Research Technical Completion Report

ENHANCEMENT OF DURATION CURVE PREDICTION USING SHORT TIME LOW FLOW MEASUREMENTS

by

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May, 1984

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ABSTRACT

This report presents an analysis of the year-to-year and day-to-day variation of low-flow stream discharge used in small-scale hydroelectric power projects. Primary use was made of flow duration procedures. Past streamflow gaging records were used to evaluate the variation over time as well as the variation of simultaneous measurements at different sites. Methodologies were developed for determining the low flow percentage exceedance values at an unagaged site using a single streamflow measurement coupled with knowing the exceedance percentages at gaged streamflow sites in the area. A major contribution of this methodology is a means of estimating the confidence bounds of the estimates made. The report also includes a number of field measurements of unregulated streams in northern Idaho for which interest in hydropower development has been shown or where streams were thought to be indicators of smaller basin behavior.

FORWARD

The Idaho Water and Energy Resources Research Institute provided the 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 fields of hydrology and hydroelectric power engineering. Primary emphasis was placed on the use of one or several simultaneous field measurements to predict long-term flow duration characteristics at a particular site. The Institute encourages careful consideration of the report findings as well as other techniques developed for extending limited hydrologic data.

INTRODUCTION

Recent increases in the value of power as well as recent federal legislation have generated new interest in hydroelectric power generation. Many sites that have been in the past uneconomical to develop are now becoming feasible. Federal legislation has allowed increased opportunity for the private sector to enter into the business of hydroelectric power production and has at times provided federal aid or loans to encourage new hydropower development. Emphasis has switched from large facilities with impoundment reservoirs to small systems with less environmental impact.

This renewed interest in hydropower has called for the evaluation of many smaller, ungaged watersheds for which little or no flow information is available. Project planning is often too limited and time too short to afford the installation of stream gaging to monitor actual flows. As a result, flow magnitudes, and their variation in time, must be modeled or predicted, many times with little or no actual on-site flow data. One important mathematical tool used in analyzing the time availability of flow is the flow duration curve. Flow duration values are simply the percentage of time particular flows were equalled or exceeded during a certain period of record. To facilitate a better understanding of the material covered in this report, a glossary of technical terms used is located on page 66.

Prediction of the flow variation of ungaged streams, in particular the flow duration characteristics, have been an area of extensive research at the University of Idaho. In 1979, a resource survey of low head hydroelectric power potential in the Pacific Northwest (Gladwell, Heitz, and Warnick, 1979) was completed. This survey contained several methods of predicting flow duration for ungaged watersheds. For ungaged, unregulated streams in Idaho and Oregon, a parametric curve approach was used, wherein the discharges at various exceedance percentage values are predicted using an estimate of the average or total annual runoff and the behavior of gaged streams at the particular exceedance percentage values. In Washington, normalized or dimensionless flow duration characteristics were taken from U.S. Geological Survey data for certain gages and assigned to all ungaged sites in an assumed area of influence for each gage. Flow duration characteristics for ungaged streams in Montana were taken from smoothed or generalized curves from one or more surrounding gages.

Several later studies (Warnick and Filler, 1982), (Filler and Warnick, 1982) evaluated the applicability of the earlier developed methods. Each of these later studies revealed both weak and strong points of each of the methods, but one underlying weakness in all the methods was the lack of a tie to actual measured flows in the stream of interest. It was believed that the estimates from the parametric curve approach or the direct scaling (normalizing) approach could be improved upon using a limited number of field measurements at the ungaged sites. In particular, it was felt that such field measurements would be most effective if taken during periods of low flow as these periods would be the most free from individual basin response to spring snowmelt. Additionally, it was found that more accurate estimates of low streamflow were needed to predict power and energy production potential during the low flow periods. Other researchers had shown low flows to be the least predictable among small stream characteristics (Thomas and

Benson, 1970; Tuthill, 1974, and Riggs, 1972).

The first objective of this research effort was to study the year-to-year and day-to-day variation of low streamflows and to determine if a period or time of year exists that would be the best indicator of low flows.

The second objective of this project was to develop methods of using measurements during the low flow period to enhance previous predictions of ungaged flow using the parametric or normalizing duration curve techniques.

A third objective of this research effort was to actually make a number of field flow measurements on a number of ungaged streams in Northern Idaho. These streams were selected on the basis of their potential use for hydroelectric development or their use to evaluate the methodology developed and to provide information for larger ungaged regions in Northern Idaho.

LITERATURE REVIEW

Literature has shown that the low-flow or base-flow characteristics of small streams are the least predictable of streamflow characteristics (Thomas and Benson, 1970; Tuthill, 1974; and Riggs, 1972). A number of authors have provided regression equations relating low flow characteristics to basin characteristics (i.e., Thomas, C.A. and Harenberg, 1970; Thomas, D.M. and Benson, 1970; Tuthill, 1974; and Riggs 1972). The majority of the work in predicting low flows, including those referenced above, have been in predicting duration-recurrence interval minimum flows such as the 20-year 7-day minimum flow. Riggs (1972) shows a relationship between duration-recurrence interval minimum flows and the percentage exceedance values of such flows for a number of watersheds. A number of authors have, however, produced equations relating flows at particular percentage exeedance to drainage basin characteristics (Thomas and Benson, 1970; Benson, 1970)

The variability of low flow behavior can be pointed out by studies done by Warnick and Filler (Warnick and Filler, 1982, Studies of. . .). Figure 1 shows predicted long-term flow duration curves for a particular ungaged watershed based on two nearby stream gages. The duration curves shown were obtained by normalizing (dividing by average annual flow) the flows at particular percentage exceedances, and then multiplying these values by a predicted average annual flow for the ungaged basin. Also shown in the figure is a plot of flow duration curve constructed from parametric curves developed from a regional relationship between flows at various percentage exceedances and the average annual flow. The parametric duration curve relationships were obtained from an earlier study by Warnick, Heitz, and Filler (1982). In the case of

Figure 1, the flow at the 90 percent exceedance level, for example, predicted using one gage is nearly four times as great as that predicted using the other gage. The estimates in Figure 1 were made using identical estimates of average annual runoff for the ungaged stream, further pointing out the potential variability of specific, or in this case, normalized low flows. Figure 2 shows the normalized flow duration values used in the prediction. Figure 3 shows the location of the ungaged watershed in relationship to the two gaged watersheds used. It should be noted that one gaged site is quite close in physical location and one gaged site has a similar drainage area. Even though there is similarity in physical characteristics of the two gaged sites, there is a large difference in the dimensionless curve values for the two gaged sites.

A number of references indicate the use of field measurements or estimations to predict flows and consequently flow duration curves (Crawford and Thurin, 1981, and Klingeman, 1980). These references, however, require enough data to compute flow duration values directly by arranging the flows in order of magnitude and computing the percent of time equalled or exceeded.

McKinney, Warnick, and others (1983) show how measurements of ungaged streamflow may be related to a nearby gage for duration of ungaged flow duration values. Correlation numbers, or the ratios of ungaged streamflow to simultaneous discharge at the gaged stream are computed and compared. If a good relationship exists between the two streams, the correlation numbers calculated will be approximately equal. Additional gaged flows can then be used with an average

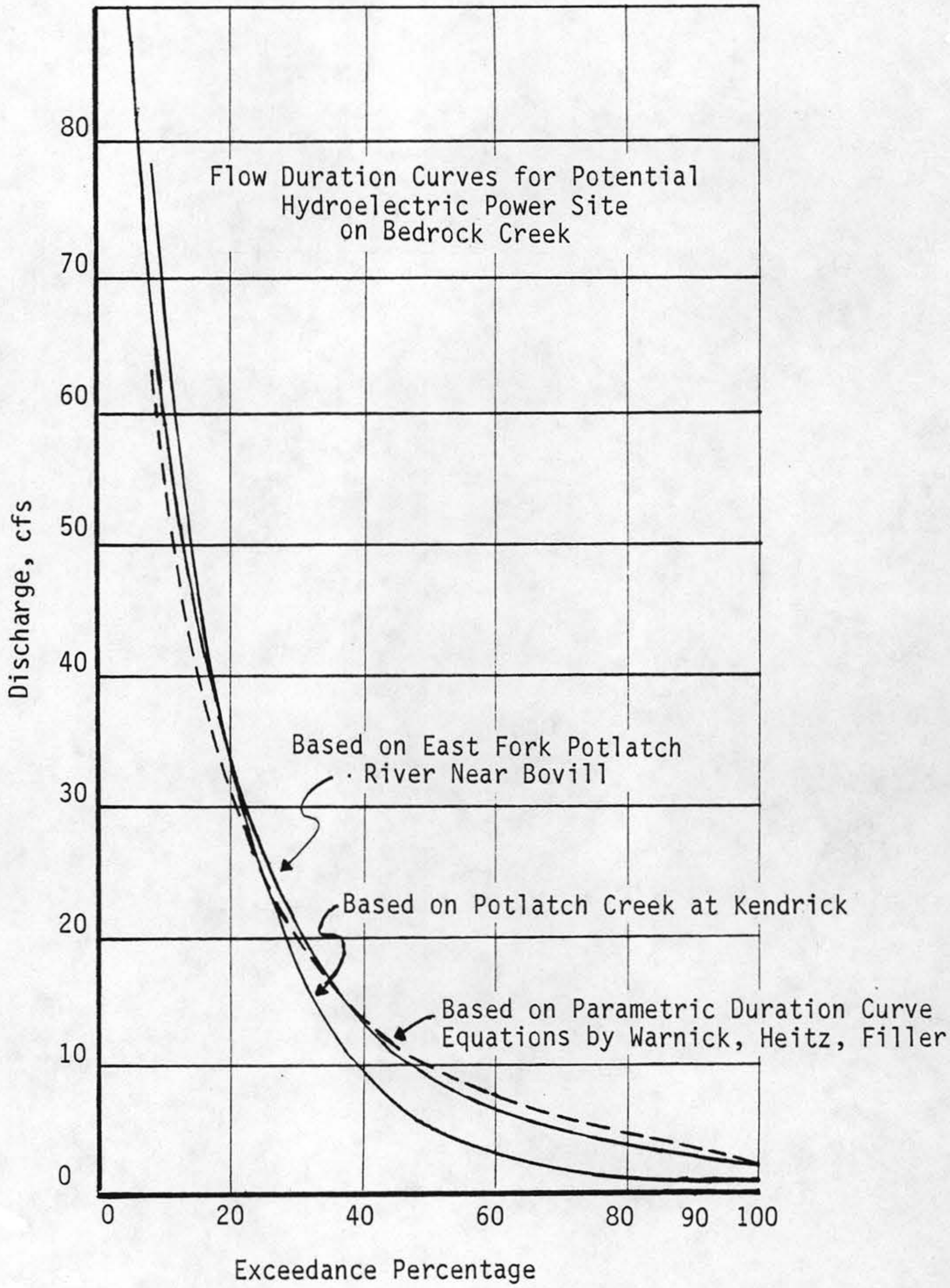

Fig. 1. Predicted Flow Duration Curves for a Potential Small-Scale Hydroelectric Power Plant. Source: Warnick and Filler, 1982, Studies of ....

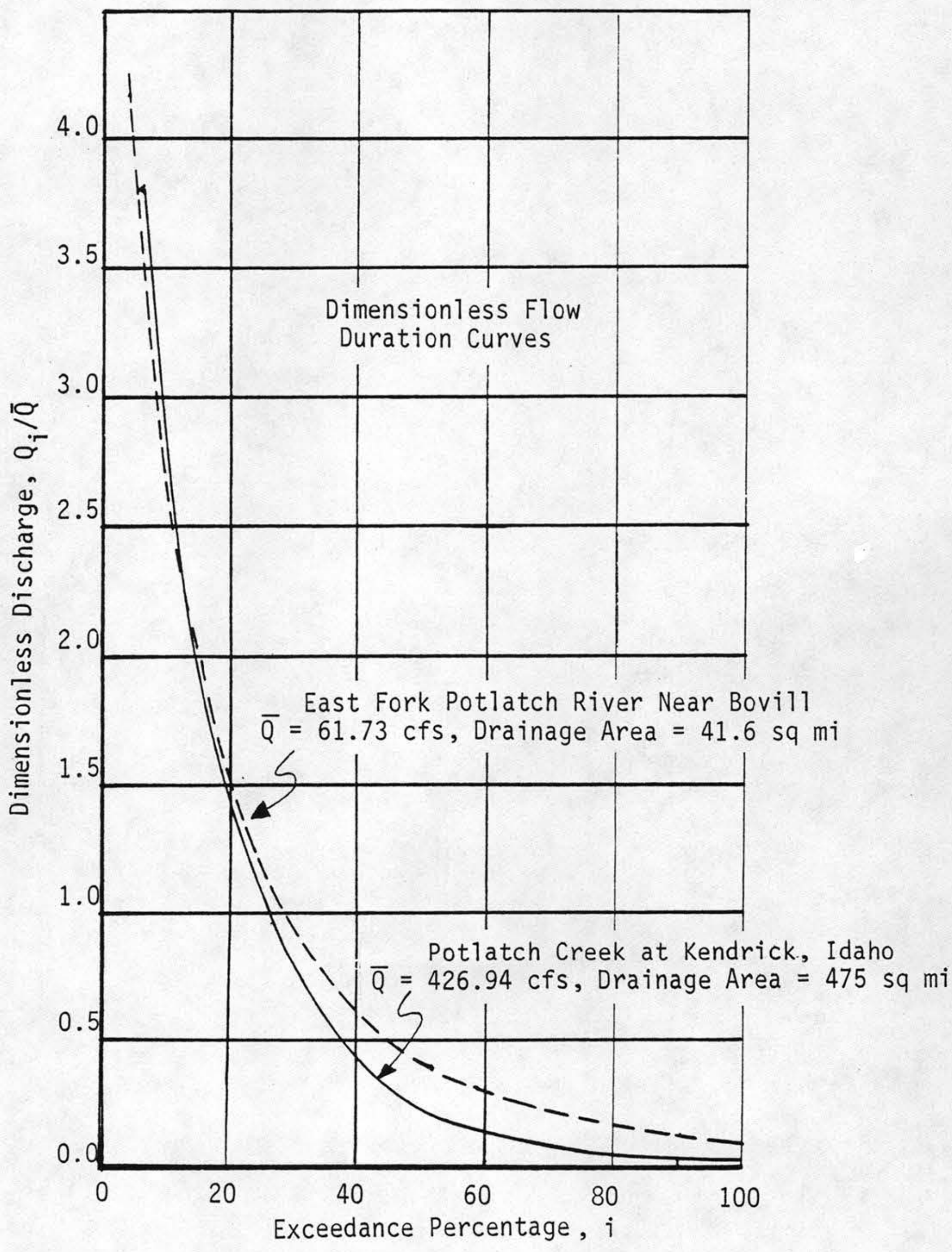

Fig. 2. Dimensionless Flow Duration Curves.
Source: Warnick and Filler, 1982, Studies of ...

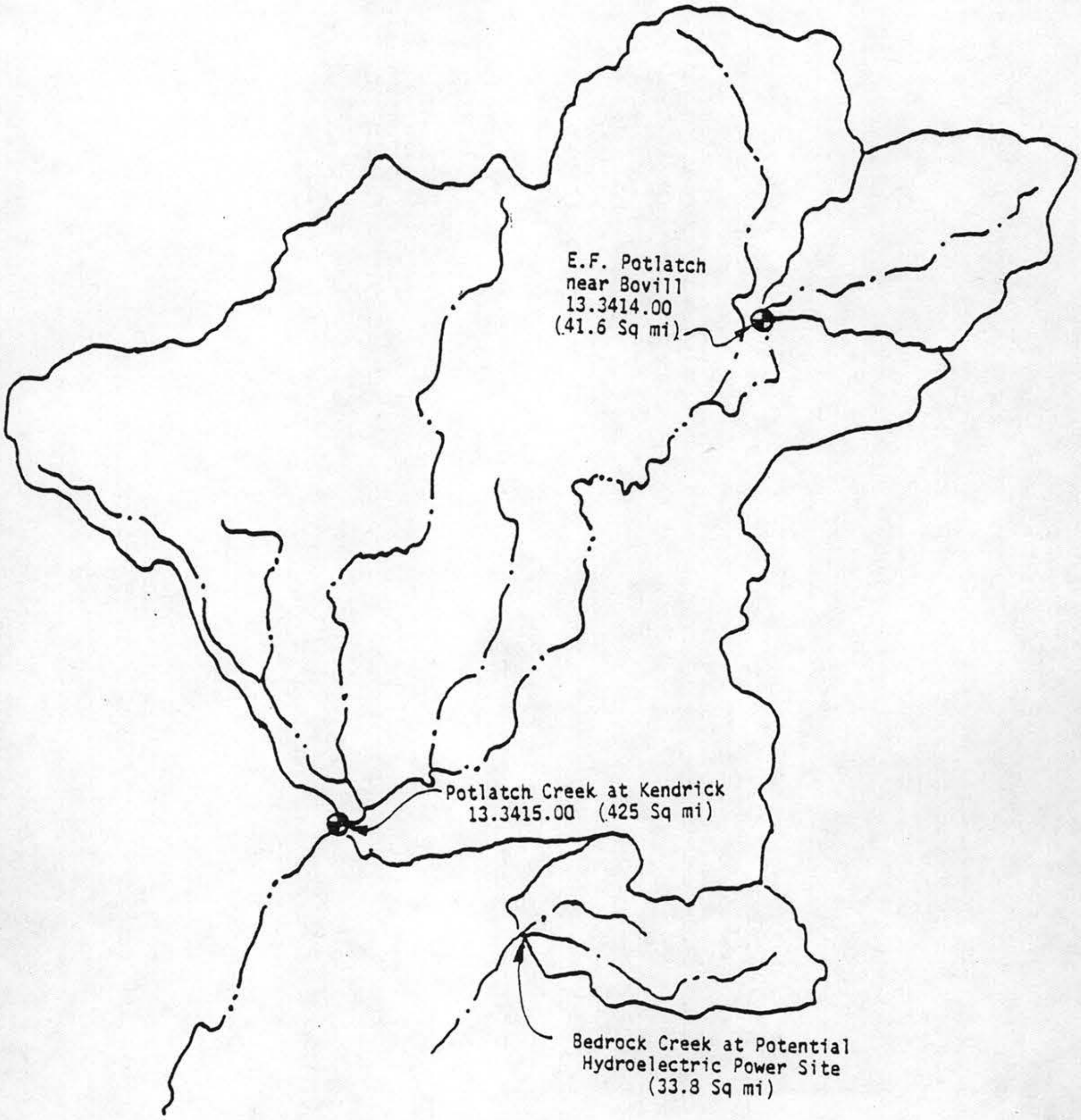

Fig. 3. Map Showing the Location of Two Gaged and One Ungaged Streamflow Sites.

correlation number to predict ungaged flows.

The correlation number technique, while taking advantage of a few field measurements at an ungaged site, is only applicable to similar streams. McKinney, Warnick and others (1983) suggest that correlation numbers not differ more than 0.15 for there to be a good relationship.

Whereas literature has provided relationships between certain low flow characteristics and drainage basin characteristics, these relationships could only be weakly defined (Thomas and Benson, 1970). Estimates using such relationships would tend to be average over the pool of gaged data used to establish the relationships, where, with small streams in particular, the differences may be relatively large.

Where enough streamflow data can be collected or estimated for an ungaged site, a flow duration curve may be predicted by arranging the flows in order of magnitude. Such resulting flow duration data reflects flow behavior for the period of measurement only. Quite often, flow duration data representing long-term average or critical low-flow conditions is desired, and there is, therefore, the need to extrapolate flow duration data to different periods of record.

Essentially no literature was found applicable to the use of a relatively small number of field flow measurements to predict overall stream behavior where the gaged and ungaged streams have potential or known dissimilarities. Needed, therefore, is a method utilizing a small number of ungaged flow measurements to estimate overall ungaged flow behavior and to fit previous predictions made without measurements where potential exists for the ungaged and surrounding gaged streams to behave differently.

ANALYSIS OF THE YEAR TO YEAR, DAY TO DAY, AND GAGE TO GAGED VARIATION OF LOW FLOWS

In an effort to evaluate the usefulness or reliability of using a small number discharge measurements in ungaged streams to predict the exceedance percentage characteristics of that stream, the flow duration exceedance percentage behavior of a number of gaged streams in Northern Idaho was evaluated for a 30-year period. Six gaged streams were selected on the basis of representing diversity within the Northern Idaho region as well as being able to provide data from a common 30-year study period. The location of the gages on these six streams is shown in Figure 4. The gage numbers, names and drainage areas for the six gages are listed in Table 1. Simultaneous flows were studied for particular days over the 30-year period. Nine dates were selected at approximately 10-day intervals through the summer and fall low flow period that were believed would adequately portray flows during that period. The selection of only nine dates reduced the overall computations required. As it was the intention that simultaneous streamflows could be related through simultaneous percentage exceedance behavior, percentage exceedance values for flows on the nine dates were calculated for each year of the 30-year period. Table 2 shows the flow exceedance percentage values for the flows on July 20 for the six gages selected. These values were calculated by taking the actual daily average streamflow (discharge) for those dates and determining what percentage of the time during the 30-year period that these particular flows were equalled or exceeded. The average daily streamflow values are shown in Table 3. Dates previous to July 20 were not used because of the varied effect of snowmelt in the higher elevation watersheds.

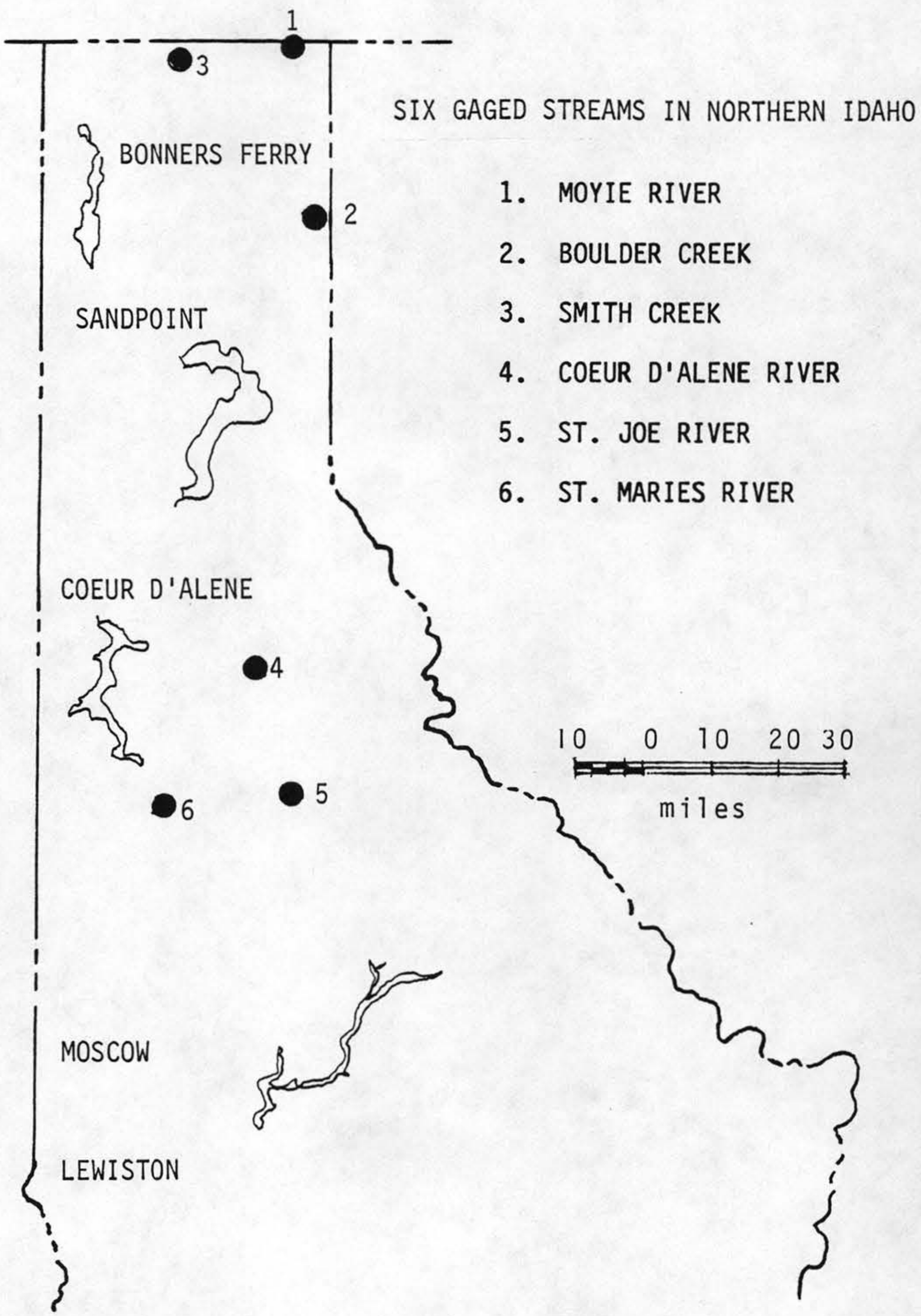

Fig. 4. Map Showing the Location of Six Gaged Streams in Northern Idaho.

Table 1. Sample Streamflow Gages in Northern Idaho.

Gage No.	Gage No. (USGS)	Name	Drainage Area (sq mi.)
1.	12.3065.00	Moyie River at Eastport, Idaho	570
2.	12.3055.00	Boulder Creek near Leonia, Idaho	53
3.	12.3210.00	Smith Creek near Porthill, Idaho	70
4.	12.4135.00	Coeur d'Alene River near Cataldo, Idaho	1220
5.	12.4145.00	St. Joe River at Calder, Idaho	1030
6.	12.4150.00	St. Maries River at Lotus, Idaho	437
		Additional Streamflow Gages	
A.1	12.3923.00	Pack River near Colburn, Idaho	124
A.2	12.3924.00	Rapid Lightning Creek near Samuels, Idaho	45
A.3	12.3075.00	Moyie River at Eileen, Idaho	755
A.4	12.3125.00	Boundary Creek near Porthill, Idaho	97

Table 2. Exceedance Percentage Values for July 20, Water Years 1931 Through 1960.

Water Year	Gage Number[a]					
	1	2	3	4	5	6
1931	61.73	90.55	66.60	87.84	65.04	94.72
1932	43.45	67.99	50.01	61.85	48.82	68.07
1933	31.41	44.50	28.51	54.65	43.58	65.00
1934	53.50	95.98	71.44	74.99	68.53	81.01
1935	33.16	57.40	36.21	63.33	51.62	70.87
1936	68.41	85.22	83.65	68.26	58.38	72.59
1937	39.02	52.45	49.27	63.89	53.45	72.81
1938	39.32	63.27	44.83	65.73	49.84	77.66
1939	43.05	67.99	50.60	70.32	56.11	75.95
1940	76.36	93.60	88.31	85.48	71.12	95.77
1941	55.90	72.36	50.60	74.91	61.54	70.50
1942	25.28	37.10	30.81	53.10	44.10	52.90
1943	27.70	47.66	30.37	52.48	34.40	55.04
1944	63.31	85.22	73.44	81.77	63.94	85.77
1945	45.03	70.71	48.54	67.53	54.07	76.47
1946	36.67	48.70	32.86	63.46	49.64	68.07
1947	45.90	61.87	50.99	68.08	51.15	72.59
1948	29.43	35.44	34.12	37.14	29.74	40.72
1949	49.00	61.87	55.99	65.94	56.17	68.85
1950	25.19	26.72	21.73	41.22	27.42	45.09
1951	29.36	50.30	36.05	62.04	46.85	69.44
1952	36.97	48.30	46.40	59.94	46.19	60.42
1953	37.32	60.70	34.12	57.85	44.95	64.23
1954	23.48	29.95	20.26	51.41	36.70	60.67
1955	27.07	35.79	23.80	47.51	29.49	48.85
1956	35.41	50.30	33.28	56.81	44.95	60.12
1957	53.25	64.46	51.88	58.40	48.54	65.64
1958	55.54	67.99	60.89	68.77	53.98	62.11
1959	34.60	52.45	40.15	55.65	42.00	64.31
1960	42.97	57.40	44.83	61.78	50.34	69.33

a. Gage numbers throughout text refer to those as indicated in the first column of Table 1.

Table 3. Streamflow Discharge Values for July 20, Water Years 1931 through 1960.

Water Year	GAGE 1	GAGE 2	GAGE 3	GAGE 4	GAGE 5	GAGE 6
1931	138.00	10.00	34.00	354.00	632.00	44.00
1932	238.00	19.00	55.00	737.00	1010.00	96.00
1933	433.00	45.00	144.00	960.00	1210.00	107.00
1934	168.00	8.00	30.00	480.00	582.00	67.00
1935	398.00	27.00	95.00	694.00	909.00	87.00
1936	118.00	12.00	20.00	576.00	747.00	82.00
1937	291.00	32.00	56.00	681.00	855.00	81.00
1938	288.00	22.00	86.00	632.00	978.00	73.00
1939	242.00	19.00	54.00	542.00	795.00	76.00
1940	96.00	9.00	16.00	372.00	546.00	41.00
1941	159.00	17.00	54.00	482.00	686.00	89.00
1942	656.00	61.00	126.00	1020.00	1200.00	171.00
1943	544.00	39.00	130.00	1050.00	1720.00	158.00
1944	132.00	12.00	28.00	410.00	650.00	58.00
1945	224.00	18.00	58.00	595.00	838.00	75.00
1946	330.00	37.00	114.00	693.00	984.00	96.00
1947	216.00	23.00	53.00	581.00	928.00	82.00
1948	483.00	65.00	107.00	1880.00	2100.00	300.00
1949	191.00	23.00	45.00	630.00	790.00	94.00
1950	658.00	110.00	228.00	1610.00	2360.00	242.00
1951	437.00	35.00	96.00	732.00	1090.00	91.00
1952	324.00	38.00	62.00	796.00	1110.00	126.00
1953	319.00	24.00	107.00	860.00	1160.00	110.00
1954	750.00	90.00	261.00	1090.00	1580.00	125.00
1955	572.00	65.00	194.00	1270.00	2130.00	201.00
1956	353.00	35.00	111.00	892.00	1150.00	128.00
1957	170.00	21.00	51.00	844.00	1020.00	104.00
1958	160.00	19.00	39.00	567.00	840.00	120.00
1959	369.00	32.00	79.00	930.00	1300.00	109.00
1960	243.00	27.00	66.00	738.00	953.00	92.00

Streamflow runoff has been shown to experience a shift in runoff timing between gages according to basin elevation. (Warnick and Filler, 1982, Studies of. . .). Dates after October were not used due to the varied effect of increased precipitation during these months occurring as either rain or snow. It is recognized, however, that low streamflows do occur during the late fall and winter months as a result of continued dry or freezing conditions. This research effort did not study winter low flows as obtaining field measurements for study and future application would be relatively difficult.

Table 4 shows average flow percentage exceedance values for the nine dates selected and illustrates that flow percentage exceedance values tended to increase from July to September and then decrease from September through October. The increase corresponds to the tendency for streamflow discharges to decrease and hence be equalled or exceeded a greater percentage of the time. The decrease in the percentage exceedance values after September, reflects increased flows due to autumn precipitation.

The overall average exceedance percentage values and the 95 percent occurrence intervals (the intervals on which 95 percent of the observed data fell) are tabulated in Table 5 and illustrated in Figure 5. The broad bounds for the 95% interval is due to year to year variations in runoff and the occurrence of randomly distributed summer rainfall events. Either of these two factors can cause a rather broad range of percentage exceedance flows to occur over a long period of time on any single day of the year.

As can be seen in Table 2 or Tables A-1 through A-8 in Appendix A, relatively high percentage exceedance values experienced in a

Table 4. Average Flow Percentage Exceedance Values for Water Years 1931 Through 1960.

	July	August			September			October	
Gage	20	1	10	20	1	10	20	1	10
1	42.29	56.45	65.57	75.47	78.36	79.98	79.97	79.53	75.82
2	59.47	72.88	80.18	85.77	85.30	84.27	81.90	80.40	74.00
3	46.35	64.22	73.83	83.69	83.48	79.84	77.59	73.91	70.58
4	62.74	70.37	75.76	80.80	83.00	83.66	83.31	84.38	81.47
5	49.42	59.38	66.92	74.53	79.42	80.86	82.32	83.45	80.45
6	67.85	76.10	81.96	84.98	85.70	83.92	84.18	82.97	77.88
Total Average	54.69	66.57	74.04	80.87	82.54	81.92	81.55	80.77	76.70

Table 5. Ninety-five Percent Occurrence Intervals for Percentage Exceedance Values of all Six Gages for the Nine Dates Shown, Water Years 1931 Through 1960.

Date		95 Percent Percentage Prediction Interval Exceedance Values: Lower Bound	95 Percent Percentage Prediction Interval Exceedance Values: Upper Bound	Total Average Exceedance Percentage
July	20	24.50	92.08	54.69
August	1	34.68	97.42	66.57
	10	44.93	98.88	74.04
	20	50.54	99.37	80.87
September	1	48.33	99.77	82.54
	10	45.63	99.50	81.92
	20	30.29	97.46	81.55
October	1	28.35	98.80	80.77
	10	19.81	98.84	76.70

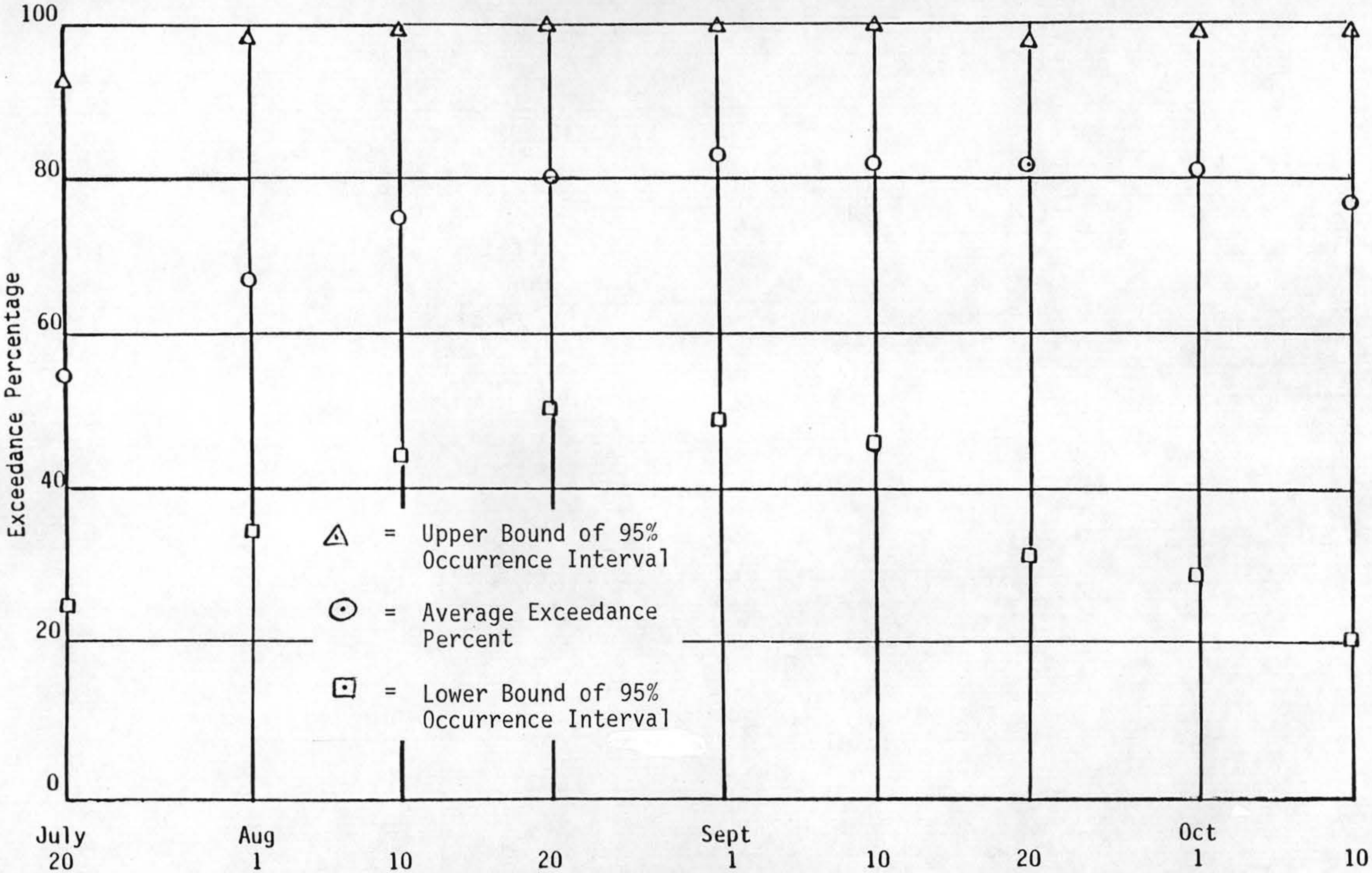

Fig. 5. Overall Average Percentage Exceedance Values and Ninety-five Percent Occurrence Intervals for All Six Gaged Streams for Each of Nine Dates, 1931 Through 1960 Water Years

particular year by one or several gages on a particular day during a particular year were simultaneously experienced by the other gages as well, and likewise with lower exceedance values. Such tendencies for all the gages to be relatively high, low, or average at a particular point in time reflects the total region response to varying weather or runoff conditions.

If the six gaging stations used in the analysis can be assumed to be distributed 'randomly' throughout the study region, then their corresponding percentage exceedance values for a particular day and year can be assumed to represent a random sample of percentage exceedance values of all gaged or ungaged streamflow in the region on that day during that year. The spread (or dispersion) of the percentage exceedance values for the gaged flows, likewise, can then be used as a measure or sample of the spread of all gaged or ungaged percentage exceedance values for that particular day during that year. The sample standard deviation was used as a measure of this spread of simultaneous percentage exceedance values. Sample standard deviations for the simultaneous percentage exceedance values for the nine dates over the 30-year period are shown in Table 6. The average values in Table 6 indicate that spread of percentage exceedance values between gages tended to be the least near September 1.

It can also be seen from comparing Tables 4 and 6 that spread values tended to decrease with increasing percentage exceedance values.

In an effort to use the gaged data to evaluate the spread of ungaged flow, the six gages were again considered to produce a random sample of flow (gaged or ungaged) on any particular day. One gaged percentage exceedance value was used as a 'dummy' value whose value was

Table 6. Sample Spread (Standard Deviation) Values for the Six Gages or Nine Dates for Water Years 1931 through 1960

	July	August			September			October	
Year	20	1	10	20	1	10	20	1	10
1931	14.807	10.295	7.541	2.787	0.798	8.706	2.891	5.971	3.776
1932	10.637	9.829	11.692	9.038	7.934	6.733	7.057	1.789	2.415
1933	13.792	11.208	10.429	12.028	9.759	7.249	5.243	5.425	4.127
1934	14.069	9.829	7.941	3.589	2.140	5.164	3.232	11.957	11.547
1935	14.953	14.055	13.292	8.188	9.080	7.381	3.678	1.735	2.232
1936	10.197	9.972	9.684	6.460	4.420	3.023	1.707	3.399	3.695
1937	11.775	10.361	8.784	6.236	4.843	4.539	3.426	1.002	1.889
1938	14.519	12.227	10.104	6.741	5.276	13.424	3.332	9.897	8.574
1939	12.750	10.032	7.930	5.477	2.387	1.733	1.195	4.127	2.408
1940	9.680	4.222	3.611	2.106	1.050	1.497	8.538	0.790	2.466
1941	9.817	6.418	6.324	6.657	3.767	15.630	20.897	13.850	7.440
1942	11.511	13.638	17.198	13.783	9.400	10.669	9.000	26.474	17.904
1943	11.885	12.422	9.886	9.560	5.774	5.679	4.284	7.811	7.001
1944	10.254	7.788	5.852	3.650	1.494	0.845	12.213	2.745	4.145
1945	12.902	8.660	7.388	5.855	3.719	3.730	8.930	10.899	10.900
1946	14.007	10.481	6.916	5.748	5.346	5.011	5.949	6.505	1.956
1947	10.685	9.406	9.828	6.534	6.661	12.996	9.062	7.453	7.565
1948	4.359	5.596	5.361	6.737	7.050	7.308	7.258	11.836	17.324
1949	7.322	5.625	6.096	3.573	3.791	3.920	7.397	3.929	11.647
1950	9.524	8.315	7.590	6.897	5.862	4.242	4.534	1.849	6.457
1951	15.150	12.685	10.403	7.410	17.661	13.621	9.863	3.479	15.794
1952	9.022	8.211	6.192	6.734	5.330	4.437	4.175	17.047	20.345
1953	12.782	9.694	9.756	4.756	6.191	3.430	1.889	3.330	2.763
1954	16.004	11.944	9.221	7.945	10.736	10.592	8.600	19.990	4.933
1955	10.645	12.168	9.393	6.646	5.876	5.108	5.413	8.076	6.595
1956	11.007	7.014	6.604	6.053	7.708	5.873	5.314	8.087	10.727
1957	6.988	8.485	8.130	4.881	5.534	4.600	6.969	7.556	5.402
1958	6.129	5.974	6.026	6.730	6.336	3.484	7.256	4.532	5.489
1959	11.147	8.612	8.214	5.148	6.089	16.002	22.130	6.019	12.296
1960	10.248	6.708	7.081	4.492	3.646	8.737	5.899	13.922	8.742
Total Average	11.186	9.396	8.482	6.415	5.855	6.845	6.911	7.716	7.618

predicted, for example, by taking the average of the remaining five gaged values. Predicted and observed percentage exceedance values were then compared.

To construct 95 percent occurrence intervals, all combinations of actual percentage exceedance values, X_i, for any one gage versus the corresponding averages of all remaining gages, $X_{j,\ j \neq i}$ were tabulated. These values divided into classes according to the averages of the remaining gages. Occurrence intervals were determined using the cummulative frequencies of ranked observed values. Next the tabulated values were grouped according to the values of the remaining gage average exceedance values ($X_{j,\ j \neq i}$). For example all values of X_i whose $X_{j,\ j \neq i}$ values were between 20% and 30% were assigned to one group. Another group with $X_{i,\ j \neq i}$ value for 30% through 40% exceedance percentage values was developed. This procedure was repeated until the group covered all computed average exceedance values. An estimate of the bounds of the 95% occurrence interval was found for each of the groups. The first being the X_i value where 2.5% of the X_i parts were higher than this value and the second being where 2.5% of the total X_i parts in the group. This procedure was repeated for each grouping. The smoothest occurrence intervals for each class were found when classes contained 200 or more data points. Ninety-five percent occurrence intervals for the sumultaneous data of all nine dates are shown in Figure 6. The corresponding classes and $X_{i,0.025}$ and $X_{i,0.975}$ values are shown in Table 7.

It should be noted that sound theoretically defensable prediction intervals may be constructed using only the simultaneous gaged flow percentage exceedances, using either a normal or beta distribution.

However, to justify the use of such distributions would require more simultaneous exceedance data. Obtaining the data necessary to establish goodness-of-fit to the distribution would generally require a much larger study area and would then include unnecessary hydrologic variations from the ungaged stream. For this reason, the study area was chosen only large enough to include the gaged streams that were believed would represent the area wherein the methodology was tested, and a more intuitive statistical confidence bound defining techniques described above was used.

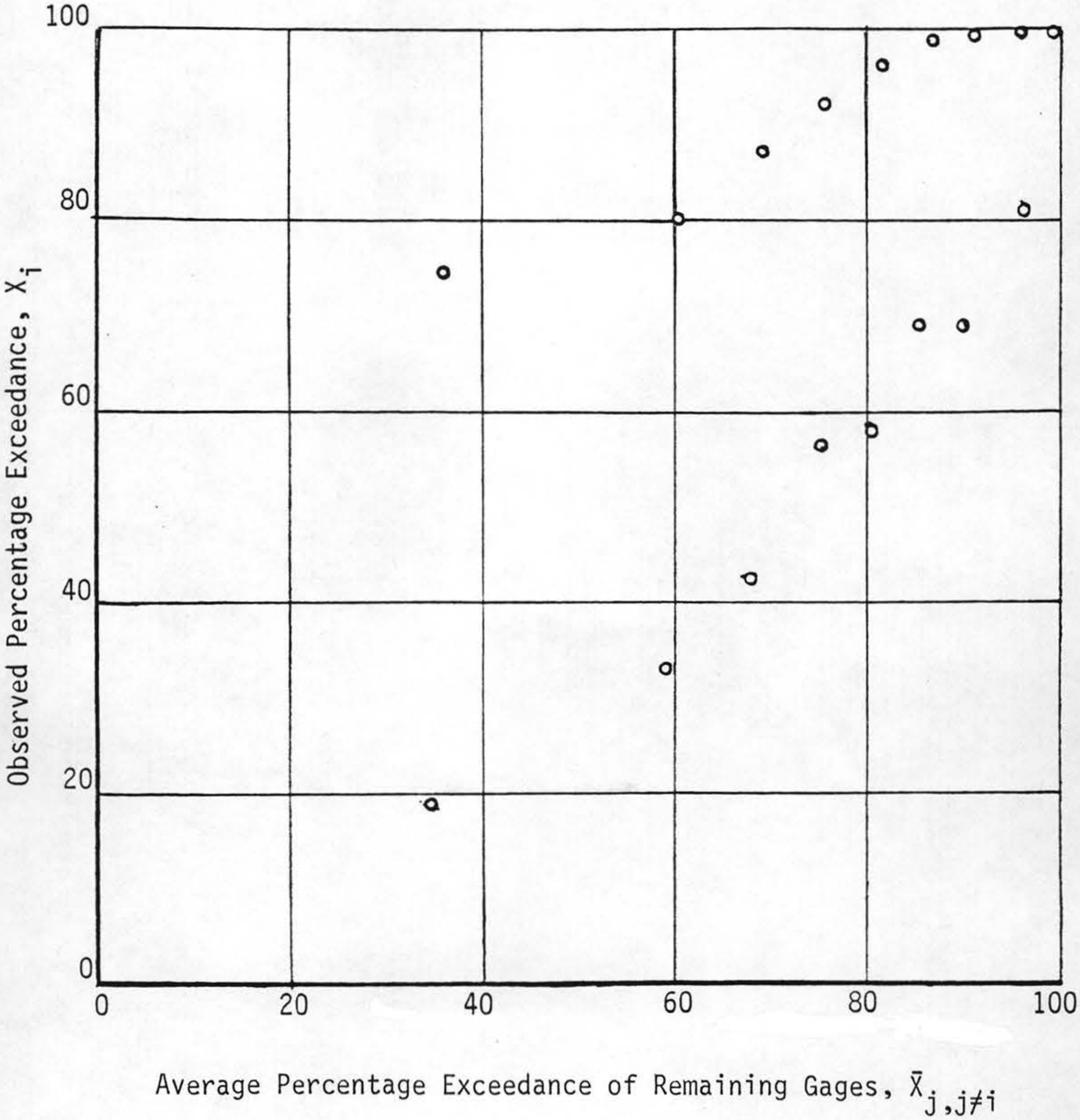

Fig. 6. Ninety-Five Percent Occurrence Intervals for a Single Gaged Percentage Exceedance Value.

Table 7. Ninety-five Percent Occurrence Intervals For a Single Gaged Percentage Exceedance Value (X_i) as a Function of the Average of All Remaining Gaged Percentage Exceedance Values on a Particular Day ($\overline{X}_{j,j\neq i}$).

Class	Lower Bound	Upper Bound	Mid-Point	$X_{i,\ 0.025}$	$X_{i,\ 0.975}$	n_i[a]
	$\overline{X}_{i,j\neq i}$			X_i		
1	15.76	54.42	35.09	19.14	74.51	200
2	54.42	64.51	59.47	33.32	79.80	200
3	64.54	72.09	68.32	42.81	87.00	200
4	72.14	78.38	75.26	56.58	91.97	200
5	78.39	83.95	81.17	58.02	96.11	200
6	83.98	88.07	86.03	69.33	98.38	200
7	88.17	93.13	90.65	68.98	99.50	200
8	93.14	99.38	96.26	81.19	99.83	220

a. n_i is the number of data points used with the particular interval to establish the ninety-five percent occurrence intervals

THE INFLUENCE OF PRECIPITATION ON PERCENTAGE EXCEEDANCE VALUES

For the 30-year study period, rainfall or precipitation was found to have a marked effect on percentage exceedance values and their range among gages at any particular time. To evaluate the effect of rainfall, three rainfall gaging stations were selected in the Northern Idaho study area as shown in Figure 7. The recorded precipitation at the three gages for a sample year, 1952, is shown with the corresponding time sequence of flow duration percentage exceedance values at two of the sample streamflow gages in Figure 8.

Several generalizations can be drawn from the data illustrated in Figure 8. First of all, prior to late July, overall percentage exceedance behavior is governed largely by phenomena other than direct runoff from rainfall, even though large amounts of precipitation do fall during this time. Precipitation during the times of low flow has a more marked effect on percentage exceedance values. Secondly, as flows decrease, percentage values increase, and the variations between simultaneous flow duration percentage exceedance values decrease (mentioned earlier). Thirdly, precipitation has a more varied effect during the low flow period, sometimes causing the change in percentage exceedance values at one site to be several times that of another. Fourthly, exclusive of precipitation, percentage exceedance values can be expected to continue to increase through the early fall and the variations of simultaneous percentage exceedance values remain roughly similar.

Furthermore, from Figure 8, precipitation experienced at one station in the region was generally experienced at other precipitation

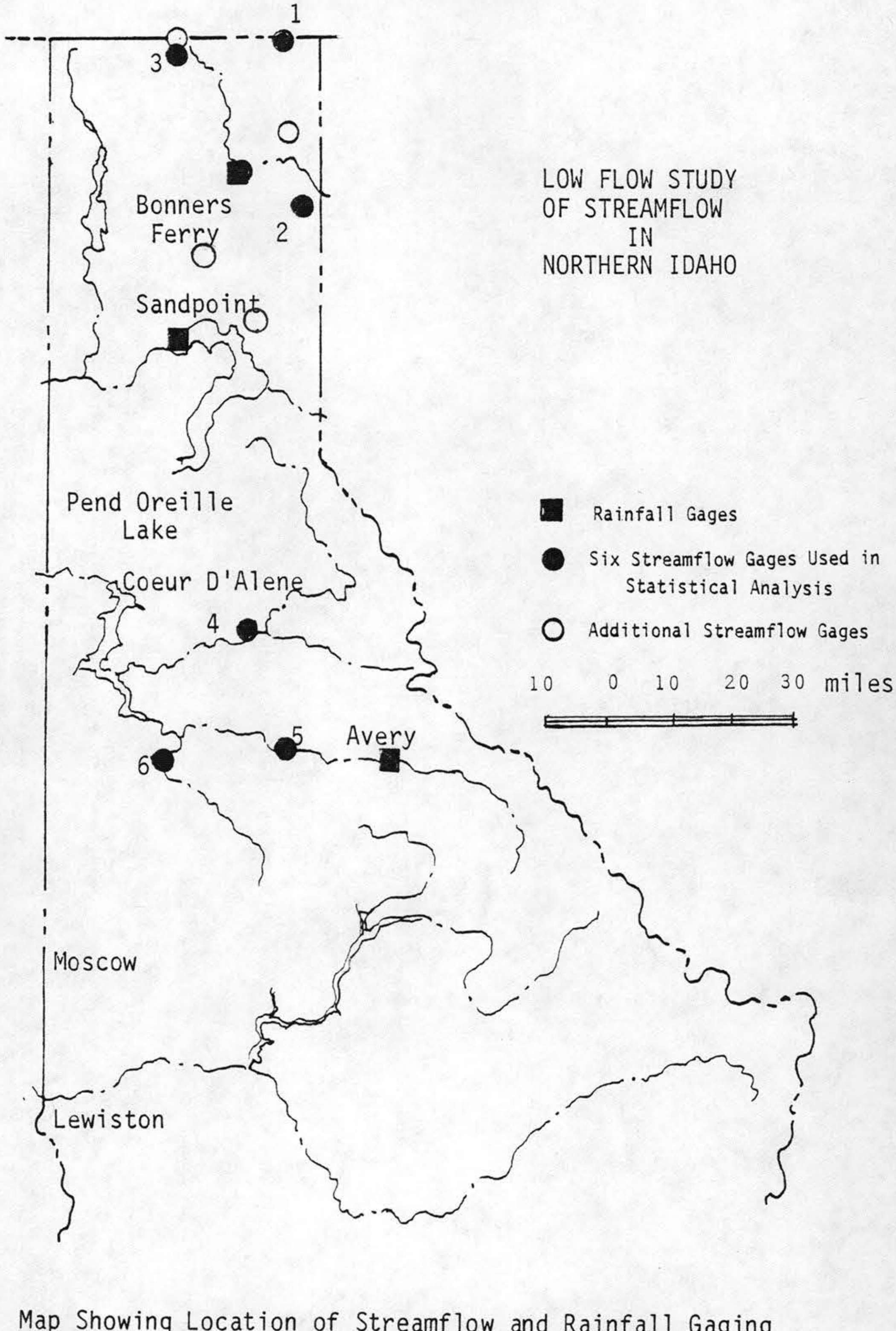

Fig. 7. Map Showing Location of Streamflow and Rainfall Gaging Stations Used to Evaluate the Effect of Rainfall on Percentage Exceedance Values.

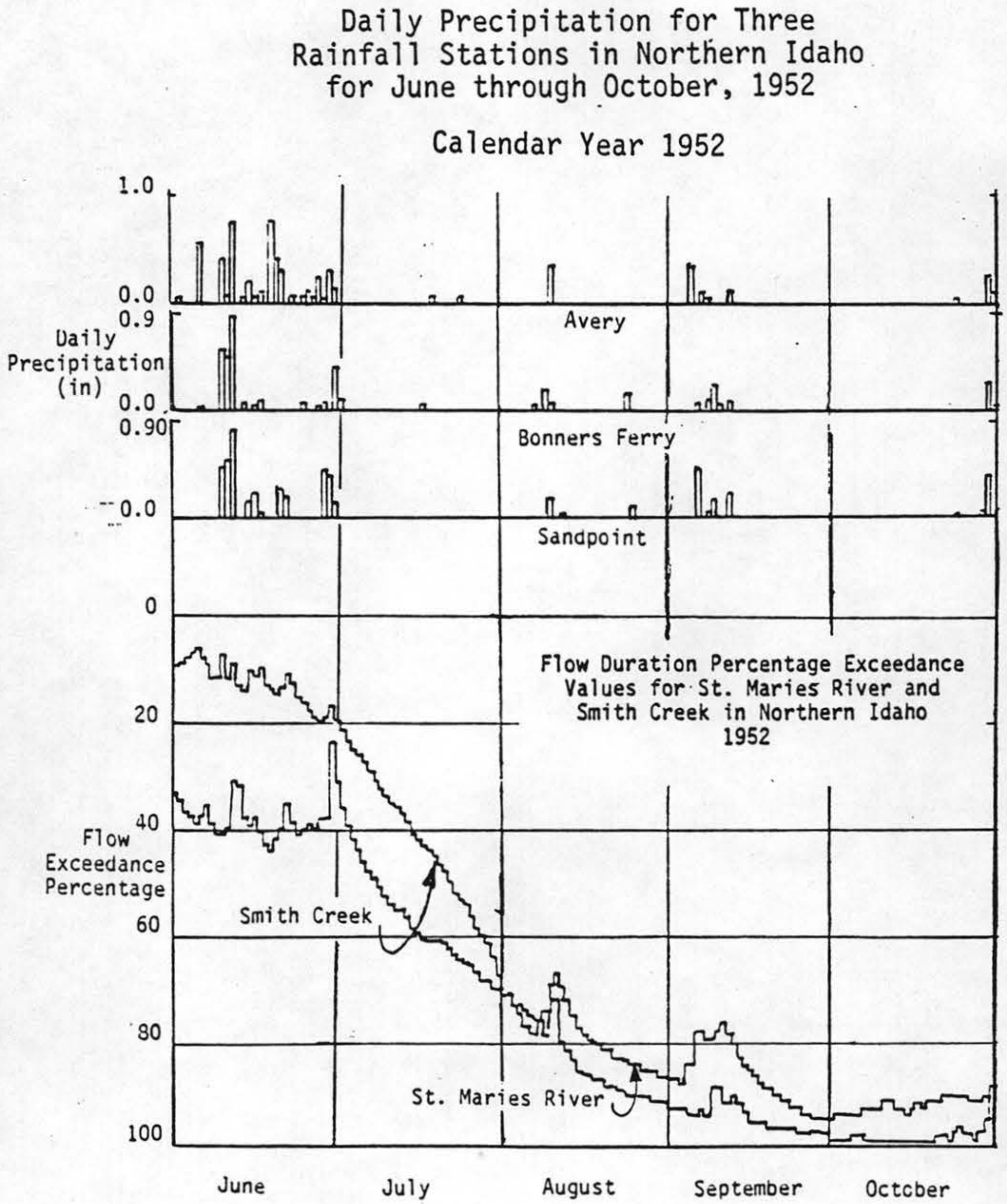

Fig. 8. Comparison of Daily Precipitation and Flow Percentage Exceedance Values.

stations in different magnitudes, and sometimes on different days. Precipitation amounts of less than 0.25 in. recorded at a particular precipitation gage as shown in the figure can correspond to marked changes in exceedance percentage values at a sample stream gaging station.

In an effort to further analyze the effects of precipitation, the data for the nine dates over the 30-year period was screened to exclude those values suspected to be affected directly by rainfall. As a criterion for screening, all percentage exceedance values for which precipitation had been experienced in any amount at any of the three rainfall gages six days prior to the date of measurement and up to one day afterward were excluded. This criterion was based on the observation (See Figure 8) that most of effect of precipitation appeared to disappear within six or seven days following the last day of recorded precipitation. Percentage exceedance values for which precipitation was recorded at any of the three rainfall gages were excluded based on analysis of Figure 8 and the premise that any gaged precipitation could easily be preceeded by one-day precipitation in an ungaged watershed. The occurrence of rain-free periods longer than seven days was believed to be too infrequent to provide adequate amounts of data as well as be impractical in its application.

The sample average percentage exceedance values and their variations for September 1 are shown in Table 8. Those values underscored are values not eliminated by the criterion above. Averages and average spreads for values not excluded by screening using the same criterion for all nine dates are shown with the values for the entire sample in Table 9. As can be seen in the tables, percentage exceedance values

Table 8. Sample Average and Sample Spread of Percentage Exceedance Values for September 1 Showing Those Values Not Excluded by Screening.

Year	Sample Average	Sample Spread (Standard Deviation)
1931	99.16	0.798
1932	85.52	7.934
1933	74.72	9.759
1934	97.73	2.140
1935	86.37	9.080
1936	96.28	4.420
1937	86.48	4.843
1938	91.34	5.276
1939	96.78	2.387
1940	98.81	1.050
1941	80.94	3.767
1942	76.30	9.400
1943	77.05	5.774
1944	97.47	1.494
1945	95.91	3.719
1946	83.74	5.346
1947	78.70	6.661
1948	66.12	7.050
1949	88.29	3.791
1950	69.58	5.862
1951	59.74	17.661
1952	84.31	5.330
1953	76.44	6.191
1954	53.99	10.736
1955	78.54	5.876
1956	75.04	7.708
1957	86.04	5.534
1958	89.71	6.336
1959	69.73	6.089
1960	75.45	3.646
Average	82.54	5.855
Average Excluding Screened Values	88.10	3.934

Table 9. Exceedance Percentage Averages and Average Sample Spreads for Unscreened and Screened Data.

	July	August			September			October	
	20	1	10	20	1	10	20	1	10
Unscreened Data (Entire Sample)									
Average Percentage Exceedance	54.69	66.57	74.04	80.87	82.54	81.92	81.55	80.77	76.70
Average Spread	11.286	9.396	8.482	6.415	5.855	6.845	6.911	7.716	7.618
Screened Data									
Average Percentage Exceedance	58.86	65.77	79.42	83.50	88.10	87.24	89.77	93.46	88.17
Average Spread	12.927	10.423	8.056	6.631	3.934	5.201	4.208	3.158	4.692
Number Not Excluded by Screening	8	10	10	12	9	5	4	3	5

expected not to be affected by precipitation tended to be higher and grouped closer together (smaller sample variations). High percentage exceedances and small spreads on particular days may be experienced after September 1, although the frequency of such rain-free periods is much less.

APPLICATIONS OF ANALYSIS

Assuming, as stated earlier, that the gages represent a random sample of percentage exceedance values for a particular day, Figure 6 may also be used to determine the 95 percent prediction intervals for any site percentage exceedance, gaged or ungaged, as a function of the average of five gaged percentage exceedance values taken on the same day. It should be noted that the expected value of the prediction is the average of the five gaged values itself. Figure 6 is shown again as Figure 9 with the expected value line and the 95 percent prediction intervals.

It should be pointed out that the traditional least-squares linear regression model is unappropriate in this case as the spread of the X_i values is not the same for all $X_{j,\ j \neq i}$, and that the distribution of X_i about the expected value is not normally distributed (See Devoe, 1982). Figure 9, in fact, again illustrates that the spread in percentage exceedance values decreases with increasing percentage exceedance. In addition, all exceedance values must lie between 0 and 100.

New occurrence and prediction intervals were not constructed for the data screened of the effect of precipitation. It is believed that, in practice, smaller spreads due to rain-free periods will be roughly recovered in that Figure 9 and Table 8 will be entered at higher sample average percentage exceedances values.

As an example application of the methodology, field measurements of Riser Creek, a small stream in Northern Idaho, taken during this

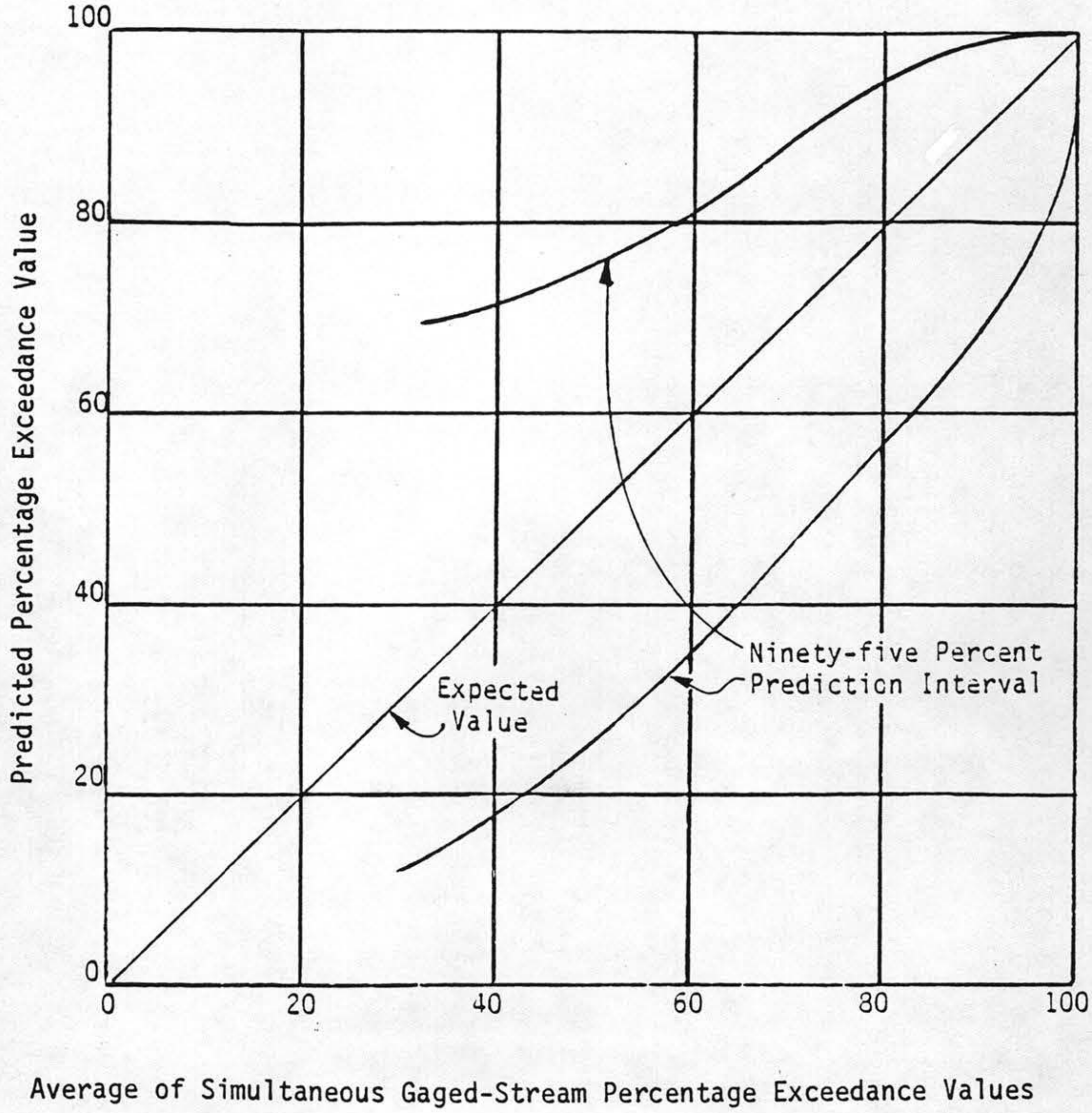

Fig. 9. Predicted Percentage Exceedance Values of an Ungaged Stream (Based on Six Gaged Watersheds in Northern Idaho).

research effort have been used to check or fit a predicted long-term flow duration curve for that site.

The measured data for Riser Creek is summarized in Appendix C. The general location of Riser Creek is shown in Figure 10. A more detailed illustration of the basin's characteristics is shown as Figure 11.

For a preliminary estimate of the long-term flow duration behavior of Riser Creek, dimensionless percentage exceedance flows were obtained from Rapid Lightning Creek for the water years 1964-1968. Original flow duration data was obtained and processed through the Hydrologic Information Storage and Retrieval System of the University of Idaho. Similar flow duration data are also available through the U.S. Geological Survey and, for some gages, the U.S. Army Corps of Engineers.

The basic flow duration data for Rapid Lightning Creek is shown in Table 10. These values were normalized by dividing by the average discharge and then scaled to Riser Creek by multiplying the normalized or dimensionless flows by the predicted average annual flow at Riser Creek. The predicted Riser Creek flows and the normalized Rapid Lightning Creek flows are shown in Table 11. The predicted Riser Creek flows are plotted in Figure 12.

It is recognized that the period of record for the original Rapid Lightning Creek flows is relatively short (5 years). Although it is unlikely that the average flow for the 5 years of available record is equal to the long-term average, it is assumed that the distributions of dimensionless flows for the short and long-term periods are similar.

The predicted average annual flow for Riser Creek was estimated on the basis of average annual precipitation and corresponding runoff

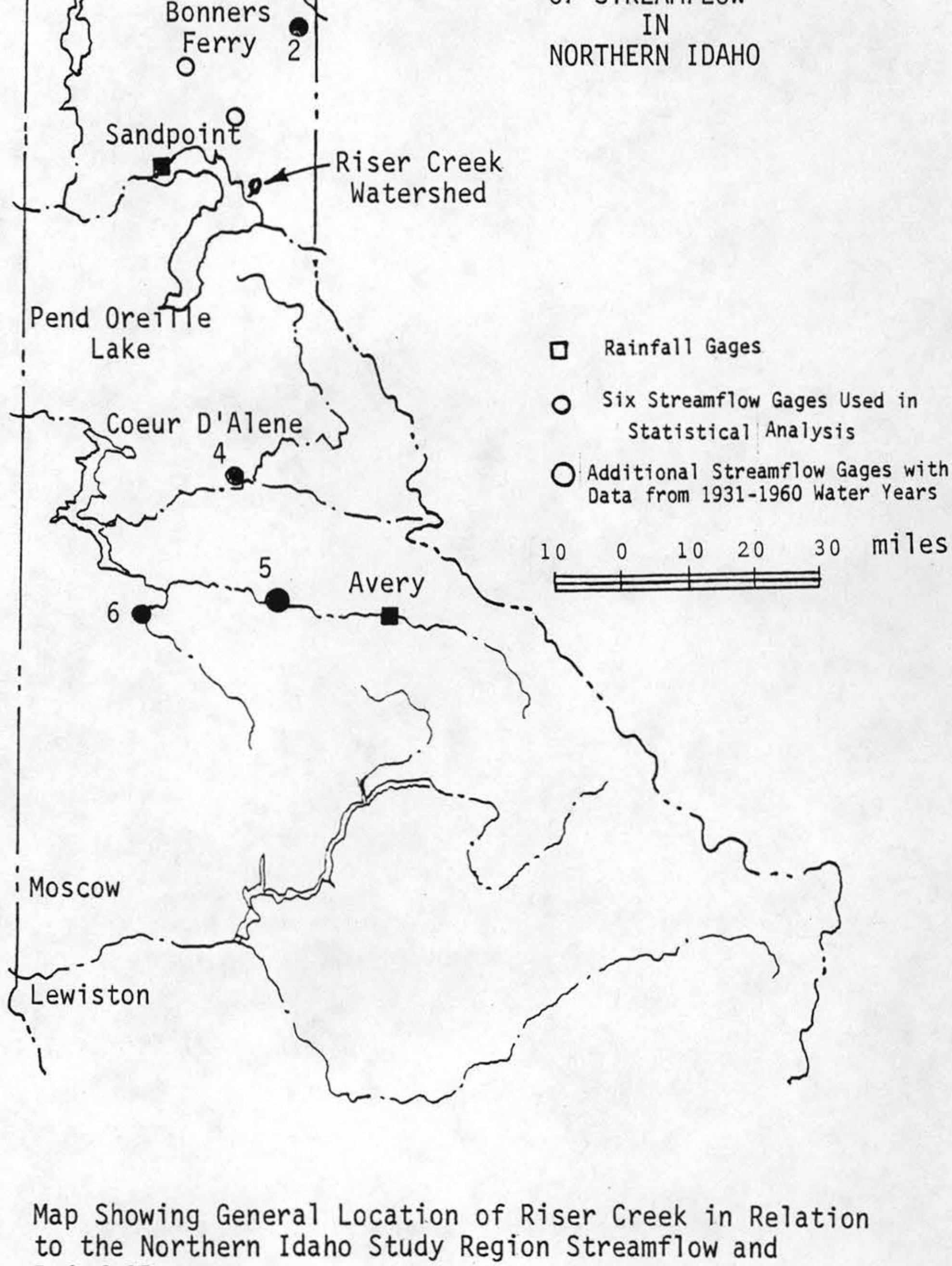

Fig. 10. Map Showing General Location of Riser Creek in Relation to the Northern Idaho Study Region Streamflow and Rainfall Gages.

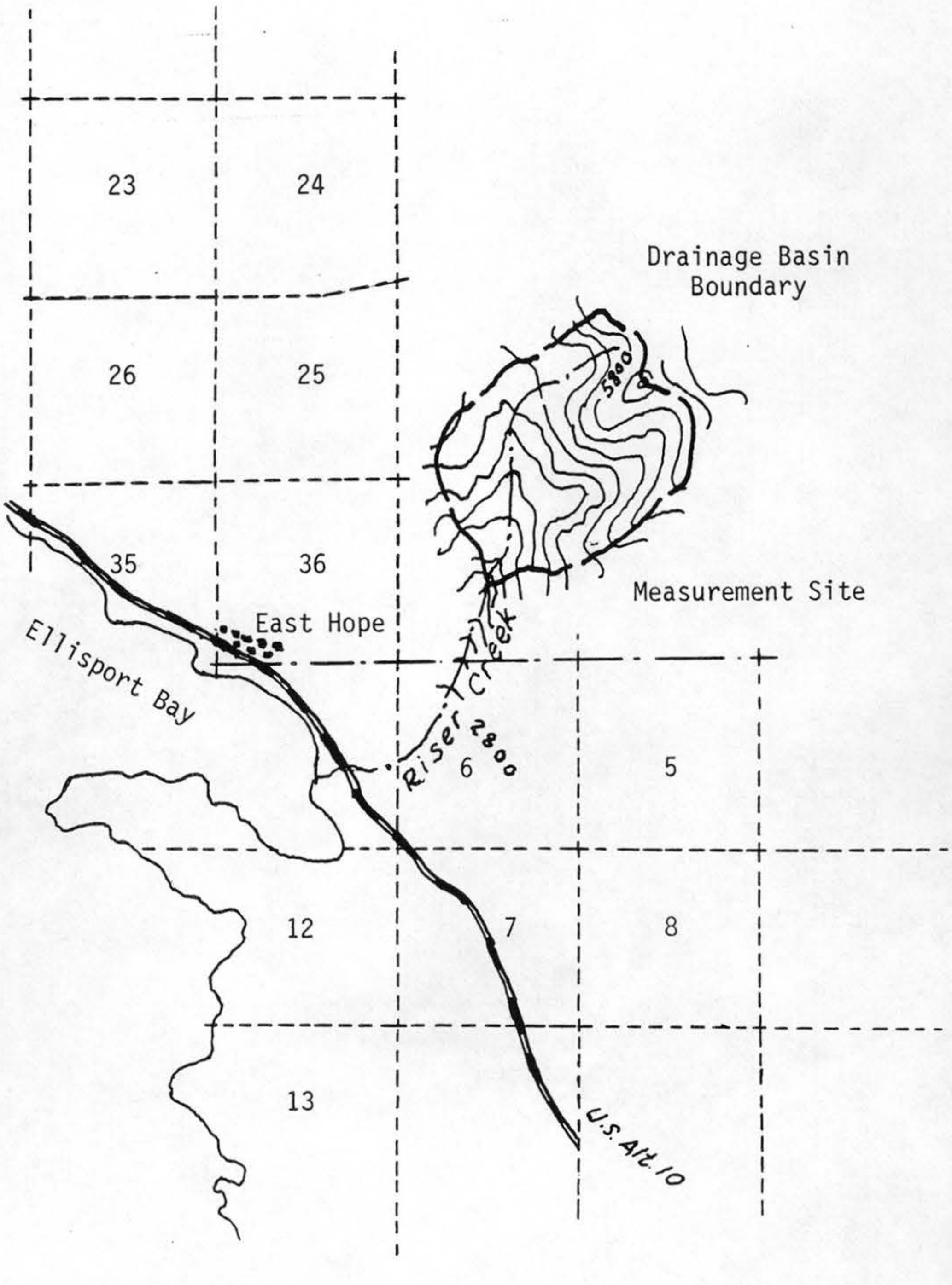

Fig. 11. Location Map of Riser Creek Drainage Basin Above Measurement Site.

Table 10. Original Flow Duration Data for Rapid Lightning Creek near Samuels

RAPID LIGHTNING CREEK NEAR SAMUELS, IDAHO STATION NO. 12.3924.00

FLOW DURATION TABLE

NUMBER OF DAYS IN CLASS

CLASS / WATER YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1964	0	0	7	11	18	18	16	12	8	15	50	32	20	14	15	16	5	5	6	4	5	6	8	8	9	19	25	14	0	0	0	0
1965	0	0	0	0	0	15	33	22	17	20	10	9	8	10	32	25	11	13	16	18	14	14	6	15	17	18	10	10	2	0	0	0
1966	0	0	16	17	17	32	16	10	32	23	15	16	8	14	7	9	2	2	11	9	7	8	22	20	16	17	12	7	0	0	0	0
1967	0	30	31	16	19	6	6	4	5	3	4	15	7	5	8	17	14	17	12	17	26	24	26	8	14	14	11	6	0	0	0	0
1968	0	0	8	7	5	27	17	23	40	29	11	8	12	6	5	12	6	12	13	16	8	18	13	29	23	9	8	1	0	0	0	0

TOTAL DISCHARGE 136995.60 CFS-DAYS
MEAN DAILY DISCHARGE 74.98 CFS
DRAINAGE AREA 4 SQ MI

CLASS	CFS	TOTAL COUNTS	ACCUM	PERCENT	CFS/ SQ MI	CFS/ MEAN DAILY	CLASS	CFS	TOTAL COUNTS	ACCUM	PERCENT	CFS/ SQ MI	CFS/ MEAN DAILY
1	4	0	1827	100.0	1.0	0.1	17	50	38	756	41.4	12.5	0.7
2	7	30	1827	100.0	1.8	0.1	18	54	49	718	39.3	13.5	0.7
3	10	62	1797	98.4	2.5	0.1	19	60	58	669	36.6	15.0	0.8
4	12	51	1735	95.0	3.0	0.2	20	70	64	611	33.4	17.5	0.9
5	14	59	1684	92.2	3.5	0.2	21	85	60	547	29.9	21.3	1.1
6	16	98	1625	88.9	4.0	0.2	22	100	70	487	26.7	25.0	1.3
7	18	88	1527	83.6	4.5	0.2	23	115	75	417	22.8	28.8	1.5
8	20	71	1439	78.8	5.0	0.3	24	140	80	342	18.7	35.0	1.9
9	22	102	1368	74.9	5.5	0.3	25	165	79	262	14.3	41.3	2.2
10	24	90	1266	69.3	6.0	0.3	26	200	77	183	10.0	50.0	2.7
11	27	90	1176	64.4	6.8	0.4	27	240	66	106	5.8	60.0	3.2
12	30	80	1086	59.4	7.5	0.4	28	300	38	40	2.2	75.0	4.0
13	33	55	1006	55.1	8.3	0.4	29	450	2	2	0.1	112.5	6.0
14	36	49	951	52.1	9.0	0.5	30	700	0	0	0.0	175.0	9.3
15	40	67	902	49.4	10.0	0.5	31	1000	0	0	0.0	250.0	13.3
16	44	79	835	45.7	11.0	0.6	32	10000	0	0	0.0	2500.0	133.4

Table 11. Computation of Normalized Flows for Rapid Lightning Creek and Predicted or Scaled Flows for Riser Creek.

No.	Percentage Exceedance	Rapid Lightning Creek Discharge (cfs)	Normalized Discharge (dimensionless)	Predicted or Scaled Riser Discharge (cfs)
1	100.0	4	0.053	0.120
2	100.0	7	0.093	0.210
3	98.4	10	0.133	0.300
4	95.0	12	0.160	0.360
5	92.2	14	0.187	0.420
6	88.9	16	0.213	0.480
7	83.6	18	0.240	0.540
8	78.8	20	0.267	0.600
9	74.9	22	0.293	0.660
10	69.3	24	0.320	0.720
11	64.4	27	0.360	0.810
12	59.4	30	0.400	0.900
13	55.1	33	0.440	0.990
14	52.1	36	0.480	1.080
15	49.4	40	0.533	1.200
16	45.7	44	0.587	1.320
17	41.4	50	0.667	1.500
18	39.3	54	0.720	1.620
19	36.6	60	0.800	1.801
20	33.4	70	0.934	2.101
21	29.9	85	1.134	2.551
22	26.7	100	1.334	3.001
23	22.8	115	1.534	3.451
24	18.7	140	1.867	4.201
25	14.3	165	2.200	4.951
26	10.0	200	2.667	6.002
27	5.8	240	3.201	7.202
28	2.2	300	4.001	9.003
29	0.1	450	6.001	13.504
30	0.0	700	9.336	21.006
31	0.0	1000	13.337	30.008
32	0.0	10000	133.369	300.080

Average Discharge of Rapid Lightning Creek = 74.98 cfs
Predicted Average Discharge of Riser Creek = 2.75 cfs

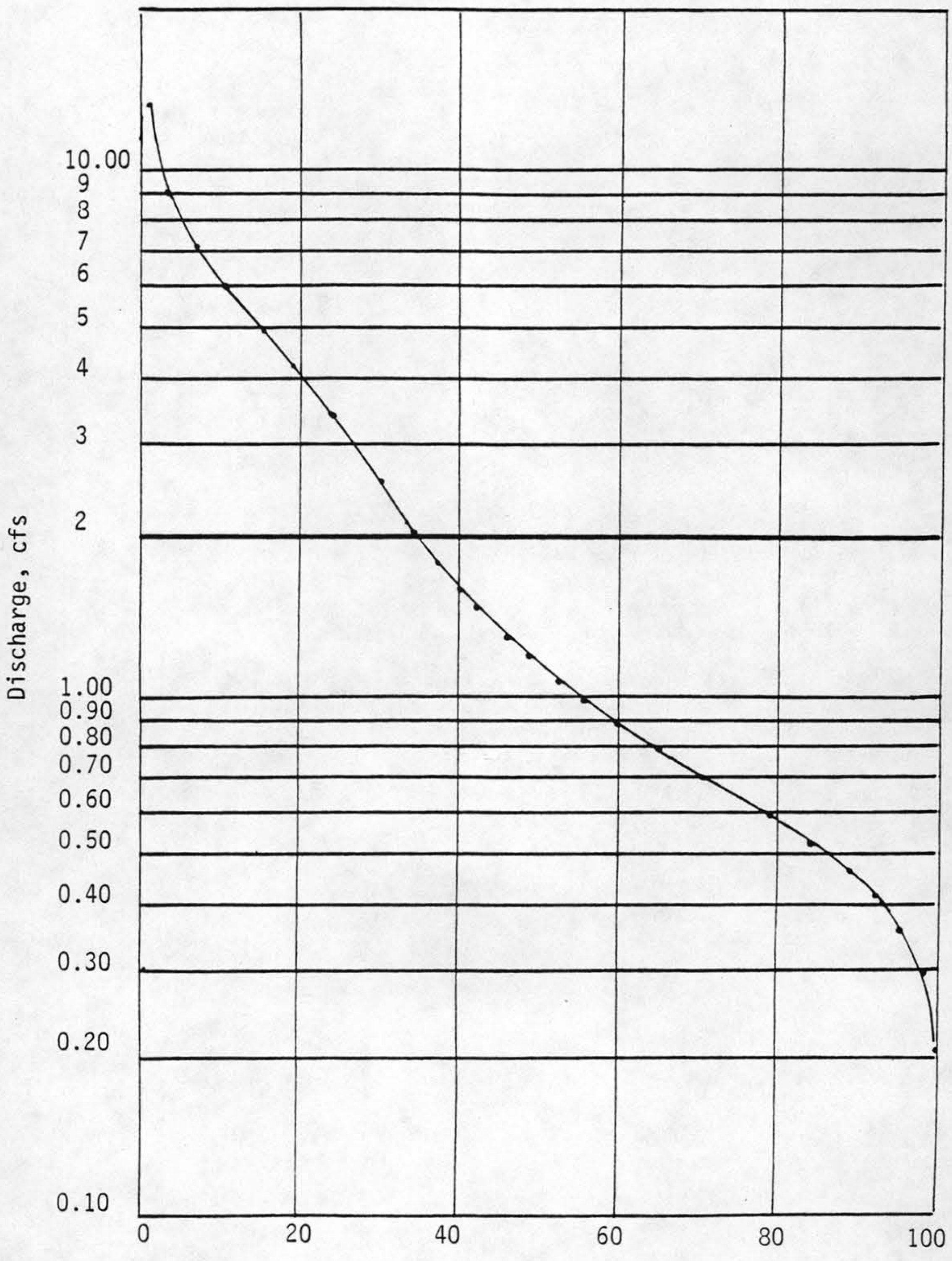

Fig. 12. Initially Predicted Flows for Riser Creek near East Hope, Idaho. (Based on Rapid Lightning Creek near Samuels, 1964-1968 Water Years)

coefficients for streams in the area. Weighted average annual precipitation was calculated using 1:250,000-scale mean annual precipitation maps (Idaho Hydrologic Maps, 1980) and was found to be approximately 40 in. The Riser Creek watersheds and isohytes from the Idaho Hydrologic Maps are shown in Figure 13. Runoff coefficients corresponding to the above annual precipitation maps for a number of nearby stream reaches were obtained from Warnick, Heitz, Kirkland, and Burke (1981). A runoff coefficient of 0.60 was selected on the basis of engineering judgment and evaluation of surrounding gaged stream's runoff coefficients.

Using a drainage basin area of 1.27 (sq mi) determined from 1:62,500-scale maps of the area (see Figure 11), the average annual runoff at the measurement site was estimated by

$$AAR = K\ C\ A\ P,$$

where

AAR = average annual runoff in cfs,

K = appropriate runoff coefficient,

C = conversion factor of 0.07367 cfs-yr/in-sq mi,

A = drainage basin area in sq mi.

and

P = mean annual precipitation in in.

Using the above values,

$$AAR = 0.60(0.07367)(1.27)(40)$$

$$= 2.25 \text{ cfs.}$$

In application of the methodology, the percentage exceedance behavior of gaged streams in the Northern Idaho region was studied for the same time the field measurements were taken at Riser Creek.

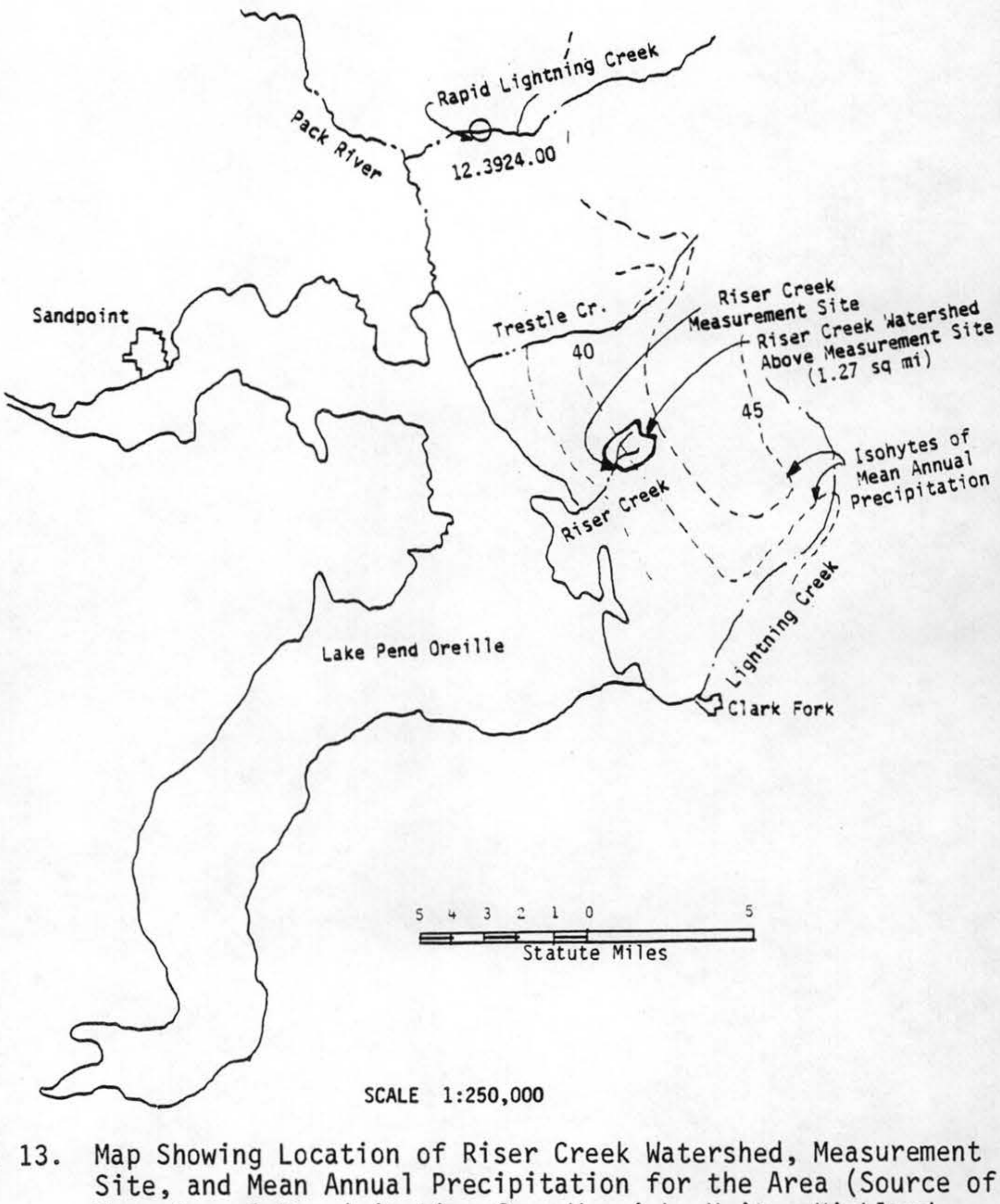

Fig. 13. Map Showing Location of Riser Creek Watershed, Measurement Site, and Mean Annual Precipitation for the Area (Source of Mean Annual Precipitation from Warnick, Heitz, Kirkland, Burke, 1981).

These field measurements are shown below and are also listed in Appendix B.

Date	Discharge cfs
7/19/83	10.88
8/16/83	1.32
9/14/83	0.84

Long-term flow duration curves were plotted for five gages in the Northern Idaho region. The flow duration curve for Moyie River at Eastport is shown as Figure 14. Flow duration curves for the other four gaged streams used are shown in Appendix C. The period of record for all gages used was water years 1931 through 1960.

Gaged values for the dates on which measurements were taken on Riser Creek are shown for the Moyie River in Table 12. Shown also are the corresponding 1931-1960 percentage exceedances for these flows. The percentage exceedance values were obtained from Figure 14. Assuming that Riser Creek was behaving roughly similar to the Moyie River during those measurement dates, the Moyie percentage exceedance values are assigned to the Riser Creek flows and the resulting points plotted in Figure 15 along with the originally predicted Riser Creek flow duration curve. As can be seen in Figure 15, for the two latter dates, use of the simultaneous percentage values for Moyie River produce points that agree well with the initial flow duration curve prediction based on Rapid Lightning Creek. Use of the Moyie River exceedance value for the first measurement date is assumed erroneous due to precipitation in the Riser Creek area prior to the measurement.

To further evaluate the behavior of Riser Creek during the field measurements, percentage exceedance behavior of the other four long-

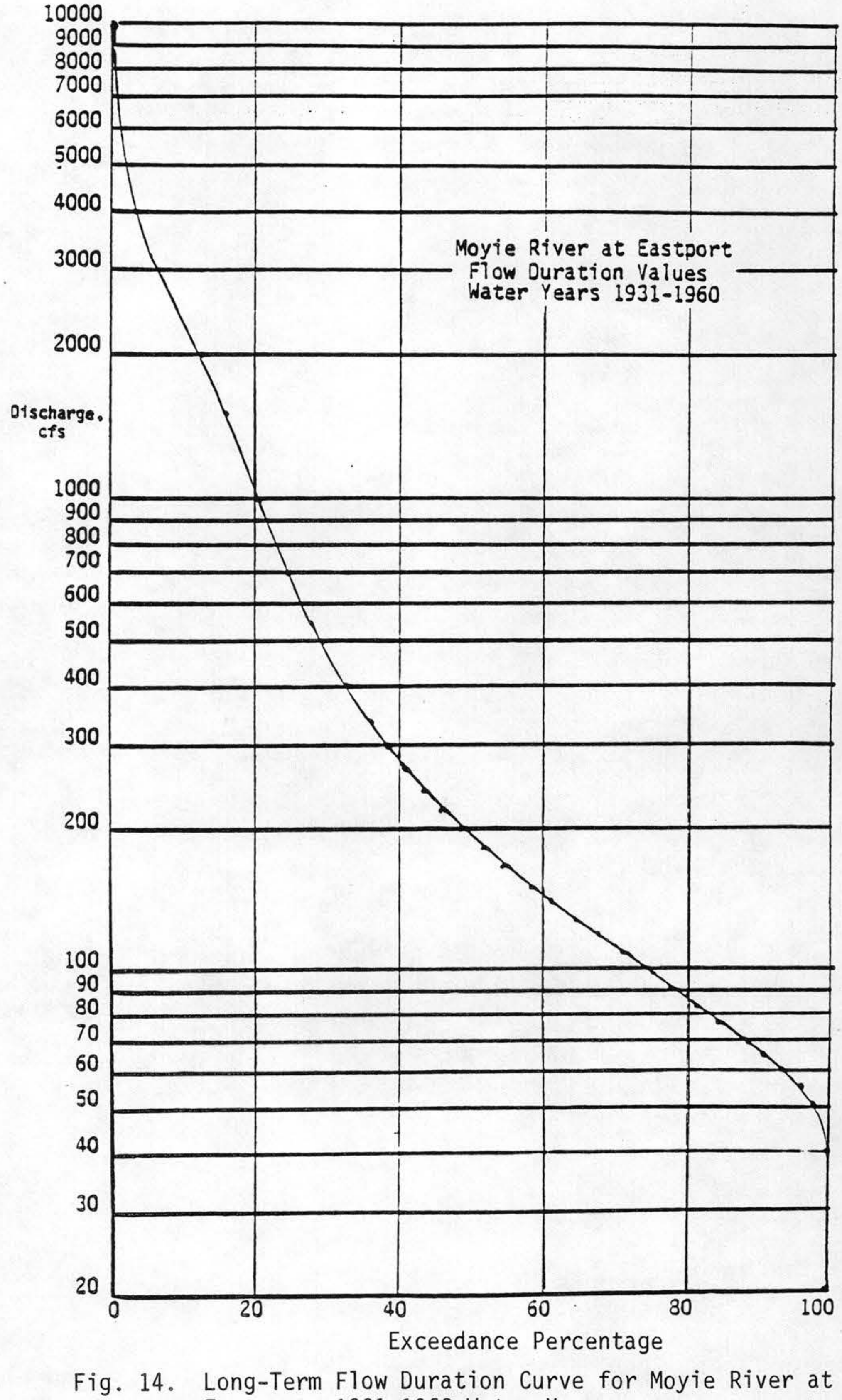

Fig. 14. Long-Term Flow Duration Curve for Moyie River at Eastport, 1931-1960 Water Years.

Table 12. Streamflow Discharge for Riser Creek and Moyie River Near Eastport and Corresponding 1931 Through 1960 Percentage Exceedance Values.

Date	Moyie River Discharge[a] (cfs)	Corresponding 1931 - 1960 Percentage Exceedance	Riser Creek Flow (cfs)
7/19/83	831	22	10.88
8/16/83	247	42	1.32
9/14/83	136	62	0.85

a. Discharge values for Moyie River near Eastport are from provisional data supplied by U.S. Geological Survey

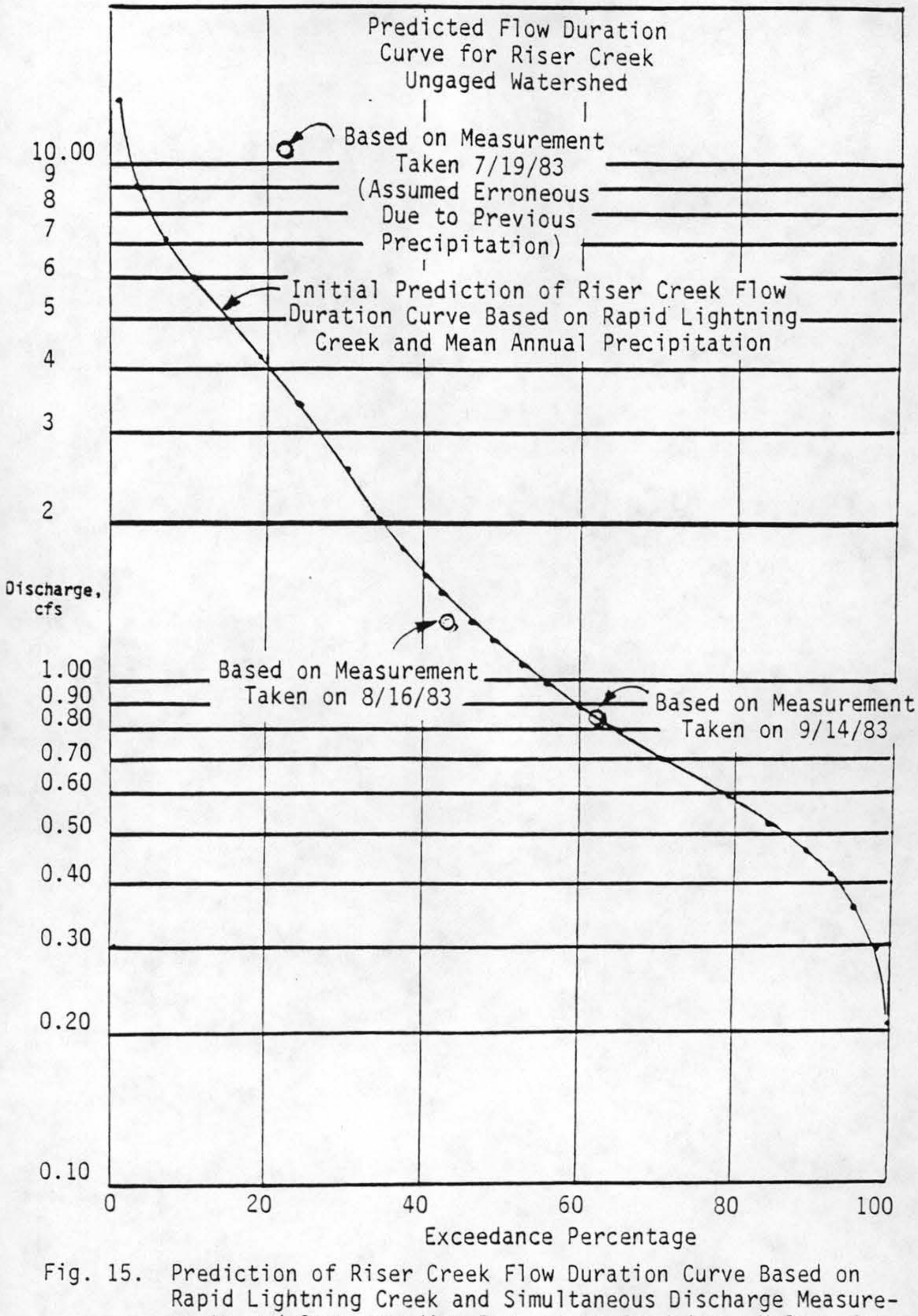

Fig. 15. Prediction of Riser Creek Flow Duration Curve Based on Rapid Lightning Creek and Simultaneous Discharge Measurements and Corresponding Percentage Exceedance Values from the Moyie River at Eastport.

term stream gages were also evaluated for the same dates. The simultaneous discharge values for the gaged streams on the three dates, as well as the discharge for the Moyie River and Riser Creek are shown in Table 13. The discharge values for the St. Maries River at Lotus were estimated from gaged discharge values from the St. Maries River at Santa. This estimation was based on drainage basin area extrapolation only. Precipitation was found to be roughly the same for the two basins (See Idaho Hydrologic Maps, 1980 and Warnick, Heitz, Kirkland, and Burke, 1981). Differences in basin precipitation and runoff coefficients were considered minor and were therefore not used in the scaling of the flows to the different Lotus gaging site. The 1931-1960 percentage exceedance values corresponding to the simultaneous gaged discharges are shown in Table 14. These values are plotted with the simultaneous discharge at Riser Creek in Figure 16.

The mean of the five gaged percentage exceedance values is also shown in Table 14. Assuming the five gages used in the Riser Creek study are a sample representative of the same geographic area used to develop occurrence intervals and prediction intervals in Figures 6 and 9, Figure 9 may also be used to plot 95 percent prediction intervals to the Riser Creek flow percentage exceedance values. It should be noted that use of Figure 9 assumes that Riser Creek behaves somewhere within a range of behavior of which the five gaged streams are a sample. Use of Figure 9, therefore, provides a check independent of selecting any single gage to represent the ungaged flow. The mean or predicted percentage exceedance values as well as the 95 percent prediction interval values from Figure 9 are shown in Table 15 and Figure 17.

Table 13. Discharge Values for Riser Creek and Five Gaged Streams in Northern Idaho for Three Dates in 1983.

Gaged or Ungaged Stream	Date	Discharge in cfs[a] 7/19/83	8/16/83	9/14/83
Moyie River near Eastport		831	247	136
Boundary Creek near Porthill (USGS)		242	81	57
Boulder Creek near Leonia (USGS-USFS)		104	29.4	20.9
St. Joe River at Calder (USGS)		1780	730	550
St. Maries River near Santa (Estimated)		248	141	145
Riser Creek		10.88	1.32	0.85

a. Discharge values are from provisional data supplied by U.S. Geological Survey.

Table 14. Long-term 1931 - 1960 Flow Duration Percentage Exceedance Values for Streamflow Discharge Values of 5 Gaged Streams in Northern Idaho for Three Dates in 1983.

		Percentage Exceedance		
Gaged or Ungaged Stream	Date	7/19/83	8/16/83	9/14/83
Moyie River near Eastport		22	42	62
Boundary Creek near Porthill		21	38	47
Boulder Creek near Leonia		27	55	65
St. Joe River at Calder		34	59	71
St. Maries River near Santa (Based on estimated discharge)		43	58	57
Mean		29	50	60

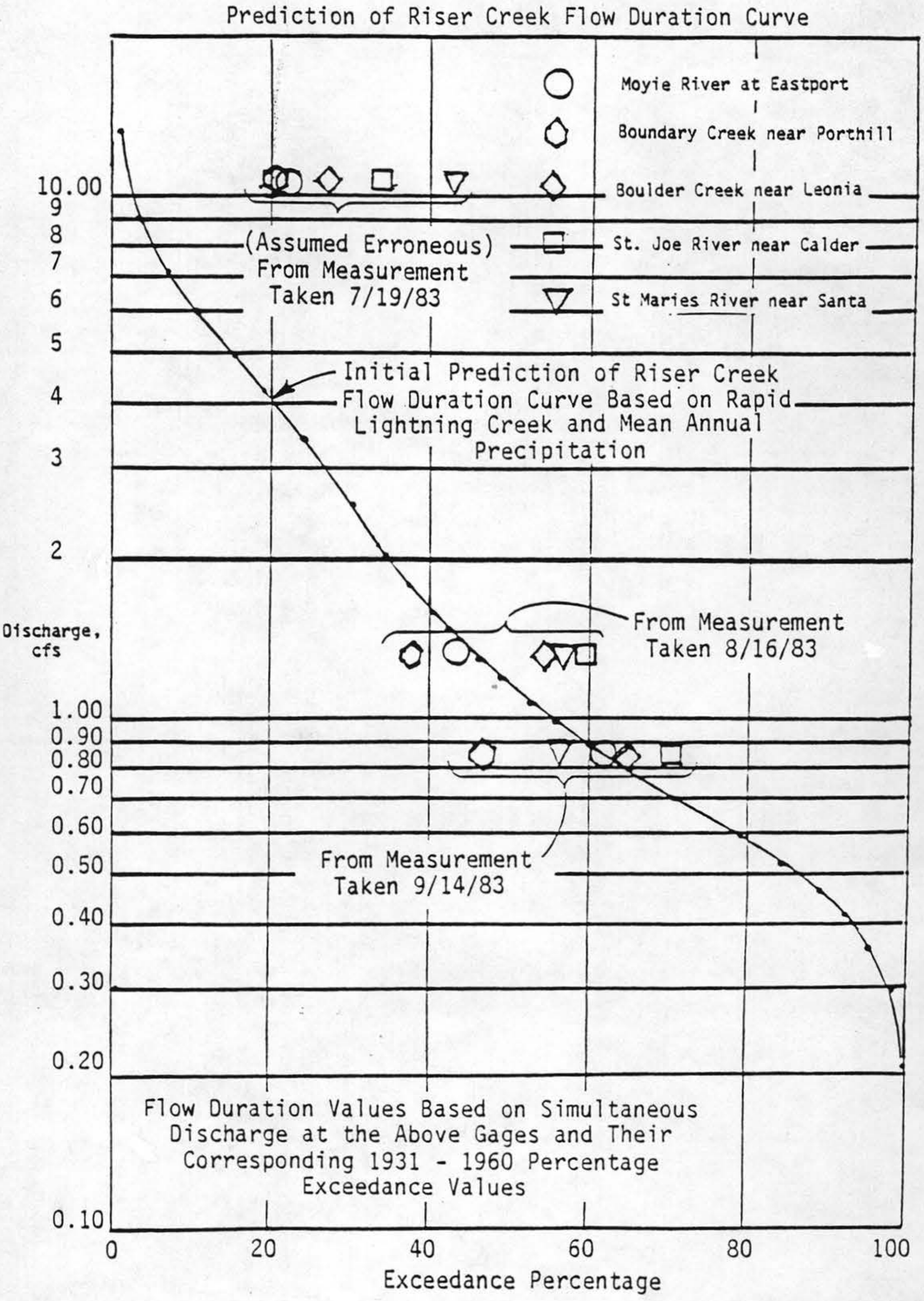

Fig. 16. Predicted Riser Creek Flow Duration Curve and Simultaneous Predictions of Discharge and Percentage Exceedance Values Based on Five Surrounding Gaged Streams.

Table 15. Predicted Percentage Exceedance Values and Ninety-Five Percent Prediction Intervals for Three Streamflow Discharge Measurements of Riser Creek.

Date	Average Simultaneous Percentage Exceedance Value For Five Gaged Streams	Predicted Percentage Exceedance Value	Ninety-Five Percent Prediction Interval		Riser Creek Discharge
			Lower Bound	Upper Bound	(cfs)
7/19/83	29	29	12	69	10.88
8/16/83	50	50	26	76	1.32
9/14/83	60	60	35	81	0.85

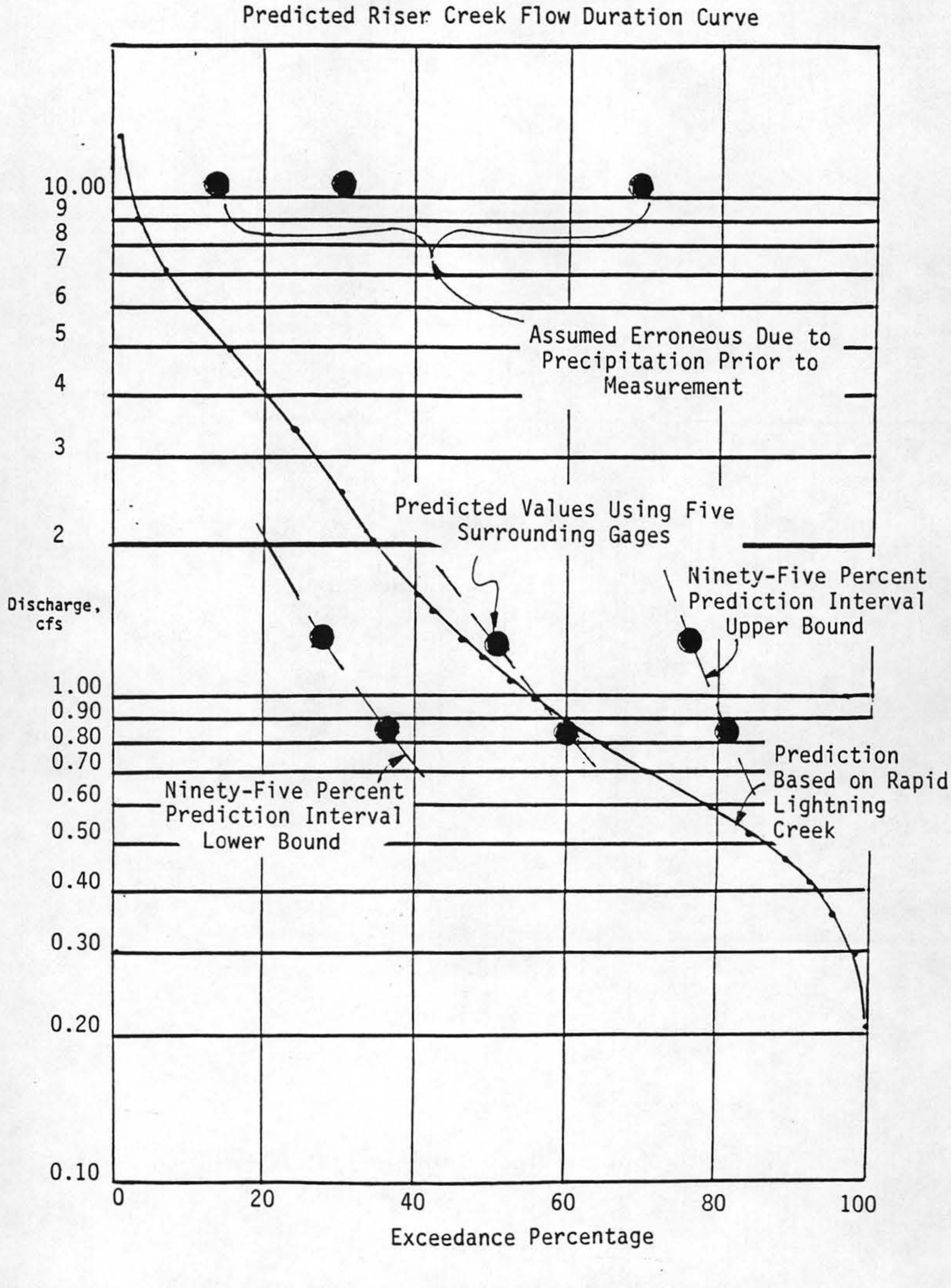

Fig. 17. Predicted Percentage Exceedance Values and Ninety-Five Percent Prediction Intervals for Riser Creek Based on Simultaneous Behavior of Five Surrounding Gaged Streams.

From the preceeding analysis, the predicted flow duration curve appears to be quite reasonable with respect to the simultaneous percentage exceedance behavior of the five surrounding gaged streams (based on the two later measurements). If there is no reason to assume otherwise, the closeness of fit to the behavior of the Moyie River (See Figure 15) may be justification alone to use the previously predicted flows using Rapid Lightning Creek (Figure 12).

If the analysis of the simultaneous percentage exceedance values of surrounding gaged streams had produced predicted percentage exceedances and prediction intervals substantially different from the predictions using Rapid Lightning Creek, the Rapid Lightning Creek prediction could be adjusted to better match the simultaneous behavior of the surrounding streams. Care must be taken to insure that such an adjustment does not result in an unreasonable total or average annual runoff volume. Referring to discussion of Figure 1, it may only be necessary to adjust the low flow portion of the duration curve.

It should be pointed out once again the effect of precipitation prior to measurement, as was the case for the measurements on 7/19/83. It is suspected in this example that the response of Riser Creek to prior precipitation was much greater than that of the other larger stream basins. Hence, use of the measured discharge with the simultaneous gaged percentage exceedances produced an erroneous result (resulting average annual runoff of 15 to 20 cfs (unreasonably high).

If no streamflow measurements were available for an initial prediction, like Rapid Lightning Creek in the preceeding example, a flow duration curve may have been constructed using the overall basin exceedance percentage behavior as was done as a check in the preceeding example and by connecting the individual predicted percentage exceedance values. Again, however, care must be taken such that total runoff volumes or annual averages are reasonable.

The analysis and methodology used in this text could be applied in areas other than the Northern Idaho study area used herein. For ungaged streams of closer proximity and similarity with gaged streams, smaller prediction intervals than those in Figure 9 would be expected. For larger areas or where there is greater streamflow characteristic diversity, wider prediction intervals would result.

If prediction intervals are not necessary, one or several nearby gaged streams may be used to evaluate simultaneous exceedance percentage behavior. Where an initial prediction has been constructed based on another stream, such an analysis would either confirm the prediction or begin to provide a basis of modifying the prediction. Where no particular stream is available on which to base an initial prediction, exceedance percentage behavior should be based on the average and prediction intervals of a number of gages believed to representative samples of the possible range of ungaged flow exceedance values.

A summary list of the steps of using the methodology are as follows:

1. Make an initial prediction of the ungaged flow duration curve based on a nearby gaged stream.
2. Measure the ungaged stream and obtain simultaneous discharge measurements for surrounding gaged stream or streams.
3. Determine the long-term percentage exceedance values at which the gaged streams were behaving at the time of the simultaneous measurements.

4. Assign to the ungaged discharge the exceedance percentage value or values from the gaged streams.
5. Plot the ungaged discharge measurements with the gaged exceedance values to evaluate the initial prediction or to use as a basis of adjusting the initial prediction.
6. Check to be sure any adjustments to the original prediction are reasonable, i.e., produce reasonable total or average annual runoff values.
7. If no single gaged stream can be chosen on which to base an initial prediction of the ungaged flow duration curve, individual ungaged percentage exceedance values may be estimated using the average of simultaneous gaged stream exceedance values assigned to the ungaged discharge value. Prediction intervals may be estimated by first determining the occurrence intervals of individual stream percentage exceedance values versus the average of the percentage exceedance values of the remaining streams. (Described in the section title Analysis of Year-to-Year, Day-to-Day, and Gage-to-Gage Variation of Low Flows). The occurrence intervals, then, can be used to estimate prediction intervals for future or unknown ungaged percentage exceedance values based on the simultaneous exceedance percentage behavior of surrounding gages.

DISCHARGE MEASUREMENT ACTIVITIES AND COMMENTS

Streamflow discharge measurements for this project were made as outlined by Buchanan and Somers (1969). The method primarily involved determining and adding the discharge of vertical sub-sections of stream cross sections at particular points of interest on the selected ungaged streams.

The streams measured were selected based on accessibility within the area of interest and the location of potential hydropower diversions. The locations for the discharge measurement sites along the streams were selected on the basis of channel or flow characteristics. Channel or flow characteristics sought were those that were believed would produce the most accurate measurements. The time spent necessary to locate the most favorable measurement sites was considered well spent. Sites with steep gradients often afforded measurement sites that, due to turbulence and obstructions, could at best have 'fair' accuracy. Attention was also paid to select sites that would minimize, if possible, groundwater flow around or 'under' the channel at that particular point.

Once the measurement site was selected, a channel section was selected whose flow was most nearly perpendicular to the section and whose vertical velocity gradient(s) were assumed nearly 'typical' (Linsley, Kohler, and Paulhus, 1958).

The cross section was then partitioned into vertical subsections whose individual discharges would be no more than ten percent of the total flow (usually 15 to 30 vertical subsections). Discharges for each vertical subsection were determined using an electronic flow meter or pygmy price AA meter to estimate the average velocity for the subsection and then multiplying the average velocity by the subsection area. Overall section discharge was assumed steady for each site measurement although instantaneous velocities at points in each subsection varied significantly due to turbulence. Point velocities were effectively averaged over a short period of time in each subsection by either the damping or averaging effect built into the electronic flow meter or by accummulated revolutions divided by total time with the pygmy meter. Point velocities for each subsection were taken at six-tenths the depth, where, typically, the velocity closely approximates the average velocity in the vertical direction (Linsley, Kohler and Paulhus, 1958), subsection areas were determined by going half the distance to the adjacent subsection measurement points and multiplying by the depth at the point in the subsection being measured.

Where vertical subsections were judged 'nontypical' (where the measurement at six-tenths the depth would not produce the average velocity) such as due to a boulder or other obstruction immediately upstream, velocity measurements were taken in a way to give a representative average of the subsection velocity. It should be noted that due to the smallness of the streams and their turbulence, few subsections, if any were believed truly typical, but that the variations from typical were assumed roughly compensative using the six-tenths depth method. Due to the low flow or nearly low flow conditions of the streams measured, all the current meter measurements were made by wading and mounting the current meter on a top-setting wading rod. Point or subsection velocities (electronic flow meter) or revolutions and time intervals (pygmy price meter) were fairly rapidly read and recorded for later computation. Where possible, discharge measurements were compared with others made from other field information such as flows over diversion spillways, diversion rates, flow through culverts, and stage readings on nearby gaging stations.

At some locations, velocities were roughly checked using a float. A short float length was determined and time intervals recorded for a bobber or small float to travel the float distance. Corresponding velocities were averaged for each subsection to determine a surface velocity for each subsection. The surface velocity was then multiplied by 0.65 to estimate the average velocity in the verticle and then multiplied by the subsection area to determine discharge, although literature suggests a value between 0.85 and 1.00 (Buchanan and Somers, 1969). The 0.65 value used by the authors was determined by comparing a small number of surface velocity rates and corresponding discharges determined by other methods.This value may be more appropriate for small highly turbulent streams.

The discharge measurements taken as a part of this project are listed in Appendix B, Figure 18 shows the general location of the ungaged streams that were measured under this research effort. Appendix B also gives information on the exact locations of the measurements for future reference.

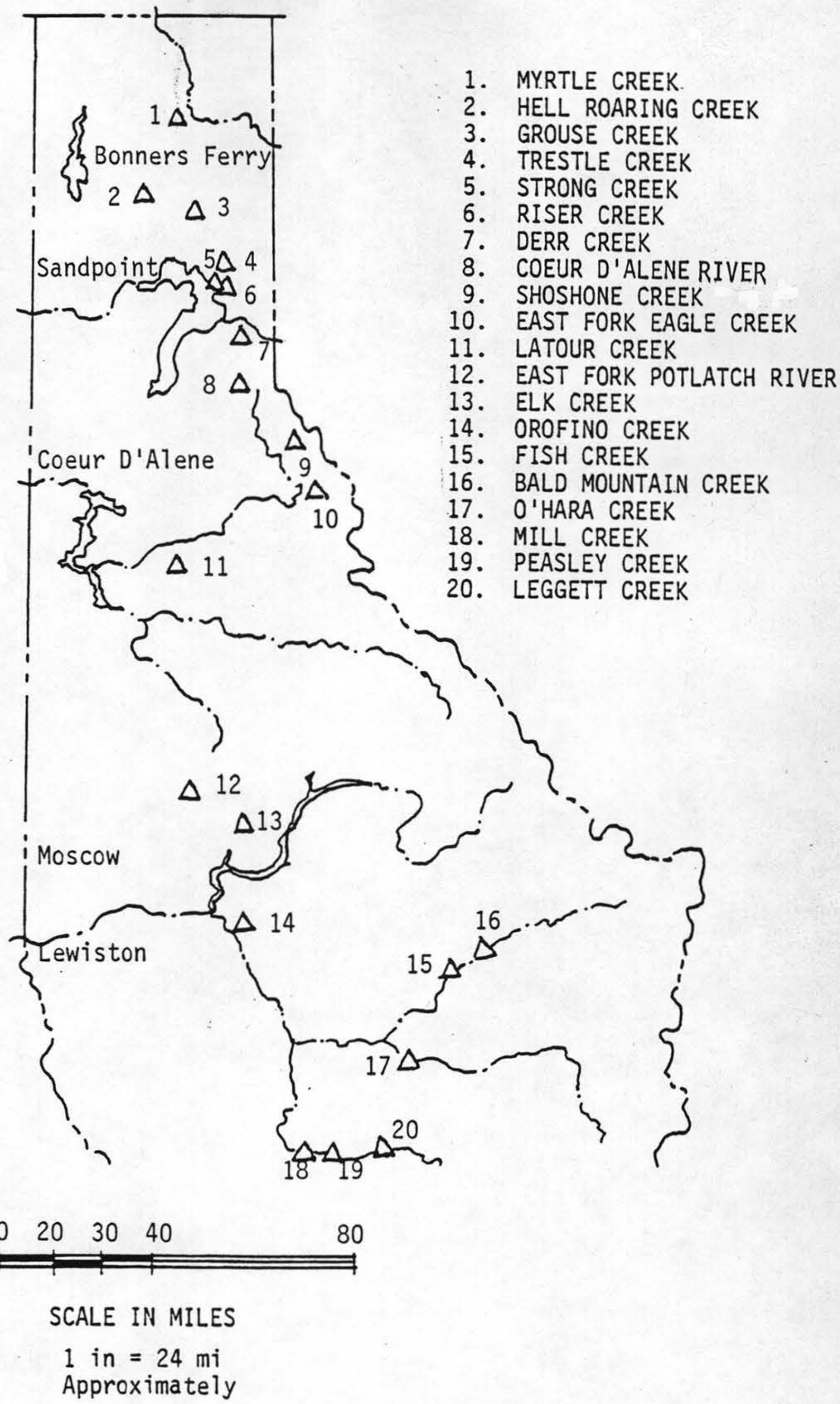

Fig. 18. Location of Ungaged Stream Measurement Sites.

CONCLUSIONS AND RECOMMENDATIONS

As shown in the literature, low flows, and hence the low flow portion of the duration curve, are the least predictable of ungaged streamflow characteristics. This investigation evaluated the practice of assigning exceedance percentage values to single streamflow measurements from the percentage exceedance values of flows simultaneously recorded at gaged sites.

In an effort to evaluate the accuracy of using these simultaneous percentage exceedances, the percentage exceedance values of six streams believed to be a random sample of ungaged streamflow in northern Idaho were studied. Simultaneous percentage exceedance values were found to be highly correlated between stations and tended to be similar, but the exceedance values were spread over a range of values at any particular point in time.

This report does show, however, that the spread or range of simultaneous percentage exceedance values tended to decrease with higher average exceedance values and also tended to reach a minimum around September 1 in the northern Idaho region. Simultaneous discharge measurements taken under these conditions, therefore, would be expected to yield more accurate results. As illustrated in Table 6, the magnitude of the spread is shown to decrease further into the early fall if there has been no recent precipitation.

In general when it is felt that an ungaged streamflow site cannot be characterized by any particular gaged site then it may be necessary to use the average of several gages to obtain exceedance percentages for the ungaged site. In this case a much broader prediction interval may be expected. A methodology estimating the prediction intervals has been developed in this research and is outlined on page 53.

Application of the report results and methodology can be used only as a check-of-fit to flow duration values estimated by other methods. Values or duration curves lying outside prediction intervals established by overall basin behavior should be explained or re-examined.

The methodologies developed allows those studying the flow duration characteristics of a stream to establish a crude estimate of the reliability of the data. This estimate of reliability was not available prior to this investigation and is an important contribution to the hydrologic analyses techniques for those making hydropower studies. Those using the predicted low flow values can now check the sensitivity of their preliminary designs and economic calculation to the variabilities in the low flow predictions.

Whereas sufficient data were available for the development and testing of methods for using short-time field measurements, the field measurements taken as a part of this research effort provide a sampling of ungaged streamflow in relatively ungaged areas in northern Idaho. These data can be added to the existing pool of gaged and ungaged data for the State of Idaho. As well, it was found that field measurements are valuable not only in providing raw instantaneous discharge data but also allow those making the measurements to make important overall site and stream observations.

The affects of precipitation during low flow months was also investigated. Figure 8 illustrates that precipitation in the early summer periods has a smaller effect on streamflow percentage exceedance values than precipitation during the late summer when percentage exceedance values are at their highest. Thus when making single low flow measure care must be taken to avoid taking these measurements when the time interval between streamflow measurement and a precipitation event is relatively short.

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GLOSSARY OF SELECTED TERMS

Correlation Coefficient - value commonly referred to in statistical literature which measures statistical correlation between pairs of data.

Correlation Number - ratio of simultaneous ungaged to gaged streamflows as explained in McKinney, Warnick, and others, 1983.

Dimensionless Flow or Dimensionless Flow Duration Curve - flow or flow duration curve values divided by the average discharge.

Electronic Flow Meter - an electronic device with a probe that electronically measures water velocity directly.

Normalized Flow or Normalized Flow Duration Curve - same as dimensionless flow or dimensionless flow duration curve.

Occurrence Interval - the interval or bounds in which a certain percentage of data were observed to occur.

Parametric Flow Duration Curve - a flow duration curve developed from particular percentage exceedance flows determined by regression or best-fit analysis of data taken from gages in a particular region.

Percentage Exceedance - the percentage of time a particular flow was or will be equalled or exceeded.

Prediction Interval - the interval or bounds in which a certain percentage of all future or predicted values would be expected to fall.

Pygmy Price AA Meter - a small current meter used to measure streamflow velocity by counting the number or rate of revolutions of a small wheel with cups caused to rotate by placement in the stream.

Regression Analysis - statistical least-squares fit of data to an equation or curve or mathematical relationship.

Specific Discharge or Specific Low Flow Discharge - discharge divided by drainage basin area.

Water Year - a 365- (or 366) day period from October 1 to September 30 of the following year commonly used in water resource planning and study. The water year number is the same as the number of the calendar year from or for which the January through September data are drawn.

APPENDIX A

Exceedance Percentage Values for
Streamflow on Nine Dates
for a 30-year Period

Exceedance Percentage Values are
Based on a Water Years
1931-1960 Study Period

Exceedance Percentage Values for July 20
are included as Table 2 in the
Main Text

Table A-1 Exceedance Percentage Values for August 1, Water Years 1931 Through 1960.

Water Year	Gage 1	2	3	4	5	6
1931	79.52	98.38	84.49	91.34	73.22	98.46
1932	66.00	85.22	73.44	70.48	57.62	79.80
1933	45.67	67.99	50.01	62.97	54.47	74.91
1934	69.56	99.37	85.92	83.30	78.97	86.96
1935	42.81	77.91	56.66	68.19	59.08	79.80
1936	87.01	97.46	93.10	81.09	68.98	86.96
1937	47.07	54.42	58.53	64.67	58.38	77.66
1938	53.53	82.42	71.44	74.44	59.41	83.87
1939	63.31	87.63	76.98	80.74	68.73	88.06
1940	81.83	90.55	87.31	84.87	79.89	89.38
1941	71.98	87.63	79.93	81.77	70.31	77.66
1942	33.01	47.66	37.84	62.34	54.07	67.90
1943	41.42	66.47	50.99	61.52	48.27	74.51
1944	80.37	95.98	83.65	91.60	80.15	97.38
1945	66.61	85.22	76.98	79.10	67.48	87.22
1946	52.51	70.71	55.18	72.07	57.92	77.90
1947	58.63	70.71	64.00	76.33	59.22	81.63
1948	34.34	45.81	41.64	46.52	38.53	33.41
1949	61.43	66.47	75.54	70.73	64.71	74.51
1950	35.82	47.25	37.38	53.68	38.79	54.26
1951	43.45	64.46	55.99	70.73	58.28	80.12
1952	50.31	64.46	69.61	68.44	56.57	70.75
1953	52.24	75.60	54.58	67.53	59.22	72.59
1954	36.72	48.70	38.56	59.14	49.32	67.90
1955	35.02	45.33	27.98	55.83	41.47	59.98
1956	51.29	66.47	60.37	63.26	52.71	68.07
1957	69.76	80.79	75.54	66.23	56.58	74.51
1958	75.83	82.42	81.44	73.60	65.92	76.47
1959	49.00	66.47	63.00	63.78	51.62	70.87
1960	57.45	66.47	58.53	64.92	51.48	69.44

Table A-2 Exceedance Percentage Values for August 10, Water Years 1931 Through 1960.

Water Year	Gage 1	2	3	4	5	6
1931	88.07	99.83	91.66	95.99	80.36	99.62
1932	76.36	98.38	85.92	74.54	64.92	86.96
1933	53.29	80.79	61.84	66.92	59.88	76.47
1934	77.83	99.83	93.10	89.39	81.35	88.74
1935	50.31	87.63	74.24	74.06	70.09	85.05
1936	94.27	98.38	96.74	85.86	72.53	93.59
1937	57.50	77.91	75.54	70.32	64.54	80.64
1938	66.91	87.63	83.65	80.74	68.38	91.50
1939	76.36	93.60	85.92	87.75	77.11	95.03
1940	93.63	99.37	95.46	96.91	89.31	98.02
1941	83.41	93.60	88.31	88.95	77.48	78.65
1942	39.61	57.40	53.16	70.32	62.85	90.44
1943	49.00	70.71	60.37	65.66	55.82	75.95
1944	92.55	97.46	93.10	92.35	81.19	96.82
1945	79.26	93.60	87.31	83.30	75.77	93.59
1946	66.61	80.79	75.54	79.62	67.48	82.63
1947	66.61	70.71	58.53	79.10	66.06	85.77
1948	38.87	50.99	51.50	54.07	48.36	46.30
1949	74.00	80.79	85.92	77.02	69.70	83.56
1950	43.79	57.40	48.54	60.21	47.67	62.17
1951	53.75	70.71	72.28	75.44	65.19	84.81
1952	57.45	66.47	68.94	72.07	62.03	73.80
1953	57.45	72.36	53.45	68.44	63.04	79.80
1954	44.83	60.70	55.99	63.76	58.57	72.81
1955	45.03	60.70	45.98	62.27	51.72	67.90
1956	59.99	75.60	72.28	66.79	60.28	72.11
1957	70.23	80.79	58.53	66.23	62.86	74.91
1958	87.01	87.63	90.58	82.98	73.54	81.63
1959	63.31	77.91	78.39	69.64	60.22	78.65
1960	59.76	75.60	72.28	72.17	69.33	81.01

Table A-3 Exceedance Percentage Values for August 20, Water Years 1931 Through 1960.

Water Year	Gage 1	2	3	4	5	6
1931	94.74	99.98	98.84	98.52	93.45	99.90
1932	84.20	99.37	88.31	80.61	72.09	82.63
1933	69.56	98.38	81.44	71.19	67.66	86.96
1934	89.34	99.83	96.74	95.11	92.60	95.52
1935	58.99	82.42	79.93	73.63	71.66	72.59
1936	95.53	99.37	98.84	92.35	82.47	98.46
1937	75.66	87.63	88.31	80.17	79.25	91.50
1938	72.42	87.63	81.44	77.56	68.38	77.66
1939	93.63	95.98	93.10	94.96	82.83	98.80
1940	96.64	99.37	98.84	99.06	94.10	99.19
1941	87.01	95.98	94.31	93.80	85.71	78.65
1942	49.79	77.91	74.24	78.16	71.12	91.97
1943	62.72	82.42	78.39	73.00	65.37	86.96
1944	91.31	95.98	95.46	96.44	88.01	97.38
1945	90.46	97.46	95.46	88.09	83.30	98.02
1946	79.26	90.55	84.49	87.43	76.21	89.38
1947	77.42	85.22	85.92	83.82	75.39	93.59
1948	45.90	60.70	65.78	60.21	55.10	56.82
1949	82.31	85.22	89.41	82.16	79.14	85.77
1950	52.24	66.47	60.37	65.94	56.33	70.50
1951	66.00	80.79	79.93	81.77	75.49	88.06
1952	72.42	80.79	88.31	79.10	69.86	82.20
1953	75.11	85.22	81.44	81.09	73.22	83.56
1954	51.29	57.40	39.45	59.31	49.67	60.67
1955	59.99	75.60	68.94	67.81	62.03	75.95
1956	69.76	80.79	83.65	73.00	69.15	78.65
1957	80.37	85.22	84.49	73.00	76.60	83.56
1958	98.03	93.73	94.31	90.13	79.36	85.93
1959	66.82	63.27	76.98	68.77	64.92	72.81
1960	75.11	82.42	83.65	77.83	75.56	85.77

Table A-4 Exceedance Percentage Values for September 1, Water Years 1931 Through 1960.

Water Year	Gage					
	1	2	3	4	5	6
1931	98.06	99.98	99.50	99.08	98.43	99.90
1932	84.20	97.46	85.92	80.61	74.48	90.44
1933	59.99	87.63	76.98	73.55	68.53	81.63
1934	94.27	99.83	99.50	98.21	96.13	98.46
1935	70.16	93.60	90.58	85.86	83.30	94.72
1936	98.76	99.37	99.77	93.48	88.55	97.75
1937	80.37	87.63	88.31	85.48	82.83	94.28
1938	86.33	95.98	95.46	94.37	83.30	92.63
1939	98.03	98.38	96.74	96.44	92.30	98.80
1940	99.04	98.38	99.77	99.42	96.90	99.33
1941	79.26	75.60	85.92	82.93	83.30	78.65
1942	59.37	75.60	81.44	79.76	74.67	86.96
1943	71.98	85.22	81.44	76.33	69.70	77.66
1944	98.42	97.46	98.84	97.87	94.62	97.60
1945	98.42	97.46	98.84	93.06	89.65	98.02
1946	79.26	85.22	81.44	90.03	77.11	89.38
1947	70.16	75.60	78.39	79.62	77.98	90.44
1948	54.65	70.71	75.54	66.79	65.37	63.65
1949	88.74	82.42	90.58	86.38	88.01	93.59
1950	62.04	75.60	65.78	70.32	66.70	77.02
1951	42.00	58.50	35.09	74.91	73.22	74.70
1952	79.26	85.22	93.10	82.16	79.14	86.96
1953	73.51	80.79	65.78	80.55	75.84	82.20
1954	40.93	59.49	39.45	62.27	61.12	60.67
1955	77.54	85.22	84.49	73.00	70.90	80.12
1956	78.67	77.91	87.31	70.32	66.59	69.44
1957	90.46	90.55	91.66	78.80	81.24	83.56
1958	99.39	90.95	94.31	85.86	82.97	84.81
1959	62.47	75.60	73.44	75.94	63.29	67.63
1960	75.11	75.60	68.94	76.58	76.33	80.12

Table A-5 Exceedance Percentage Values for September 10, Water Years 1931 Through 1960.

Water Year	Gage 1	2	3	4	5	6
1931	88.07	85.22	87.31	92.35	75.56	69.33
1932	90.46	99.37	96.74	85.90	82.08	95.52
1933	66.82	61.87	71.44	76.41	72.70	82.63
1934	96.11	99.37	96.74	94.49	85.89	88.74
1935	77.83	97.46	94.31	93.06	89.27	97.38
1936	94.27	97.46	98.84	93.06	91.06	97.38
1937	80.37	87.63	78.39	83.43	90.12	86.96
1938	83.02	87.63	91.66	77.02	73.85	53.95
1939	94.27	97.46	95.46	96.44	93.69	98.02
1940	93.63	97.46	96.74	97.31	95.74	97.38
1941	68.41	63.27	34.12	75.92	71.66	74.51
1942	63.31	82.42	68.94	85.48	77.11	91.97
1943	78.06	90.55	88.31	83.30	77.48	88.74
1944	99.81	98.38	99.77	98.58	97.86	99.62
1945	90.46	85.22	87.31	86.38	88.01	95.52
1946	77.42	90.55	76.98	79.99	81.19	83.56
1947	65.45	58.50	34.12	70.73	62.51	64.87
1948	61.93	75.60	83.65	73.00	71.12	68.07
1949	86.00	87.63	88.31	88.09	79.77	91.50
1950	70.16	80.79	79.93	74.91	71.85	75.95
1951	53.25	75.60	58.53	84.63	81.58	83.56
1952	76.95	80.79	88.31	76.33	79.25	77.66
1953	80.37	87.63	82.23	87.43	81.19	87.22
1954	48.29	70.71	54.58	70.73	71.85	72.81
1955	88.07	87.63	85.92	77.56	76.33	82.20
1956	86.00	82.42	93.10	79.62	80.36	76.47
1957	96.11	90.77	94.31	83.30	87.70	90.44
1958	99.87	93.79	95.54	94.49	89.82	91.50
1959	42.97	52.45	32.86	68.77	68.83	71.33
1960	71.54	82.42	60.89	81.15	80.39	82.95

Table A-6 Exceedance Percentage Values for September 20, Water Years 1931 Through 1960.

Water Year	Gage 1	2	3	4	5	6
1931	92.55	95.98	90.58	90.49	87.32	92.63
1932	92.55	97.46	88.31	83.30	78.09	92.63
1933	66.00	66.47	71.44	76.41	78.72	74.51
1934	92.55	99.37	96.74	94.49	90.47	96.82
1935	84.61	93.60	94.31	89.52	90.76	93.59
1936	96.64	93.60	93.10	93.06	92.97	91.50
1937	85.30	93.60	89.41	90.03	91.06	95.03
1938	90.95	95.98	98.84	95.35	90.12	92.63
1939	96.64	97.46	95.46	95.91	94.56	97.60
1940	90.95	93.60	81.44	93.80	92.30	72.81
1941	29.59	33.56	20.13	61.39	72.53	58.23
1942	65.45	87.63	85.92	86.38	83.85	90.44
1943	87.01	93.60	90.58	85.76	83.30	93.59
1944	96.64	80.79	61.84	77.02	75.39	90.44
1945	94.27	70.71	81.44	83.82	85.21	94.72
1946	80.37	90.55	75.54	90.03	85.71	88.06
1947	68.41	66.47	47.95	73.85	70.31	66.02
1948	67.89	80.79	87.31	78.16	76.60	69.33
1949	80.37	75.60	61.84	79.10	75.39	82.63
1950	77.42	82.42	89.41	78.16	78.02	81.63
1951	64.87	80.79	79.93	91.60	87.00	90.44
1952	87.01	90.55	96.74	86.77	85.02	88.74
1953	89.34	90.69	87.31	92.35	88.64	91.50
1954	55.90	66.47	42.47	61.27	61.38	63.65
1955	88.74	77.91	78.39	73.49	77.18	74.70
1956	92.01	85.22	95.46	85.09	83.98	81.63
1957	96.88	85.22	89.41	75.44	85.71	88.06
1958	79.52	72.36	60.37	80.21	75.39	75.95
1959	29.36	30.98	19.14	69.64	65.22	63.23
1960	79.26	87.63	76.98	87.54	87.32	92.63

Table A-7 Exceedance Percentage Values for October 1, Water Years 1931 Through 1960.

Water Year	Gage 1	2	3	4	5	6
1931	85.30	95.98	96.74	99.51	90.47	85.93
1932	98.03	98.38	95.46	94.49	98.16	98.80
1933	96.11	98.38	96.74	84.71	88.21	94.72
1934	55.96	56.21	48.54	74.15	73.60	76.47
1935	95.13	97.46	94.31	93.94	93.08	92.63
1936	88.74	98.38	96.74	93.06	95.74	95.52
1937	98.03	95.98	98.84	96.91	96.90	97.38
1938	81.26	85.22	67.98	90.66	93.31	94.28
1939	92.01	93.60	94.31	93.80	83.30	91.50
1940	96.64	97.46	96.74	97.31	97.34	98.80
1941	95.13	97.46	95.46	95.35	77.11	63.65
1942	33.32	33.79	25.75	78.80	81.90	75.95
1943	70.16	85.22	78.39	87.75	86.39	91.97
1944	92.55	95.98	93.10	90.49	88.01	93.59
1945	96.11	85.22	64.00	85.76	85.71	90.44
1946	91.31	85.22	85.92	72.07	85.21	80.64
1947	75.83	90.55	78.39	94.15	89.27	90.44
1948	66.61	72.36	58.02	87.43	87.22	80.64
1949	67.89	72.36	67.98	73.49	77.48	68.07
1950	84.20	85.22	82.23	86.38	87.22	83.56
1951	75.66	75.60	68.94	78.16	78.34	77.02
1952	38.57	28.71	18.48	60.21	56.67	55.04
1953	92.01	91.08	99.50	90.49	92.60	94.72
1954	84.61	60.70	37.84	83.82	87.00	85.77
1955	56.40	75.60	61.84	73.85	69.86	75.95
1956	75.83	70.71	53.45	67.53	72.23	73.80
1957	77.54	72.36	64.00	72.07	58.93	60.12
1958	98.42	93.73	91.66	86.38	93.31	86.96
1959	98.42	85.22	81.44	89.37	88.64	83.56
1960	27.98	37.73	24.65	59.34	50.26	51.19

Table A-8 Exceedance Percentage Values for October 10, Water Years 1931 Through 1960.

Water Year	Gage 1	2	3	4	5	6
1931	79.52	82.42	81.44	82.93	73.60	75.95
1932	97.31	90.55	94.31	93.14	96.43	94.72
1933	96.64	97.46	96.74	88.95	88.21	94.28
1934	56.96	70.71	58.53	80.64	72.70	85.77
1935	94.27	98.38	98.84	97.42	95.15	93.59
1936	90.46	99.37	98.84	91.72	96.90	94.72
1937	98.42	95.98	98.84	96.91	96.62	93.59
1938	74.00	85.22	74.24	91.87	93.69	88.06
1939	89.34	87.63	93.10	91.87	90.75	86.96
1940	90.95	93.60	90.58	95.35	96.62	95.03
1941	95.13	90.55	91.66	95.91	94.10	75.95
1942	31.44	21.01	16.95	62.34	51.32	45.63
1943	75.66	90.55	90.58	96.44	91.21	90.44
1944	91.31	95.98	90.58	92.35	83.30	90.44
1945	96.11	85.22	67.98	96.44	94.62	90.44
1946	92.55	90.55	93.10	90.03	92.60	88.06
1947	73.51	87.63	76.98	93.48	88.01	86.96
1948	46.61	32.33	21.00	63.26	61.95	58.03
1949	56.40	57.40	42.47	70.73	73.54	68.07
1950	77.42	67.99	61.84	70.73	77.48	74.87
1951	56.80	34.89	27.38	64.83	62.03	60.12
1952	38.57	49.33	34.55	72.56	78.78	78.65
1953	92.01	93.73	99.50	93.06	95.74	92.85
1954	86.00	85.22	82.23	90.49	96.39	88.06
1955	61.43	75.60	66.60	78.16	72.70	77.02
1956	32.87	4.07	8.73	19.88	26.36	19.74
1957	87.01	80.79	91.66	85.09	87.70	76.47
1958	93.63	82.42	82.23	84.29	85.93	77.02
1959	94.74	67.99	63.00	69.64	63.10	63.39
1960	27.43	25.57	22.96	43.62	36.11	41.53

APPENDIX B

Low Flow Streamflow Field Measurements
at Various Sites in Northern Idaho

FIELD MEASUREMENT SUMMARY

		Discharge in cfs			
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float Method	Other (Specify)
8/15/83	Myrtle Creek[1]				
	South channel	7.27	6.95		
	North channel	16.85	17.70		
	Total	24.12	24.65		
	blw div and ab overflow				25.94 (estimated discharge over spillway assuming sharp-crested weir)
9/13/83	South channel	3.53			
	North channel	11.40			
	Total	14.93			20.36 (calculated discharge over spillway + overflow + discharge through south culvert)

1. Location: SW 1/4 Sec 23, T 62 N, R 1 W, at diversion to Bonners Ferry City Water Supply, approximately 1 mi upstream of crossing of west side road approximately 5 mi west of Bonners Ferry.

r. rough check

FIELD MEASUREMENT SUMMARY

Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
		Discharge in cfs			
7/18/83	Grouse Creek[2]	171.13		142.93	
8/15/83		39.66		38.10	
9/13/83		23.05			

1. using $\bar{v} = 0.65v_s$

2. Location: NW 1/4 Sec 30, T 59 N, R 1 E, approximately 0.35 mi by road from gravel road crossing and approximately 6 mi by road east of Samuels.

FIELD MEASUREMENT SUMMARY

Date	Stream or Site	Discharge in cfs: Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
7/18/83	Hell Roaring Creek[2]	27.15		25.01r	
8/15/83		7.62		7.94	
9/13/83		6.38			

1. using $\overline{v} = 0.65v_s$

2. Location: NW 1/4 Sec 3, T 59 N, R 2 W, at end of private road approximately 1/2 mi upstream of Pack River Road crossing and at mouth of mountainous canyon.

r. rough check

FIELD MEASUREMENT SUMMARY

Date	Stream or Site	Discharge in cfs			
		Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
7/19/83	Trestle Creek[2]				
	North channel	18.01		17.16	
	South channel	4.29		4.40	
	Total	22.30		21.56	
8/15/83	Main channel	7.16	6.51		
	Small channel	0.45			
	Total	7.61	6.96		
9/14/83	Main channel	4.67			
	Small channel	0.13			
	Total	4.80			

1. using $\overline{v} = 0.65v_s$

2. Location: at forest road no. 1082 crossing approximately 5.3 mi by road northeast of Highway 200.

FIELD MEASUREMENT SUMMARY

Date	Stream or Site	Discharge in cfs: Electronic Flowmeter	Pygmy Meter	Float Method	Other (Specify)
7/19/83	Strong Creek[1]				
	North channel	22.22			
		19.49r			
	South channel	2.17			
	Total	24.39			
9/14/83		4.49			

1. Location: SW 1/4 Sec 25, T 57 N, R 1 E, upstream from City of East Hope diversion for city water supply.

r. rough check

FIELD MEASUREMENT SUMMARY

		Discharge in cfs			
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
7/19/83	Riser Creek[2]	10.88		5.74	
8/16/83		1.32		1.46	
9/14/83		0.85			

1. using $\overline{v} = 0.65v_s$
2. Location: Approximately 1 1/2 mi upstream from crossing of Highway 200 approximately 1 1/2 mi east of East Hope.

FIELD MEASUREMENT SUMMARY

		Discharge in cfs			
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float Method	Other (Specify)
6/28/83	Derr Creek[1]				
	Upper site	8.70(8.13a)			
		8.92(8.34a)			
	Lower site	3.22e(3.01ae)		6.23r	
		3.29e(3.07ae)		11.2r	
7/19/83	Upper site	8.98			
	Lower site	4.69			
	below culvert	1.53			
8/16/83	Upper site	4.62	4.53		
	lower site	2.42e	4.41		
9/14/83	Upper site	2.42	2.63		
	Lower site		3.06		

1. Location: Approximately 2 mi south of Clark Fork.

a. adjusted discharge = measured discharge ÷ 1.07 calibration factor

e. erroneous

r. rough check

FIELD MEASUREMENT SUMMARY

Date	Stream or Site	Discharge in cfs Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
7/19/83	Coeur d'Alene River[2]	82.70		68.72	
8/16/83			24.11		
9/14/83		17.27			

1. using $\overline{v} = 0.65v_s$

2. Location: NE 1/4 Sec 4, T 53 N, R 2 E, immediately upstream of forest road bridge near Beaver Work Center, roughly 40 mi by road northwest of Prichard.

FIELD MEASUREMENT SUMMARY

		Discharge in cfs			
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float Method	Other (Specify)
7/20/83	Shoshone Creek[1]	93.28			
8/17/83		26.21	26.34		
9/15/83		13.81			

1. Location: NE 1/4 Sec 32, T 52 N, R 4 E, near upstream end of rip-rap bank on east side of stream above highway bridge about 1/2 mi above Rampike Creek and approximately 10 mi upstream from mouth.

FIELD MEASUREMENT SUMMARY

		Discharge in cfs			
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float Method	Other (Specify)
7/20/83	West Fork Eagle Cr.[1]	37.57			
8/17/83		11.29	9.66		
9/15/83		5.93			

1. Location: NE 1/4 Sec 24, T 50 N, R 4 E, immediately downstream of forest road crossing approximately 2.8 mi northeast of Eagle and approximately 1.8 mi above mouth.

FIELD MEASUREMENT SUMMARY

Date	Stream or Site	Discharge in cfs Electronic Flowmeter	Pygmy Meter	Float Method	Other (Specify)
8/17/83	Latour Creek[1]	11.65	11.79		
9/15/83		8.49			

1. Location: NE 1/4 Sec 34, T 48 N, R 1 W, at bridge approximately 7.2 mi by road from Cataldo-Dudley road and approximately 0.4 mi, above Baldy Creek.

FIELD MEASUREMENT SUMMARY

Date	Stream or Site	Discharge in cfs: Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
7/26/83	E.F. Potlatch River[2]	13.98	11.60	17.14	
8/26/83		13.28			
9/29/83		8.16			

1. using $\overline{v} = 0.65v_s$

2. Location: SW 1/4 Sec 6, T 40 N, R 1 W, immediately upstream of Bovill-Elk River Highway and about 1.5 mi south of Bovill.

FIELD MEASUREMENT SUMMARY

			Discharge in cfs		
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
7/26/83	Elk Creek[2]	32.77	30.31	27.25	
8/26/83		28.89			
9/29/83		17.13			

1. Using $\overline{v} = 0.65v_s$

2. Location: NW 1/4 Sec 11, T 39 N, R 2 E, approximately 1/2 mi by stream upstream of main Elk Creek Falls and approximately 2 1/2 miles south of Elk River.

FIELD MEASUREMENT SUMMARY

		Discharge in cfs			
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float Method	Other (Specify)
7/21/83	Orofino Creek[1]				96.93 (USGS rating curve)
8/18/83					9.80e (USGS rating curve)

1. Location: SW 1/4 Sec 11, T 36 N, R 2 E, at country road bridge 4.7 mi above mouth, 1.4 mi upstream from Whiskey Creek, and approximately 2 mi Southeast of Orofino City limits.

e. erroneous due to rating change

FIELD MEASUREMENT SUMMARY

		Discharge in cfs			
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
7/21/83	Bald Mtn. Creek[2]	27.67		22.78(21.36b)	
8/18/83		12.35	13.65		
9/10/83		9.25			
10/14/83		7.51			

1. using $\bar{v} - 0.65v_s$

2. Location: Approximately 100 ft downstream of Highway 12 crossing near State Highway Department shop and approximately 31 miles from Lowell.

b. adjusted discharge = discharge x ratio of float distances, 7.5/8.0

FIELD MEASUREMENT SUMMARY

		Discharge in cfs			
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float Method	Other (Specify)
7/21/83	Fish Creek[1]				
	Main channel	90.14			
	Small channel	2.50 (1.25c)			
	Small channel	1.19 (0.89c)			
	North Channel	2.38			
	Total	96.21 (94.66c)			
8/18/83		41.42	41.88		
9/10/83		32.40			
10/14/83		32.59			

1. Location: near Highway 12 crossing, 1.3 mi southwest of Lochsa ranger station and 18 miles northeast of Lowell.

c. alternative calculation or distribution of flow

FIELD MEASUREMENT SUMMARY

			Discharge in cfs		
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
7/21/83	O'Hara Creek[2]	37.97		44.10(41.34b)	
8/18/83		24.90		21.86	
9/10/83		18.55			
10/13/83		19.85			

1. using $\overline{v} = 0.65v_s$
2. Location: SE 1/4 Sec 25, T 32 N, R 7 E, 0.3 mi upstream from mouth, approximately 7 mi from Lowell.

b. adjusted discharge = discharge x ratio of float distances, 7.5/8.0

FIELD MEASUREMENT SUMMARY

Date	Stream or Site	Discharge in cfs: Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
7/22/83	Leggett Creek[2]	6.55m 4.82		4.79(4.49b)	
8/18/83		1.51		1.84	
10/13/83		1.25			

1. using $\overline{v} = 0.65v_s$

2. Location: Immediately downstream of crossing of Elk City-Grangeville highway approximately 13 mi west of Elk City.

b. adjusted discharge = discharge x ratio of float distances, 7.5/8.0

m. error suspected because of surrounding metal

FIELD MEASUREMENT SUMMARY

		Discharge in cfs			
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
7/22/83	Peasley Creek[2]	7.96		7.57(7.10b)	
8/18/83		4.04		4.37	
10/13/83		3.09			

1. using $\overline{v} = 0.65v_s$
2. location: upstream of Highway 14 crossing and 6.6 mi west of Golden.

b. adjusted discharge = discharge x ratio of float distances, 7.5/8.0

FIELD MEASUREMENT SUMMARY

		Discharge in cfs			
Date	Stream or Site	Electronic Flowmeter	Pygmy Meter	Float[1] Method	Other (Specify)
7/22/83	Mill Creek[2]	21.08		22.31(20.92b)	36.24 (USFS rating curve)
8/18/83		10.89		10.47	
9/10/83		9.30			
10/13/83		9.06			

1. using $\overline{v} = 0.65v_s$

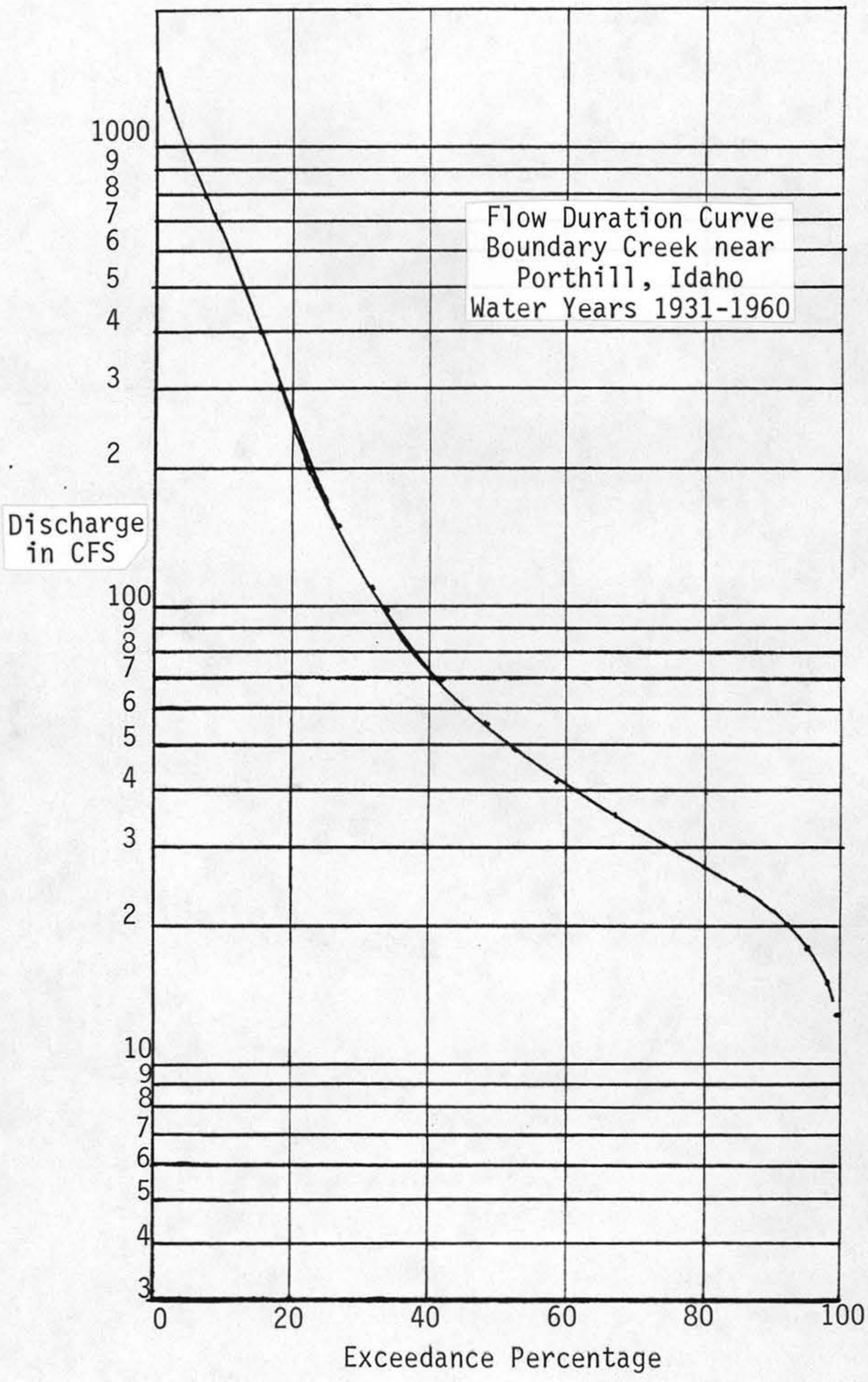
2. location: NW 1/4 Sec 26, T 29 N, R 4 E, immediately below forest road crossing 0.9 mi by road upstream from mouth.

b. adjusted discharge = discharge x ratio of float distances, 7.5/8.0

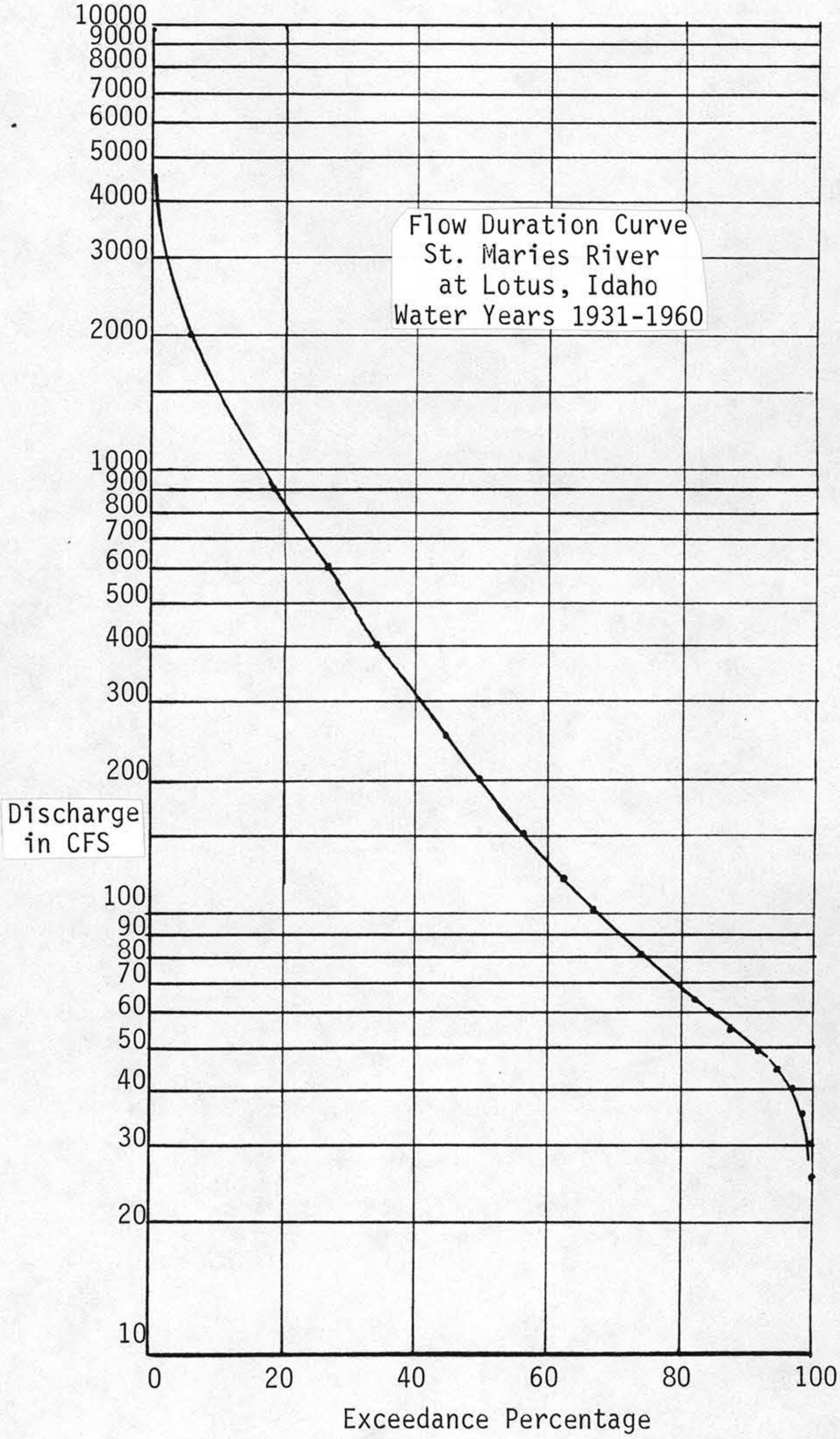
APPENDIX C

Flow Duration Curves for Four Gaged
Streams in Northern Idaho

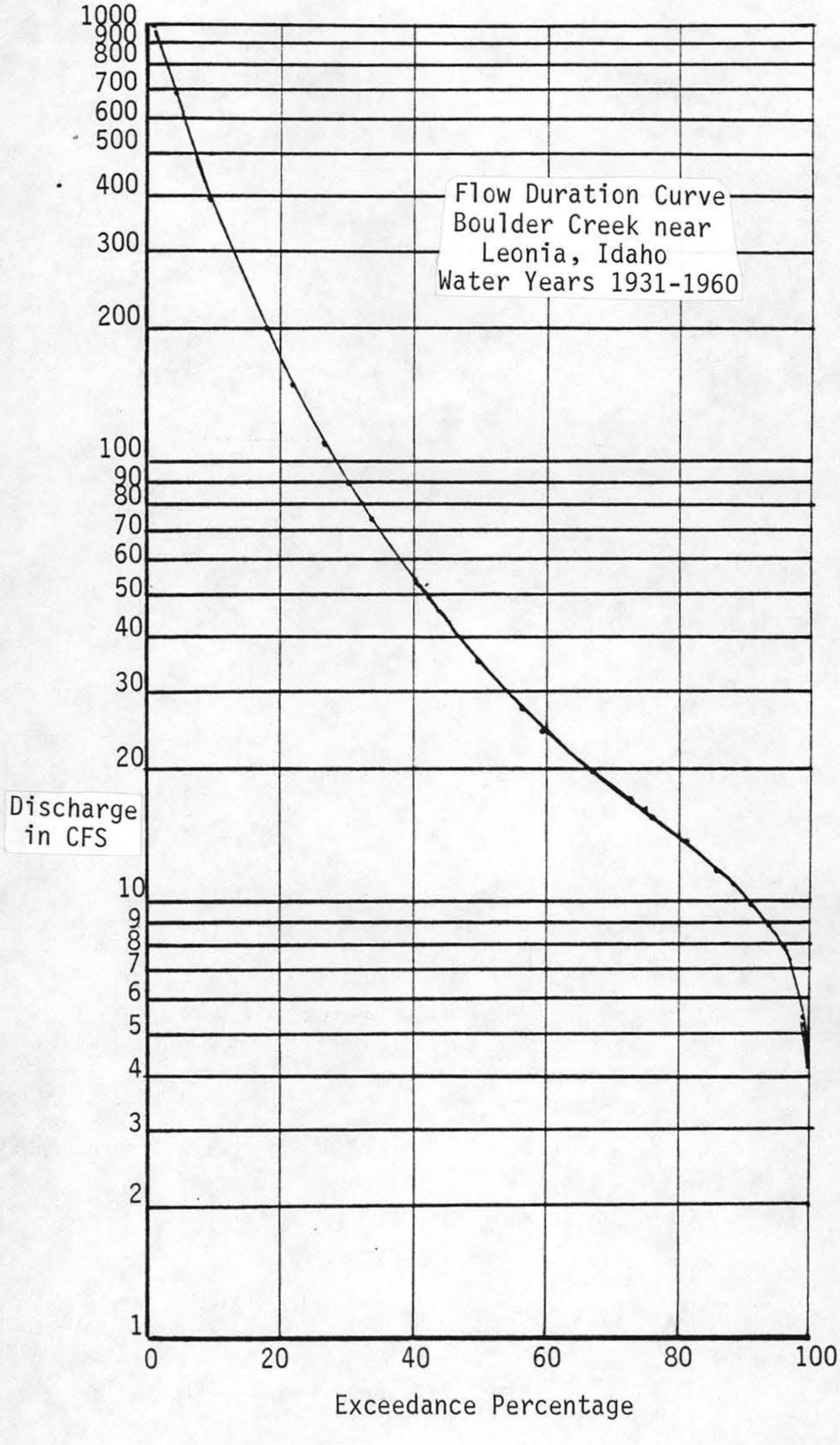
Water Years 1931-1960



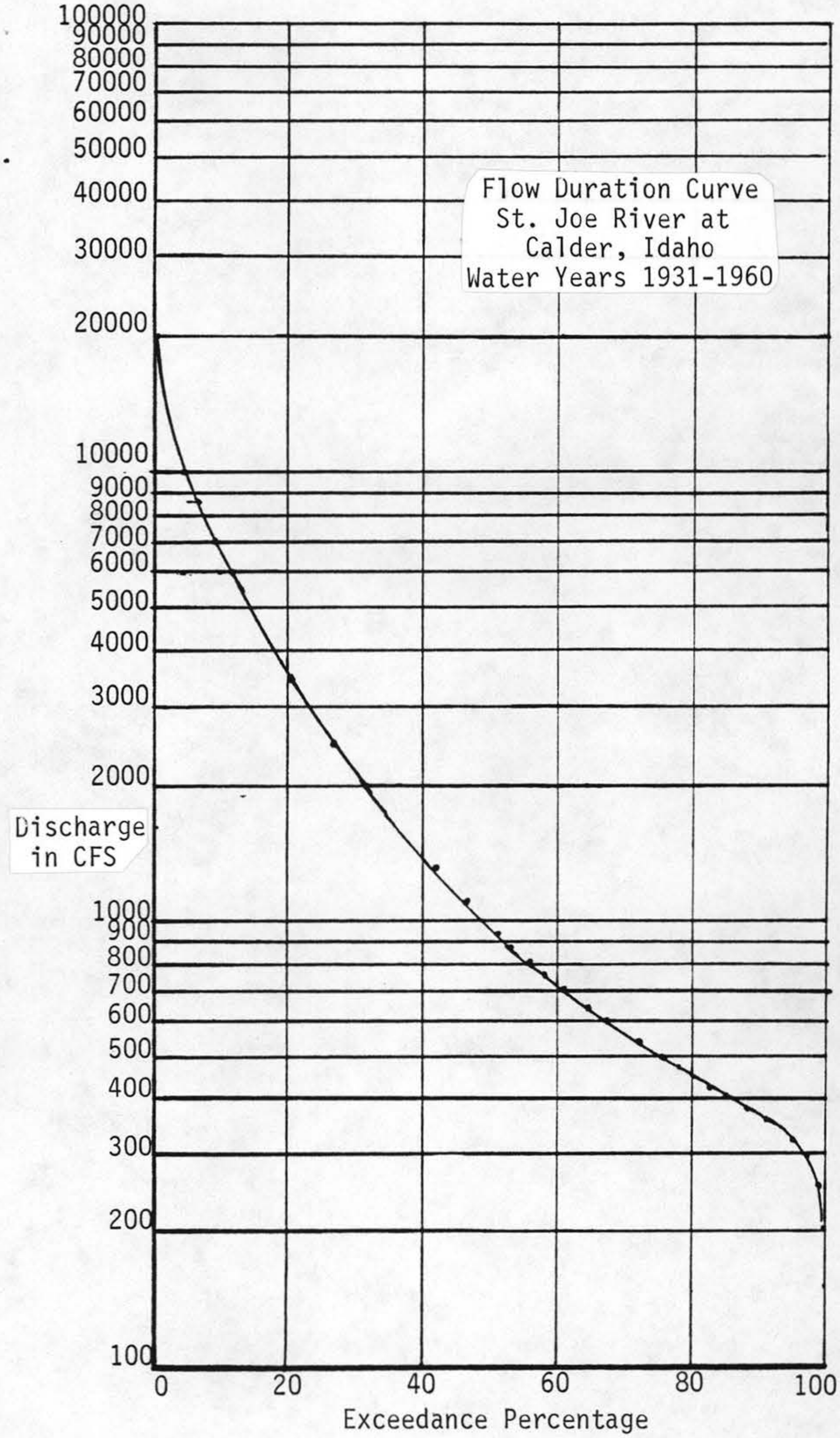
Flow Duration Curve
Boundary Creek near
Porthill, Idaho
Water Years 1931-1960
Discharge in CFS
1000
9
8
7
6
5
4
3
2
100
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
0
20
40
60
80
100
Exceedance Percentage



Flow Duration Curve
St. Maries River
at Lotus, Idaho
Water Years 1931-1960
Discharge in CFS
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
20
40
60
80
100
Exceedance Percentage



Flow Duration Curve
Boulder Creek near
Leonia, Idaho
Water Years 1931-1960
Discharge in CFS
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0
20
40
60
80
100
Exceedance Percentage



100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
0
20
40
60
80
100
Exceedance Percentage
Discharge in CFS
Flow Duration Curve St. Joe River at Calder, Idaho Water Years 1931-1960