloped hydropower potential of the entire country. That study used a very simplified estimation of the flow of streams to arrive at the estimate of potential energy available. These various studies revealed that on small ungaged streams and at places where there is a scarcity of stream gaging it is difficult to determine the energy potential of various streams. The need was pointed out for better assessment of what variation in flow data can be expected on streams having hydropower potential, and what processes should be used to extend flow data. Particularly needed was information on the applicability of a parametric curve technique for estimating flow duration curves at locations where the streams were very small and there were limited flow records on which to base estimates. A need was to determine the consequences in feasibility studies of using the parameteric duration approach if very limited number of stream gage records were available.

The previous studies of the authors revealed that Idaho streams and record situations presented a good opportunity to study the aforementioned needs. The U.S. Forest Service has for several years been gaging very small streams within the larger Clearwater River drainage basin. Extensive research has already been done on developing the parametric flow duration approach for flow estimation on the Clearwater basin. The records of the small streams were not available in earlier studies so the use of them to study estimation of flows on small streams compared with estimation on larger streams was a unique opportunity. Likewise, the Salmon River is a very large drainage basin that is essentially unregulated and has very great variation in runoff per unit area of basin area that must be accounted for in making evaluations of hydroelectric energy potential. The research conducted on this project centered on analysis of data for these two specific geographic areas in Idaho. Later sections in the report gives details about the drainage basins used in the study.

In developing the studies on hydropower potential an extensive group of computers programs were developed. Heitz on this project refined those programs and as part of his Ph.D. dissertation (Heitz, 1981) documented the programs and made them uniquely available to analyze the problems of this project. Because those programs are lengthy and of unique computer format, that material is published separately from this completion report, yet it forms a part of the results of this study.

The U.S. Department of Energy, through its program at the Idaho National Engineering Laboratory has been charged with evaluating feasibility studies of various consulting firms on the loan program of the Federal government. In doing this a computer program routine has been developed known as Hydropower Computerized Reconnaissance (HCR) Package (Broadus, 1981). This has a set of routines designed to make preliminary engineering and economic evaluation of hydropower at existing dams that are not presently producing power. Availability of this computer package has made it possible to do certain economic analyses that assess the impact of using hydrologic estimates from procedures developed in previous research and treating new data generated under this project.

PURPOSE AND OBJECTIVES

The purpose of this research has been to extend the usefulness of limited hydrologic data in making analyses for the study of hydroelectric resource potential and the study of feasibility of hydropower developments. The specific objections were: (1) to seek methodologies for the estimation of stream flow data for use in hydroelectric studies where measured data are very limited and of considerable geographic variation, (2) to seek methods for extension of flow data to make useful estimates of energy available and give an indication as to how much gaging is necessary to arrive at satisfactory estimates, and (3) to demonstrate the significance of variation in accuracy of flow estimates with respect to the economic viabiity of hydroelectric projects in selected areas. The ultimate goal of the research is to make the findings available in a practical way to engineers and scientists working with hydrologic analysis for hydropower developments.

SMALL BASIN EXTRAPOLATION

Earlier studies by Heitz, et al. (1980) had dealt with rather large drainage basins and the parametric flow duration curves that were developed had limited data from drainage basins with areas less than 100 square miles. Yet, there is a tendency to extrapolate the parametric flow duration curves down in the lower realms of average flow. Figure 1 shows a typical parametric flow duration curve wherein is marked the area where little is known and for which extrapolation might be desired.

To understand the behavior of parametric flow duration curves in this realm of small average discharge and small contributing drainage area, data were needed from very small watersheds. Fortunately the U.S. Forest Service has established an experimental watershed study known as the Horse Creek Experimental Watershed. The Horse Creek drainage is an unregulated stream system in the Clearwater River basin of Idaho. Figure 2 gives a general map of the relative location of the Horse Creek drainage which is a tributary to Meadow Creek, and Figure 3 gives more detail of the individual drainages and shows the location of the stream gages. Flow data for this basin are available for the period 1974 to 1979 from which it is possible to make studies of parametric flow duration in a more detailed way.

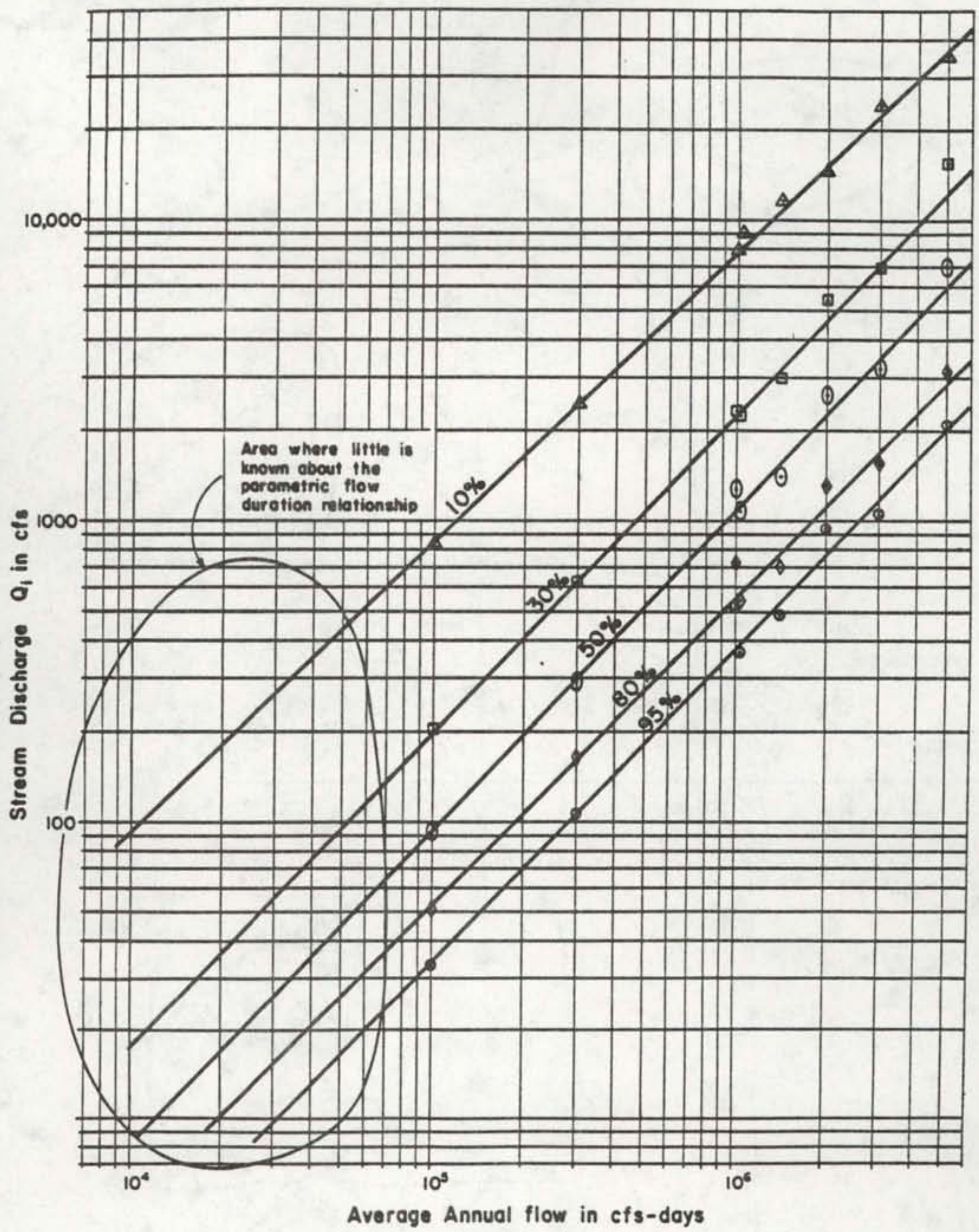

Figure 1. Typical regression lines for parametric flow duration curves (taken from Clearwater River studies by Heitz)

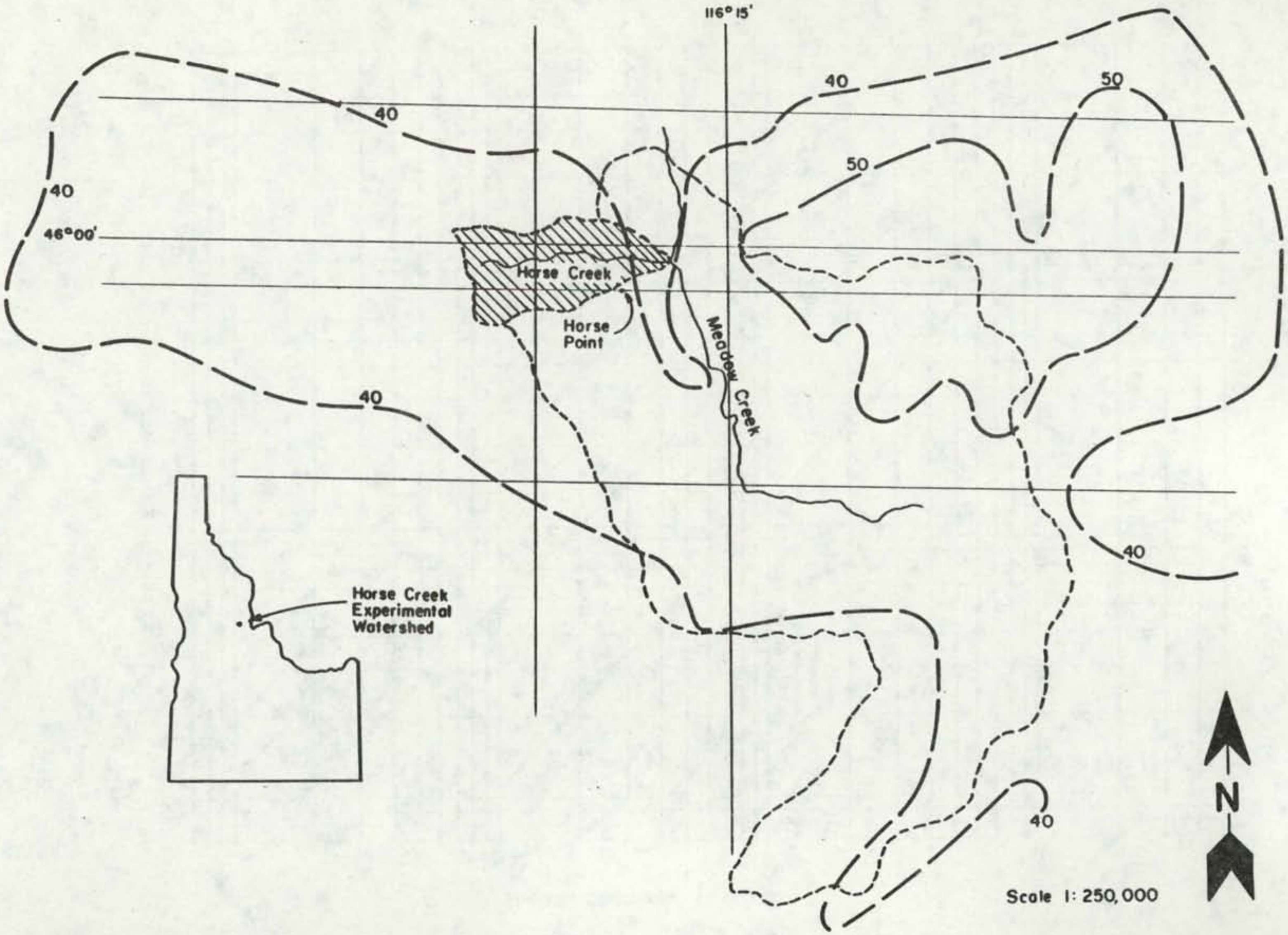

Figure 2. General location map of Horse Creek

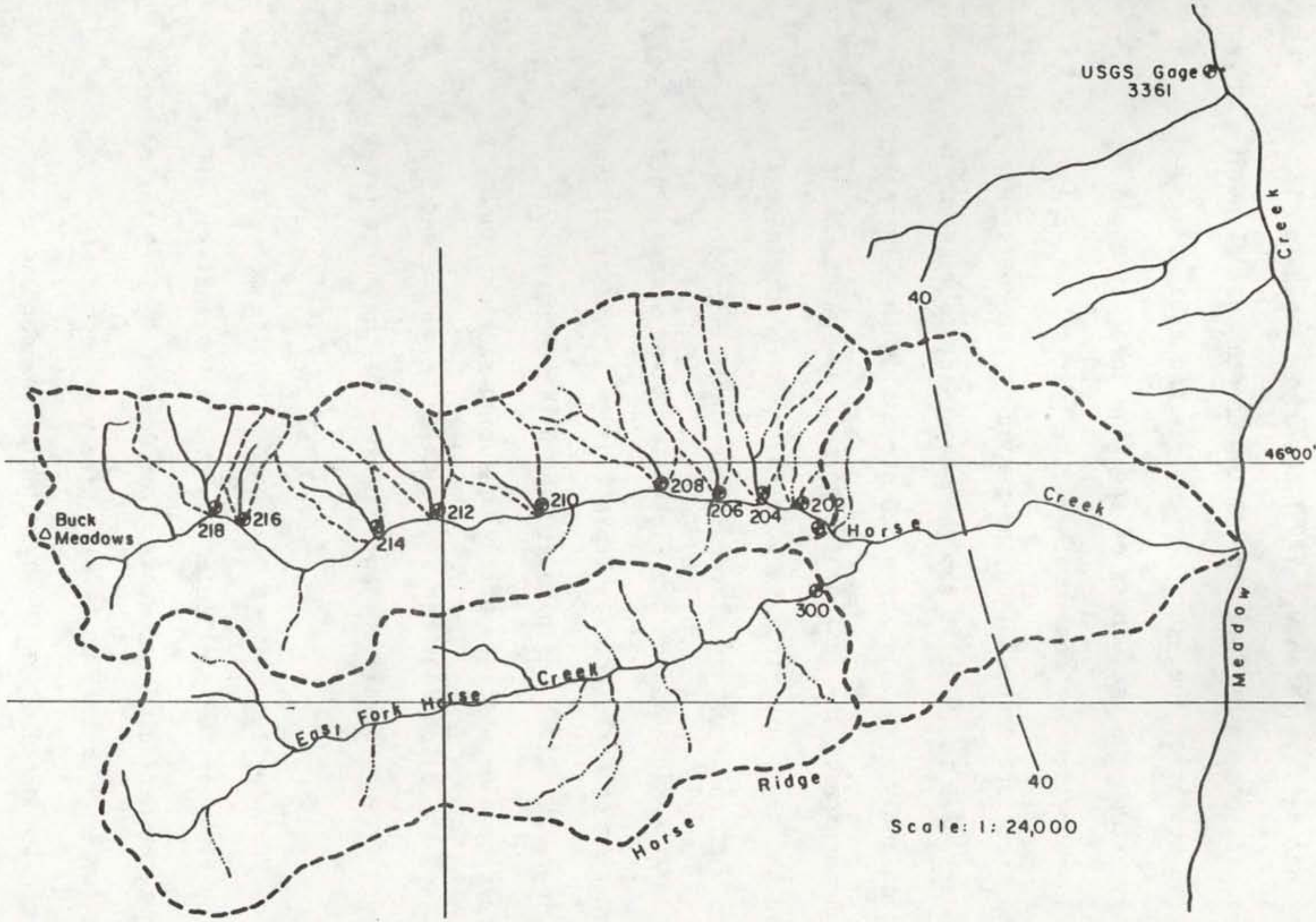

Figure 3. Detailed map of Horse Creek watersheds

Monthly Flow Duration Analysis

Earlier studies had dealt with only daily flows on an annual period of analysis, however, in some cases data are limited due to unavailability of data during certain months of the year. To analyze the data more specifically and possibly extend the usefulness of the flow information, a study was made of flow duration for each month of the year on the various streams of the Horse Creek drainage. Since the period of record is relatively short and covers 1975 to 1979, it was then necessary to make month by month flow duration analyses of all the gaged streams in the Clearwater Basin for comparison purposes. The list of the Horse Creek gages, their period of record and the gages used from the Clearwater River drainage for comparative purposes with their period of record are shown in Figure 4. Figure 5 shows the relative location of the Clearwater River stream gages and the relative location of Horse Creek. Table 1 gives a summary of the gages used in the Clearwater River drainage studies with the period of record used, the drainage area upstream of the measuring station, the average discharges, and the discharges per square mile. Figure 2 and 3 as previously mentioned give more detail on gage locations of the Horse Creek system.

The monthly flow duration curves were developed using the mean daily discharge for all the flows of the particular month. In the analysis of the Horse Creek gages the period of record was from October 1, 1974 to September 30, 1979; (water year 1975 to 1979) a five-year period of record. In an attempt to characterize the hydrologic flow data on a comparable basis a dimensionless flow duration curve was developed by dividing the flow Q_i, at a particular exceedance percentage by the average flow for the month of record, $\overline{Q}$. To illustrate the results of this part of analysis the No. 208 stream gage of Horse Creek has been chosen to show

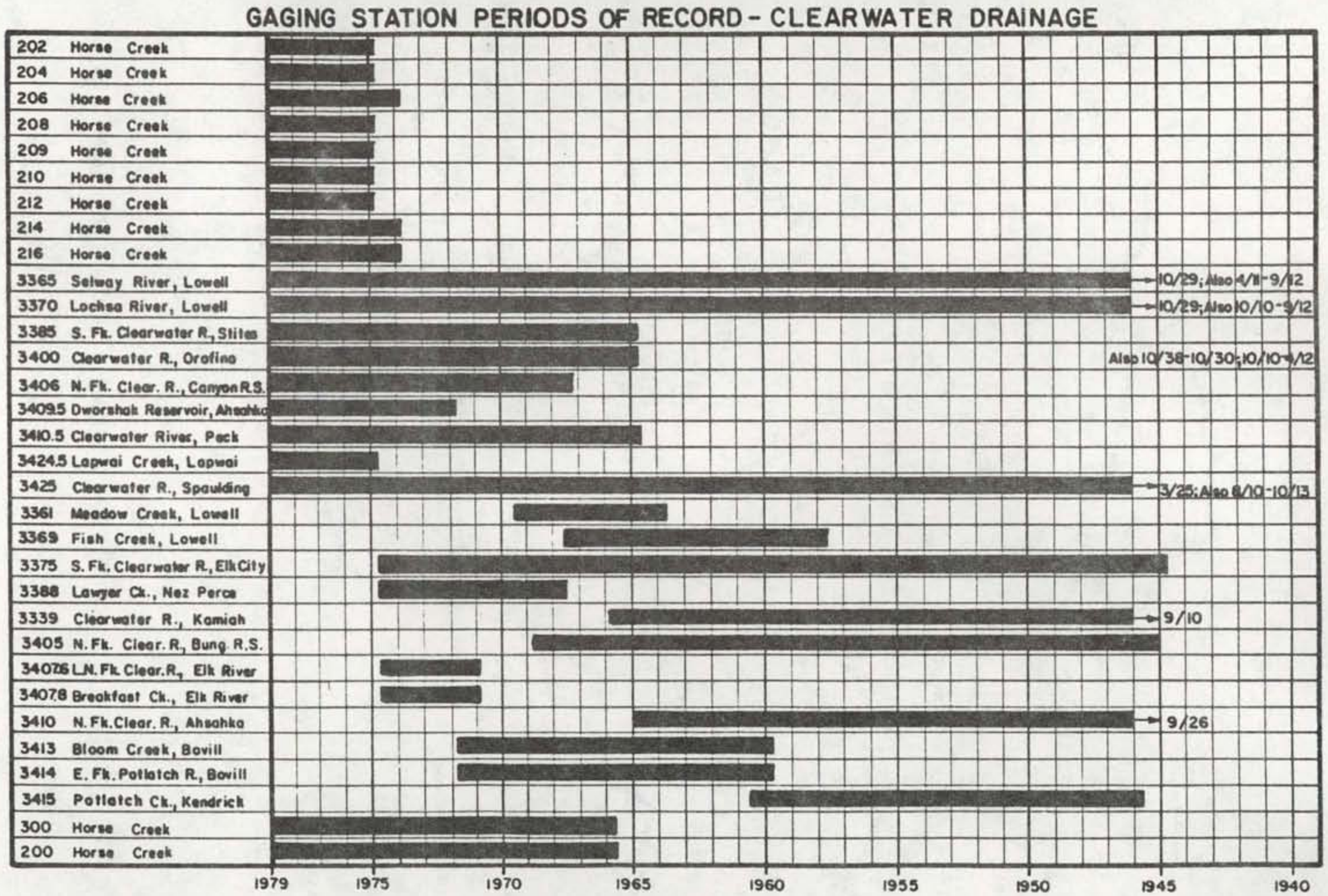

Figure 4. Gaging station periods of record - Clearwater River Basin

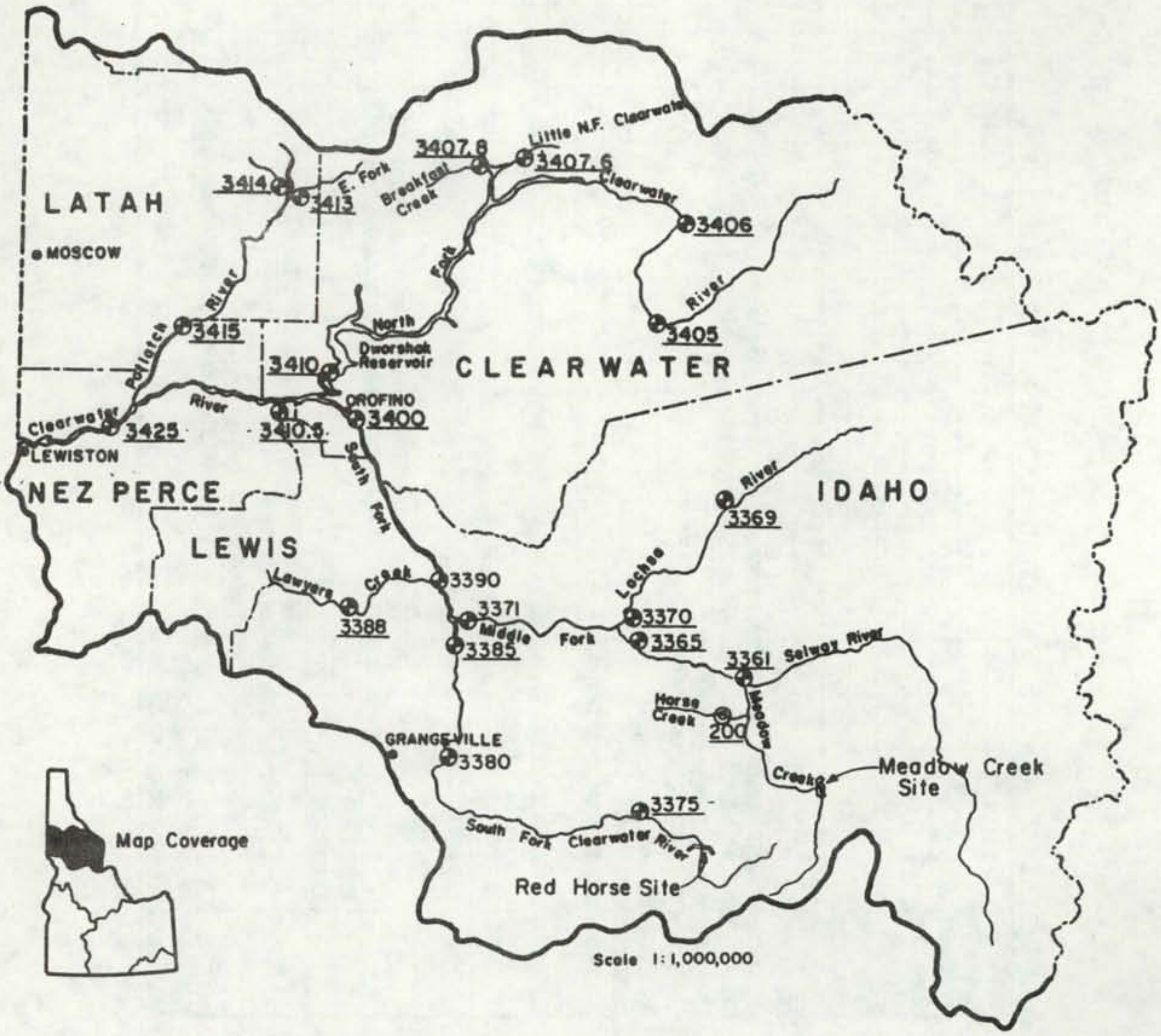

Figure 5. Location map of stream gages - Clearwater River Basin

TABLE 1. Summary of information on stream gaging stations in the Clearwater River basin

Stream	Gage Location	Gage No.	Period of Record	Drainage Area mi^2	Mean Annual Discharge CFS	M.A.D. per Square Mile CFS/mi^2
Selway R.	Lowell	133365	1968-77	1910	3776	1.98
Lochsa R.	Lowell	133370	1968-77	1180	3190	2.70
S. Fork Clearwater R.	Grangeville	133380	1917-16,1924-63	865	875	1.01
S. Fork Clearwater R.	Elk City	133375	1965-69	261	288	1.10
S. Fork Clearwater R.	Stites	133385	1968-77	1150	1129	0.98
N. Fork Clearwater R.	Bungalow R.S.	133405	1945-60	996	2842	2.85
N. Fork Clearwater R.	Canyon R.S.	133406	1968-77	1360	4187	3.08
N. Fork Clearwater R.	Ahsahka	133410	1927-64	2440	5708	2.34
Clearwater R.	Spalding	133425	1911-13,1926-74	9570	15533	1.62
Clearwater R.	Kamiah	133390	1911-1965	4850	8200	1.69
Bloom Creek	Bovill	133413	1960-71	3.15	5.0	1.59
E.F. Potlatch R.	Bovill	133414	1960-71	41.6	61.7	1.48
Horse Creek		200	1975-79	6.50	9.49	1.46
" "		202	1975-79	0.23	0.20	0.88
" "		204	1975-79	0.55	0.64	1.16
" "		206	1975-79	0.40	0.55	1.38
" "		208	1975-79	0.56	0.82	1.46
" "		209	1975-79	0.09	0.11	1.22
" "		210	1975-79	0.26	0.35	1.35
" "		212	1975-79	0.32	0.47	1.47
" "		214	1975-79	0.25	0.36	1.44
" "		216	1975-79	0.09	0.15	1.67
" "		218	1975-79	0.32	0.70	2.18
" "		300	1975-78	5.58	7.93	1.42

how the monthly flow duration curves vary by month. Figure 6 shows the dimensionless duration curve for each month October through September for the No. 208 Horse Creek station. These curves, three separate groups, were developed for each of 12 stations where flow measurements were made during the period from Oct. 1, 1974 to Sept. 30, 1979. The representative pattern of these are shown in Figure 7. The lines on the graphs represent the enveloping limit of values of the dimensionless ratio of $Q_i/\overline{Q}$ for the 12 monthly flow duration curves. The pattern is similar and usually there is less variation in value close to the 30 percent exceedance percentage. This shows that a variation in values can range from a $Q_i/\overline{Q}$ for the 30 percent exceedance of from slightly less than 1.0 to slightly above 1.4. This would indicate that if a single value of the flows that could be consistantly computed or estimated were to be used in the hydrologic studies of hydropower then the Q_{30} or the $Q_{30}/\overline{Q}$ would be most likely to furnish a more consistant term than other exceedance levels of flow. In studies in both the Clearwater River basin and the Salmon River drainage the Q_{30} approaches the values of $\overline{Q}$.

Similar evaluations were made of five U.S.G.S. streamflow records in the Clearwater River drainage covering the same period. The characteristic variation of the dimensionless flow duration curves is shown graphically in Figure 8. The variation of the $Q_i/\overline{Q}$ value at the 30 percent exceedance is relatively less at the U.S.G.S. stations. The $Q_i/\overline{Q}$ value at the 30 percent exceedance was always above 1.0 and was less than 1.4. This then gives the range one would expect of variation in flow at that exceedance percentage.

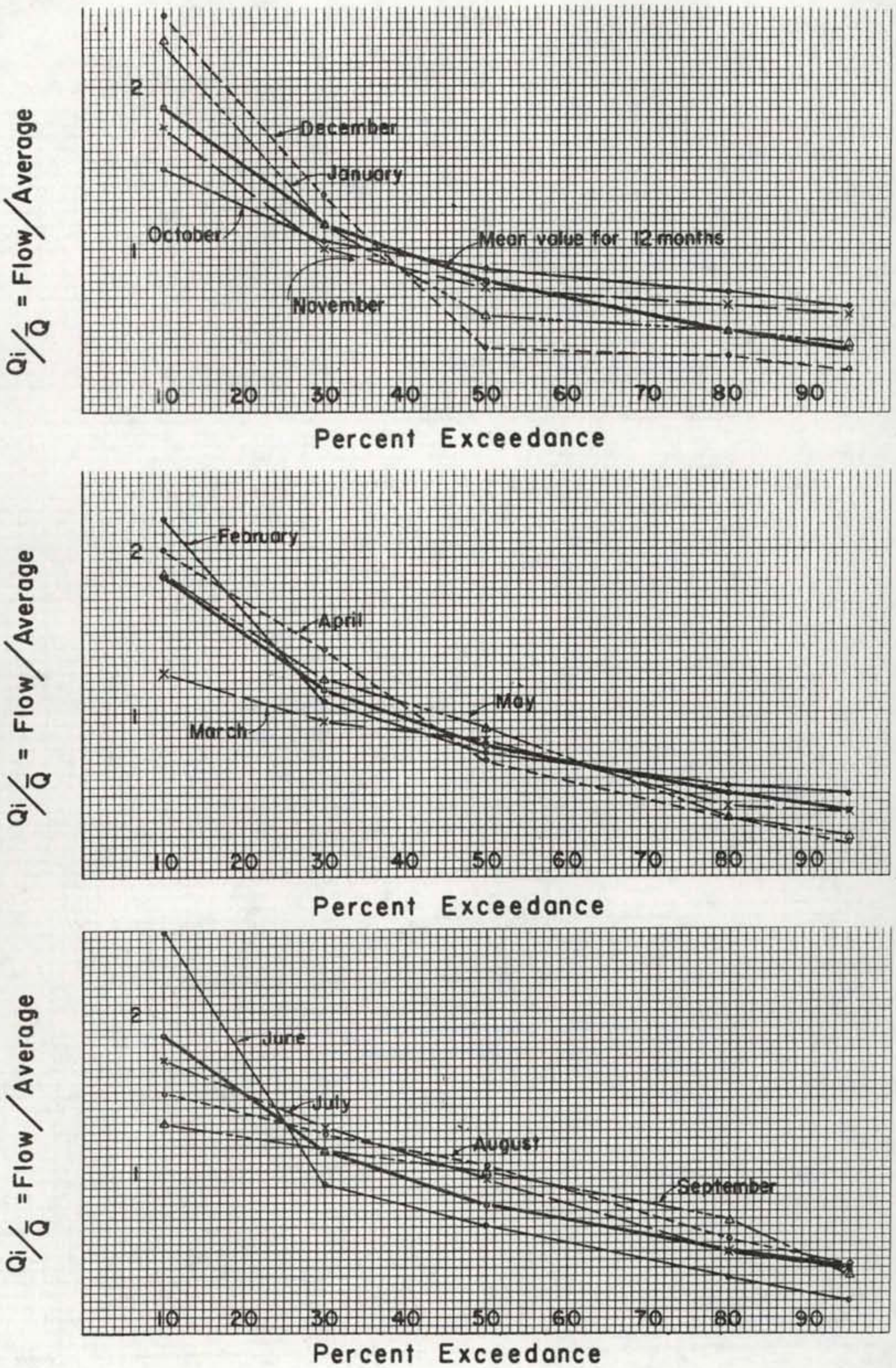

Figure 6. Dimensionless flow duration curves for each month of the year - Horse Creek No. 208

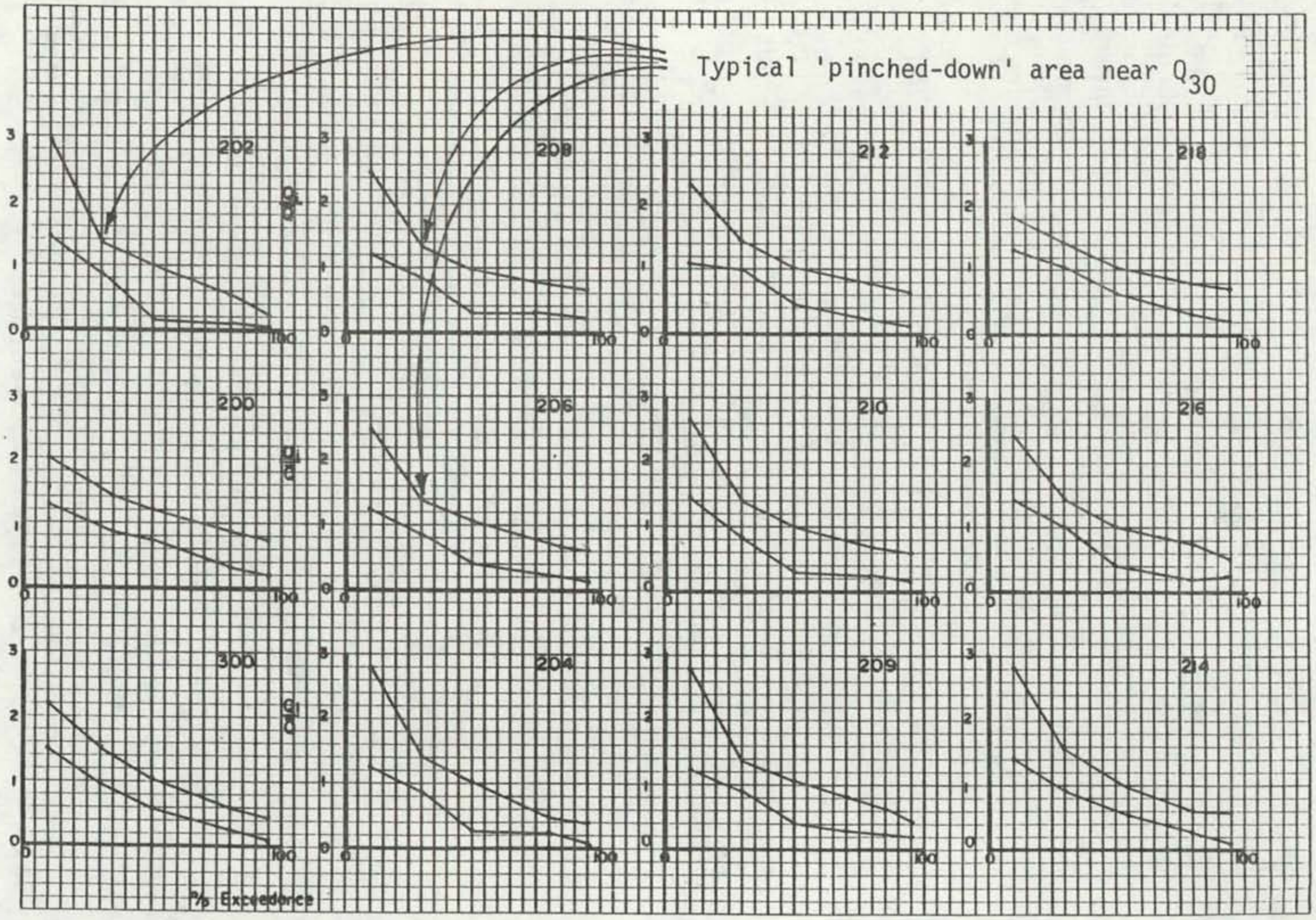

Figure 7. Enveloping values for monthly dimensionless flow duration for Horse Creek gaging stations

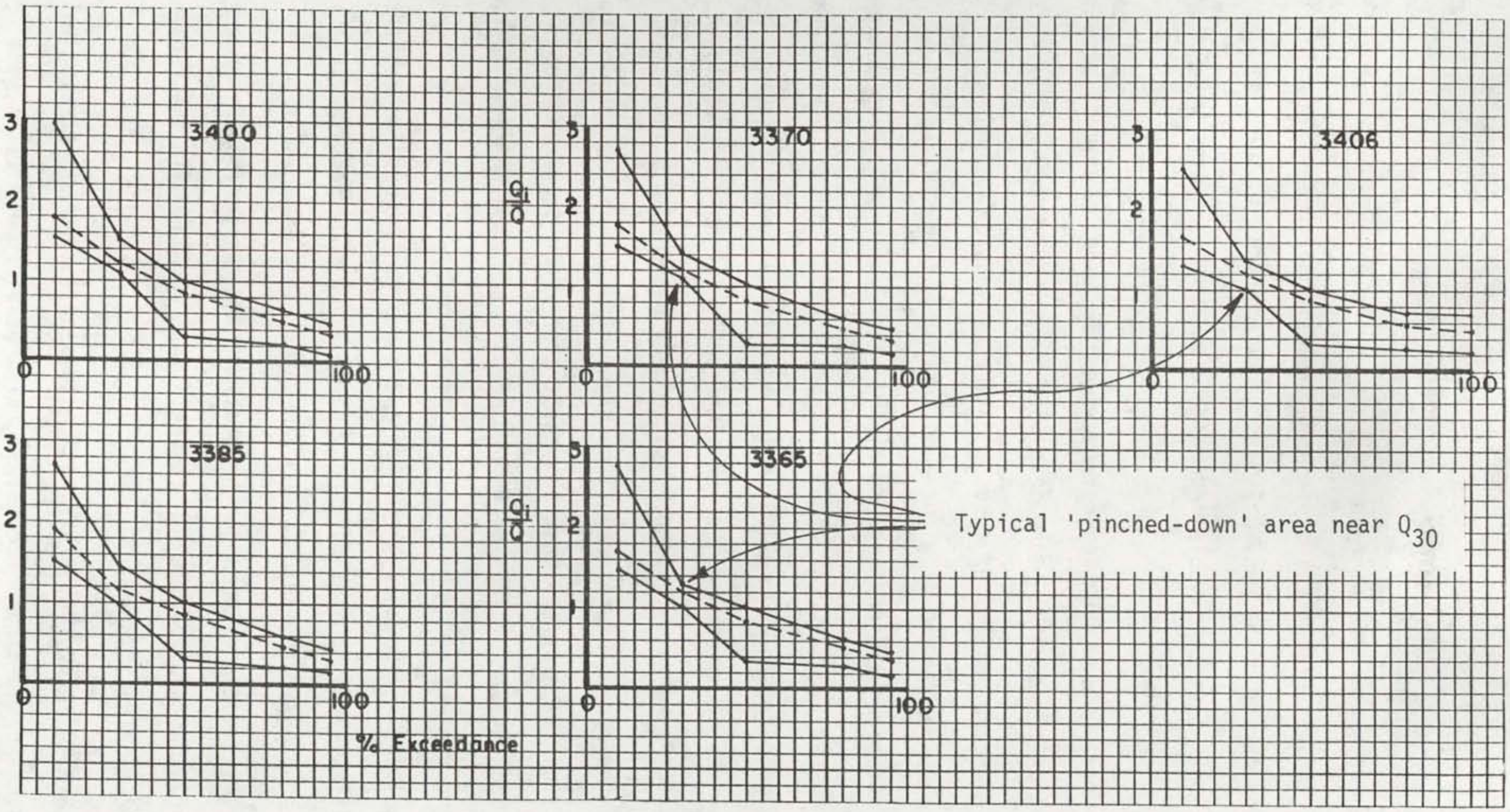

Figure 8. Variation in monthly dimensionless flow duration values for Clearwater River gaging stations.

Yearly Flow Duration Analysis

Next a study was made of flow duration curves on an annual basis for the streams in the Horse Creek experimental watershed area along with flow duration curves of as many U.S.G.S. gaged stations in the Clearwater River basin that have compatable records and where the streams were unregulated.

These data on flow duration curves were then used to develop parametric duration curves like those developed by Heitz, et al. (1980). Nine different combinations of gages and time periods of records were used to develop parametric flow duration curves. Figures 9, 10 and 11 show representative sets of these parametric flow duration curves using the data from the flow records of smaller watersheds. These curves show comparisons of parametric duration curves with the parametric curves generated by the studies of Heitz, et al. (1980). It should be pointed out that the work of Heitz was based on as many gages as had long-time records and the period of record at the gages were somewhat different but usually of a duration of at least 20 years. The newer data reported in this study had shorter periods of record but in each case whenever a station's record was included the same time period of record was used on all stations included in the analysis. Table 2 gives the regression equation for each analysis of the nine different combinations for each exceedance percentage studied of 10, 30, 50, 80, and 95 percent exceedances and indicates what gages were used in the analysis and the period of stream gaging record that was involved in the data that were used in the flow duration curve calculations.

It should be noted that a statistically significant correlation was obtained in all cases except for Set 9. Figures 9, 10 and 11 do show

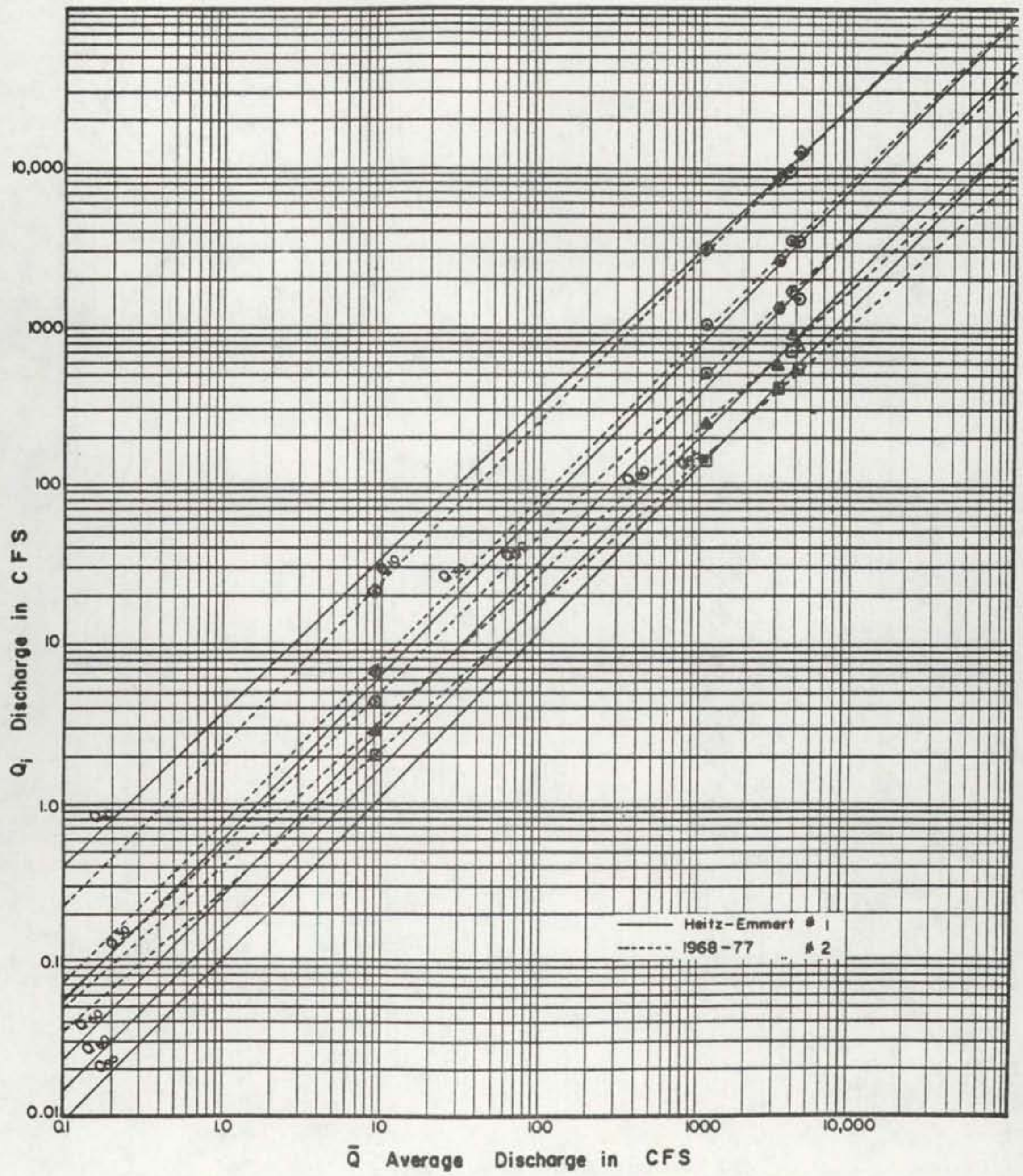

Figure 9. Comparison of parametric flow duration curves Set 1 (Heitz-Emmert) and Set 2 (1968-77) - Clearwater River Basin

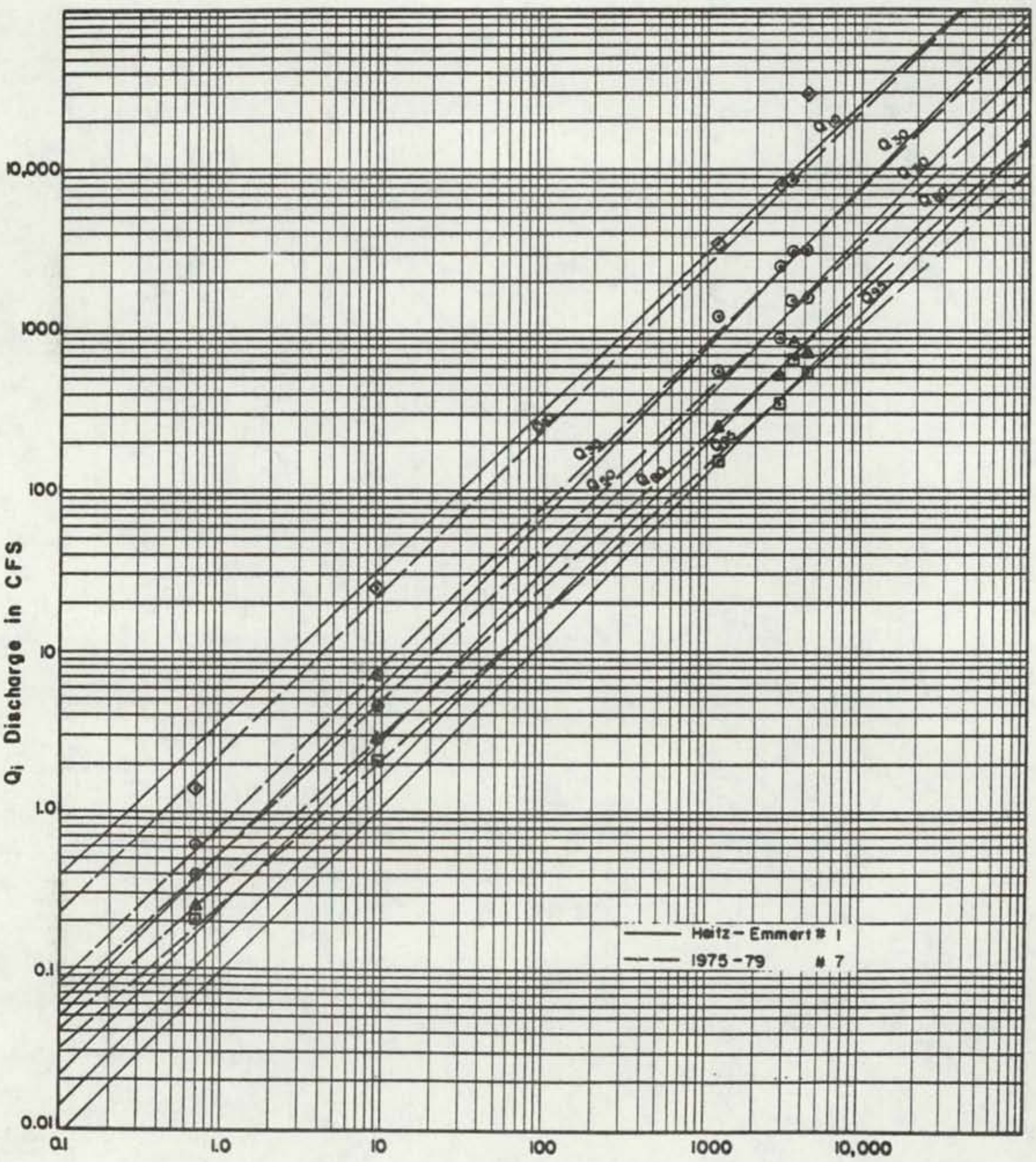

Figure 10. Comparison of parametric flow duration curves Set 1 (Heitz-Emmert) and Set 7 (1975-1979) - Clearwater River Basin

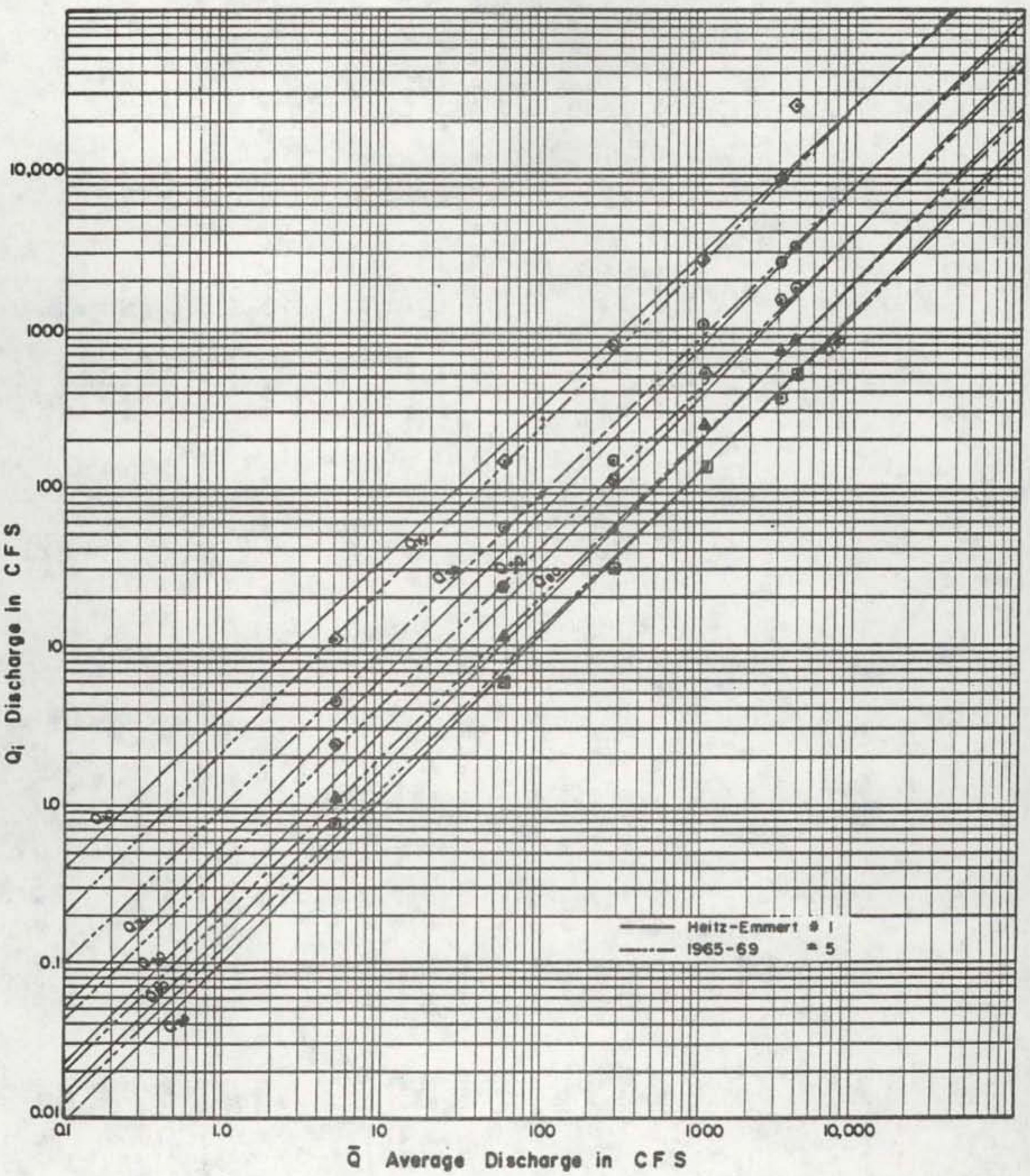

Figure 11. Comparison of parametric flow duration curves Set 1 (Heitz-Emmert) and Set 5 (1965-1969) - Clearwater River Basin

Table 2. Summary of regression equations for parametric flow duration curves - Clearwater River Basin

COMBINATION NUMBER	NUMBER OF GAGES INVOLVED	STREAM NAME	GAGE LOCATION AND NUMBER	PERIOD OF RECORD	REGRESSION EQUATIONS FOR PARAMETRIC FLOW DURATION CURVES
		Selway	Lowell 133365	1930-1974	$\log Q_{10} = -1.9149 + 0.9696 \log 365 \bar{Q}$
		Lochsa	Lowell 133370	1911-1974	
1	8	S.F. Clearwater	Grangeville 133380	1912-1963	$\log Q_{30} = -2.9892 + 1.0598 \log 365 \bar{Q}$
		S.F. Clearwater	Elk City 133375	1945-1974	$\log Q_{50} = -3.3067 + 1.0583 \log 365 \bar{Q}$
		N.F. Clearwater	Ahsahka 133410	1927-1964	$\log Q_{80} = -3.4147 + 1.0282 \log 365 \bar{Q}$
		N.F. Clearwater	Bungalow 133405	1945-1969	
		Clearwater	Spalding 133425	1926-1971	$\log Q_{95} = -3.6757 + 1.0423 \log 365 \bar{Q}$
		Clearwater	Kamiah 133390	1911-1965	
		Selway	Lowell 133365	1968-1977	$\log Q_{10} = 0.364 + 1.023 \log \bar{Q}$
		Lochsa	Lowell 133370	1968-1977	$\log Q_{30} = -0.135 + 1.022 \log \bar{Q}$
2	5	S.F. Clearwater	Stites 133385	1968-1977	$\log Q_{50} = -0.292 + 0.981 \log \bar{Q}$
		N.F. Clearwater	Canyon R.S. 133406	1968-1977	$\log Q_{80} = -0.416 + 0.924 \log \bar{Q}$
		Horse Creek	No. 200	1968-1977	$\log Q_{95} = -0.566 + 0.922 \log \bar{Q}$
		Selway	Lowell 133365	1968-1970	$\log Q_{10} = 0.376 + 1.018 \log \bar{Q}$
		Lochsa	Lowell 133370	1968-1970	$\log Q_{30} = -0.008 + 0.991 \log \bar{Q}$
3	5	S.F. Clearwater	Stites 133385	1968-1970	$\log Q_{50} = -0.241 + 0.991 \log \bar{Q}$
		N.F. Clearwater	Canyon R.S. 133406	1968-1970	$\log Q_{80} = -0.394 + 0.945 \log \bar{Q}$
		Horse Creek	No. 200	1968-1970	$\log Q_{95} = -0.509 + 0.928 \log \bar{Q}$
		Selway	Lowell 133365	1975-1979	$\log Q_{10} = 0.400 + 1.016 \log \bar{Q}$
		Lochsa	Lowell 133370	1975-1979	$\log Q_{30} = -0.125 + 1.019 \log \bar{Q}$
4	5	S.F. Clearwater	Stites 133385	1975-1979	$\log Q_{50} = -0.272 + 0.975 \log \bar{Q}$
		N.F. Clearwater	Canyon R.S. 133406	1975-1979	$\log Q_{80} = -0.422 + 0.924 \log \bar{Q}$
		Horse Creek	No. 200	1975-1979	$\log Q_{95} = -0.571 + 0.912 \log \bar{Q}$
		Selway	Lowell 133365	1965-1969	$\log Q_{10} = 0.354 + 1.033 \log \bar{Q}$
		Lochsa	Lowell 133370	1965-1969	$\log Q_{30} = -0.039 + 0.999 \log \bar{Q}$
5	6	S.F. Clearwater	Elk City 133375	1965-1969	$\log Q_{50} = -0.369 + 1.012 \log \bar{Q}$
		S.F. Clearwater	Stites 133385	1965-1969	$\log Q_{80} = -0.720 + 1.020 \log \bar{Q}$
		Bloom Creek	Bovill 133413	1965-1969	$\log Q_{95} = -0.907 + 1.006 \log \bar{Q}$
		E.F. Potlatch	Bovill 133414	1965-1969	
		Selway	Lowell 133365	1965-1969	$\log Q_{10} = 0.370 + 1.026 \log \bar{Q}$
		Lochsa	Lowell 133370	1965-1969	$\log Q_{30} = -0.051 + 1.004 \log \bar{Q}$
6	5	S.F. Clearwater	Elk City 133375	1965-1969	$\log Q_{50} = -0.320 + 0.997 \log \bar{Q}$
		S.F. Clearwater	Stites 133385	1965-1969	$\log Q_{80} = -0.687 + 1.009 \log \bar{Q}$
		Bloom Creek	Bovill 133413	1965-1969	$\log Q_{95} = -0.887 + 1.002 \log \bar{Q}$
		Selway	Lowell 133365	1975-1979	$\log Q_{10} = 0.367 + 1.026 \log \bar{Q}$
		Lochsa	Lowell 133370	1975-1979	$\log Q_{30} = -0.080 + 1.007 \log \bar{Q}$
7	6	S.F. Clearwater	Stites 133385	1975-1979	$\log Q_{50} = -0.258 + 0.961 \log \bar{Q}$
		N.F. Clearwater	Canyon R.S.	1975-1979	$\log Q_{80} = -0.441 + 0.930 \log \bar{Q}$
		Horse Creek	No. 200	1975-1979	$\log Q_{95} = -0.558 + 0.920 \log \bar{Q}$
		Horse Creek	No. 218	1975-1979	
		Selway	Lowell 133365	1975-1979	$\log Q_{10} = 0.396 + 1.019 \log \bar{Q}$
		Lochsa	Lowell 133370	1975-1979	$\log Q_{30} = -0.106 + 1.013 \log \bar{Q}$
8	7	S.F. Clearwater	Stites 133385	1975-1979	$\log Q_{50} = -0.297 + 0.971 \log \bar{Q}$
		N.F. Clearwater	Canyon R.S. 133406	1975-1979	$\log Q_{80} = -0.511 + 0.948 \log \bar{Q}$
		Horse Creek	No. 200	1975-1979	$\log Q_{95} = -0.707 + 0.958 \log \bar{Q}$
		Horse Creek	No. 218	1975-1979	
		Horse Creek	No. 300	1975-1979	
		Selway	Lowell 133365	1975-1979	$\log Q_{10} = 0.420 + 1.011 \log \bar{Q}$
		Lochsa	Lowell 133370	1975-1979	$\log Q_{30} = -1.001 + 1.357 \log \bar{Q}$*
		S.F. Clearwater	Stites 133385		$\log Q_{50} = -2.042 + 1.600 \log \bar{Q}$*
9	12	N.F. Clearwater	Canyon R.S. 133406	1975-1979	$\log Q_{80} = -3.772 + 2.048 \log \bar{Q}$*
		Horse Creek	No. 200	1975-1979	$\log Q_{95} = -4.625 + 2.240 \log \bar{Q}$*
		Horse Creek	No. 204	1975-1979	
		Horse Creek	No. 208	1975-1979	
		Horse Creek	No. 212	1975-1979	
		Horse Creek	No. 214	1975-1979	
		Horse Creek	No. 216	1975-1979	
		Horse Creek	No. 218	1975-1979	
		Horse Creek	No. 300	1975-1979	

*On these regressions the flows at these small streams receded to essentially zero. To make regressions with logarithmic plots a value of 0.0000001 was used for Q.

that there is variation in the parametric flow duration curves when the records of flow at smaller gages are included. A comparison table of the predicted values of flow using various average flow magnitudes, for two exceedance percentages, the 10% exceedance value of flow and the 30% exceedance percentage, reveals some interesting variations shown in Table 3. At the 10% exceedance flow, Q_{10} for a basin having an average flow of 10 CFS the Heitz parametric flow study gives 34.60 CFS while combination No. 2 using regressions including smaller watersheds gives 24.38 CFS. In contrast at the 30% exceedance flow Q_{30} the Heitz parametric flow study gives 6.11 CFS while combination No. 2 using regressions including smaller watersheds gives 7.71 CFS. This shows a reversal of the sign of the difference between the two studies as one goes from Q_{10} to Q_{30} for values of average discharge, Q, less than 1000 CFS. This is also shown in Figures 9 and 10. The extreme variations in Set 9 are indicative of the fact that streams with zero-value flows are inapplicable for use in parametric curve development. To generate the values in Tables 2 and 3 a value of 0.0000001 (1×10^{-7}) was used in place of zero on data from these smaller streams. This was done because the regression analysis was done as a logarithmic regression which cannot be used with zero values of flow.

Economic Significance of Variation in Flow Duration Curves

To give an indication of how the variation in the values of the flow duration data might influence the economic viability of hydro development a study was undertaken of a particular power site. This was done to show how the hydrologic uncertainties influence the relation between benefits and costs. The site selected was the Red Horse site on the Red River a

Table 3. Comparison of predicted flow duration values from parametric flow duration curves Clearwater River basin

Average Discharges Values

Combination Number	2 CFS	10 CFS	100 CFS	1000 CFS	5000 CFS
	Values of Q_{10} - Flow at 10% Exceedance				
	CFS	CFS	CFS	CFS	CFS
1 (Heitz-Emmert)	7.27	34.60	322.6	3008.1	14,323
2	4.70	24.38	257.0	2710.2	14,062
3	4.81	24.77	258.2	2691.5	13,853
4	5.08	26.06	270.4	2805.4	14,393
5	4.62	24.38	263.0	2837.9	14,964
6	4.77	24.89	264.2	2805.4	14,627
7	4.74	24.72	262.4	2786.1	14,526
8	5.04	26.00	271.6	2837.9	14,630
9	5.30	26.98	276.7	2837.9	14,443
	Values of Q_{30} - Flow at 30% Exceedance				
	CFS	CFS	CFS	CFS	CFS
1 (Heitz-Emmert)	1.11	6.11	70.14	805.0	4431
2	1.49	7.71	81.10	853.1	4419
3	1.95	9.62	94.2	922.6	4547
4	1.52	7.83	81.85	855.1	4408
5	1.83	9.12	90.99	907.8	4532
6	1.78	8.97	90.57	914.1	4600
7	1.67	8.45	85.90	873.0	4414
8	1.58	8.07	83.18	857.0	4376
9	0.26	2.27	51.64	1174.9	10,435

tributary to the South Fork of the Clearwater River. The site location is marked on Figure 5.

The flow duration curve for the Red Horse site was developed using different parametric flow duration relations as developed and indicated in Table 2. The average discharge, $\overline{Q}$, for the Red Horse site was taken from the studies of Heitz (1980). Five combinations were chosen to show the variation. Combination No. 1 (Heitz, Emmert curves), Combination 2 (5 Clearwater gages for period 1968-77), Combination 3 (5 Clearwater gages for period 1965-69), Combination 4(5 Clearwater gages for period 1975-79), and Combination 5 (6 Clearwater gages for 1965-69).

To make this analysis it was possible to use a computerized program, Hydropower Computerized Reconnaissance (HCR) Package that was developed by C.R. Broadus (1981) at the Idaho National Engineering Laboratory. Two main programs of that system were used in the analysis of the Red Horse Site. The first is HYDRO-CALC, which performs preliminary engineering computations for a given power site and the second program is HYDRO-ECON which does economic calculations. The flow duration curve is an input to the HYDRO-CALC computer program. The program has capability of utilizing sequential monthly flow data also. The program provides for choices of different types of turbines, and combinations of turbines and allows for the calculation of rated power capacity and annual amount of energy produced. The HYDRO-ECON provides a way of calculating the annual costs and the annual benefits.

In the analysis it was necessary to make several assumptions and to make a very brief sensitivity analysis to obtain a useful comparison. The assumption was made that different heads might be utilized in developing the energy at the site. Two different heads, a 25-foot development and a 100-foot development were selected to bracket a range of possible heads. The head is the net effective head that would be expected to be utilized in a given development. Another assumption was that two turbine units of essentially the same size could be used to develop as much of the range of flow as turbine operating practice would permit. A third assumption was that the dependable energy would be that available from the flow available 95 percent of the time and the total energy benefits would be given by the following formula:

$$B_T = (E_A - E_D)\ V_e + E_D(V_c)$$

where

B_T = total annual benefits in dollars
E_A = total annual energy in KWH
E_D = annual dependable energy in KWH
V_e = value of energy in mills/KWH
V_c = value of dependable energy in mills/KWH

In calculation of this study V_e was taken as \$0.035/KWH and V_c was taken as \$0.040/KWH (35 and 40 mills per KWH, respectively). These are values being offered in 1982 for avoided costs of new power in Idaho.

A further assumption was that two discount rates for discounting costs could be considered $i = 9\%$ and $i = 12\%$ and project life was assumed to be 30 years.

For the cost side of the economic analysis, a simplification and sensitivity analyses was made by assuming that total capital cost would be \$1000/KW, \$1250/KW, and \$1500/KW and that annual operation and maintenance costs would be 0.001/KWH per year. The values of \$1000/KW, \$1250/-KW, and \$1500/KW are what small plants have been built for in recent times and represent a reasonable range one might expect in the next few years in the west. The $0.001/KW per year was taken from a study made by R. Hogg in 1979 and represents a reasonable value for present day costs of operation and maintenance of small-scale hydropower plants. These capital costs should be in the general range of new units now being considered as possible for economic development under present day technology.

The results of the analysis are shown in Table 4 showing results of using as input flow duration data from different combinations of Set 1, through Set 5 of the parametric flow duration curves. This shows there is a sizeable variation in net benefits and indicates the magnitude in dollars that the variation in flow duration can make in economic returns from a small hydro power development. Further comments on the significance of this variation will be discussed in the conclusion section of the report.

Table 4. Variation in economic returns using flow data from different parametric flow duration curves
Clearwater River Basin

Combination or set	Rated Power Capacity KW	Discount Rate %	Total Annual Costs $1000/KW $	Total Annual Costs $1250/KW $	Total Annual Costs $1500/KW $	Total Annual Benefit $	Net Benefits $1000/KW $	Net Benefits $1250/KW $	Net Benefits $1500/KW $
1	2	3	4	5	6	7	8	9	10
Utilizing 25-Ft Head at Site (Red Horse Site)									
Set 1	183.1	9	18,557	23,010	27,464	26,771	8,215	3,761	-692
Heitz-Emmert		12	23,463	29,143	34,823	26,771	3,308	-2,372	-8,052
Set 2	187.1	9	19,042	23,594	28,146	30,404	11,362	6,818	2,258
1968-77 Records		12	24,057	29,863	35,669	30,404	6,341	542	-5,256
Set 3	207.6	9	21,153	26,203	31,253	34,737	13,584	8,534	3,484
1968-70 Records		12	26,717	33,158	39,599	34,737	8,020	1,579	-4,862
Set 4	190.4	9	19,464	24,120	28,776	30,531	11,067	6,411	1,755
1975-79 Records		12	24,594	30,532	36,471	30,531	5,837	- 1	-5,940
Set 5	203.9	9	20,657	25,617	30,577	29,374	8,717	3,757	-1,203
1965-69 Records		12	26,121	32,448	38,774	29,374	3,252	-3,074	-9,400
Utilizing 100-Ft Head at Site									
Set 1	732.3	9	74,229	92,043	109,858	107,085	32,856	15,042	-2,772
Heitz-Emmert		12	93,856	116,577	139,298	107,085	13,229	-9,491	-32,212
Set 2	744.3	9	75,723	93,827	111,932	120,558	44,834	26,730	8,626
1968-77 Records		12	95,670	118,760	141,851	120,558	24,888	1,797	-21,293
Set 3	825.7	9	84,117	104,202	124,287	137,840	53,723	33,638	13,553
1968-70 Records		12	106,245	131,862	157,479	137,840	31,594	5,977	-19,640
Set 4	761.2	9	77,396	95,913	114,429	121,063	43,667	25,150	6,634
1975-79 Records		12	97,797	121,414	145,030	121,063	23,266	-351	-23,967
Set 5	811.0	9	82,143	101,870	121,597	116,524	34,380	14,654	-5,073
1965-69 Records		12	103,877	129,037	154,197	116,524	12,647	-12,513	-37,673

LARGE BASIN EXTRAPOLATION

The Salmon River drainage above its most downstream measuring station represents an area of more than 13,000 square miles and includes some of the most diverse variation in topography and hydrologic variation in the entire country. Likewise, it is essentially an unregulated flow situation. As a result of these diversities and unregulated nature it represented an excellent opportunity to study what differences would result in the extrapolations made by using parametric flow duration curves developed from a very few station's records of streamflow. Figure 12 is a map of the Salmon River basin showing the drainage boundary and the location of the gaging station. Figure 13 gives a graphical listing of stream gaging and the period that records have been maintained of measured flow. Earlier in studies by Heitz, et al. (1980) parametric flow duration curves were developed using flow records from as many as 24 of the gages. One set of parametric flow duration curves was developed using a linear regression of the logarithms of the flow and the logarithms of average annual flows. Another set of flow duration curves was developed using a curvilinear best fit on logarithmic paper. Figure 14 is a reproduction of that best-fit parametric flow duration curve that has been extended down on a straight line extrapolation to include average flows as small as streams having an average annual flow of 2 CFS. These two sets of flow duration curves were utilized as a base to compare research results of this study. In each case of these studies by Heitz, et al. the records used in developing the parametric curves were of mixed length of record, but usually of greater than twenty years length.

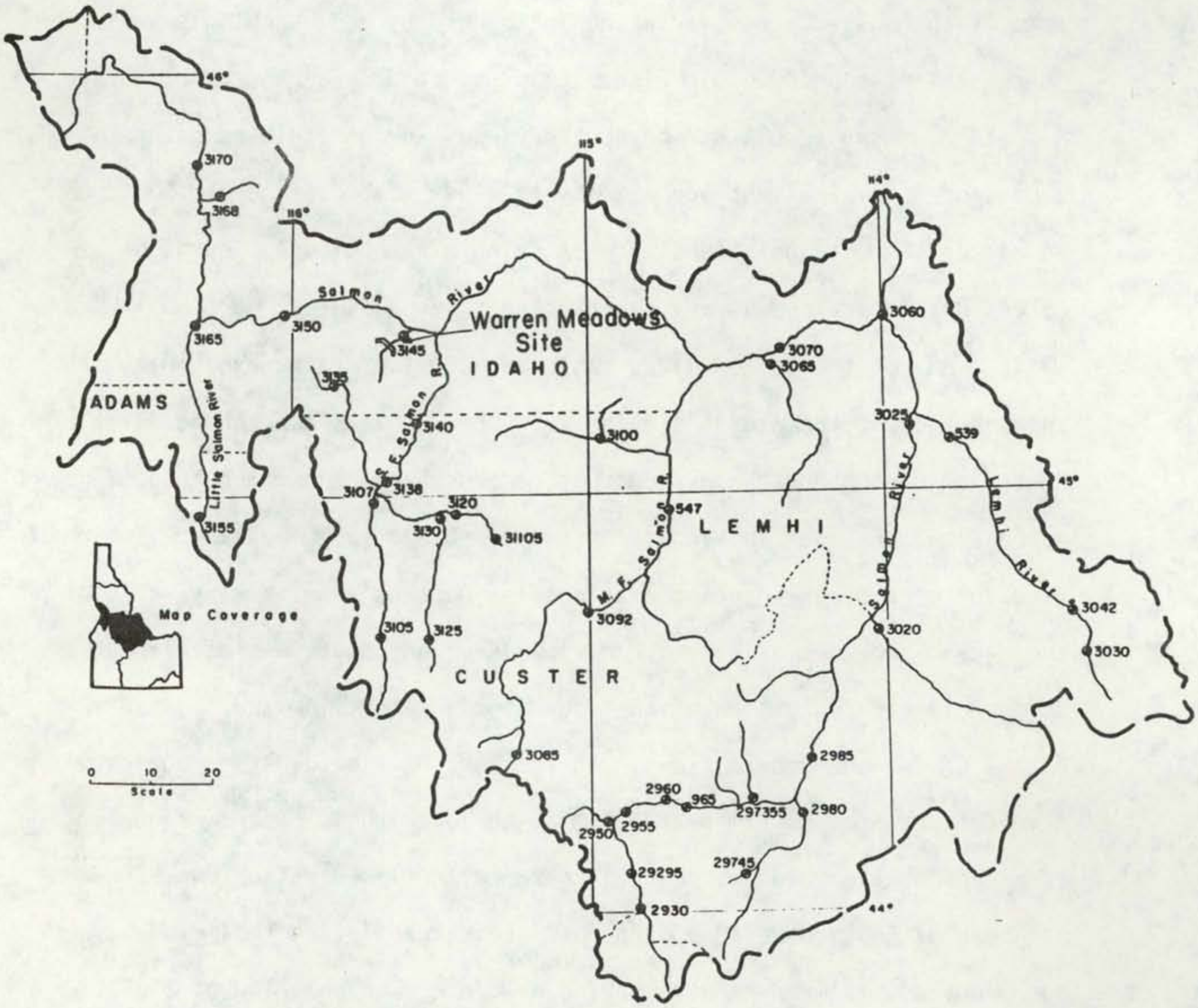

Figure 12. Location map of stream gages - Salmon River Basin

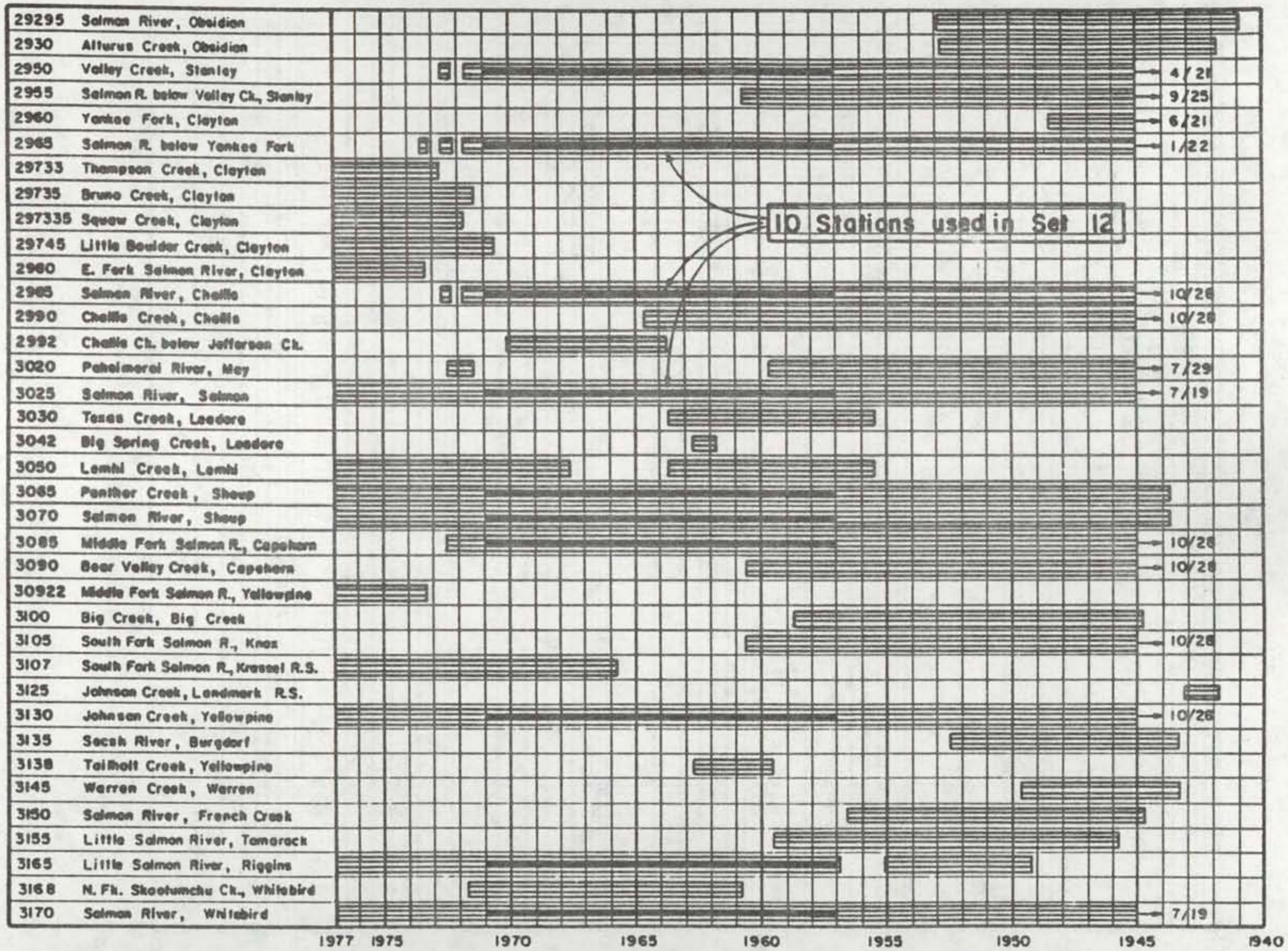

Figure 13. Gaging stations' periods of record - Salmon River Basin

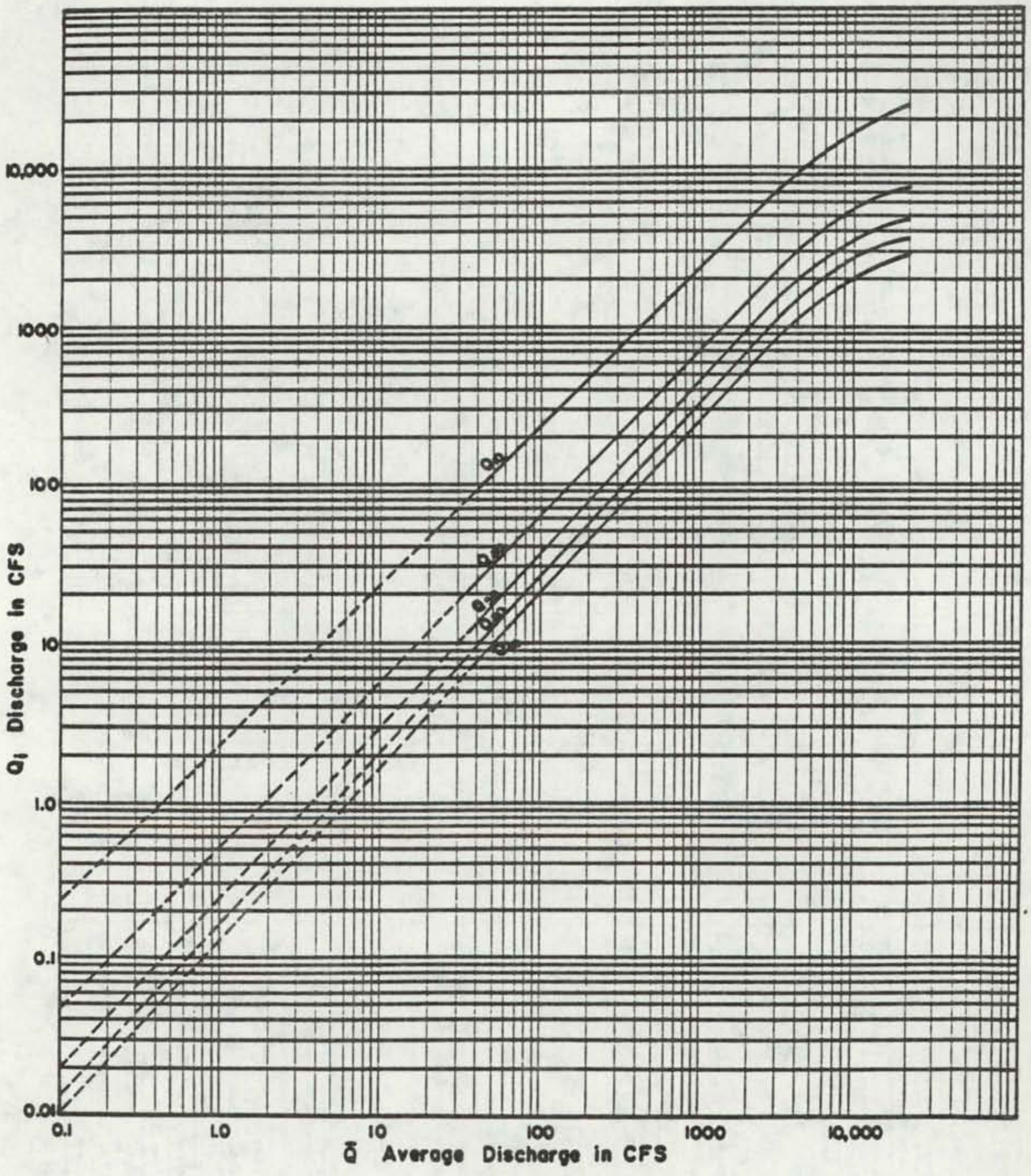

Figure 14. Parametric flow duration curve - Heitz study
(Salmon River Basin)

In this research it was found that there was a consistent record at ten gages in the Salmon River drainage from 1957 to 1971 that represented a reasonably long record in which the gages were distributed in a good geographic representation and also represented a spectrum of average annual flow values. Figure 13 shows the period of record of the ten gages marked with heavy black bars to indicate the relative period of record. Data from the 10 stations were used to develop a parametric flow duration curves using the procedure indicated in the work of Heitz (1981).

Once this 10-gage analysis was completed, a similar study was undertaken to select just three flow duration curves from the ten stations' flow duration curves and develop a parametric flow duration curve using just three stations' records and flow duration. Actually three sets of three were selected and analyzed to prepare and a parametric flow duration curve developed for each set of stations. In choosing the stations an attempt was made to select gages so that a reasonable coverage of the geographic area was included in each set of three and a variation in drainage size so that a more representative sampling was considered.

The three sets of six gaged stations' flow duration curves were also selected to develop parametric flow duration curves. The selection of the sets of six gages was done to give as good a geographic representation as possible and also give consideration to choosing different sizes of drainage basins that represented a range of river flows.

The results of this analysis are presented in Table 5 and in Figure 15. Figure 15 shows variation of the set of parametric duration curves developed with a 3 gage record of flow with that developed with a ten gage records of flow. Figure 15 shows graphically the variation that can be expected. As further demonstration of variation, hypothetical sites

Table 5. Summary of regression equations for parametric flow duration curves - Salmon River Basin

Combination No. or Set No. (1)	No. of Gages (2)	Stream Name (3)	Gage No. Location (4)	Period of Record (5)	Regression Equation for Flow Duration Curve (6)
10 Heitz Study	29	Salmon River	Many locations	Mixed lengths	Best fit - graphical curve-see Fig. 14
11 Heitz study	29	Salmon River	Many locations	Mixed lengths	$\log Q_{10} = -1.8591 + 0.94973 \log 365 \bar{Q}$
Linear log Regression					$\log Q_{30} = -3.03026 + 1.05765 \log 365 \bar{Q}$
					$\log Q_{50} = -3.44889 + 1.10195 \log 365 \bar{Q}$
					$\log Q_{80} = -3.66681 + 1.11735 \log 365 \bar{Q}$
					$\log Q_{95} = -3.73030 + 1.10869 \log 365 \bar{Q}$
12	10	Valley Creek	Stanley 132950	1957-71	
		Salmon River	Clayton 132965	1957-71	$\log Q_{10} = 0.534 + 0.965 \log \bar{Q}$
		Salmon River	Challis 132985	1957-71	
		Salmon River	Salmon 133025	1957-71	$\log Q_{30} = -0.299 + 1.049 \log \bar{Q}$
		Panther Creek	Shoup 133065	1957-71	
		Salmon River	Shoup 133070	1957-71	$\log Q_{50} = -0.574 + 1.084 \log \bar{Q}$
		M.F.Salmon River	Capehorn 133085	1957-71	
		Johnson Creek	Yellow Pine 133130	1957-71	$\log Q_{80} = -0.754 + 1.101 \log \bar{Q}$
		Little Salmon R.	Riggins 133165	1957-71	$\log Q_{95} = -0.853 + 1.107 \log \bar{Q}$
		Salmon River	Whitebird 133170	1957-71	
13	6	Valley Creek	Stanley 132950	1957-71	$\log Q_{10} = 0.451 + 0.998 \log \bar{Q}$
		Salmon River	Challis 132985	1957-71	$\log Q_{30} = -0.244 + 1.028 \log \bar{Q}$
		Panther Creek	Shoup 133070	1957-71	$\log Q_{50} = -0.475 + 1.040 \log \bar{Q}$
		Johnson Creek	Yellow Pine 133130	1957-71	$\log Q_{80} = -0.617 + 1.039 \log \bar{Q}$
		L.Salmon River	Riggins 133165	1957-71	$\log Q_{95} = -0.729 + 1.048 \log \bar{Q}$
14	6	Salmon River	Clayton 132965	1957-71	$\log Q_{10} = 0.574 + 0.957 \log \bar{Q}$
		Salmon River	Salmon 133025	1957-71	$\log Q_{30} = -0.322 + 1.054 \log \bar{Q}$
		M.Fork Salmon R.	Capehorn 133085	1957-71	$\log Q_{50} = -0.635 + 1.094 \log \bar{Q}$
		Johnson Creek	Yellow Pine 133130	1957-71	$\log Q_{80} = -0.867 + 1.123 \log \bar{Q}$
		L.Salmon River	Riggins 133165	1957-71	$\log Q_{95} = -0.961 + 1.128 \log \bar{Q}$
		Salmon River	Whitebird 133170	1957-71	
15	6	Valley Creek	Stanley 132950	1957-71	$\log Q_{10} = 0.463 + 0.988 \log \bar{Q}$
		Salmon River	Challis 132965	1957-71	$\log Q_{30} = -0.238 + 1.027 \log \bar{Q}$
		Salmon River	Salmon 133025	1957-71	$\log Q_{50} = -0.427 + 1.039 \log \bar{Q}$
		Panther Creek	Shoup 133070	1957-71	$\log Q_{80} = -0.562 + 1.045 \log \bar{Q}$
		M. Fork Salmon R.	Capehorn 133085	1957-71	$\log Q_{95} = -0.656 + 1.050 \log \bar{Q}$
		Salmon River	Whitebird 133170	1957-71	
16	3	Little Salmon R.	Riggins 133165	1957-71	$\log Q_{10} = 0.873 + 0.852 \log \bar{Q}$
		Salmon River	Shoup 133070	1957-71	$\log Q_{30} = 0.084 + 0.943 \log \bar{Q}$
		Salmon River	Clayton 132965	1957-71	$\log Q_{50} = -1.148 + 1.275 \log \bar{Q}$
					$\log Q_{80} = -1.788 + 1.435 \log \bar{Q}$
					$\log Q_{95} = -1.908 + 1.446 \log \bar{Q}$
17	3				$\log Q_{10} = 0.575 + 0.956 \log \bar{Q}$
		Johnson Creek	Yellow Pine 133130	1957-71	$\log Q_{30} = -0.577 + 1.135 \log \bar{Q}$
		Panther Creek	Shoup 1330655	1957-71	$\log Q_{50} = -0.883 + 1.181 \log \bar{Q}$
		Salmon River	Challis 132985	1957-71	$\log Q_{80} = -1.104 + 1.213 \log \bar{Q}$
					$\log Q_{95} = -1.333 + 1.263 \log \bar{Q}$
18	3				$\log Q_{10} = 0.685 + 0.901 \log \bar{Q}$
		M.F.Salmon River	Capehorn 133085	1957-71	$\log Q_{30} = -0.332 + 1.067 \log \bar{Q}$
		Valley Creek	Stanley 132905	1957-71	$\log Q_{50} = -0.685 + 1.145 \log \bar{Q}$
		Salmon River	Salmon 133025	1957-71	$\log Q_{80} = -0.899 + 1.181 \log \bar{Q}$
					$\log Q_{95} = -0.931 + 1.166 \log \bar{Q}$

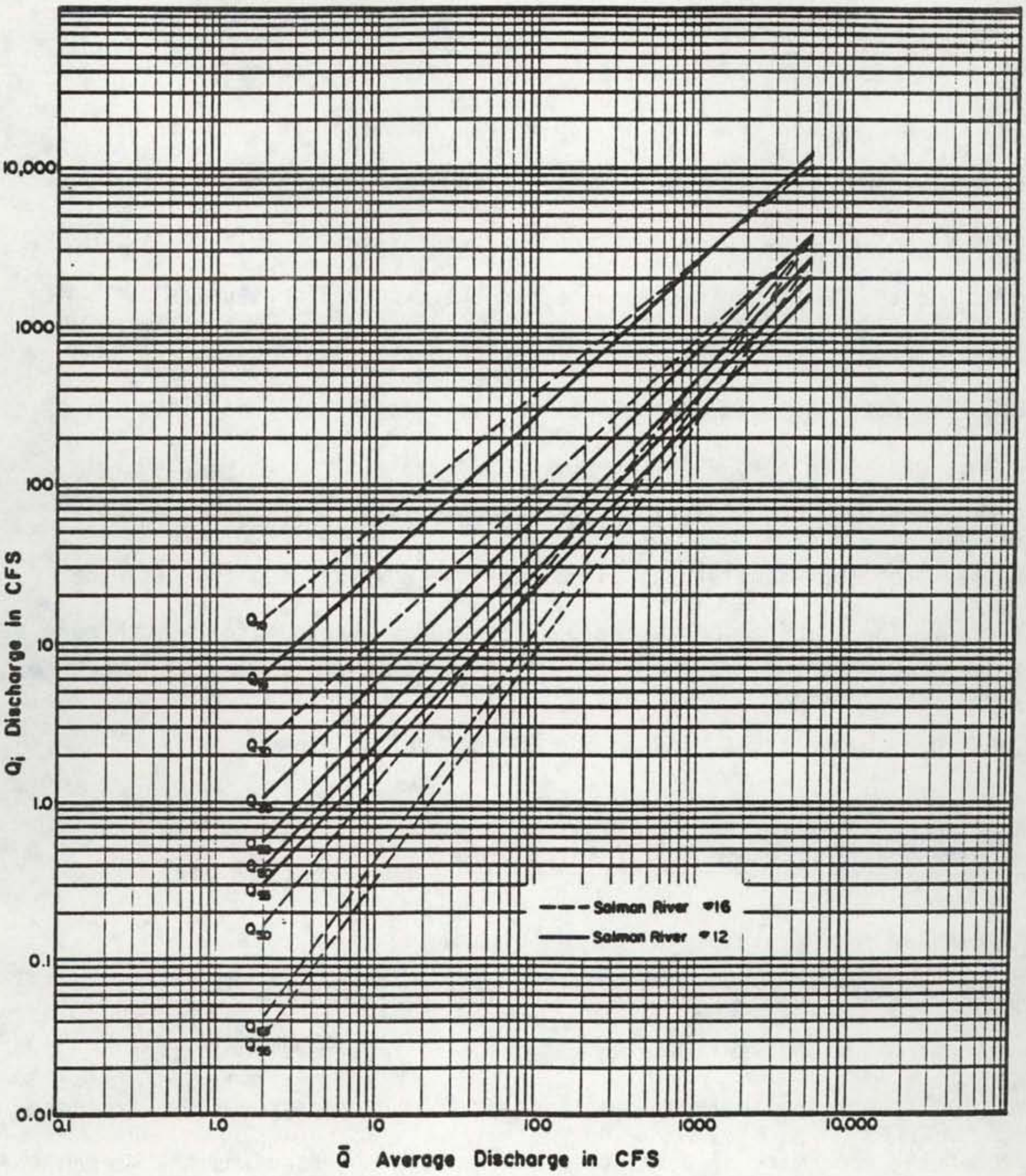

Figure 15. Parametric flow duration curves Set 12 and Set 16 (1957 - 1971) - Salmon River Basin

having average annual flows of 2, 10, 100, 1000 and 5000 CFS were assumed and the predicted values of the flow duration were computed or read from the curves using the various parametric curves and the appropriate regression equations. This was a similar analysis to that done in generating the comparison reported in Table 3 in the study of small basins in the Clearwater River drainage. Table 6 shows the variation in the predicted values of flow for two exceedance percentages of 10 percent exceedance and 30 percent exceedance for the two earlier studies by Heitz-1979 (Sets 10 and 11), the 10-station analysis using 1957-71 streamflow data (Set 12), three sets of six-station analysis (Sets 13, 14 and 15), and three sets of three-station analysis (Sets 16, 17 and 18).

There appears to be reasonably close agreement between the values obtained from the Heitz studies, the ten-gage analysis and the six-gage analysis. The combinations using 3 gage records appear to give much more variation between sets and in general appear to give higher predicted values than the Heitz studies or the 10-station analysis.

Economic Significance of Using Limited Records of Flow

Similar to the study made on the Clearwater River data, a preliminary benefit and cost analysis was made of a particular hydro power site to determine how the variation in magnitude of flow duration curves developed from a limited number of records from gaged streamflow stations affected the economics of development. The site selected was the Warren Meadows site on the Salmon River drainage. The site location is marked on Figure 12.

Table 6. Comparison of predicted duration values from parametric flow duration curves - Salmon River basin

Combination or Set No.	Average Discharge 2 CFS	10 CFS	100 CFS	1000 CFS	5000 CFS
	Values of Q_{10} - Flow at 10% Exceedance				
10	4.6	24.1	241	2450	12,000
11	7.25	33.43	297.7	2652	12,230
12	6.68	31.55	291.1	2685	12,691
13	5.64	28.12	279.9	2786	13,886
14	7.28	33.96	307.6	2786	12,999
15	5.76	28.25	274.8	2673	13,109
16	13.47	53.09	377.6	2685	10,581
17	7.29	33.96	306.9	2773	12,919
18	9.04	38.55	306.9	2443	10,418
	Values of Q_{30} - Flow at 30% Exceedance				
10	1.01	5.35	62.	705	3,900
11	1.00	5.46	62.38	712.4	3,908
12	1.04	5.62	62.95	704.7	3,813
13	1.16	6.08	64.86	691.8	3,619
14	0.99	5.40	61.09	691.8	3,773
15	1.18	6.15	65.46	696.6	3,638
16	2.33	10.64	93.33	818.5	3,734
17	0.58	3.61	49.31	673.0	4,181
18	0.98	5.43	63.39	739.6	4,119

Flows duration curves were developed and generated using parametric curves from Set 12 (the 10-station study utilizing data covering the period from 1957-71), Set 13 (a six-station study utilizing data covering the period 1957-71) and Sets 16, 17, and 18 (all three-station studies utilizing data covering the period 1957-71). The Hydropower Computerized Reconnaissance (HCR) Package developed by Broadus (1981) was again used to generate data on size of installations, power output and annual energy output. A portion of HYDRO ECON program of HCR was used to compute annual benefits and costs. The costs were estimated by using a sensitivity analysis of varying the capital investment cost in three different magnitudes of $1000/KW, $1250/KW and $1500/KW. An annual operation and maintenance cost of $0.001/KWH was assumed for computing annual costs. Similar assumptions as to number of units and as to the value of dependable energy and energy capacity were assumed as was done in the Clearwater River economic analysis. The results of the economic analysis are shown in Table 7 using as input the flow duration data from the different combinations of gages including Sets 11, 12, 13, 16, 17 and 18.

The results of economic analysis show that tendency in the Salmon River drainage that using a small number of gages gives inconsistent predictions of net benefit as indicated by the variation shown in Table 7 and much more variation in the net benefits than would be logical. Results of analyses using data from the ten-gage system of gages appears to be rather close to the results using data from the Heitz study and would tend to indicate that a representative sampling of the drainage's hydrologic variation has been achieved. Since this is rather an extreme case one might use this as a guide to accepting extrapolation of flow duration data in hydropower studies. Certainly more gages with longer

Table 7. Variation in economic returns using flow data from different parametric flow duration curves
Salmon River Basin

Combination or Set	Rated Power Capacity	Discount Rate	Total Annual Costs			Total Annual Benefits	Net Benefits		
			$1000/KW	$1250/KW	$1500/KW		$1000/KW	$1250/KW	$1500/KW
	KW	%	$	$	$	$	$	$	$
1	2	3	4	5	6	7	8	9	10
			Utilizing 25 ft. Head at Site						
Set 11	153.04	9	15,596	19,319	23,041	29,927	10,331	6,608	2,886
		12	19,697	24,446	29,194	29,927	5,229	1,481	-3,267
Set 12	152.72	9	15,556	19,280	22,995	26,051	10,486	6,771	3,056
		12	19,658	24,397	29,135	26,051	6,393	1,655	-3,084
Set 13	153.88	9	15,711	19,454	23,197	27,189	11,478	7,735	3,991
		12	19,835	24,609	29,383	27,189	7,354	2,580	-2,194
Set 16	218.44	9	21,949	27,263	32,577	24,886	2,936	-2,377	-7,691
		12	27,804	34,581	41,358	24,886	-2,918	-9,695	-16,472
Set 17	132.1	9	13,413	16,627	19,840	20,414	7,001	3,787	574
		12	16,954	21,053	25,152	20,414	3,460	-639	-4,738
Set 18	156.7	9	15,969	19,781	25,593	26,744	10,774	6,963	3,151
		12	20,169	25,030	29,892	26,744	6,575	1,713	-3,148
			Utilizing 100 ft. Head at Site						
Set 11	612.18	9	62,386	77,277	92,169	103,708	41,322	26,430	11,539
		12	78,792	97,785	116,778	103,708	24,915	5,922	-13,070
Set 12	607.34	9	61,893	76,666	91,440	103,331	41,438	26,665	11,891
		12	78,170	97,012	115,855	103,331	25,162	6,319	-12,524
Set 13	615.50	9	62,842	77,814	92,786	108,755	45,913	30,941	15,969
		12	79,337	98,433	117,529	108,755	29,418	10,322	-8,774
Set 16	868.76	9	87,297	108,430	129,562	99,049	11,751	-9,381	-30,514
		12	110,580	137,533	164,487	99,049	-11,531	-38,485	-65,438
Set 17	525.48	9	53,336	66,118	78,901	80,844	27,508	14,726	1,944
		12	67,419	83,722	100,025	80,844	13,425	-2,878	-19,181
Set 18	623.18	9	63,500	78,659	93,817	106,108	42,608	27,449	12,290
		12	80,201	99,535	118,869	106,108	25,907	6,573	-12,762

records will always be desirable. Three gages cannot adequately represent basin hydrologic variation. In addition, caution should be used in extrapolating down to small flow sizes of drainages.

CONCLUSIONS AND RECOMMENDATIONS

This study of methods of extrapolating gaged flow information to ungaged locations has been helpful to obtain better ways of estimating flows for study of hydropower potential and for possible use in hydropower feasibility studies.

The relatively new development of using parametric flow durations to predict flows for hydro power analysis needed to be tested with limited amounts of gaged data. The analysis of small-basin flow data using short periods of record and limiting the number of gaged stations has shown the variations in estimates of flow that can be expected.

The study of flow duration curves for individual months has shown that there is considerable variation in the shape of the duration curve from month to month. Dimensionless flow duration curves used to illustrate this variation in Figure 6 could be used to predict flow duration once monthly average flor data were calculated. Dimensionless flow deviation plots of the twelve small gaged streams in the Horse Creek watershed show a similar pattern of the flow duration curves and again show what wide variation in flow values can be expected for particular exceedance percentages. A brief inspection of the various duration curves that are compared in this study tends to indicate that there is relatively less variation in the values of flow at the 30 percent exceedance value. This is indicated in Figure 7 by the 'pinched-down' variation of the enveloping curves and also on Figure 6 where the variation curves pinch together and tend to cross one another. A real explanation for this phenomenon is not apparent.

The study of flow duration curves of the Clearwater River on an annual basis using mean daily flow values with shorter periods of record and different periods of record did not show a significant variation in the predicted values for flow duration curves. One might expect such a result because the hydrologic variation in the Clearwater River is not great.

Comparison of data from Heitz studies on the Clearwater River with these studies of including small basin flow data would indicate that in the small basin predictions (average flows less than 100 CFS) the Heitz-Emmert studies would tend to give too high of values for the Q_{10} flows and too low of values for Q_{30}, Q_{50}, Q_{80}, and Q_{95}. Because the Heitz records were of longer duration it is difficult to say that all the variation is due to including small basin data. Some of the variation may be due to variation caused by longer-time records compared with short-time records of this study. The length of records for the flow data from small basins used is relatively short so longer records are needed from small basins to provide a better basis for developing a suitable parametric flow duration curve that will apply over a wide range of watershed sizes.

A demonstration of the effect of variation in predicted flow duration values at a representative potential small-scale power site, the Red Horse site in the upper portions of the Clearwater River, shows that variation in predicted flow values can make several thousands of dollars difference in net benefits that will result. However, more variation in economic viability is caused by varying the interest rates. In these studies the data from shorter periods of records tended to over estimate values of power capacity and at the same time give greater inconsistency in the revenues to be expected and variation in the net benefits that were predicted.

The studies in the Salmon River basin of Idaho, choosing a very few stations on which to base development of parametric flow duration curves, indicate that sets of six to ten gages selected to give good geographic distribution of the gaged records and also a selection that represents different sizes of drainages give a rather consistent prediction of flows at ungaged locations. Caution should be exercised, however, in trying to extrapolate down to very small drainage basins where average annual flows are less than 10 CFS. This limited study of a very particular basin should not be used as proof that six to ten gages give an adequate sampling of variation in a hydrologic basin but because of the extreme variation in precipitation distribution in the Salmon River Basin, this study does give encouragement to the efficacy of using parametric flow duration curves in predicting flow variation at ungaged sites when a few good records of flow are available for periods of at least ten years.

The demonstration of the effect of variation in predicted flow duration values at a representative small-scale power site on the Salmon River basin shows that using too few of gages will cause considerable opportunity to over estimate or under estimate the net benefits. The variations one might expect are shown in Table 7.

Recommendation is made that more effort be made to obtain data from smaller drainage basins with longer record and different hydrologic regimes to determine how much variation occurs in parametric flow duration curves. Studies to date appear to be limited to areas of the Pacific Northwest United States.

More effort should be made to try to find characteristics of watersheds that might be factors that influence the variation in the regressions that are apparent in development of the logarithmic expressions for parametric flow duration curves.

As an academic matter an explanation should be sought for why there is less variation in the values of flow at the 30 percent exceedance percentages for flow duration curves studied in the river basins of Idaho.

A final recommendation is a caution that extrapolation using parametric flow duration curves is by its very nature a process that tends to give average values of a hydrologic process, therefore use of parametric flow duration curves for basins and flows that are not representative of average conditions should be treated with much care and not used to represent rather exact or precise values.

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16. *Abstract*

This report has defined methods of extrapolating hydrologic data for use in hydropower feasibility studies. Two large drainage basins in Idaho were studied and the measured flow data from various streams in those basins were used to develop parametric duration curves similar to those developed by Heitz at the University of Idaho in earlier studies.

Comparison studies made in the report defined the general limits of curve extrapolation and indicated the required flow data input for making acceptable flow duration analysis. In addition, the economic consequences of using different predicted values of flow duration were demonstrated.

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