STREAMFLOW DATA REQUIREMENTS TO ASSESS MICRO-HYDROPOWER POTENTIAL FOR SMALL RAINFALL-REGIME BASINS IN WESTERN OREGON

HYDROLOGIC RESEARCH SERVICES
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SYNOPSIS

Various amounts of streamflow data were used to estimate the streamflow and flow-duration characteristics for a small stream and compare them with the actual complete record. The data options tested included once-weekly, twice-weekly, and daily water level measurements, with and without intervening maximum and minimum extreme levels, for full-year periods and for the wet-season only. The purpose was to better specify the minimum amount of streamflow data needed to make micro-hydropower assessments for sites having no prior hydrologic data.

Once-daily measurement of stage gives good accuracy in predicting streamflow characteristics. Use of once-or-twice-weekly measurements plus the recorded intervening minimum stage offers a slightly less accurate but conservative estimate that is suitable for hydropower potential evaluations.

Concurrent precipitation information from a nearby station can be used to determine the representativeness of the period of site stage readings, compared to long-term conditions. If precipitation data are also collected in the basin near the site, additional predictions of flow conditions can be made using regional prediction equations. This gives an added check on the hydropower potential.

Information on maximum intervening stages is desirable. Although these flows are seldom used to generate hydropower, they indicate water levels for which intake and diversion structures should be designed so as to avoid high-water damage.

The findings are considered to be highly applicable for small basins in Western Oregon having rainfall as the dominant form of precipitation. The techniques developed are considered to be valid for a wide range of basin sizes, both smaller and larger than the 2.7 square mile test basin.

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INTRODUCTION

This report presents a comparison of streamflow and flow-duration characteristics for a small stream based on use of differing amounts of streamflow data. The purpose is to compare the resulting accuracies in order to better specify the amount of streamflow information that is needed for micro-hydropower assessment.

The options considered are:

a. continuous recorded values (the full actual record);
b. once-weekly measurement (at noon every seventh day);
c. once-weekly measurement supplemented by recorded maximum/minimum extremes between measurements;
d. twice-weekly measurement (at noon every third and seventh day);
e. twice-weekly measurement supplemented by recorded maximum/minimum extremes between measurements;
f. daily measurement (at noon);
g. daily measurement supplemented by recorded maximum/minimum extremes between measurements; and
h. wet season (October-April) once-weekly measurement supplemented by recorded minimum extremes between measurements.

To implement these options, stage (water level) observations are needed. These can be obtained by reading a staff gage, by reading a maximum/minimum recorder (e.g., movable clips on both sides of a float cable), or by using a continuously operating strip-chart recorder. It is assumed that some type of weir would be installed just downstream of the point of stage measurement, both to stabilize the stage and to allow use of a rating relation to convert stages to discharges.

The comparison was made using available records from Oak Creek, which drains a small Coast Range watershed five miles west of Corvallis. The vegetative cover, terrain, geology, and rainfall patterns there are typical for much of Western Oregon where snowfall is not a factor. The drainage area above the weir is 2.7 square miles (7.0 square kilometers). The stream width is 10-to-15 feet, bank height is 2-to-3 feet, and local stream gradient near the weir is about 3 feet per 100 feet. Higher in the basin the gradient in well-defined tributary channels increases to 30 feet per 100 feet.

The characteristics of the Oak Creek watershed allow extrapolation of data evaluations to many sites in Western Oregon that have micro-hydropower potential. The main constraints on extrapolation are to be sure that hydrologic and other basin features are roughly similar and that basin size does not exceed about 5 square miles. On larger basins, streamflows are less responsive to quick changes in local rainfall intensity; the main channel collects runoff from many source areas, not all of which simultaneously receive high intensity rain, thus causing the hydrograph to be smoother.

DATA BASE USED

The most complete water level record available for Oak Creek is that for the 1979-80 water year. This was used for the basic analysis. Gaps in the record were filled by estimating missing stages from the available preceding and following stages and from hourly precipitation data (the latter from National Weather Service records). Appendix A presents reduced-size copies of the adjusted water level records. Information about the gaging station characteristics and rating curve are also shown in Appendix A.

The actual Oak Creek streamflow characteristics (depicted in Appendix A) were used to extract the average annual discharge, the monthly discharge pattern, and the flow-duration curve for Oak Creek. Stages were read from the charts at 2-hour intervals (4,392 data points) and tabulated. Average monthly and annual streamflows are shown in Table 1. The flow-duration tabulation is summarized in Table 2. The resulting flow-duration curve is shown in Figure 1.

The information presented in Appendix A, Tables 1 and 2, and Figure 1 constitutes data collection option A. This is the norm against which all other options are compared for accuracy. For this option, the average annual discharge is 5.09 cubic feet per second (cfs), and is exceeded 29.6 percent of the time, the instantaneous maximum and minimum discharges are 133.69 cfs and 0.59 cfs, respectively, and the median discharge is 2.45 cfs. (Here and elsewhere in this report, discharges are given to the nearest 0.01 cfs, for convenience in tabulation. However, accuracy in determining discharges from the rating curve does not exceed three significant figures, even though stages can be read to the nearest 0.001 foot.)

TABLE 1. AVERAGE MONTHLY AND ANNUAL DISCHARGES
AT OAK CREEK SEDIMENT RESEARCH WEIR, 1979-80 WATER YEAR

Month	Average Discharge, cfs
October	4.60
November	4.75
December	6.21
January	16.00
February	6.38
March	9.38
April	7.47
May	2.08
June	1.49
July	1.02
August	0.84
September	0.80
Average Annual Discharge, cfs	5.09

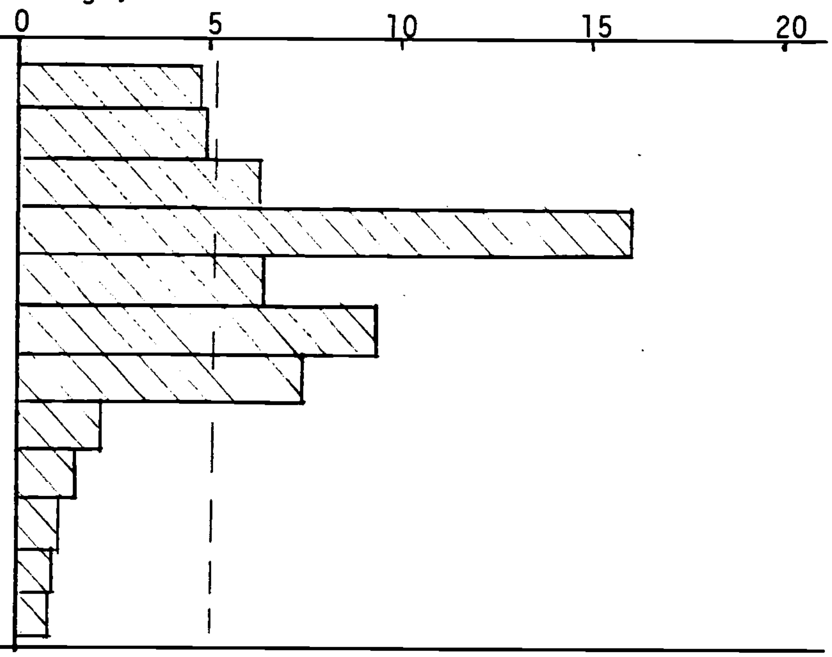


TABLE 2. FLOW-DURATION TABULATION OF STREAMFLOW AT OAK CREEK SEDIMENT RESEARCH WEIR, 1979-80 WATER YEAR (USING 2-HOUR INTERVALS)

Discharge, Q, cfs	Number of Times Q ≧ Indicated Value But < Next Larger Value	Cumulative Total	Cumulative Percent of Grand Total	Discharge, Q, cfs	Number of Times Q ≧ Indicated Value But < Next Larger Value	Cumulative Total	Cumulative Percent of Grand Total
125	0	0	0	70	0	9	0.20
124	1	1	0.02	69	0	9	0.20
⋮	⋮	⋮	⋮	68	2	11	0.25
⋮	⋮	⋮	⋮	67	0	11	0.25
112	0	1	0.02	66	0	11	0.25
111	1	2	0.05	65	0	11	0.25
⋮	⋮	⋮	⋮	64	1	12	0.27
⋮	⋮	⋮	⋮	63	1	13	0.30
98	0	2	0.05	62	0	13	0.30
97	1	3	0.07	61	1	14	0.32
96	0	3	0.07	60	1	15	0.34
95	0	3	0.07	59	0	15	0.34
94	1	4	0.09	58	1	16	0.36
93	1	5	0.11	57	1	17	0.39
92	0	5	0.11	56	0	17	0.39
91	0	5	0.11	55	0	17	0.39
90	1	6	0.14	54	3	20	0.46
⋮	⋮	⋮	⋮	53	1	21	0.48
⋮	⋮	⋮	⋮	52	1	22	0.50
82	0	6	0.14	51	0	22	0.50
81	1	7	0.16	50	1	23	0.52
80	0	7	0.16	49	1	24	0.55
79	0	7	0.16	48	0	24	0.55
78	0	7	0.16	47	0	24	0.55
77	1	8	0.18	46	3	27	0.61
⋮	⋮	⋮	⋮	45	1	28	0.64
⋮	⋮	⋮	⋮	44	2	30	0.68
72	0	8	0.18	43	2	32	0.73
71	1	9	0.20	42	0	32	0.73
				41	2	34	0.77
				40	1	35	0.80

TABLE 2. Continued

Discharge, Q, cfs	Number of Times Q ≧ Indicated Value But < Next Larger Value	Cumulative Total	Cumulative Percent of Grand Total
39	1	36	0.82
38	1	37	0.84
37	1	38	0.87
36	5	43	0.98
35	2	45	1.02
34	6	51	1.16
33	3	54	1.23
32	3	57	1.30
31	5	62	1.41
30	3	65	1.48
29	6	71	1.62
28	8	79	1.80
27	3	82	1.87
26	6	88	2.00
25	6	94	2.14
24	10	104	2.37
23	11	115	2.62
22	16	131	2.98
21	17	148	3.37
20	17	165	3.76
19	13	178	4.05
18	22	200	4.55
17	27	227	5.17
16	36	263	5.99
15	33	296	6.74
14	49	345	7.86
13	55	400	9.11
12	58	458	10.4
11	76	534	12.2
10	79	613	14.0
9	96	709	16.1
8	107	816	18.6
7	121	937	21.3
6	178	1115	25.4
5	202	1317	30.0
4	328	1645	37.5
3	342	1987	45.2
2	383	2370	54.0
1	1139	3509	79.9
0	883	4392	100.0
Grand Total		4392	

Maximum instantaneous discharge = 134 cfs (1/12/80)

Minimum instantaneous discharge = 0.59 cfs (9/8/80)

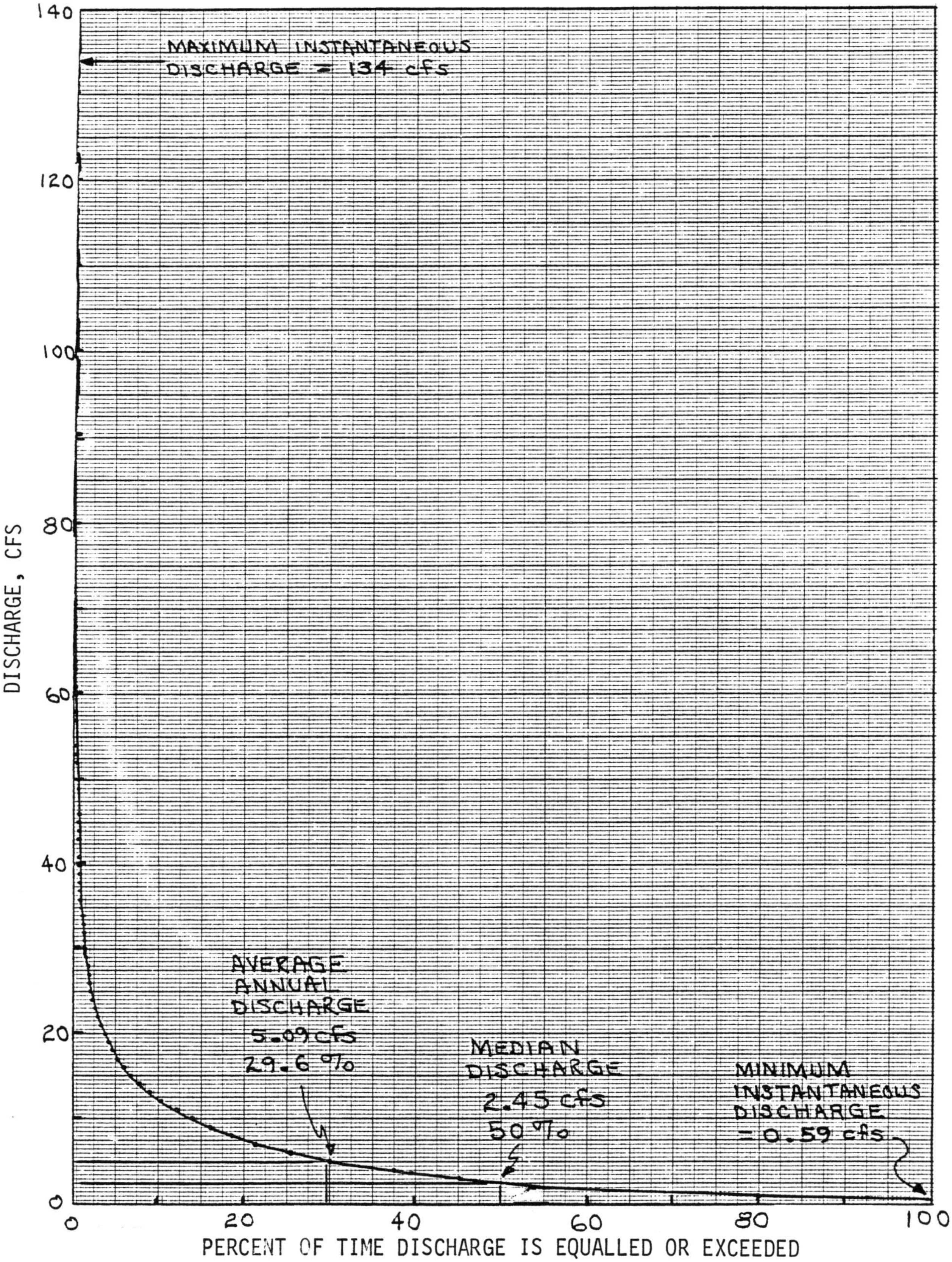


FIGURE 1. FLOW-DURATION CURVE FOR OAK CREEK AT SEDIMENT RESEARCH WEIR, 1979-80 WATER YEAR

Options B through H require portions of the full set of data used to develop option A. These needed data are summarized in Appendix B.

RESOLUTION OF PROCEDURAL QUESTIONS

The use of periodic stage observations, rather than continuous data, poses two procedural questions: (1) which day(s) of the week should be specified and (2) what time of day should be selected? For purposes of analysis, these questions were resolved by selecting noon of every day, every third and seventh day, and every seventh day, beginning with the first day of the water year. However, a brief supplemental study was made of effects of possible cyclical patterns for winter storm fronts and effects of growing-season transpiration on base flow.

Table 3 shows the influence of starting day on flow-duration characteristics and calculated average annual discharge from once-weekly-at-noon measurements. The supporting data are given in Appendix C. Differences result in the calculated average annual discharge, with departures of up to 17 percent from the group mean value. These differences reflect the chance inclusion or omission of one or two large discharges in each data set. The underlines in Table 3 emphasize the number of data entries exceeding 20 cfs (varing from one to four entries) and the number exceeding 10 cfs (varing from six to ten). The group mean for average annual discharge, 5.28 cfs, compares quite well with the true value of 5.09 cfs; however, individual data sets underestimate or overestimate the average annual flow by more than 10 percent in four of the seven cases. In terms of flow-duration characteristics, discharges of 20 cfs are exceeded 1.9-to-7.7 percent of the time and discharges of 10 cfs are exceeded 11.5-to-19.2 percent of the time, depending upon which day is chosen to begin the weekly readings.

Table 4 shows the influence of time-of-day on calculated average annual discharge. Late afternoon readings are lower and earlier morning readings are higher than noon readings; noon readings are higher than midnight readings. From the hydrograph (see Appendix A), it was initially assumed that such a situation would occur because of plant transpiration effects on base flow in the stream during the dry, warm growing season. However, when data were stratified on the basis of cool, wet season and warm, dry season it was found that the time-of-day effect was similar but more pronounced in the winter months. From the observed pattern, one might conclude that rains diminsh during daylight

TABLE 3. COMPARISON OF RESULTING DISCHARGE RANKINGS AND AVERAGE ANNUAL DISCHARGE DETERMINATIONS FROM ONCE-WEEKLY-AT-NOON STAGE READINGS, BASED ON DIFFERENT CHOICES FOR STARTING DAY, OAK CREEK AT SEDIMENT RESEARCH WEIR, 1979-80 WATER YEAR

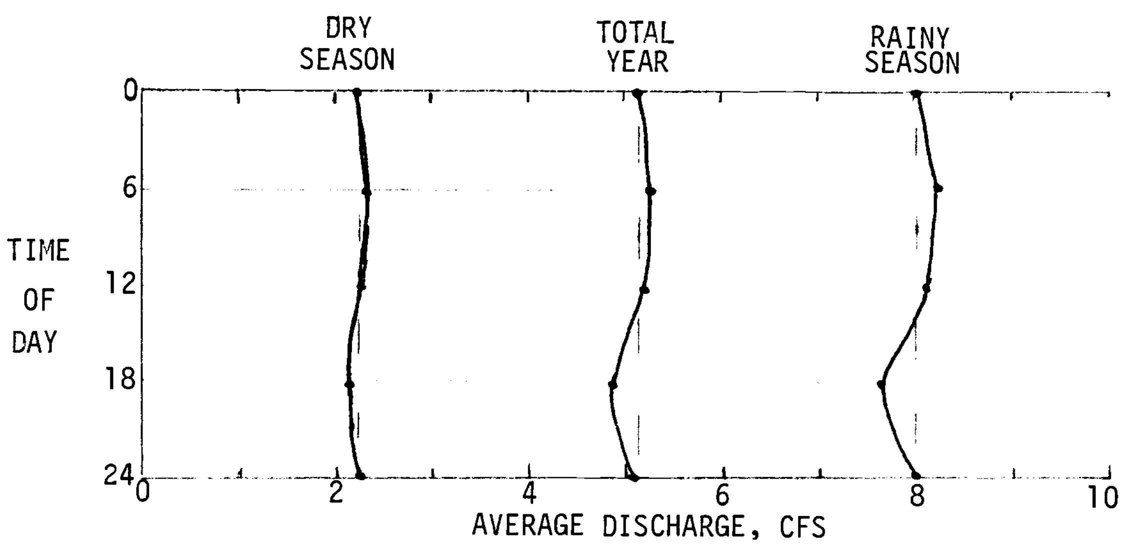
Rank Order Number	Percent of Time Equalled or Exceeded	Starting Date for 52 Weekly Observations and Corresponding Discharges						
		Oct. 1	Oct. 2	Oct. 3	Oct. 4	Oct. 5	Oct. 6	Oct. 7
1	1.9	68.2	25.6	46.6	21.4	29.2	90.2	49.4
2	3.8	19.4	19.8	22.2	15.9	28.9	21.6	24.4
3	5.8	18.8	17.3	13.4	14.3	14.8	21.0	22.3
4	7.7	18.1	13.9	13.4	14.3	12.5	18.3	20.6
5	9.6	14.7	12.6	11.0	13.7	11.3	17.6	16.6
6	11.5	11.6	12.2	10.2	12.4	10.7	14.6	13.0
7	13.5	9.8	12.1	10.2	9.0	10.7	10.3	12.2
8	15.4	9.4	11.1	10.1	8.2	8.8	9.7	8.6
9	17.3	9.3	11.1	9.7	8.1	7.8	8.9	8.2
10	19.2	7.2	10.3	8.9	7.8	6.6	8.8	8.1
'	'	'	'	'	'	'	'	'
'	'	'	'	'	'	'	'	'
'	'	'	'	'	'	'	'	'
'	'	'	'	'	'	'	'	'
'	'	'	'	'	'	'	'	'
52	100.0	0.8	0.8	0.7	0.7	0.7	0.7	0.8
Average Annual Discharge, cfs[1]		5.65	4.95	5.27	4.55	4.68	6.16	5.70

Group Value for Average Annual Discharge = 5.28 cfs

[1] Based on sum of weekly observed values divided by 52.

TABLE 4. COMPARISON OF AVERAGE ANNUAL DISCHARGES AND AVERAGE HALF-YEAR DISCHARGES DETERMINED FROM ONCE-DAILY STAGE READINGS, BASED ON DIFFERENT CHOICES FOR READING TIME, OAK CREEK AT SEDIMENT RESEARCH WEIR, 1979-80 WATER YEAR

Time of Day for Stage Reading	Total, cfs-days			Average Discharge, cfs		
	Oct. 1 thru Mar.31	Apr. 1 thru Sept.30	Total Year	Oct. 1 thru Mar.31	Apr. 1 thru Sept.30	Total Year
6 a.m.	1505.51	429.84	1935.35	8.23	2.35	5.29
noon	1493.59	419.70	1913.29	8.16	2.29	5.23
6 p.m.	1406.49	394.58	1801.07	7.69	2.16	4.92
Midnight	1468.56	407.07	1875.63	8.02	2.22	5.12
Group Averages				8.03	2.26	5.14



and strengthen in the evening, since the streamflow pattern lags the precipitation pattern by only one-to-two hours on the small Oak Creek drainage basin.

Another important procedural question concerns how to incorporate recorded maximum and minimum stages from the interval between observations with observed stages to expand the data base. Three methods were given serious consideration: (a) average together each set of three readings (the noon reading, R, the recorded high, H, and the recorded low, L) in the form:

$$\overline{R} = 1/3(R + H + L):$$

(b) average together the recorded high and recorded low for the previous interval and then average this result with the noon observation:

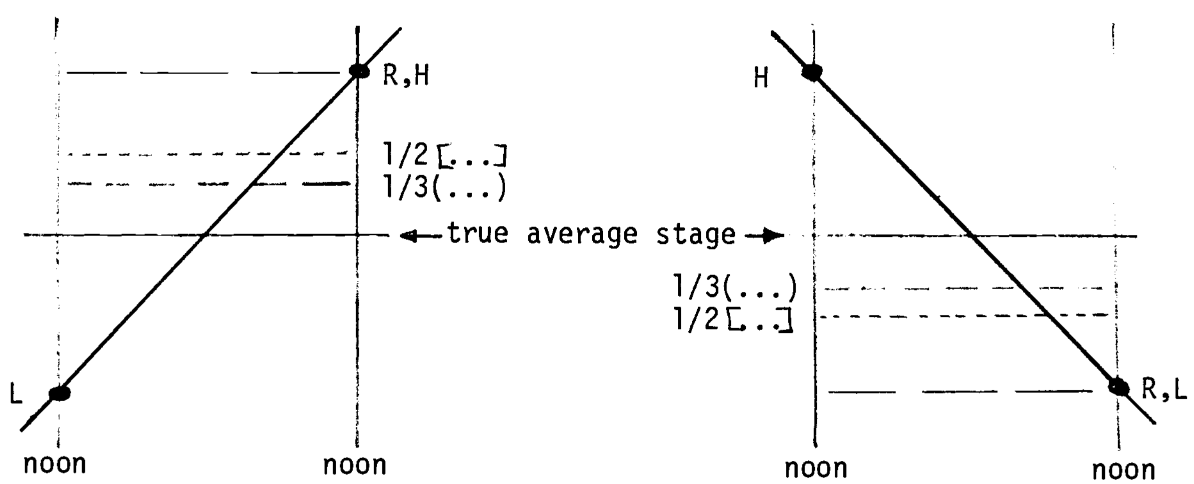
$$\overline{R} = 1/2[R + 1/2(H + L)];$$

and (c) average together each set of three readings plus the prior noon reading (P) in the form:

$$\overline{R} = 1/4(R + H + L + P).$$

Method (c) was not selected (except for one test case) because of its use of prior data; it was decided instead to select a method that only included the three concurrently read values.

For steady discharges, the method used makes no difference in the result. For a rising hydrograph, the noon-only method overestimates the true value most severely whereas the equal-weighting procedure (a) is closest to the true value; procedure (b) is intermediate. For a falling hydrograph, the noon-only method underestimates the true value most severely whereas procedure (a) is closest to the true value. The sketch below illustrates these situations.



For the fluctuating discharges shown in Appendix A, procedures (a) and (b) give fairly close agreement with each other and often give poor agreement with the noon-only method.

For all circumstances combined, it appears that procedure (a) is generally most reliable. Furthermore, it has the advantage of being simpler for a lay-person to understand and use. Therefore, we recommend that the periodic observation and recorded maximum and minimum values be given equal weight and combined in the form:

$$\begin{matrix}\text{Weighted}\\ \text{reading}\end{matrix} = 1/3\left[\begin{matrix}\text{Periodic}\\ \text{reading}\end{matrix} + \begin{matrix}\text{Maximum}\\ \text{for prior}\\ \text{interval}\end{matrix} + \begin{matrix}\text{Minimum}\\ \text{for prior}\\ \text{interval}\end{matrix}\right]$$

or

$$\overline{R} = 1/3(R + H + L).$$

PRESENTATION OF OPTION DATA

Option A: Continuous Recorded Values

Several streamflow characteristics extracted from the full actual record are summarized in Table 5 for comparison with corresponding characteristics determined for other data analysis options. The discharges and flow-duration information presented include the calculated average annual discharge and its percent exceedance, the maximum and minimum observed discharges for the data gathering technique used, the median discharge, the discharges exceeded 15, 25, and 35 percent of the time, and the discharge equal to 30 percent of the discharge exceeded 35 percent of the time, together with its percent exceedance.

Option B: Once-Weekly-at-Noon

The water stages and discharges that would have been determined using option B have already been discussed in a different context-- the effect of day-of-the-week chosen for observations. Appendix C presents the chronological and ranked data for determining average annual discharge and flow-duration characteristics. Graphs in Appendix C on pages C-15 and C-16 display particular aspects of the data. Table 3 (discussed in the preceding section of this report) gives a comparison of the findings. For this option, the data set which begins with October 1 is used. Several streamflow characteristics have been extracted and are summarized in Table 5. A limited amount of information is also given in Table 5 regarding flow characteristics determined by starting the weekly analysis on different days.

TABLE 5. SUMMARY OF DISCHARGES AND STREAMFLOW CHARACTERISTICS DETERMINED BY VARIOUS DATA OPTIONS, OAK CREEK AT SEDIMENT RESEARCH WEIR, 1979-80 WATER YEAR

Option	Average Annual Discharge		Maximum Observed Discharge, cfs	Minimum Observed Discharge, cfs	Q_{15}, cfs	Q_{25}, cfs	Q_{35}, cfs	Q_{50}, cfs	$(0.30)xQ_{35}$	
	cfs	Percent Exceedence							cfs	Percent Exceedence
A = Actual Continuous Record										
	5.09	29.6	133.69	0.59	9.52	6.10	4.33	2.45	1.30	72.1
B = Once-Weekly-at-Noon										
Start Oct. 1	5.65	29.2	68.20	0.85	9.45	6.74	4.72	2.25	1.41	63.3
Start Oct. 2	4.95	34.3	25.65	0.84	11.30	6.25	4.62	2.64	1.39	67.7
Start Oct. 3	5.27	35.1	46.56	0.72	10.08	7.71	5.30	2.52	1.59	64.0
Start Oct. 4	4.55	37.0	21.36	0.72	8.33	6.77	4.75	2.81	1.43	68.3
Start Oct. 5	4.68	29.4	29.19	0.73	9.19	5.06	4.32	2.61	1.30	70.9
Start Oct. 6	6.16	20.8	90.15	0.74	9.82	4.92	4.10	2.44	1.23	74.6
Start Oct. 7	5.70	30.2	49.41	0.75	9.39	7.59	4.36	2.79	1.31	68.7
C = Once-Weekly-at-Noon plus Maximum plus Minimum (start Oct. 1/8)										
Basic weighted set	7.25	28.6	133.69	0.59	15.52	8.89	6.87	4.56	2.06	64.6
Plus prior noon	6.85	31.6	133.69	0.59	14.01	8.21	6.11	4.68	1.83	66.5
Unweighted set	7.25	22.1	133.69	0.59	11.75	7.01	4.63	2.28	1.39	64.4
C Variation = Once-Weekly-at-Noon plus Minimum (start Oct. 1/8)										
Unweighted set	4.06	28.9	68.2	0.59	6.86	4.59	3.45	1.77	1.04	78.9
D = Twice-Weekly-at-Noon (start Oct. 3/7)										
	5.39	29.8	49.41	0.72	9.86	7.36	4.34	2.53	1.30	69.0
E = Twice-Weekly-at-Noon plus Maximum plus Minimum (start Oct. 3/7)										
	6.29	30.6	133.69	0.59	10.18	7.16	6.03	3.32	1.81	60.1
F = Daily-at-Noon										
Basic set	5.23	28.8	90.15	0.71	9.26	6.18	4.28	2.45	1.28	73.3
6 a.m.	5.29									
6 p.m.	4.92									
Midnight	5.12									
G = Daily-at-Noon plus Maximum plus Minimum										
	5.33	29.1	79.69	0.67	9.59	6.24	4.48	2.63	1.34	71.9
H = Wet Season Once-Weekly-at-Noon plus Minimum (start Oct. 1)										
Weighted set	4.11	32.3	68.20	1.05	7.06	5.82	3.73	1.60	1.12	100.0
Unweighted set	4.11	27.9	68.20	1.05	6.86	4.59	3.45	1.72	1.04	100.0

Option C: Once-Weekly-at-Noon plus Maximum plus Minimum

The data for water stages and discharges that would have been determined using option C are included in Appendix B. Table D-1 in Appendix D summarizes the pertinent data from Appendix B. The weighted discharges, determined from Table D-1, are shown in chronological and ranked order in Table D-2 of Appendix D, together with flow-duration characteristics (the intervening maximum and minimum discharges were added to the noon discharge and averaged to give the weighted discharge, as already discussed). Several streamflow characteristics have been extracted and are summarized in Table 5.

Variation on Option C: Once-Weekly-at Noon plus Maximum plus Minimum plus Prior Noon

As a test of the method for handling maximum and minimum intervening stages, a variation on option C was used which includes the prior week's noon reading. Using data from Appendix B, weighted discharges were determined by this method and analyzed as with option C. Results are shown in Table D-3 (Appendix D) and in Table 5.

Variation on Option C: Once-Weekly-at-Noon plus Maximum plus Minimum as Unweighted Set

After reviewing results obtained for options A through H, a variation on option C was tested using the noon, maximum, and minimum readings as an unweighted set of 156 individual numbers (i.e., without calculating weekly weighted values). Results are shown in Table D-12 (Appendix D) and in Table 5.

Variation on Option C: Once-Weekly-at-Noon plus Minimum as Unweighted Set

After reviewing results from options A through H, another variation on option C was tested using the noon and minimum readings as an unweighted set of 104 individual numbers. Results are shown in Table D-13 (Appendix D) and in Table 5.

Option D: Twice-Weekly-at-Noon

The data for water stages and discharges that would have been determined using option D are included in Appendix B. The pertinent data are summarized in Table D-4 of Appendix D, both in chronological and ranked order, together with flow-duration characteristics. Several streamflow characteristics are summarized in Table 5.

Option E: Twice-Weekly-at-Noon plus Maximum plus Minimum

The data for water discharges that would have been determined using option E are summarized in chronological order in Table D-5 (Appendix D), based on data in Appendix B. The weighted discharges, determined from Table D-5, are shown in chronological and ranked order in Table D-6 (Appendix D), together with flow-duration characteristics. Several streamflow characteristics are summarized in Table 5.

Option F: Daily-at-Noon

The data for water stages and discharges that would have been determined using option F are summarized in chronological order as part of Appendix B. In Table D-7 (Appendix D), these are shown in ranked order, along with flow-duration characteristics. Several streamflow characteristics are summarized in Table 5.

Under option F in Table 5, the calculated average annual discharges are also shown for data collected at other times of day.

Option G: Daily-at-Noon plus Maximum plus Minimum

The data for water stages and discharges that would have been determined using option G are summarized in chronological order as part of Appendix B. The weighted discharges, determined from Appendix B, are shown in Table D-8 (Appendix D). These are ranked and shown with flow-duration characteristics in Table D-9 (Appendix D). Several streamflow characteristics are summarized in Table 5.

Option H: Wet Season Once-Weekly-at-Noon plus Minimum

After options A through G had been analyzed, it appeared that the seven-month wet period from October 1 through April 30 contained nearly all of the significant runoff for economical hydropower generation. Also, it appeared that inclusion of maximum readings between periodic noon measurements tended to bias the calculated averages upward, potentially giving misleading optimism as to the streamflow potential. Furthermore, once-weekly-at-noon readings appeared to provide a calculated average annual discharge fairly close to (but higher than) the true average. Consequently, option H was devised, whereby stage would be measured once-weekly along with an intervening minimum value for the seven-month period from October through April. For the remainder of the year, the unknown weekly weighted discharge was assumed to be equal to the smallest observed weekly weighted discharge. The data for water stages and discharges that would have been determined using option H are summarized in chronological order as part of Appendix B. The weighted discharges, determined from Appendix B, are shown in chronological and ranked order in Table D-10 (Appendix D), together with flow-duration characteristics.

Variation on Option H: Wet Season Once-Weekly-at-Noon plus Minimum without Weighting

After reviewing the results obtained for options A through H, it was decided to further investigate option H. A variation was examined whereby the noon and minimum readings for the seven-month period plus estimated values for the remaining five-month period (in same manner as for basic option H) were used as a set of 104 individual readings, without calculating weekly weighted values. Results are shown in Table D-11 (Appendix D) and in Table 5.

COMPARISON OF OPTIONS FOR PRESENTING STREAMFLOW CHARACTERISTICS

Actual Record--Option A

The full actual record shows that Oak Creek has very large discharges only very briefly. Although the maximum instantaneous discharge during the 1979-80 water year was 134 cfs, the discharge that was exceeded for 24 hours (1 day) during the year was only 64 cfs, the discharge exceeded for 48 hours during the year was only 45 cfs, and the discharge exceeded for one week during the year was 26 cfs (see Table 2).

The actual record also shows that Oak Creek streamflow recessions are very gradual, once the discharge has diminished below the median discharge (see Figure 1). Such conditions prevailed in the 1979-80 water year for the first half of October and for almost all of the period from May through September (see Appendix A). The perennial flow is sustained by drainage from hillslopes and from the narrow alluvial valley along the creek upstream of the weir.

The actual record shows that the average annual discharge is about twice the magnitude of the median discharge and is exceeded 30 percent of the time (see Table 5). That flow exceeded only half as often as the average annual flow (i.e., Q_{15}) is not quite twice as large in magnitude.

Once-Weekly Measurement--Option B

When the streamflow characteristics are determined from once-weekly stage readings, the results are fairly close to the actual record. However, there is much variation among the seven sets of data based on different starting day of the week--a situation due to chance. The main shortcoming of option B is its poor representation of the larger discharges. For example, the average annual discharge might vary from 4.55 to 6.16 cfs and be exceeded from 21 to 37 percent of the time, just due to the chance selection of starting date. The problem is that very large discharges occur very briefly and are not included in each data set for option B.

Twice-Weekly Measurement--Option D

Twice-weekly measurement of stage slightly improves the accuracy of determination of streamflow characteristics over once-weekly measurement (see Table 5). The same shortcomings remain with option D as with option B.

Daily Measurement--Option F

Daily measurement of stage further improves the accuracy of determination of streamflow characteristics over once-weekly and twice-weekly measurement (see Table 5).

Inclusion of Intervening Maximum and Minimum Stages--Option C, E, G

The inclusion of maximum and minimum intervening stages along with once-weekly measurements (option C) or twice-weekly measurements (option E) to calculate a weighted average causes streamflow magnitudes to be overestimated (see Table 5). Only when daily measurements are made (option G) are streamflow magnitudes of comparable accuracy to the once-weekly, twice-weekly, and daily measurements without use of extreme intervening values. Accuracy can be improved if the three numbers (noon, intervening maximum, intervening minimum) are not weighted in making calculations (see the appropriate variation for option C). The annual average will not change but the flows at various exceedence levels shift. One benefit of measuring extreme values is to alert the analyst to these extremes and to the range of variation of streamflow that occurs between the periodic measurements. This may be of particular value in design of hydropower facilities for indicating the magnitude of spillway discharge in excess of turbine capacity.

Inclusion of Intervening Minimum Stages--Option C Variation

If the intervening maximum stages are ignored but the intervening minimum stages used with the periodic readings to form an unweighted set, much smaller discharges are determined for each exceedence level. When this was tried as a variation on option C, the resulting values were smaller than for the actual record.

Wet Season Once-Weekly and Minimum Intervening Stages--Option H

Option H shortens the period of data collection while including most major runoff. A low-flow assumption is needed in estimating the annual characteristics of streamflow and exceedence time for specific flows. However, the main loss of accuracy appears to be due to the use of minimum-stage intervening values. These cause most characterizing streamflows to be underestimated (see Table 5). Using weighted or unweighted values each week has less effect here than with option C.

COMPARISON OF OPTIONS FOR ASSESSING HYDROPOWER POTENTIAL

The micro-hydropower turbine installed on a rainfall-regime stream like Oak Creek generally would not be sized for large discharges exceeded less than 10 percent of the time, due to the steepness of that part of the flow-duration curve (see Figure 1). The selected design flow is more likely to be one exceeded about 15-to-35 percent of the time. Furthermore, the chosen turbine should be expected to perform fairly well at flows as small as 25-to-30 percent of the design discharge because the flow-duration curve has some slope at all exceedence levels. For Oak Creek data from the 1979-80 water year, the selected design discharge would have been between 4 cfs and 10 cfs. The minimum usable flow would have been about 1 cfs to 2 cfs, such flows (or larger) being available 54-to-80 percent of the time.

The actual record and the partial records obtained through options B, D, and F (once-weekly, twice-weekly, and daily stage reading) all will result in similar estimates of annual hydroelectric energy generation. This is because the flow-duration characteristics are similar (see Table 5): all Q_{15} values are roughly 9.5 cfs, all Q_{25} values are about 6.5 cfs, all Q_{35} values are close to 4.5 cfs, all average annual discharges are about 5.3 cfs and are exceeded about 30 percent of the time, all median discharges are close to 2.5 cfs, and the discharges corresponding to 30 percent of Q_{35} are all about 1.3 cfs and exceeded about 70 percent of the time.

The partial records obtained through options C and E (once or twice-weekly plus intervening maximum and minimum stages) will result in overestimates of annual hydroelectric energy generation. Expanding the data base to daily readings plus extremes (option G) will lead to better estimates that are similar to the actual record. But using the weekly readings plus intervening low stages (option H) will result in underestimates of annual energy generation.

When intervening maximum and minimum values are used, the calculation of a weighted value for each subset of three numbers leads to larger discharges at each exceedence level than when all three numbers for each such interval are used individually to determine the flow-duration curve. The latter approach appears to be more accurate.

When taken separately, the set of intervening maximum values and the set of intervening minimum values each give a flow-duration curve quite distinct from that based on periodic noon readings. This is shown in Figure 2, using once-weekly data from option C. The use of a flow-duration curve based only on minimum readings will considerably underestimate the energy potential of the stream but use of only maximum readings will even more greatly overestimate the stream's energy potential. For the conditions of Figure 2, if the 20 percent exceedance level is used to draw horizontal lines (representing maximum turbine capacity), the area under this line with the minimum-value data set flow-duration curve is only 42 percent of the corresponding area for the noon-value data set.

Critical to the estimation of energy generation is the choice of exceedance level to use for selecting the turbine capacity. If a large discharge is selected, the lower-limit discharge for good turbine efficiency will also be large. Because of the curvature of the flow-duration curve, large design flows will lead to larger installed capacities but shorter generation times than will smaller design flows.

This difficulty can be shown using calculations from the actual record. To do so, assume that the turbine will perform efficiently for discharges as small as 30 percent of the installed capacity. Also, assume that the flow-duration curve can be estimated using linear changes between the successive discharge/percentage coordinates given by Q_{15}, Q_{25}, $Q_{\text{ave. annual}}$, Q_{35}, Q_{median}, and $Q_{30\% \text{ of } Q_{35}}$. The power, P, is calculated from:

$$P = \frac{QHe}{11.8} \quad \text{kw}$$

and the energy generated, E, is calculated from:

$$E = P \cdot \Delta T = \frac{QHe}{11.8} \cdot \Delta T \quad \text{kw-hr}$$

where Q = discharge, cfs; H = head, feet; e = efficiency, as a decimal fraction; T = time interval, hours; and 11.8 = a conversion factor. As further assumptions, let the head and efficiency be constant over the range of usable discharges. Hence the equations become:

$$P = C \cdot Q \quad \text{kw}$$

$$E = C \cdot Q \cdot \Delta T \quad \text{kw-hr.}$$

These are usable for comparative purposes without the need to determine the numerical value of the constant.

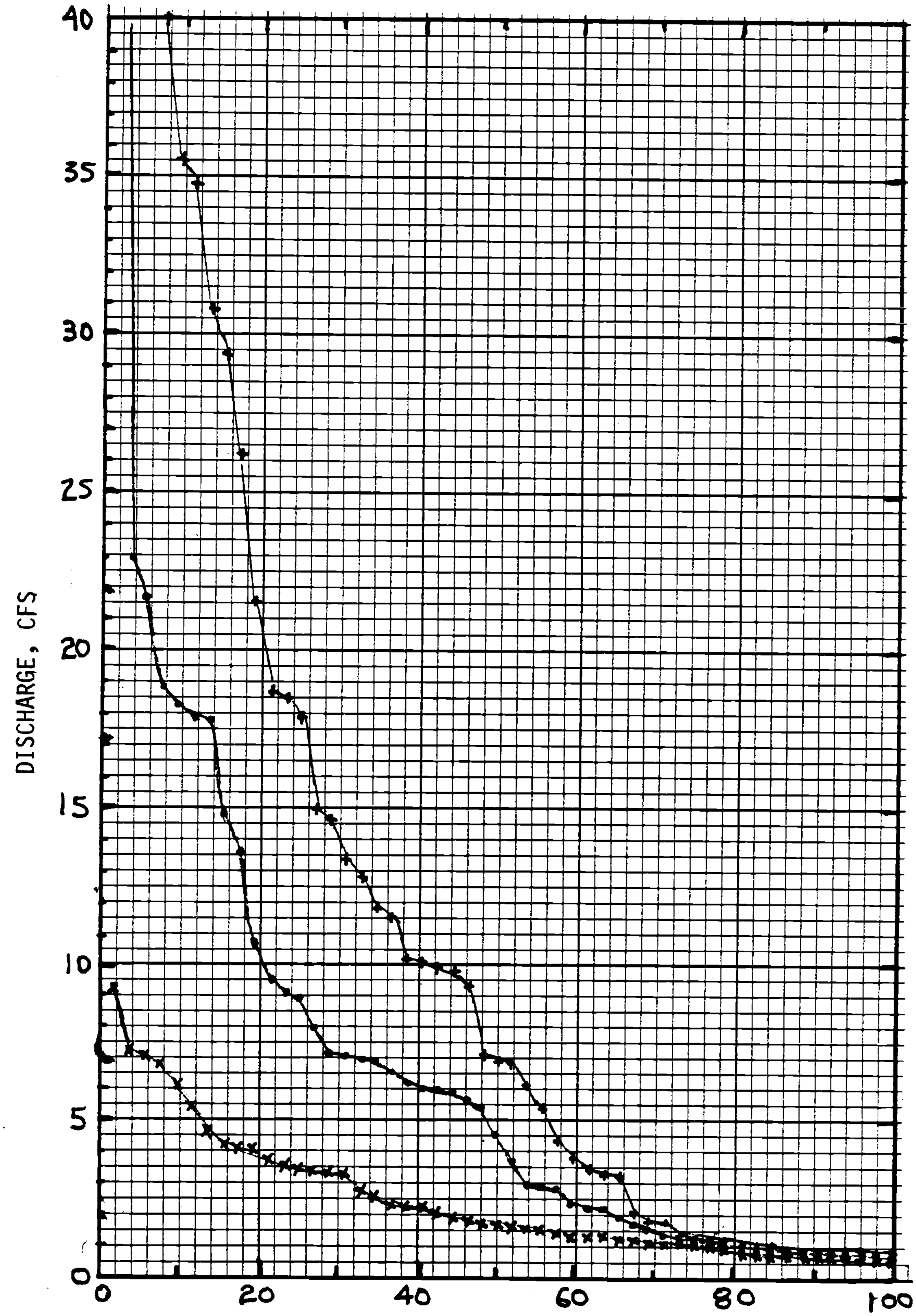
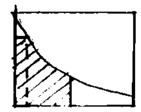
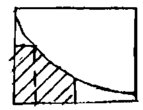
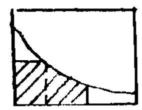
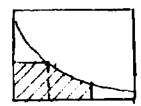
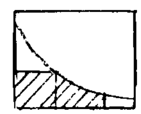
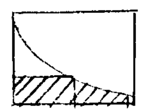


FIGURE 2. SEPARATE FLOW-DURATION CURVES BASED ON ONCE-WEEKLY STAGE MEASUREMENTS AT NOON, FOR MAXIMUM INTERVENING EXTREME, AND FOR MINIMUM INTERVENING EXTREME, OAK CREEK AT SEDIMENT RESEARCH WEIR, 1979-80 WATER YEAR

Table 6 shows the calculated annual energy production for various assumed installed hydropower capacities and for the stated assumptions. When Q_{15} is selected as the design discharge, a large amount of energy is produced but production time is limited to 46 percent of the year when flows exceed 2.8 cfs. When Q_{median} is selected, the installed capacity is reduced to one-quarter of that for Q_{15} but production can occur 95 percent of the time and the energy production is about 62 percent of that for the Q_{15} case. Intermediate selected design flows lead to intermediate energy production. If Q_{10} is selected instead of Q_{15} as the design discharge, the installed capacity increases by 29 percent but the total energy produced only increases by 5 percent because the production time decreases by 6 percent.

The ultimate selection of a hydropower system would combine the hydrologic assessment with an economic evaluation. As the example shows, installed capacity can vary much more than energy output because of the shape of the flow-duration curve. This means that capital costs will vary considerably more than energy revenues for different choices of installed capacity.

TABLE 6. EXAMPLE CALCULATIONS OF ANNUAL HYDROPOWER ENERGY PRODUCTION AT OAK CREEK SEDIMENT RESEARCH WEIR, 1979-80 WATER YEAR

Design Flow Used	Installed Capacity		Minimum Capacity		Annual Energy Produced, kw-hr	
	cfs	Percent Exceedence	cfs	Percent Exceedence		
Q_{10}	12.3	10	3.7	40		28,724·C[1]
Q_{15}	9.5	15	2.8	46		27,323·C
Q_{25}	6.1	25	1.8	59		23,994·C
$Q_{avg.\ annual}$	5.1	30	1.5	67		22,830·C
Q_{35}	4.3	35	1.3	72		21,209·C
Q_{median}	2.4	50	0.7	95		16,668·C

[1] $E = [(0.10)(12.3) + (0.05)(\frac{12.3 + 9.5}{2}) + (0.10)(\frac{9.5 + 6.1}{2}) + (0.05)(\frac{6.1 + 5.1}{2}) + (0.05)(\frac{5.1 + 4.3}{2}) + (0.05)(\frac{4.3 + 3.7}{2})][24 \times 366 \times C]$

All other values computed in similar manner.

HOW REPRESENTATIVE ARE THE COLLECTED DATA?

If stage and discharge data are collected on a stream for a one-year period to assess the micro-hydropower potential, the question arises "how representative was that year for showing long-term conditions?"

For small rainfall-regime basins in Western Oregon, this question is most readily resolved by use of rainfall records--comparing precipitation for that year with long-term rainfall records. Statistical information is available from the National Weather Service (NWS) regarding annual records, normal annual precipitation (30-year average), extreme wet and dry years, and particular statistical variations from the mean. Hence, the representativeness of the precipitation during the year of streamflow data collection can be determined in considerable detail.

The NWS precipitation station used for checking streamflow representativeness should be near the stream and have similar exposure to storms. Fortunately, in this regard, the storms that produce most of the rainfall and runoff in Western Oregon are frontal-system storms that cover a wide path as they move inland from the Pacific Ocean. For this same reason, it is not essential to have a temporary precipitation gage at the creek site: no long-term record will be available for comparison and the precipitation at the site will be proportional to that at a nearby gage when annual totals are used (but there can be much variability over short periods for individual storms).

The representativeness of the Oak Creek 1979-80 water year data were checked using 1931-1980 precipitation records for the Corvallis precipitation station (OSU Hyslop Farm). This immediately revealed a minor difficulty: precipitation records are reported for the calendar year rather than the water year. Nevertheless, the 12-month rainfall amount corresponding to the 1979-80 water year could be determined from monthly totals published by the NWS and compared to long-term precipitation records based on calendar years.

During the 1979-80 water year, the Corvallis precipitation station reported 40.22 inches of precipitation. For the 50-year period from January 1931 through December 1980, the long-term average annual precipitation was 39.89 inches, the standard deviation in annual precipitation was ±8.5 inches (i.e., about two-thirds of the annual precipitation values were between 31.4 inches and 48.4 inches), and the extreme annual values were 22.99 inches (1944) and

and 58.73 inches (1968)--about two standard deviations from the mean. The long-term record shows that drier-than-normal conditions persisted for 10 years over a 12-year period from the late 1930's through the 1940's. A 7-year period of wetter-than-normal conditions extended from the late 1960's through the middle 1970's. For comparision, the 1951-1980 normal annual precipitation was 42.35 inches.

It may be concluded that the 1979-80 water year was very representative of the 50-year long-term average conditions and only slightly drier than the 30-year normal conditions. Furthermore, the mean and standard deviation for long-term precipitation show that two-thirds of the time the precipitation can be expected to be within ±21 percent of the long-term mean. Assuming the same relative runoff for various amounts of annual precipitation, this implies that two-thirds of the time at Oak Creek the annual streamflow can be expected to be within ±21 percent of the long-term value (which was closely represented by the 1979-80 data). Furthermore, making the same runoff assumption with the extremes of annual precipitation, the annual streamflow should always be within about ±42 percent of the long-term value closely represented by 1979-80 data. For much-wetter-than-normal years, the flow-duration curve is probably much steeper and higher at large discharges due to more storms and larger storms. At much-drier-than-normal years, the curve is probably much flatter and lower there due to fewer storms and smaller storms. However, precipitation data are insufficient alone for determining the modified shapes of the flow-duration curve for very wet or very dry years.

ESTIMATING LONG-TERM FLOW-DURATION CHARACTERISTICS BY CORRELATION WITH A NEARBY GAGING STATION

Once the streamflow characteristics have been established for one water year at a hydropower site, the long-term characteristics can be estimated by correlation with records from a nearby gaging station. To do this, certain hydrologic requirements should be met as well as possible:

(a) the gaging station should be nearby:

(b) the drainage area should be similar to that for the site so that peak flow and base flow conditions correspond;

(c) the drainage basin above the gaging station should not have significant lake or reservoir development that modifies the natural runoff pattern (unless the hydropower site has similar features);

(d) the gaging station records must include the year for which hydropower site data were collected; and

(e) the gaging station records should span 10 or more years so that the indicated long-term pattern is not too distorted by the chance occurrence of extremely wet or dry years during the period of record.

Various techniques exist for correlating streamflow records from two sites and extending a short record at one site through use of a long-term record at the other site. The simplest technique for obtaining flow-duration information is as follows: (1) determine and plot the long-term flow-duration curve for the long-record station; (2) determine and plot on the same graph the flow-duration curve for the long-record station for only the period of concurrent data at the two stations; (3) determine and plot the flow-duration curve for the short-record station; (4) select several points (half a dozen or more) along the percent-of-time-exceeded scale; (5) enter the flow-duration curve of the long-record station at each of these exceedence percentages and read off the corresponding discharges from the long record and the concurrent record--these form a scaling ratio at each exceedence percentage used; (6) enter the flow-duration curve of the short-record station at the same percentages and read off the discharges; (7) multiply these discharges by their respective scaling ratios to determine the estimated long-term discharge for each percentage; and (8) plot these discharges to obtain the estimated long-term flow-duration curve. In essence, this technique uses a proportioning relation between flows at the two stations for the long period and short period for each selected percent exceedence:

$$\left(\frac{Q \text{ long-record, long period}}{Q \text{ long-record, short period}}\right)_{\%} = \left(\frac{Q \text{ short-record, long period}}{Q \text{ short-record, short period}}\right)_{\%}$$

Application of this approach to Oak Creek or other small basins involves some difficulties. First, most long-record stations are on streams draining basins 50 or more square miles in size. Therefore, the shape of the high-flow portion of the flow-duration curve will not be as narrow and steep; the quick, flashy hydrograph changes on the small basins will be somewhat dampened out in the larger basin. Also, the low-flow portion of the curve will probably differ for the larger drainage basins due to greater alluvial deposits and ground water reserves to better sustain baseflow (unless wells there deplete this source or even draw water from the streambed during summer). A second problem is that long-term flow-duration curves may not be available in convenient form to the user, requiring considerable data workup.

The nearest long-record gaging station to Oak Creek is the Marys River near Philomath (drainage area = 159 square miles). The nearest small basin with a long-term record is at Rock Creek on Marys Peak (drainage area = 15 square miles), but no records were obtained there during the 1979-80 water year. Other small basins where records were obtained during the 1979-80 water year are about 50 miles away. Therefore, the Marys River records were used to demonstrate the correlation technique.

Available U.S. Geological Survey WATSTORE data for 1941-76 were used to define the longe-term flow-duration curve for the Marys River near Philomath. The 1979-80 water year data were tabulated using 17 size ranges to determine the short-period flow-duration curve. These were then used with the Oak Creek short-period data to estimate the long-term flow-duration curve there. Table 7 summarizes the values obtained in making this estimation.

The results of this correlation show that the flow-duration curve for the Marys River for the 1980 water year deviated in shape from the long-term pattern (see the ratio column in Table 7). The average discharge for 1980 was only 84 percent of the long-term value. These features carried over into the long-term estimate for Oak Creek. Furthermore, the gaging station correlation led to slightly different results than would have been expected from the precipitation comparison discussed earlier. However, the long-term precipitation data represented different periods of time than for the Marys River streamflow data.

PREDICTING STREAMFLOW CHARACTERISTICS FROM NEARBY GAGING STATIONS WITHOUT STREAMFLOW DATA AT SITE

An alternative to measuring streamflow at a hydropower site for a one-year period (by one of the options already discussed) is to predict the streamflow characteristics. The basic work essential to such predictions has already been done as part of the WRRI low-head hydropower study (Resource Survey of River Energy and Low-Head Hydroelectric Power Potential in Oregon; WRRI-61 plus Appendices; Water Resources Research Institute, Oregon State University; Corvallis; 1979).

TABLE 7. ESTIMATION OF LONG-TERM FLOW-DURATION CHARACTERISTICS AT OAK CREEK SEDIMENT RESEARCH WEIR BY CORRELATION WITH MARYS RIVER NEAR PHILOMATH

Percent Exceedence	Marys River Discharge near Philomath, cfs			Oak Creek Discharge, cfs	
	1941-76 Water Years	1980 Water Year	$\frac{Q_{1980}}{Q_{1941-76}}$	1980 Water Year	Long-Term Estimate[1]
10	1300	928	0.71	12.31	17.24
25	580	536	0.92	6.10	6.60
30	455	463	1.02	5.00	4.91
50	160	201	1.26	2.45	1.95
70	44	54	1.23	1.38	1.12
75	32	29	0.91	1.19	1.31
80	24	19	0.79	1.00	1.26
90	15	14	0.93	0.80	0.86
95	11	12	1.09	0.70	0.64
Average Discharge, cfs:	475	400	0.84	5.09	6.04
Interpolated Percent Exceedence:	29	35		29	27

[1] By proportioning: $\frac{Q_{MR\ 1980}}{Q_{MR\ 1941-76}} = \frac{Q_{OC\ 1980}}{Q_{OC\ Long-Term}}$

The initial information needed for a hydropower site is its location. From this, the drainage area (DA) can be determined using a topographic map. The normal annual precipitation (NAP) over the basin can be determined from maps prepared by the Pacific Northwest River Basins Commission or the Oregon Water Resources Department. The numerical inputs to the prediction equations are DA and NAP.

The equations predict (a) the long-term average annual discharge (Q_{AA}) from the basin and (b) the flow-duration characteristics based on five discharges at different percent exceedences ($Q_{\%}$). These equations are as follows:

$$Q_{AA} = a[(NAP)(DA)]^{b}$$

and

$$Q_{\%} = a_{\%}[Q_{AA}]^{b_{\%}}$$

Where $\%$ = 10, 30, 50, 80, 95.

a, b, $a_{\%}$, $b_{\%}$ = geographically determined coefficients.

The equations were determined by correlating precipitation and discharge data from long-term records, using stations in hydrologically similar geographical groupings.

For streamflow predictions spanning a short period such as one year, the concurrent average annual precipitation (rather than long-term normal annual precipitation) should be used.

Figure 3 shows the geographical zones for different sets of prediction equations applicable to the rainfall-regime basins of Western Oregon. Table 8 lists the prediction equations.

Equation set 2B-1 was used to predict the streamflow characteristics for Oak Creek. The computations were made twice: once using the 1979-80 water year precipitation and once using the 30-year normal annual precipitation. The results are shown on Table 9.

The average annual flow predicted for the 1979-80 water year is within about 12 percent of the correct value (see Table 5). The predicted Q_{10} and Q_{30} have comparable accuracy (see Table 6). However, the predicted median discharge has a 35 percent error and smaller predicted flows are even more in error. Evidently, the baseflow conditions differed at Oak Creek from those at the gaged basins from which the regional prediction equations were derived.

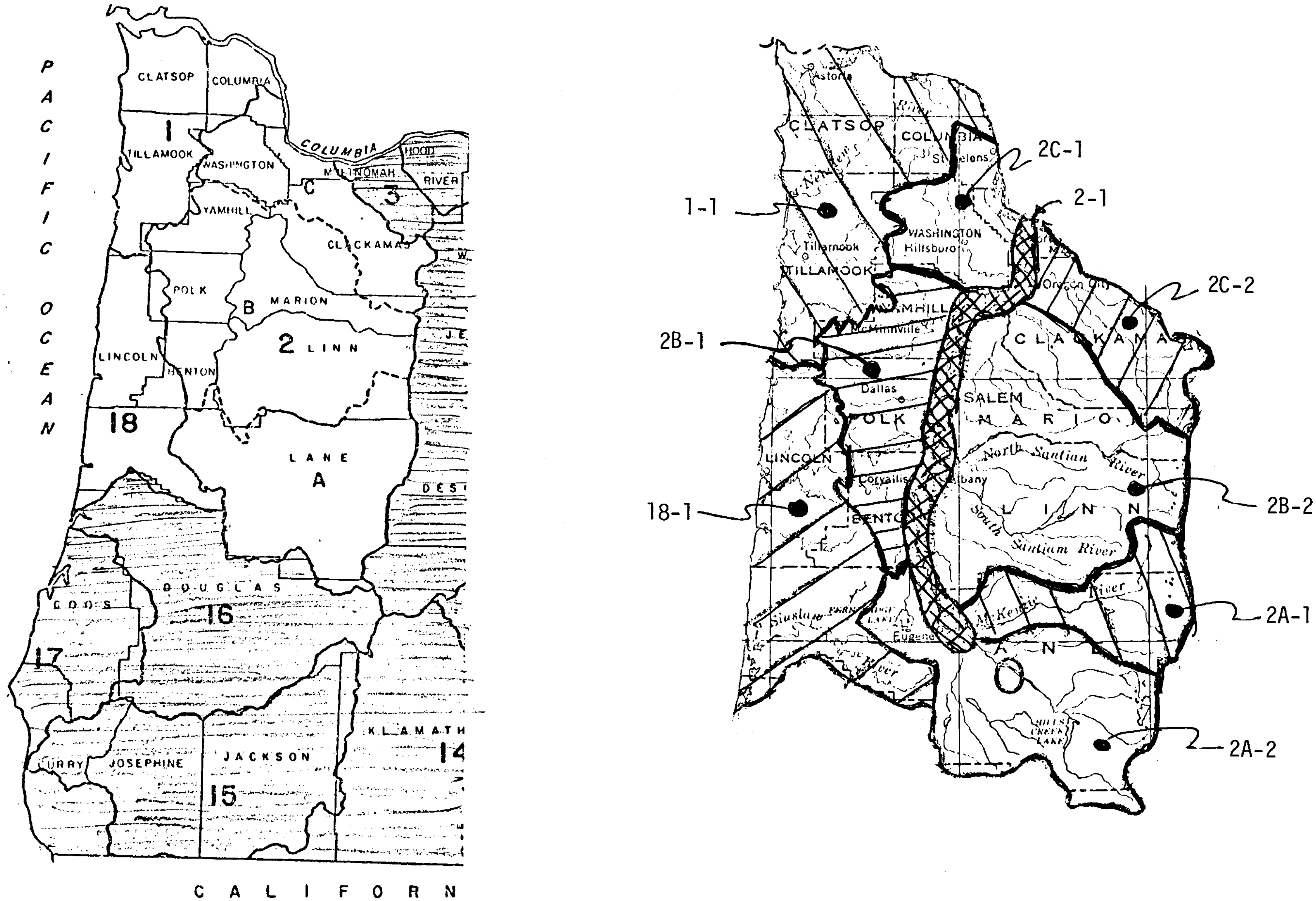


FIGURE 3. GEOGRAPHICAL ZONES IN RAINFALL-REGIME BASINS OF WESTERN OREGON TO WHICH STREAMFLOW PREDICTION EQUATIONS APPLY

TABLE 8. PREDICTION EQUATIONS FOR AVERAGE ANNUAL DISCHARGE AND FLOW-DURATION CHARACTERISTICS FOR NORTH COAST, MID COAST, AND WILLAMETTE BASINS

Basin and Equation Set	$Q_{AA} = a[(NAP)(DA)]^b$		$Q_{\%} = a_{\%}[Q_{AA}]^{b_{\%}}$									
			10		30		50		80		95	
	a	b	a	b	a	b	a	b	a	b	a	b
North Coast (1) 1-1= all	0.0621	0.9808	2.5580	1.0020	1.0020	1.0018	0.3823	1.0305	0.1021	0.9982	0.0477	1.0181
Mid Coast (18) 18-1= all	0.0866	0.9430	2.7198	0.9996	1.1231	0.9808	0.5624	0.9548	0.1466	0.9272	0.0695	0.9466
Willamette (2)												
2-1 main stem	0.0440	1.0123	1.8456	1.0221	1.9828	0.9384	0.7557	0.9878	0.1672	1.0542	0.0667	1.1049
2A-1 McKenzie	0.0732	0.9707	3.6231	0.9064	1.2152	0.9863	0.4146	1.0834	0.0189	1.4063	0.0049	1.5454
2A-2 rest of upper basin	0.0303	1.0493	2.7230	0.9765	0.8673	1.0260	0.2273	1.1181	0.0132	1.3770	0.0085	1.3590
2B-1 west side middle basin	0.0326	1.0492	2.5838	0.9984	1.1680	0.9610	0.3528	1.0015	0.0420	1.0470	0.0160	.0730
2B-2 east side middle basin	0.0977	0.9456	2.6360	0.9800	1.0270	1.0100	0.4750	1.0364	0.0760	1.1020	0.0320	1.1240
2C-1 west side lower basin	0.0584	0.9762	1.1191	1.1399	0.5074	1.1099	0.2911	1.0223	0.0648	0.9955	0.1125	0.6987
2C-2 east side lower basin	0.0209	1.0832	2.7815	0.9462	0.9034	1.0311	0.2477	1.1545	0.0284	1.3618	0.0116	1.4484

TABLE 9. PREDICTED STREAMFLOW CHARACTERISTICS FOR OAK CREEK AT SEDIMENT RESEARCH WEIR BASED ON PRECIPITATION AND DRAINAGE AREA[1]

Precipitation Data		Predicted Discharge, cfs					
Period	Amount, inches	Q_{AA}	Q_{10}	Q_{30}	Q_{50}	Q_{80}	Q_{95}
1979-80 Water Year	40.22	4.46	11.49	4.91	1.58	0.20	0.08
1951-80	42.35	4.71	12.13	5.17	1.66	0.21	0.08

[1] DA = 2.7 mi.^{2}

There is no record against which to verify the predicted long-term streamflow characteristics. However, comparable results to those for 1979-80 can be expected. Support for this contention is offered by the correlation with records at Marys River (see Table 7).

With respect to hydropower assessment, it appears that the prediction results are satisfactory for Oak Creek. They provide realistic estimates for selecting the design discharge. But because of low-flow errors they lead to underestimates of the energy that could be generated. Hence, the prediction equations err in favor of caution rather than optimism about the hydropower potential.

DEVELOPMENT OF LONG-TERM PREDICTION EQUATIONS FROM ONE YEAR OF PRECIPITATION AND STREAMFLOW DATA

If concurrent records of precipitation and streamflow are collected at a site, these can be used to develop prediction equations. The equations can then be used with other precipitation values, by correlation with a nearby long-record precipitation station, to generate streamflow characteristics.

The prediction equations would be of the from:

$$Q_{AA} = a[(P)(DA)]$$

$$Q_{\%} = a_{\%}[Q_{AA}]$$

where terms are all as defined earlier. Here, the exponent b of earlier equations is set equal to 1. The reasonableness of doing this can be argued from Table 8, where most b values are close to 1 except at the 95% exceedence level (flows too small for hydropower generation).

The precipitation correlation would involve two steps. First, the concurrent 1-year data would be compared to determine a proportionality factor between the site and the precipitation station. Second, other precipitation values from that station would be chosen, such as the normal annual precipitation or a dry year's precipitation. The corresponding precipitation at the site would then be estimated from the proportionality factor. Then the prediction equations would be used to obtain streamflow characteristics and estimate the hydropower potential.

This approach cannot be demonstrated at Oak Creek because no full-year precipitation data were collected in 1979-80.

RECOMMENDATIONS

A reliable, minimal-effort data collection program to develop streamflow characteristics should include three elements: (1) monthly total precipitation at the site for one year so that the representativeness of streamflow data compared to long-term conditions can be determined by checking against National Weather Service information; (2) frequent (daily or weekly) measurement of stage near a calibrated weir for one year, with the possible substitution of infrequent (once or twice monthly) measurements from May through September; and (3) extreme maximum intervening stages between measurements. The frequent measurements might be a set of once-daily readings to give good detail. However, a set of once-or-twice-weekly-plus-intervening-minimum readings (used individually for calculations) that cover the seven months from October 1 through April 30 (as a minimum period) would be adequate if less accuracy were acceptable.

From the collected data, the annual average discharge and the flow-duration curve can be estimated to within about 10-to-20 percent of the correct values. Use of intervening minimum readings will tend to give underestimates. Greater expenditures of effort do not appear to proportionately increase the accuracy unless a continuous stage recorder is installed. The minimum readings, if included, will add conservatism to any hydroelectric potential estimates. Hence, projects that are at least minimally feasible on that basis are likely to perform somewhat better than estimated. This gives a slight margin of safety against the risk that the data set are not as accurate as a complete, continuous record.

Prediction equations based on the WRRI low-head hydropower study can also be used to estimate streamflow characteristics. However, greater inaccuracies are possible than with the recommended on-site observations if the basin is small and the local conditions differ from those at the large stations used to develop the prediction equations.

For accurate prediction of streamflow characteristics, the basin size should not be much less than that of Oak Creek if only once-weekly information are collected. For basins as small as one square mile, daily values will be needed for accuracy but weekly values can be still used with intervening minimum stages to get a conservative (low) estimate of these characteristics. The technique is also valid on larger basins than Oak Creek as long as a conservative estimate is sought. However, the magnitude of steamflow available for basins 10-to-25 or more square miles in size will definitely warrant the collection of accurate data with a continuously recording device.