# A Resource Survey of River Energy and Low-Head Hydroelectric Power Potential in Oregon

by

Peter C. Klingeman

Water Resources Research Institute
Oregon State University
Corvallis, Oregon

WRRI-61 April 1979

# A RESOURCE SURVEY
# OF RIVER ENERGY AND
# LOW-HEAD HYDROELECTRIC POWER
# POTENTIAL IN OREGON

By

Peter C. Klingeman
Principal Investigator

Oregon Water Resources Research Institute
Oregon State University
Corvallis, Oregon 97331

in cooperation with

State of Washington Water Research Center
Idaho Water Resources Research Institute
Montana University Joint Water Resources Research Center

This Project was Funded by the
United States Department of Energy
CONTRACT NO. EG-77-S-07-1691
Through The
Idaho Water Resources Research Institute

WRRI-61

April 1979

Water Resources
Research Institute

Oregon
State
University

Corvallis, Oregon 97331 (503) 754-4022

August 31, 1983

## WRRI-61 ERRATA INFORMATION

### Appendix 1

| | |
|---|---|
| p. 0-1-110 | Map is upside down but flow arrow is correct |
| p. 0-1-114 | Map is upside down but flow arrow is correct |

### Appendix 5

| | |
|---|---|
| p. 0-5-32 or<br>p. 0-5-33 | Doug Parrow (Oregon DOE) inquired about accuracy in June 1982 (no followup note in our files) |

### Appendix 17

| | |
|---|---|
| p. 0-17-69<br>p. 0-17-70 | 1st reach was shortened to RM 5.4, to allow for N. Fork Chetco River, but elevation at end of reach was not adjusted accordingly. N. Fork Chetco River was omitted from analysis. |

# ABSTRACT

A systematic, statewide investigation of stream power and energy has been made for all reaches of Oregon streams not presently having dams but capable of producing 200 kw or more at least 50 percent of the time. From available precipitation data, topographic maps and stream gaging station records, hydrologic techniques were used to generate mean discharges, discharge patterns, flow-duration curves, stream power values and stream energy values for 7626 miles of rivers in Oregon, grouped into 1443 reaches. The information was developed to inventory the theoretical developable low-head hydro power potential for Oregon. Assumptions were made to use run-of-river conditions (rather than reservoir storage) and 100 percent efficiency in generating electrical energy from streamflow.

The resulting theoretical maximum developable low-head power and energy potential, respectively, are found to be about 2 GW and 15,000 GWh, for near-firm-power conditions of 95 percent-of-time exceedance, about 6 GW and 43,000 GWh for median flow conditions of 50 percent exceedance, and 11 GW and 61,000 GWh for near-mean flow conditions of 30 percent exceedance. Streams influenced by large precipitation in the Coastal and Cascade Ranges possess the greatest developable power and energy potential; Southeast Oregon streams have comparatively small potentials. Using practical but limited assessment criteria, preliminary feasibility analyses and screening were used to identify for near-future investigation 56 reaches out of the 1443 studied (39 of them in the Willamette Basin) that had relatively few constraints and had nearby energy marketing possibilities.

In comparison with other Pacific Northwest states and adjacent state's having some land in the Columbia River Basin, Oregon ranks second and possesses about one-fourth of the region's total developable low-head stream power and energy potential.

# FOREWORD

The Water Resources Research Institute, located on the Oregon State University Campus, serves the State of Oregon. The Institute fosters, encourages and facilitates water resources research and education involving all aspects of the quality and quantity of water available for beneficial use. The Institute administers and coordinates statewide and regional programs of multidisciplinary research in water and related land resources. The Institute provides a necessary communications and coordination link between the agencies of local, state and federal government, as well as the private sector, and the broad research community at universities in the state on matters of water-related research. The Institute also coordinates the inter-disciplinary program of graduate education in water resources at Oregon State University.

It is Institute policy to make available the results of significant water-related research conducted in Oregon's universities and colleges. The Institute neither endorses nor rejects the findings of the authors of such research. It does recommend careful consideration of the accumulated facts by those concerned with the solution of water-related problems.

# ACKNOWLEDGEMENTS

The assistance and sharing of ideas among members of the Idaho, Montana and Washington study teams and the sponsoring U.S. Department of Energy and its representatives is gratefully acknowledged for the benefits derived by the Oregon study team in this regional effort.

The contributions of the dozen members of the Oregon study team are most particularly appreciated. They devoted countless hours to the painstaking tasks involved in this project. In succession, Ronald C. Scheidt, William F. Galli and Nasser Talebbeydokhti served as project engineers, with Ron and Bill getting the project started before completing their work and studies at the university. During various phases of the project they were ably assisted by Judy A. Kelly, Carolyn J. Choquette, Milo N. Ullstad, Suzanne Townsen, Philip G. Newton, Ruthanne Rubenstein, James R. Hyneman, Alice Tulloch, and Henry W. Howe. The appendices to this report represent their collective effort, which is gratefully acknowledged.

# TABLE OF CONTENTS

Chapter

Appendices — Number of Pages

# LIST OF FIGURES

## LIST OF TABLES

# I. STUDY BACKGROUND AND PURPOSE

The University of Idaho Water Resources Research Institute entered into a contract with the U. S. Department of Energy in September, 1977, to make a study entitled "A Resource Survey of Low-Head Hydroelectric Potential -- Pacific Northwest Region". The University of Idaho Water Resources Research Institute in turn entered into subcontracts with the Water Resources Research Institutes in Oregon, Washington and Montana to do the portions of that study involving streams in their respective states.

The purpose of this study was to evaluate the low-head hydroelectric potential of the Pacific Northwest region. For purposes of this study, low-head hydroelectric power was defined as power produced from power sites with gross hydraulic heads ranging from 3 to 20 meters (m) and with resulting power plant sizes greater than 200 kilowatts (kW).

The study included all of the Columbia River Basin. It also included all other river basins in Idaho, Oregon and Washington. The study area is shown in Figure 1. The total area studied is approximately 292,000 square miles. The Oregon study team was responsible for evaluating the low-head hydroelectric potential of the State of Oregon, an area of approximately 97,000 square miles -- about one-third of the total study area.

The regional study was coordinated by the Idaho study team. The study was initiated in October 1977 by a one-day meeting of all state study teams with representatives of the U.S. Department of Energy to establish study methodologies and deal with the logistics of accomplishing the project objectives. A briefing meeting was held on the following day to discuss the study with interested state and federal agencies. Subsequently, study team coordination meetings were held quarterly to discuss study progress, problems encountered in applying methodologies, and tasks still to be completed. Additional briefing meetings and discussions with agencies and the public in general occurred throughout the study to provide information and to answer inquiries.

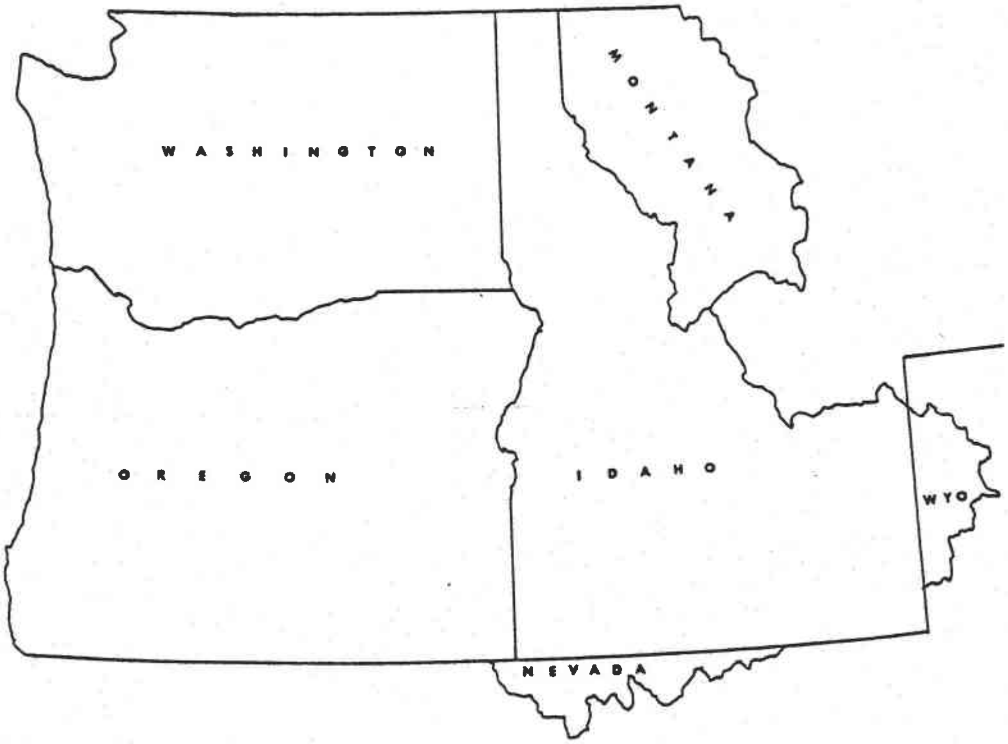


FIGURE 1. REGIONAL STUDY AREA

## II. HYDROLOGIC AND ENERGY ANALYSIS TECHNIQUES

### State River Basins

The 18 major drainage basins identified by the Oregon Water Resources Department (OWRD) were adopted as analytical units to provide evaluations useful for future river basin planning. These subdivisions of the state are shown in Figure 2. Each basin consists of one or more hydrologically homogeneous areas for which streamflow gaging station records could be correlated to develop runoff relations.

### Use of Reaches

The initial study assignment was to define the low-head hydro potential by identifying all possible low-head hydroelectric sites. It was soon determined that this task was too formidable under the limitations of the available project time and budget. Therefore, the study approach followed was to define the power potential for consecutive reaches (lengths) of the streams. A reach is defined here as any length of stream with designated upstream and downstream boundaries such that average values taken over the reach give reasonable descriptions of the reach. Stream reaches were chosen so that major tributary streams would enter at the upstream or downstream end points of the reach rather than within the reach. Reaches did not include existing dams and reservoirs; instead, they terminated just upstream and downstream.

Reaches were assigned to all segments of streams that had flow capabilities of 36 cubic feet per second (cfs) -- about 1 cubic meter per second -- at least 50 percent of the time. This corresponds to the flow required to produce 200 kW at a 20 m head.

### Synopsis of General Analytical Approach

The streamflow regime for each reach was determined by means of flow-duration curves. At locations where streamgaging stations existed, these curves were developed directly from data records. However, most reaches had no such stations and it was, therefore, necessary to generate synthetic flow-duration curves for them. An appropriate technique for doing this was developed, involving correlations among (1) precipitation data that had already been generalized to give isohyetal maps covering the entire state, (2) drainage areas that could be obtained for each reach from available maps, (3) average annual discharges available at gaging stations and

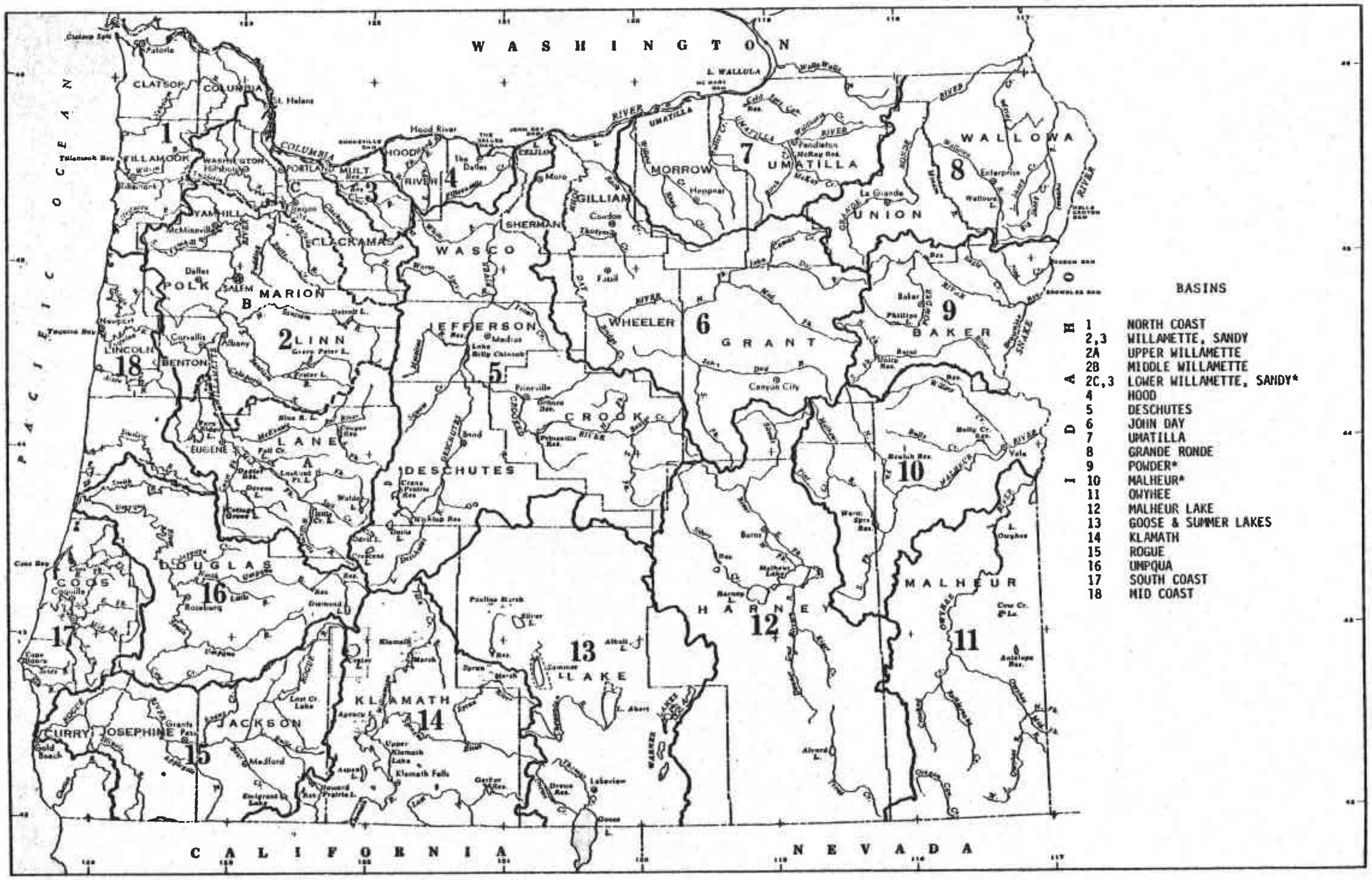


FIGURE 2. OREGON'S MAJOR DRAINAGE BASINS

adjustable to match the period of concurrent precipitation data, and (4) flow-duration curves at these gaging stations. Correlations using the first three parameters (precipitation, drainage area, and average annual discharge) at existing stations gave relations to predict average annual discharges at ungaged sites from precipitation and drainage area estimates. Correlations using the last two parameters (average annual discharge and flow-duration characteristics) gave additional relations so that the predicted average annual discharges at ungaged sites were converted into predicted flow-duration curve discharges.

The energy characteristics for each reach were determined by using five exceedance flows from the predicted flow-duration curves (flows that were exceeded 10, 30, 50, 80, and 95 percent of the time, based on long-term conditions). Each exceedance flow was used with the water power equation, which incorporates these flows with the available head in the reach. Power values were then converted to energy values by application of appropriate time intervals for power availability.

The plant load conditions for each reach were determined by comparing the energy outputs for the five exceedance flows under their predicted variable streamflow regimes with the energy output for the same flows if they instead were available without variation 100 percent of the time. The resulting ratios were called plant factors to distinguish them from other plant load terms commonly used.

## Flow-Duration Approach

To describe the regime of flows available in a reach over time, a flow-duration curve approach was used. A typical flow-duration curve is shown in Figure 3.

The flow-duration curve is a cumulative frequency curve of discharges. The curve depicts the amounts of time that the flow rate of a stream can be expected to equal or exceed various specific flow values during some period. It combines in one curve the flow characteristics of a stream throughout its observed range of discharge, without regard to the sequence or frequency of occurrence of different discharges. The period used is normally one or more complete years of record. Mean daily streamflows are typically used in the development of the curve. Streamflow is depicted on the ordinate scale, which may be an arithmetic or logarithmic scale,

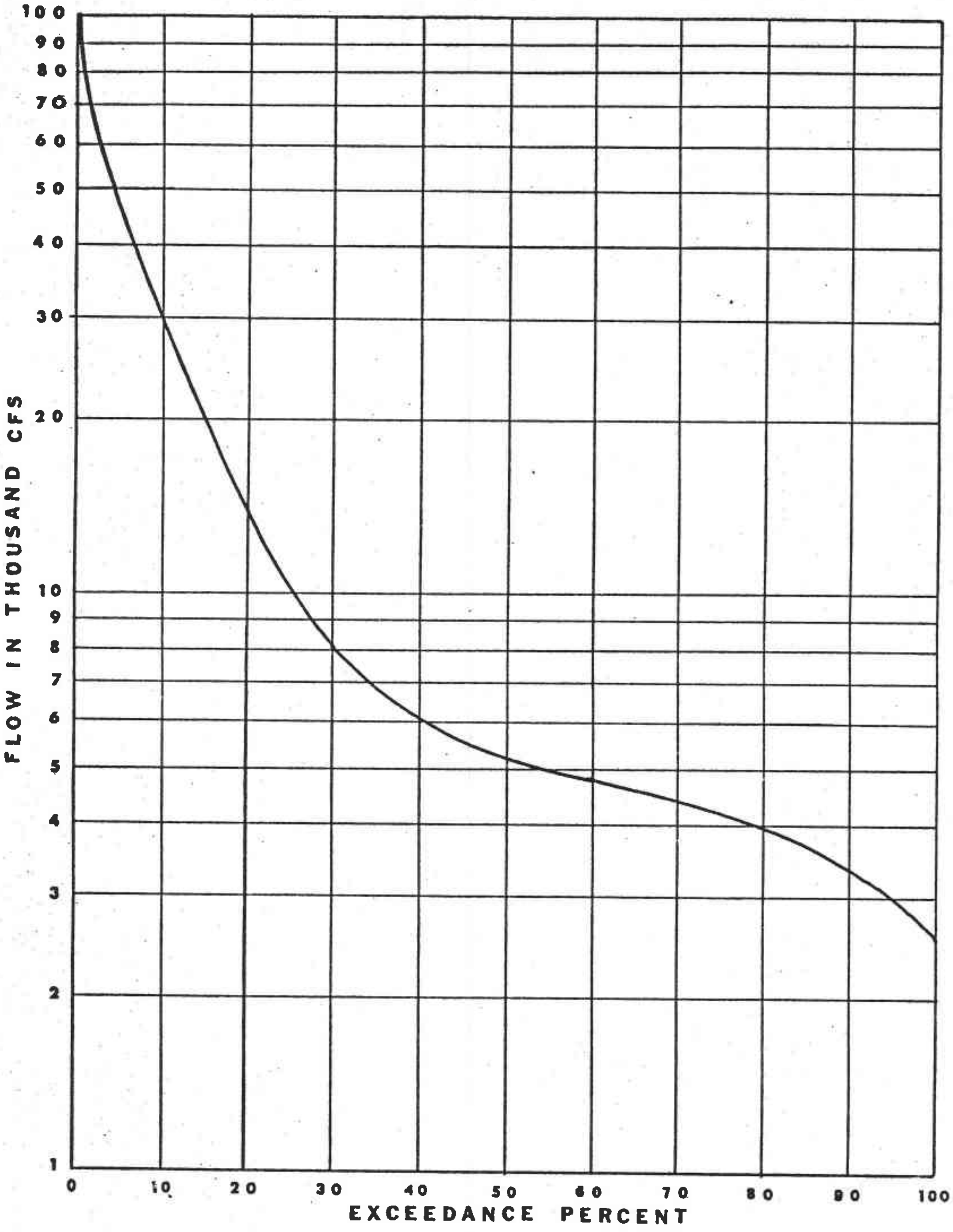


FIGURE 3. TYPICAL FLOW-DURATION CURVE

depending upon the range of flows involved. The amounts of time are not chronological series but instead are magnitude series and are usually depicted on the abscissa scale as "percent of time that the specified flow is equalled or exceeded", or, more simply, "exceedance percent".

The flow-duration curve technique was chosen because it provides a complete yet compact description of streamflow variability. Because of the use of mean daily flows over a long period of several years of record, a detailed description of the common and extreme events that have occurred in a basin is depicted. This gives far more information than is conveyed when only the average, maximum and minimum discharges for the period are known. The flow-duration curve thus gives an effective means of assessing energy capabilities of a stream reach or of a specific hydropower site at various levels of flow availability, including average conditions and any other conditions of interest.

For purposes of this study, it was assumed that any new low-head hydroelectric projects would operate essentially as run-of-river power plants, taking flow as it was available without impoundment. Thus, any storage that would be made available at new sites would make more power and energy available than was computed using the run-of-river assumption. Therefore, the power and energy estimates that have been made in this study are conservative (i.e., are underestimates) as far as the effect of on-site storage is concerned. Also, the assumption of run-of-river conditions means that the flow-duration curve for a particular reach would not be altered if a low-head site is developed upstream (whereas upstream storage would affect all downstream flow-duration curves and would normally cause an increase in downstream power and energy available).

### Flow-Duration Curve Development

Flow-duration curves are normally developed from data at gaging stations. Therefore, methods had to be developed to construct synthetic flow-duration curves for reaches of the stream where no stream gages were available.

For natural, unregulated streams, generalized flow-duration curves were developed at known gage locations for application to ungaged locations. The first step in this procedure was to develop flow-duration curves for all gage locations within each basin of interest. Daily flow-duration curves for all gaging stations were provided by the U.S. Geological Survey (USGS), using their computerized streamflow data access system WATSTORE. These duration values were determined by categorizing each daily flow for the period of record into one of a series of pre-selected flow intervals. The number of daily flows in each interval was then determined. The exceedance percentage of each interval was computed by first determining the number of flow values contained in intervals with flow magnitudes higher than the interval of interest. This number was divided by the total number of flows in all intervals to obtain the exceedance percentage. The flow-duration curve was then developed by plotting the upper flow value for each interval versus the exceedance percent for the interval.

The second step in getting the generalized flow-duration curves was to develop a family of parametric flow-duration curves from the available flow-duration curves for each major river basin. To do this, the flow-duration curves for all available gages in the basin were plotted individually. Flow values for several pre-selected exceedance values (10, 30, 50, 80, and 95 percent) were determined from each of these curves, as illustrated in Figure 4. These flow values for each gage and for each exceedance percentage were plotted against the average annual runoff (QAA) at each gage. A separate curve was then developed for each exceedance percentage (rather than each gage). A correlation analysis was performed for each set of data points to obtain a line of best fit to the data. An example of the resulting family of parametric flow-duration curves developed from this approach is shown in Figure 5.

To use these generalized flow-duration curves, all that is required is the value of QAA at the reach or site of interest. (The procedure for getting average annual runoff at ungaged points is discussed later in this report.) To construct the required flow-duration curves at the unknown point, the abscissa of the graph is entered with the known QAA value and a line is extended vertically upward from this value to intersect with the five curves of percent exceedance so that flow values can be obtained from the ordinate scale. These five flow values can then be plotted against the five percent exceedance values to get the new synthetic flow-duration curve (which will look like that in Figure 3).

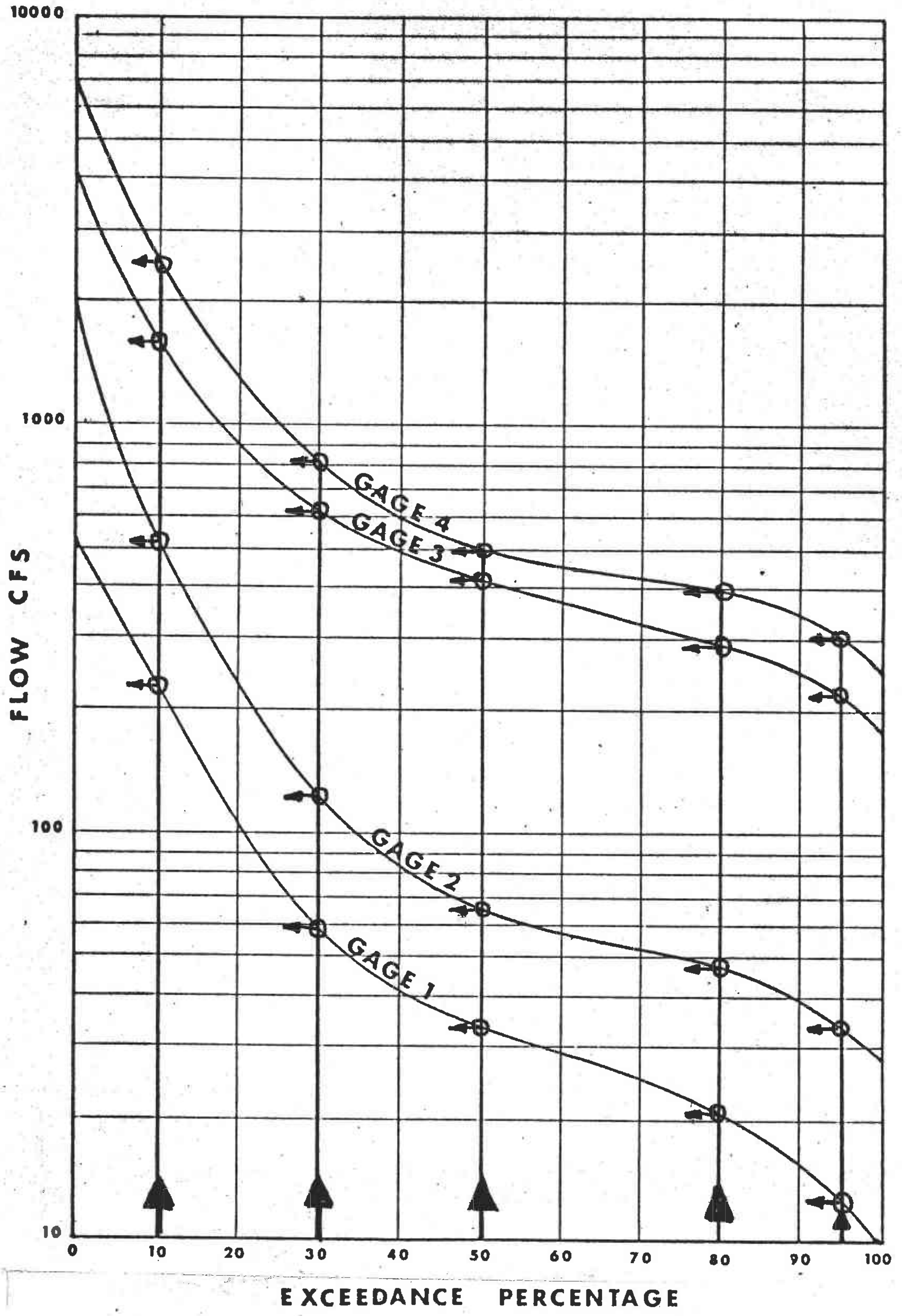


FIGURE 4. FLOW-DURATION CURVES FOR GAGING STATIONS IN A BASIN

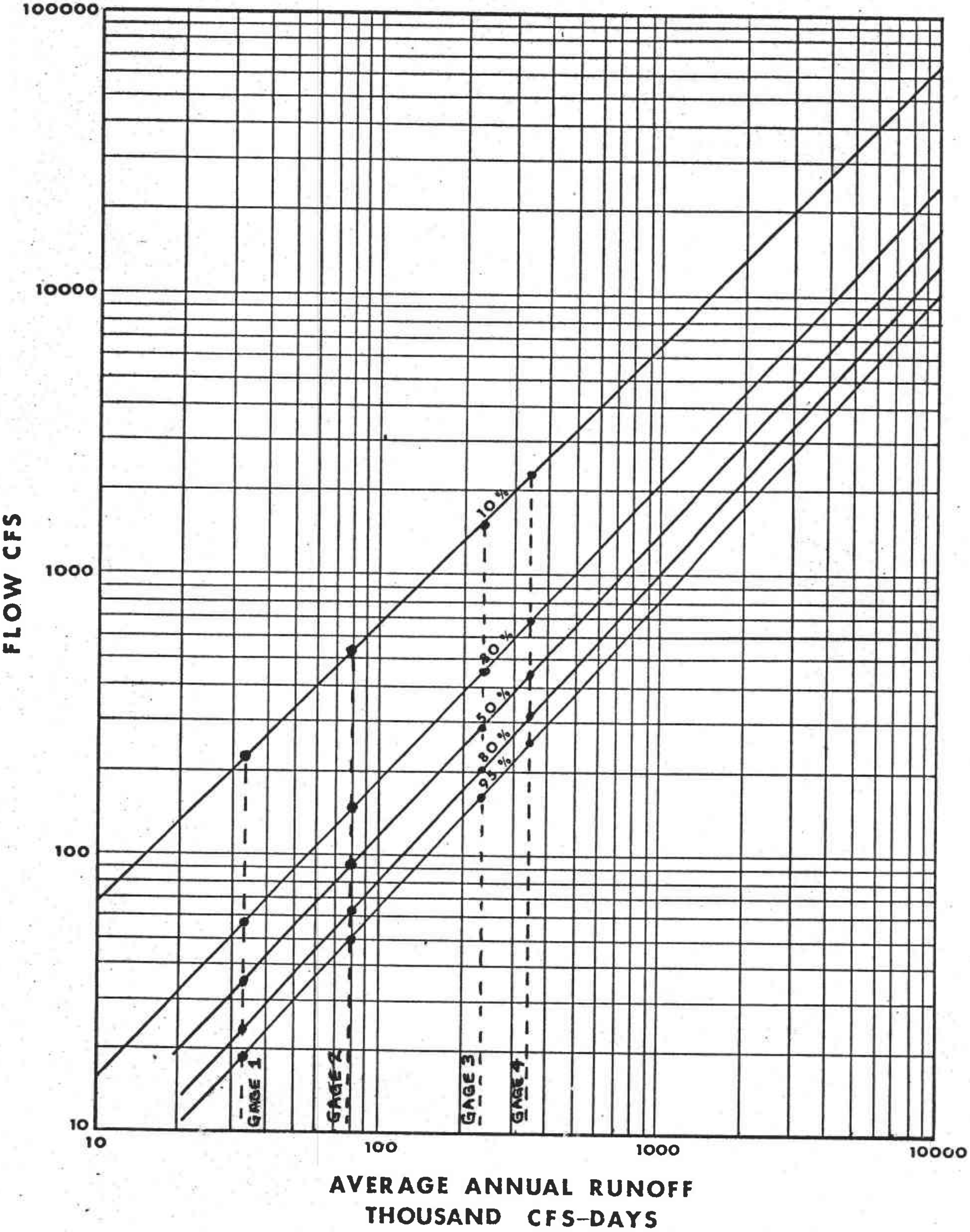


FIGURE 5. PARAMETRIC FLOW-DURATION CURVES FOR A BASIN

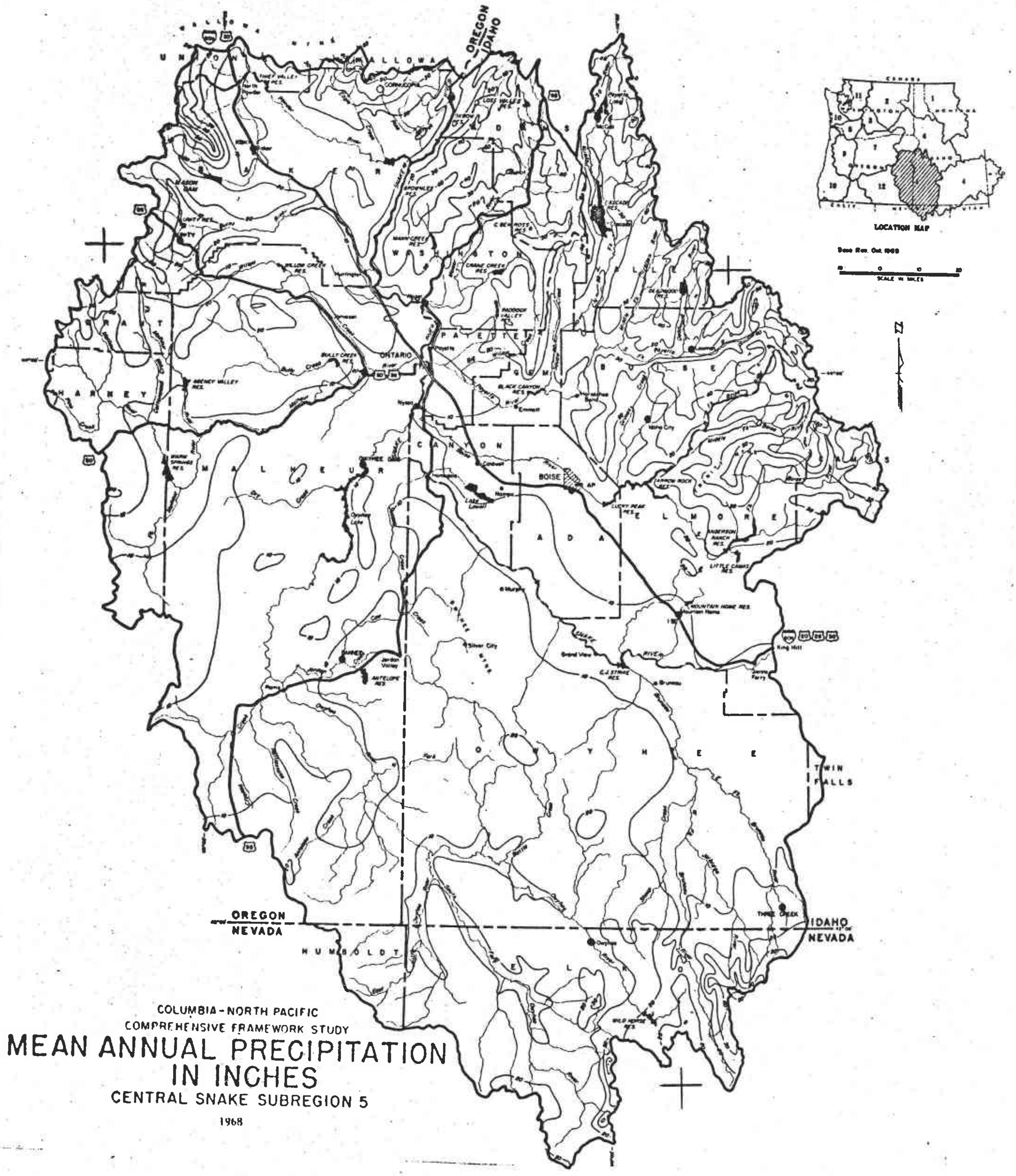
An alternative method to that used on natural streams was considered for obtaining flow-duration curves for regulated stream reaches. Monthly synthetic streamflow data for rivers with major power dams were available from the Bonneville Power Administration (BPA). These data had been developed in connection with BPA simulation studies wherein 1930-1968 streamflows were adjusted to reflect 1978 levels of flow depletion and 1978 power loads. However because the USGS flow-duration curves reflected regulation conditions well for most streams where dams have existed over a long period, it was decided to use the USGS daily information rather than to mix in monthly BPA data for a few rivers. Hence, flow-duration curve analyses for some regulated streams give somewhat conservative underestimates of the power and energy by not adequately reflecting the full benefits of storage.

## Average Annual Runoff

The technique for obtaining average annual runoff for the ungaged portions of each river basin was based upon a correlation of drainage basin area, normal annual precipitation and concurrent average annual runoff for gaged portions.

To develop this correlation involved the integration of areas between precipitation isohyetal lines. This required use of the best available long-term mean or normal annual precipitation maps for the particular study areas (in this study, the NAP abbreviation was used to identify both the long-term mean and the 30-year normal annual precipitation). The sources of these maps were the Oregon Water Resources Department (OWRD) and the Pacific Northwest River Basins Commission (PNRBC) from its "Columbia-North Pacific Region Comprehensive Framework Study". An example of one of the PNRBC maps is shown in Figure 6. Precipitation data generally covered the 1930-1957 period.

USGS topographic maps were used for basin area analyses. The scales of maps used varied with hydrologic productivity of the area of interest. In areas of large runoff, maps of 1:24,000 and 1:62,500 scale were used to identify all streams that could produce the minimum power output of 200 kW at the maximum head of 20 m. These high runoff areas were primarily associated with the coastal drainage basins. In areas of less water production, maps with scales ranging between 1:125,000 and 1:360,000 proved to be quite adequate.



COLUMBIA-NORTH PACIFIC
COMPREHENSIVE FRAMEWORK STUDY
MEAN ANNUAL PRECIPITATION
IN INCHES
CENTRAL SNAKE SUBREGION 5
1968

FIGURE 6. NORMAL ANNUAL PRECIPITATION MAP

The topographic maps were first used to trace all major drainage basins. Reaches that had been selected from OWRD basin maps were marked on the tracings of the topographic maps and their drainage divides were also traced. In some cases, part of this work had been done previously by the USGS; by using projection techniques the basin boundaries would be transferred from the USGS basin maps to maps of a more suitable scale with only minor corrections required.

The next step involved matching the NAP map scale to the scale of the drainage basin maps used to delineate the various reaches. Two optical projection techniques were used. The first involved making 35 mm slides of portions of the original NAP maps. By projecting the slides through a 35 mm slide projector, the scales of the drainage basin and NPA maps could be matched very easily. The second technique involved using large (8½ x 11) transparencies of the NAP maps. These transparencies were projected onto the drainage basin maps using an overhead projector. Both methods resulted in good scale and placement accuracy when care was taken in adjusting the location and magnification of the projection. The choice of method depended upon the size of the available NAP map.

The next step was to measure the areas between adjacent isohyetal lines within each individual reach drainage area. Several techniques were explored to measure the area between isohyetal lines. Use of an electronic planimeter proved to be very accurate and by far the quickest method for obtaining these values. Each of the isohyetal zones was assigned an average precipitation amount based on the values of the adjacent isohyetal lines. The planimetered basin sub-areas for each isohyetal zone were then multiplied by the average precipitation for each zone to obtain the total annual precipitation volume available. Because of the various maps scales used to cover some basins, different conversion factors were sometimes required to develop the total annual precipitation volume. These sub-basin precipitation volume inputs were summed to get the total precipitation input for the basin upstream of the mouth of each reach.

Next, the annual precipitation and annual runoff data were adjusted to a comparable basis. Since the USGS stream gaging station records have various time bases and NAP maps are based on a particular time period, it was desirable to use a single, common time base. The time base selected was the same as the time period used in developing the NAP maps that were used for a particular river basin. This permitted use of the isohyetal map without modification and required adjustment of streamflows to compensate for wet and dry trends during periods other than the selected time base.

When gaging stations had records concurrent with or longer than the NAP time base, QAA values were calculated for the concurrent span of years. However, if any part of the streamflow record was missing during the base period, a correlation procedure was used to estimate the missing data. To do this, a reference station with a long period of record spanning the base period was selected. The choice was limited to stations typical for the drainage area, free of significant flow regulation, and free of abnormal conditions. In some cases, the reference station had to be selected form an adjacent basin. The calculated base period QAA values for the adjusted stations were obtained form the following equation:

$$QAA_{\substack{\text{Base Period,}\\ \text{Adj. Sta.}}} = \left[QAA_{\substack{\text{Base Period,}\\ \text{Ref. Sta.}}}\right] \bullet \left[\frac{QAA_{\substack{\text{Comparison Yrs.,}\\ \text{Adj. Sta.}}}}{QAA_{\substack{\text{Comparison Yrs.,}\\ \text{Ref. Sta.}}}}\right]$$

With a common time base established for NAP and QAA, the product of NAP and drainage area (DA) was obtained for each gaging station and plotted against the corresponding adjusted QAA. A regression analysis led to the relationship

$$QAA = a[(NAP)\ (DA)]^b$$

for that time base used for each river basin, with coefficients a and b influenced by river basin hydrologic conditions. Figure 7 illustrates this.

To apply the method for estimating QAA for ungaged portions of each river basin, DA and NAP were first obtained from planimetry of topographic and NAP maps. The QAA formula was then used. Planimetry progressed from headwaters downstream to mouths of rivers. Therefore, it was convenient to maintain cumulative totals for DA and [(NAP) (DA)] in the downstream direction. For each reach, the representative QAA was calculated from the average of the values for the upstream and downstream products of [(NAP) (DA)]:

$$QAA = a\ [\overline{(NAP)\ (DA)}]^b$$

where

$$\overline{(NAP)\ (DA)} = \tfrac{1}{2}\left\{[(NAP)\ (DA)]_{\text{upstream}} + [(NAP)\ (DA)]_{\text{downstream}}\right\}.$$

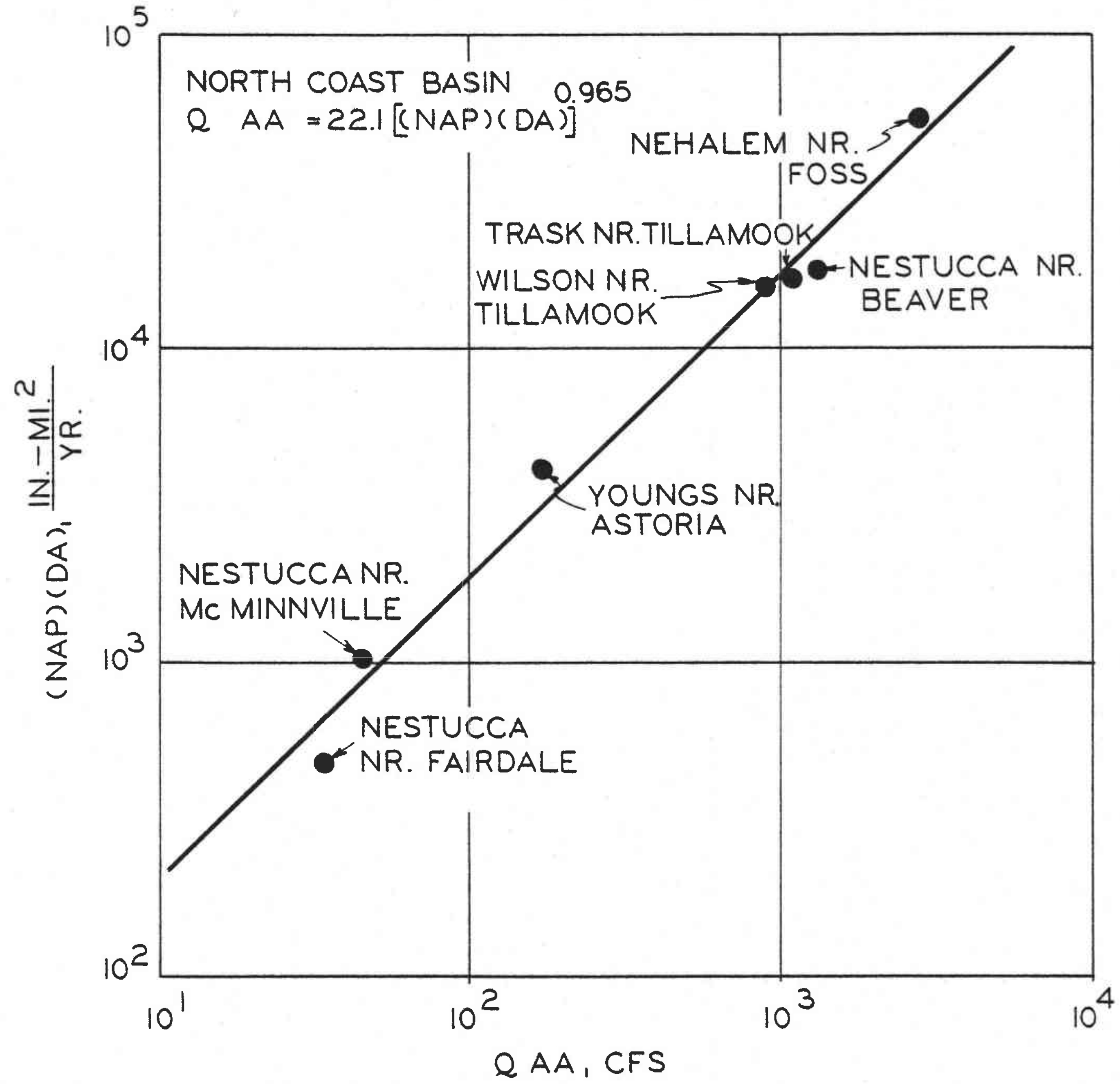


FIGURE 7. PRECIPITATION-AREA-RUNOFF CORRELATION

Once the representative QAA was obtained for each reach, procedures already described were used to obtain flow values at several exceedance percentages from the generalized flow duration curves. However, rather than use the graphical relationships depicted in Figure 5, those parametric curves were used in the regression form

$$Q_{\%} = a_{\%} \, (QAA)^{b_{\%}}$$

where the % symbol represents any of the selected exceedance percentages and the coefficients a and b take on corresponding numerical values.

## Power and Energy Computations

After generating the average annual discharge and flow-duration curve for each reach, the next step was to compute the hydro power potential available. The power, energy, and plant capacity were computed for five different flow rates corresponding to the 10, 30, 50, 80 and 95 percent exceedance levels. The basic water power equation used was:

$$P = \frac{QH}{11{,}800} \, e$$

where:

$P$ = power, megawatts
$Q$ = flow, cfs
$H$ = head available in reach, feet
$e$ = efficiency
11,800 = conversion factor

The Q value used was the $Q_{\%}$ based on the representative QAA for the reach and, hence, approximately that available at the midpoint of the reach. The head used was the total usable head in the reach, which was computed by subtracting the stream elevation at the downstream end of the reach from the stream elevation at the upstream end of the reach. In the farthest upstream reach of a stream, the flow value used was that at the downstream boundary (at least 36 cfs) and head was taken as 20 m (66 feet).

The efficiency used in all power computations was 1.0. It is recognized that no hydro power generating system could operate at this efficiency. But since it is not possible to predict the actual system efficiencies that might be achieved by various low-head power developments, it was felt that using an ideal efficiency of 1.0 would be best in this study. The user of study findings can then apply particular efficiencies directly to the values represented in the tables and figures to estimate the actual power generated.

The theoretical energy available from the power plants sized at the specific exceedance values of Q was computed by integrating the area under the curve of Q versus percent exceedance and multiplying this by the proper conversion factors to get the average energy output per year. Figure 8 illustrates this area under the curve for the 30% exceedance value.

Another value that is computed at each exceedance value is the plant factor. This is the ratio of the actual energy generated (computed by using the area under the curve) to the energy that would be gernerated if the plant was operated at the full capacity for a given exceedance value 100% of the time. Figure 8 shows the actual energy generated (as noted above) and the additional energy that could be obtained if the plant operated at full power capacity all of the time. Hence, the combined shaded area corresponds to the denominator in the plant factor ratio.

The power and energy values computed for each reach are theoretical values based on the total head available in the reach. These values should not be confused with the power and energy available at existing or proposed sites in a reach. The correlation between the theoretical values and that available at existing or proposed sites in dependent on such factors as total head and storage available at the existing or proposed site and the location of the site within the reach.

## Summary of Analysis Techniques

Table I presents a summary of the more important data sources and analysis techniques that were applied to particular streams and river basins in Oregon. The first column, identifies the basin and its streams. The next two columns under "Basin Characteristics" are used to describe the flow classification; e.g., whether it is a natural flow system or has reservoir regulation and the type of regulation of the stream, if any. The "Source of Flow Data" column documents the source of flow data used in a particular basin. The "Duration Curve Development" column and the "Duration Curve for Regulated Stream" column are used to identify the technique used to generate the flow-duration curves for a particular basin. For the regional study, variations of the previously described analytical techniques were used by different state study teams. Some techniques were used by more than one state. For example, the flow-duration curve technique used in Oregon was like one of several used in Idaho. Each technique or variation

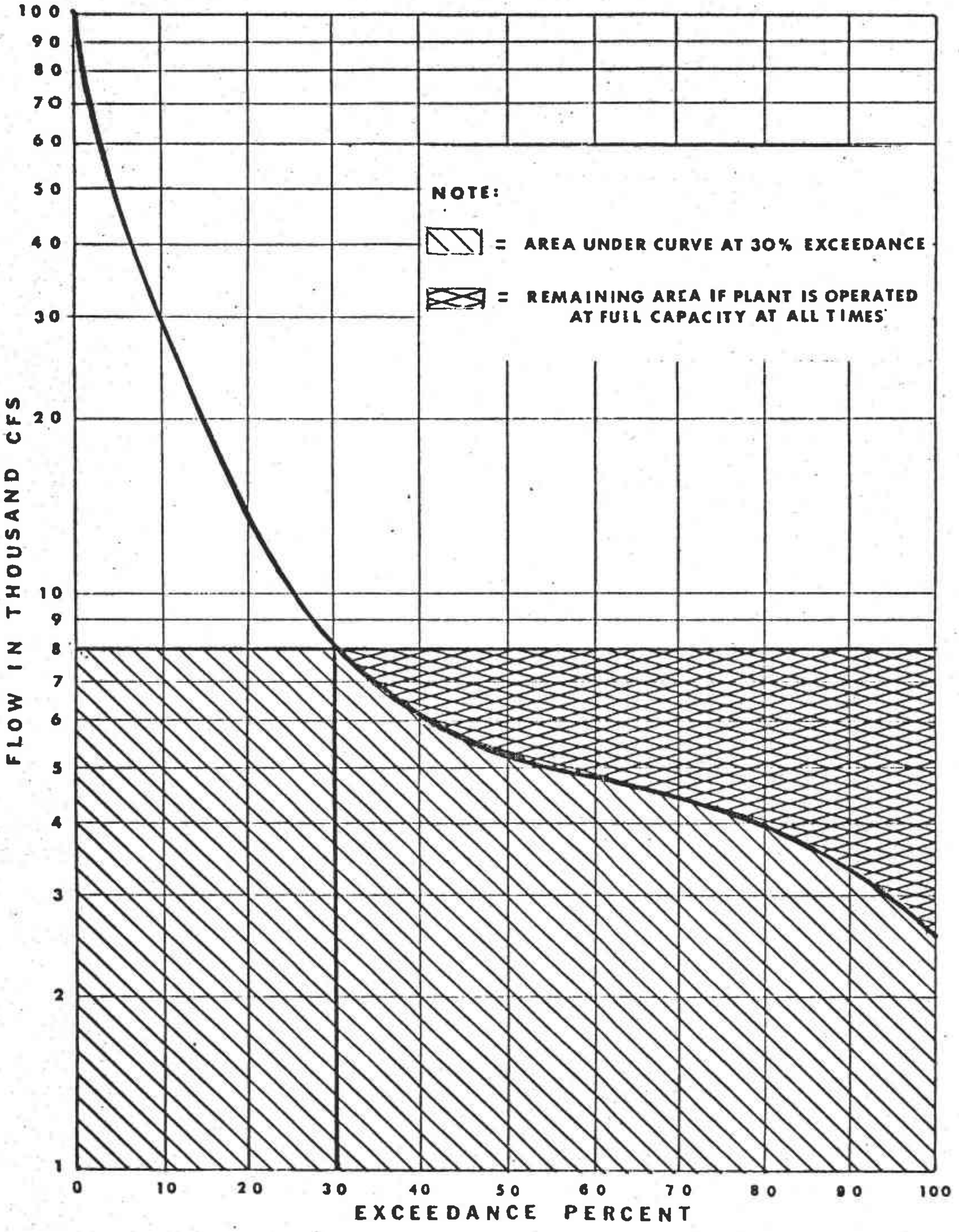


FIGURE 8. EXAMPLE OF ENERGY AND PLANT FACTOR RELATIONSHIP

## TABLE I. HYDROELECTRIC POTENTIAL ANALYSIS TECHNIQUES

| BASIN NAME | BASIN CHARACTERISTICS |  | HYDROELECTRIC POTENTIAL ANALYSIS TECHNIQUES |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | FLOW CLASSIFI-CATION | REGULATION[1] TYPE | SOURCE OF FLOW DATA | DURATION CURVE DEVELOPMENT | MAP SCALES USED | SOURCE OF MAP MAPS | DURATION CURVE FOR REGULATED STREAM |
| 1. North Coast Basin |  |  |  |  |  |  |  |
| Nestucca R. | Natural & Regulated | M&I | USGS/OWRD[2] | Idaho A | 1:240,000<br>1:62,500<br>1:24,000 | OWRD | USGS |
| Other Streams | Natural | none | " | " | " | " | " |
| 2A. Upper Willamette Basin |  |  |  |  |  |  |  |
| Willamette R. Main Stem (R0021 - R0024) | Natural & Regulated | MP | USGS/OWRD[2] | Idaho A | 1:250,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| Long Tom R. | " | " | " | " | " | " | " |
| McKenzie R. | " | " | " | " | " | " | " |
| Coast Fork Willamette R. | " | " | " | " | " | " | " |
| Middle Fork Willamette R. | " | " | " | " | " | " | " |
| 2B. Mid-Willamette Basin |  |  |  |  |  |  |  |
| Willamette R. Main Stem (R0005 - R0020) | Natural & Regulated | MP | USGS/OWRD[2] | Idaho A | 1:360,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| Yamhill R. | " | I, M&I | " | " | " | " | " |
| Rickreall Cr. | " | M&I | " | " | " | " | " |
| Santiam R. | " | MP | " | " | " | " | " |
| Other Streams | Natural | none | " | " | " | " | " |
| 2C. Lower Willamette Basin |  |  |  |  |  |  |  |
| Scapoose Cr. | Natural | none | USGS/OWRD[2] | Idaho A | 1:250,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| Willamette R. Main Stem (R0001 - R0004) | Natural & Regulated | MP | " | " | " | " | " |
| Clackamas R. | " | P,R | " | " | " | " | " |
| Tualatin R. | " | I | " | " | " | " | " |
| 3. Sandy Basin |  |  |  |  |  |  |  |
| Sandy R. Main Stem | Natural & Regulated | M&I,P | USGS/OWRD[2] | Idaho A | 1:250,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| Bull Run R. | " | " | " | " | " | " | " |
| Other Streams | Natural | none | " | " | " | " | " |
| 4. Hood Basin |  |  |  |  |  |  |  |
| All Streams | Natural | none | USGS/OWRD[2] | Idaho A | 1:125,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| 5. Deschutes Basin |  |  |  |  |  |  |  |
| Deschutes R. Main Stem | Natural & Regulated | I,P | USGS/OWRD[2] | Idaho A | 1:350,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| Crooked R. | " | I | " | " | " | " | " |
| Little Deschutes R. | " | " | " | " | " | " | " |
| Other Streams | Natural | none | " | " | " | " | " |

[1] FC = Flood Control; I = Irrigation; MP = Multiple Purpose; M&I = Municipal and/or Industrial; N = Navigation; P = Power; R = Recreation.

[2] USGS = U.S. Geological Survey; OWRD = Oregon Water Resources Department

TABLE I. Cont'd.

| BASIN NAME | BASIN CHARACTERISTICS | | HYDROELECTRIC POTENTIAL ANALYSIS TECHNIQUES | | | | |
|---|---|---|---|---|---|---|---|
| | FLOW CLASSIFICATION | REGULATION[1] TYPE | SOURCE OF FLOW DATA | DURATION CURVE DEVELOPMENT | MAP SCALES USED | SOURCE OF MAP MAPS | DURATION CURVE FOR REGULATED STREAM |
| 6. John Day Basin | | | | | | | |
| John Day R. Main Stem | Natural & Regulated | I | USGS/OWRD[2] | Idaho A | 1:300,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| North Fork John Day R. | " | " | " | " | " | " | " |
| Other Streams | Natural | none | " | " | " | " | " |
| 7. Umatilla Basin | | | | | | | |
| Umatilla R. Main Stem | Natural & Regulated | I,R | USGS/OWRD[2] | Idaho A | 1:200,000<br>1:24,000 | OWRD | USGS |
| Other Streams | Natural | none | " | " | " | " | " |
| 8. Grande Ronde Basin | | | | | | | |
| Grande Ronde R. Main Stem | Natural & Regulated | I | USGS/OWRD[2] | Idaho A | 1:220,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| Wallowa R. | " | I, M&I | " | " | " | " | " |
| Other Streams | Natural | none | " | " | " | " | " |
| 9. Powder Basin | | | | | | | |
| Pine Cr. | Natural | none | USGS/OWRD[2] | Idaho A | 1:190,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| Powder R. Main Stem | Natural & Regulated | I | " | " | " | " | " |
| Eagle Cr. | Natural | none | " | " | " | " | " |
| Burnt R. | Regulated | I | " | " | " | " | " |
| 10. Malheur Basin | | | | | | | |
| Malheur R. Main Stem | Natural & Regulated | I | USGS/OWRD[2] | Idaho A | 1:300,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| North Fork Malheur R. | " | " | " | " | " | " | " |
| 11. Owyhee Basin | | | | | | | |
| Owyhee R. Main Stem | Natural & Regulated | I | USGS/OWRD[2] | Idaho A | 1:250,000<br>1:62,500<br>1:24,000 | OWRD | USGS |
| Crooked Cr. | Natural | none | " | " | " | " | " |
| Jordon Cr. | Regulated | I | " | " | " | " | " |
| 12. Malheur Lake Basin | | | | | | | |
| Silvies R. | Natural | none | USGS/OWRD[2] | Idaho A | 1:330,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| Donner & Blitzen R. | " | " | " | " | " | " | " |

[1] FC = Flood Control; I = Irrigation; MP = Multiple Purpose; M&I = Municipal and/or Industrial; N = Navigation; P = Power; R = Recreation.

[2] USGS = U.S. Geological Survey; OWRD = Oregon Water Resources Department

TABLE I. Cont'd.

| BASIN NAME | BASIN CHARACTERISTICS | | HYDROELECTRIC POTENTIAL ANALYSIS TECHNIQUES | | | | |
|---|---|---|---|---|---|---|---|
| | FLOW CLASSIFI-CATION | REGULATION[1] TYPE | SOURCE OF FLOW DATA | DURATION CURVE DEVELOPMENT | MAP SCALES USED | SOURCE OF MAP MAPS | DURATION CURVE FOR REGULATED STREAM |
| 13. Goose & Summer Lakes Basin | | | | | | | |
| Chewaucan R. | Natural | none | USGS/OWRD[2] | Idaho A | 1:315,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| 14. Klamath Basin | | | | | | | |
| Jenny Cr. | Regulated | I | USGS/OWRD[2] | Idaho A | 1:280,000<br>1:64,500<br>1:24,000 | OWRD | USGS |
| Klamath R. | " | I,P | " | " | " | " | " |
| Sprague R. | Natural & Regulated | I | " | " | " | " | " |
| Williamson R. | " | " | " | " | " | " | " |
| 15. Rogue Basin | | | | | | | |
| Rogue R. Main Stem | Natural & Regulated | MP | USGS/OWRD[2] | Idaho A | 1:260,000<br>1:64,500 | OWRD | USGS |
| Applegate R. | " | I | " | " | " | " | " |
| Evans Cr. | " | " | " | " | " | " | " |
| Bear Cr. | " | " | " | " | " | " | " |
| Big Butte Cr. | " | I, M&I | " | " | " | " | " |
| Little Butte Cr. | " | " | " | " | " | " | " |
| Other Streams | Natural | none | " | " | " | " | " |
| 16. Umpqua Basin | | | | | | | |
| North Umpqua R. & Tribs. | Natural & Regulated | P,R | USGS/OWRD[2] | Idaho A | 1:260,000<br>1:62,500 | OWRD | USGS |
| Other Streams | Natural | none | " | " | " | " | " |
| 17. South Coast Basin | | | | | | | |
| All Streams | Natural | none | USGS/OWRD[2] | Idaho A | 1:200,000<br>1:62,500<br>1:24,000 | OWRD | USGS |
| 18. Mid-Coast Basin | | | | | | | |
| Siletz R. | Natural & Regulated | M&I | USGS/OWRD[2] | Idaho A | 1:180,000<br>1:62,500 | OWRD | USGS |
| Other Streams | Natural | none | " | " | " | " | " |

[1] FC = Flood Control; I = Irrigation; MP = Multiple Purpose; M&I = Municipal and/or Industrial; N = Navigation; P = Power; R = Recreation.

[2] USGS = U.S. Geological Survey; OWRD = Oregon Water Resources Department

was assigned an identifier which is listed in this column. The column entitled "Map Scales Used" describes the scales of maps used in the analysis. The column entitled "Source of NAP Maps" is used to identify the source of the long-term mean or normal annual precipitation maps used in determining the average annual runoff.

## Reporting of Reach Hydro-potential Characteristics

Table II illustrates the regional format used to describe the hydrologic and energy characteristics for each stream reach. These reach sheets contain the vital statistics for all of the reaches studied -- 1443 reaches in Oregon and 3609 for the region. Because of the number of reach sheets involved, they have been assembled separately in appendices to this and the regional reports.

The first item on this table is the reach identification number. This is a 19 digit identifier number used to identify each reach in the study. The number is constructed as shown below:

```
(1) (2) (3) (4) (5)  (6)
 XX-XXX-XXX-XXX-XXX-RXXXXX
```

(1) State Identifier: 01 = Washington, 02 = Oregon, 03 = Idaho, 04 = Montana.

(2) Numbers identifying all rivers discharging directly into the Pacific Ocean or first order streams is closed basins.

(3) (4) (5) Numbers identifying rivers tributary to rivers listed in group (2), extending in detail to tributaries of tributaries of the tributary to rivers listed in group (2).

(6) Number assigned to the particular reach (the first character in this group is the letter R -- for "reach").

The first major group of items on the reach characteristics sheet gives the reach location. This includes the state and county or counties in which a particular reach is contained, the township and range for the midpoint of the reach, the approximate latitude and longitude of the midpoint of the reach, the name of the stream and the major basin on which the reach is located.

The second major group on the reach characteristics sheet gives hydrologic and hydraulic characteristics. This group contains results of the hydrologic analysis portion of the study. The upstream and downstream elevations are listed for each reach, based upon the most detailed topographic maps available or published lists of channel elevation versus river mile. The total available head is also shown. In most cases this

# TABLE II. FORMAT USED TO DESCRIBE REACH HYDRO-POTENTIAL CHARACTERISTICS

## REACH HYDRO POTENTIAL CHARACTERISTICS

**REACH #** 02-500-220-000-000-R0001

**I. LOCATION**

| | |
|---|---|
| A. State | Oregon |
| B. County | Umatilla |
| C. Township, Range | Sec.9, T4N, R28E |
| D. Latitude, Longitude | 45°50'N,119°19'W |
| E. Stream Name | Umatilla River |
| F. Major Basin Name | Umatilla |
| G. River Mile | 0.0 to 15.2 |

**II. HYDROLOGIC AND HYDRAULIC CHARACTERISTICS**

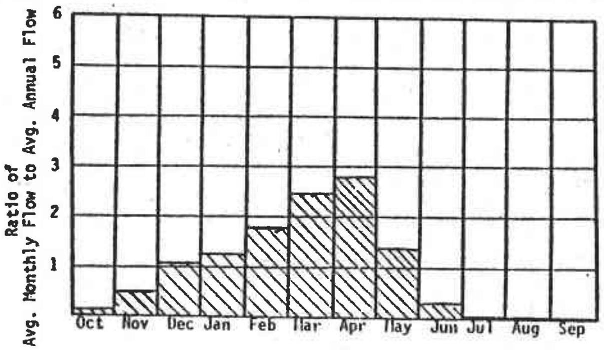
| | | |
|---|---|---|
| A. Upstream Elevation of Reach | 525 | Ft. MSL |
| B. Downstream Elevation of Reach | 240 | Ft. MSL |
| C. Total Available Head in Reach | 285 | Ft. |
| D. Average Slope in Reach | 18.7 | Ft./Mi. |
| E. Drainage Area above Reach Mouth | 2130.5 | Sq.Mi. |
| F. Inflow Classification | Natural | |

**III. REACH FLOW DURATION AND THEORETICAL POTENTIAL ENERGY CHARACTERISTICS**

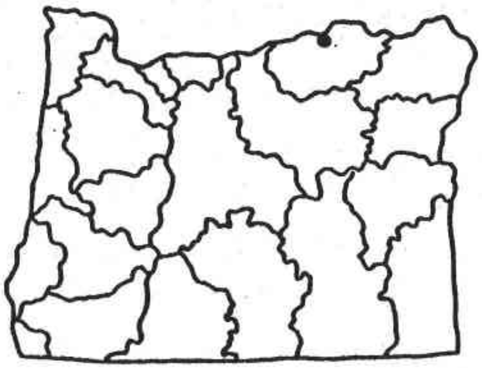
| EXCEEDANCE PERCENTAGE | DISCHARGE CFS | THEORETICAL PLANT SIZE MW | ANNUAL ENERGY AVAILABLE GWH | PLANT FACTOR |
|---|---|---|---|---|
| 95 | 29.1 | .70 | 6.15 | 1.000 |
| 80 | 265.2 | 6.41 | 49.86 | .889 |
| 50 | 757.0 | 18.28 | 117.51 | .734 |
| 30 | 1699.2 | 41.04 | 197.24 | .549 |
| 10 | 3324.9 | 80.30 | 266.03 | .378 |

**IV. TYPICAL ANNUAL HYDROGRAPH**

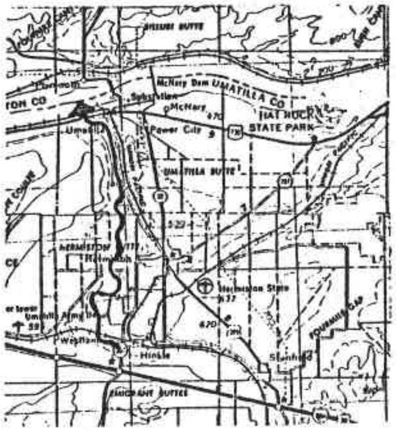
AVG. ANNUAL FLOW = 1636 CFS



0 7-1



U.S.G.S. TOPO. SERIES
1:250,000 SCALE
MAP NAME: PENDLETON



is merely the upstream elevation minus the downstream elevation for the reach. In the reach located farthest upstream on a stream, this corresponds to 20 meters of head. The average slope in the reach is calculated from the difference in upstream and downstream reach elevations divided by the length of the reach. The drainage area above the farthest downstream point in the reach is shown next. The inflow classification tells whether flow into the reach is natural (unaffected by regulation) or is regulated by upstream reservoir management for flood control, power production, irrigation, etc. Because small diversions directly from most stream have been commonplace for long periods and are presumably reflected by streamflow records, no special note is made of such diversions.

The third major group contains the flow and theoretical maximum potential power and energy production in the reach. The flows shown in the table are those which are representative for the reach (i.e., mid-reach) for the given exceedance values. The power plant size and available energy shown are based on these flows combined with the total head available for the reach. These power and energy values are theoretical (100 percent efficiency and full reach development). The calculated plant factor is also shown.

The next item is the average annual flow and a typical annual hydrograph pattern for the reach. The abscissa for this graph shows time in months and the ordinate shows the ratio of average monthly flow to average annual flow. The values presented in the graph are obtained from analyzing the record of a nearby stream gage that would be characteristic for the reach. To obtain the approximate annual pattern of monthly discharges for the reach, all that is required is to multiply the graph ratios by the given average annual flow for the reach.

The upper map shown on the right hand side of the reach characteristics sheet is merely a locator map. It indicates the position of the reach in its major drainage basin. The note below the map shows on which USGS 1:250,000 scale map the reach is located. The lower map shows the approximate location of the reach on a copy of this USGS map. The reach is denoted by a heavy line traced onto the USGS map. The arrowhead denotes the direction of flow and the downstream point of the reach. While the topography is not sharply reproducable from the original color map, sufficient details are evident from this map to allow quick location of the reach on a USGS map.

The reach sheets are arranged systematically in each appendix. They are numbered beginning at the mouth of the major river and progressing upstream, interrupting this movement up the main river at each tributary to progress up to its headwater reach before returning to the main stream. These page numbers are preceeded by the appendix number, which in turn is preceeded by the letter O to denote Oregon in the regional report. Thus O 15-32 denotes the 32nd page in Appendix 15 (Rogue Basin) for Oregon.

# III. PRELIMINARY FEASIBILITY ANALYSIS TECHNIQUES

## Scope

Beyond the extensive hydrologic and energy analyses required to evaluate the low-head hydroelectric potential in Oregon and the Pacific Northwest region, the U.S. Department of Energy also asked that a preliminary feasibility analysis be conducted so that an initial screening and ranking of reaches might be made. The regional approach taken was to evaluate each reach on the basis of feasibility restraints and on the basis of transmission and load considerations.

The intention of this preliminary feasibility analysis was not as much to determine if low-head development might be feasible in a given reach as it was to point out some factors that could be expected to significantly affect the feasibility of development. Many other factors, such as site geology, sociologic considerations and project economics, have not been taken into account. It has been assumed in this study that such investigations would be part of any future detailed reconnaissance investigation of individual rivers and basins that might be undertaken by an electric utility, state agency, or consulting firm.

In all cases it was assumed that the low-head potential would be developed by use of some sort of dam. However, other methods could be used, such as a long penstock and relatively small diversion structure. Hence, some of the adverse effects identified in this study might be reduced or eliminated.

## Feasibility Restraints

Four categories of feasibility restraints were considered: land use restrictions, utility displacement, building displacement, and special fish problems. Each of these could cause problems related to the development of a low-head hydro project in a particular reach.

Existing land use often restricts alternative development. Therefore, the feasibility restraints considered in this study that might be applicable to a given reach were partially based upon the identification of a particular land use. These constraints included wild and scenic rivers, national recreation areas, national parks, national wilderness areas, known reserved natural areas, or identified archaeological sites. Information on existing land uses was obtained from USGS maps. Information on identified archaeological sites was obtained from the University of Oregon's Department of Anthropology.

The displacement of existing utilities poses a potential problem if a hydro development would cause their relocation. Several types of utility displacement were considered, including major highways, railroads, power lines, telephone lines or gas and oil lines. Location of these items was based on USGS maps or other easily accessible mapping. A ground reconnaissance was not carried out for each reach.

The displacement, removal or relocation of existing residential and commercial buildings due to low-head hydro development represents another potential problem. The location of buildings in potential areas of inundation was determined by inspection of USGS quadrangle mpas. Again, a ground reconnaissance was not carried out for each reach. In general, no constraint was identified unless more than four residences or commercial buildings appeared to be in danger of inundation in any mile of the reach.

Aquatic ecosystems pose significant potential problems for all types of stream development activities. However, it was determined not to deal in detail with the extensive and complex habitat relationships at this preliminary level of evaluation of hydropower potential. Instead, it was decided to focus on special problems related to fish passage, these being considered to represent the most significant feasibility restraint. In particular, a restraint was indicated if the reach supports a run of salmonids or if a sturgeon population that is an endangered species is present. Information was based upon the basin reports of the Oregon Department of Fish and Wildlife (and its predecessor agencies) and upon similar readily available documents.

## Transmission and Load Considerations

Two types of transmission considerations were examined. First, the distance from the center of the reach to the nearest power line was of concern as affecting feasibility of site development. Information was obtained from detailed transmission line maps published by Bonneville Power Administration to identify this factor. Second, the capacity of the transmission line shown on the maps was taken into account. The utility that operates the line was also noted.

Two types of load considerations were also examined. The first was to identify the type of local load that is present in that area closer to the reach than the transmission line identified above. The load was subdivided into three types as follows:

1) Known local residential load
2) Known local industrial load
3) Known local water pumping load.

Again, no ground reconnaissance was made for each reach to identify these loads. Load information was instead obtained from available maps. The second consideration was the distance in miles from the center of the reach to the nearest town with a population greater than 1000 people (1970 census). USGS maps were used to determine these distances.

## Reporting of Preliminary Feasibility Analysis

Table III illustrates the format selected for reporting the results of the preliminary feasibility analyses. The first column identifies the reach as already described. The next four columns deal with the four categories of feasibility restraints and the last four columns summarize the transmission and load considerations, all of which have just been described in detail.

An "X" marked in any of the columns representing feasibility restraints means that the particular feasibility category has been identified as posing problems for that reach. Distances, line capacities and load types in the local marked area are shown in the remaining columns.

Because of the number of reaches involved in Oregon and the region, the feasibility sheets have been assembled separately in appendices to this and the regional reports.

## Screening and Ranking of Reaches

Reaches were screened on the basis of the preliminary feasibility analysis. From these, the reaches that were found to be relatively unconstrained and to have a market potential were selected. They were then ranked on the basis of the amount of streamflow available.

The screening process consisted of examining all reach feasibility analysis sheets (see Table III). First, if a feasibility restraint was shown due to land use restrictions, the reach was eliminated from further

TABLE III. FORMAT USED TO SUMMARIZE PRELIMINARY FEASIBILITY ANALYSIS

| REACH IDENTIFICATION NUMBER | FEASIBILITY RESTRAINT | | | | TRANSMISSION AND LOAD CONSIDERATIONS | | | |
|---|---|---|---|---|---|---|---|---|
| | LAND USE RESTRICTIONS | UTILITY DISPLACEMENT | BUILDING DISPLACEMENT | SPECIAL FISH PROBLEMS | DISTANCE TO NEAREST LINE Miles | LINE CAPACITY KVA | LOCAL * MARKET | DISTANCE TO CITY > 1000 Miles |
| 02-500-220- | | | | | | | | |
| 000-000-R0001 | X | X | X | X | 0.8 | 69-U-C | - | 27 |
| 000-000-R0002 | - | X | X | X | 2.8 | 230-B | - | 23.5 |
| 000-000-R0003 | - | X | - | X | 1.0 | 230-B | - | 18.0 |
| 000-000-R0004 | - | X | - | X | 1.0 | 230-B | - | 9.2 |
| 000-000-R0005 | - | X | X | X | 1.2 | 230-B | 1,2 | 6.0 |
| 000-000-R0006 | - | X | X | X | 0.2 | 69-PPL | 1,2 | 1.0 |
| 010-000-R0001 | - | X | X | - | 1.0 | 69-PPL | 1,2 | 3.6 |
| 000-000-R0007 | X | X | X | X | 3.2 | 69-PPL | 1,2 | 9.0 |
| 000-000-R0008 | X | X | X | X | 8.0 | 230-B | - | 20.0 |
| 000-000-R0009 | X | X | X | X | 10.0 | 230-B | - | 22.8 |
| 015-000-R0001 | - | X | - | X | 10.8 | 230-B | - | 27.0 |
| 015-000-R0002 | - | X | - | X | 10.9 | 230-B | - | 31.0 |
| 000-000-R0010 | X | - | X | X | 14.5 | 230-B | - | 28.0 |
| 000-000-R0011 | X | - | X | X | 16.8 | 230-B | - | 31.0 |

* 1, 2 and 3 identify known local residential, industrial, and water pumping loads, respectively.

consideration. Second, for all remaining reaches, the next three columns were used for further screening; if more than one feasibility restraint was shown among utility displacement, building displacement, or special fish problems, the reach was eliminated from further consideration.

The third and fourth levels of screening involved transmission and load considerations. Somewhat arbitrarily, it was believed that if the nearest transmission line were less than 10 miles away, then the distance would not pose a severe constraint. Hence, those reaches farther than 10 miles from an existing tranmission line were eliminated from further consideration. It was also believed that some type of local market was needed for low-head development (at least at higher-priority areas). If no local market existed, reaches were eliminated from further consideration.

After the four levels of screening, all remaining reaches were listed on the basis of the amount of streamflow available 30 percent of the time ($Q_{30}$). That reach with the largest $Q_{30}$ was ranked highest, and so on. The 30 percent streamflow exceedance was selected because it roughly corresponds to the arithmetic average (mean) flow.

# IV. FINDINGS FROM HYDROLOGIC AND ENERGY ANALYSES

## Use of Appendices to Present the Analysis Findings

Because of the extensiveness of the analyses conducted, the bulkiness of tables and graphs that portray the results of these analyses, and the importance of making the investigation findings available for use by others, a great deal of information has been assembled in appendices. There are 18 appendices, each corresponding in its appendix number to the OWRD drainage basin number. (These numbers begin at the north coast and generally proceed in a clockwise direction around the state.) Because of its size, Basin 2 has been subdivided into 3 parts. Each appendix consists of a title page, an index, a drainage basin map, the reach characteristics sheets for all reaches analyzed in that basin, and the tabulated preliminary feasibility analyses for those reaches.

## Reaches Analyzed

Table IV summarizes the number of reaches analyzed in each of the 18 OWRD drainage basins and for the state as a whole. The reaches met or exceeded the minimum low-head requirements of having sufficient flow to provide 36 cfs at least 50 percent of the time and, in addition, sufficient head to produce 200 kW. Reaches in California and Washington on streams entering Oregon were not included in the Oregon analysis.

The majority of reaches (1068 out of 1443) were along streams west of the Cascade divide. Over one-third of the reaches (608) were on streams in the five coastal basins flowing directly to the Pacific Ocean via California. About one-half (788) of the reaches analyzed were on streams that drained to the Snake and Columbia Rivers. Closed basins, with no surface outflow, had 13 reaches meeting the low-head requirements.

Figure 9 shows the stretches of streams in Oregon that satisfy the low-head criteria, superimposed on a map of streams in Oregon. Individual reaches are not shown in the figure. The influence of the precipitation pattern over Oregon and the related effects of mountainous topography are clearly reflected by the stream pattern.

The actual number of river miles analyzed for the 1443 reaches depicted in Figure 9 is shown in Table IV, including a breakdown by basin. Of the 7626 miles of undeveloped reaches possessing a median flow in excess of

TABLE IV. NUMBER OF LOW-HEAD REACHES AND RIVER MILES ANALYZED FOR OREGON RIVER BASINS

| River Basin | Number of Reaches | | Number of River Miles Represented | |
|---|---|---|---|---|
| 1. North Coast | | 138 | | 478 |
| 2. Willamette | | 406 | | 1942 |
| 2A. Upper | 124 | | 525 | |
| 2B. Middle | 216 | | 1105 | |
| 2C. Lower | 66 | | 312 | |
| 3. Sandy | | 50 | | 141 |
| 4. Hood | | 17 | | 58 |
| 5. Deschutes | | 120 | | 762 |
| 6. John Day | | 44 | | 445 |
| 7. Umatilla | | 14 | | 95 |
| 8. Grande Ronde | | 63 | | 410 |
| 9. Powder | | 31 | | 236 |
| 10. Malheur | | 20 | | 183 |
| 11. Owyhee | | 23 | | 260 |
| 12. Malheur Lake | | 8 | | 108 |
| 13. Goose & Summer Lakes | | 5 | | 28 |
| 14. Klamath | | 30 | | 223 |
| 15. Rogue | | 135 | | 577 |
| 16. Umpqua | | 114 | | 635 |
| 17. South Coast | | 86 | | 454 |
| 18. Mid-Coast | | 139 | | 593 |
| Total for State | | 1443 | | 7626 |

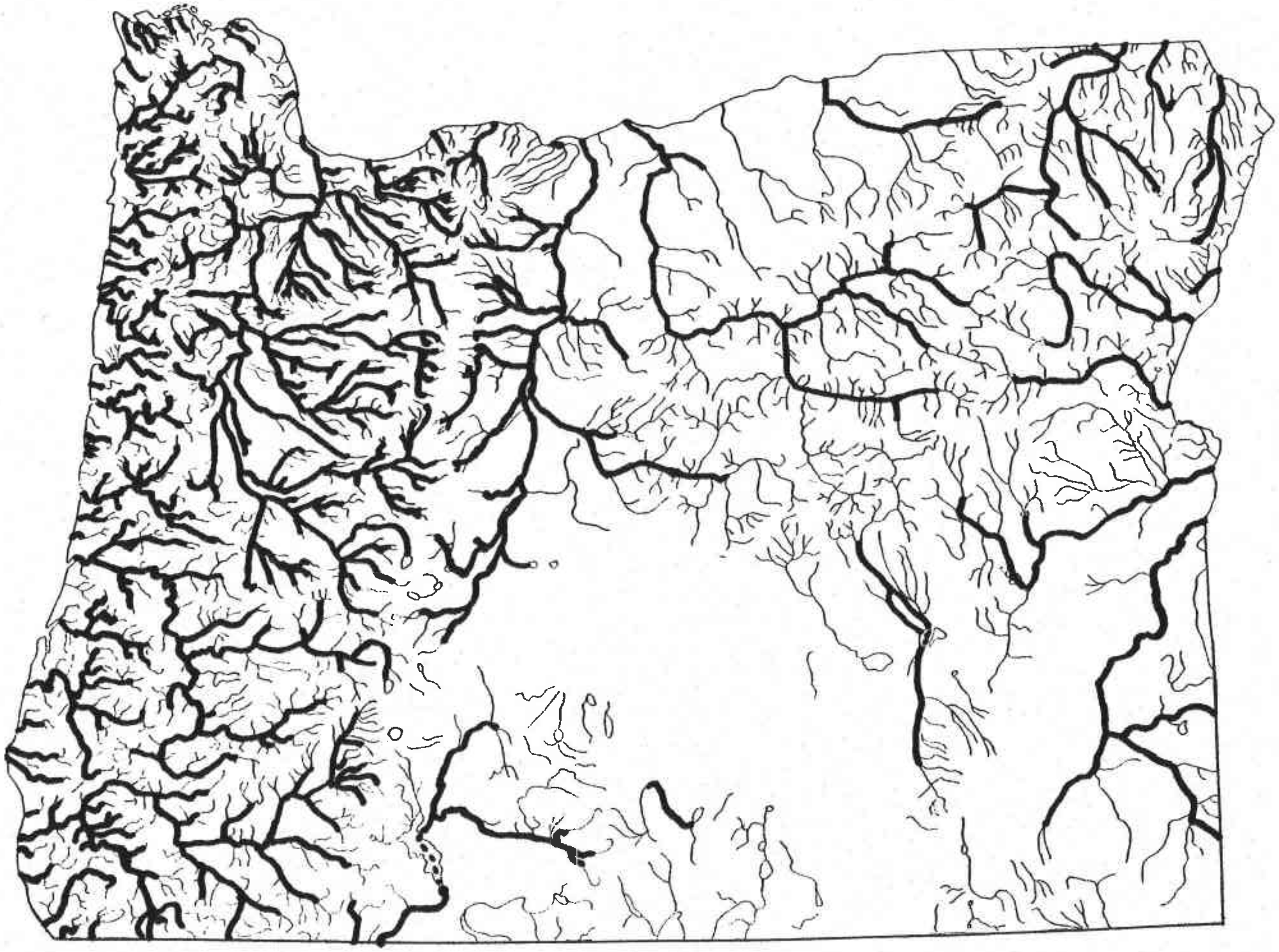


FIGURE 9. STREAM REACHES MEETING THE LOW-HEAD CRITERIA

36 cfs, about two-thirds (4820 miles) are west of the Cascade Divide. Most of the remainder drain the mountains of Northeast Oregon and the eastern flanks of the Cascades. It has been informally estimated that the combined lengths of all streams in Oregon is on the order of 110,000 miles (more than 10,000 named streams are estimated to exist in Oregon). Based upon that mileage estimate, about 7 percent of Oregon's streams have median flows equalling or exceeding 36 cfs. All of these were analyzed in this study.

## Reach Hydro Potential Characteristics

The hydro potential characteristics of all reaches analyzed are summarized on the reach sheets that appear in their appropriate appendices. Some general comments at this point regarding the reaches and their analysis will help in the interpretation of the presented data.

The most downstream reach for coastal streams entering the Pacific Ocean was designated to begin at River Mile (RM) 0.0, which often placed the beginning of the reach in a tidal zone. The corresponding downstream reach elevation was taken as 0.0 ft., mean sea level (msl). It should be recognized that the full head shown as available in many such situations probably would not actually be available, due to the wide estuarine zone and the tidal fluctuations of water level.

Not all reaches had the required minimum available head of 3 m, even though the water discharge was adequate. This situation arose due to the method used for assigning reach identification numbers. Wherever a stream was joined by a tributary that had a reach satisfying the low-head criteria of head and discharge, the junction point mandatorily marked the end point of the two contiguous reaches (one upstream and one downstream) on the larger stream. Thus, trunk streams joined by numerous large tributaries could have several consecutive reaches with heads of less than 3 m. Nevertheless, they are included as separate reaches to better assess the energy available. The alternative of combining several reaches to obtain the needed minimum head would have led to difficulties in assigning a representative discharge, because of the large incremental flows added by the tributaries along the reach. The minimum power criterion of 200 kW was also not met in some reaches due to these circumstances.

The reach numbers were not always consecutive along streams. Sometimes reach numbers were skipped to allow possible future subdivision of the initally selected reaches. Also, reach numbers were sometimes skipped to leave numbers available for designating tributaries. Occasionally gaps occurred in such sequences because reach identification numbers were assigned before the runoff analyses were made, only to later find that some of these tributaries did not meet the reach discharge criterion.

A brief examination of the reach sheets in the appendices shows that many reaches have available heads that far exceed the 3-20 m low-head range. Presumably, several low-head facilities might be considered for such reaches as an alternative to a high-head dam.

## Theoretical Developable Power and Energy

Tables V and VI show the theoretical maximum developable power and energy potential for all streams in Oregon, based on the low-head criteria of 36 cfs available at least 50 percent of the time, sufficient head to produce 200 kW, 100 percent efficiency, and run-of-river conditions at the low-head site.

Table V presents the totaled data for each of the 18 major OWRD drainage basins and for the state as a whole. This table is based upon the information presented in Table VI, where data from the individual reach characteristics sheets (see appendices) are combined by streams and totaled by drainage basin. In Tables V and VI, the power and energy categories are each subdivided according to the five exceedance percentages used for the individual reach sheets (10, 30, 50, 80, and 95 percent). Power is summarized in megawatts (MW) and energy in gigawatt-hours (GWh). (1 GW = 1,000 MW = 1,000,000 kW.)

The data reported in Tables V and VI may appear to be extremely precise -- up to seven non-zero digits reported in some instances. This gives a false impression of the accuracy of the analyses. In actuality, the basic hydrologic and topographic data available for this study limit the accuracy of findings to only two or three digits. But because of the necessity of combining very small numbers with very large numbers, excess digits from the computations were retained rather than rounded off.

The tables do not include any interstate reaches along the Columbia River that serve as common boundaries for Oregon with Washington, since this part of the Columbia is considered to be fully developed. In the

TABLE V. SUMMARY OF THEORETICAL MAXIMUM DEVELOPABLE POWER AND ENERGY POTENTIAL FOR OREGON

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| 1. North Coast | 970.24 | 377.74 | 172.67 | 37.84 | 19.97 | 2336.27 | 1798.20 | 1079.64 | 311.89 | 174.90 |
| 2. Willamette | 7036.17 | 3484.58 | 2040.66 | 781.32 | 517.59 | 24906.06 | 18785.83 | 13726.39 | 6555.69 | 4543.90 |
| 3. Sandy | 790.59 | 445.45 | 265.67 | 84.91 | 51.30 | 2970.91 | 2366.23 | 1736.28 | 707.01 | 449.42 |
| 4. Hood | 265.17 | 138.34 | 78.91 | 37.97 | 25.61 | 982.67 | 760.46 | 552.22 | 319.11 | 224.35 |
| 5. Deschutes | 1936.76 | 1283.35 | 981.49 | 713.48 | 585.16 | 9836.16 | 8691.40 | 7633.72 | 6101.70 | 5125.98 |
| 6. John Day | 1193.75 | 475.44 | 193.95 | 78.27 | 31.52 | 3537.97 | 2279.49 | 1293.12 | 634.46 | 276.13 |
| 7. Umatilla | 274.29 | 132.64 | 54.46 | 16.18 | 1.67 | 865.92 | 617.75 | 343.80 | 125.85 | 14.60 |
| 8. Grand Ronde | 1663.19 | 573.98 | 255.21 | 132.31 | 95.33 | 4843.60 | 2935.31 | 1818.32 | 1118.45 | 835.07 |
| 9. Powder | 181.65 | 64.24 | 28.09 | 10.54 | 4.94 | 518.49 | 312.79 | 186.15 | 86.19 | 43.25 |
| 10. Malheur | 62.99 | 27.84 | 13.72 | 6.37 | 3.65 | 205.76 | 144.15 | 94.75 | 52.90 | 32.01 |
| 11. Owyhee | 528.02 | 125.05 | 47.11 | 24.41 | 16.85 | 1313.91 | 607.90 | 334.83 | 205.56 | 147.59 |
| 12. Malheur Lake | 9.59 | 2.49 | 1.16 | 0.48 | 0.21 | 24.87 | 12.43 | 7.78 | 3.91 | 1.84 |
| 13. Goose&SummerL | 9.68 | 2.83 | 1.34 | 0.73 | 0.47 | 26.82 | 14.83 | 9.62 | 6.13 | 4.14 |
| 14. Klamath | 2441.81 | 1311.35 | 678.76 | 67.90 | 37.75 | 8241.56 | 6261.02 | 4051.44 | 561.84 | 330.69 |
| 15. Rogue | 2875.26 | 1462.19 | 787.13 | 281.28 | 165.05 | 10058.14 | 7582.45 | 5217.03 | 2336.73 | 1445.85 |
| 16. Umpqua | 2000.27 | 912.05 | 444.36 | 135.17 | 85.79 | 6435.89 | 4529.31 | 2890.53 | 1130.01 | 751.55 |
| 17. South Coast | 1092.38 | 373.01 | 131.01 | 20.53 | 9.81 | 2906.18 | 1645.83 | 799.01 | 168.12 | 85.96 |
| 18. Mid-Coast | 738.37 | 272.38 | 116.76 | 25.82 | 13.74 | 2092.48 | 1276.06 | 730.78 | 212.99 | 120.37 |
| State Total | 24070.18 | 11464.87 | 6292.46 | 2455.51 | 1666.41 | 82603.66 | 60621.44 | 42505.41 | 20638.54 | 14607.60 |

## TABLE VI. THEORETICAL MAXIMUM DEVELOPABLE POWER AND ENERGY POTENTIAL FOR RIVERS AND BASINS IN OREGON

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| 1. North Coast Basin | | | | | | | | | | |
| Lewis & Clark R. | 21.42 | 8.35 | 3.70 | 0.84 | 0.43 | 62.40 | 39.49 | 23.21 | 6.90 | 3.80 |
| Youngs R. | 25.85 | 10.08 | 4.45 | 1.01 | 0.52 | 75.26 | 47.62 | 27.91 | 8.33 | 4.57 |
| Big Cr. | 18.82 | 7.34 | 3.23 | 0.74 | 0.38 | 54.78 | 34.66 | 20.27 | 6.07 | 3.33 |
| Gnat Cr. | 1.58 | 0.62 | 0.27 | 0.06 | 0.03 | 4.60 | 2.91 | 1.70 | 0.51 | 0.28 |
| Clatskanie R. | 19.63 | 7.65 | 3.41 | 0.77 | 0.40 | 57.20 | 36.21 | 21.36 | 6.32 | 3.49 |
| Beaver Cr. | 9.39 | 3.66 | 1.61 | 0.37 | 0.19 | 27.32 | 17.28 | 10.08 | 3.03 | 1.66 |
| Necanicum R. | 11.08 | 4.32 | 1.94 | 0.43 | 0.23 | 32.31 | 20.46 | 12.12 | 3.57 | 1.98 |
| Elk Cr. | 2.72 | 1.06 | 0.47 | 0.11 | 0.05 | 7.91 | 5.00 | 2.92 | 0.88 | 0.48 |
| Nehalem R. | 409.83 | 159.47 | 74.14 | 15.95 | 8.51 | 1200.51 | 761.88 | 462.88 | 131.56 | 74.56 |
| Miami R. | 6.53 | 2.54 | 1.12 | 0.26 | 0.13 | 18.99 | 12.01 | 7.01 | 2.11 | 1.15 |
| Kilchis R. | 27.86 | 10.86 | 4.83 | 1.09 | 0.57 | 81.20 | 51.40 | 30.29 | 8.98 | 4.95 |
| Wilson R. | 149.15 | 58.07 | 26.52 | 5.82 | 3.07 | 435.96 | 276.38 | 165.82 | 47.95 | 26.87 |
| Trask R. | 124.92 | 48.64 | 22.10 | 4.88 | 2.56 | 364.89 | 231.26 | 138.25 | 40.17 | 22.44 |
| Tillamook R. | 5.06 | 1.97 | 0.87 | 0.20 | 0.10 | 14.74 | 9.33 | 5.47 | 1.63 | 0.90 |
| Nestucca R. | 116.11 | 45.21 | 20.51 | 4.53 | 2.38 | 339.10 | 214.89 | 128.33 | 37.35 | 20.84 |
| Little Nestucca R. | 18.19 | 7.09 | 3.15 | 0.71 | 0.37 | 53.00 | 33.55 | 19.77 | 5.86 | 3.23 |
| Neskowin R. | 2.10 | 0.82 | 0.36 | 0.08 | 0.04 | 6.11 | 3.86 | 2.24 | 0.68 | 0.37 |
| Basin Total | 970.24 | 377.74 | 172.67 | 37.84 | 19.97 | 2836.27 | 1798.20 | 1079.64 | 311.89 | 174.90 |

TABLE VI. Continued

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| 2A. Upper Willamette Basin | | | | | | | | | | |
| Willamette R. Main Stem | 356.48 | 178.09 | 106.65 | 43.32 | 27.49 | 1285.63 | 973.09 | 722.75 | 362.18 | 240.83 |
| Long Tom R. | 24.12 | 10.44 | 4.86 | 1.43 | 0.82 | 74.91 | 50.96 | 31.38 | 11.90 | 7.22 |
| McKenzie R. | 1177.11 | 679.53 | 454.82 | 215.69 | 159.32 | 4848.49 | 3976.70 | 3189.32 | 1827.73 | 1395.67 |
| Coast Fork Willamette R. | 155.54 | 67.56 | 31.74 | 9.92 | 5.67 | 486.13 | 331.98 | 206.46 | 82.22 | 49.67 |
| Middle Fork Willamette R. | 876.26 | 386.62 | 187.10 | 64.06 | 36.39 | 2788.44 | 1930.57 | 1231.49 | 630.91 | 318.69 |
| Sub-Basin Total | 2589.52 | 1322.24 | 785.16 | 344.42 | 229.69 | 9483.60 | 7263.30 | 5381.40 | 2814.94 | 2012.07 |
| 2B. Mid-Willamette Basin | | | | | | | | | | |
| Willamette R. Main Stem | 664.29 | 311.99 | 193.77 | 82.67 | 54.46 | 2357.37 | 1740.14 | 1325.88 | 693.27 | 477.03 |
| Molalla R. | 438.89 | 203.72 | 109.98 | 25.90 | 12.43 | 1431.37 | 1019.34 | 690.90 | 212.17 | 108.86 |
| Yamhill R. | 133.81 | 48.63 | 18.61 | 2.89 | 1.29 | 367.50 | 218.26 | 113.06 | 23.59 | 11.27 |
| Rickreall Cr. | 16.26 | 6.11 | 2.25 | 0.34 | 0.15 | 44.94 | 27.16 | 13.66 | 2.74 | 1.28 |
| Luckiamute R. | 39.33 | 14.60 | 5.46 | 0.83 | 0.36 | 108.45 | 65.13 | 33.10 | 6.73 | 3.16 |
| Santiam R. Main Stem | 70.38 | 35.80 | 20.91 | 5.98 | 3.06 | 246.95 | 186.37 | 134.22 | 49.18 | 26.80 |

TABLE VI. Continued

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| North Santiam R. | 909.62 | 435.48 | 241.44 | 60.85 | 29.87 | 3035.91 | 2207.38 | 1527.41 | 499.23 | 271.80 |
| South Santiam R. | 750.77 | 352.83 | 192.43 | 46.60 | 22.57 | 2371.49 | 1774.31 | 1212.30 | 381.80 | 197.67 |
| Calapooia R. | 120.37 | 56.21 | 30.47 | 7.24 | 3.48 | 394.17 | 281.77 | 191.57 | 59.29 | 30.49 |
| Mary's R. | 42.46 | 15.51 | 5.90 | 0.91 | 0.40 | 116.74 | 69.52 | 35.84 | 7.42 | 3.53 |
| Rest of Basin | 29.48 | 13.47 | 7.16 | 1.62 | 0.77 | 94.98 | 66.92 | 44.82 | 13.28 | 6.73 |
| Sub-Basin Total | 3215.66 | 1494.35 | 828.38 | 235.83 | 128.86 | 10569.87 | 7656.30 | 5322.76 | 1948.70 | 1138.62 |
| 2C. Lower Willamette Basin | | | | | | | | | | |
| Scappoose Cr. | 2.55 | 0.99 | 0.37 | 0.07 | 0.03 | 7.18 | 4.46 | 2.27 | 0.58 | 0.25 |
| Willamette R. Main Stem | 284.66 | 128.75 | 81.76 | 35.94 | 24.21 | 1000.70 | 727.53 | 562.91 | 301.96 | 212.10 |
| Johnson Cr. | 0.89 | 0.41 | 0.19 | 0.05 | 0.03 | 2.84 | 2.01 | 1.23 | 0.44 | 0.28 |
| Clackamas R. | 872.44 | 511.25 | 335.82 | 173.31 | 134.24 | 3648.26 | 3015.47 | 2400.74 | 1475.43 | 1175.94 |
| Tualatin R. | 70.45 | 26.59 | 8.98 | 1.70 | 0.53 | 193.61 | 116.76 | 55.08 | 13.64 | 4.64 |
| Sub-Basin Total | 1230.99 | 667.99 | 427.12 | 211.07 | 159.04 | 4852.59 | 3866.23 | 3022.23 | 1792.05 | 1393.21 |
| Basin Total (Upper, Middle & Lower Basins) | 7036.17 | 3484.58 | 2040.66 | 781.32 | 517.59 | 24906.06 | 18785.83 | 13726.39 | 6555.69 | 4543.90 |

TABLE VI. Continued

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| 3. Sandy Basin | | | | | | | | | | |
| Sandy R. Main Stem | 369.13 | 201.76 | 114.59 | 29.73 | 17.15 | 1328.52 | 1035.28 | 729.85 | 246.67 | 150.24 |
| Tributaries | 421.46 | 243.70 | 151.09 | 55.18 | 34.15 | 1642.39 | 1330.95 | 1006.44 | 460.34 | 299.18 |
| Basin Total | 790.59 | 445.45 | 265.67 | 84.91 | 51.30 | 2970.91 | 2366.23 | 1736.28 | 707.01 | 449.42 |
| 4. Hood Basin | | | | | | | | | | |
| Eagle Cr. | 14.93 | 7.00 | 3.68 | 1.81 | 1.24 | 51.41 | 37.52 | 25.90 | 15.25 | 10.83 |
| Hood R. | 243.20 | 127.84 | 73.30 | 35.22 | 23.74 | 906.01 | 703.90 | 512.81 | 295.99 | 207.96 |
| Fifteenmile Cr. | 7.04 | 3.51 | 1.93 | 0.94 | 0.63 | 25.24 | 19.04 | 13.51 | 7.87 | 5.56 |
| Basin Total | 265.17 | 138.34 | 78.91 | 37.97 | 25.61 | 982.67 | 760.46 | 552.22 | 319.11 | 224.35 |
| 5. Deschutes Basin | | | | | | | | | | |
| Deschutes R. Main Stem | 1080.58 | 812.88 | 658.44 | 487.29 | 403.88 | 6162.02 | 5693.01 | 5151.86 | 4177.32 | 3538.02 |
| White R. | 82.91 | 45.75 | 28.10 | 17.36 | 13.58 | 336.04 | 270.93 | 209.08 | 147.90 | 118.93 |
| Wapinitia Cr. | 7.81 | 3.92 | 2.39 | 1.49 | 1.16 | 30.00 | 23.19 | 17.82 | 12.66 | 10.20 |
| Warm Springs R. | 131.51 | 73.88 | 45.44 | 28.04 | 21.92 | 538.62 | 437.64 | 337.99 | 238.90 | 192.04 |
| Trout Cr. | 36.98 | 19.73 | 12.09 | 7.48 | 5.86 | 147.00 | 116.78 | 89.99 | 63.75 | 51.30 |
| Shitike Cr. | 32.79 | 16.76 | 10.23 | 6.35 | 4.97 | 127.19 | 99.11 | 76.24 | 54.10 | 43.57 |

TABLE VI. Continued

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| Metolius R. | 137.51 | 111.00 | 98.98 | 82.74 | 73.64 | 895.87 | 849.43 | 807.33 | 714.83 | 645.05 |
| Crooked R. | 147.35 | 41.87 | 19.91 | 3.74 | 0.58 | 383.13 | 198.32 | 121.39 | 29.29 | 5.08 |
| Squaw Cr. | 185.47 | 102.42 | 67.97 | 51.22 | 39.79 | 797.76 | 652.27 | 531.55 | 436.12 | 348.57 |
| Tumalo Cr. | 75.37 | 41.62 | 27.62 | 20.81 | 16.17 | 324.18 | 265.05 | 216.00 | 177.22 | 141.64 |
| Little Deshutes R. | 15.56 | 11.38 | 8.69 | 5.03 | 3.05 | 79.50 | 72.19 | 62.77 | 41.90 | 26.70 |
| Fall R.& Cultus R. | 2.92 | 2.14 | 1.63 | 0.93 | 0.56 | 14.85 | 13.48 | 11.70 | 7.71 | 4.88 |
| Basin Total | 1936.76 | 1283.35 | 981.49 | 713.48 | 585.16 | 9836.16 | 8691.40 | 7633.72 | 6101.70 | 5125.98 |
| 6. John Day Basin | | | | | | | | | | |
| John Day R. Main Stem | 883.64 | 370.29 | 154.72 | 66.13 | 27.50 | 2696.18 | 1796.79 | 1041.40 | 537.00 | 240.91 |
| Rock Cr. | 25.40 | 7.72 | 2.70 | 0.68 | 0.19 | 65.49 | 34.51 | 16.94 | 5.45 | 1.69 |
| N. Fk.John Day R. (except Middle Fk.) | 201.76 | 71.23 | 27.15 | 8.92 | 3.08 | 558.67 | 329.98 | 175.54 | 71.74 | 26.95 |
| Middle Fk. John Day R. | 62.45 | 20.01 | 7.21 | 1.99 | 0.60 | 164.84 | 90.47 | 45.65 | 15.91 | 5.24 |
| South Fk. John Day R. | 20.50 | 6.20 | 2.17 | 0.55 | 0.15 | 52.78 | 27.73 | 13.59 | 4.35 | 1.34 |
| Basin Total | 1193.75 | 475.44 | 193.95 | 78.27 | 31.52 | 3537.97 | 2279.49 | 1293.12 | 634.46 | 276.13 |
| 7. Umatilla Basin | | | | | | | | | | |
| Umatilla R. | 274.29 | 132.64 | 54.46 | 16.18 | 1.67 | 865.92 | 617.75 | 343.80 | 125.85 | 14.60 |

TABLE VI. Continued

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| 8. Grande Ronde Basin | | | | | | | | | | |
| Grande Ronde R. Main Stem | 549.80 | 240.50 | 102.57 | 47.44 | 33.24 | 1739.14 | 1197.26 | 713.94 | 400.06 | 291.22 |
| Joseph Creek | 104.18 | 30.56 | 14.06 | 7.74 | 5.25 | 287.86 | 158.88 | 101.06 | 65.04 | 45.95 |
| Wenaha R. | 125.10 | 37.38 | 17.12 | 9.51 | 6.89 | 348.45 | 194.76 | 123.77 | 80.40 | 60.32 |
| Wallowa R. (except Minam R.) | 215.95 | 65.68 | 29.95 | 16.78 | 12.96 | 606.27 | 343.00 | 217.79 | 142.79 | 113.51 |
| Minam R. | 191.41 | 56.99 | 26.12 | 14.48 | 10.34 | 532.26 | 296.75 | 188.61 | 122.29 | 90.59 |
| Other Tribs. of Grande Ronde R. | 21.37 | 6.25 | 2.88 | 1.58 | 1.06 | 58.97 | 32.48 | 20.66 | 13.28 | 9.28 |
| Imnaha R. | 455.38 | 136.62 | 62.51 | 34.78 | 25.59 | 1270.65 | 712.18 | 452.49 | 294.59 | 224.20 |
| Basin Total | 1663.19 | 573.98 | 255.21 | 132.31 | 95.33 | 4843.6 | 2935.31 | 1818.32 | 1118.45 | 835.07 |
| 9. Powder Basin | | | | | | | | | | |
| Pine Creek | 18.12 | 6.78 | 3.09 | 1.12 | 0.51 | 53.15 | 33.28 | 20.35 | 9.15 | 4.46 |
| Powder R. (except Eagle Cr.) | 76.37 | 26.06 | 11.09 | 4.25 | 2.03 | 214.34 | 126.20 | 73.77 | 34.82 | 17.81 |
| Eagle Cr. | 28.83 | 10.85 | 4.96 | 1.80 | 0.81 | 84.82 | 53.33 | 32.70 | 14.66 | 7.12 |
| Burnt R. | 58.33 | 20.55 | 8.95 | 3.37 | 1.58 | 166.17 | 99.98 | 59.33 | 27.56 | 13.86 |
| Basin Total | 181.65 | 64.24 | 28.09 | 10.54 | 4.94 | 518.49 | 312.79 | 186.15 | 86.19 | 43.25 |

TABLE VI. Continued

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| 10. Malheur Basin | | | | | | | | | | |
| Malheur R. Main Stem below Warm Springs Dam | 30.56 | 17.47 | 8.47 | 3.80 | 1.94 | 112.31 | 89.37 | 57.87 | 31.29 | 17.02 |
| N. Fk. Malheur R. | 14.38 | 5.35 | 2.87 | 2.02 | 1.62 | 46.62 | 30.78 | 22.12 | 17.27 | 14.17 |
| Malheur R. above Warm Springs Reservoir | 18.05 | 5.02 | 2.38 | 0.55 | 0.09 | 46.83 | 24.00 | 14.76 | 4.34 | 0.82 |
| Basin Total | 62.99 | 27.84 | 13.72 | 6.37 | 3.65 | 205.76 | 144.15 | 94.75 | 52.90 | 32.01 |
| 11. Owyhee Basin | | | | | | | | | | |
| Owyhee R. below Owyhee Dam | 62.63 | 14.63 | 6.03 | 3.39 | 2.35 | 157.81 | 73.72 | 43.60 | 28.55 | 20.56 |
| Owyhee R. Main Stem above Owyhee Reservoir | 359.70 | 84.23 | 34.58 | 19.47 | 13.48 | 906.63 | 424.00 | 250.01 | 164.00 | 118.08 |
| Crooked Cr. | 20.25 | 4.84 | 1.24 | 0.41 | 0.30 | 47.82 | 20.82 | 8.23 | 3.51 | 2.66 |
| Jordon Cr. | 85.44 | 21.35 | 5.26 | 1.14 | 0.72 | 201.65 | 89.36 | 32.99 | 9.50 | 6.29 |
| Basin Total | 528.02 | 125.05 | 47.11 | 24.41 | 16.85 | 1313.91 | 607.90 | 334.83 | 205.56 | 147.59 |

TABLE VI. Continued

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| 12. Malheur Lake Basin | | | | | | | | | | |
| Silvies R. | 6.47 | 1.54 | 0.67 | 0.24 | 0.10 | 16.09 | 7.46 | 4.41 | 1.97 | 0.84 |
| Donner & Blitzen R. | 3.12 | 0.94 | 0.49 | 0.24 | 0.11 | 8.78 | 4.97 | 3.38 | 1.94 | 1.00 |
| Basin Total | 9.59 | 2.49 | 1.16 | 0.48 | 0.21 | 24.87 | 12.43 | 7.78 | 3.91 | 1.83 |
| 13. Goose & Summer Lakes Basin | | | | | | | | | | |
| Chewaucan R. | 9.68 | 2.83 | 1.34 | 0.73 | 0.47 | 26.82 | 14.83 | 9.62 | 6.13 | 4.14 |
| 14. Klamath Basin | | | | | | | | | | |
| Jenny Cr. | 21.79 | 18.67 | 14.01 | 4.09 | 0.12 | 109.75 | 104.30 | 87.94 | 31.50 | 1.02 |
| Klamath R. | 194.67 | 108.15 | 69.22 | 49.75 | 34.61 | 818.09 | 666.51 | 530.08 | 419.23 | 303.17 |
| Williamson R. Main Stem | 2210.35 | 1176.20 | 590.20 | 10.23 | 0.35 | 7250.69 | 5438.86 | 3392.58 | 78.81 | 3.14 |
| Sprague R. | 15.00 | 8.33 | 5.33 | 3.83 | 2.67 | 63.03 | 51.35 | 40.84 | 32.30 | 23.36 |
| Basin Total | 2441.81 | 1311.35 | 678.76 | 67.90 | 37.75 | 8241.56 | 6261.02 | 4051.44 | 561.84 | 330.69 |
| 15. Rogue Basin | | | | | | | | | | |
| Illinois R. | 642.44 | 320.65 | 167.90 | 59.00 | 32.56 | 2206.98 | 1643.21 | 1107.95 | 487.92 | 285.19 |
| Applegate R. | 158.16 | 78.93 | 41.28 | 14.49 | 7.94 | 543.05 | 404.24 | 272.32 | 119.77 | 69.55 |

TABLE VI. Continued

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| Bear Cr. | 28.86 | 13.96 | 6.97 | 2.38 | 1.18 | 96.29 | 70.17 | 45.70 | 19.56 | 10.37 |
| S. Fk. Rogue R. | 176.51 | 85.11 | 42.36 | 14.44 | 7.13 | 587.41 | 427.27 | 277.46 | 118.50 | 62.46 |
| Rogue R. Main Stem & all tribs. not listed above | 1869.28 | 963.54 | 528.62 | 190.96 | 116.24 | 6624.42 | 5037.56 | 3513.60 | 1590.99 | 1018.29 |
| Basin Total | 2875.26 | 1462.19 | 787.13 | 281.28 | 165.05 | 10058.14 | 7582.45 | 5217.03 | 2336.73 | 1445.85 |
| 16. Umpqua Basin | | | | | | | | | | |
| Smith R. | 47.35 | 19.49 | 7.76 | 1.45 | 0.73 | 137.75 | 88.94 | 47.85 | 11.91 | 6.35 |
| North Umpqua R. | 884.02 | 390.16 | 177.63 | 45.19 | 26.16 | 2739.08 | 1873.84 | 1129.12 | 374.99 | 229.13 |
| South Umpqua R. | 472.14 | 207.51 | 93.85 | 23.66 | 13.68 | 1457.89 | 994.25 | 596.01 | 196.36 | 119.80 |
| Umpqua R. Main Stem & local tribs. | 596.76 | 294.89 | 165.11 | 64.87 | 45.24 | 2101.17 | 1572.28 | 1117.54 | 546.75 | 396.27 |
| Basin Total | 2000.27 | 912.05 | 444.36 | 135.17 | 85.79 | 6435.89 | 4529.31 | 2890.53 | 1130.01 | 751.55 |
| 17. South Coast Basin | | | | | | | | | | |
| Coos R. | 182.37 | 63.58 | 22.29 | 3.31 | 1.46 | 487.83 | 279.72 | 135.03 | 26.97 | 12.80 |
| Coquille R. | 371.85 | 129.22 | 45.48 | 6.87 | 3.09 | 994.42 | 569.34 | 275.91 | 56.07 | 27.11 |
| Floras Cr. | 24.55 | 8.7 | 2.99 | 0.40 | 0.16 | 65.76 | 38.00 | 17.98 | 3.25 | 1.38 |
| Sixes R. | 29.46 | 10.30 | 3.60 | 0.52 | 0.22 | 78.81 | 45.25 | 21.76 | 4.24 | 1.95 |

TABLE VI. Continued

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| Elk Cr. | 50.11 | 17.63 | 6.11 | 0.86 | 0.35 | 134.13 | 77.24 | 36.86 | 6.94 | 3.08 |
| Euchre Cr. | 2.95 | 1.07 | 0.36 | 0.04 | 0.02 | 7.92 | 4.62 | 2.14 | 0.35 | 0.13 |
| Hunter Cr. | 3.94 | 1.30 | 0.46 | 0.08 | 0.04 | 10.38 | 5.77 | 2.82 | 0.64 | 0.36 |
| Pistol R. | 62.36 | 20.61 | 7.31 | 1.23 | 0.65 | 164.53 | 91.38 | 44.75 | 10.17 | 5.71 |
| Chetco R. | 311.47 | 102.95 | 36.49 | 6.16 | 3.26 | 821.69 | 456.37 | 223.48 | 50.79 | 28.54 |
| Winchuck R. | 21.09 | 6.97 | 2.47 | 0.42 | 0.22 | 55.63 | 30.90 | 15.13 | 3.44 | 1.93 |
| N. Fk. Smith R. | 32.25 | 10.66 | 3.78 | 0.64 | 0.34 | 85.08 | 47.25 | 23.14 | 5.26 | 2.96 |
| Basin Total | 1092.38 | 373.01 | 131.01 | 20.53 | 9.81 | 2906.18 | 1645.83 | 799.01 | 168.12 | 85.96 |
| <u>18. Mid-Coast Basin</u> | | | | | | | | | | |
| Salmon R. | 27.84 | 10.43 | 4.57 | 1.03 | 0.54 | 79.68 | 49.18 | 28.63 | 8.51 | 4.74 |
| Schooner Cr. | 3.09 | 1.17 | 0.52 | 0.12 | 0.06 | 8.93 | 5.57 | 3.29 | 1.00 | 0.55 |
| Drift Cr. | 19.86 | 7.44 | 3.26 | 0.74 | 0.39 | 56.84 | 35.07 | 20.41 | 6.06 | 3.38 |
| Siletz R. | 219.53 | 80.55 | 34.27 | 7.52 | 4.02 | 620.03 | 376.55 | 214.39 | 62.05 | 35.25 |
| Yaquina R. | 29.99 | 11.16 | 4.84 | 1.08 | 0.57 | 85.46 | 52.48 | 30.34 | 8.94 | 5.01 |
| Beaver Cr. | 2.22 | 0.84 | 0.37 | 0.09 | 0.04 | 6.41 | 3.99 | 2.34 | 0.71 | 0.39 |
| Alsea R. | 174.42 | 64.48 | 27.72 | 6.15 | 3.26 | 494.94 | 302.32 | 173.52 | 50.71 | 28.60 |
| Yachats R. | 8.16 | 3.07 | 1.35 | 0.31 | 0.16 | 23.43 | 14.51 | 8.49 | 2.54 | 1.41 |
| Tenmile Cr. | 8.41 | 3.18 | 1.41 | 0.32 | 0.17 | 24.24 | 15.08 | 8.87 | 2.67 | 1.47 |

TABLE VI. Continued

| AREA OF INTEREST | POWER (MW) | | | | | ENERGY (GWh) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $P_{10}$ | $P_{30}$ | $P_{50}$ | $P_{80}$ | $P_{95}$ | $E_{10}$ | $E_{30}$ | $E_{50}$ | $E_{80}$ | $E_{95}$ |
| Big Cr. | 2.53 | 0.96 | 0.43 | 0.10 | 0.05 | 7.30 | 4.56 | 2.70 | 0.82 | 0.45 |
| Siuslaw R. | 236.07 | 86.72 | 36.96 | 8.13 | 4.34 | 667.25 | 405.59 | 231.24 | 67.04 | 38.04 |
| Siltcoos R. | 3.96 | 1.50 | 0.66 | 0.15 | 0.08 | 11.39 | 7.08 | 4.16 | 1.25 | 0.69 |
| Tahkenitch Cr. | 2.30 | 0.86 | 0.38 | 0.09 | 0.05 | 6.59 | 4.08 | 2.38 | 0.71 | 0.39 |
| Basin Total | 738.37 | 272.38 | 116.76 | 25.82 | 13.74 | 2092.48 | 1276.06 | 730.78 | 212.99 | 120.37 |
| Snake River in Oregon and one-half of Snake River reaches on Oregon-Idaho border | 953.62 | 640.15 | 494.09 | 356.88 | 287.76 | 4879.22 | 4330.01 | 3818.24 | 3037.02 | 2507.14 |

regional study, the interstate Snake River reaches were analyzed and included in the regional totals for power and energy. Those applicable to Oregon are shown in Table VI for reference, but are not shown in Table V.

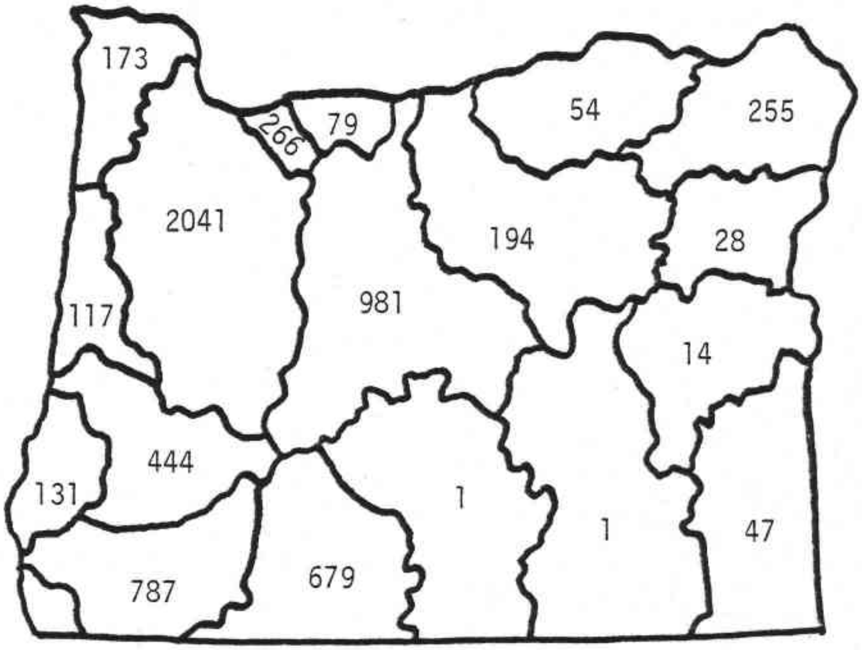
The large quantity of information contained in Tables V and VI can be summarized in many different ways. A few of these are presented in the following discussion. However, the greater task of detailed comparison is left to the reader.

A general idea of the theoretical power and energy potential of streamflow may be had by examining the power and energy available 50 percent of the time, representing median flow conditions. For Oregon as a whole, this amounts to 6,292 MW and 42,505 GWh, respectively, as shown in Table V. Figure 10 shows the distribution, among drainage basins, of power and energy available 50 percent of the time. Among the 18 OWRD drainage basins, this varies from 1 MW and 8-to-10 GWh for the two closed basins in southeastern Oregon (Basins 12 and 13) to 2,041 MW and 13,726 GWh for the Willamette Basin.

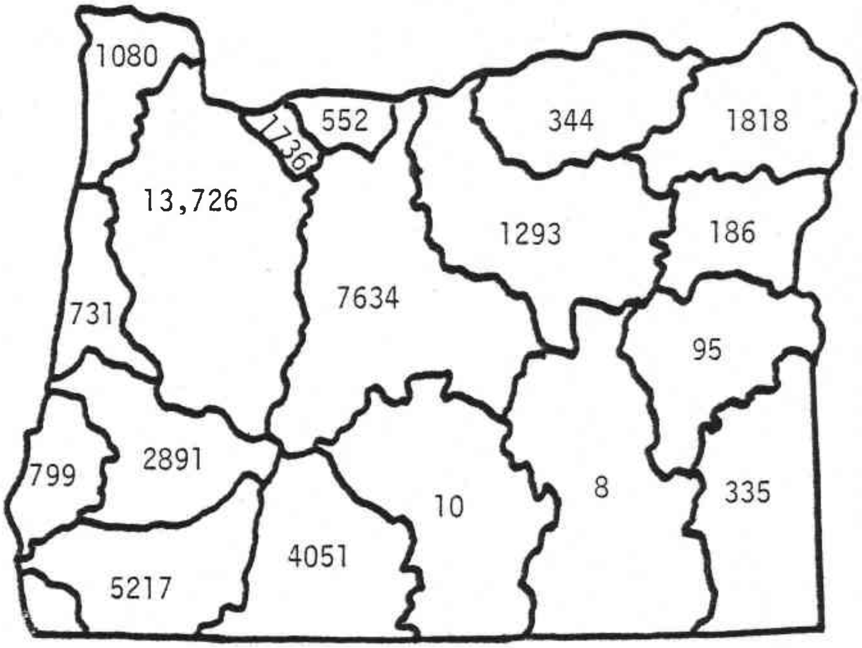
The distribution of power and energy around the state can also be noted by combining data from basins in particular geographical locations. Again using that theoretical power available 50 percent of the time, Figure 11 shows two such geographical groupings. Figure 11A shows seven geographical areas: north-central coastal, south coastal, Willamette-Sandy, north central, south central, north eastern, and south eastern. Figure 11B shows two major groupings: one west of and one east of the Cascade Mountain Range crest and its southward extension.

Figure 10 and 11 demonstrate the great significance of heavy precipitation and topography associated with the Cascade Range and the Coast Range. These influence streamflow and water power on the eastern slopes of the Cascade Range as well as for Western Oregon. The mountains of Northeastern Oregon have a similar effect, but in a region with less precipitation.

A more complete impression of the theoretical power and energy potential of streamflow may be had from Figures 12 and 13, respectively. These incorporate other exceedance levels of streamflow to show the influence of time. The long records analyzed assure that significant wet and dry periods are included in the record. From Figures 12 and 13 it is evident that

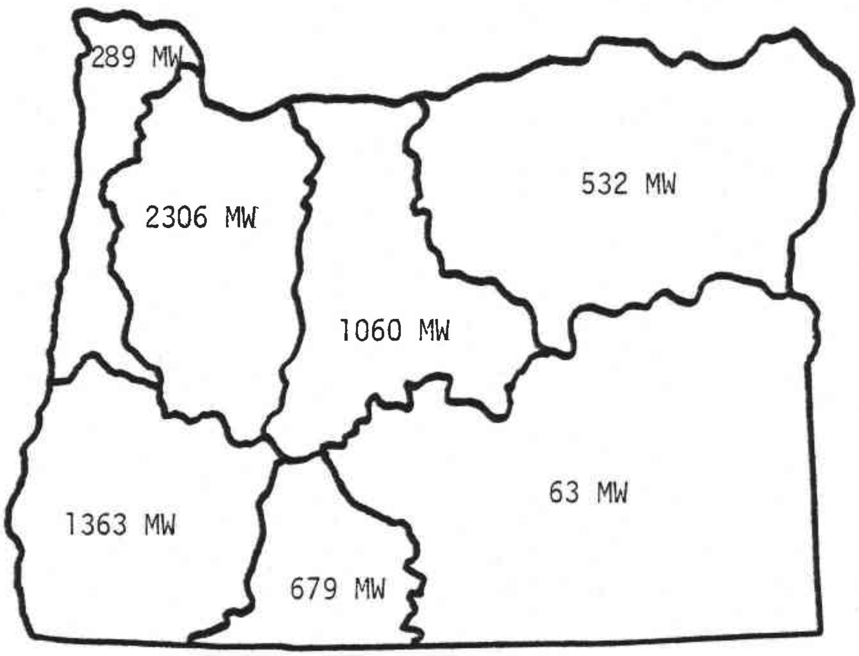


10A. POWER, MW

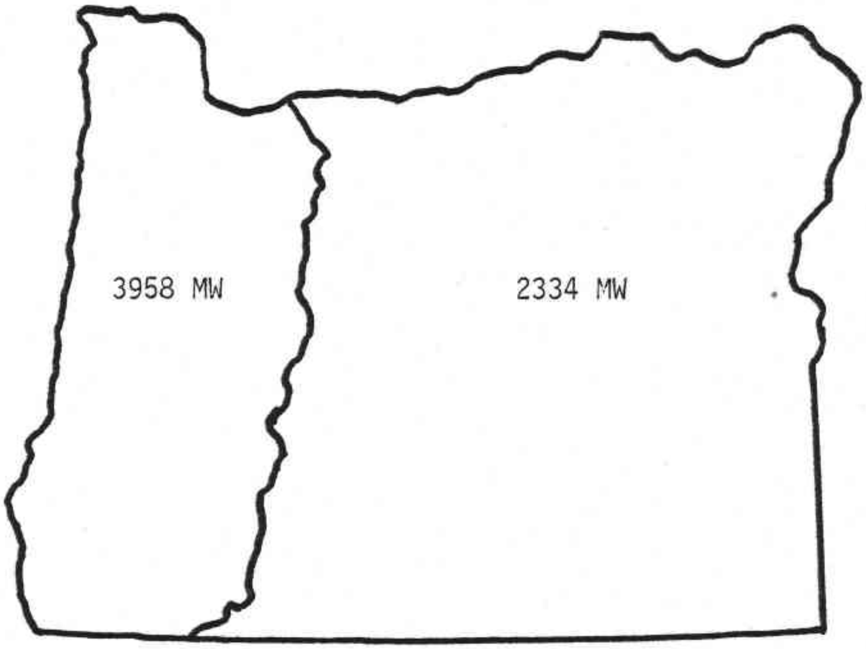


10B. ENERGY, GWh

FIGURE 10. THEORETICAL POWER AND ENERGY AVAILABLE FROM STREAMFLOW 50 PERCENT OF THE TIME



11A. BASED ON SEVEN GEOGRAPHIC ZONES.



11B. BASED ON THE CASCADE CREST.

FIGURE 11. GEOGRAPHICAL DISTRIBUTION OF THEORETICAL POWER AVAILABLE 50 PERCENT OF THE TIME

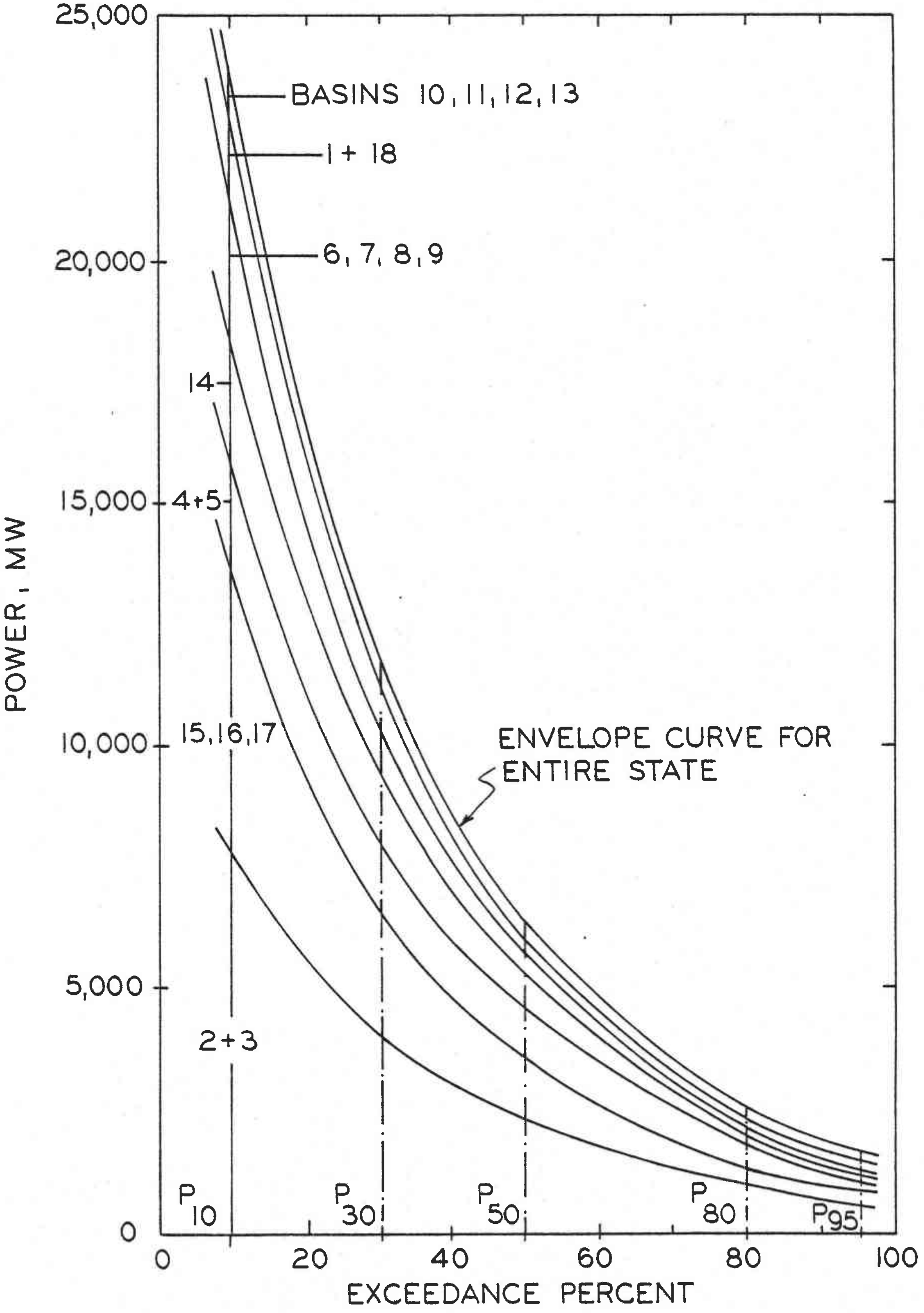


FIGURE 12. THEORETICAL POWER AVAILABLE FROM STREAMFLOW, BASED ON LOW-HEAD CRITERIA

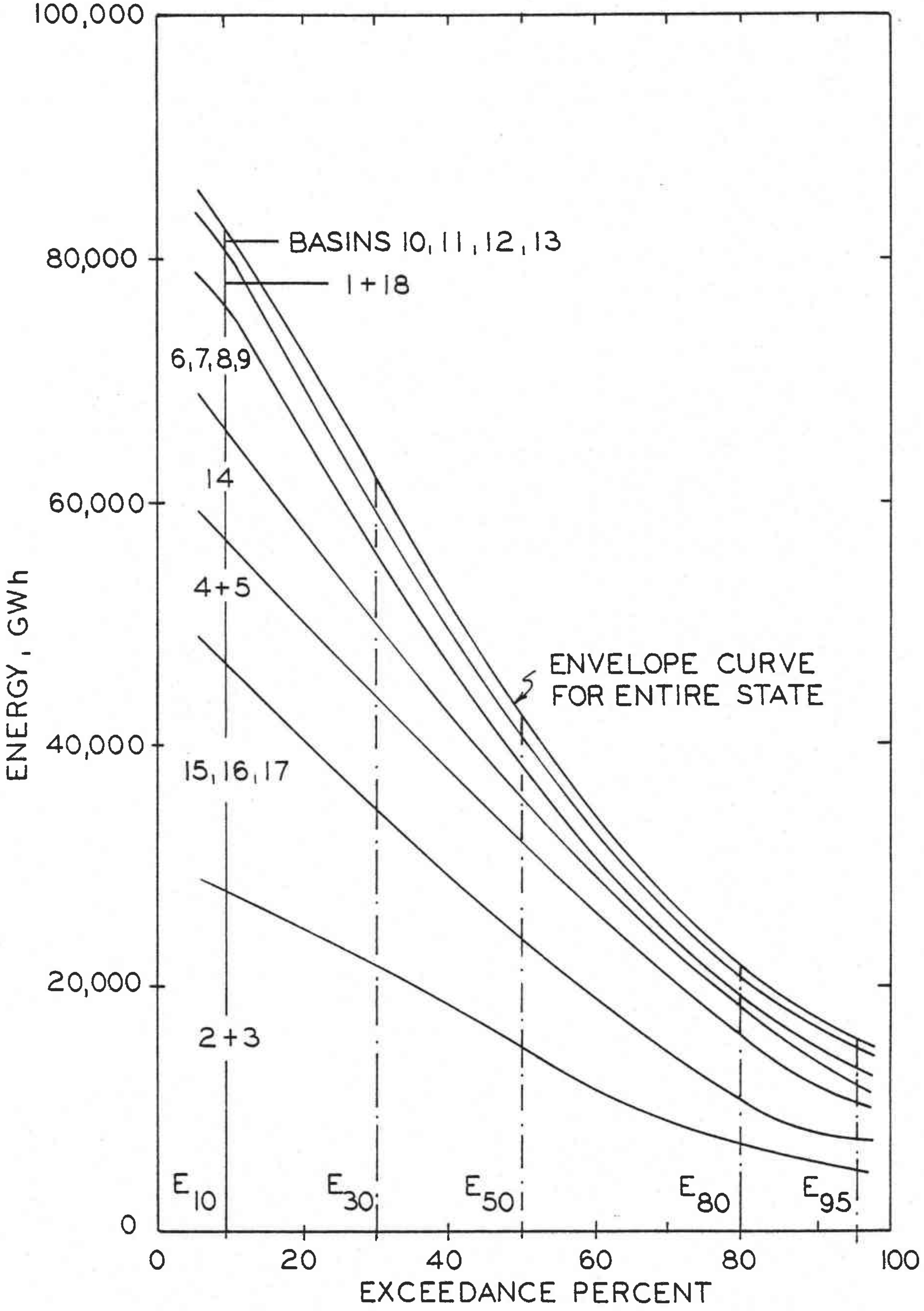


FIGURE 13. THEORETICAL ENERGY AVAILABLE FROM STREAMFLOW, BASED ON LOW-HEAD CRITERIA

during short periods a great deal of power and energy can be produced from reaches in individual basins and from the state as a whole, but that the "firm" power and energy available all of the time is, relatively, much less. The power and energy productivities of various geographical regions in Oregon are also indicated.

Examination of Table VI reveals that some streams far exceed others in terms of power and energy available from streamflow. Thus, the Nehalem stands out as one of the largest energy producers flowing west from the Coastal Range. But it is far smaller than the Rogue and Umpqua Rivers, which flow west from basins that breach the Coastal Range from interior drainage areas. In the Willamette Basin, the energy-producing dominance of the McKenzie, Santiam and Clackamas Rivers is evident, as is the relatively minor role of west-side streams (from the Coastal Range) compared to east-side streams (from the Cascade Range). In the Deschutes Basin, streams draining the eastern flanks of the Cascades account for much of the power produced, as does the Deschutes River main stem on its northward course to the Columbia. The John Day main stem, in its long journey through canyons to the Columbia, likewise accounts for a substantial amount of power and energy, a situation repeated on a smaller scale by the Grande Ronde River main stem. Elsewhere in the state, the Williamson River main stem and the Klamath River are quite noteworthy in terms of power and energy available.

## Regional Comparison

It is a matter of curiosity and interest to see how Oregon compares with its regional neighbors with respect to developable river energy and low-head hydroelectric power potential. Based upon data presented in the regional study, such a comparison is made in Table VII.

The data in Table VII show that Washington streams possess the greatest developable stream power and energy potential in the region. But Oregon streams follow close behind, with about one-fourth of the total developable stream power and energy potential in the region. Again, it should be borne in mind that these numbers do not represent the total river power and energy in each state, but only that in presently undeveloped reaches where sufficient flow, head and power are available to satisfy the low-head criteria.

TABLE VII. SUMMARY OF THEORETICAL MAXIMUM DEVELOPABLE POWER AND ENERGY POTENTIAL FOR PACIFIC NORTHWEST STREAMS

| State | Power (MW) | | Energy (GWh) | |
|---|---|---|---|---|
| | $P_{30}$ | $P_{50}$ | $E_{30}$ | $E_{50}$ |
| Washington[1] | 13,928 | 8,641 | 80,125 | 61,584 |
| Oregon[1] | 12,105 | 6,787 | 64,951 | 46,324 |
| Idaho[1] | 9,147 | 5,443 | 53,365 | 38,338 |
| Montana in Columbia Basin | 3,576 | 2,044 | 19,848 | 14,689 |
| Wyoming in Columbia Basin | 620 | 295 | 3,345 | 2,205 |
| Nevada in Columbia Basin | 15 | 8 | 76 | 53 |
| Total | 39,391 | 23,218 | 221,710 | 163,193 |
| Portion of Regional Potential in Oregon | 0.31 | 0.29 | 0.29 | 0.28 |

[1] State totals adjusted to equally share power and energy totals for common-boundary reaches of Columbia and Snake Rivers.

# V. FINDINGS FROM PRELIMINARY FEASIBILITY ANALYSES

## Feasibility Characteristics

The feasibility analysis sheets for all reaches are presented in the appendices, organized by drainage basin as already discussed. To facilitate their review, Table VIII has been prepared to show the types and numbers of restraints and constraints identified for reaches during the preliminary feasibility assessment. The reader is reminded that although the latest available published material was used, some is now several years old and, hence, somewhat out-of-date.

The restrictions due to existing land use were based primarily on federal usage and jurisdiction. A review of all reaches was made for known archaeological sites. Special state and local restrictions, such as zoning or the Willamette Greenway program were considered but not used for exclusion purposes, because these were under state or local control. It was found that 11 percent of the reaches analyzed had some form of land use restraint in one or more of the classification categories. The restraint appeared to be most prevalent for reaches in northcentral and southwestern parts of the state. The northeastern portion also had a high relative proportion of its reaches restrained in this manner, although the absolute number was small.

The displacement of existing mapped utilities was found to be a restraint for more than one-third of the reaches. This restraint was common to most parts of the state. However, some basins showed interesting departures from the pattern. Thus, in terms of percent of reaches affected, the restraint occurred least often in the Owyhee Basin (0 percent) and most often in the Umatilla Basin (86 percent).

Displacement of mapped residential and commercial buildings was also found to be a restraint for about one-third of the 1443 reaches. This was a restraint for 44 percent of the total number of reaches in the five coastal basins but for only about 13 percent of reaches in eastern basins. However, 71 percent of the Umatilla Basin reaches had restraints due to existing structures. Generally, the lack of recent detailed maps for much of the state, together with continual population growth, may have led to an underestimation of the magnitude of this restraint.

TABLE VIII. FEASIBILITY RESTRAINTS AND CONSTRAINTS AFFECTING REACHES

| Basin | Number of Reaches | Number of Reaches Having Feasibility Restraints Due to: | | | | Number of Reaches Having Transmission or Load Constraints Due to: | |
|---|---|---|---|---|---|---|---|
| | | Land Use Restrictions | Utility Displacement | Building Displacement | Special Fish Problems | Distance to Nearest Line | Local Market |
| 1 North Coast | 138 | 3 | 63 | 74 | 134 | 3 | 114 |
| 2A Upper Willamette | 124 | 7 | 46 | 41 | 68 | 21 | 94 |
| 2B Middle Willamette | 216 | 3 | 79 | 66 | 117 | 18 | 187 |
| 2C Lower Willamette | 66 | 6 | 16 | 12 | 58 | 0 | 35 |
| 3 Sandy | 50 | 3 | 15 | 18 | 29 | 0 | 45 |
| 4 Hood | 17 | 1 | 8 | 1 | 16 | 0 | 15 |
| 5 Deschutes | 120 | 32 | 18 | 8 | 102 | 15 | 113 |
| 6 John Day | 44 | 19 | 19 | 12 | 41 | 23 | 42 |
| 7 Umatilla | 14 | 6 | 12 | 10 | 13 | 5 | 10 |
| 8 Grande Ronde | 63 | 11 | 23 | 11 | 63 | 16 | 58 |
| 9 Powder | 31 | 4 | 17 | 4 | 0 | 5 | 28 |
| 10 Malheur | 20 | 0 | 9 | 4 | 0 | 3 | 17 |
| 11 Owyhee | 23 | 5 | 0 | 0 | 0 | 19 | 22 |
| 12 Malheur Lake | 8 | 2 | 2 | 1 | 0 | 0 | 7 |
| 13 Goose & Summer Lakes | 5 | 1 | 2 | 0 | 0 | 0 | 5 |
| 14 Klamath | 30 | 2 | 5 | 2 | 4 | 0 | 29 |
| 15 Rogue | 135 | 27 | 50 | 50 | 77 | 31 | 130 |
| 16 Umpqua | 114 | 14 | 54 | 36 | 97 | 13 | 97 |
| 17 South Coast | 86 | 2 | 29 | 29 | 72 | 21 | 74 |
| 18 Mid-Coast | 139 | 5 | 48 | 80 | 132 | 3 | 133 |
| Total | 1443 | 153 | 515 | 459 | 1023 | 196 | 1255 |

Aquatic ecosystems would be affected by low-head power development in any of the reaches. Beyond that, special fish problems involving salmonids or sturgeon populations were identified for 1023 of the 1443 reaches -- 71 percent. These restraints were predominant for coastal streams, where 84 percent of reaches in the five coastal basins had special fish restraints, and for basins adjacent to the Columbia River. But the 87 reaches in south-east parts of the state had no special fish constraints.

Most reaches were found to be near transmission lines that would allow new low-head facilities to be integrated with existing grid systems. However, 14 percent of the 1443 reaches were constrained by being rather far from such lines. This was most common in mountainous areas.

The lack of availability of a local market, whether residential, industrial or agricultural, was a constraint upon 1255 of the 1443 reaches -- 87 percent! This constraint was found to occur statewide, with no significant regional variation.

## Screening for Minimally Constrained Reaches

The preliminary feasibility analyses of reaches were used for screening to find relatively unconstrained reaches, as discussed earlier. The lack of proximity to local markets eliminated 87 percent (1255) of all reaches analyzed. Constraints based on other screening criteria caused the elimination of 132 additional reaches from the 188 passing the local market criterion. Hence, only 56 reaches were identified as being relatively unconstrained. These undoubtedly merit further feasibility investigation in the near future. But other reaches, eliminated by the screening criteria, might be more significant for future feasibility study, particularly if their greater constraints are recognized from the outset or if different screening criteria or criteria emphasis is used.

The 56 reaches which passed the preliminary screening criteria are shown in Figure 14. They are identified with pertinent information in Table IX. There, these reaches are grouped according to their OWRD drainage basin. The majority of these potentially feasibile reaches are located in the Willamette Basin, near to local markets. Within the drainage basin lists, the screened reaches are ranked by their magnitude

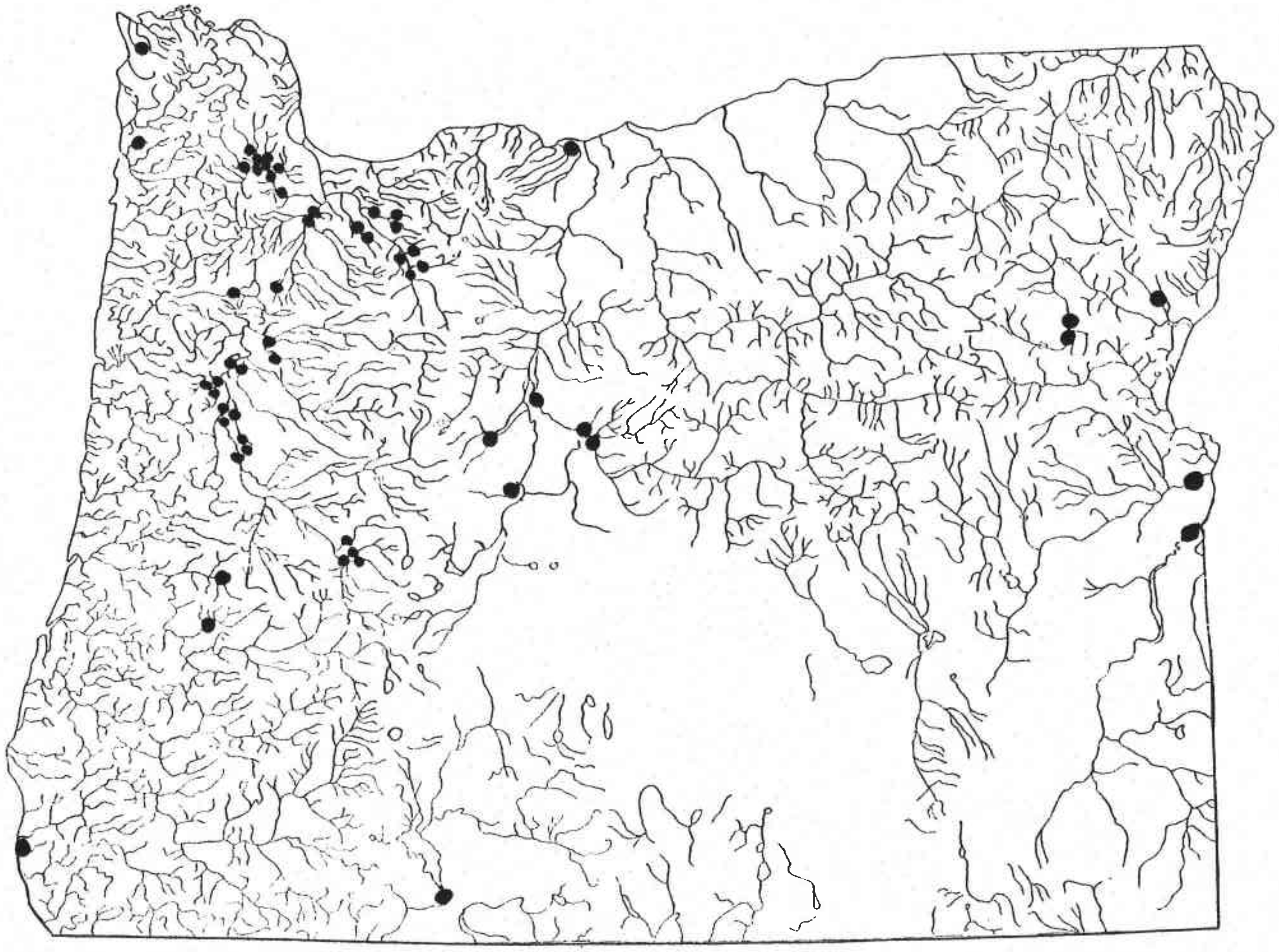


FIGURE 14. LOCATIONS OF REACHES PASSING PRELIMINARY FEASIBILITY SCREENING

TABLE IX. IDENTIFICATION AND RANKING OF REACHES PASSING PRELIMINARY SCREENING

| STREAM DESCRIPTION | REACH NUMBER | $Q_{30}$ (CFS) | PAGE |
|---|---|---|---|
| 1. North Coast Basin | | | |
| Miami River | 02-520-000-000-000-R0002 | 111 | 0 1-72 |
| Lewis and Clark River | -500-003-000-000-R0003 | 106 | 0 1-3 |
| 2. Willamette Basin | | | |
| 2A. Upper Willamette Basin | | | |
| Willamette River Main Stem | 02-500-060-000-000-R0021 | 13,158 | 0 2A-1 |
| Willamette River Main Stem | -R0022 | 12,106 | 0 2A-10 |
| Willamette River Main Stem | -R0024 | 11,982 | 0 2A-12 |
| Middle Fk. Willamette River | -192-000-R0013 | 1,131 | 0 2A-118 |
| N. Fk. of Middle Fk. Willamette River | -192-010-R0001 | 718 | 0 2A-103 |
| Salmon Creek | -020-R0001 | 347 | 0 2A-111 |
| Salt Creek | -030-R0001 | 291 | 0 2A-115 |
| 2B. Mid-Willamette Basin | | | |
| Willamette River Main Stem | 02-500-060-000-000-R0005 | 30,521 | 0 2B-1 |
| Willamette River Main Stem | -R0017 | 14,738 | 0 2B-194 |
| South Santiam River | -110-020-R0001 | 4,427 | 0 2B-139 |
| South Santiam River | -R0017 | 3,278 | 0 2B-155 |
| Molalla River | -036-000-R0001 | 3,254 | 0 2B-2 |
| Calapooia River | -120-000-R0002 | 1,067 | 0 2B-186 |
| Mary's River | -131-000-R0001 | 867 | 0 2B-196 |
| Mary's River | -R0002 | 497 | 0 2B-200 |
| Muddy Creek | -134-000-R0002 | 335 | 0 2B-210 |

TABLE IX. Continued

| STREAM DESCRIPTION | REACH NUMBER | $Q_{30}$ (CFS) | PAGE |
|---|---|---|---|
| Muddy Creek (West) | 02-500-060-131-010-R0001 | 304 | 0 2B-197 |
| Rickreall Creek | -089-000-R0001 | 205 | 0 2B-88 |
| Muddy Creek | -134-000-R0003 | 142 | 0 2B-213 |
| Little Pudding River | -036-005-R0016 | 84 | 0 2B-18 |
| Muddy Creek | -134-000-R0005 | 74 | 0 2B-215 |
| <u>2C. Lower Willamette Basin</u> | | | |
| Tualatin River | 02-500-060-029-000-R0003 | 1,638 | 0 2C-44 |
| Clackamas River | -024-000-R0008 | 1,431 | 0 2C-28 |
| Tualatin River | -029-000-R0005 | 1,295 | 0 2C-48 |
| Tualatin River | -000-R0006 | 675 | 0 2C-57 |
| Dairy Creek | -005-R0001 | 516 | 0 2C-49 |
| Oak Grove Fork Clackamas River | -024-009-R0001 | 429 | 0 2C-25 |
| Dairy Creek | -029-005-R0004 | 336 | 0 2C-52 |
| Eagle Creek | -024-004-R0001 | 286 | 0 2C-11 |
| Gales Creek | -029-007-R0001 | 195 | 0 2C-58 |
| Eagle Creek | -024-004-R0003 | 134 | 0 2C-13 |
| Fish Creek | -006-R0001 | 130 | 0 2C-19 |
| McKay Creek | -029-005-R0002 | 124 | 0 2C-50 |
| Rock Creek | -003-R0001 | 122 | 0 2C-46 |
| Clear Creek | -024-003-R0002 | 120 | 0 2C-8 |
| West Fork Dairy Creek | -029-005-R0005 | 118 | 0 2C-53 |
| Roaring River | -024-007-R0001 | 117 | 0 2C-22 |

TABLE IX. Continued

| STREAM DESCRIPTION | REACH NUMBER | $Q_{30}$ (CFS) | PAGE |
|---|---|---|---|
| Clear Creek | 02-500-060-024-003-R0003 | 93 | 0 2C-9 |
| North Fork Eagle Creek | -004-R0002 | 87 | 0 2C-12 |
| 3. Sandy Basin | None | | |
| 4. Hood Basin | | | |
| Fifteenmile Creek | 02-500-165-000-000-R0002 | 136 | 0 4-17 |
| 5. Deschutes Basin | | | |
| Squaw Creek | 02-500-180-040-000-R0003 | 527 | 0 5-85 |
| Tumalo Creek | -050-000-R0001 | 384 | 0 5-95 |
| Crooked River | -030-000-R0001 | 338 | 0 5-70 |
| Crooked River | -R0006 | 329 | 0 5-72 |
| Crooked River | -R0007 | 292 | 0 5-73 |
| 6. John Day Basin | None | | |
| 7. Umatilla Basin | None | | |
| 8. Grande Ronde Basin | None | | |
| 9. Powder Basin | | | |
| Powder River | 02-500-240-120-000-R0012 | 111 | 0 9-14 |
| Powder River | -R0013 | 100 | 0 9-15 |
| Eagle Creek | -010-R0002 | 96 | 0 9-19 |

TABLE IX. Continued

| STREAM DESCRIPTION | REACH NUMBER | $Q_{30}$ (CFS) | PAGE |
|---|---|---|---|
| 10. Malheur Basin | | | |
| Malheur River | 02-500-240-180-000-R0001 | 245 | 0 10-1 |
| 11. Owyhee Basin | | | |
| Owyhee River | 02-500-240-200-000-R0001 | 867 | 0 11-1 |
| 12. Malheur Lake Basin | None | | |
| 13. Goose and Summer Lakes Basin | None | | |
| 14. Klamath Basin | | | |
| Klamath River | 02-000-014-002-000-R0003 | 904 | 0 14-7 |
| 15. Rogue Basin | None | | |
| 16. Umpqua Basin | | | |
| Calapooya Creek | 02-700-030-000-000-R0002 | 328 | 0 16-35 |
| Elk Creek | -020-000-000-R0006 | 110 | 0 16-27 |
| 17. South Coast Basin | | | |
| Hunter Creek | 02-950-000-000-000-R0001 | 233 | 0 17-64 |
| 18. Mid-Coast Basin | None | | |

of streamflow available 30 percent of the time (about equal to the mean flow). Page numbers shown in Table IX are preceded by the appendix number, in turn preceded by letter O as used in the regional report to indicate "Oregon".

Table X shows, by basin, the number of reaches passing the preliminary feasibility screening. The corresponding theoretical developable power and energy potentials are also shown at the 30 percent and 50 percent exceedance conditions.

For the combined 56 reaches, about 228 MW of power could be developed from flows equaled or exceeded 50 percent of the time. About 79 percent of this potential is represented by the 39 sites in the Willamette Basin; the five Deschutes Basin reaches passing screening could provide 17 percent of this combined potential. Comparing these 56 reaches to the entire group of 1443 reaches, they represent about 4 percent of the theoretical developable potential.

TABLE X. NUMBER AND THEORETICAL POWER AND ENERGY POTENTIALS OF REACHES PASSING PRELIMINARY FEASIBILITY SCREENING

| River Basin | Number of "feasible" Reaches [1] | Corresponding Power (MW) & Energy (GWh) | | | |
|---|---|---|---|---|---|
| | | $P_{30}$ | $P_{50}$ | $E_{30}$ | $E_{50}$ |
| 1. North Coast | 2 | 2.1 | 0.9 | 10.1 | 5.9 |
| 2. Willamette | 39 | 327.9 | 179.0 | 1712.5 | 1190.7 |
| 2A. Upper | 7 | (173.1) | (92.7) | (898.4) | (616.5) |
| 2B. Middle | 14 | (64.7) | (37.2) | (340.3) | (244.0) |
| 2C. Lower | 18 | (90.1) | (49.1) | (473.8) | (330.2) |
| 4. Hood | 1 | 0.8 | 0.4 | 4.1 | 2.9 |
| 5. Deschutes | 5 | 63.0 | 37.8 | 361.8 | 273.7 |
| 9. Powder | 3 | 5.7 | 2.6 | 27.7 | 17.0 |
| 10. Malheur | 1 | 1.5 | 0.9 | 8.0 | 5.9 |
| 11. Owyhee | 1 | 3.7 | 1.5 | 18.5 | 11.0 |
| 14. Klamath | 1 | 5.4 | 3.4 | 33.0 | 26.3 |
| 16. Umpqua | 2 | 1.4 | 0.5 | 6.1 | 3.2 |
| 17. South Coast | 1 | 1.3 | 0.5 | 5.8 | 2.8 |
| Totals | 56 | 412.8 | 227.5 | 2187.6 | 1539.4 |

[1] Based on preliminary feasibility analysis and screening.

# VI. DISCUSSION AND CONCLUSIONS

## General Comments

This study has provided the basic data gathering, preliminary hydrologic analyses and related evaluations of power and energy, together with preliminary feasibility-of-development assessments, essential for resource inventory and appraisal purposes. The information has been assembled in formats to facilitate its use for those purposes. The information reflects a very great amount of time and painstaking attention to detail, as well as frustration over limitations on mapped or published data that had to be used to develop the analyses made. Much time was devoted to checking, double-checking, and cross-checking the work done, in order to eliminate as many errors as possible. In this review process it became evident that different interpretations are possible of the reference maps and reports, due to limited precision, scales used, and conflicting reported information.

This investigation is limited in scope in two respects. First, rivers were only analysed for reaches where no dams or reservoirs now exist. (However, a second phase of this investigation, not reported here, will analyze those sites.) Second, a lower limit was set on the size of stream analyzed, based on a median flow of 36 cfs. To inventory all streams as far upstream as the point where perennial flow begins, would be a monumental task exceeding the capabilities of available topographic maps and the reliability of precipitation mapping detail in many parts of the state.

## Importance of Study

The investigation reported on here is, as far as the author can determine, the first systemmatic state-wide and region-wide study of its type. There have been many other studies to identify potential hydroelectric power development sites. They have generally focused on larger projects -- not the small, low-head hydro development considered in this investigation. Nor have other studies attempted a stream power and stream energy inventory for river reaches as was done here.

Recognizing the limits to the inventory, there is now available through this study new information to describe the mean discharges, discharge patterns, stream power and its variability, stream energy and its variability, more-evident restraints affecting the feasibility of development, and constraints on transmitting and marketing electricity for 1443 reaches involving 7626 miles of streams in Oregon where future low-head hydro power development might be considered. Beyond such descriptions, those reaches that appear to have minimal restraints on the feasibility of development, based on the criteria used, have been identified.

## Broader Implications of This Study

The information presented in this report and its appendices has focused upon hydroelectric power applications. To generalize the information beyond hydroelectric development possibilities, it is essential to keep in mind that the power and energy amounts report here represent power and energy that are presently being dissipated by natural processes as the water flows to the Pacific Ocean (or to lakes, in the case of the closed basins). Potential energy due to a relatively higher elevation in the basin is converted to the kinetic energy of flowing water as it moves down the basin. This energy is dissipated in frictional and turbulence-associated losses. The energy involved is considerable and has many presumably crucial but largely uninvestigated roles in the physical-biological-chemical processes of streams.

Therefore, it is hoped that the study results will be widely used and not restricted solely to hydro power development studies. The findings should be broadly applicable for resource inventory purposes, for preliminary appraisals of many types of projects (not restricted to hydro power projects), for further investigation of physical-biological-chemical processes in streams, and for broader water resource planning and management uses.

## Conclusions Based Upon Study Findings

1. Approximately 7626 miles of streams in Oregon that are presently undeveloped by dams meet the low-head flow and power criteria of 36 cfs at least 50 percent of the time and of at least 200 kW of producable power. The majority of these are along streams west of the Cascade divide. For analytical purposes they have been separately analyzed in 1443 individual reaches.

2. The theoretical maximum developable power and energy potential for these streams is sufficiently large to represent an important consideration in planning studies for future energy development.

3. State-wide, the power potential, as influenced by low-head assumptions (100 percent efficiency, run-of-river flows) and streamflow variability, is as follows:

   Available 95 percent of time (approx. firm) = $2^-$ GW
   " 80 " " " - - - - - - - - = $2^+$ GW
   " 50 " " " (median) = $6^+$ GW
   " 30 " " " (approx. mean) = $11^+$ GW
   " 10 " " : - - - - - - - - = 24 GW

4. State-wide, the energy potential, as influenced by low-head assumptions and streamflow variability, is as follows:

   Available 95 percent of time (approx. firm) = $15^- \times 10^3$ GWh
   " 80 " " " - - - - - - - - = $21^- \times 10^3$ GWh
   " 50 " " " (median) = $43^- \times 10^3$ GWh
   " 30 " " " (approx. mean) = $61^- \times 10^3$ GWh
   " 10 " " " - - - - - - - - = $83^- \times 10^3$ GWh

5. Among the 18 drainage basins that OWRD uses to subdivide the state hydrologically, extreme variability in developable low-head power and energy potential exists. The most extreme comparison is between the Willamette Basin and Malheur Lake Basin, two basins of comparable size, the Willamette having over 1600 times the power and energy potential of the Malheur Lake Basin.

6. On a geographical basis, the greatest developable low-head power and energy potential is found in the Willamette Basin. Streams in Central Oregon influenced by runoff from the Cascades and Coastal streams draining to the Pacific Ocean have comparable potentials, and collectively exceed that of the Willamette Basin. Streams in Southeast Oregon have the lowest developable power and energy potential. The described comparison is illustrated by use of the power available at least 50 percent of the time as follows:

   Willamette Basin streams, $P_{50}$ = 2.3 GW
   Central Oregon streams, $P_{50}$ = 1.7 GW
   Coastal-draining streams, $P_{50}$ = 1.7 GW
   Northeast Oregon streams, $P_{50}$ = 0.5 GW
   Southeast Oregon streams, $P_{50}$ = 0.1 GW

   ---

   All Streams, $P_{50}$ = 6.3 GW

7. Oregon streams rank second and possess about one-fourth of the total developable stream power and energy potential in the Pacific Northwest region, based upon low-head hydro power assumptions. Washington streams possess roughly 20 percent more power and energy whereas Idaho streams possess roughly 20 percent less power and energy than do Oregon streams. Montana, Wyoming, and Nevada add minor contributions in Columbia River Basin headwater portions of the Pacific Northwest.

8. Preliminary feasibility analyses and screening were used to identify relatively unconstrained reaches with energy marketing potentials that might be recommended for further, more-detailed examination in the near future. Based upon practical but somewhat arbitrary criteria, 56 such reaches were identified, 39 of them located in the Willamette Basin. Collectively, these represent theoretical developable power of 228 MW available 50 percent of the time (median conditions) and 413 MW available 30 percent of the time (near-mean conditions). This corresponds to 1539 GWh and 2188 GWh, respectively, and is about 4 percent of the total state low-head power potential.

9. The investigation reported here focused predominantly upon the hydrologic and physical aspects of low-head hydroelectric power development. The feasibility assessment of stream reaches was necessarily limited to available maps and published material, not all of which contained recent information. The impacts of low-head hydro development were not specifically addressed. Therefore, the findings and conclusions regarding the low-head hydro power potential in Oregon do not constitute and should not be considered to constitute either an endorsement or a rejection of low-head development. Rather, the findings and conclusions should be viewed as objective results of data gathering, evaluation, synthesis and interpretation to make information available in readily useful form for continued serious assessment of "low-head" or "small" hydroelectric power as an available technology for meeting Oregon's energy needs.

# VII. REFERENCES

Gladwell, J. S. and L. F. Heitz; A Resource Survey of Low-Head Hydroelectric Potential in the Pacific Northwest Region; Draft Completion Report, Phase I, to U.S. Department of Energy; Idaho Water Resources Research Institute; University of Idaho; Moscow; 1979.

Gladwell, J. S. and C. C. Warnick; Low Head Hydro, an Examination of an Alternative Energy Source; Idaho Water Resources Research Institute; University of Idaho; Moscow; 1978.