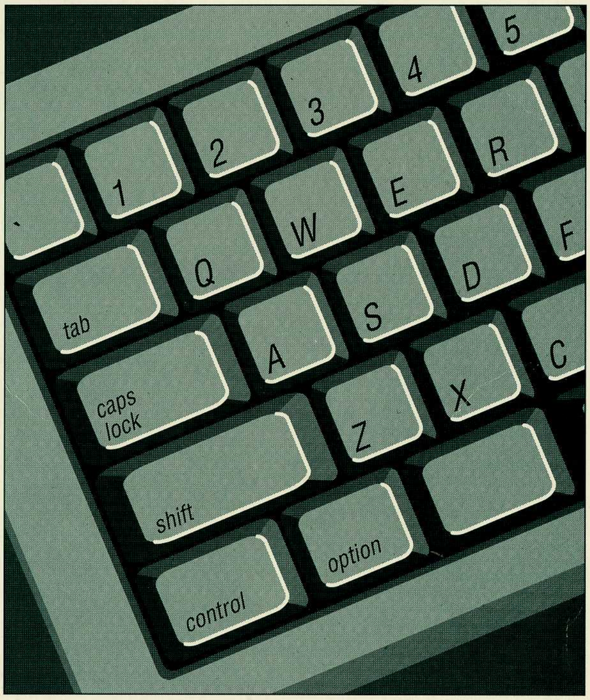

MODELING THE SYSTEM

HOW COMPUTERS ARE USED IN COLUMBIA RIVER PLANNING

MODELING THE SYSTEM:

HOW COMPUTERS ARE USED IN COLUMBIA RIVER PLANNING

U.S. DEPARTMENT OF ENERGY, BONNEVILLE POWER ADMINISTRATION

U.S. DEPARTMENT OF THE ARMY, CORPS OF ENGINEERS, NORTH PACIFIC DIVISION

U.S. DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION, PACIFIC NORTHWEST REGION

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Introduction

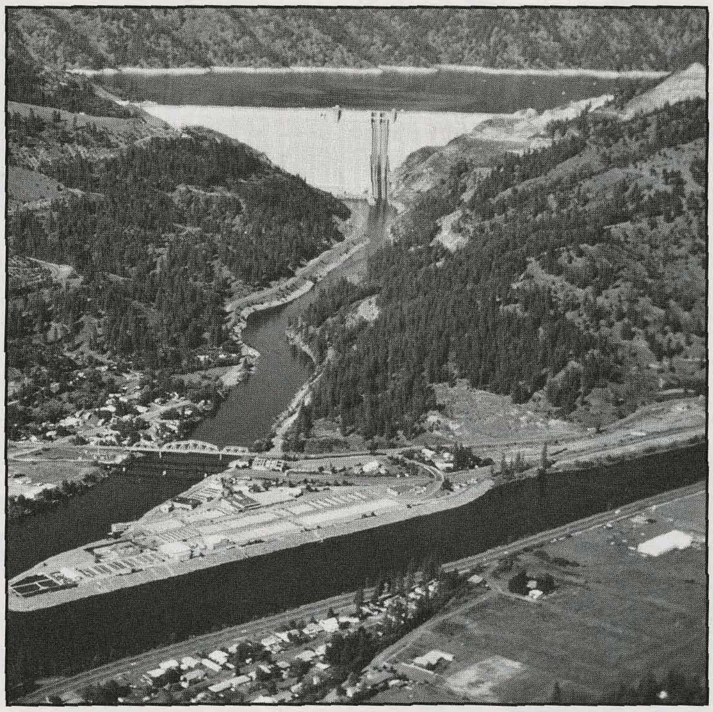
Water surges past the giant turbines and into the tailrace at Grand Coulee Dam. Tailwater levels below the dam rise, and the current swells as the Columbia River moves along its 1,200 mile journey to the Pacific Ocean. Fifty miles downstream at Chief Joseph Dam, operators will either hold back some of the flow or release it all on to Wells, Rocky Reach, and Rock Island dams.

From one project to the next, runoff from Canadian and Northwest snowfields makes its way down the river. Streamflows build and diminish, and reservoir elevations rise and fall as the water enters manmade lakes and is released through powerhouses and over spillways.

Hydroregulation — regulating water — is the process planners and operators use to make decisions about routing water through the series of hydro projects in the Columbia River Basin. Those decisions are geared to make the most efficient use of the water in the river and its tributaries, and to meet multiple objectives — from controlling floods to irrigating crops to generating electricity.

Regulating a system as complex as the Columbia requires continuous planning and powerful tools.

Today, planning and regulation are assisted by automation. The tools of the trade are sophisticated computer programs that in a matter of minutes can calculate the river system's response to a variety of streamflow and operating conditions. The programs are also referred to as "models" because they model or simulate operations of the river system. From the data the models provide, analysts can estimate the systemwide impacts of projected operations.



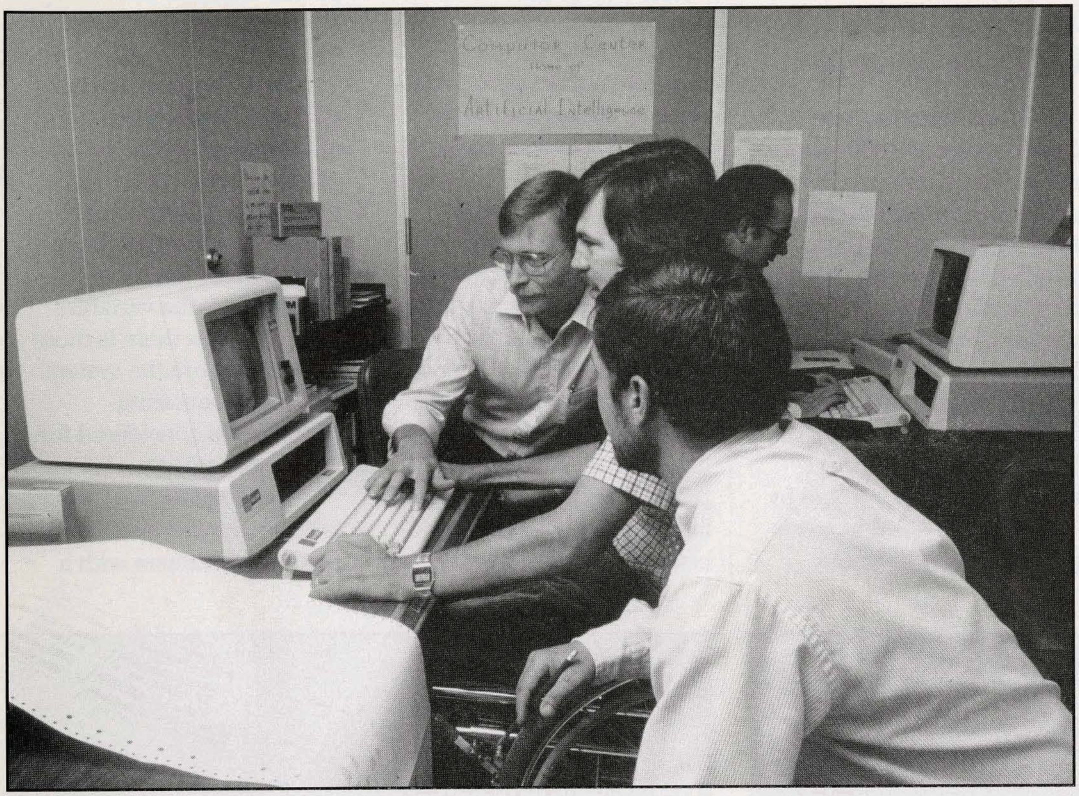
Computer simulations play an important role in helping Federal agencies plan operations on the Columbia River system.

This publication describes the three computer models Federal agencies and the Northwest Power Pool use regularly to help plan hydro operations in the Columbia River Basin: HYSSR, HYDROSIM, and HYDREG. It is one of a series of booklets written for participants in the System Operation Review (SOR) being conducted jointly by the U.S. Army Corps of Engineers (Corps), the U.S. Bureau of Reclamation (Reclamation), and the Bonneville Power Administration (BPA). A list of the other publications appears on the inside front cover.

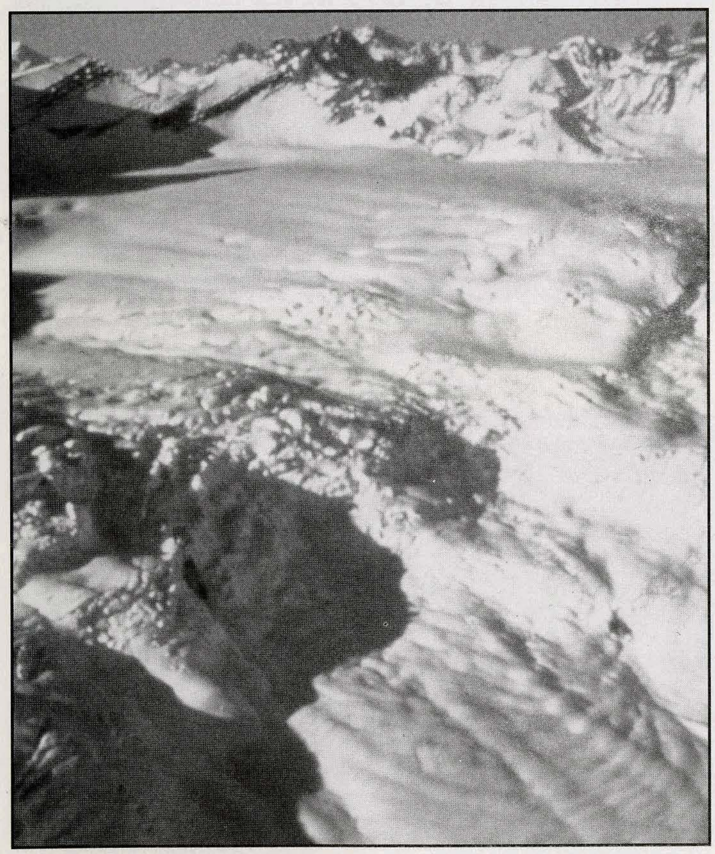
The System Operation Review

The SOR is the environmental analysis required to consider changes in Columbia River system operations and related contract arrangements. Over the next few years, the agencies will develop a new multiple-use operation strategy for the Columbia River. At the same time, the Pacific Northwest Coordination Agreement (PNCA) and other contracts related to the Columbia River Treaty between the United States and Canada will be renegotiated and renewed.

Many alternative ways of operating individual projects and the river system as a whole will be considered in the SOR. To analyze how these changes would affect the system's ability to meet its multiple-use goals, various operating scenarios will be thoroughly evaluated. The three computer models, HYSSR, HYDROSIM, and HYDREG, will play an important role in this evaluation.



Three complex hydroregulation models — HYSSR, HYDROSIM, HYDREG — help system planners determine how the river system will respond to operating changes.



A key to planning river operations is predicting the amount of runoff that will flow from high mountain snowfields.

The region's hydroregulation models will play an important role in SOR.

Chapter One: The Role of Models in Planning

Why We Need Computer Models

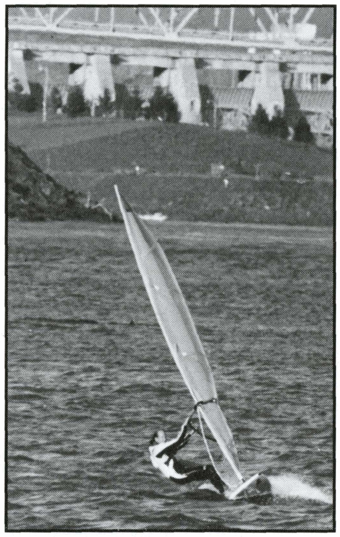
The Columbia River Basin covers 258,000 square miles. The Columbia River and dozens of large tributaries drain this vast area, which extends from Canada to Nevada and from western Wyoming to the Pacific Ocean.

There are more than 150 dams and reservoirs on the coordinated river system, 30 of them operated by Federal agencies that work together to satisfy many needs. The computer models simulate how the major projects in this system will react to changes in operations and to a wide range of runoff conditions. They also help plan how to use the water most efficiently.

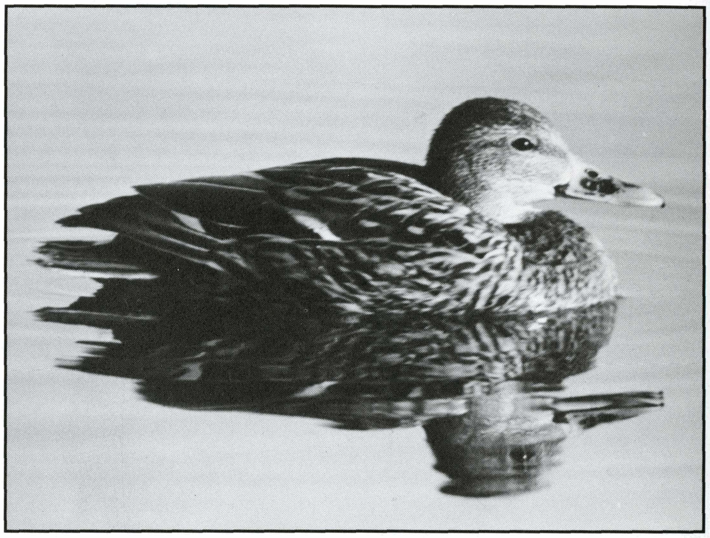
Planners and operators aim to serve nine major river uses: navigation, flood control, irrigation, electric power generation, anadromous fish migration, resident fish habitat, wildlife habitat, recreation, and water quality and supply. A tenth consideration is protecting cultural and historical sites along the river banks.

What happens at each project to meet one or more of these objectives has an effect on other projects, both up and downstream. Computer models enlarge the planners' ability to analyze how the variables interact when there is more or less water in the system and when operating changes are considered for any or all projects.

Calculations that would take weeks and months by hand take minutes with a



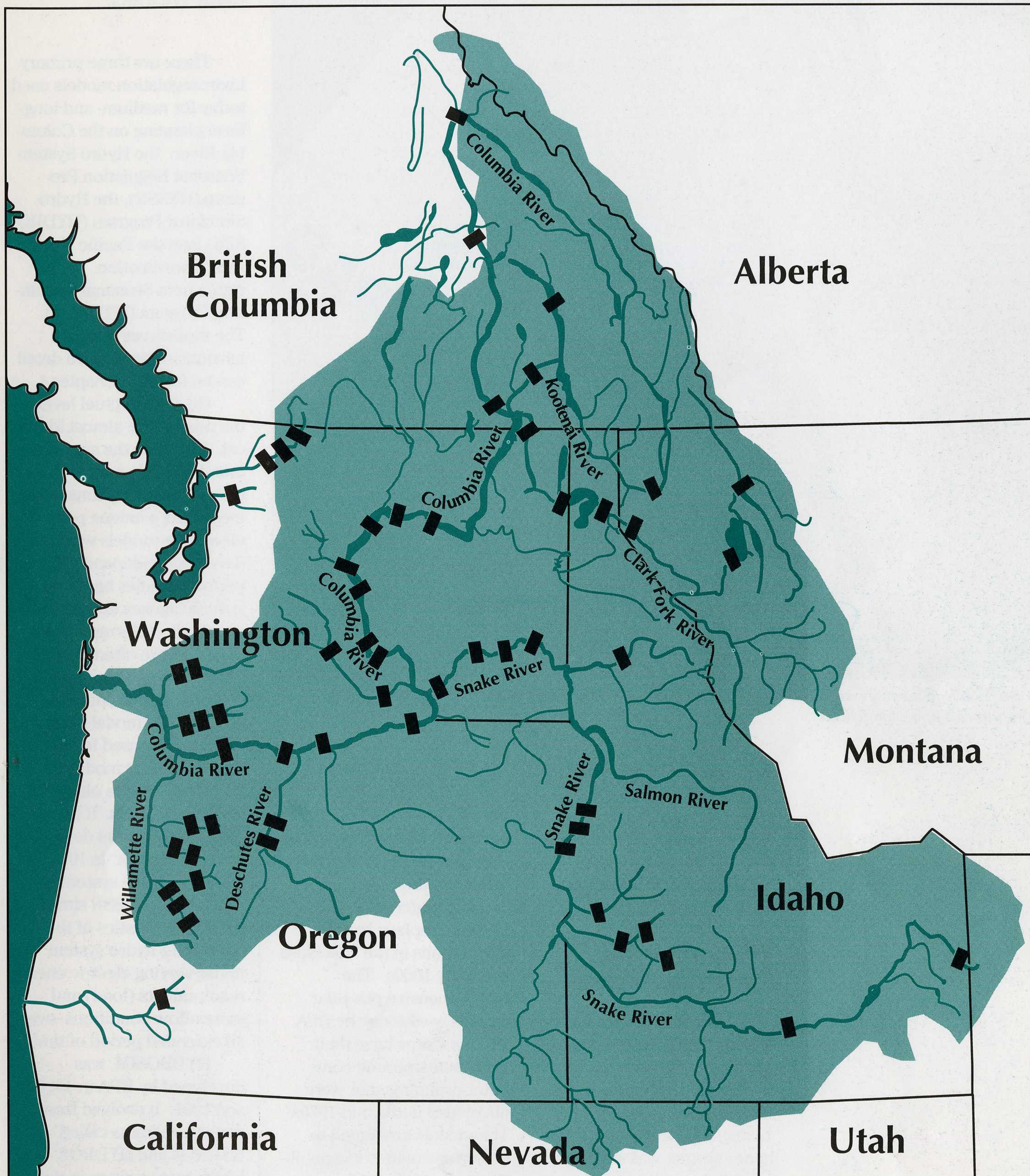
The Columbia River attracts thousands of visitors each year, including sailboard enthusiasts from around the world.



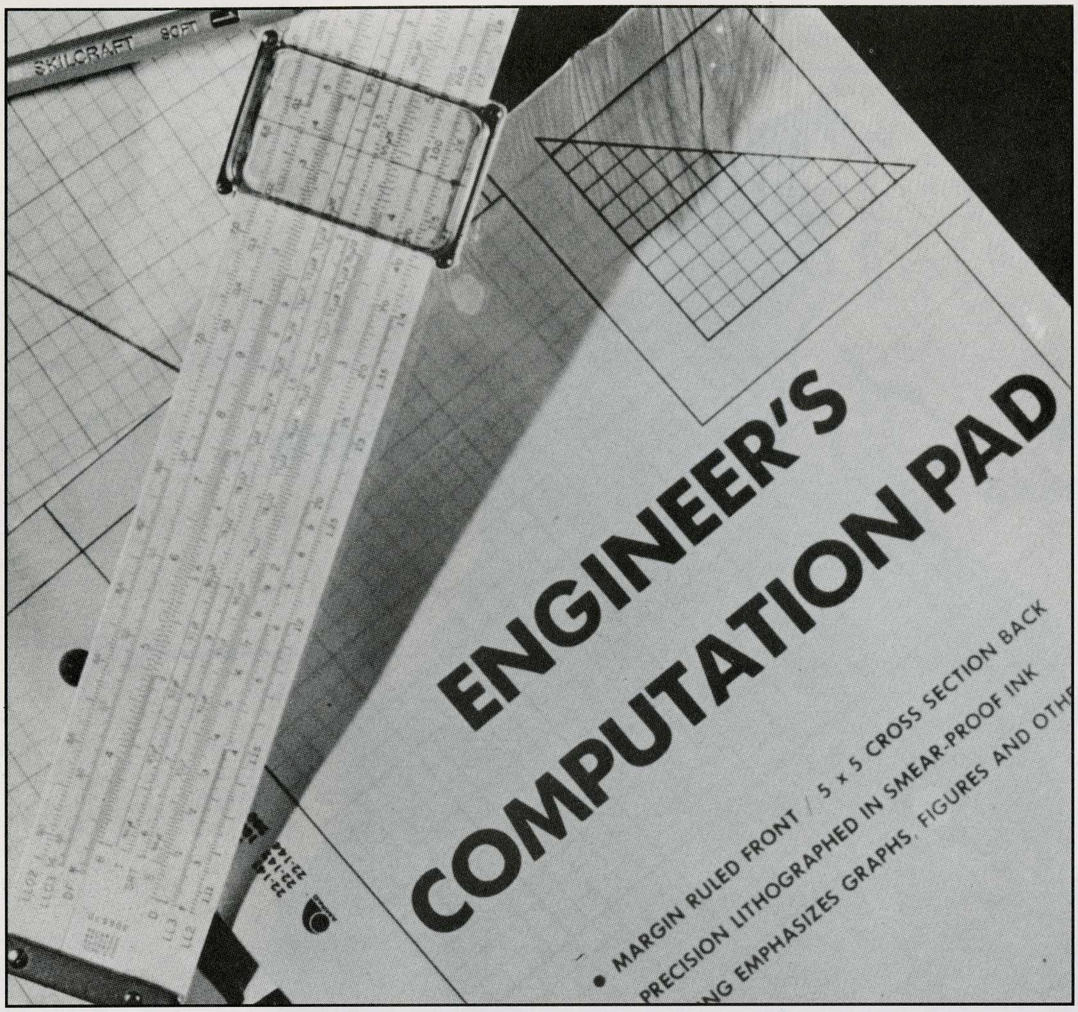
Many species of wildlife depend on river operations that protect their habitat.

Federal hydro projects on the Columbia and Snake Rivers provide irrigation water for millions of acres of agriculture in the western United States.

Columbia River Basin Major Dams



The Columbia River Basin covers 258,000 square miles in the United States and Canada. There are over 150 hydro projects in the Columbia River system; each of the hydroregulation models uses a different number of projects in its runs, and the number can change depending upon the study being conducted.



In the 1960s, automation revolutionized system planning. Computers began to replace hand-drawn spreadsheets and slide rules.

computer. The speed with which the computer processes data makes it possible to consider far more information and to make timely and precise adjustments to operations.

When Were the Models Developed?

Computer models have become so pervasive in the planning environment, it's hard to remember life without them. But in the 1930s, 40s, and 50s, when the hydro system was smaller and less complex, hydroregulation was done using mechanical desk calculators and hand-drawn spreadsheets. This limited the amount of operating information that could be analyzed. Operations at each project were updated piece-by-piece.

Computer programs began to replace hand calculations in the late 1950s and early 1960s. The comprehensive planning models used today by BPA and the Corps have their roots in mainframe computer programs that were developed in the mid-1950s. The models continued to evolve as computer capabilities expanded, precision in modeling increased, and river operations became more complicated.

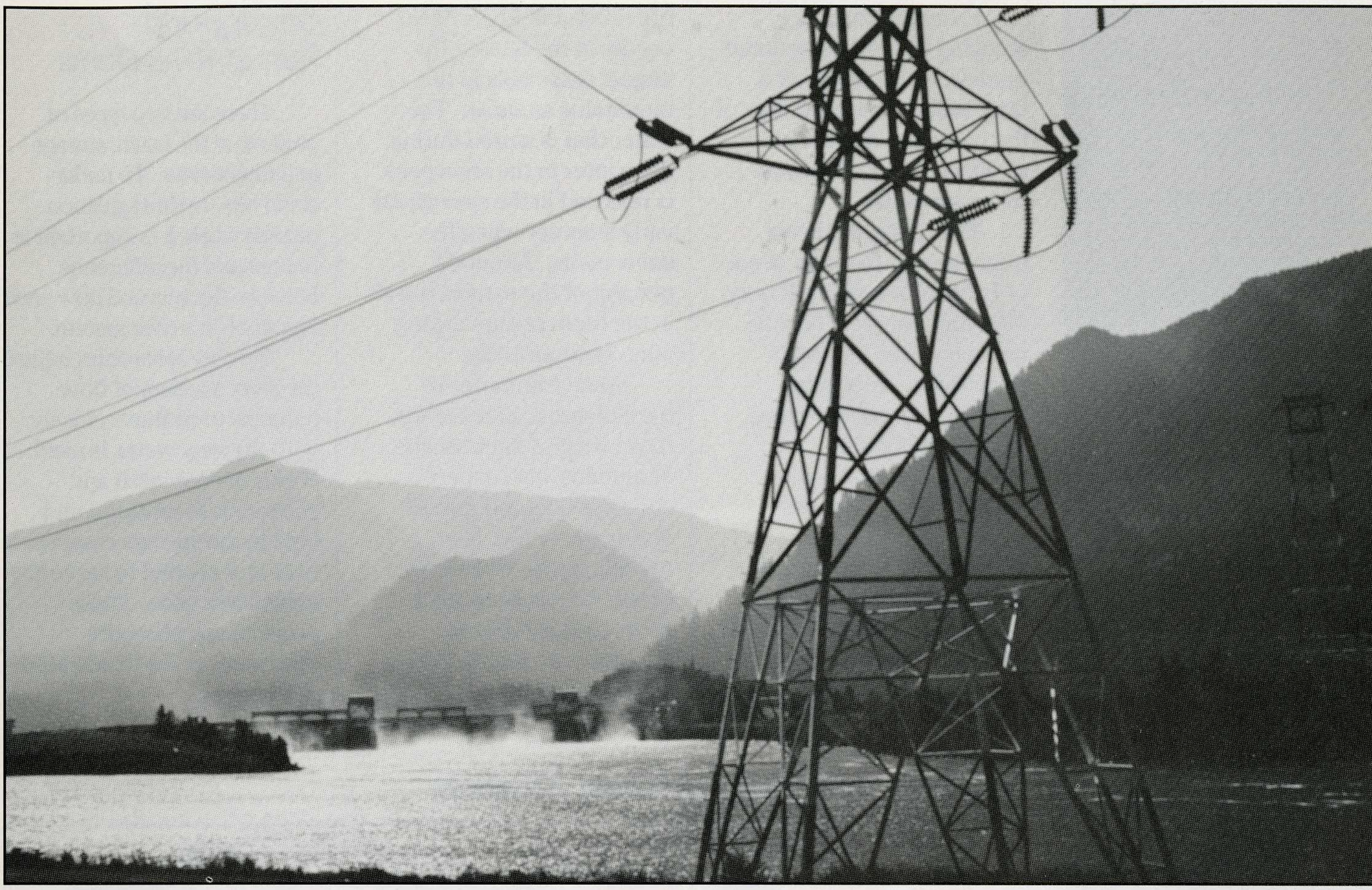
The Columbia River Models

There are three primary hydroregulation models used today for medium- and long-term planning on the Columbia River: the Hydro System Seasonal Regulation Program (HYSSR), the Hydro Simulator Program (HYDROSIM), and the Pacific Northwest Coordination Agreement Seasonal Regulation Program (HYDREG). The models are briefly introduced here; more detail can be found in Chapter 4.

On a conceptual level, the models are almost identical. But since the agencies that designed and use them have distinct missions, each model has a unique point of view. The models were developed independently and perform studies based on specific agency and constituent needs. Information and expertise are often shared among the agencies and the analysts. And in some instances, one model produces data that are used for studies run on another model.

HYSSR is the oldest of the three models. It has its genesis in a model developed by the Corps for its 1958 comprehensive system planning study. HYSSR simulates the characteristics of the Northwest hydro system under varying electric energy requirements (load) and streamflow conditions, over an extended period of time.

HYDROSIM was developed by BPA in 1990 and 1991. It evolved from earlier programs called HYDRO2 and HYDRO6, which were written in the 1960s. Like HYSSR, HYDROSIM simulates the operating characteristics of



One of the earliest uses of a hydroregulation model in the region was to assist in the coordinated planning and operations required under the 1964 Pacific Northwest Coordination Agreement.

the Northwest hydro system under varying load and flow conditions, over an extended period of time.

HYDREG was originally developed in the 1960s at BPA, but it is now maintained and operated by the Northwest Power Pool. HYDREG is used to establish seasonal guidelines for coordinated operation of hydro projects included in the Pacific Northwest Coordination Agreement (PNCA). The guidelines maximize power benefits while satisfying multiple nonpower uses of the river.

Chapter Two: A Quick Look Around the Basin

To set the stage for studying the hydroregulation models, we've included a brief look at the hydrology of the basin and a description of the two major types of hydro projects.

The Columbia River originates on the west slope of British Columbia's Rocky Mountain range. About 25 percent of the Columbia River flow comes from Canada. Before any dams were built, natural streamflow at the border ranged from as low as 14,000 cubic feet per second (cfs) to as high as 550,000 cfs.

This enormous variation in flow is seasonal. Most of the annual precipitation in the Columbia River Basin occurs in the winter; the largest share falls in the mountains as snow. The water that is stored during the winter in the snowpack is released in the spring and early summer when the snow melts. About 60 percent of the natural runoff in the basin occurs during May, June, and July.

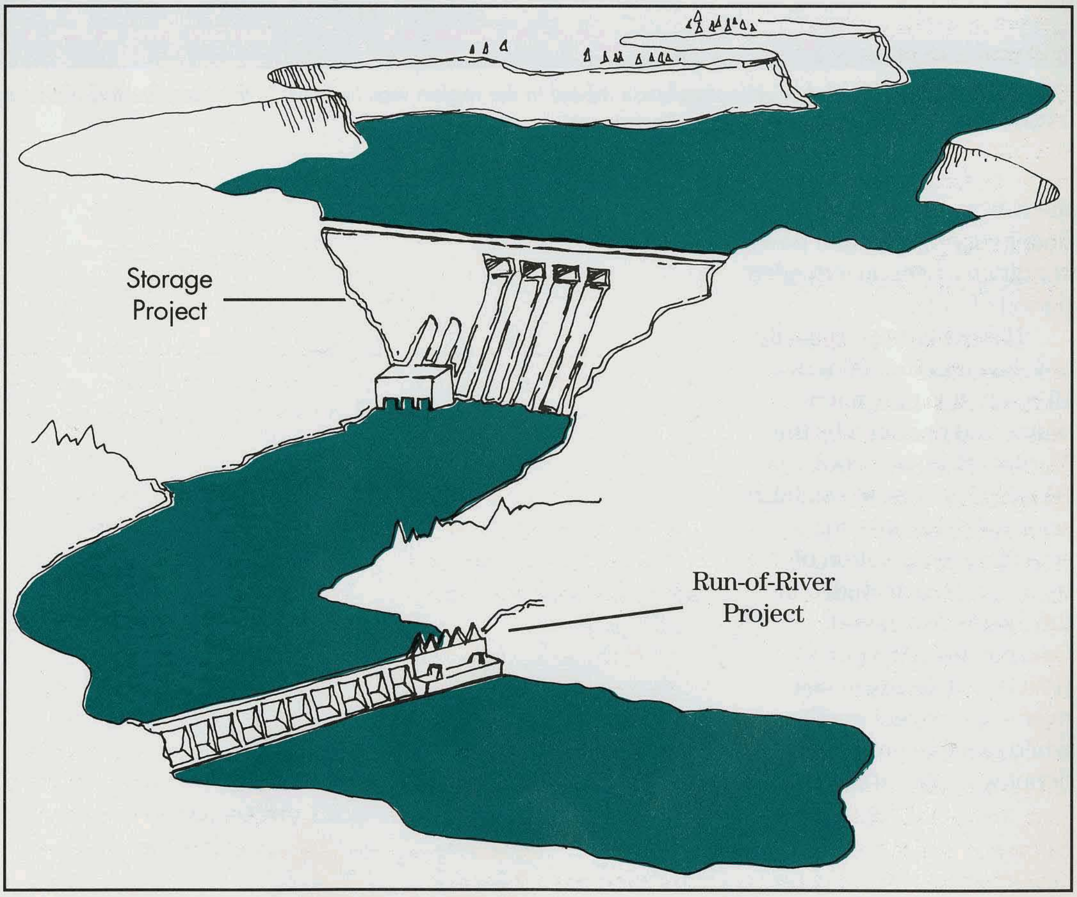
Some tributaries of the Columbia, particularly those west of the Cascade Mountains, also experience considerable runoff during the winter from rainfall. In the Willamette Basin, for example, peak flows can occur from November to March during major rainstorms.

Storage and Run-of-River Dams

There are two types of projects in the basin, storage and run-of-river. To understand how hydroregulation models work, it is important to understand the difference between the two and how each functions in a river system.

Storage reservoirs adjust the river's seasonal flow patterns to fit more closely with the way water is used. Water from rainfall and snowmelt is captured and held in the storage reservoirs until it is needed to serve the many river uses. These projects are generally upstream, at the headwaters of the river.

Storage and Run-of-River Projects



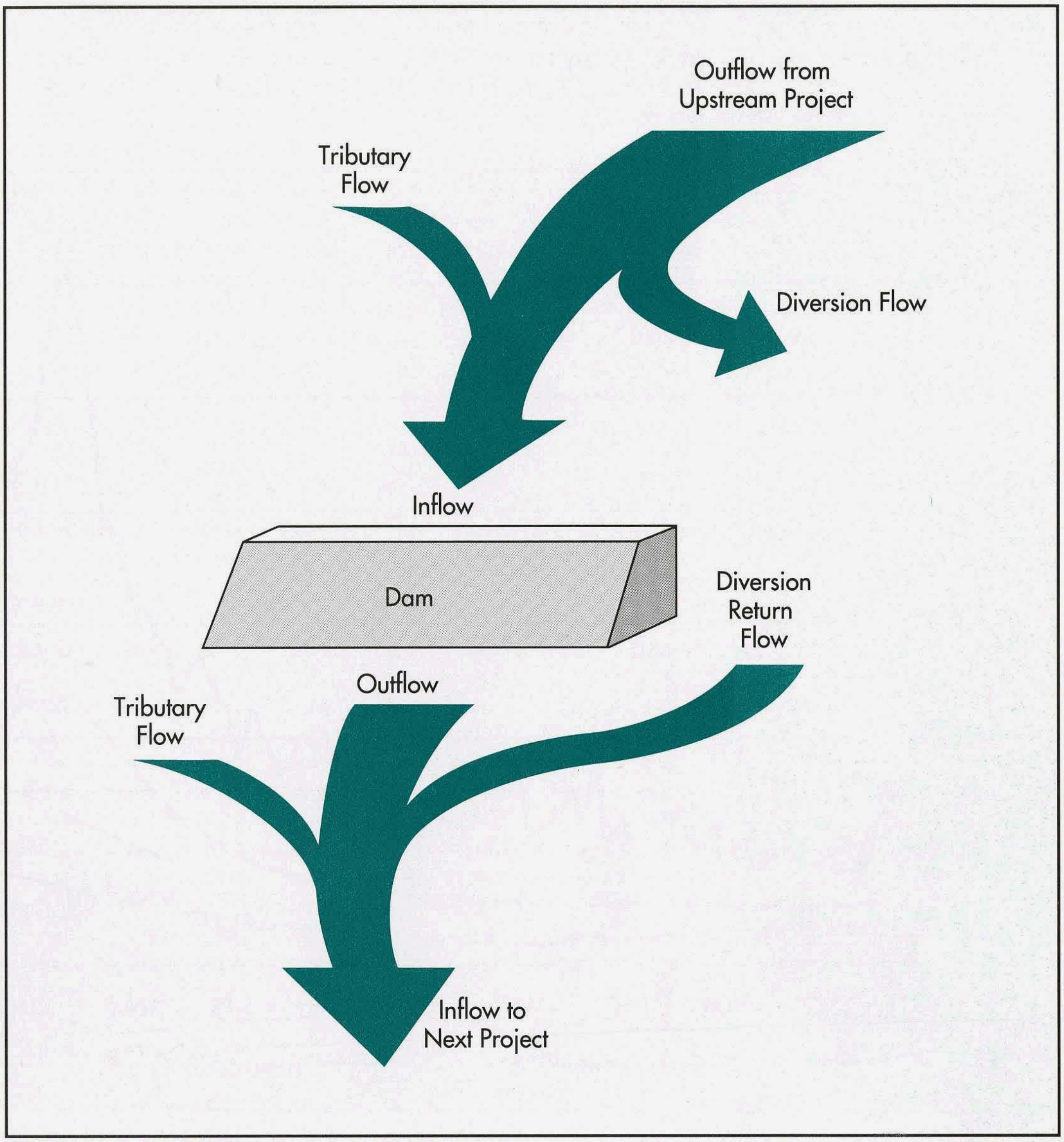
Storage projects may hold water from high runoff years for use in low runoff years. Run-of-river projects, on the other hand, draft and fill in a matter of hours or days.

Run-of-river projects have limited storage and were developed primarily for navigation and hydropower generation. Water that backs up behind these projects is referred to as pondage. At run-of-river projects, water passes through the dam at approximately the same rate it enters the project. This means the pond behind the dam is maintained at nearly the same elevation year round.

Water is stored at reservoirs, and it is released when needed. It travels down the river and becomes "inflow" to the next project. If the downstream project is a storage reservoir, some of the water may be held over an extended time. The portion released is called the "outflow."

The Columbia River system is a mix of storage and run-of-river projects, which are operated together in an attempt to gain the maximum benefit from the water in the basin.

Schematic of Inflow and Outflow



Inflow, which is the water that enters a project, and outflow, which is the water that is released through a powerhouse or dam, are major components of the equation that underlies hydroregulation modeling.

Hydrology and Seasonal Operations

In the late spring and summer, the reservoirs east of the Cascades fill with water from the snowmelt runoff. They are held as full as possible through the summer to enhance recreation and conserve water for later use. Some drawdown of storage may occur in the summer for irrigation, water supply, fish passage, and power generation.

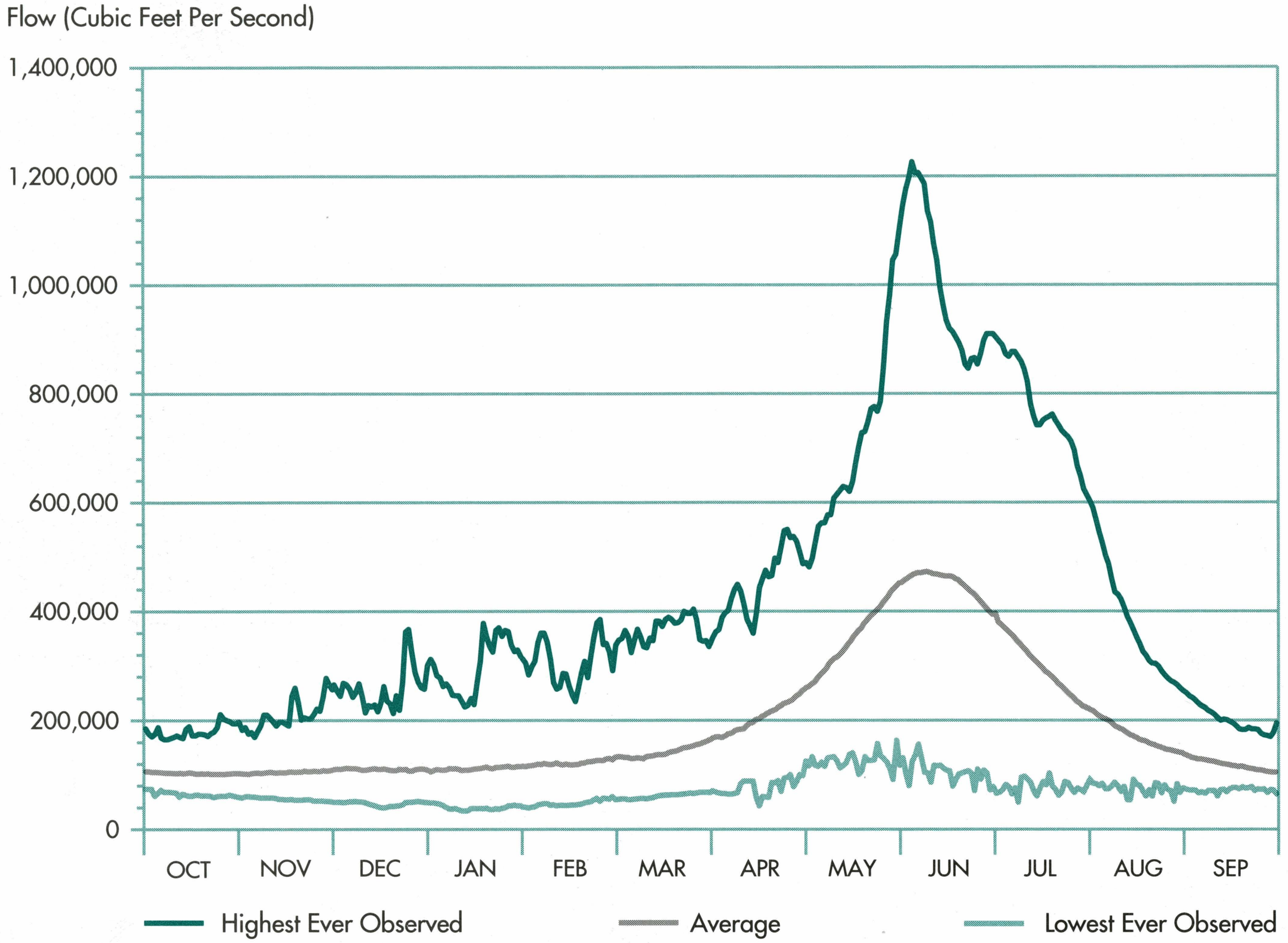
The major drafting of the reservoir system accelerates early in the fall when temperatures and streamflows begin to drop. At this time, power demand increases and recreational use of the lakes and reservoirs decreases. Drawdown must also begin in the fall to make storage space available for winter flood control.

The reservoirs reach their lowest elevations in February to early April. Snowmelt typically begins in about mid-April and reaches a peak in June. A portion of the resulting high flows is stored to reduce flood danger downstream and to refill the reservoirs.

This is a general description of how the system operates. The hydroregulation models calculate the system's performance in terms of power generation, outflows from the projects, and ending reservoir levels for any given month and for any changes in the operation of projects or new requirements on the river system.

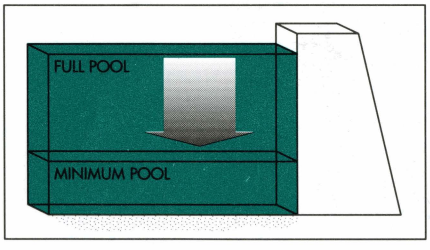
Three Seasons of Reservoir Operation

Flow Measured at The Dalles, Oregon



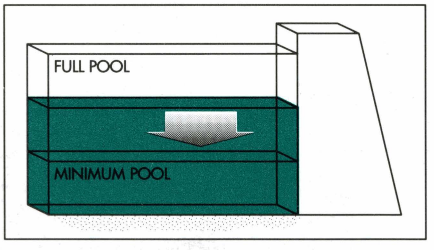
Three Seasons of Reservoir Operation

August through December



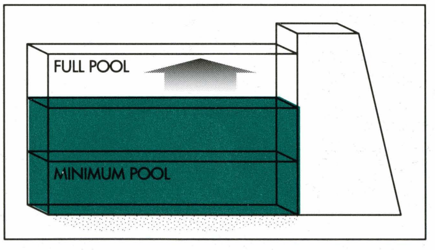
Fixed Drawdown: During the late summer and fall when the volume of the next spring runoff is unknown, reservoir operations are guided by fixed rule curves that follow historical patterns.

January through March



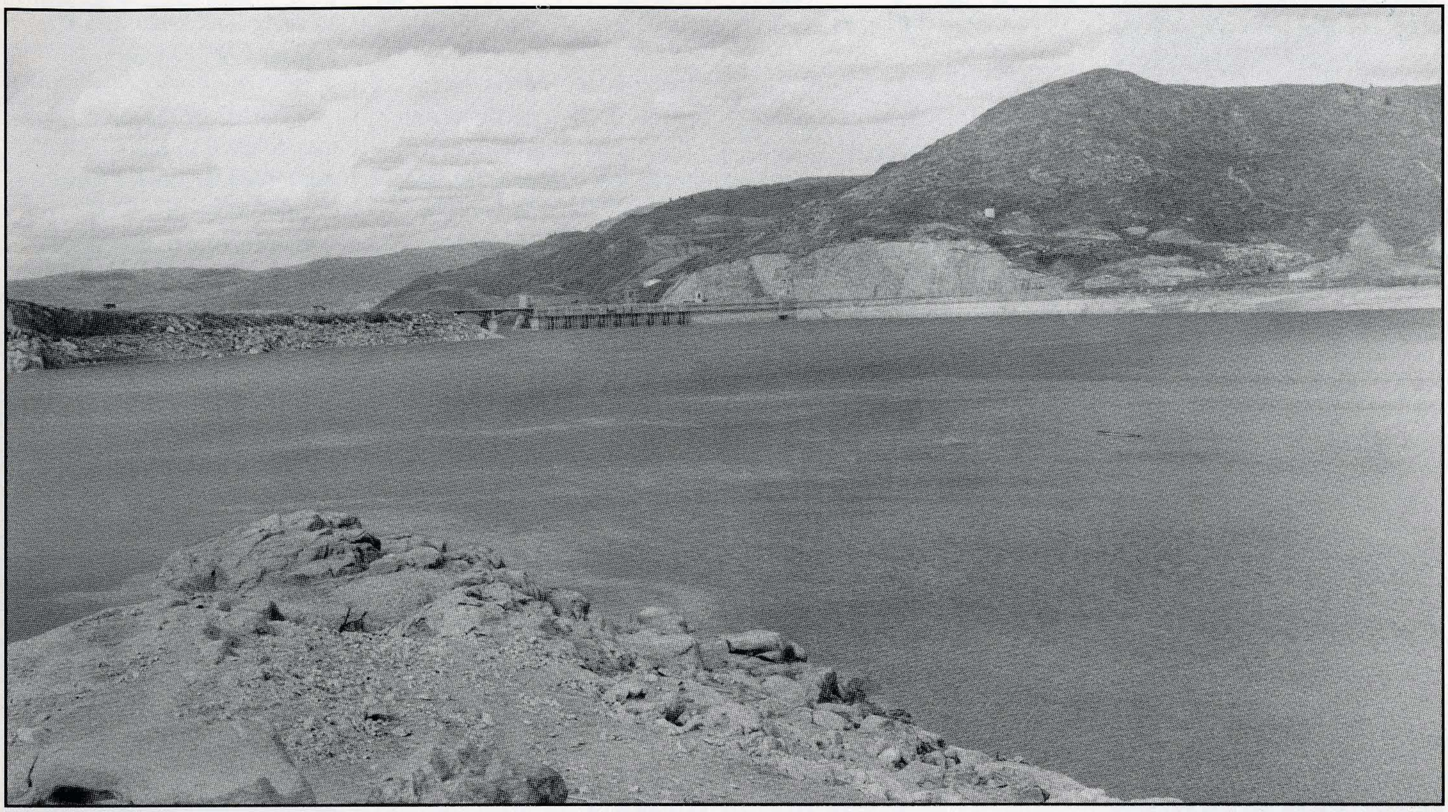
Variable Drawdown: Spring runoff forecasts are available beginning in January. They are the basis for rule curves that guide operations through the runoff and refill season.

April through July

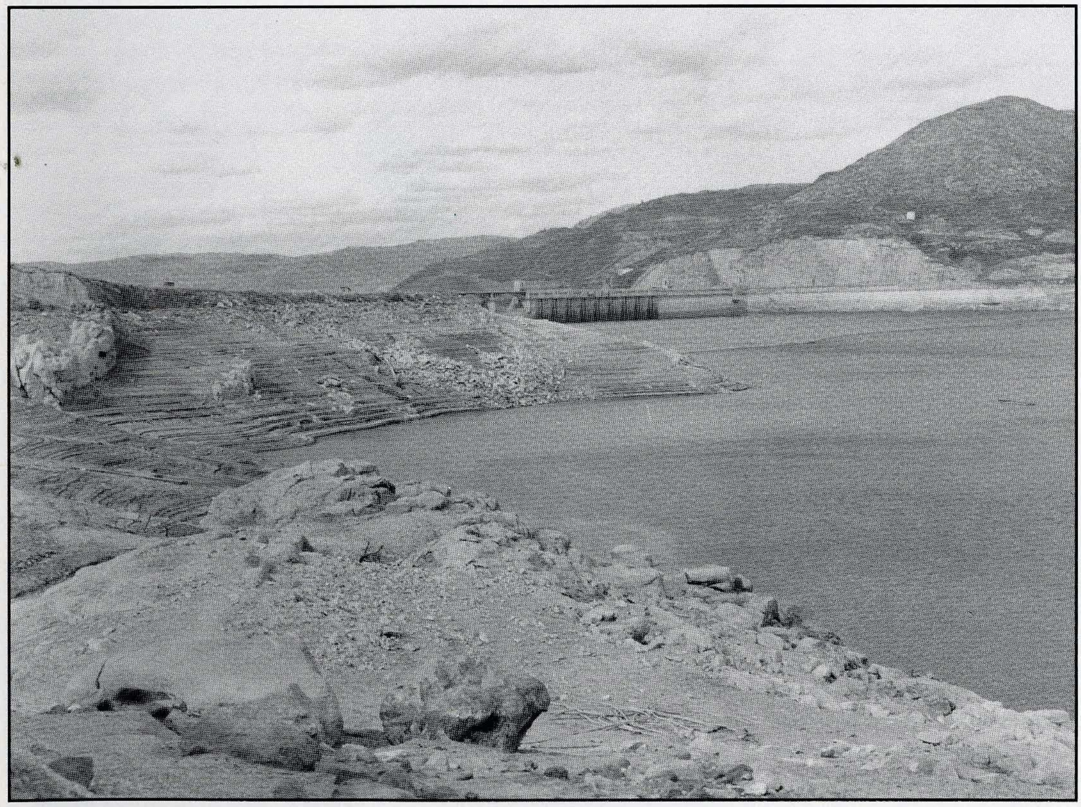


Refill Season: Operators focus on capturing enough runoff to refill reservoirs by the end of July. When runoff is low, reservoirs may not refill, and future operations are partially shaped by how low reservoir levels are on July 31.

Operations on the Columbia River system are built around seasonal streamflow conditions. The water in the river can vary dramatically from month-to-month, depending upon precipitation and snowmelt.



Snowmelt is captured and stored in reservoirs until it is needed. During the summer months, the lake levels are purposely held high for recreation.



The amount of storage and release is carefully regulated to avoid flooding. Reservoirs are drawn down in early winter and spring to make room for heavy inflows from the snowmelt.

Chapter Three: The Basics of Streamflow Routing

The Continuity Equation

The three hydroregulation programs discussed in this paper are sequential streamflow routing models. They are referred to interchangeably here as hydroregulation models and streamflow routing models. At the heart of each model is the same calculation. It is called the continuity equation, and it goes like this:

The reservoir outflow (O) in any time period is equal to reservoir inflow (I) during the same period minus the change in reservoir storage (ΔS) minus losses (L).

Put another way,

$O = I - \Delta S - L.$

For each dam in the system, the program calculates what the outflow would be:

- given the inflow (from natural runoff and releases from any upstream projects), and
- the change in storage at that dam (ΔS is positive if water is added to storage; ΔS is negative if water is released from storage), minus
- losses (from diversions, withdrawals, or evaporation).

In many cases, the object of operation is to provide a particular flow on a river reach for navigation, fish passage, or power generation. The problem then is to determine how storage must change in the reservoir to ensure that this flow requirement is met. In such cases, the continuity equation would be set up and solved as follows:

$\Delta S = I - O - L.$

The calculation in this instance determines the change in storage given inflow, outflow, and losses.

The model repeats the continuity equation for each project considered and for each period in an analysis.

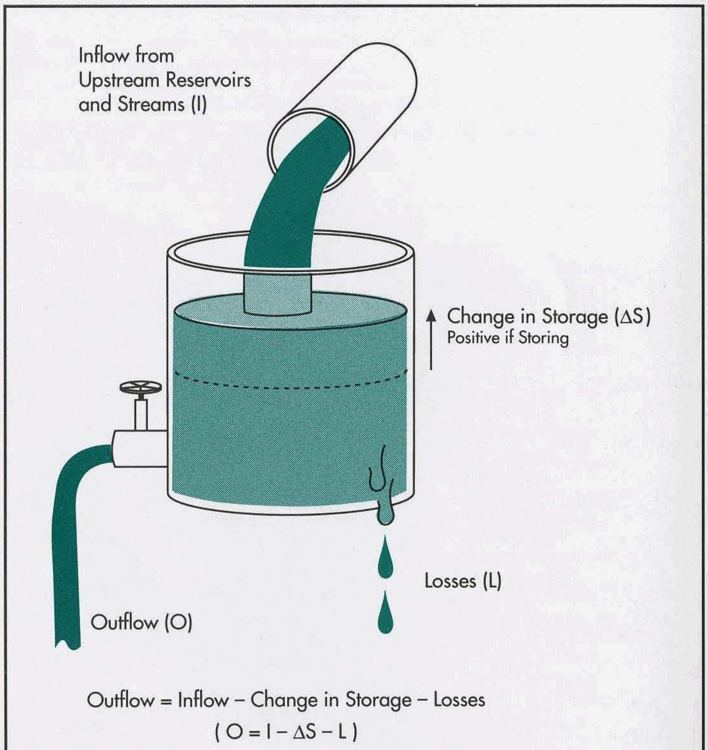
The model calculates this information sequentially. In a full system analysis, the computation starts with the uppermost storage reservoir on the system. The outflow at the first project, plus or minus any major changes along the way, such as an irrigation diversion or the confluence with a tributary, becomes the inflow at the next project. And so the model continues, calculating the streamflows and reservoir elevations for each time period at every project on the system.

Using the Models to Meet Objectives

Hydroregulation models can be used to help determine how to meet a variety of operating objectives. For example, one of the objectives on the Columbia River system is power generation. The models compute the outflow at each dam. Using another set of equations, the outflow can be converted to electrical power production, that is, megawatts (MW). The conversion is shown in the adjacent box.

Once the conversion to power is made, the model adds up the power generation (megawatts) determined for all of the projects. The result is a figure that represents the systemwide power output in megawatts.

Continuity Equation



The continuity equation is a formula that is used in hydroregulation modeling. Water going out of a reservoir equals the water coming in, minus any storage and losses that occur.

Determining Power Generation

Falling water produces power. The amount of power produced depends on three factors:

1) How much water is falling through the turbines, usually measured in cfs.

2) The vertical distance the water falls, called "head." This is the difference between the height of the water behind the dam (forebay elevation) and the height of the water below the dam (tailwater elevation).

3) The efficiency of the generating equipment. Hydro project efficiencies generally range from 85 to 95 percent.

The equation for calculating how much power can be generated at a project is:

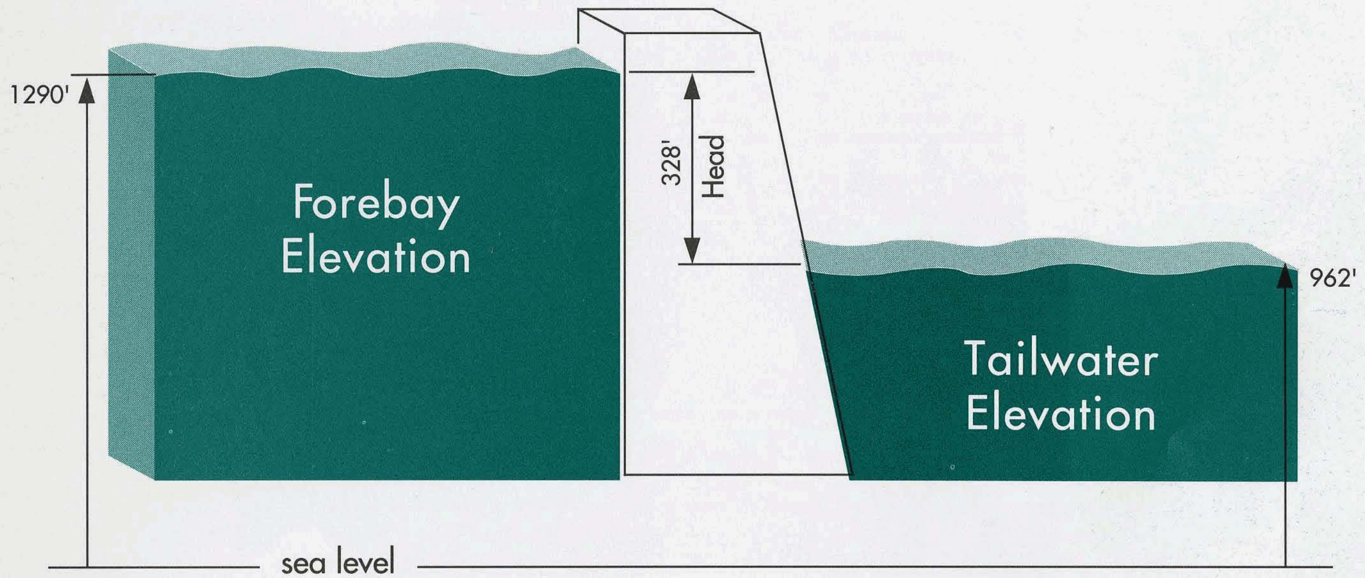
$$\text{Power (kw)} = \text{Flow (cfs)} \times \text{Head (feet)} \times \text{Efficiency} \times \frac{1}{11.8}$$

or, $$P = \frac{Q \times H \times E}{11.8}$$

As an example: Power from 100,000 cfs of water flowing through Grand Coulee at full pool would be calculated as follows:

- Head = 1290 - 962 = 328 ft
- Efficiency is about .88

$$\text{so, } P = \frac{100{,}000 \times 328 \times .88}{11.8} = 2{,}450{,}000 \text{ KW} = 2{,}450 \text{ MW}$$



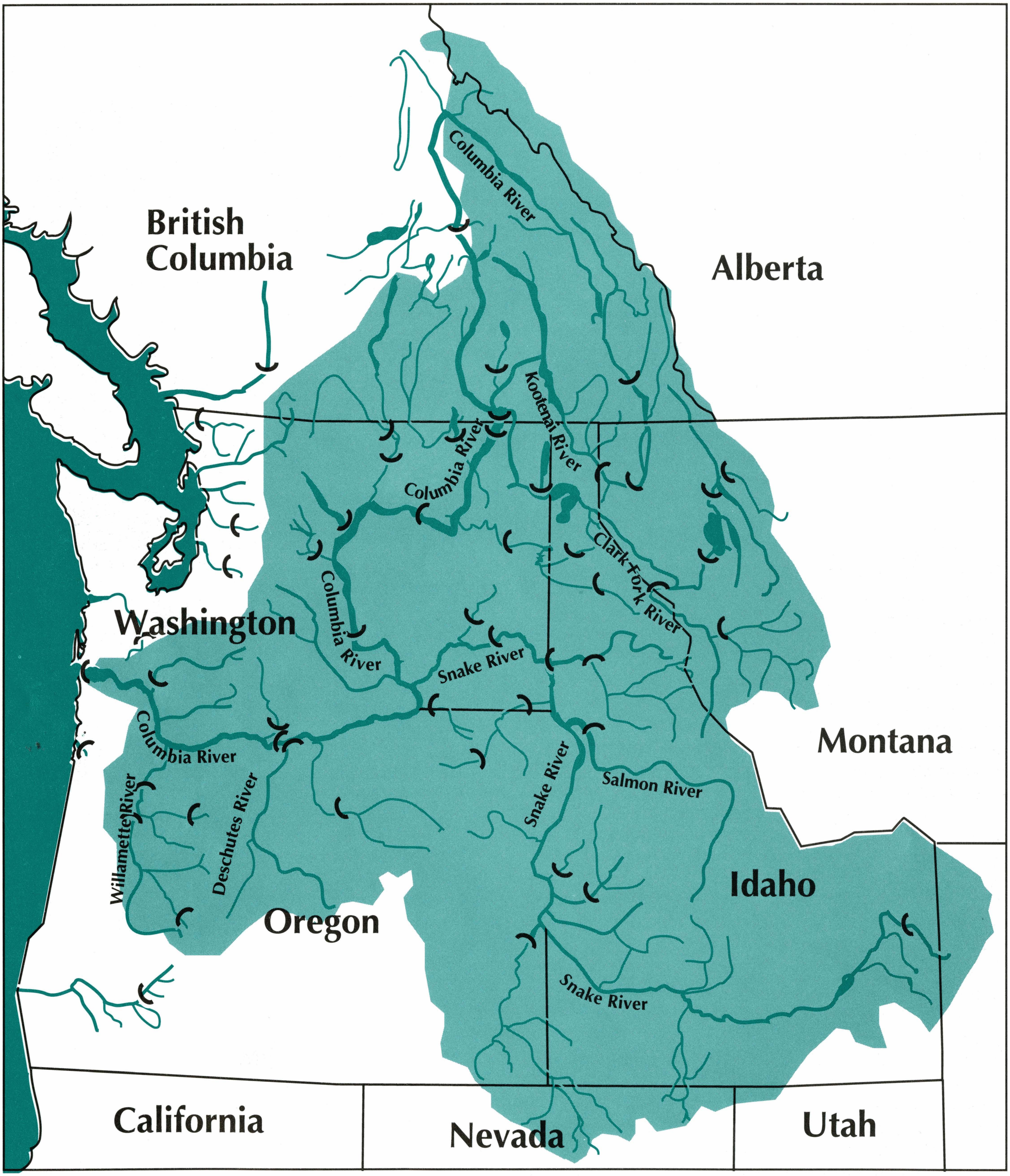
Flood control is another key objective in Columbia River operations. Maximum flows, above which flooding will occur, have been established at key points on the river. Streamflow routing models can help determine how much water must be stored in the reservoirs during flood periods so that rivers will be kept below flood levels.

At Vancouver, Washington, for instance, flows that exceed 600,000 cfs will cause floods. The models can demonstrate whether planned operations upriver will contain the flood or whether the maximum flow target at Vancouver will be exceeded.

Hydroregulation models can be used to assess whether planned operations will provide flows adequate to protect fish and wildlife habitat at various places on the river and to move young salmon to sea. For example, the Water Budget, established by the Northwest Power Planning Council in 1984, aims to achieve a minimum flow target during the spring and early summer at Priest Rapids Dam on the Columbia River and at Lower Granite Dam on the Snake River. This helps fish move more quickly between projects. The models are used to determine how much water must be released from storage projects to ensure that these flow targets are met.

On a complex river system such as the Columbia, where there are numerous competing river uses, streamflow routing models help in planning operations that attempt to satisfy a combination of objectives at

Gaging Stations



A network of gaging stations has been established around the region. The measurements taken at these sites serve as data for computer simulations that will be made to help plan system operations.

the same time. The three models discussed in this paper consider all system uses simultaneously.

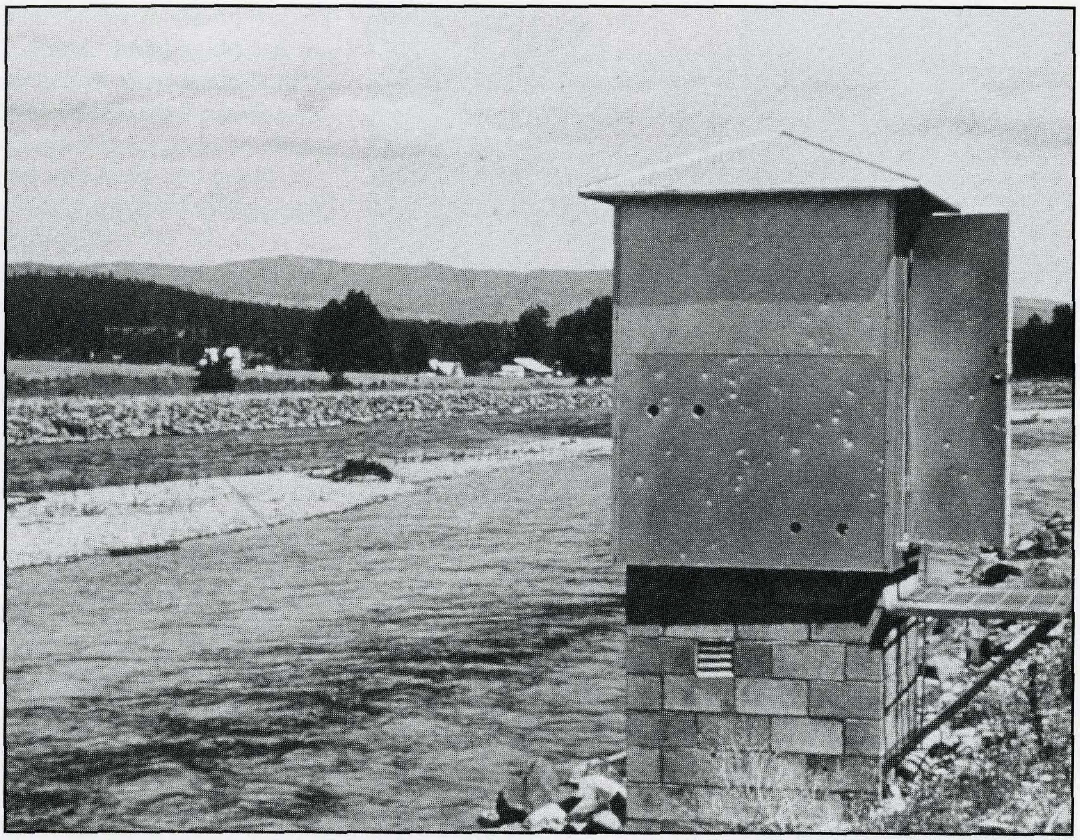
Control Points

The previous discussion touched on an essential part of the streamflow routing models, control points. Control points are identified and characterized in the models. They are points on the river where streamflow or elevation targets or both have been established and where they are measured or gaged. In the Columbia River models, all of the run-of-river dams and storage reservoirs are control points.

There are other control points on the system where flow or elevation targets have been established to meet a particular need. At Vernita Bar on the mid-Columbia River, for example, a seasonal flow target protects chinook salmon spawning grounds. Releases from Hells Canyon Dam are made to keep an adequate navigation depth on the Snake River downstream at Lime Point, another example of a control point. And, as noted earlier, Vancouver, Washington, is the control point used to gage flood control operations to protect the highly developed areas along the lower Columbia River.

Given an operating proposal, the models attempt to operate the reservoir system to meet the specified objectives, and they report elevations and streamflows at each control point. If the computer output shows that a certain operation will not meet the targets at one or more points, adjustments to the operating criteria may be made to bring outcomes closer. More water may be held upriver if the elevation at a downriver control point is too high. Additional water may be released from a reservoir if the flow at a downriver control point is too low.

It should be noted, however, that at times not all of the targets can be met simultaneously. The models have built-in priority lists (which can be changed if necessary) on which some targets take precedence over others at a given control point. For example, flood control objectives always take precedence over hydropower requirements. This topic appears again in Chapter 4 when specific types of model runs are described.



Many of the gaging stations are equipped with radio communication devices that relay information on streamflow and river levels from remote locations.

Chapter Four: Model Inputs

A product is only as good as the parts that go into it. And the output of the hydroregulation models is only as up-to-date and accurate as the data that are input. The models themselves can run in a matter of minutes. Preparing the data in anticipation of a run can take weeks.

HYSSR, HYDROSIM, and HYDREG are general purpose models, designed to be driven by the data. Each model is basically a suite of programs. The "hydroregulator" is the centerpiece of the models and there are 20 to 30 subroutines. These subroutines or ancillary programs prepare data files that will be used by the hydroregulation models.

The key pieces of input data are described below. Much of the data for each model are stored as tables and graphs in master project files.

Streamflow Records

Streamflow records are the backbone of the hydroregulation studies. These records are essentially the inflow of water at various points in the system. The Columbia River hydroregulation models currently have at their disposal a 50-year historical streamflow record, 1928 to 1978. (The record is periodically extended, and 10 more years will soon be added.) The streamflow measurements recorded for these years are adjusted to account for irrigation diversions and depletions and other changes in conditions since the measurements were gathered. The adjustments are made to simulate natural streamflows as closely as possible and to put the entire set of streamflows on a common base.

For example, the irrigation system in the region was developed gradually. Measurements taken in 1928 at any control point on the river would not reflect the level of irrigation diversions that now take place. The records are adjusted on a 10-year cycle to recognize present-day conditions. They also reflect current operation of tributary reservoirs that are not modeled in the hydroregulator, such as those in the upper Snake, Yakima, and Deschutes Basins.

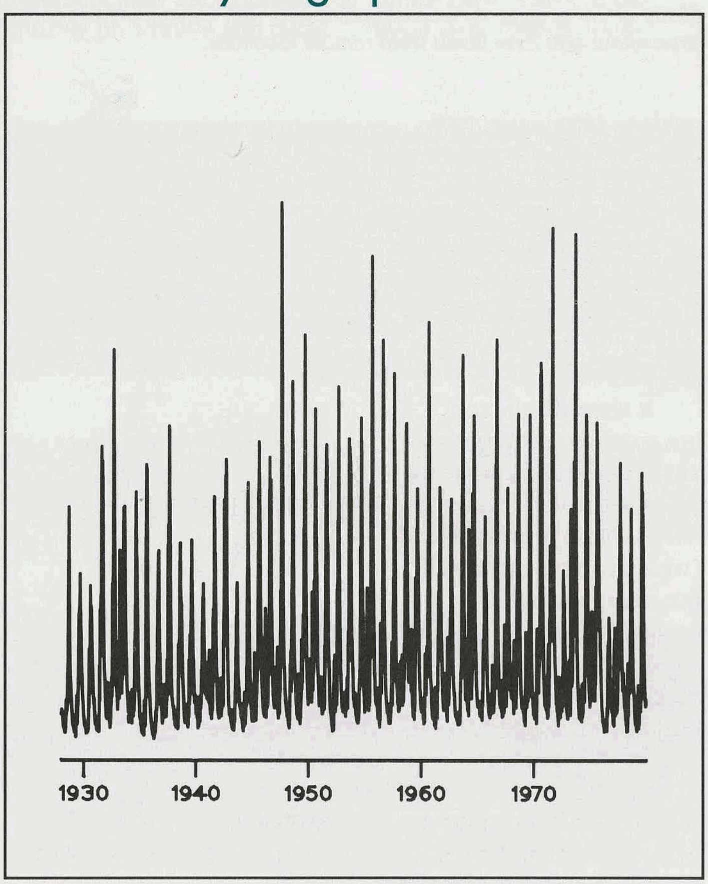
In essence, the model simulates what would happen on today's river system given the precipitation and weather conditions that actually occurred in 1928. The source for the current streamflow data is the Columbia River Water Management Group's publication, *1980 Level Modified Streamflow*.

Project Characteristics

The models also incorporate the physical characteristics of the projects in the Columbia River system. These include minimum and maximum reservoir elevations, storage-elevation relationships, tailwater elevations, and power plant characteristics.

The number of projects for which this information is

Historical Hydrograph



The 50-year historical runoff record is at the heart of hydroregulation studies. The record is made up of streamflow measurements taken at The Dalles, Oregon.

included varies with each model. And it can change with the particular study or operation being simulated. HYSSR generally runs with 65 projects. HYDROSIM uses 80, but it also performs studies that use only 36. The Northwest Power Pool model, HYDREG, includes the largest number of projects, 150. A list of the projects in each model is contained in Appendix A.

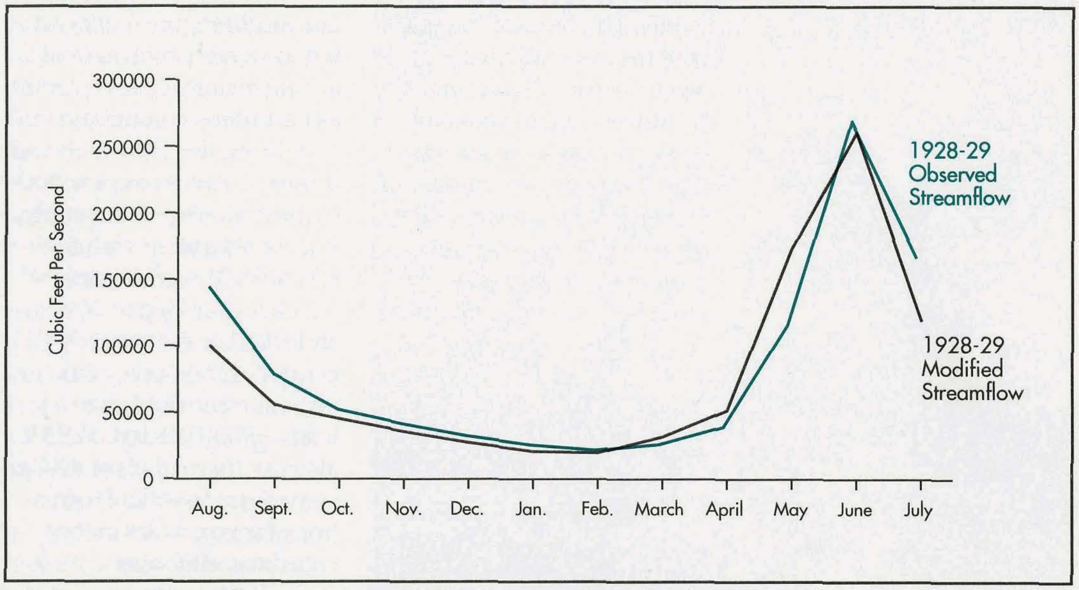
Project Operating Requirements

Operating requirements are the power production and nonpower requirements that define a project's operation. These include the maximum and minimum amount of water that can be released from a project at one time (discharge), and the maximum and minimum reservoir content. These constraints may serve to protect areas downstream from a project. For example, a large instantaneous release could endanger fish spawning grounds below a dam. Constraints may also aim to preserve resources at a reservoir: when water is drawn down too low, resident fish and shoreline vegetation suffer.

Many operating requirements are seasonal. For example, to keep reservoirs from overflowing their banks during the high runoff period, reservoirs must be drawn down before the middle of April in anticipation of the spring snowmelt. Reservoir elevations are allowed to go higher in July, when the danger of flooding is gone, and vacationers want a full lake for boating. Tables in the model incorporate these seasonal variations.

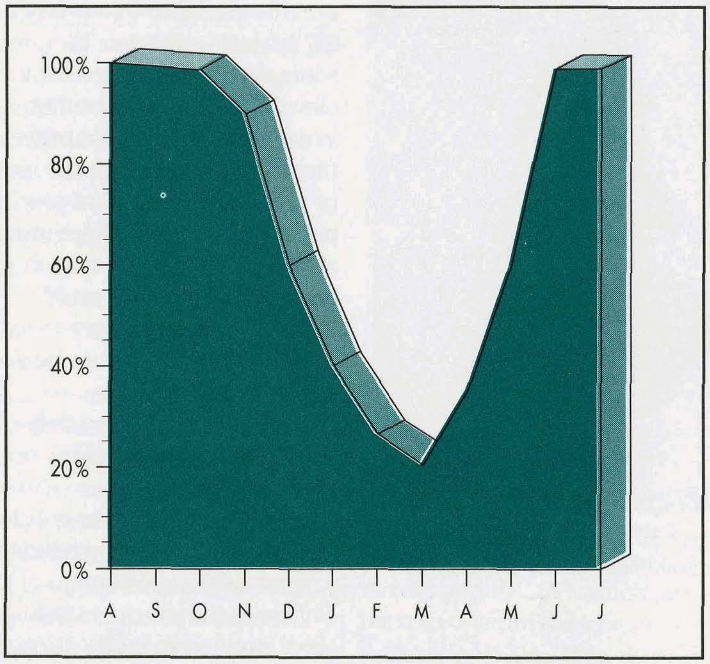
Grand Coulee Project

1928-29 Observed Streamflow vs. 1928-29 Modified Streamflow



All 50 years of streamflow records are put on a common base for the hydroregulation studies. The observed or actual measurements are adjusted to reflect conditions on today's river system.

Typical Flood Control Rule Curve

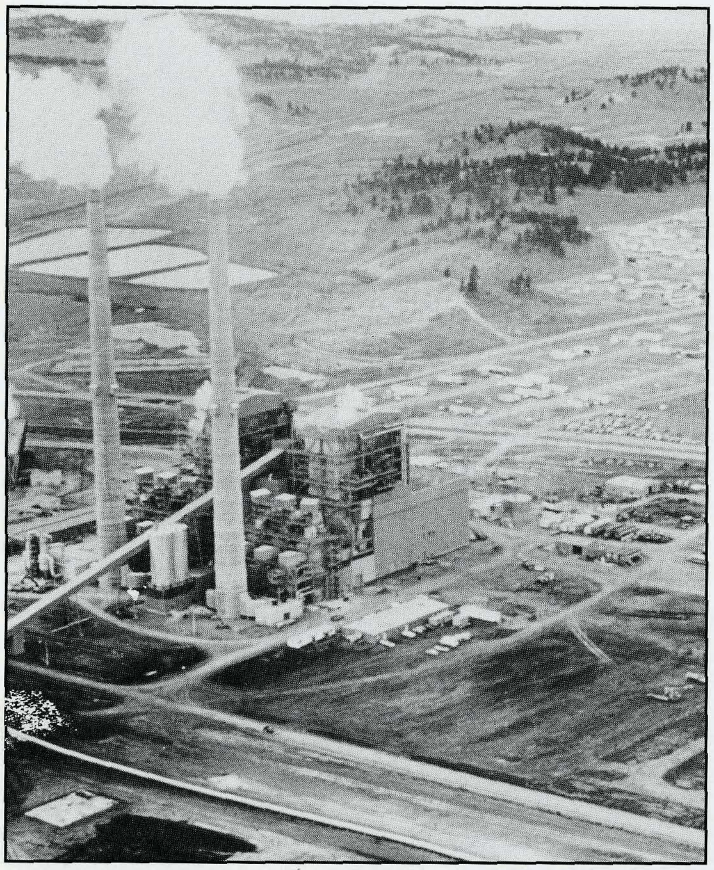


The flood control rule curve defines the drawdown required to assure adequate space is available in the reservoir to regulate the predicted runoff for the year without causing flooding downstream.

Normally, operating requirements are specified by the project owners and submitted to the Northwest Power Pool for PNCA planning. In the SOR, the operating requirements are being specified by technical work groups that are developing operating alternatives.

System Power Loads

The hydroregulation models can be used to compute the system's ability to meet electricity loads in the Northwest and to generate power for sales outside the region. Loads (the amount of power that customers of the power system need at any given time) are input to the models. Different computer studies answer different questions: Is the system capable of meeting the projected load? How much power can be generated under a given set of operating conditions? Will thermal generation be needed in addition to hydro generation to meet the load? If so, how much?



Thermal power projects represent about 30% of the region's total energy capability. The contributions from these plants are a factor in hydro system planning.

Thermal Resources

The models may incorporate other power generating resources, such as coal and nuclear (thermal) plants, as part of the computation in certain studies. The ability of these resources to contribute to the region's power supply is a consideration with the HYDROSIM studies, most of which are looking at how and whether the region's generating resources can meet current and future loads. HYDREG and HYSSR also use thermal plant data in some form to set the regulations for reservoirs in the coordinated system.

Rule Curves

Rule curves represent reservoir water levels and provide guidance in meeting project purposes. In some cases, the curves set elevations that must be met in each time period. At other times, they specify upper or lower elevations that are not to be violated. There are also occasions when rule curves define a range over which operations are permitted. Rule curves can be a product of the hydroregulation models, and they can be data input used to compute operations.

The operating year on the Columbia River system is August 1 through July 31. Before each new operating year, studies are made using the hydroregulation models and historical streamflow records to derive the rule curves for multipurpose operation of the dams on the river. The models use the rule curves to determine reservoir operations during the coming year under differing water conditions.

Ranges of Requirements

One valuable use of the hydroregulation models is to test ranges of operating requirements to evaluate the impact on project outputs and river uses. For example, possible operating scenarios may be established to compare current operations with a hypothetical or future situation. The models will compute and report the flows and elevations that would result from a number of operations.

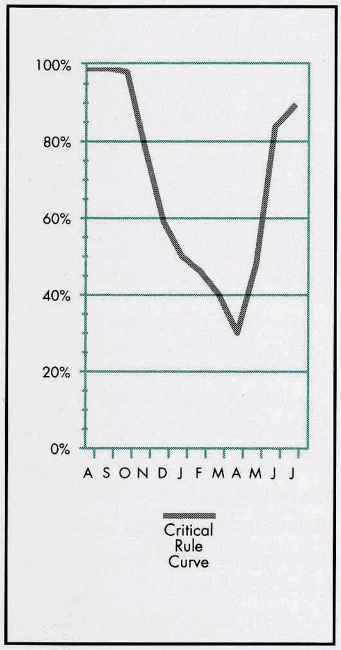
This use of the models is essential to programs such as the SOR. As demands on the system evolve and grow, planners must be increasingly attuned to how operating changes affect the interaction among multiple uses. How can the system best accommodate these new pressures and uses? What will be gained and what will be lost? The answers to these questions can be found, in part, in the flow and elevation data the hydroregulation models produce.

Where Do the Data Come From?

Input data are developed in several different ways. The Corps, BPA, Reclamation, and the Northwest Power Pool have long-established means for collecting and preparing the data needed for the models. The data falls roughly into three categories:

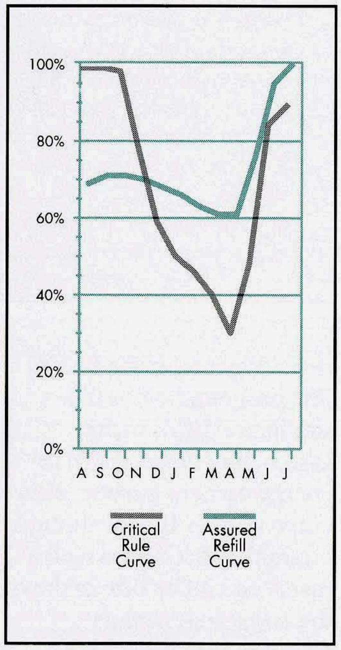
- Data that are long-term
- Data that are revised annually
- Data that are revised only as needed.

Critical Rule Curve



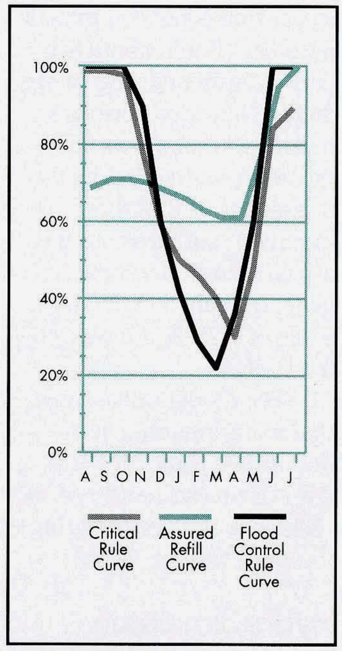
The critical rule curve defines reservoir elevations that meet firm hydro energy requirements under the most adverse streamflows on record.

Assured Refill Curve
with Critical Rule Curve



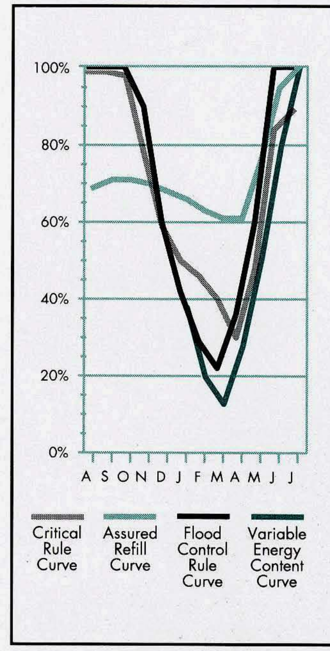
The assured refill curve represents the level from which the reservoir could refill if the low runoff conditions observed in 1931 occur again.

Flood Control Rule Curve
with Critical Rule Curve and Assured Refill Curve



The flood control rule curve defines the drawdown required to assure adequate space is available in the reservoir to regulate the predicted runoff for the year without causing flooding downstream.

Variable Energy Content Curve
with Critical Rule Curve, Assured Refill Curve, and Flood Control Rule Curve



The variable energy content curve, which guides nonfirm energy generation, is usually the lowest of the four curves during the winter and early spring and is based on predicted runoff during the year.

Many program files operate year after year with no changes. In general, these are the physical characteristics of hydro projects. Load and power rule curves, on the other hand, are updated annually. Appropriate revisions are made to reflect such things as current lists of resources and operating requirements. Data that are revised only as needed include such things as nonpower operating requirements. If a new requirement is established, the information goes into the program files. For example, in 1984, when fish-related flow targets were established in the Water Budget, these were entered into the data files.

Some data come from other government agencies. The U.S. Geological Survey collects streamflow measurements; the U.S. Soil Conservation Service calculates snowpack; and the Northwest River Forecast Center uses much of this information to develop streamflow (volume) forecasts.

And as described above with rule curves, the output of one hydroregulation model becomes the input for another, or for a new computation with the same model. HYDROSIM calculates rule curves that are used in many studies elsewhere, and both HYSSR and HYDROSIM are used to develop new operating requirements that are input to HYDREG in developing rule curves under the PNCA.

Chapter Five: A Closeup of the Columbia River Models

Planning for the "Critical Period"

Critical period planning is required by the Pacific Northwest Coordination Agreement. The critical period is the portion of the historical 50-year streamflow record that would produce the least amount of energy, with all reservoirs drafted from full to empty. This energy value is called the hydro system's Firm Energy Load Carrying Capability (FELCC). The hydroregulation computer studies produce rule curves that define reservoir elevations that meet firm energy requirements under the most adverse historical streamflow conditions.

In recent years, the critical period has been based on the 42-month interval from September 1, 1928, through February 29, 1932. This is often referred to as the four-year critical period. A critical rule curve is derived for each year of the four years; they are called Critical Rule Curves 1,2,3,and 4.

The three Columbia River hydroregulation models are similar in many ways. They are all sequential streamflow routing models that simulate the same basic physics. Each operates over a year that is divided into 14 periods. (Each month is a period; April and August are divided into two periods because streamflows vary greatly from the first half to the second half of these months.) All three models are written in a computer language called FORTRAN. Parts of HYSSR are written in COBOL.

The models all assume that water released at the uppermost project on the river during a specific period will reach the ocean during the same period.

Hydro Simulator Program (HYDROSIM)

HYDROSIM is the newest of the three models. It was written to replace two of BPA's earlier hydroregulation programs that could not share data with some of the agency's new power marketing and economic models, in particular the System Analysis Model (SAM). HYDROSIM incorporated the hydroregulation code used in SAM so data files can be easily interchanged between the models.

HYDROSIM models operations of the Pacific Northwest hydro system. HYDROSIM can be used to determine critical rule curves and the availability of firm energy, or to examine operations under other historical streamflow conditions.

In its "Proportional Draft" mode, HYDROSIM simulates operations of the reservoirs under the PNCA. The program begins the simulation by drawing system reservoirs down to energy content curves. This curve defines the lower limit under the PNCA to which a reservoir can be drawn down to produce secondary (nonfirm) energy. If the simulated system is unable to meet the system's firm load, all reservoirs are drafted to first-year critical rule curves; if the system is still short of energy, reservoirs are drafted to second-year critical rule curves. (The critical rule curves are described on the previous page.) And so the simulation continues until the firm load is met.

In the "Fixed" mode, each period's operation for all or some of the reservoirs is specified in advance by the modeler. Storage at each reservoir will be drafted or filled as specified (unless constrained by physical or operational limits). The program begins at the most upstream project and proceeds downstream, setting operation at each plant based on the user-specified operating mode. After operation is set, the program calculates flows and megawatt values.

Most studies use a combination of fixed mode and proportional draft. Some projects are fixed, and others are free to draft among rule curves to meet loads.

The program checks project operating requirements against the flows and elevations it is calculating. There are 10 "flags" in the program to alert the user that a target operation was not reached due to a physical or operational limit. When a requirement is flagged, the operator may make adjustments appropriate to the situation.

The flags are in the program in priority order, as shown in the adjacent box.

The operational studies HYDROSIM supports include the calculation of benefits and the development of operating plans required by the Columbia River Treaty. The model is also used for BPA's "White Book," a study of the region's load/resource balance; rate determinations; and evaluations of changes to operating requirements. It is being used, along with HYSSR, to evaluate proposals under consideration in the SOR.

Hydro System Seasonal Regulation Program (HYSSR)

HYSSR was written primarily to analyze the Columbia River system, although it has been used in planning studies in other basins, including the Mekong River Basin in Southeast Asia. It is capable of simulating the region's hydro and flood control operations as they are to be carried out under terms of the PNCA and the Columbia River Treaty between the United States and Canada. It also accounts for a variety of other nonpower operating requirements.

The Corps uses a separate model called Streamflow Synthesis and Reservoir Regulation (SSARR) for its flood control operations and daily river forecasting. (SSARR also develops the flood control rule curves used in the three hydroregulation models.)

HYSSR can be used in one of several single-objective modes or in a combination of modes. For example, in the "Fixed Rule-Curve Level" mode, the user specifies the rule curve to which each storage project will be operated. There are seven rule curves from which to choose: the flood control (upper) rule curve; the energy content curve; the first, second, third, or fourth year critical rule curves; and empty. Flows and power generation are computed based on the rule curve specified.

HYSSR is often used to model target flows. In the "Meet Target Stream Flows" mode, the user specifies the target streamflows at control points on the river. The model will attempt to meet these targets, starting at the uppermost control point in the basin and proceeding downstream. Selected storage projects upstream of a control point will be drafted proportionately to meet the desired target.

In all modes, the model checks the operating constraints at each project. That means the model is programmed to look at all operating limits and alert the user if a simulation shows operations would be outside those bounds.

HYSSR is used to support several regular annual studies, including the region's refill studies. The PNCA planning goal is to generate secondary energy only to the extent that there is a 95% confidence that reservoirs will refill. Analysts use HYSSR to determine whether planned operations will meet that goal in any given year by running simulations that span the 50 years of streamflow records.

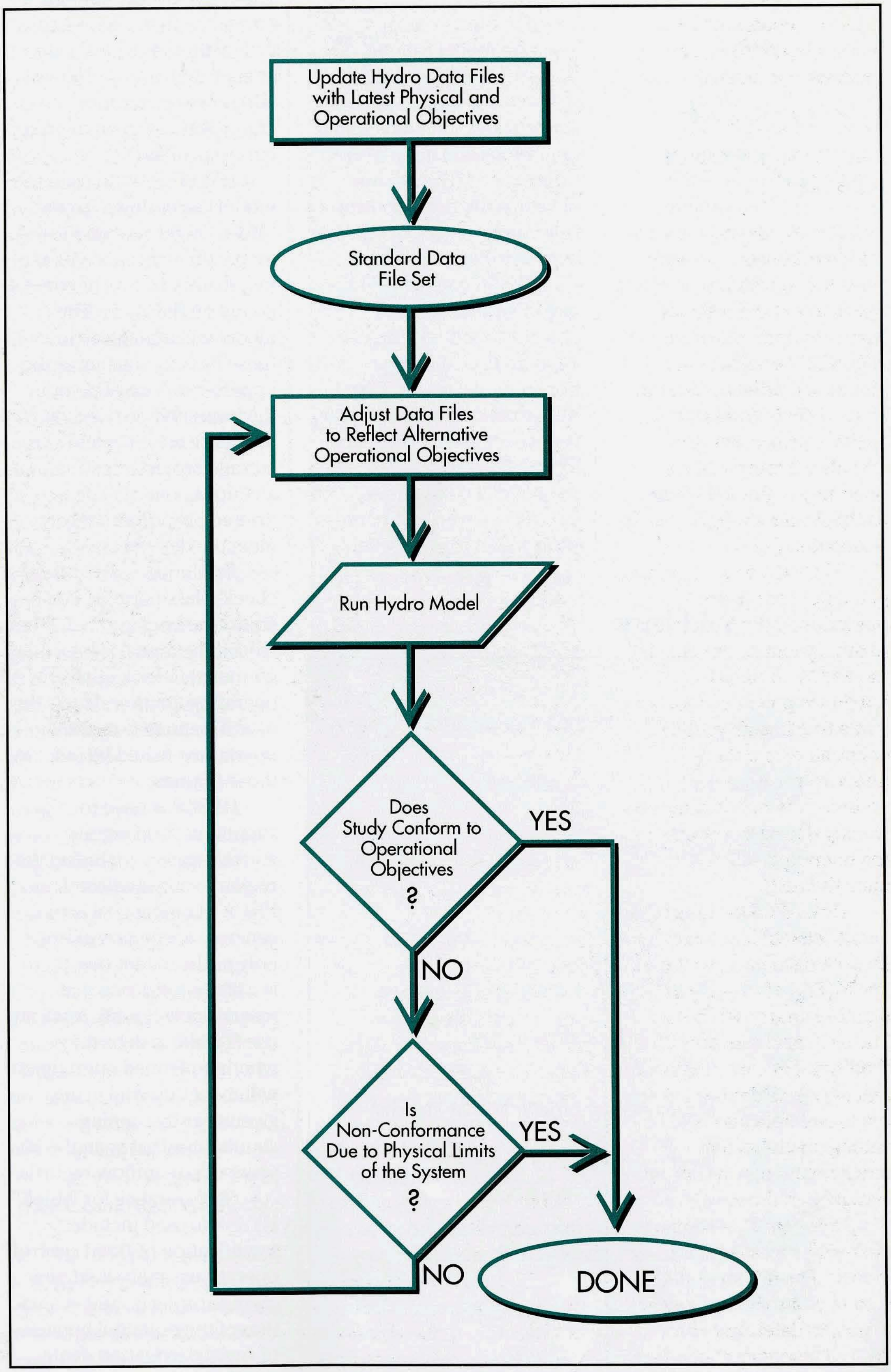
Other studies for which HYSSR is used include: modification of flood control operations; analysis of new storage projects; and evaluation of the potential impacts of revised irrigation depletion levels, water budget alternatives, and various provisional draft strategies.

HYDROSIM Flags

SH	Permanent Storage Maximum
SL	Permanent Storage Minimum
QR	Restriction Flow
UR	Flood Control
KR	Kerr split period operation (Specific to Kerr Dam)
QH	Maximum discharge or flow in the river
QL	Minimum discharge or flow in the river
DR	Draft rate limit (bank erosion) or recreation season limits
SM	Minimum reservoir content for nonpower uses, e.g. irrigation
FG	Full Gate (Water above full gate is spill)

The computer programs have built in "flags" to alert hydro modelers an operating requirement prevented operation to an identified target.

Simulation Process



Hydro modelers begin with a standard set of data which they can change to reflect the needs of a particular study. The data files can be altered to bring about certain outcomes; however, an operation cannot exceed the physical limits of the system.

HYSSR currently operates on an IBM mainframe computer, but it is being adapted to run on personal computers.

PNCA Seasonal Regulation Program (HYDREG)

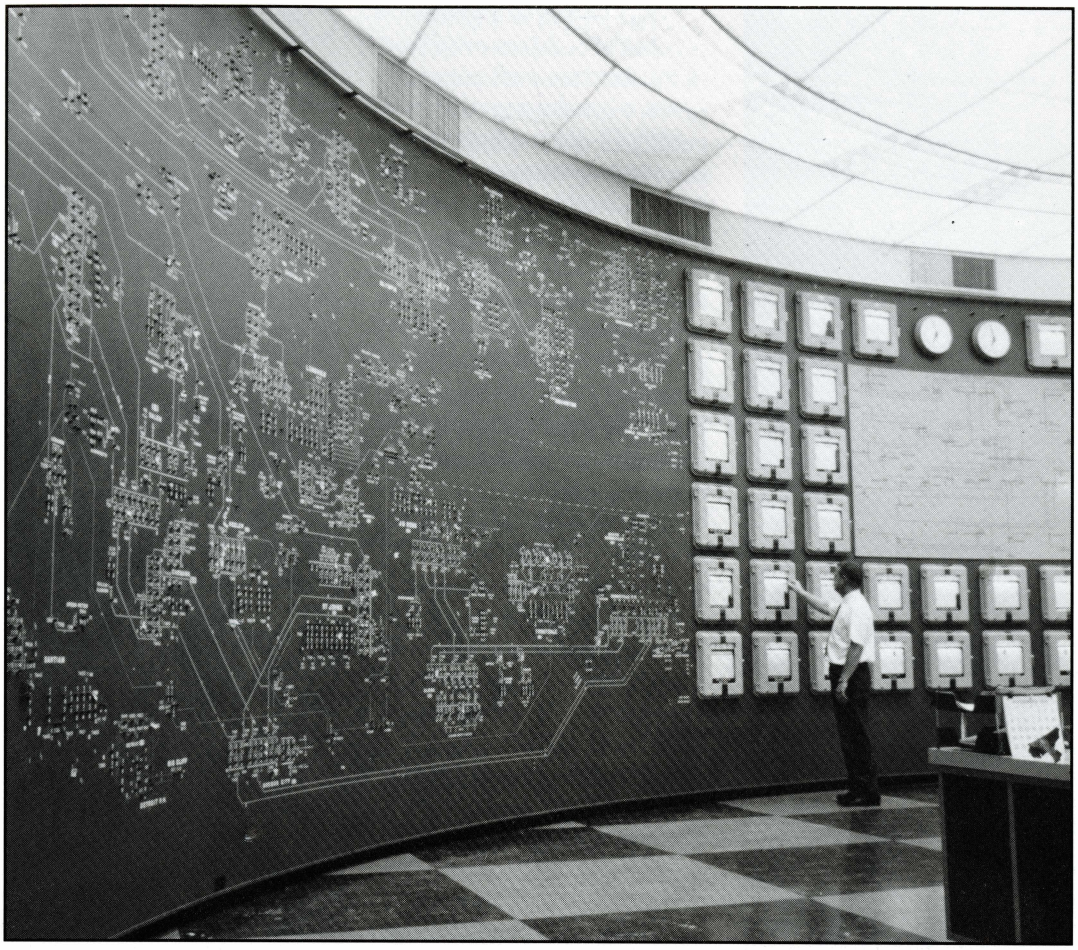
The Northwest Power Pool model sets the regulations for coordinated operation of the region's hydroelectric system. HYDREG takes the individual operating rights and requirements from the region's project owners and blends them into an operating regimen known as the Actual Energy Regulation (AER).

HYDREG was written to guide the coordinated operation of the Northwest hydro system as directed by the PNCA. It aims to maximize power production while fulfilling all project constraints and the nonpower uses of the system. It is run as often as weekly during the course of the operating year to produce the AER.

The AER determines the energy capability of each project, each party to the PNCA, and of the coordinated system as a whole. The AER also provides the draft point at each reservoir that serves as the basis for rights and obligations among upstream and downstream parties during actual operations.

There are three components or processes in the model. The driving function is to regulate the reservoirs, that is, to determine the desired reservoir contents at the end of each of the 14 periods, based on reservoir rule curves and utility loads. (HYDREG reports reservoir contents, which are derived from elevations.) The second process simulates the operation of individual projects. This process successively operates each hydro plant and calculates discharge, tailwater, and forebay elevations, and flow reductions for fish spill and bypass. A third process computes the energy generation and peak capability at each hydro project.

HYDREG supports many studies in the region. It is used to develop the Northwest Power Pool Operating Program for the PNCA members and for the Pool as a whole. (Not all utilities in the Pool are parties to the PNCA.) It calculates the Firm Energy Load Carrying Capability (FELCC) for the coordinated system and for each utility within the system, and it determines what are known as "headwater benefits," the payments downstream beneficiaries make to storage project owners. HYDREG also calculates each party's interchange rights and obligations under the PNCA. These are sales and exchanges among utilities that keep the coordinated system operating most efficiently.



The Northwest Power Pool uses hydroregulation studies to develop the Actual Energy Regulation (AER). The AER sets the real draft points which guide reservoir operations day-to-day and week-to-week.

Chapter Six: From Data to Decisions

The output of a hydroregulation computer run is numbers. There are streamflows, expressed in thousand cubic feet per second (kcfs); reservoir elevations, given as feet above mean sea level; reservoir contents, represented in either million acre feet (MAF) or thousand second-foot days (ksfd); power generation in megawatts; and spill, expressed in cfs. (The adjacent box illustrates some common conversions.)

Conversion Factors

Energy:
- 1 Kilowatt hour = 3,413 Btus = 3.6 million Joules
- 1 Btu = .000293 Kwh = 1,054 Joules
- 1 Calorie = 4.186 Joules
- 1 K Calorie = 4,186 Joules = 3.97 Btus
- 1 Foot-Pound = 1.356 Joules
- 1 Therm = 100,000 Btus

Power:
- 1 Watt = 1 Joule/second
- 1 Kilowatt = 1,000 Watts = 1.34 Horsepower
- 1 Horsepower = 746 Watts = 550 ft-lbs/sec

Volume:
- 1 Cubic Foot = 7.48 Gallons = .0283 cu. Meters
- 1 sfd = 1(cu. ft/sec)-days = 1.98 Acre Feet
- 1 Acre Foot = .504 sfd = 326,000 Gallons

Energy Content of Various Substances:
- 1 Gallon of Gasoline = 125,000 Btus = 39.8 Kwh
- 1 Barrel of Oil (42 US Gallons) = 5.8 Million Btus = 1,700 Kwh
- 1 Cubic Foot of Natural Gas = 1,000 Btus = .29 Kwh
- 1 Ton of Coal = 18 Million Btus = 5,100 Kwh
- 1 Ounce of Uranium Fuel = 1.8 Billion Btus = 510,000 Kwh
- 1 Hour of Sunshine on 1 Acre = 13.5 Million Btus = 4,000 Kwh
- 1 Cubic Foot of Water Falling 100 feet = 7.9 Btus = .0023 Kwh
- 1 Cubic Foot of Water Falling 1,290 feet = 102 Btus = .03 Kwh

Efficiency of Various Generating Types:

Grand Coulee Dam	90%
Coal Plant	30%
Combustion Turbines	50%
Nuclear	25%
Solar Photovoltaic	10-20%
Solar Thermal	18%

Data are presented by project and for the total system. But how are these numbers used to make planning and operating decisions? What links computer printouts to new policies, operating strategies, and resource planning?

The footings of the bridge between data and decisions are built when computer studies are designed. The analyses that are accomplished with the aid of the hydroregulation models answer particular questions about Columbia River system operations. Some of the specific studies were mentioned in the preceding chapter.

In general, there are three types of studies: 50-year continuous; 50-year refill; and critical period. Each of these studies answers a different kind of question or set of questions about system operations.

The Continuous Study

The 50-year continuous study gives planners an opportunity to look at what would happen on today's system of hydro projects under a typical long-term sequence of streamflow conditions, such as the 50-year historical period from August 1928 to July 1978. The model begins its simulation on August 1, 1928, with all reservoirs full and with a prescribed set of rule curves or operating criteria for the upcoming year. It then sequentially calculates the flows and reservoir elevations that would result for each project on the river for each period in that year.

At the end of the 12-month (14-period) calculation, the study continues, modeling system operations using the July 31, 1929, reservoir elevations to begin the subsequent contract year. And so the analysis goes over 50 years, with the final elevations at the end of each water year becoming the starting elevations for the upcoming year. This is the type of study which is used to determine the critical period, which is the sequence of months in the historical streamflow records that would produce the least water for power generation.

Adjusting Operations. A primary use of the continuous study is to determine the impacts of a specific operating change. For example, a proposal may be made to keep a certain reservoir full

Computer Printout of a HYDROSIM Run

BPA Regulator Output for April 1-15 — Water Year 1931, Study Year 1992

	PLANT NO.	NAT Q	Q OUT	QMIN	FORCE	BYPAS	OTHER	INC HKSM	AVMW	DRAFT	ENDSTO	ELEV	URC	ECC	CON VIOL
Libby	1760	3000	3000	0	0	0	200	97.21	57	0	1309.9	2400	2511	1663.3	
Hungry Horse	1530	2553	2553	0	0	0	0	164.73	86	0	1313.1	3540	1549	1121.4	
Albeni Falls	1465	19340	19107	0	13905	0	50	100.52	3	-0.7	14	2050	582.4	57.6	QR
Grand Coulee	1280	61210	61344	0	0	0	0	76.85	1490	0	2408.3	1285	2614	2343.6	
Chief Joseph	1270	61200	61334	0	0	0	500	52.55	816	0	0	955	0	0	
Brownlee	767	12180	11487	5000	0	0	0	84.07	228	-10.4	481.3	2075.5	491.7	466.5	
Dworshak	535	10900	0	0	0	0	0	88.36	0	-164	810.3	1577	1016	790.3	QL
Lower Granite	520	60390	48797	0	0	0	920	41.69	330	0	235.1	736	1001	78.1	
Little Goose	518	60370	48777	0	0	0	880	34.8	331	0	275	636	1001	128.6	
Lower Monumental	504	61320	49727	0	0	0	750	27.88	349	0	186.2	539	1001	83.2	
Ice Harbor	502	61310	49717	0	0	398	3340	20.75	322	0	200.5	439	1001	90.8	
McNary	488	142300	131882	0	0	0	4000	13.81	714	0	0	338	0	0	UR
John Day	440	143500	133082	0	0	0	900	8.22	986	0	115.4	262	269.7	114.9	
The Dalles	365	149900	139589	0	0	0	4000	0.76	161						
Bonneville	320	159900	149589	0	0	0	8400	-0.19	100						

PLANT NO. BPA's numerical designation for projects in the model. Higher numbers generally indicate upstream projects.

NAT Q Unregulated streamflows in cubic feet per second (cfs). These values indicate the water that would flow down the river at each project if all reservoirs remained at fixed elevations. Irrigation diversions and depletions are already factored into these numbers (hence "NAT Q" is something of a misnomer).

Q OUT Streamflows out of the project after changes in reservoir elevations have been taken into account (cfs).

QMIN Minimum flow requirement (cfs). Minimum flows have priority over target elevations in the model. If a target elevation is not met on account of having to meet this flow requirement, it is flagged with a "QL" under the CON VIOL columns.

FORCE Flows (cfs) past a project which could not be used to generate electricity because they were in excess of the maximum turbine flow possible at that project.

BYPASS Flows (cfs) to accommodate fish passage facilities which do not contribute to electric generation at the project.

OTHER Flows (cfs) not covered by the previous categories that circumvent the turbines. Generally this includes, water used by locks, fish ladders, and leakage around and through the dam.

INC HKSM The number of kilowatts generated by the hydro system by the next cfs of flow added to the river starting at this project and flowing to the sea (kw/cfs).

AV MW The average generation in megawatts at this project in this period.

DRAFT The amount of water taken out of reservoir storage in this month (ksfd). Negative values indicate the amount of water added to reservoir storage.

ENDSTO The end-of-period reservoir storage contents at this project (ksfd).

ELEV Reservoir forebay elevation (feet) corresponding to the end storage content above.

URC Maximum allowable storage contents (ksfd) for flood control purposes.

ECC Reservoir energy content curve (ksfd). Drafting a reservoir no lower than this point ensures a high probability of refilling by the end of the spring runoff season.

CON VIOL Shows when the target elevation was violated in order to meet other reservoir operating requirements such as minimum flow (QL), flood control (UR), or physical limitations such as restriction flows (QR).

The hydroregulation model printout is a complex report on the interaction of many different variables in system operations. This printout shows how water conditions during the first half of April in 1931 would affect today's projects (listed down the left-hand column).

for an extra month during each year to lengthen the recreation season. Instead of drawdown beginning in September, it would begin in October. A continuous study can be run to simulate how that change in operation would affect streamflows and elevations at other projects on the river over a 50-year period. The study will yield data that can be used to demonstrate the types and magnitude of impacts that delaying drawdown at this project would have on other aspects of the hydro system.

With this long-term view, planners are able to determine whether an operating change that looks feasible in the first two or three years has a fatal flaw at some point in the future. A set of operations geared to meet a particular flow target might not strain the system in the first year or two. But analysis of a 50-year continuous study could show that in five, six, or ten years, storage reservoirs are depleted, leaving boat ramps and recreation areas stranded, crops withering in dry fields, and electrical energy production greatly reduced.

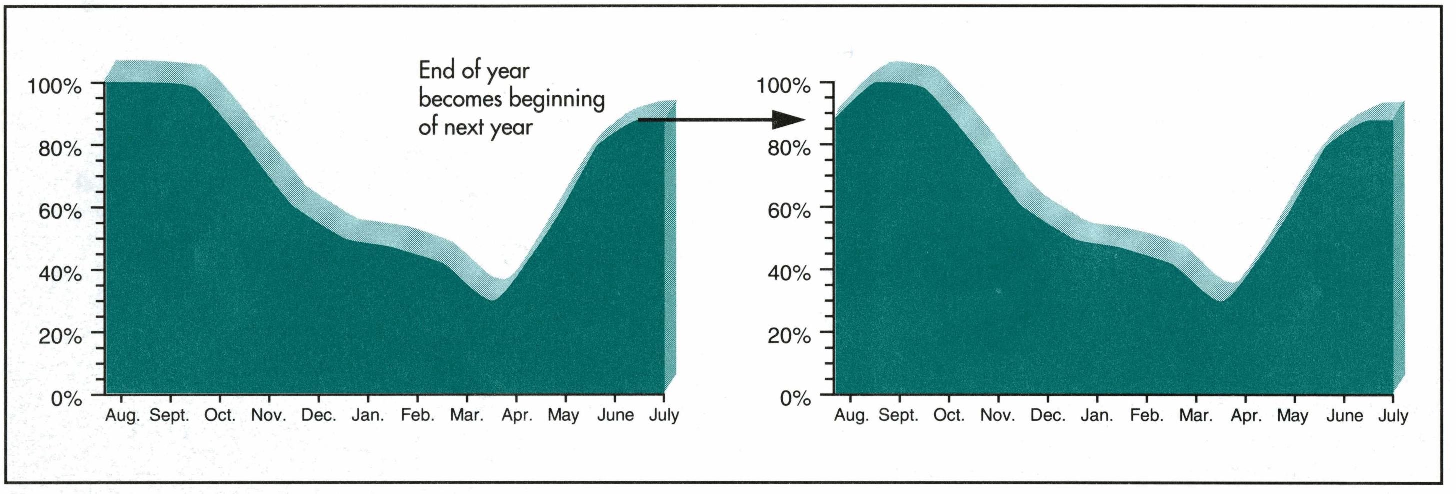
Evaluating Resources. A 50-year continuous study can also help judge if and where to install a new hydro generating plant. A computer run is made for a "base case," that is, the way the system operates without the prospective generator. Then a run is made that includes the new plant. With 50 years of operation simulated by computer, planners can determine how much energy the new generator could be expected to produce and whether historical water conditions suggest the installation would be viable.

The analysis will also show whether the addition of the new project will increase the FELCC output of other projects in the system, which could be the case if the new project has seasonal storage. Additional studies can be made with varying dam heights, more or fewer generating units, or different project locations to see where it would be of the most benefit.

The continuous study can help to point out the tradeoffs that exist with any new operating scenario on a multi-use system. And it is a mechanism to test a potential operating decision. If boaters on one lake have a longer season, what would this mean next spring for fish downriver? Would a boost in flow help this year's migrating fish at the expense of the smolts five years from now? If BPA sells a large quantity of secondary energy next year, will there be enough power to meet firm loads in the following year?

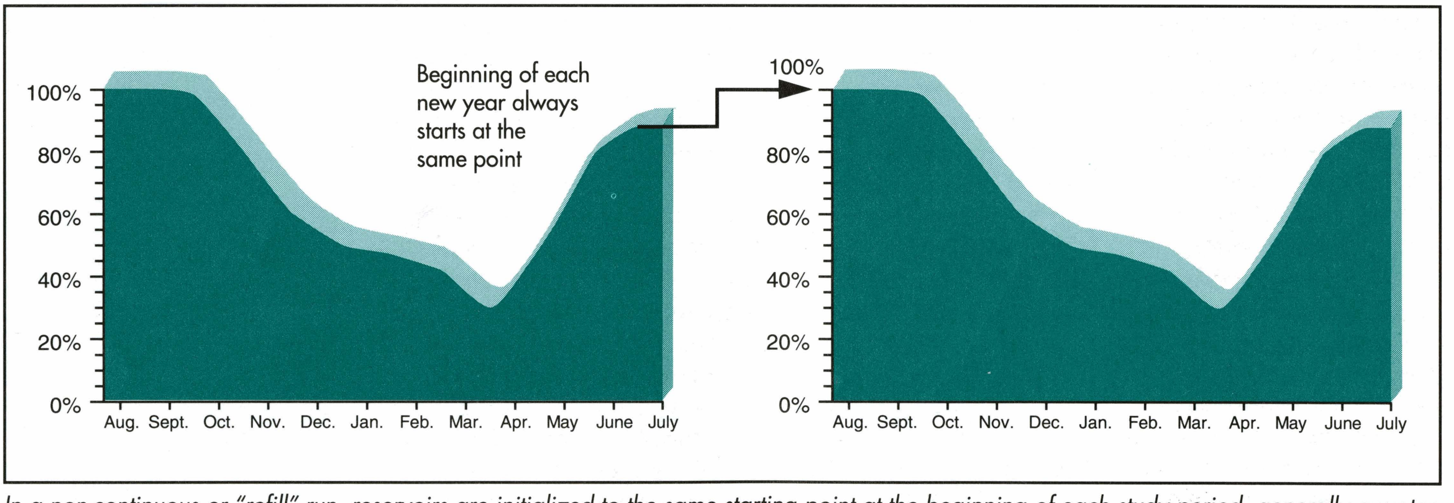
The continuous study also provides information to answer economic questions. If a new generator is installed at an existing powerhouse on the lower Columbia, how much water can be anticipated to fuel its operation? How much power would be available for sale? What percentage of the time could it be expected to operate efficiently given historical water conditions? These are real-life questions the region's power planners and water managers grapple with continually, and the computer simulations help provide the flows

Continuous Run



Each water year in a continuous run begins with the reservoir contents that remain at the end of the previous operating year. In this way, reservoir conditions can be observed over a sequence of historical water years. Continuous runs can yield information about how the system would respond to extended periods of low streamflows.

Non-Continuous Run



In a non-continuous or "refill" run, reservoirs are initialized to the same starting point at the beginning of each study period, generally a water year. Non-continuous runs are especially useful for observing how the reservoirs would respond to a variety of future water conditions, starting from their present elevations.

and elevations to assess these questions.

The Refill (Non-Continuous) Study

Using historical streamflow records, hydroregulation models simulate the likelihood reservoirs will refill over a year of operations. Refill is important for a number of reasons, but in particular, it is the region's hedge against dry years in the future. The amount of snow and rainfall is anybody's guess before winter begins, so it's prudent to have as much water on hand in the reservoirs as possible.

Non-continuous studies are actually 50 separate one-year studies. The reservoirs are set at the beginning of the study to a specific elevation. Operations are then simulated using the 50 years of streamflow record. Reservoir elevations are reset to that same elevation each year.

The Pacific Northwest Coordination Agreement Refill Test is one type of non-continuous study where the reservoir elevations at the beginning of each of the 50 years are set to the elevations shown in the AER for July 31 of the preceding operating year. This gives planners the opportunity to look at how the 50 different water conditions would play out given the most recent operation.

Likewise, non-continuous studies can be conducted starting at different times in the year and with a variety of elevations, including full pools. For example, a study may be run at mid-year to test the refill probability through the rest of the operating year. The beginning elevation is set to match the way a project has actually been operated during the first part of the year. The simulation tests 50 different historical streamflow sequences for the remainder of the year.

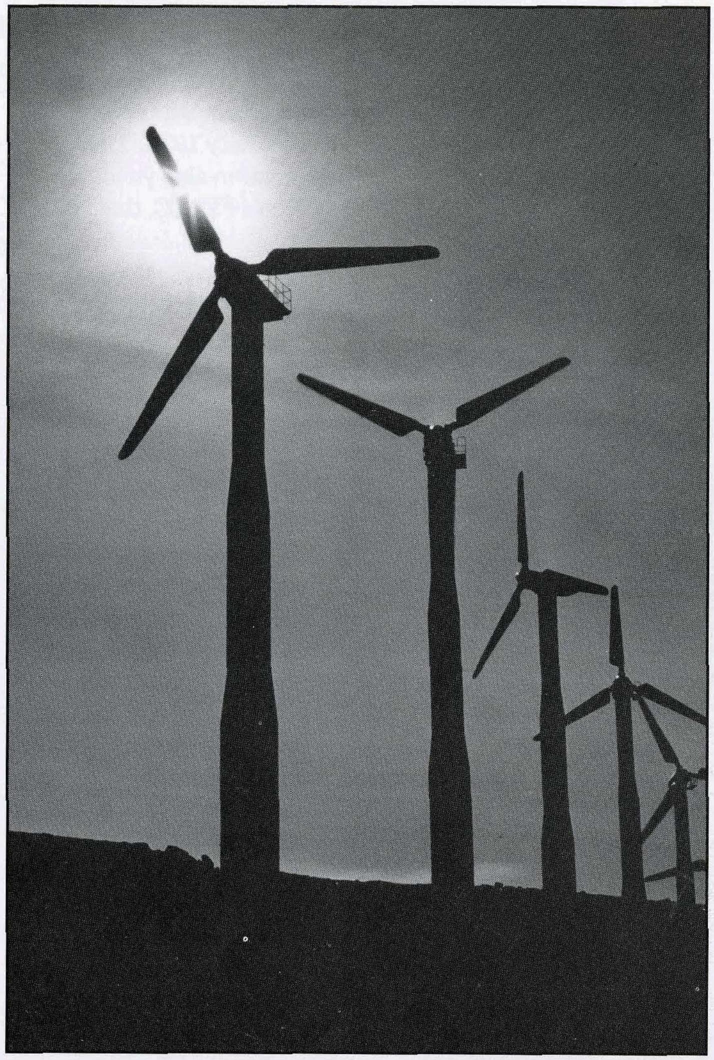
Under the PNCA, system operations are planned so there is an acceptable probability reservoirs will refill. The Corps uses its HYSSR model to run the annual 50-year PNCA Refill Test to develop the assured refill and variable energy content curves.

The Refill Test is used to verify that PNCA operations have an acceptable probability of resulting in refill, and it is used to devise these future operating rule curves. The assured refill curve will guide operations during the fixed drawdown period (late summer and fall) when the volume of the next spring runoff is unknown. The variable energy content curve is used from January through July to guide reservoir operations when spring forecasts are known.

While refill is the primary use of this study, there are other uses for the non-continuous analysis. Since the reservoirs start each contract year at the same level, it is a way to examine 50 individual water years for many purposes, such as projecting the amount of energy that could be produced given the current level of system reservoirs.

The Critical Period Study

Critical period planning defines how much hydro system energy should be considered firm. Hydroregulation models are used to generate the rule curves, which govern critical period operations, and to define FELCC of the system.



Critical period studies define the amount of firm hydro power the system can rely on. If the studies show a deficit, the region may need to acquire new resources.

The Northwest Power Pool uses HYDREG to determine the critical period rule curves and FELCC which are used to operate the system under the PNCA. BPA uses HYDROSIM for critical period studies to plan resource acquisitions and to determine the United States' benefits from Canadian reservoirs. Some of this data also goes into calculating rates and projecting revenues.

The critical rule curves are developed by simulating system operations using the streamflows that were available in the 42-month period from September 1928 to February 1932. This calculation also yields the system's FELCC, that is, how much energy the system can be expected to generate under these adverse streamflow conditions. The Northwest Power Pool's hydroregulation allocates FELCC to the members of the PNCA according to the projects they own and operate and based on other contract provisions.

In a critical period study, the model takes the initial storage content (full) for each reservoir and simulates the

Writing the White Book and Computing Treaty Benefits

BPA depends on the output of HYDROSIM for such tasks as planning new resources, determining the availability of surplus power, and calculating power benefits under the Columbia River Treaty. Two of BPA's planning studies and how they use hydroregulation data are described below.

Checking Loads Against Resources. The annual Pacific Northwest Loads and Resources Study (the White Book) tells BPA where it stands with regard to load/resource balance, i.e., are resources sufficient to meet expected loads. The study uses power generation data developed with HYDROSIM.

For the White Book, each utility or agency is allocated the generating capability of its plants for each period over the planning horizon. The load each utility is projecting is also factored into the study. BPA can then determine what its own load is likely to be, given utility loads; which utilities have which resources; and how those resources are expected to operate in the future.

Determining Downstream Power Benefits. HYDROSIM is used to generate critical rule curves for hydro projects in the United States as well as for the three storage projects built in Canada under the Columbia River Treaty. These curves are used to determine what the annual Treaty-related power benefits are for the United States. The benefits are computed using a procedure that was prescribed in the Treaty. The procedure requires that three separate systems be studied. This complex calculation is presented below in its barest form.

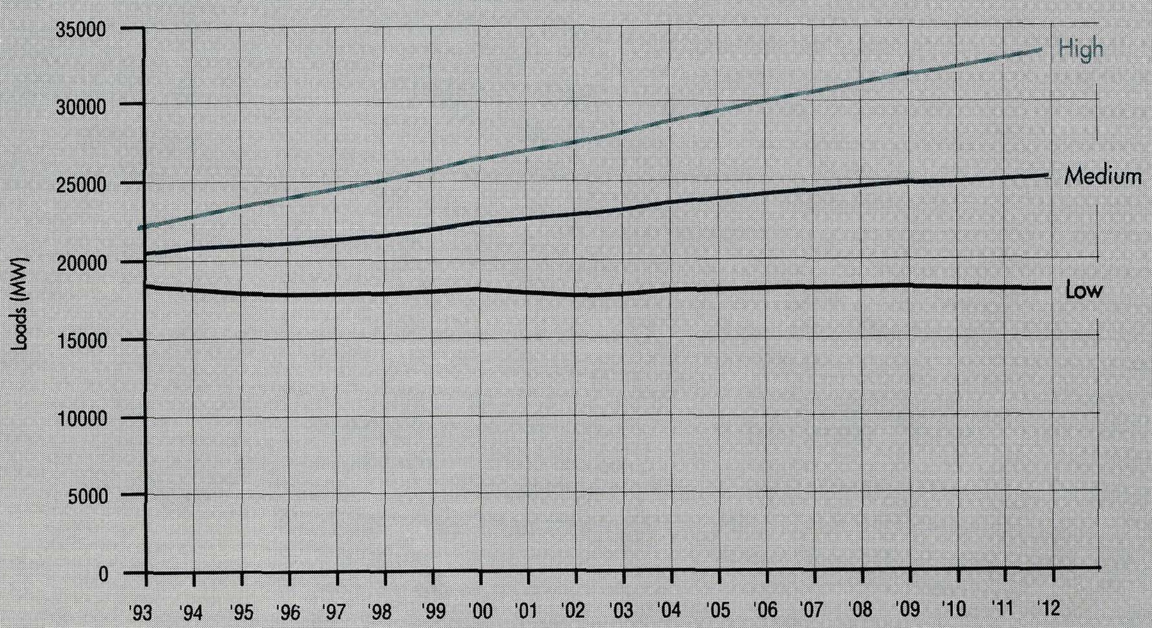
The Step I system is based on the total United States' expected hydro and thermal system generation, augmented with 15.5 MAF of Canadian Treaty storage, operated for optimum power generation (within nonpower operating requirements) in both countries.

The Step II system is based on the United States' hydro and thermal system as it existed in 1961 (when the Treaty was signed), with the Canadian Treaty storage, operated for optimum power production.

The Step III system is based on the United States' hydro and thermal system as it existed in 1961 without the Canadian storage.

In brief, the benefit is the difference between Steps II and III. The United States and Canada share the benefit equally.

Regional Load Growth



operation for each period through the first year, using 1928-29 water. The reservoir content at the end of the first period is the beginning content for the next period, and so forth. A critical rule curve is plotted using the end-of-period reservoir content numbers. This first critical rule curve is known as Critical Rule Curve 1 (CRC1).

The reservoir content at the end of the first year of the critical period becomes the beginning content for the second year. The model simulates another year of operations, and the reservoir contents at the end of the 14 periods are plotted as CRC2. The study continues through the 42-month critical period. The final result is four critical rule curves. CRC4 will indicate that all reservoirs are empty at the end of the critical period.

Planners determine how much power can be generated if all of the reservoirs are drafted to CRC1, CRC2, CRC3, and CRC4, by converting the outflow to megawatts. This type of study is particularly important for BPA in determining how much firm and secondary energy can be produced and sold from the Federal hydro system.

Critical period planning is premised on unusually low water conditions. During most years, there is more water in the system than the critical rule curves reflect. Consequently, BPA runs analyses that look at many ways to take advantage of water conditions that are more likely to occur.

"Knobs" and "Switches"

All of the computer studies can be modified, using variables in almost infinite combinations, to create different operating scenarios. For example, load growth can be held constant in a long-term analysis or a study can be run using a low, medium, or high-growth forecast. In some studies, a project or group of projects might be input as having a fixed operation in order to determine how the rest of the hydro system would compensate.

These variations in operating strategy do not mean changing the program. The models are designed to accommodate them easily. In fact, programmers and analysts refer to these as "knobs" that are turned and "switches" that are thrown within the models to shape a computer inquiry.

Monthly and Hourly Regulation

The models described above deal primarily with long-term studies that use the 50-year streamflow records to determine the system's ability to meet its multiple-use goals. However, there are analogous hydro-regulation models that examine conditions on a daily and even hourly basis. These operations studies are applied to the week-to-week and day-to-day conditions at the reservoirs.

The Northwest Power Pool's semimonthly AER is an operations study that integrates current conditions into the longer-term strategies. Daily studies performed with the SSARR model are used by the Corps to route large floods through the system. The daily studies develop the flood control rule curves that are then input into the monthly models.

Computer simulations allow planners to test many different operations without making physical adjustments to the system. The insights gained are invaluable in planning for the future.

Hourly models are also used for several purposes: (1) to define the peak power generating capability of the system (also called "peaking"); (2) to examine the feasibility of adding more generating units; (3) to evaluate the environmental impact of peaking operations on the reservoirs and downstream river reaches; (4) to determine the impact of new operating contracts (for nonpower river uses) on project peaking capability; and (5) to determine the impact of proposed hourly power sales contracts on project operation.

Both the Corps and BPA have models that simulate the operation of the system on an hourly basis for one week at a time. They operate using basic streamflow and reservoir elevation data obtained from one of the monthly models, such as HYSSR.

Chapter Seven: The Computer Meets the Basin's Wildlife

In the preceding chapters, we've introduced the Columbia River hydro system, the hydroregulation computer models, and the types of studies for which the models are used. The following pages describe a real-life simulation done as part of the environmental study of operations on the Columbia and Snake Rivers known as the System Operation Review (SOR).

This scenario was developed by a group of wildlife experts who devised a system operating strategy they believed would be ideal for the birds and beasts that are affected by the 14 major Federal dams and reservoirs in the Columbia Basin. Keep in mind that this scenario is a single-use strategy for a multi-use river system; it puts the emphasis entirely on wildlife and takes none of the other nine river uses into account. It is nicknamed "WILD-IDEAL" and is referred to that way in this discussion.

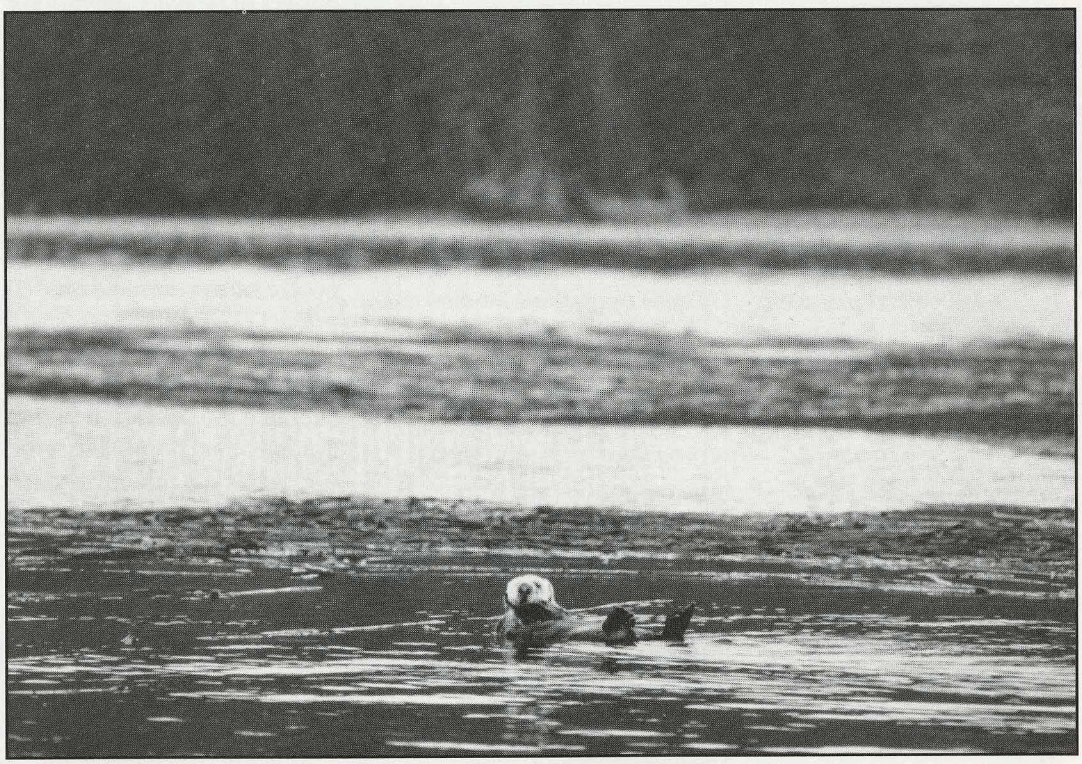
This simulation was made with HYDROSIM, but the other two models discussed in this paper could have been set up to make this run as well. In fact, HYSSR was also used in the SOR, from which this wildlife example was taken.

WILD-IDEAL: What Is It and What Would It Do?

Many animal species live in the riparian and wetlands habitat along river banks. This habitat consists of deciduous trees, including cottonwoods and elm, thick brush, swamp grass, and reeds. Hawks nest in the trees, deer take cover in the undergrowth, mink traverse the damp shorelines, and wood ducks feed in the marshes.

The wildlife experts determined that the best possible conditions for animals would be: first, to draw reservoirs down to expose the maximum riparian, wetland, and nesting island acreage; and, second, to keep reservoir elevations or levels stable year round. In other words, already low reservoir elevations would fluctuate very little from one season to the next.

Based on what biologists already know about nesting islands and other habitat along the river, the group came up with desired elevations at five storage reservoirs and nine run-of-river projects. Again, all other river uses were



A scenario called "WILD-IDEAL" would operate the Columbia River system solely for the long-term benefit of wildlife, such as this river otter. Hydroregulation models were the first step in determining what this operation would do to the system as a whole.

Sample Plant Data for John Day Project

TABLE ID	NO. 0
EFF DATE	0
IDENT TABLE	
OWNR CODE	1
ABBREV	J DAY
IN DATE	0
FMO	0
WEEK	0
PTYPE11	
ULT KDOWN	365
DISP CODE	++++

TABLE ID	NO. 0
EFF DATE	0
IDENT TABLE	
OWNR CODE	1
ABBREV	J DAY
IN DATE	0
FMO	0
WEEK	0
PTYPE11	
ULT KDOWN	365
DISP CODE	++++

TABLE TT	NO. 1
EFF DATE	2025031
TITLE TABLE	
17 UNITS	

TABLE TT	NO. 2
EFF DATE	2025041
TITLE TABLE	
18 UNITS	

TABLE TT	NO. 3
EFF DATE	2025051
TITLE TABLE	
19 UNITS	

TABLE TT	NO. 4
EFF DATE	2025061
TITLE TABLE	
20 UNITS	

TABLE LT	NO. 0
EFF DATE	0
LIMITS TABLE (KSFD,CFS)	
SEMIN	0.0
SEMAX	269.7
QMIN	0.0
QMAX	0.0
QLOFLO	0.0
QRELEAS	0.0
FG QEST	330000.0

TABLE LT	NO. 1
EFF DATE	2025031
LIMITS TABLE (KSFD,CFS)	
SEMIN	0.0
SEMAX	269.7
QMIN	0.0
QMAX	0.0
QLOFLO	0.0
QRELEAS	0.0
FG QEST	355000.0

TABLE LT	NO. 2
EFF DATE	2025041
LIMITS TABLE (KSFD,CFS)	
SEMIN	0.0
SEMAX	269.7
QMIN	0.0
QMAX	0.0
QLOFLO	0.0
QRELEAS	0.0
FG QEST	375000.0

TABLE LT	NO. 3
EFF DATE	2025051
LIMITS TABLE (KSFD,CFS)	
SEMIN	0.0
SEMAX	269.7
QMIN	0.0
QMAX	0.0
QLOFLO	0.0
QRELEAS	0.0
FG QEST	395000.0

TABLE LT	NO. 4
EFF DATE	2025061
LIMITS TABLE (KSFD,CFS)	
SEMIN	0.0
SEMAX	269.7
QMIN	0.0
QMAX	0.0
QLOFLO	0.0
QRELEAS	0.0
FG QEST	415000.0

TABLE LT	NO. 0
EFF DATE	0
STORAGE (FSKF)	FB ELEV (FT)
0.00	257.00
21.10	258.00
90.70	261.00
164.80	264.00
269.70	268.00

TABLE TW	NO. 0
EFF DATE	0
DISCHARGE (CFS)	TW ELEV (FT)
0.00	158.60
50000.00	158.90
100000.00	159.70
200000.00	161.60
300000.00	163.70
400000.00	166.20
500000.00	168.60
600000.00	171.40
800000.00	176.30
999999.88	176.30

TABLE HK	NO. 0
EFF DATE	0
HEAD (FT)	H/K (KW/CFS)
0.00	0.00
84.00	5.96
92.00	6.67
100.00	7.33
114.00	8.83

TABLE MG	NO. 0
EFF DATE	0
HEAD (FT)	MAXGEN (MW)
0.00	-448.00
91.62	2484.00

TABLE MG	NO. 1
EFF DATE	2025031
HEAD	MAXGEN

TABLE MG	NO. 2
EFF DATE	2025041
HEAD	MAXGEN

TABLE MG	NO. 3
EFF DATE	2025051
HEAD	MAXGEN

TABLE MG	NO. 4
EFF DATE	2025061
HEAD	MAXGEN

This table illustrates the actual plant data that was used in the WILD-IDEAL run for the John Day project.

ignored in developing these elevations, which are shown in the adjacent table.

The Model: What Did the Analyst Do to Run the Study?

A hydroregulation modeler, whom we'll call Pat, took the operating specifications developed by the wildlife group and adapted them to run on the HYDROSIM program. There were many steps in this process. In addition to maintaining the elevations on the table, WILD-IDEAL directed the modeler to generate power only to the extent that would be possible given the outflows allowed by this operation, and to relax flood control if necessary to maintain elevation targets.

Configuring the Study. The first thing Pat did was to come up with a format for the study. An abbreviated five-year historical streamflow record had already been constructed for the environmental analysis of which this wildlife example was a part. Five water years were abstracted from the 50-year streamflow record to represent low (1931), medium-low (1940), medium (1938), medium-high (1957), and high (1956) water conditions.

Pat originally intended to run the wildlife strategy as a refill study, with each of the five years in the streamflow record beginning with reservoirs at target elevations. It later became clear that twelve-month water years, from June to July, would fail to capture an entire anadromous fish migration cycle, so the study had to be revamped to incorporate five two-year intervals. It was important to cover the full migration cycle in order to assess comprehensively WILD-IDEAL's impact on fish runs.

At the end of the computation for each of the two-year intervals, the reservoirs were reset. The study was, in other words, a hybrid refill/continuous study which used 1931-32, 1940-41, 1938-39, 1957-58, and 1956-57 water.

By the way, remember the continuity equation? In this example, the calculation yielded the outflow at each project. The wildlife experts specified the project elevations, which implies change in storage for each project in each month; the amount of inflow (I) was predetermined by the historical streamflow record the study uses and upstream reservoir operations; and the losses (L) are preset in tables in the model. The question for the model, then, was: What is the outflow (0) at each project required to maintain the stable elevations?

Operating Requirements and Project Characteristics. Pat's first step was to access tables in the data files that contain project operating requirements. These are described more specifically in Chapter 4, Model Inputs. The codes in these files fix some aspect of plant operation during a hydroregulation run. All of the usual reservoir elevations are kept here. Pat input the elevations

Reservoir Target Elevations for Wildlife
(WILD-IDEAL Strategy)

Project	Elevations (Feet) JULY	AUG 15	AUG 31	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR 15	APR 30	MAY	JUNE
Bonneville	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8
The Dalles	95	95	95	95	95	95	95	95	95	95	95	95	95	95
John Day	262	262	262	262	262	262	262	262	262	262	262	262	262	262
McNary	338	338	338	338	338	338	338	338	338	338	338	338	338	338
Chief Joseph	955	955	955	955	955	955	955	955	955	955	955	955	955	955
Grand Coulee	1285	1285	1285	1285	1285	1285	1285	1285	1285	1285	1285	1285	1285	1285
Albeni Falls	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2062.5	2050
Libby	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Hungry Horse	3560	3560	3560	3540	3540	3540	3540	3540	3540	3540	3540	3560	3560	3560
Ice Harbor	437	437	437	437	437	437	437	439	439	438-440	438-440	438-440	437	437
Lower Monumental	537	537	537	537	537	539	539	539	539	538-540	538-540	538-540	537	537
Little Goose	633	633	633	633	633	636	636	636	636	635-637	635-637	635-637	633	633
Lower Granite	733	733	733	733	733	736	736	736	736	735-737	735-737	735-737	733	733
Dworshak	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1600	1600	1600	1600

The reservoir elevations on this chart were specified by the wildlife experts for 14 Federal hydro projects.

Plant Data

HYDROSIM stores physical characteristics of hydro projects in the "plant data" file. Projects are displayed differently according to whether they are reservoir or run-of-river projects.

Run-of-river projects are represented by a fairly simple table that returns a certain amount of generation for a given rate of flow through the turbines. For example, the table for Bonneville Dam looks like this:

Generation (MWs)	Discharge (cfs)
0	0
275	50000
652	135000
727	155000
826	180000
903	203000
1056	256500
1147	308500
904	600000
732	999999

This table allows the computer to calculate the generation expected from Bonneville Dam once the amount of water coming in from upstream has been established. Remember that the amount of generation possible depends upon the amount of water multiplied by the distance it falls multiplied by the efficiency of the project. This table is based on observations of flow and generation at Bonneville Dam under typical operating conditions (forebay elevation near normal, full pool).

The WILD-IDEAL alternative proposed a significant change in the forebay elevation for Bonneville Dam. Instead of operating at the usual 71.5 to 76.5 feet, WILD-IDEAL called for a forebay elevation of 22.8 feet. The normal range of tailwater elevation for Bonneville Dam is from 10 to 27 feet. Under high flow conditions, the tailwater would naturally rise to an elevation as high or higher than the specified forebay.

Instead of water falling a distance of about 65 feet, under WILD-IDEAL the water would drop no more than 12.8 feet. A change in the generation versus discharge table to reflect this difference was needed. Under high flow conditions, Bonneville Dam would not be able to generate any power as the tailwater could rise to nearly equal the forebay. Changes were made to approximate the new operation as follows:

Generation (MWs)	Discharge (cfs)
0	0
53	50000
109	135000
105	155000
93	180000
88	203000
0	256500
0	999999

The result: Under average (1938) water conditions, generation at Bonneville Dam under the WILD-IDEAL case was 77 average megawatts (aMW) compared with 685 aMW in the base case operation.

specified in WILD-IDEAL for storage projects. In another file, called the plant data file, Pat made changes specified in WILD-IDEAL for the elevations at run-of-river projects; see the box at left.

The First Run Missed the Mark

The first run-through of the WILD-IDEAL simulation showed the target elevations were not met by the model. Pat studied the results and recognized that flood control, flow limits, and minimum storage constraints were the problem.

Flood Control. The flood control curves in the model were inhibiting the operation called for in WILD-IDEAL. In this simulation, the wildlife group members foresaw that operations would at times violate the flood control constraints, and they had specified that the elevation targets should have priority over flood control. Pat went into the flood control files and input numbers that were so high they would not interfere with meeting the target elevations.

Flow Limits. These files contain the limits on the amount of discharge (outflow) that is allowed from a project at any time. WILD-IDEAL specified that the model pay no attention to these limits. So Pat set all the minimum flow requirements to zero.

The Picture Gets Clearer on the Second Try

When the second run was complete, with the new adjustments, Pat compared the resulting elevations to the targets in WILD-IDEAL. The results in the second run were much closer to the targets. Pat determined why the targets were not met in places and whether any

Elevations at Projects Showing Targets Not Met

1991 SOR Study (WILD-IDEAL) 1465 Albeni

End Elevation (Ft)	JULY	AUG	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	APR	MAY	JUNE
1931	2062.0	2062.0	2062.0	2060.0	2054.0	2051.0	2051.0	2051.0	2051.0	2051.0	2051.0	2054.0	2062.5	2060.0
1932	2062.0	2062.0	2062.0	2060.0	2054.0	2051.0	2051.0	2051.0	2050.0	2051.0	2054.0	2055.2	2062.5	2062.0
1938	2062.0	2062.0	2062.0	2060.0	2054.0	2051.0	2051.0	2051.0	2051.0	2051.0	2054.0	2055.3	2062.5	2062.0
1939	2062.0	2062.0	2062.0	2060.0	2054.0	2051.0	2051.0	2051.0	2051.0	2051.0	2054.0	2054.0	2062.5	2062.0
1940	2062.0	2062.0	2062.0	2060.0	2054.0	2051.0	2051.0	2051.0	2051.0	2051.0	2054.0	2054.0	2062.5	2062.0
1941	2062.0	2062.0	2062.0	2060.0	2054.0	2051.0	2051.0	2051.0	2051.0	2051.0	2054.0	2054.0	2062.5	2062.0
1956	2062.0	2062.0	2062.0	2060.0	2054.0	2051.0	2051.0	2051.0	2051.0	2052.1	2054.0	2059.8	2063.6	2062.0
1957	2062.0	2062.0	2062.0	2060.0	2054.0	2051.0	2051.0	2051.0	2051.0	2051.0	2054.0	2054.0	2062.9	2062.0
1957	2062.0	2062.0	2062.0	2060.0	2054.0	2051.0	2051.0	2051.0	2051.0	2051.0	2054.0	2054.0	2062.9	2062.0
1958	2062.0	2062.0	2062.0	2060.0	2054.0	2051.0	2051.0	2051.0	2051.0	2051.0	2054.0	2054.0	2062.5	2062.0

1991 SOR Study (WILD-IDEAL) 535 Dwrshk

End Elevation (Ft)	JULY	AUG	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	APR	MAY	JUNE
1931	1599.9	1600.0	1599.9	1587.7	1581.9	1568.9	1556.0	1554.3	1553.7	1556.0	1573.3	1585.0	1596.1	1600.0
1932	1598.5	1598.5	1598.2	1587.7	1581.9	1568.9	1556.0	1526.2	1490.2	1445.0	1445.0	1459.3	1573.2	1600.0
1938	1600.0	1600.0	1600.0	1587.7	1581.9	1568.9	1556.0	1537.9	1524.5	1511.6	1497.5	1532.6	1587.8	1600.0
1939	1600.0	1600.0	1600.0	1587.7	1581.9	1568.9	1556.0	1549.9	1547.4	1556.0	1556.4	1559.3	1600.0	1600.0
1940	1600.0	1600.0	1599.9	1587.7	1581.9	1568.9	1556.0	1556.0	1556.0	1556.0	1574.1	1582.4	1600.0	1600.0
1941	1598.9	1599.0	1598.7	1587.7	1581.9	1568.9	1556.0	1556.0	1556.0	1556.0	1564.0	1570.9	1594.5	1600.0
1956	1600.0	1600.0	1600.0	1587.7	1581.9	1568.9	1556.0	1526.2	1490.2	1445.0	1445.0	1445.0	1564.4	1598.3
1957	1600.0	1600.0	1600.0	1587.7	1581.9	1568.9	1556.0	1526.7	1494.2	1449.7	1453.8	1479.9	1578.1	1600.0
1957	1600.0	1600.0	1600.0	1587.7	1581.9	1568.9	1556.0	1526.7	1494.2	1449.7	1453.8	1479.9	1578.1	1600.0
1958	1600.0	1600.0	1600.0	1587.7	1581.9	1568.9	1556.0	1535.6	1520.4	1503.6	1486.8	1513.7	1589.4	1600.0

[shaded] = Target Elevations not met

Pat found that the first run missed the target elevations because the program was using standard flood control and minimum flow data. Those data files were altered to allow the targets to be met more consistently.

Results of Second Run

1991 SOR Study (WILD-IDEAL) 1465 Albeni

End Elevation (Ft)	JULY	AUG	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	APR	MAY	JUNE
1931	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2062.5	2050
1932	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2052.1	2053.9	2062.5	2058.2
1938	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050.3	2054.2	2062.5	2057.5
1939	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2051.2	2051.4	2062.5	2051.2
1940	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050.4	2051.3	2051.9	2062.5	2050
1941	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2062.5	2050
1956	2056.7	2050	2050	2050	2050	2050.5	2050.8	2050	2050	2051.5	2052.2	2057.5	2065.4	2060.8
1957	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050.5	2051.2	2064.8	2055.7
1957	2053.2	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050.5	2051.2	2064.8	2055.7
1958	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050.3	2052	2062.5	2054.3

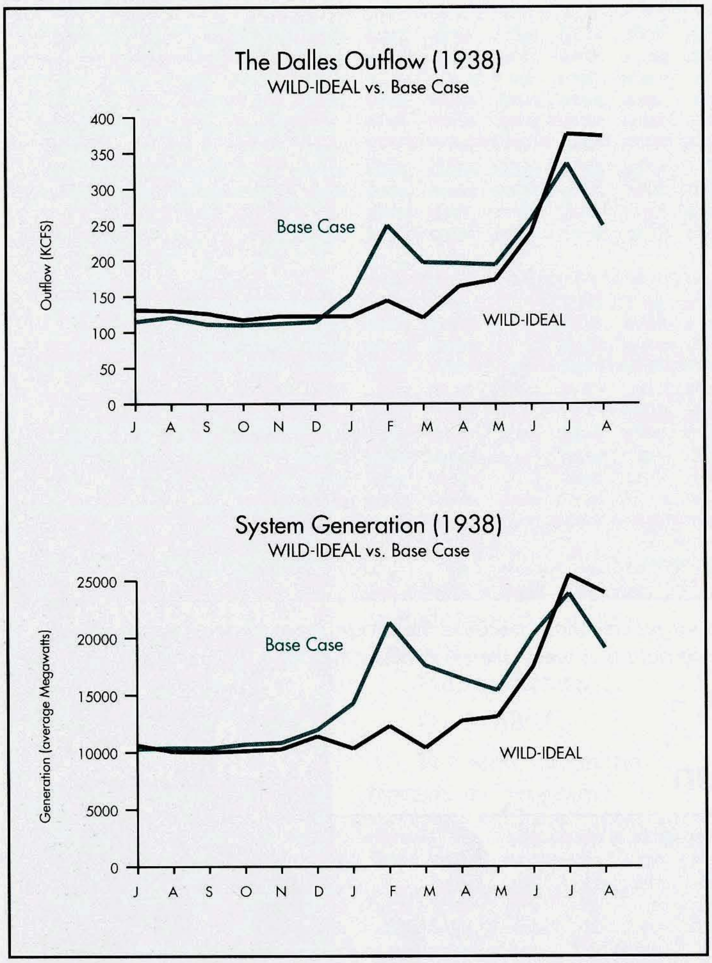
1991 SOR Study (WILD-IDEAL) 535 Dwrshk

End Elevation (Ft)	JULY	AUG	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	APR	MAY	JUNE
1931	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1577	1591.7	1600	1600
1932	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1582.9	1600	1600	1600
1938	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1569.3	1600	1600	1600
1939	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1574.9	1600	1600	1600
1940	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1577.7	1597.9	1600	1600
1941	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1567.9	1578.2	1600	1600
1956	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1579.2	1600	1600	1600
1957	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1579.7	1600	1600	1600
1957	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1579.7	1600	1600	1600
1958	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1571	1599.9	1600	1600

[shaded] = Targets not met

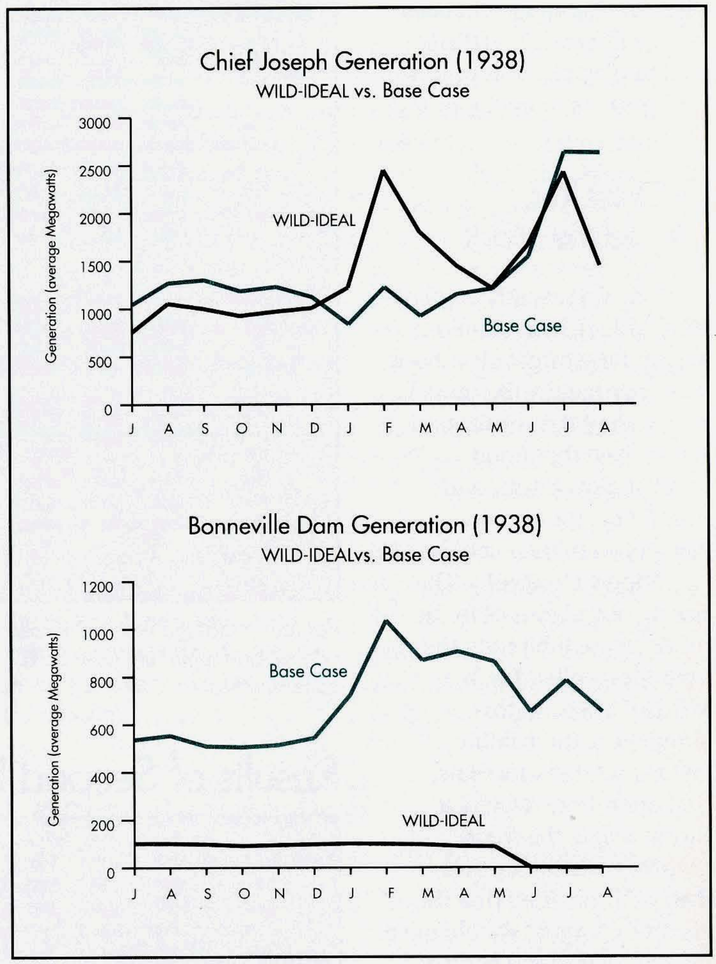
Pat determined that the unmet elevation targets in this second run were due to physical limitations on the system that could not be altered.

WILD-IDEAL vs. Base Case
Outflow



WILD-IDEAL shifted flows and elevations toward a more natural river runoff profile and away from the peak electricity generating months in winter.

WILD-IDEAL vs. Base Case
Power Generation



Power generation was shifted in time and also generally reduced because of the drop in reservoir levels.

adjustments could be made to get closer.

Looking at the Big Picture

The run yielded information in addition to outflow and elevations. It also converted the flow to the power generation available under these operating conditions, and it calculated if and how much water would be spilled at any of the projects during the 14 periods.

Base Case. Just as a special streamflow record had been created for the multi-faceted environmental analysis that produced WILD-IDEAL, a "standard planning assumption" study was also devised. This study incorporated the assumptions that would be made in planning studies under ordinary conditions. This was the "Base Case" against which the results of runs, such as WILD-IDEAL, were compared.

Let's take a look at the results of WILD-IDEAL side-by-side with the Base Case in a couple of areas. The graphs compare total flows at The Dalles, system generation, and power generation at Bonneville and Chief Joseph Dams. The table shows how the reservoir and run-of-river elevations look under both scenarios.

The computer runs, coupled with Pat's careful analysis, give a good picture of what would happen on the system under WILD-IDEAL. And they suggest some new questions. How will these elevations affect other river uses? What are the tradeoffs? What would be the costs — both economic

WILD-IDEAL and Base Case Elevations

WILD-IDEAL Elevations (1938 water conditions)

	JULY	AUG	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	APR	MAY	JUNE
* Bonneville	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8
* The Dalles	95	95	95	95	95	95	95	95	95	95	95	95	95	95
John Day	262	262	262	262	262	262	262	262	262	262	262	262	262	262
McNary	338	338	338	338	338	338	338	338	338	338	338	338	338	338
Chief Joseph	955	955	955	955	955	955	955	955	955	955	955	955	955	955
Grand Coulee	1285	1285	1285	1285	1285	1285	1285	1285	1285	1285	1285	1285	1285	1285
Albeni Falls	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050.3	2054.2	2062.5	2057.5
Libby	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Hungry Horse	3560	3560	3560	3540	3540	3540	3540	3540	3540	3540	3540	3551.4	3560	3560
Ice Harbor	437	437	437	437	437	439	439	439	439	439	439	439	437	437
Lower Monumental	537	537	537	537	537	539	539	539	539	539	539	539	537	537
Little Goose	633	633	633	633	633	636	636	636	636	636	636	636	633	633
Lower Granite	733	733	733	733	733	736	736	736	736	736	736	736	733	733
Dworshak	1600	1600	1600	1600	1600	1580	1556	1556	1556	1556	1569.3	1600	1600	1600

* Bonneville and The Dalles reservoir elevations were not directly represented in the model. Changes were made to plant data to reflect reduced generation due to the lower elevations.

Base Case Elevations (1938 Water Conditions)

	JULY	AUG	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	APR	MAY	JUN
Bonneville	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5
The Dalles	160	160	160	160	160	160	160	160	160	160	160	160	160	160
John Day	268	268	268	267	263.6	263.6	263.6	263.6	263.6	263.6	262	262	262	268
McNary	339	339	339	339	339	339	339	339	339	339	339	339	339	339
Chief Joseph	953.2	953.2	953.2	953.2	953.2	953.2	953.2	953.2	953.2	953.2	953.2	953.2	953.2	953.2
Grand Coulee	1289.8	1290	1290	1288	1288	1288	1287	1256.1	1240.6	1226.5	1220	1220	1235.8	1282.2
Albeni Falls	2062.5	2062.5	2062.5	2060	2054	2054	2051	2051	2051	2051	2054	2055.1	2057.3	2062.5
Libby	2455.9	2455.2	2452.5	2447.6	2444	2430	2411	2371.4	2336.6	2323.5	2323.5	2323.5	2377.4	2441.2
Hungry Horse	3554.3	3553.9	3547.1	3528.7	3517.3	3515.9	3512.3	3509.1	3505.2	3501.8	3504.3	3509.4	3536	3557.2
Ice Harbor	440	440	440	440	440	440	440	440	440	440	440	440	440	440
Lower Monumental	540	540	540	540	540	540	540	540	540	540	540	540	540	540
Little Goose	638	638	638	638	638	638	638	638	638	638	638	638	638	638
Lower Granite	738	738	738	738	738	738	738	738	738	738	738	738	738	738
Dworshak	1595.6	1593.7	1589.5	1565.5	1531.2	1560.7	1548.4	1537.9	1524.5	1511.6	1497.5	1532.6	1576.3	1600

This table shows the difference in elevations between a study with today's standard planning assumptions and the reservoir elevations specified in WILD-IDEAL operations under average water conditions (represented in this study as 1938 water).

and environmental? The hydroregulation models generate information that helps policymakers respond to these questions.

Summing It Up

The hydroregulation models discussed in this paper are used routinely to plan for the operation of the Columbia River system. New issues about river management have been raised in recent years. These concerns are being addressed, in part, by asking computers to simulate "what if" situations. What if we draw reservoirs down to their minimum operating pools? What if we increase flows in the river throughout the year?

Computer simulations help us see whether an action taken today would create more serious problems tomorrow or would successfully fulfill an unmet need. They are used increasingly for environmental analysis and preparing information needed for environmental impact statements, such as the System Operation Review. In the end, the models help to define the limits and possibilities to which the system can be stretched to serve its many constituencies, both human and environmental.

The hydroregulation models are one way — short of a crystal ball — to look into the years ahead.

Appendix A

Projects Included in HYDREG (Northwest Power Pool) Model

Albeni Falls
Alder
Anderson Ranch Small Plants
Arrow
Big Cliff
Bonneville
Bonneville Power Small Plants
Boundary
Box Canyon
Boyle
Brilliant
Brownlee
Bull Run
Cabinet Gorge
Canal Plant
Carmen Smith
Chelan
Chief Joseph
Columbia Falls
Copco
Corra Linn
Cougar
Cushman 1
Cushman 2
Dalles
Detroit
Dexter
Diablo
Duncan
Dworshak
Faraday
Foster
Gorge
Grand Coulee
Green Peter
Hells Canyon
Hills Creek
Hungry Horse
Ice Harbor
Idaho Small Plants
Iron Gate
Jackson
John Day
Kerr
Klamath
Kootenay
La Grande
Leaburg
Libby
Little Falls
Little Goose
Long Lake
Lookout Point
Lost Creek
Lower Baker
Lower Bonnington
Lower Granite
Lower Monumental
Mayfield
McNary
Merwin
Meyers Falls
Mica
Monroe Street
Montana Small Plants
Mossyrock
Nine Mile
North Fork
Noxon
Oak Grove
Oxbow
Pacific Small Plants
Palisades Small Plants
Pelton
Post Falls
Priest Lake
Priest Rapids
Puget Small Plants
Reclamation Small Plants
Revelstoke
River Mill
Rock Island
Rocky Reach
Rogue River Small Plants
Ross
Round Butte
Seattle Small Plants
Seven Mile
Sullivan
Swift 1
Swift 2
T.W. Sullivan
Thompson Falls
Timothy
Trail Bridge
Umpqua Small Plants
Upper Baker
Upper Bonnington
Upper Falls
Upper Snake Small Plants
Walterville
Wanapum
Waneta
Wells
White River
Yale

Projects Included in HYDROSIM (BPA) Model

Albeni Falls
Alder
Arrow
Bonneville
Boundary
Box Canyon
Brilliant
Brownlee
Cabinet Gorge
Canal Plant
Carmen Smith
Chelan Lake
Chief Joseph
Coeur D'Alene Lake
Columbia Falls
Corra Linn
Cushman 1
Cushman 2
Diablo
Duncan
Dworshak
Faraday
Grand Coulee
Hells Canyon
Hungry Horse
Ice Harbor
John Day
Kerr
La Grande
Leaburg
Libby
Little Falls
Little Goose
Long Lake
Lower Baker
Lower Bonnington
Lower Granite
Lower Monumental
Mayfield
McNary Dam
Merwin
Mica
Monroe Street
Mossy Rock
Nine Mile
North Fork
Noxon Rapids
Oak Grove
Oxbow
Packwood
Packwood Lake
Pelton
Pelton Reregulation

Post Falls
Priest Lake
Priest Rapids
Revelstoke
River Mill
Rock Island
Rocky Reach
Ross
Round Butte
Seven Mile
South Slocan
Swift 1
Swift 2
The Dalles
Thompson Falls
Timothy Lake
Trail Bridge
Upper Baker
Upper Bonnington
Upper Falls
Walterville
Wanapum
Waneta
Wells
White River
Yale

Projects Included in HYSSR (Corps) Model

Albeni Falls
Alder
Arrow
Big Cliff
Bonneville
Boundary
Box Canyon
Brilliant
Brownlee
Cabinet Gorge
Canal Plant
Chelan
Chief Joseph
Clackamas
Corra Linn
Cougar
Cushman 1
Cushman 2
Detroit
Dexter
Diablo
Duncan
Dworshak
Foster
Gorge
Grand Coulee
Green Peter
Hells Canyon
Hills Creek
Hungry Horse
Ice Harbor
John Day
Kerr
Kootenay PLT
La Grande
Libby
Little Falls
Little Goose
Long Lake
Lookout Point
Lower Baker
Lower Granite
Lower Monumental
Mayfield
McNary
Merwin
Mica
Monroe Street
Mossyrock
Nine Mile
Noxon
Oxbow
Pelton
Post Falls
Priest Rapids
Revelstoke
Rock Island
Rocky Reach
Ross
Round Butte
Seven Mile
Swift 1
Swift 2
The Dalles
Thompson Falls
Timothy
Upper Baker
Upper Falls
Wanapum
Waneta
Wells
White River
Yale

Glossary

Acre-foot — The volume of water that will cover an area of one acre to a depth of one foot (326,000 gallons or 0.5 second foot days).

Actual energy regulation (AER) — The AER studies, conducted by the Northwest Power Pool, result in an energy content curve for each storage project. When reservoirs must be drafted below this curve to meet firm energy loads, the AER sets proportional draft points to equitably distribute the draft among all reservoirs.

Anadromous fish — Fish, such as salmon or steelhead trout, that hatch in fresh water, migrate to and mature in the ocean, and return to fresh water as adults to spawn.

Annual operating plan — A yearly plan for operating reservoirs on the Columbia River. Such a plan is specifically required by the Columbia River Treaty and by the Pacific Northwest Coordination Agreement.

Assured Operating Plan — A study mandated by the Columbia River Treaty that determines U.S. and Canadian benefits of Treaty projects.

Assured refill curve (ARC) — A curve showing minimum elevations that must be maintained at each project to ensure refill even if the third lowest historical water year occurred; it sets limits on the production of secondary energy.

Average megawatts (aMW) — The average amount of power (number of megawatts) supplied or demanded over a specified period of time.

Capacity — The maximum amount of power that can be produced by a generator or carried by a transmission facility at any instant.

Columbia River Treaty — A Treaty between the United States and Canada allowing the construction and coordinated operation of Libby Dam in the United States, and Mica, Duncan, and Keenleyside (Arrow Lakes) Dams in Canada.

Content — An amount of water stored in a reservoir, usually expressed in terms of KSFD or MAF.

Critical period — The portion of the historical 50-year streamflow record that would produce the least amount of energy with all reservoirs drafted from full to empty.

Critical rule curves (CRC) — A set of curves that define reservoir elevations that must be maintained to ensure that firm energy requirements can be met under the most adverse historical streamflow conditions. Critical rule curves are derived for all years in the critical period. They are used for proportional draft of reservoirs.

Cubic feet per second (cfs) — A unit of measurement pertaining to flow or discharge of water. One cfs is equal to 449 gallons per minute. A thousand cubic feet per second is abbreviated as kcfs.

Demand — The rate at which electric energy is used, whether at a given instant, or averaged over any designated period of time.

Discharge — Volume of water released from a dam or powerhouse at a given time, usually expressed in cubic feet per second.

Draft — Release of water from a storage reservoir.

Drawdown — The distance that the water surface of a reservoir is lowered from a given elevation as water is released from the reservoir. Also refers to the act of lowering reservoir levels. (Similar to draft.)

Elevation — Height in feet above sea level. Usually refers to reservoir forebay; used interchangeably with content because a forebay elevation implies a specific reservoir content. Tailwater level is also expressed as an elevation.

Energy — The ability to do work (i.e., exert a force over distance). Energy is measured in calories, joules, KWH, BTUs, MW-hours, and average MWs.

Energy content curves (ECC) — A set of curves that establishes limits on the amount of reservoir drawdown permitted to produce energy in excess of FELCC.

FELCC — Firm energy load carrying capability (FELCC) is the amount of energy the region's generating system, or an individual utility or project, can be called on to produce on a firm basis during actual operations. FELCC is made up of both hydro and non-hydro reservoirs and generating projects. (Also see nonpower operating requirements, above, and operating requirements, below.)

Operating requirements — Guidelines and limits that must be followed in the operation of a reservoir or generating project. These requirements may originate from authorizing legislation, physical plant limitations, environmental impact analysis or input from government agencies and other entities representing specific river uses. Operating requirements are submitted annually to the Northwest Power Pool by project owners for planning purposes.

Operating rule curve — A composite curve, derived from a family of curves, indicating how a reservoir is to be operated under specific conditions. The operating rule curve accounts for multiple operating objectives, including flood control, hydropower generation, releases for fish migration, and refill.

Operating year — The 12-month period from August 1 through July 31.

Outflow — The water that is released from a project during a specified period.

Pacific Northwest Coordination Agreement — A binding agreement among BPA, the Corps, Reclamation, and the major hydro generating utilities in the Pacific Northwest that stemmed from the Columbia River Treaty. The Agreement specifies a multitude of operating rules, criteria, and procedures for coordinating operation of the Pacific Northwest hydropower system for power production. It directs operation of major generating facilities as though they belonged to a single owner.

Project — Run-of-river or storage dam and related facilities; also a diversion facility.

Project outflow — The volume of water per unit of time released from a project. Same as discharge and outflow.

Proportional draft — A condition in which all reservoirs are drafted among rule curves in the same proportion to meet firm loads.

Refill — The point at which the hydro system is considered "full" from the seasonal snowmelt runoff. Also, refers to the annual process of filling a reservoir.

Reliability — For a power system, a measure of the degree of certainty that the system will continue to meet load for a specified period of time.

Reservoir content — See content and reservoir storage.

Reservoir draft rate — The rate at which water, released from storage behind a dam, reduces the elevation of the reservoir.

Reservoir elevation — The height above sea level of the water stored behind a dam. Same as forebay elevation.

Reservoir storage — The volume of water in a reservoir at a given time. Same as reservoir content. Reservoir storage implies a reservoir elevation. Tables are used to convert content to elevation at each reservoir.

Resident fish — Fish species that reside in fresh water throughout their lives.

Rule curves — Water levels, represented graphically as curves, that guide reservoir operations. See critical rule curves, energy content curves, and flood control rule curves.

Run-of-river dams — Hydroelectric generating plants that operate based only on available inflow and a limited amount of short-term storage (daily/weekly pondage).

Secondary energy — Hydroelectric energy in excess of firm energy, often used to displace thermal resources. Sometimes called nonfirm energy.

Shaping — The scheduling and operation of generating resources to meet seasonal and hourly load variations. Load shaping on a hydro system usually involves the adjustment of reservoir releases so that generation and load are continuously in balance.

Smolt — A juvenile salmon or steelhead migrating to the ocean and undergoing physiological changes to adapt its body from a freshwater to a saltwater environment.

Spawning — The releasing and fertilizing of eggs by fish.

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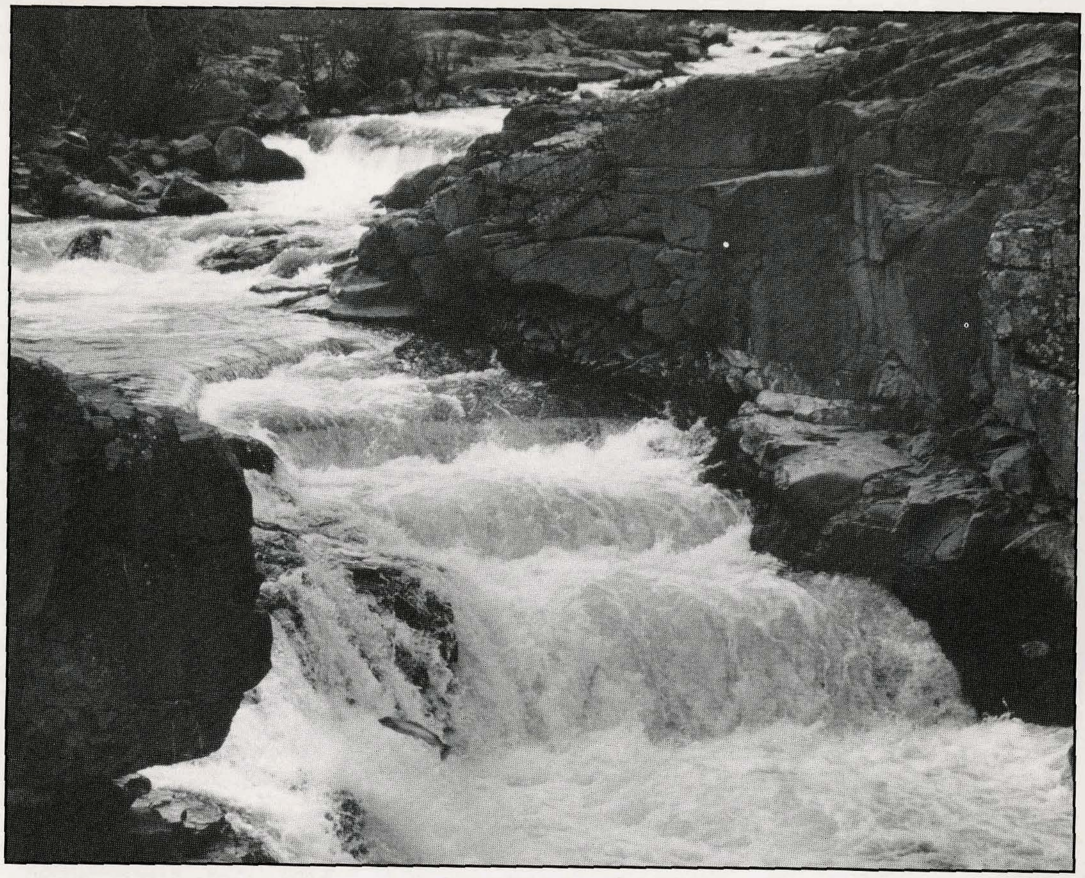
Smolt — A juvenile salmon or steelhead migrating to the ocean and undergoing physiological changes to adapt its body from a freshwater to a saltwater environment.

Spawning — The releasing and fertilizing of eggs by fish.

Spill — Water passed over a spillway without going through turbines to produce electricity. Spill can be forced, when there is no storage capability and flows exceed turbine capacity, or planned, for example, when water is spilled to enhance juvenile fish survival.

Spillway — Overflow structure of a dam.

Storage reservoirs — Reservoirs that have space for retaining water from springtime snowmelts. Careful scheduling of reservoir refill serves to prevent floods in high runoff years. Retained water is released as necessary for multiple uses — power production, fish passage, irrigation, and navigation.



Streamflow — The rate at which water passes a given point in a stream, usually expressed in cubic feet per second (cfs).

Surplus — Energy generated that is beyond the immediate needs of the producing system. This energy may be sold on an interruptible basis or as nonfirm power.

Tailwater — Water immediately below the power plant. Tailwater elevation refers to the level of that water.

Thermal power plant — Generating plant that converts heat energy into electrical energy. Coal, oil, and gas-fired power plants and nuclear power plants are common thermal resources.

Turbine — Machinery that converts kinetic energy of a moving fluid, such as falling water or steam, to mechanical power. Turbines are used to turn generators that convert mechanical energy to electricity.

Usable storage — Water occupying active storage capacity of a reservoir.

Usable storage capacity — The portion of the reservoir storage capacity in which water normally is stored, or from which water is withdrawn for beneficial uses, in compliance with operating agreements.

Variable energy content curve (VECC) — The January through July portion of the energy content curve. The VECC is based on the expected amount of spring runoff.

Watt — A measure of the rate at which energy is produced, exchanged, or consumed.