PUMPED STORAGE POTENTIAL OF THE HELL'S CANYON AREA

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ABSTRACT

This thesis contains the results of a preliminary investigation of the Hell's Canyon area's potential for pumped storage hydroelectric development, an alternative use of the region's water resource. The concept and application of pumped storage are discussed, particularly as they relate to the Pacific Northwest. An overview of the Hell's Canyon area is presented, focusing on its physical characteristics, history, and current National Recreation Area status. Eighteen potential pumped storage sites are noted, and three of the most promising are selected for more detailed analysis.

For the three selected sites, preliminary designs are developed based on characteristics of actual pumped storage projects. Also presented are the results of a computer study of the reservoir water level fluctuations which would be induced by pumped storage operation. The computer program developed for the study is documented in the Appendix. The three sites are analyzed for economic feasibility, based on a procedure developed by the U. S. Army Corps of Engineers. It is concluded that pumped storage in the area is too expensive to be competitive at the present time, but may be feasible in the future. Possible major social and environmental effects are noted, although no actual analysis was performed. The three selected sites are compared, and one (Barber Flat in Idaho) is recommended for further consideration.

Two possible alternative uses of pumped storage in the Hell's Canyon area are briefly discussed: (1) the use of pumped storage to relieve Hell's Canyon Dam of objectionable peaking duties; and (2) the

use of a pumped storage reservoir to cool a nuclear power plant. On this last point, one site (Bear Creek #1 in Idaho) is recommended for more study.

CHAPTER 1

INTRODUCTION

Electric energy in the Pacific Northwest has been supplied primarily by conventional hydroelectric systems. To meet increasing loads, new methods of generation must be used. A proven method of supplying peak energy is pumped storage.

One promising region for pumped storage development is the Hell's Canyon area, on the border of Idaho and Oregon. This area is a center of hydroelectric development, recreation, and related controversy. The purpose of this study is to analyze the potential for pumped storage development in Hell's Canyon, and to determine some of the effects it would have.

This analysis involves several stages. First is a review and presentation of the concept and application of pumped storage. Second is an overview of the natural and human aspects of the Hell's Canyon area. Third is an inventory of possible pumped storage sites in the region. This inventory is a combination of investigations made for this study and by the Corps of Engineers. The fourth stage is an analysis of three particularly promising sites; this stage comprises the major portion of this study. A final stage considers two possible supplemental uses of pumped storage in the Hell's Canyon area: the relief of the existing Hell's Canyon Dam from peaking duties and the cooling of a nuclear power plant with the pumped storage reservoir water.

The analysis of the three individual sites is done in four parts. First is a preliminary design for each site based on other pumped storage projects. The water level effects of pumped storage operation are analyzed in the second part. The third part is an economic analysis based on procedures developed by the Corps of Engineers. The fourth part presents some opinions concerning social and environmental aspects of the sites.

CHAPTER 2

THE CONCEPT OF PUMPED STORAGE AND ITS ROLE IN THE PACIFIC NORTHWEST

THE POWER SYSTEM OF THE PACIFIC NORTHWEST

The Pacific Northwest is comprised of the states of Washington, Oregon, Idaho, and western Montana. This region has historically experienced continuous growth, which is reflected in an increasing demand for electricity. To meet this demand, new methods of generating electricity are being investigated. Pumped storage is one of these methods.

The Northwest power system is a mixture of federal agencies and public and private utilities. Most of the electricity demand and population occur west of the Cascade Mountains. The remaining population is located primarily in the agricultural areas of western Washington and southern Idaho.

The energy situation of the Pacific Northwest is unique in a few features. Hydroelectric plants, particularly those on the Columbia and Snake rivers, supply about 85 percent of the generated electricity. This is a much greater percentage than any other region (Bruton and Mittelstadt 1974). The remaining electricity is supplied by nuclear or coal-fired thermal plants. Per capita electricity consumption in the Northwest is the highest in the nation, and the peak demand occurs in the winter because of electrical space heating (Mangan 1971). (An important exception to this is Idaho Power Company serving southern

Idaho, which experiences a summer peak due to irrigation pumping demands.)

Because of the reliance on the Columbia and Snake rivers for the bulk of the power generation, utilities attempt to coordinate their activities closely, particularly concerning water releases. The Pacific Northwest is interconnected by an extensive transmission grid, with the federal Bonneville Power Administration lines forming the backbone. Power interchanges between utilities are common, as are joint construction ventures. This cooperation generally provides for an efficient use of resources.

Most new generating facilities will be thermal plants. Because thermal plants operate best in a near-steady state condition, they will be used to supply constant (base) loads, as shown in Figure 2-1. Hydro generation, which can respond quickly and efficiently to load changes, will be used mostly for the peaking requirement. Some hydro will be used for the base load to satisfy river flow requirements. Utilities and involved agencies have formulated a plan, known as the Hydro-Thermal Program, to coordinate and promote development of generating facilities.

FUTURE PEAKING REQUIREMENTS

The recommended development scheme of the Hydro-Thermal Program includes the construction of base load thermal plants and the installation of more turbines at existing dams to supply the peaking requirement. Nuclear plants are expected to supply most of the future power, although coal-fired plants will also be important. The Hydro-Thermal

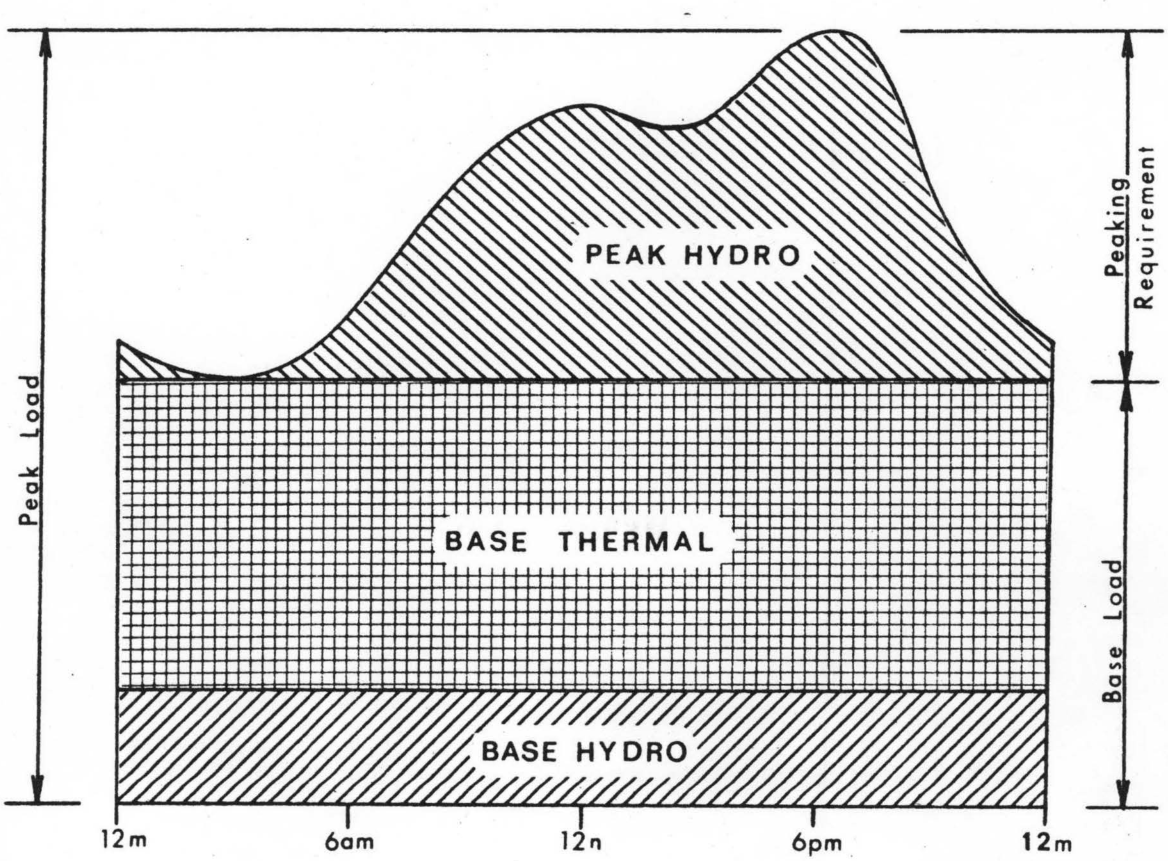


Figure 2-1.--Typical daily load shape.

Program is well under way now. The third powerhouse at Grand Coulee Dam and a proposed second powerhouse at McNary Dam are examples of installing more turbines at existing dams. The Centralia, Washington coal plant and Trojan nuclear plant near Portland, Oregon are examples of the thermal development.

Installing additional units at existing dams is the most economical method of meeting the growth in peaking requirement, but it is a limited resource as there is only a finite quantity of water in the system. Also, the increasing use of hydro plants for peaking will cause increasingly large amounts of objectionable river and reservoir level fluctuation. Future minimum flow or peaking restrictions could mean loss of peaking capability. The amount of peaking potential at existing dams is thus somewhat uncertain, but it should be sufficient for the next 10 to 20 years.

Shown on Table 2-1 are the 1975 load and resource forecasts of the West Group (Oregon, Washington, and northern Idaho utilities). These forecasts predict that a deficiency in peak power will occur in the 1987-88 season under adverse hydrologic conditions unless additional projects are built (Pacific Northwest River Basins Commission, Power Planning Committee 1975). As can be seen from Table 2-1, the Northwest's major need is average (base) energy. Idaho Power Company forecasts do not show a deficiency in this period. However, their forecasts are based on average hydrologic conditions and utilization of the proposed Pioneer coal-fired plant near Boise (Barclay 1975). The Pioneer plant has been rejected, and planning with average hydrologic

COMPARISON OF LOADS AND RESOURCES
WEST GROUP AREA - CRITICAL CONDITIONS

Figures in Megawatts

	Total Load		Firm Resources		Surplus or (Deficit)	
Period	Peak	Ave.	Peak	Ave.	Peak	Ave.
76-77	25,278	15,766	26,422	15,145	1,144	(621)
77-78	26,860	16,222	27,568	15,331	708	(1,291)
78-79	28,345	17,560	30,370	15,407	2,025	(2,153)
79-80	29,655	18,358	32,163	16,126	2,508	(2,232)
80-81	31,113	19,277	32,719	16,924	1,606	(2,353)
81-82	32,014	19,892	32,941	17,473	927	(2,419)
82-83	33,428	20,546	33,766	18,024	338	(2,522)
83-84	34,694	21,355	36,948	20,246	2,254	(1,089)
84-85	36,221	22,255	36,460	21,314	239	(941)
85-86	37,814	23,152	38,520	22,685	706	(467)
86-87	39,510	24,136	39,596	23,689	86	(447)
87-88	41,200	25,156	40,496	24,873	(704)	(283)
88-89	43,107	26,242	40,114	28,848	(2,993)	(1,394)
89-90	45,104	27,411	39,715	24,819	(5,389)	(2,592)
90-91	47,208	28,608	39,294	24,798	(7,914)	(3,810)
91-92	49,353	29,874	38,865	24,766	(10,488)	(5,108)
92-93	51,716	31,219	38,393	24,727	(13,323)	(6,492)
93-94	54,188	32,643	37,898	24,687	(16,290)	(7,956)
94-95	56,806	34,145	37,375	24,650	(19,431)	(9,495)
95-96	59,547	35,722	36,826	24,613	(22,721)	(11,109)

Table 2-1.--Projected Northwest electricity requirements (from Review of Power Planning in the Pacific Northwest 1975).

conditions assumes readily available imported power, which is unreasonable to expect (Bruce 1975). Thus, the Idaho Power Company forecasts are probably too optimistic.

The above forecasts must be viewed with caution, as the power supply situation is in a state of flux. Nevertheless, these are the projections used by utilities to plan projects, and they show a need for additional peaking capacity for the Northwest in the future.

PEAKING CAPACITY ALTERNATIVES

One possible way of providing the additional peaking capacity is to build more hydroelectric dams. However, most of the sites that could provide a significant amount of energy have either been developed already or reserved for other uses. Thus, few major conventional hydroelectric dams will be built in the future.

Another peaking method is the use of special thermal peaking installations. These are usually gas turbines or oil-fired steam electric plants. Such installations suffer from several drawbacks. The fuels are natural gas or petroleum products, which have an uncertain supply and very high cost in the Northwest. Thermal peaking units can also suffer from noise and air pollution problems and tend to be less economical than other peaking methods (Pacific Northwest River Basins Commission 1970).

Energy storage is another means of providing peak power. Energy storage utilizes excess energy generated during off-peak periods (such as at night), by storing it in some form and then releasing during peak periods. This storage capability is also required before intermittent forms of generation, such as solar or wind power, can be used effectively. Many storage schemes have been proposed, including batteries, electrolysis of water to form hydrogen (a fuel), flywheels, and compressed air. None of these systems is as yet economically and/or technically feasible at the large scale required for a regional power system (Vanderryn 1975). An energy storage scheme which has been in use for decades is pumped storage.

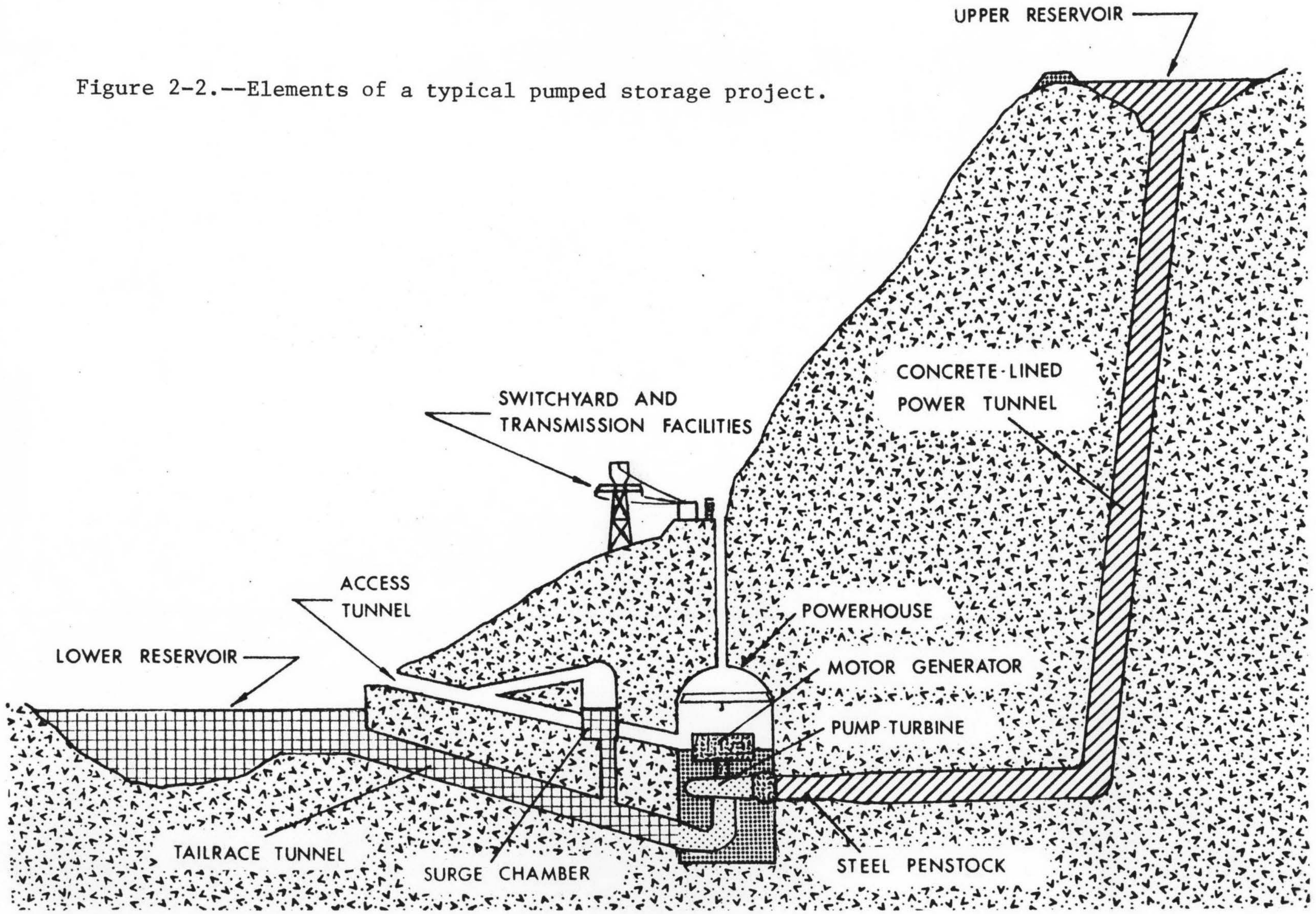
THE CONCEPT OF PUMPED STORAGE

Pumped storage is basically a refinement of the conventional hydroelectric scheme. Figure 2-2 is a diagram of a typical pumped storage installation. Water is pumped from a lower reservoir to an upper reservoir using power available during off-peak hours. During peak hours, the water is released to the lower reservoir.

Pumped storage development began in Europe in the 1930's. Large-scale development did not reach North America until the 1950's. In the United States, early development centered in the Northeast and has spread throughout the country.

Figure 2-3 shows how pumped storage usually fits into a load pattern. This illustrates a basic requirement for pumped storage feasibility--the availability of base load energy for pumping. In most cases, this base load energy comes from thermal plants. When thermal base capacity is available, pumped storage can be of significant benefit. Pumped storage can allow a thermal plant to continue producing during low load periods, thus avoiding the marked inefficiencies caused

Figure 2-2.--Elements of a typical pumped storage project.



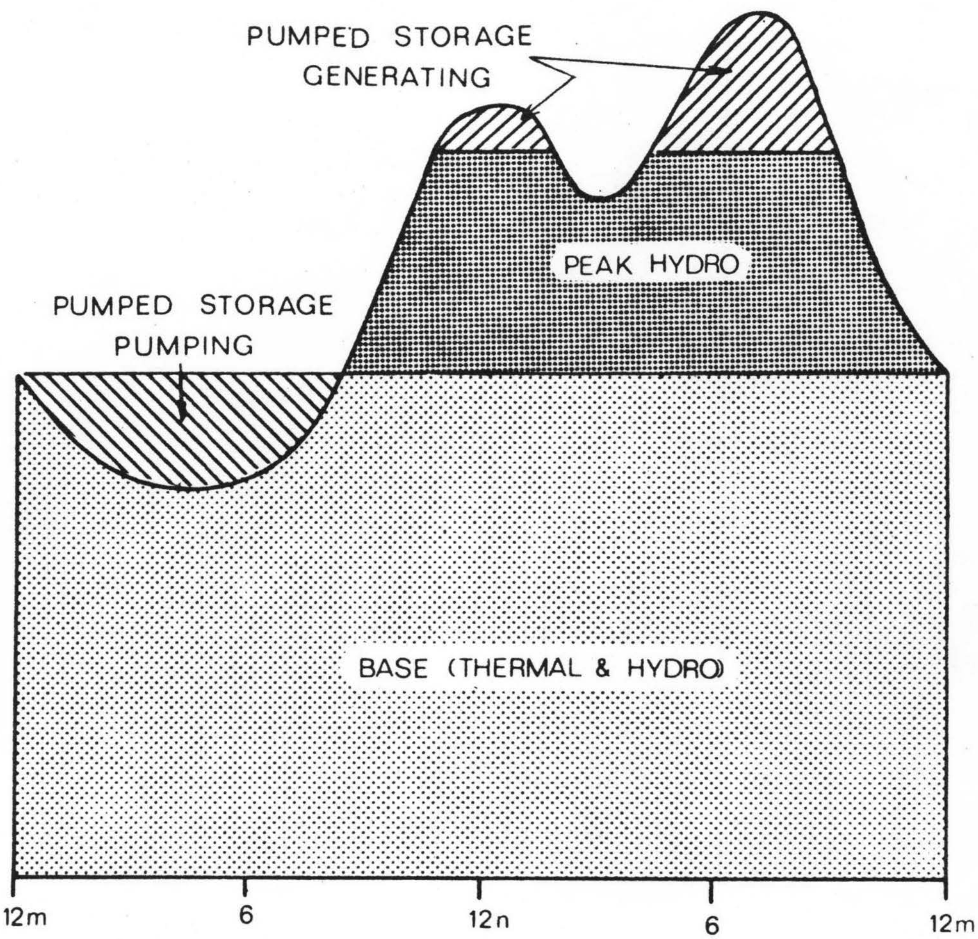


Figure 2-3.--Typical daily load shape with pumped storage.

by varying the output. This is the concept of "load-leveling."

Pumped storage is often erroneously considered to be an independent peaking power source. Because pumped storage is <u>just</u> storage, the pumping energy source must be considered also. Therefore, the source of the pumping energy is very important. In a thermal system, the pumping energy comes from the plants that would normally be shut down first. These are usually the older, more inefficient, and expensive plants. In a mixed hydroelectric and thermal system, the possibility exists for storing base hydropower which othermise might not be used. Once again, the option of shutting down thermal operations must be considered.

Because of normal mechanical inefficiencies in pumped storage operation, about three units of pumping power are required for every two units of peak power produced. Thus, pumped storage is a net energy consumer rather than a producer. This may seem paradoxical and wasteful considering the current energy shortage, but economically the loss can be justified because the value of the peak power produced is greater than that of the power consumed. The net loss of one unit of energy normally comes from thermal sources. The loss for a 1,000 megawatt (MW) pumped storage plant is equivalent to about 50 MW of continuous base load (Mittelstadt and Bruton 1974). This points out that a large amount of peaking power can be obtained from a relatively small amount of energy. This is, of course, the result of the operation of pumped storage at a low plant factor (around 10 percent usually).

Recent studies have shown that pumped storage may not be as feasible as once believed, particularly when nuclear plants supply the pumping energy (Kusko 1971). The increasing costs for nuclear energy and pumped storage construction are eroding the necessary price differential between off-peak and peak energy.

Pumped storage projects are categorized by their type of operation. Seasonal pumped storage involves pumping water during the high streamflow period of spring and early summer, then releasing during the high demand winter period. The weekly-type operation involves pumping during weekends and weeknights, generating during weekdays. The daily-type operation involves simply pumping at night and releasing during the day. Many projects in the country are operated on a combination daily/weekly cycle. The seasonal pumped storage operation requires a much larger upper reservoir than the daily/weekly type. This large upper reservoir can offer significant benefits other than power, such as recreation, irrigation, and flood control. However, the stricter site requirements for seasonal pumped storage make practical sites scarce. Therefore, most new pumped storage installations will be the daily/ weekly type.

To be economically feasible, several general siting requirements apply to a pumped storage project using the daily/weekly cycle. First, the project must be a fairly large installation, both to take advantage of economies of scale and to minimize the number of installations in a region. In the Northwest, the minimum size is considered 1,000 MW (U. S. Army Corps of Engineers 1972). Second, the site should have a fairly high hydraulic head; the minimum is considered to be about 700 feet (U. S. Army Corps of Engineers 1976). The high heads allow smaller conduits and reservoirs for a given plant capacity.

Third, the upper and lower reservoirs should be relatively close horizontally to minimize expensive tunneling. Together these last two requirements mean the project must be located in relatively steep terrain. A measure commonly used to minimize the cost of pumped storage is the use of an existing reservoir as one of the pumped storage reservoirs (usually the lower).

The powerhouse for a pumped storage project can be located either underground, as shown in Figure 2-2, or at the surface near the lower reservoir. Underground powerhouses can be advantageous by allowing the use of relatively high speed turbines at deep submergences (often greater than 100 feet is required). Advances in cavern design and excavation technology are making underground powerhouses routinely competitive. Tailrace surge chambers are sometimes required, depending on the site characteristics.

The type of pump-turbine used is dependent on the head. Axial-flow reversible pump-turbines are available for low head applications. However, because of the large flow rates required at low heads, practical low head sites are rare. Up to heads of about 2,400 feet, reversible single-stage Francis-type units can be used (Bechtel, Inc. 1975). The head limit for using this type of machine has increased in the past, but how much more it can increase is not known. For higher head applications, separate pump and turbine units connected to a common motor/generator can be used. Designs for separate units are numerous, and such installations are fairly common in Europe.

The upper reservoirs are generally sized to contain a volume of active storage equal to a specified number of hours of full plant capacity generation. This time period can vary, but 14 hours is often recommended for a daily/weekly installation. A 1,000 MW pumped storage installation, with 1,500 feet of head sized at 14 hours, would require an active storage of approximately 12,000 acre-feet (U. S. Army Corps of Engineers 1972). Experience in pumped storage operation has often produced a desire for more storage to allow greater flexibility (Woodward 1975).

If the upper reservoir is used only for power, little dead storage is required and drawdowns can be quite large. If the reservoir has other uses, particularly recreation, drawdowns must be minimized because of aesthetics and safety; this would require a reservoir with a large surface area. An upper reservoir can have severe leakage problems, and liners and other expensive preventive measures are often required.

Multipurpose development may make a project more politically and/or economically feasible. Daily/weekly pumped storage can offer limited multipurpose usage, such as water supply and possibly irrigation. Another purpose for which pumped storage can be used is to supply cooling water for thermal power plants. An attractive scheme to many power planners is a pumped storage plant with a reservoir which serves as a cooling pond for a nuclear power plant. The nuclear plant, in turn, supplies off-peak pumping power for the pumped storage. Advocates say this system would cause a minimum of pollution, but because of site limitations on both pumped storage and nuclear facilities, such sites are quite rare.

The preceding description is for what may be termed conventional pumped storage. Three other modified schemes are available. One is to install pump-turbines in the powerplant of a conventional hydroelectric dam. The advantage of this scheme, known as pump-back storage, is that additional reservoirs need not be constructed. A disadvantage is that economically high heads generally do not exist. Installations of this type are usually of fairly small capacity. The second modified scheme is to excavate a cavern deep underground to serve as the lower reservoir. Advantages of this system are minimum surface disruption, high heads, and flexibility of siting. Economics can be unfavorable, however, unless existing excavations are used, such as mine shafts. Environmental factors favor the underground scheme, and so it may become quite attractive. The third scheme is to store compressed gases in underground caverns. This is rather new technology, and special geological formations, such as salt domes, are best suited for development.

Pumped storage is, of course, not without its drawbacks and objectors. Major objections are usually related to environmental issues. The building of a reservoir and the inundating of land will cause objections if that land has an existing productive use, such as agriculture, recreation, or wildlife habitat. Depending on the plant output and site characteristics, a few thousand acres may be involved. The river and reservoir fluctuation associated with a pumped storage installation can be harmful to aquatic life. This is particularly important when an existing reservoir is used in the development. If the existing reservoir is used for peaking purposes already, pumped storage can magnify the fluctuations and the associated problems. The required high voltage transmission lines can also be sources of complaint.

THE ROLE OF PUMPED STORAGE IN THE PACIFIC NORTHWEST

Three main sources of peaking power are viable in the Pacific Northwest for the foreseeable future. These are conventional hydroelectric plants, gas turbines, and pumped storage. Conventional hydroelectric plants are by far the least expensive, as fuel costs are nonexistent. However, few major new dams will be built, as discussed earlier. Additional generating units at existing dams can be an inexpensive source of peaking power, but suitable sites are limited. Gas turbines are advantageous in that they can be located near the loads and can be constructed relatively quickly. They suffer from the disadvantages of scarce fuel supply, cost, and pollution.

For the Northwest, pumped storage is more expensive than conventional hydroelectric peaking power, but less expensive than thermal peaking power (U. S. Army Corps of Engineers 1972). Many potential sites exist, but environmental and social restrictions may require remote pumped storage generation. Since the Northwest's power system is mostly hydroelectric, pumped storage could store base hydroelectric energy which might not otherwise be used.

The Northwest, in fact, has some pumped storage already. The Bureau of Reclamation recently installed two 50 MW pump-turbines in the Grand Coulee Pumping Plant to develop about 300 feet of head between Banks Lake and Roosevelt Lake behind Grand Coulee Dam. Generating capacity will ultimately be increased to 300 MW. The Banks Lake development was originally an irrigation project, and the installation of pump-turbines for wintertime generation was a convenient but originally unplanned development.

Planning is well underway in the Northwest for the installation of major single-purpose pumped storage projects. Specific active studies include the Antilon Lake site near Lake Chelan and the Brown's Canyon site along the Columbia River, both in central Washington. The Corps of Engineers recently completed an inventory of potential pumped storage sites in the Northwest. This inventory listed 530 sites of at least 1,000 MW capability. Many of these sites are located in sensitive areas, such as National Parks, but 389 have no such apparent conflict. Further study would undoubtedly decrease this number even more due to geological, social, or environmental conditions. Even so, the site potential in the Northwest is far above any demand estimates (U. S. Army Corps of Engineers 1976).

Pumped storage reservoirs in the Northwest are likely to be sized larger than elsewhere in the country. This is because some reserve storage should be included to allow generation for possibly 30 to 40 hours. This would permit the project to function during a prolonged winter cold spell common to the area (Mittelstadt and Bruton 1974). This reserve could also allow for greater flexibility of operation and would minimize drawdowns during normal operation periods.

The flexibility of pumped storage is valuable. For example, pumped storage could provide immediate backup in case of a major forced outage in the system, relieve existing dams of objectionable peaking duties (although at a higher cost), store unused generation from minimum flow releases, and tide the system over until water from storage reservoirs makes its way downstream to generating plants (Mittelstadt and Bruton 1974).

The Northwest also has some additional restrictions. People of the Northwest demand a high quality environment and excellent outdoor opportunities. Excessive reservoir and river fluctuations are likely to be opposed. Of particular concern is the anadromous fishery, which is at critically low levels now due mainly to dams on the rivers. Releases from a pumped storage plant on a major fishery river, such as the Columbia, would likely have detrimental effects.

Since it seems the best method of providing supplemental peaking capacity, some pumped storage will likely be developed in the Northwest. The timing of the inclusion into the system is not certain, however. Several highly variable factors will affect the date.

One factor is the electricity demand growth rate. Basing projections on historic usage may be hazardous, for a dedication to conservation could cut the growth considerably. The population growth of the region is also important. The economic and social attractiveness of the Northwest may either increase or decrease.

Another variable factor is that pumped storage is dependent upon other power plant development. For economic reasons, pumped storage should follow the completion of adding capacity at existing dams. However, these additions will likely meet postponements and denials. Pumped storage could compensate for these losses, and thus be desirable earlier than anticipated. On the other hand, the construction of thermal powerplants, upon which pumped storage is dependent for pumping power, is also likely to be delayed. This could delay the installation of pumped storage.

The establishment of restrictive flow requirements, (such as minimum flows), could decrease the amount of peaking capability at existing dams. This would make pumped storage feasible sooner. Also working in that direction is that some utilities may need additional peaking capacity before the entire system does.

The impracticality of other peaking or energy storage methods is not definite either. A possible surplus of Alaskan oil on the West Coast could make thermal peaking competitive. Increasing energy costs may make some marginal hydroelectric sites economical. Technological advances in the next few years could make some exotic storage and generating methods feasible. In light of all of these uncertainties, a good guess is that some pumped storage will be built in the 1980's, concurrent with the installation of added capacity at existing dams (Mittelstadt and Bruton 1974).

CHAPTER 3

OVERVIEW OF THE HELL'S CANYON AREA

PHYSICAL DESCRIPTION

The Hell's Canyon area is located in western Idaho and northeastern Oregon, as shown in Figure 3-1. A stretch of the Snake River, known as the Middle Snake, flows between the states through a very deep and magnificent canyon. Although reference to Hell's Canyon occasionally means the area from Weiser to Lewiston, this paper will refer to the smaller area in Figure 3-1 as the Hell's Canyon area. Approximate boundaries are the Salmon River on the north, the Salmon and Rapid rivers on the east, Brownlee Dam on the south, and the Imnaha River on the west.

The topography of the area is characterized by extreme relief. On the Idaho side, the Seven Devils Mountains reach elevations of over 9,000 feet, while the elevation at the mouth of the Salmon River is about 900 feet. Rivers and streams in the area have cut deep canyons, with Hell's Canyon, "The Grand Canyon of the Snake," being the most prominent. The river flows in a series of large rapids and deep pools. The heavily forested uplands contrast to the gaunt lower canyon. On the Oregon side, the uplands take the form of a deeply incised plateau. On the Idaho side, forests give way to rocky peaks interspersed with many scenic alpine lakes. The area presents a varied and spectacular set of sights and experiences.

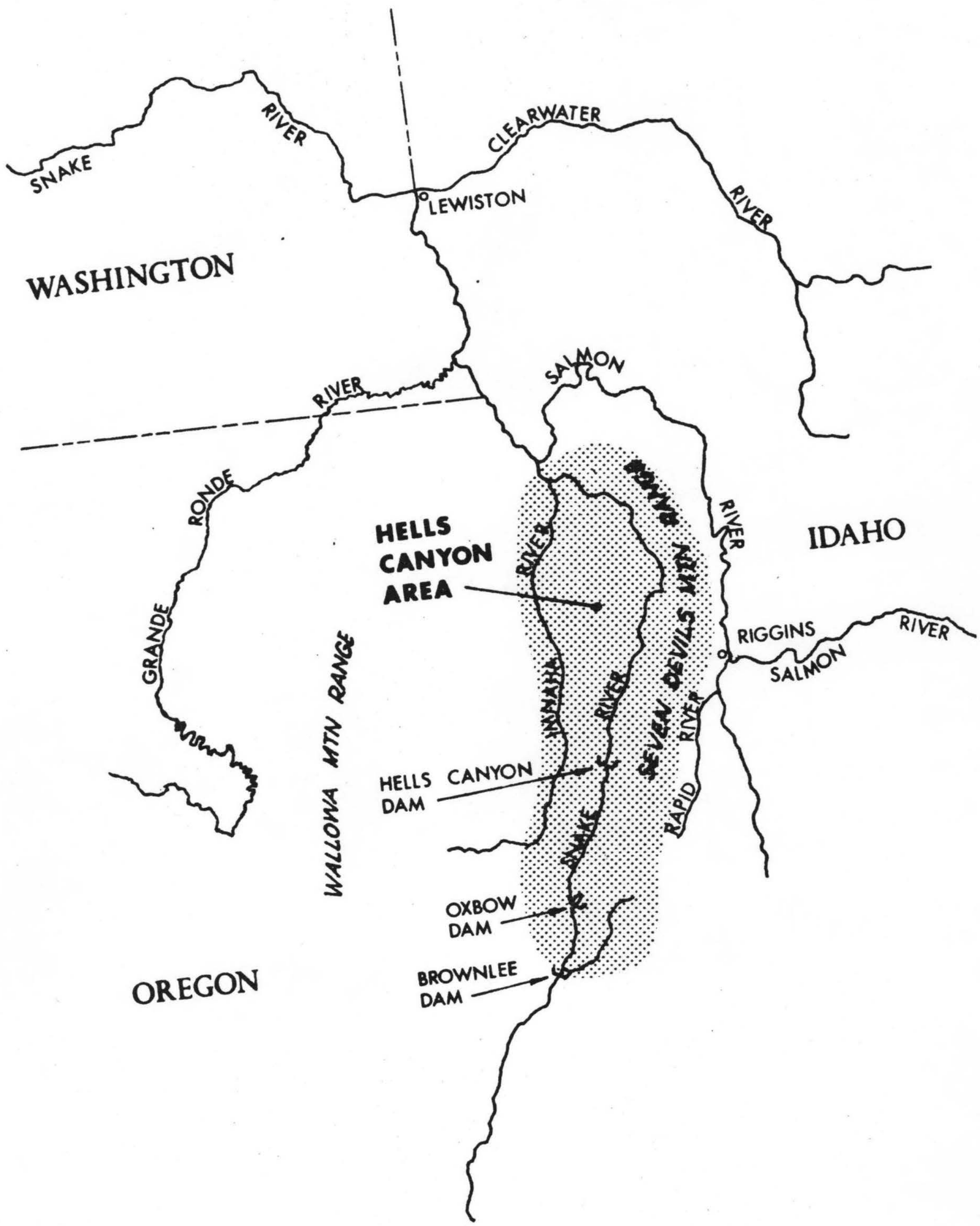


Figure 3-1.--Location of the Hell's Canyon area.

The lower elevations have mild winters and very hot summer. In contrast, the high elevations have mild summers and cold winters, with snow persisting until mid-summer. Most of the precipitation for the year falls as snow in the mountains. Therefore, the streams in the area have a characteristic late spring/early summer high flow. Stream gradients are very steep for the tributaries, often hundreds of feet per mile. The Snake River has a gradient through the canyons of about 10 feet per mile (U. S. Army Corps of Engineers 1972).

Hell's Canyon has not been heavily exploited by man, and much of the area is of a wilderness nature. Three hydroelectric dams, built by the Idaho Power Company in the southern part of the area, represent the major encroachment of civilization. Population in the area is very small, primarily a few ranches in the canyon and some isolated mines and small towns in the south. Cattle and sheep ranching has been practiced continuously since about the turn of the century (Doyle 1973). Mining has occurred sporadically since the 1870's, centering mainly on copper deposits in the south (Price 1971). Primary access to the area is provided by boat upriver from Lewiston, paved roads to the dams, and a few rough roads reaching isolated spots in the canyon.

The main human activity in the area now is recreation, and the level of this activity will increase. White-water boating is a popular activity on the Snake River. The rest of the area is used extensively for hiking, camping, fishing, hunting, and sightseeing.

GEOLOGIC HISTORY

A pumped storage design is highly dependent on the geology of the site, with principal concerns being adequacy of the geologic material for dam foundations, reservoir leakage, and tunnels and caverns. Thus, a brief discussion of the geologic history of the area is valuable.

The oldest group of exposed rock is a series of highly folded, faulted, and metamorphosed volcanics known as the Seven Devils Volcanics. This is overlain in places by a sequence of sedimentary limestone and shale. Some intrusive granitic rock associated with the Idaho Batholith occurs in the higher country. Basalts blanket much of the area. The whole region has been folded and faulted subsequent to these basalt flows. The Seven Devils Mountains have been uplifted several thousand feet. Pleistocene glaciation and stream erosion have shaped the present topography (Price 1971).

Several theories exist regarding the actual cutting of Hell's Canyon itself. The Snake River did not originally flow on its present route. A common theory is that the Snake River originally flowed to the ocean by way of northern California but was dammed by uplift in the early Pleistocene epoch. The impounded water rose and eventually spilled through a channel being cut southward by a tributary of the Salmon River. This overflow eventually diverted the Snake and cut the channel into the present canyon (Snyder 1973).

HYDROELECTRIC DEVELOPMENT

The history of hydroelectric development in Hell's Canyon should be perceived as part of the larger history of water development in the Pacific Northwest. The rivers of the Northwest, particularly the Columbia, have long been harnessed and impounded for several decades.

The purposes for the dams are numerous, with navigation, irrigation, flood control, and power generation being the most important. Main-stem Columbia dams provide the bulk of the present hydroelectric generation, and federal development in the 1930's of the Bonneville and Grand Coulee dams spearheaded the current massive hydro system. Over the decades, federal, public, and private organizations steadily built on the most economical sites. The Middle Snake, although long recognized as having outstanding power and storage potential, was not developed in the early years due to inaccessibility and corresponding high cost. In the late 1940's, however, the possibility of hydro development finally reached the Middle Snake when the Idaho Power Company initiated efforts to build a power facility at Oxbow. Over the next several years, a dispute arose over whether to build a single federal high dam or several small private power dams. In 1955, the dispute was resolved by allowing Idaho Power Company to build a three-dam complex (Brownlee, Oxbow, and Hell's Canyon). The last dam was completed in 1968.

The controversy then shifted to the northern stretch of river. A main issue was whether the development should be federal, public, or private. A concurrent issue concerned which complex of dams was "best." In 1964, a license was granted to the Pacific Northwest Power Company to build the High Mountain Sheep project. This step was contested in the federal courts, and in 1967 the Supreme Court remanded the license to the Federal Power Commission for further consideration.

Most importantly, the court added the issue of whether any dam should be built at all. This decision coincided with the rise of the environmental movement, and the Hell's Canyon controversy now became a question of preservation versus development. The issue was finally settled on the last day of 1975, when the Hell's Canyon National Recreation Area (NRA) was created, providing for inclusion of the Middle Snake in the Wild and Scenic Rivers system, and prohibiting further development.

Recreation is now to be the primary use of the Hell's Canyon area. This area is considered to have one of the best potentials for recreational development in the country. The canyon was not widely known in the past and, so, received little pressure except for hunting and fishing. With the NRA designation, visitation is expected to grow continuously.

THE NATIONAL RECREATION AREA DESIGNATION

The Hell's Canyon National Recreation Area legislation was signed into law as PL94-199 on December 31, 1975. A management plan is now being formulated, but it is not due until 1980. Key provisions of the law relating to water resources are the inclusion of the Middle Snake and the Rapid River in the Wild and Scenic Rivers system (Secs. 3 and 5(a)); a prohibition on any further water resource development in the NRA (Sec. 4); the deauthorization of the Asotin Dam (Sec. 5(b)); a safeguard against restricting upstream uses (Sec. 6(a)); and the specific disavowal of any flow requirements below Hell's Canyon Dam (Sec. 6(b)).

The key provision pertaining to pumped storage development is the restriction against further water resource development. A detailed boundary description for the NRA has not yet been issued, and is not due until the end of June 1977. Contained in the NRA Study Plan, dated May 5, 1976, is a map which is reproduced as Figure 3-2. It is assumed that this map shows the approximate boundaries, and that many of the boundaries are hydrologic basin divides. This map differs from those published for earlier legislation in that a corrider along the Snake River to Brownlee Dam is not shown. Such a corridor would rule out many of the better pumped storage sites of the Hell's Canyon Area. Earlier legislation also would have included in the Wild and Scenic Rivers System the section of the Snake River from the Oregon-Washington border to the town of Asotin, Washington. This section of river is now being studied for inclusion in the System. The pumped storage potential of this section of river has not been investigated for this thesis.

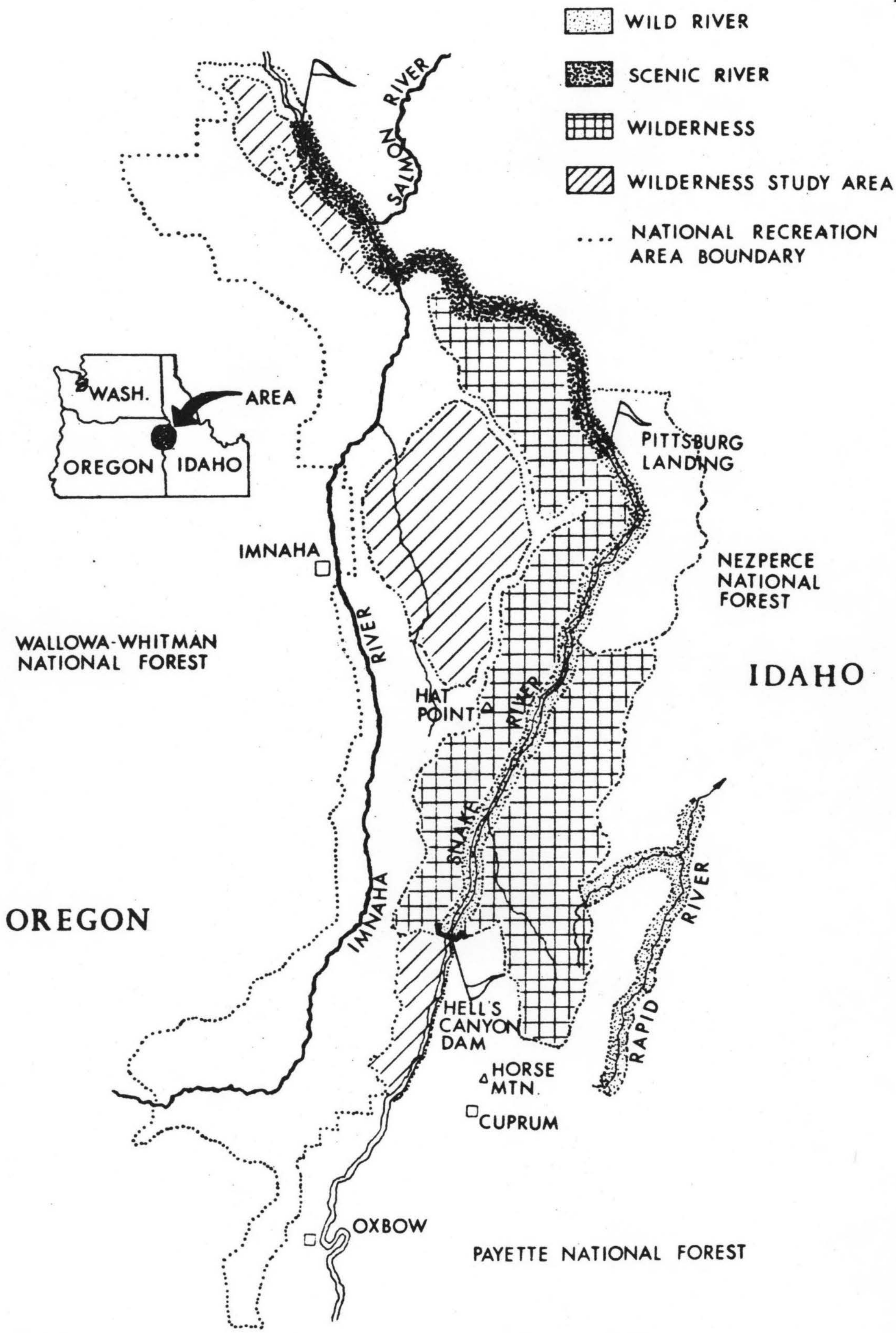


Figure 3-2.--National Recreation Area boundaries.

CHAPTER 4

PUMPED STORAGE SITES IN THE HELL'S CANYON AREA

THE CORPS OF ENGINEERS 1976 STUDY

As mentioned in Chapter 2, the North Pacific Division of the Corps of Engineers recently completed a study which attempted to inventory the pumped storage sites in the Pacific Northwest (Pumped Storage in the Pacific Northwest, an Inventory 1976). Included in their study were some reconnaissance level cost estimates; the estimating procedure is outlined in Chapter 6. Over 20 sites were found in the Hell's Canyon region, and three of these were attractive enough to warrant further study. The site location work for this thesis was completed prior to receiving the Corps study, and nearly all of their sites had already been located.

A table cataloging all sites found in the area is included in this chapter, as is a description of the site selection procedure used for this thesis. Three sites have been selected for further analysis.

SITE SELECTION PROCEDURE

Study was limited to those sites which would either use a reservoir on the Snake River or would recirculate water between two new off-stream reservoirs. This restriction primarily eliminated sites using the Salmon or Imnaha rivers. The study area was bounded by the Salmon River on the north and Brownlee Dam on the south.

For those sites downstream of Hell's Canyon Dam, use of the High Mountain Sheep reservoir was assumed. It is recognized that construction of High Mountain Sheep or any other dam on the Middle Snake is highly unlikely. However, should development ever occur, the potential for pumped storage would exist and should be recognized.

Since it had already been decided to concentrate on sites using the Snake River and/or existing reservoirs, the focus of the site selection procedure was to locate suitable upper reservoir sites. This was entirely a map study procedure. The principal maps used were the USGS topographic maps (7-1/2 and 15 minute series) and the Army Map Service plastic relief maps. The plastic relief maps were helpful in giving an indication of the terrain, while quantitative work was based on the USGS sheets. A minimum project size of 1,000 MW was assumed.

A prospective site was judged according to four criteria. These were head, tunneling length, dam size to contain the required storage, and drawdown. The major effort was to find sites with a head between 700 and 2,500 feet. A rough guide for the maximum allowable horizontal separation of the reservoir (an estimate of the tunneling length) is ten times the head (Resch and Predpall 1974).

Creek valleys provide the best reservoir sites, but most of the streams in the Hell's Canyon area have such steep slopes that the dams required to provide enough storage would be prohibitively large. A maximum dam height of 250 to 300 feet was chosen as a reasonable limit. A maximum allowable drawdown of 80 feet for a 1,000 MW installation was assumed, as recommended by the Corps of Engineers (U. S. Army Corps of Engineers 1976). The object then was to locate stream sections with relatively small gradients. Water availability for initial filling was not considered a problem, as almost all of the sites used the Snake River.

Once a possible reservoir site was located, an upper reservoir area-volume curve was developed. A problem herein occurs, as the topographic maps for most of the sites have an 80-foot contour interval. With such a large contour interval, the area-volume curves have to be based on only three or four points. Such curves must be viewed as only approximations.

From the curve of elevation versus volume, a curve of elevation versus energy stored was constructed. A site was considered feasible if it could store 14,000 megawatt-hours of energy (14 hours at 1,000 MW), while staying within the bounds of the four criteria mentioned earlier.

Three main differences exist between the procedure for this study and that used by the Corps: (1) for this study, very high head sites or large dams are neglected, (2) the Corps' judgment on feasibility is based on estimated costs while for this study feasibility is based on physical features only, and (3) for projects downstream of Hell's Canyon Dam, the Corps assumed a new small dam on the Snake River, whereas this study assumed High Mountain Sheep Dam. Both procedures were based on 14-hour storage installations.

INVENTORY OF POSSIBLE SITES

Table 4-1 contains data on the 18 pumped storage sites found in the Hell's Canyon area. Locations are shown in Figure 4-1. The table

Table 4-1.--List of pumped storage sites located in the Hell's Canyon area.

Site Name	Maximum Size (MW)	Upper Reservoir: Location	Upper Reservoir: Active Storage (Ac-ft)	Upper Reservoir: Drawdown (Ft)	Lower Reservoir: Name	Lower Reservoir: Drawdown (Ft)	Head (Ft)	Waterway Length (Ft)	Comments
Barber Flat[!]	7,000	ID,19N,4W,36	38,200	45	Oxbow	40	2,550	13,600	Different dam alignment and L.R. drawdown than Corps'.
Bear Creek #1[!]	10,000	ID,20N,3W,10	65,000	70	H. Canyon	30[**]	2,450	34,100	Lower reservoir listed by Corps as new.
Cave Creek[*]	4,000	OR,9S,47E,5	48,600	75	Brownlee	1	1,190	5,400	Actually somewhat south of Hell's Canyon.
Dry Creek #1[*]	3,000	OR,6S,48E,28	13,900	65	H. Canyon	6[**]	3,490	18,000	High head, in NRA.
Flat Creek[*]	2,000	ID,19N,3W,6	10,700	50	H. Canyon	4[**]	3,110	22,400	
Granite Creek[*]	5,000	ID,22N,2W,8	20,400	160	H. Canyon	9[**]	4,060	18,200	High head, in NRA.
Haley Ridge[*]	3,000	ID,21N,3W,1	13,500	65	H. Canyon	6[**]	3,430	16,900	High head, very near NRA.
Homestead #1[*]	3,000	OR,5S,48E,31	17,800	65	H. Canyon	7[**]	2,630	21,700	In NRA.
Indian Creek[!] (Cuprum)	4,000	ID,20N,3W,17	21,800	80	H. Canyon	9	2,550	13,900	Different dam location than Corps.
Indian Creek[*]	3,000	ID,20N,3W,1	19,300	75	H. Canyon	8[**]	2,460	23,100	
Lightning Creek #1[*]	5,000	OR,1S,49E,23	15,800	65	New	35	5,240	22,600	High head, in NRA.
North Pine F.[!] (Homestead #2)	3,000	OR,6S,47E,36	24,000	40	H. Canyon	10	1,740	13,900	
Sheep Creek WF[*]	2,000	ID,24N,2W,25	8,100	70	New	30	3,990	19,100	High head, in NRA.
Somers[*]	1,000	OR,2N,50E,22	3,700	50	New	15	4,420	22,000	High head, in NRA.
Sour Apple Flat[*]	2,000	OR,1N,49E,26	6,900	55	New	30	4,750	26,900	High head, in NRA.
Steen Creek[!]	1,000	ID,20N,4W,25	8,400	70	H. Canyon	3[**]	1,980	9,900	Lower reservoir listed by Corps as new.
Twogood Flat[+]	6,000	ID,28N,1W,8-9	27,000	72	H.M.S.	1	3,090	16,500	High head.
Vance Gulch[*]	2,000	ID,29N,3W,13	10,600	145	New	40	3,130	16,700	High head.

[*] As listed by the Corps.

[+] Not listed by the Corps.

[!] Similar to a Corps site, but slightly modified.

[**] Corrected.

Explanation of Table 4-1

Site Name: * - The name as given by the Corps.
! - The name as given by this study, followed in parentheses by the Corps' name.
+ - The name as given by this study.

Maximum Size: The maximum plant size, rounded to the nearest 1,000 MW.

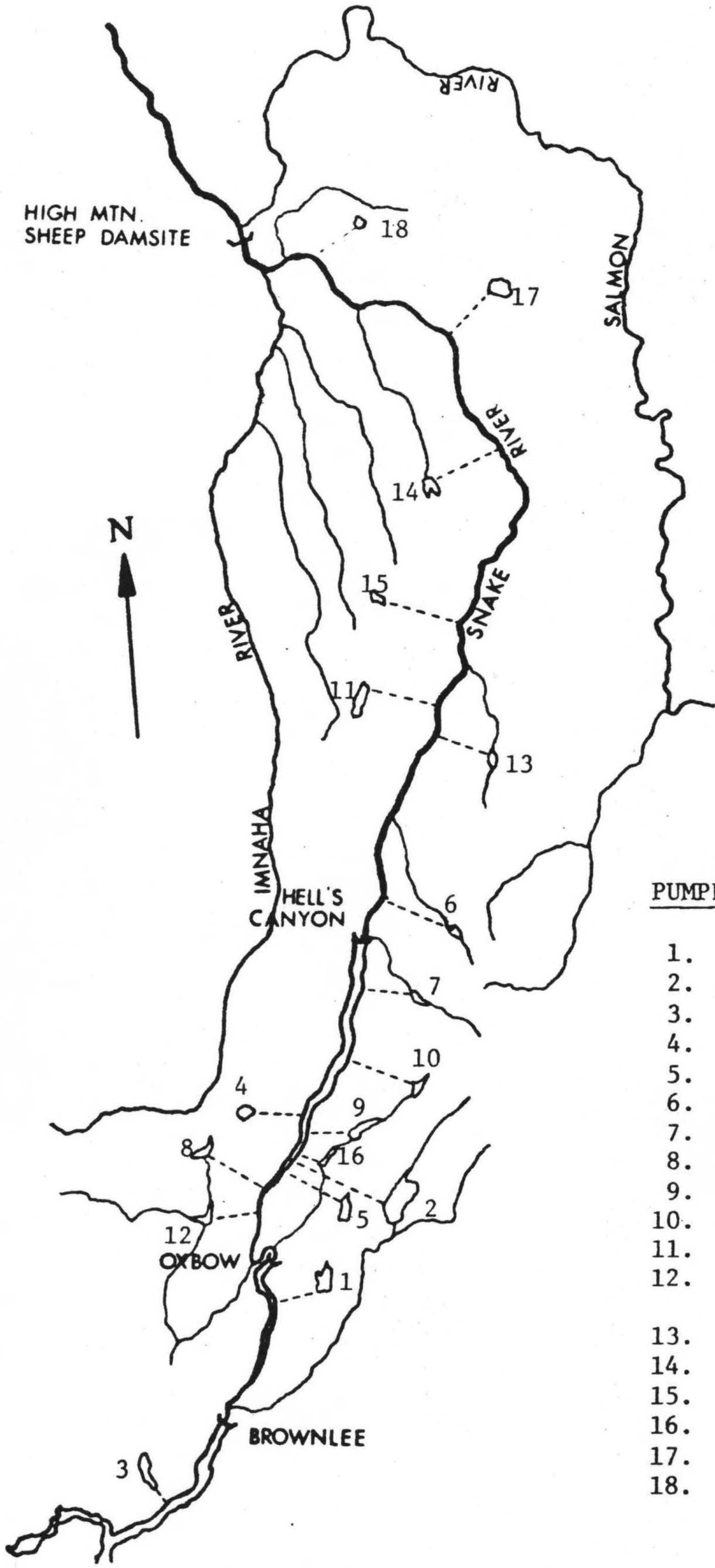
Location: The location of the upper reservoir dam; entry in the order state, township, range, section.

Active Storage: The volume in acre-feet of the 14 hours of required storage.

Drawdown: The amount the water level is lowered from full pool due to the release of the 14 hours of storage.

Lower Reservoir Name: Lower reservoirs are Brownlee, Oxbow, Hell's Canyon, High Mountain Sheep (for + sites), or new structures (for * sites).

Head: Approximate; the difference between the full pool levels of the two reservoirs.



PUMPED STORAGE SITES

1. Barber Flat
2. Bear Creek #1
3. Cave Creek
4. Dry Creek #1
5. Flat Creek
6. Granite Creek
7. Haley Ridge
8. Homestead #1
9. Indian Creek (Cuprum)
10. Indian Creek (CE)
11. Lightning Creek #1
12. North Pine F (Homestead #2)
13. Sheep Creek WF
14. Somers
15. Sour Apple Flat
16. Steen Creek
17. Twogood Flat #1
18. Vance Gulch

Figure 4-1.--Pumped storage site location map.

has three classes of sites. First, there are those contained in the Corps study but which have not been reviewed in detail. Quantities for these sites are taken from the Corps document. The name given by the Corps is used. Second, there are sites which are similar to some listed by the Corps, but are slightly different. Detailed study of a few revealed possibly better schemes. These sites are listed with two names, one from this study and one from the Corps. Third are sites located by this study but not listed in the Corps document.

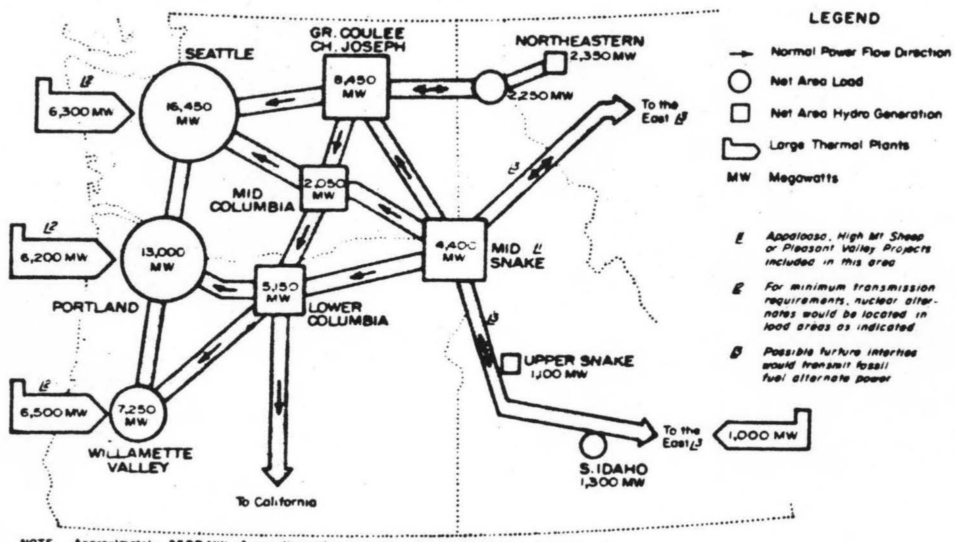
In Table 4-1, the maximum sized project, rounded to the nearest 1,000 MW, is detailed for each site. As mentioned earlier, a superior site in the Northwest will hold more than 14 hours of storage. The superior sites can be found easily in the table, (i.e., a 3,000 MW-14 hour site is also a 1,000 MW-42 hour site).

For further information on or clarification of Table 4-1, refer to the explanation following the table.

GENERAL FEASIBILITY OF PUMPED STORAGE IN THE AREA

As can be seen from the preceding table, the Hell's Canyon area has considerable pumped storage potential. Many of the sites have been precluded by the creation of the Hell's Canyon National Recreation Area, but even so, the remaining sites offer more capacity than can reasonably be expected to be developed.

The major drawback to siting in this area is the distance from any major load center. Figure 4-2 is a reproduction of a 1970 estimate of future load and generation areas (Pacific Northwest River Basins Commission 1970). Although the actual numbers may be outdated, the



NOTE Approximately 2500 MW of new thermal on reserve and not included in area totals shown

Figure 4-2.--1970 estimates of 1990 load and generation areas.
(from Pacific Northwest River Basin Commission, 1970)

relative sizes of loads are still applicable. It is important to note though that the Middle Snake region was counted on for a large quantity of energy, and this was to be sent west primarily. New transmission lines were proposed to do this.

The Hell's Canyon area could be attractive for pumped storage siting if a project were built jointly, say to serve the Idaho Power summer peaks and West Group winter peaks. The Spokane area is the closest West Group load center, but transmission ties exist to the Portland and Seattle areas, also. Development of a project in the area would require some involvement by Idaho Power, because it operates the Snake River projects to be used as the lower reservoirs.

Future development could make pumped storage in the area more attractive. The generation of energy from solar and wind sources may require storage near the generating site to be feasible. Whether the Hell's Canyon area is close enough to areas of wind or solar potential is beyond the scope of this study. Another future possibility is the siting of thermal generating facilities near the area, which would profit pumped storage siting also. Since the Pioneer coal-fired generating plant near Boise has been rejected, Idaho Power will need to explore additional means of supplying power. A nuclear plant is one alternative that Idaho Power is considering (Lewiston Morning Tribune February 25, 1977). The possibility of combining nuclear and pumped storage generation in the Hell's Canyon area will be explored further in Chapter 10.

SELECTION OF SITES FOR FURTHER STUDY

To analyze more fully the area's pumped storage potential, three of the better sites have been selected for further study. It was decided beforehand to include at least one site in each state.

The ideal pumped storage site from an engineering standpoint would store a relatively large quantity of water (approximately 40 hours) with minimal embankment volumes, have a high head (although not so high as to preclude the familiar and relatively inexpensive Francis units), and be near an existing reservoir. An ideal pumped storage site does not exist in the Hell's Canyon region. The three sites were chosen by qualitatively judging which sites tend most closely to the ideal. Therefore, the sites are chosen by engineering feasibility and implied costs. Environmental and social factors would, of course, play an equal or larger role in actual plant siting. These factors were not considered in the selection as expertise in these fields is required for an accurate assessment.

The three sites selected for further study by this qualitative procedure are Barber Flat, Indian Creek, and North Pine F. All three sites are located in the southern end of the area near the Oxbow, as shown in Figure 4-3. This part of the canyon is not the spectacular section usually associated with the name Hell's Canyon. The topography is not nearly as rugged or steep as it is farther north. As a result, the pumped storage sites around the Oxbow do not have the extremely high heads as do those sites deeper in the canyon.

The proper design and analysis of any site would, of course, involve many months of experienced, multidisciplinary work. Obviously,

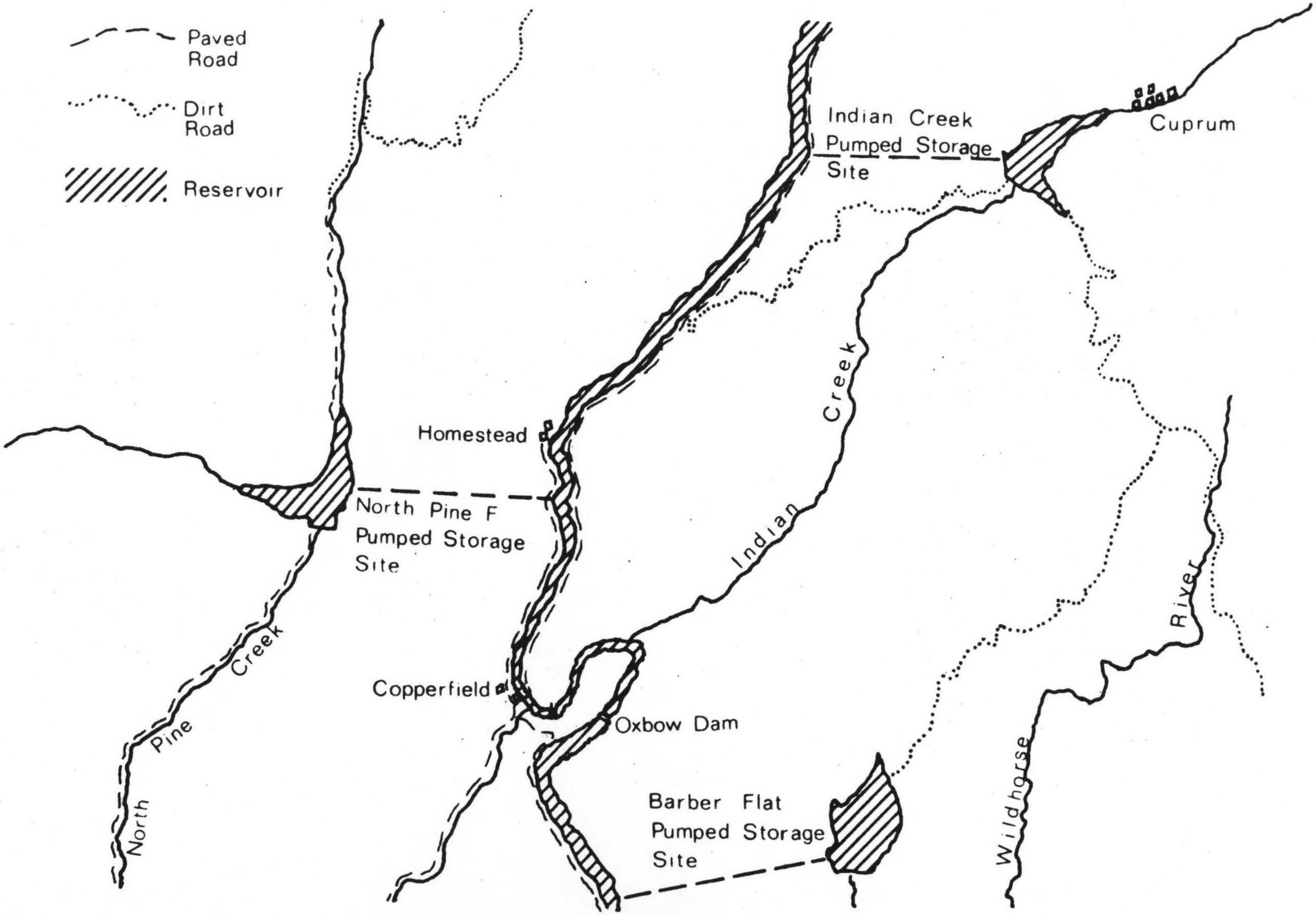


Figure 4-3.--Locations of the three selected sites.

such a thorough effort cannot be accomplished in this thesis, due to lack of time and expertise. The preliminary analysis presented here includes: (1) a layout of major physical features; (2) a preliminary analysis of the effects on the existing lower reservoirs (water levels and power production); (3) rough cost estimates; and (4) opinions with regard to possible major social and environmental aspects. This preliminary analysis is based on the designs for other actual projects. Plan and profile drawings of the general project layout for each site are presented. Other parts of the analysis are presented in a series of tables. The three sites are compared with each other based on the analyses, and judgment is made as to the overall feasibility.

CHAPTER 5

PRELIMINARY DESIGNS - THREE SELECTED SITES

The major civil engineering features of a pumped storage project are the two reservoirs, the powerhouse, water conduits, and access roads and tunnels. Major noncivil engineering aspects are the engineering geology, hydraulic machines, and electrical works (generators, switchyards, and transmission lines). The following discussion deals with the sources of information and assumptions used for the designs, which are made for 1,000 MW installations.

GENERAL ASSUMPTIONS AND FEATURES

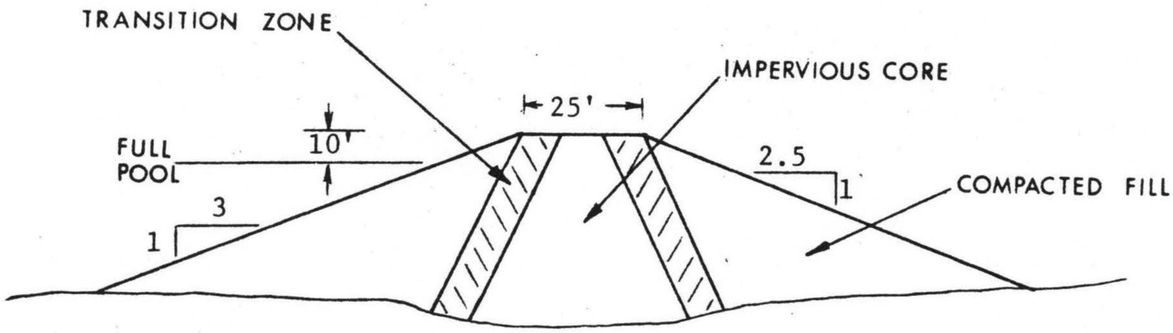
The designs presented are based on comparisons with other pumped storage projects, either existing or proposed. Of particular aid are the designs for the existing Racoon Mountain installation in Tennessee (TVA), the Helms project under construction in California (Pacific Gas and Electric Co.), and the proposed Brown's Canyon (Douglas County PUD/Bechtel, Inc.) and Antilon Lake (Chelan County PUD/R. W. Beck, Inc.) projects in central Washington.

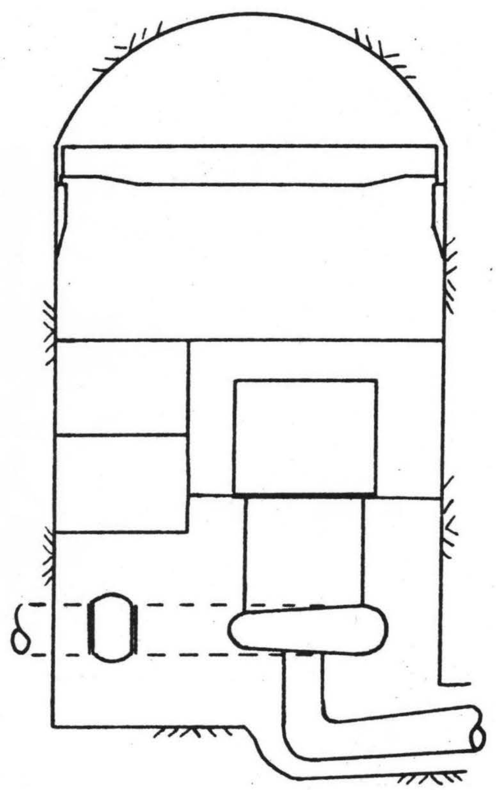
The preliminary designs for the Hell's Canyon sites are based on several assumptions derived from the above mentioned projects. First of all, an underground rather than surface powerhouse will be used. Second, a tailrace surge chamber will be required. Third, reversible Francis-type pump-turbines are specified. As mentioned before, this last assumption may be somewhat questionable, because two of the Hell's

Canyon sites have heads beyond the current range of the reversible machines. The Brown's Canyon design (Bechtel, Inc. 1975) is particularly helpful in this regard, as its head is also above the current range.

The upper reservoirs are assumed to be impounded by zoned earthfill dams, with a cross-section as shown in Figure 5-1. The type of dam and cross-section actually used would depend heavily upon geologic characteristics of the particular site. However, experience has shown that the dams and embankments contribute a relatively small fraction of the total cost of a pumped storage project (U. S. Army Corps of Engineers 1976).

For a particular site, the required height of the dam is dependent upon the volume of storage desired and the drawdown limits. The storage required may be estimated from an average head and the amount of energy desired in reserve. For this study, it is assumed that an upper reservoir should hold water enough for 40 hours of equivalent full plant generation. Furthermore, for a 1,000 MW plant, it is assumed that the 40 hours of water should be held in the top 120 feet of the reservoir, and 14 hours (for the weekly operation) in the top 40 feet. Upper reservoirs on perennial streams would require outlet works to maintain flow below the dam. The necessity of a spillway is questionable though. For sites located on small streams, the stream flood flows could probably be passed through the pumped storage plant, thus avoiding the cost of a spillway. Some projects are designed with a spillway of capacity equal to the maximum pumping flow, in case of failure and inability to stop pumping. Other designers feel such a possibility is





APPROXIMATE POWERHOUSE DIMENSIONS

1500' head - 400'x80'x175'

2500' head - 250'x70'x150'

Figure 5-1.--Assumed dam and powerhouse dimensions.

too remote to warrant the expense. Possible locations for emergency spillways are indicated for the three Hell's Canyon sites.

The waterway consists of a concrete lined power tunnel from the upper reservoir to a position just before the powerhouse, where a manifold directs the flow into individual steel penstocks. Separate draft tubes merge into a single concrete lined tailrace tunnel after leaving the powerhouse. The size of the conduits is basically an economic decision, but can be estimated as an inverse function of the head. Because of the proportionately high cost of the tunnels, high velocities are allowable. The allowable velocity in the power tunnel is greater than that for the tailrace tunnel.

To determine the flow rates, the efficiencies of the pump-turbines are estimated as follows: an overall efficiency of 66.7 percent; a generating efficiency of 85 percent; and a pumping efficiency of 78.4 percent (0.85 x 0.784 = 0.667). Flows are determined using the gross head.

Once the upper reservoir and tunnels have been sized, a more precise estimate for the head can be made. Actually, several heads are important. Maximum and minimum static head values are presented for each site, as well as estimates of friction losses for both the pump and turbine modes. As a measure of the "normal" head, the median head for a 14 hour operation is also given (i.e., the head between the 7 hour drawdown elevations of the two reservoirs).

Pump-turbine design has shown a trend toward machines with greater head, speed, and unit capacity. This trend effectively reduces the size of the powerhouse. Typical powerhouse dimensions are shown in

Figure 5-1. High speed, high head pump-turbines require deep submergence. The estimated submergence for the 2,400 foot head Brown's Canyon site is around 200 feet (Bechtel, Inc. 1975).

The alignment and location of the powerhouse and waterway are important aspects of a pumped storage design. The major factors in the decision are economics and geology. Three common arrangements are shown in Figure 5-2. The advantage of moving the powerhouse deep into the rock, such as arrangement A in Figure 5-2, is the decrease in length of expensive power tunnel and steel-lined penstock. This is offset by increases in cost for the tailrace and access tunnels, cable shaft, and so on. An arrangement like C may also decrease the expense of the power tunnel, but a headrace surge tank could be required. Geological factors, such as faults and fractures, may also influence the alignment. Thus, it is impossible without detailed geologic and economic studies to choose the optimum arrangement. For this thesis, an arrangement like A or B is assumed, with the powerhouse location determined by other factors explained later for each site.

A tailrace surge chamber is generally required when the powerhouse is located away from the lower reservoir. Maximum surge conditions are loss of power while pumping and loss of load while generating. Due to the deep submergence required for the pump-turbines, the tailrace surge chamber may be more than two hundred feet high.

A pumped storage project requires electrical interties to the system. The required transmission lines can add considerable cost to a project, both by capital investment and resistance losses. Figure 5-3 is a schematic map of the existing transmission lines in the area. As

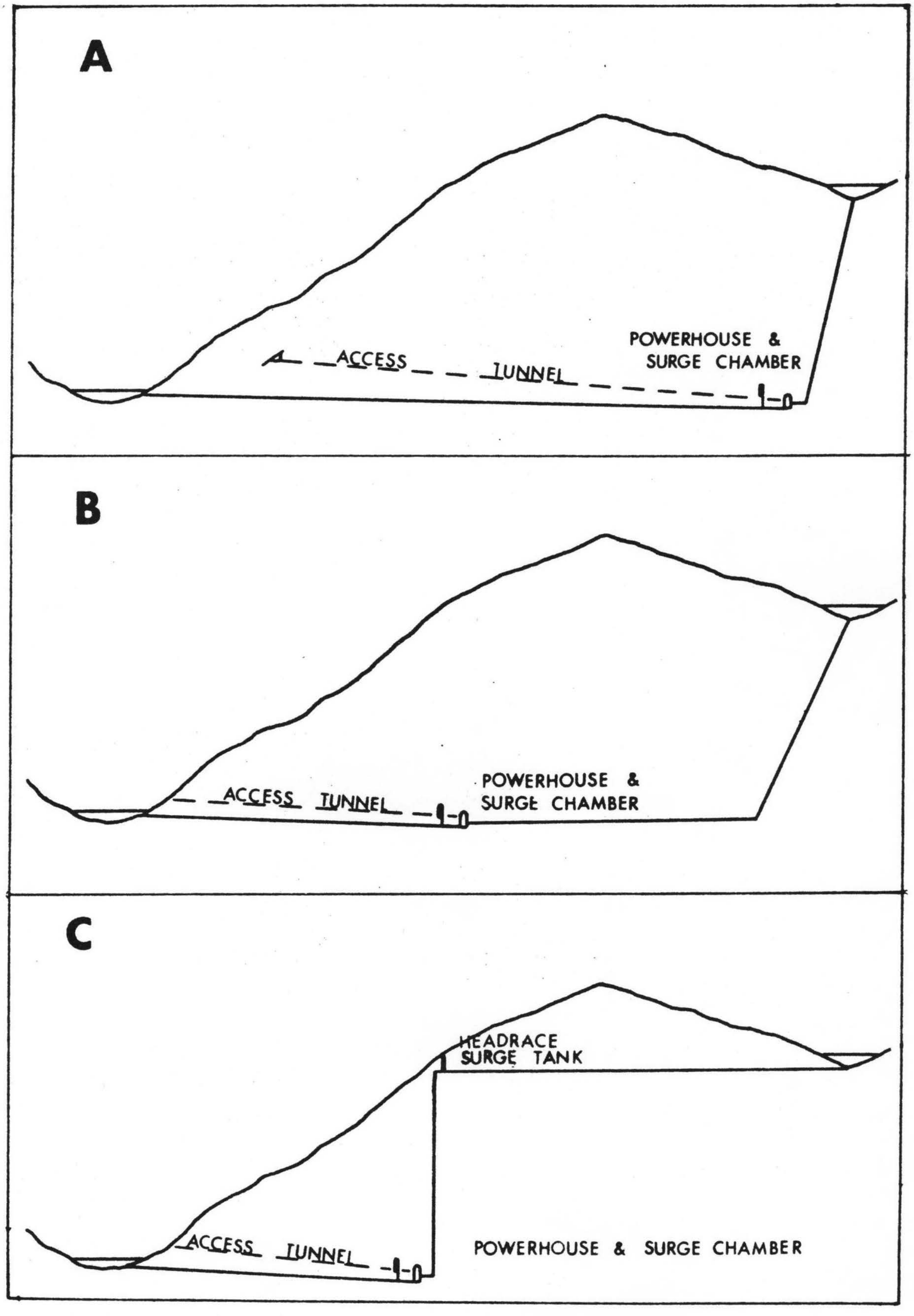


Figure 5-2.--Common powerhouse-waterway arrangements.

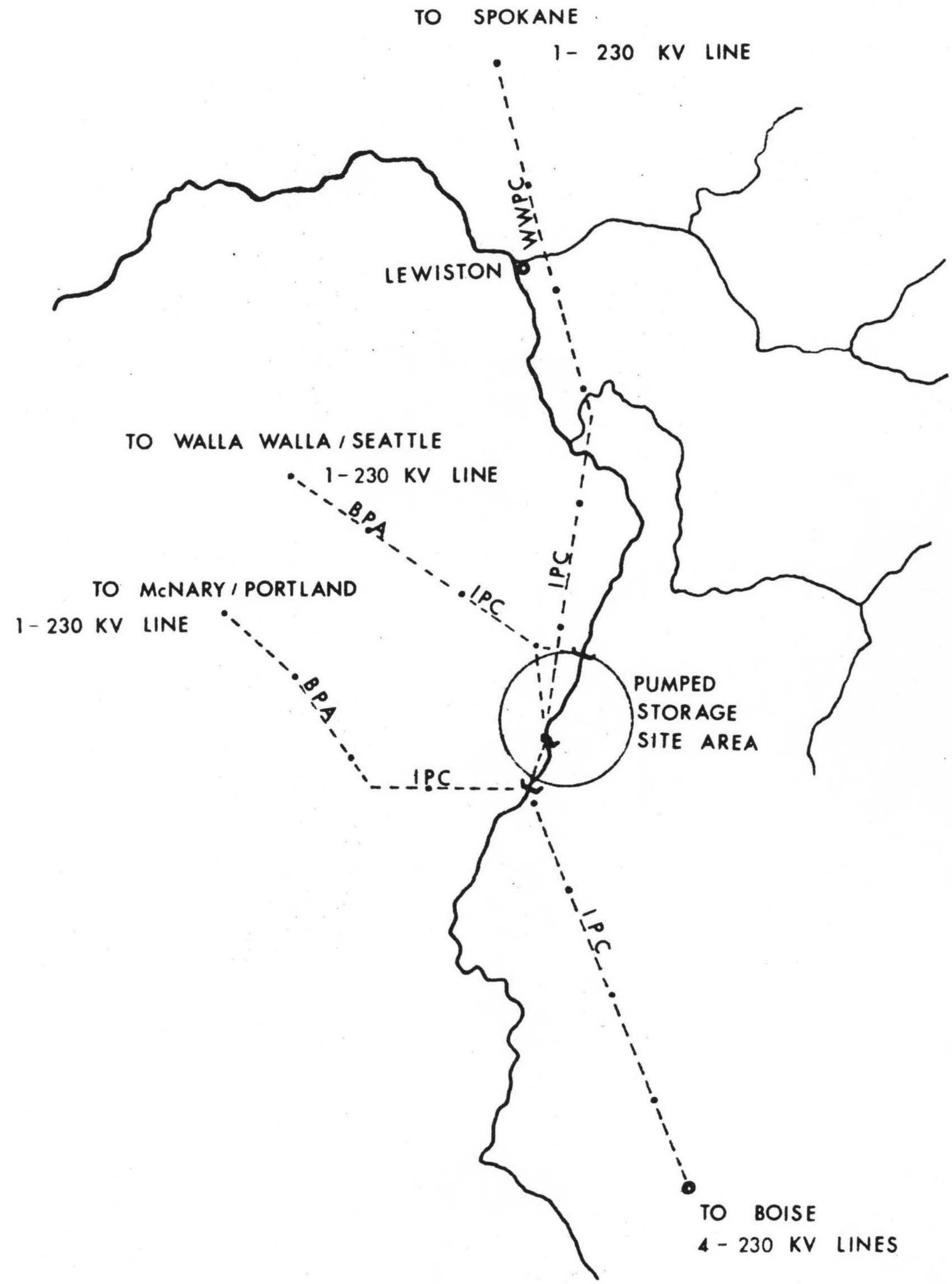


Figure 5-3.--Existing transmission lines (schematic).

can be seen, the area is connected to the major West Group load centers by single 230 KV lines, which would probably need to be augmented to handle a 1,000 MW block of power. Major high capacity lines have been proposed to connect the areas in the future (Pacific Northwest River Basins Commission 1970). The status of these proposals is uncertain at this time. For this study, new 345 KV lines are assumed from a pumped storage plant to Brownlee and from Brownlee to Boise and McNary. This will allow connection to the Idaho Power and West Group loads.

INDIVIDUAL SITE DESCRIPTIONS

The following gives a brief description for each of the three sites. More detailed information is presented in Table 5-1.

Barber Flat

The Barber Flat site is located in Idaho approximately three miles from the Oxbow reservoir, as shown in Figure 4-3. The upper reservoir site is an unusually flat area located in a region of rolling hills (Figures 5-4 and 5-5). An intermittent stream drains an area only slightly larger than the proposed reservoir. A pond several acres in size is located at the southern end of the site. The existence of the pond and the unusually flat aspect of the site may be evidence that the flat is an ancient lake bed. This could be a highly significant point, as an old lake bed would likely be floored by relatively impermeable sediments which would minimize reservoir leakage problems. The underlying rock is most likely basalt over metamorphosed granite (Vallier 1967). The Oxbow area, which is only about three miles away, has been

Figure 5-4.--Barber Flat upper reservoir area.

Figure 5-5.--Barber Flat looking toward the damsite.

identified as a major fracture region (Vallier 1967). Therefore, the rock under the site could easily contain some fractures.

The proposed design for the Barber Flat site is depicted in Figure 5-6. An area-volume curve for the upper reservoir is shown in Figure 5-7. Table 5-1 presents quantitative data on the proposed design.

The site will allow an upper reservoir of relatively large volume. The proposed reservoir is sized to contain the required active storage and a small amount of inactive storage. The drawdown limits mentioned earlier do not influence the size of the reservoir. The upper reservoir will be impounded by a long, low dam at the head of Butte Creek canyon (Figure 5-5). Inspection of the site revealed a natural ridge on the eastern edge of the site, which should be high enough to contain the reservoir. However, a more detailed study may discover that some diking is necessary there. A 1,000-foot long intake channel with a bottom elevation of 4,240 feet would convey water to the tunnel inlet at the western edge of the reservoir. A location for a spillway is indicated on the design drawings. The lower reservoir would be Oxbow. The head at the site is about 2,500 feet. The powerhouse for a 1,000 MW installation would contain three pump-turbines at an estimated submergence of 220 feet.

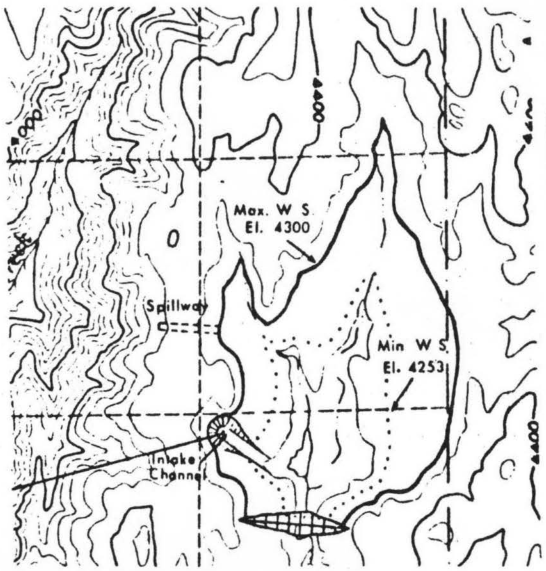
Access to the site is a major drawback. The upper reservoir area is now accessible by a 9 mile rough dirt road, which would need to be improved. This unimproved road connects with a maintained 30 mile dirt road to Council. Major highway and railroad access is available at Council. The lower reservoir area is accessible by a rough transmission

FIGURE 5-6.

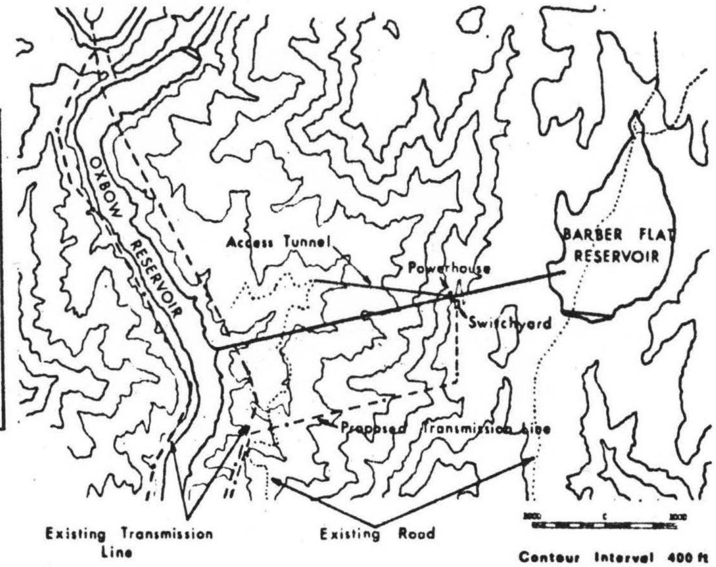
DESIGN FEATURES,

BARBER FLAT

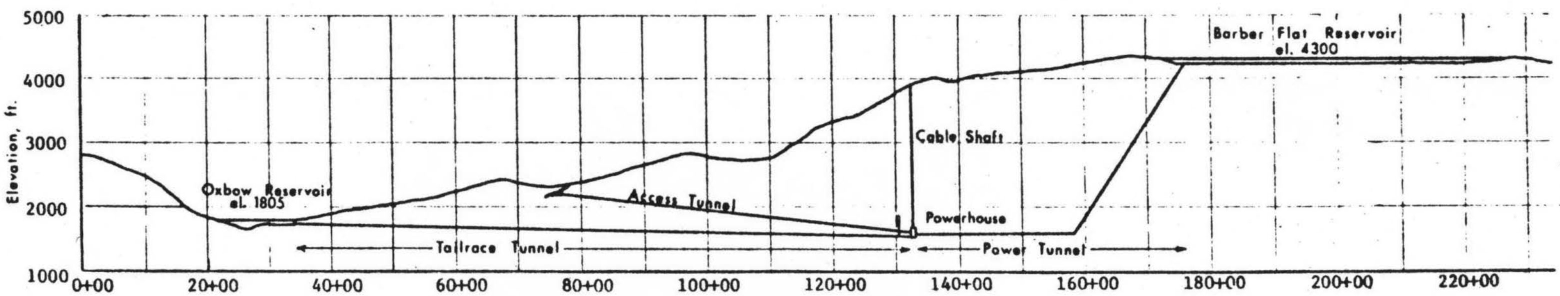
PUMPED STORAGE SITE



PLAN – UPPER RES.



PLAN – PROJECT



PROFILE ALONG WATERWAY

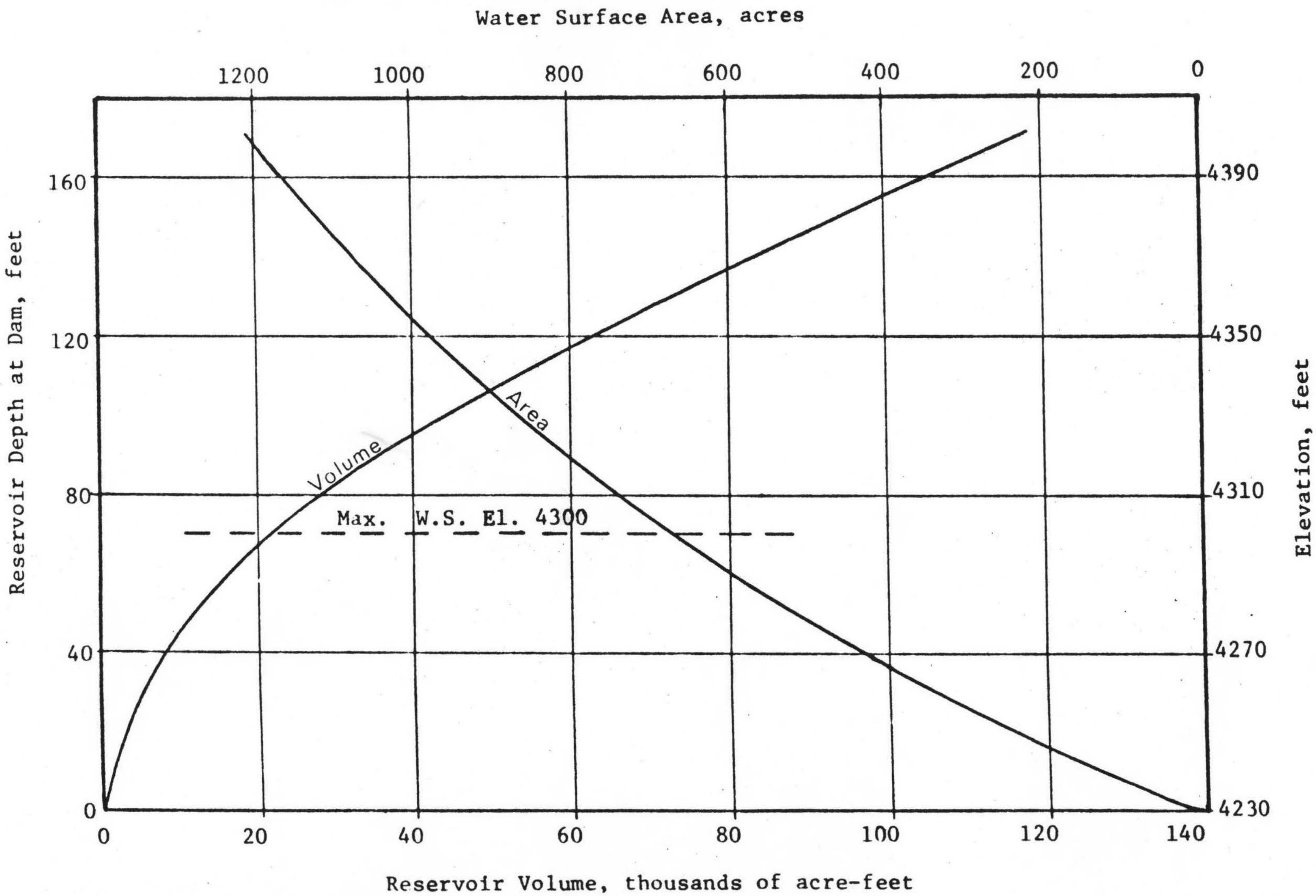


Figure 5-7.--Barber Flat area-volume curve.

line maintenance road from Brownlee Dam (11 miles). Should it be infeasible to improve this road, a new road from Oxbow Dam (4 miles) could be built, or equipment could be barged across the reservoir. For this study, improvement of the transmission line road is assumed. The Kleinschmidt Grade, a narrow winding dirt road, would allow movement of small equipment and vehicles between the two work areas.

The alignment of the waterway and location of the powerhouse are determined by the route of the access tunnel. The access tunnel would need to begin near the access road. By locating the tunnel entrance near the Salt Creek crossing, the tunnel length is minimized. The powerhouse is located to allow a 10 percent grade in the access tunnel.

The land in the upper reservoir site is now used for grazing. The area is quite remote and would seem to have little recreational potential. The majority of the land for the upper reservoir is privately owned, although the damsite is located on state property. The site is surrounded by national forest and public land. It is not in the National Recreation Area.

This Barber Flat proposal differs from the Corps of Engineers site by the location and size estimates for the embankments.

Indian Creek

The Indian Creek site is located in Idaho near the Oxbow, and about 8 miles north of the Barber Flat site (Figure 4-3). Unlike the Barber Flat site, the Indian Creek upper reservoir would be formed in a stream valley, as shown in Figures 5-8 and 5-9. Indian Creek has been found to follow an old fault exposure (Vallier 1967). This fact would

Figure 5-8.--Indian Creek valley looking west to the damsite.

Figure 5-9.--Indian Creek valley looking east toward Cuprum.

need to be investigated in subsequent studies, as it could affect the site's water holding capability. As at the Barber Flat site, the underlying rock is likely basalt over metagranites.

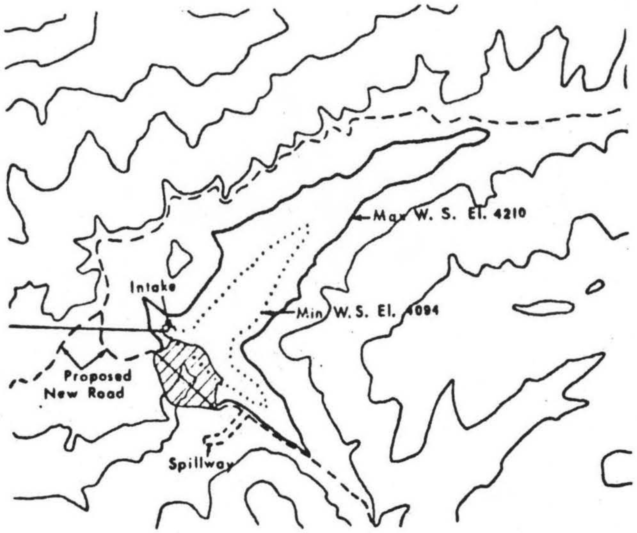
The proposed design for the Indian Creek site is depicted in Figure 5-10, and Figure 5-11 is an area-volume curve for the upper reservoir. The upper reservoir is located to avoid flooding the town of Cuprum, and also to utilize Huntley Gulch for storage. The proposed design backs water up to the edge of Cuprum. This size reservoir is near the drawdown limits, so any large-scale, multipurpose use would be unlikely. An emergency spillway is noted on the design drawings. Only minimal intake channel work would be required. The drainage area at the damsite is about 22 square miles, and the creek would require outlet works to keep it flowing. The lower reservoir is Hell's Canyon reservoir.

The head at the site is approximately 2,500 feet. The 1,000 MW powerhouse would contain three pump-turbines at an estimated submergence of 220 feet.

Primary access to the upper reservoir area would be from Council. The Council-Cuprum road passes directly through the upper reservoir area; this section of road would need to be relocated. A paved highway from Oxbow to Hell's Canyon Dam would provide direct access to the lower reservoir and tunnel area.

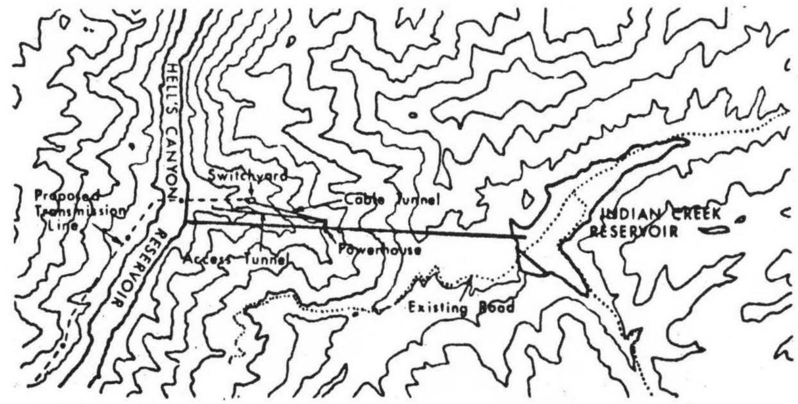
The powerhouse is located to minimize the amount of new transmission lines, yet provide adequate rock cover for the power tunnel. The new line would need to cross the Hell's Canyon reservoir.

The land in the upper reservoir is now primarily used for grazing.



Contour Interval 400 ft

PLAN-UPPER RES.



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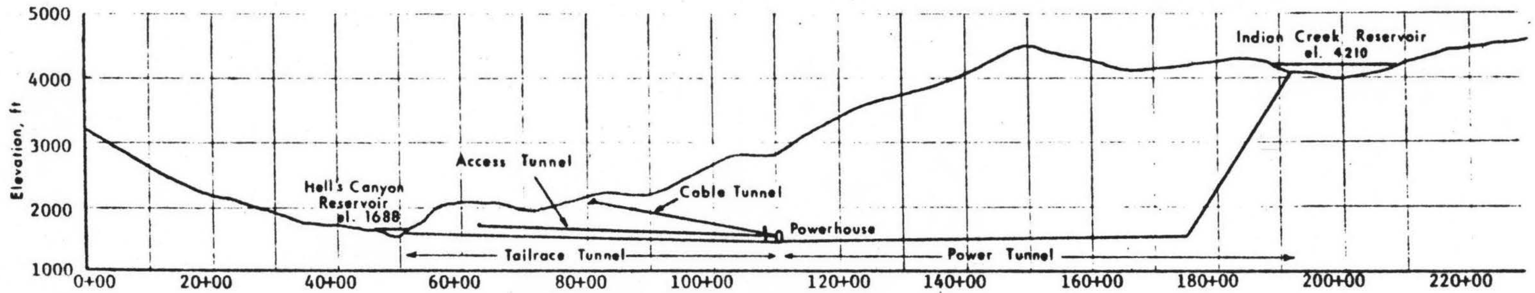
PLAN — PROJECT

FIGURE 5-10. DESIGN FEATURES, **INDIAN CREEK** PUMPED STORAGE SITE



PROFILE ALONG WATERWAY

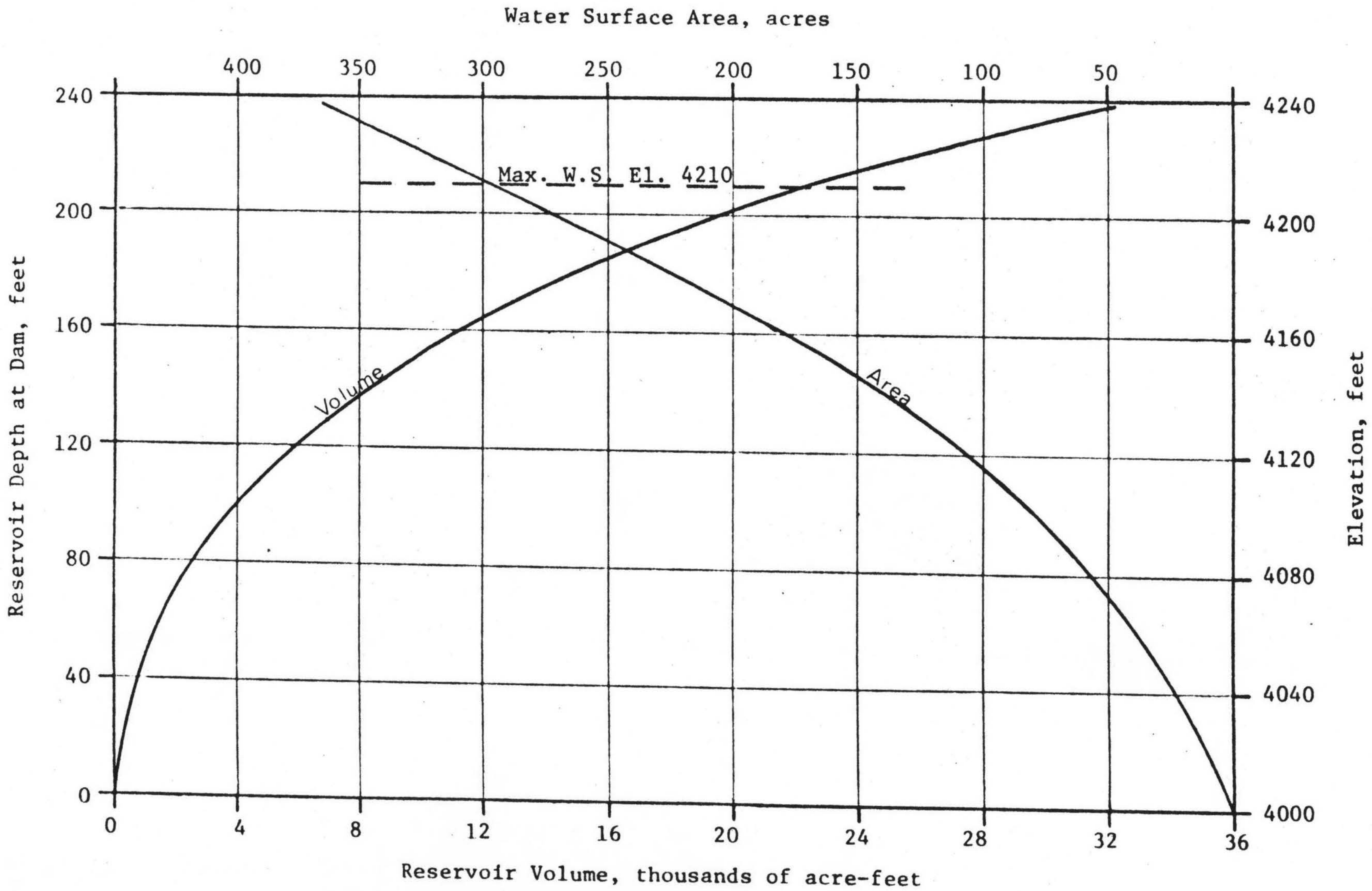


Figure 5-11.--Indian Creek area-volume curve.

However, the area is readily accessible and quite scenic, as can be seen in Figure 5-9. The upper reservoir area is primarily private land, although there is a small amount of state and federal ownership. The land around the lower reservoir area is national forest. The site is not in the National Recreation Area.

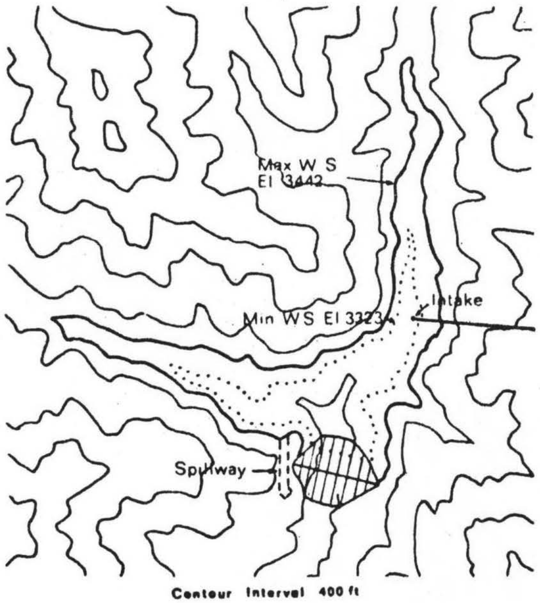
This Indian Creek site is located slightly downstream of the Corps of Engineers Cuprum site. It avoids the potential for inundating the town of Cuprum, which the Corps Cuprum site would do at the required 40 hours of storage. The lower reservoir outlets are in different locations also.

North Pine F

The North Pine F site is located in Oregon at the convergence of North Pine and Lake Fork creeks, as shown in Figures 4-3 and 5-12. A ridge separates the upper reservoir valley from Hell's Canyon reservoir. As at the other sites, the probable rock sequence is basalt over metamorphosed granite.

The proposed design for the North Pine F site is depicted in Figure 5-13, and Figure 5-14 shows an area-volume curve for the upper reservoir. The upper reservoir was located to use the valleys of both Lake Fork Creek and North Pine Creek for storage. Nevertheless, the stream gradients are steep enough to force the reservoir to approach the drawdown and dam height limits. An emergency spillway location is shown on the design drawings. The reservoir is deep enough that an intake channel is not required. The drainage area at the damsite is approximately 60 square miles, and outlet works would be required. The

Figure 5-12.--North Pine Creek near the damsite.



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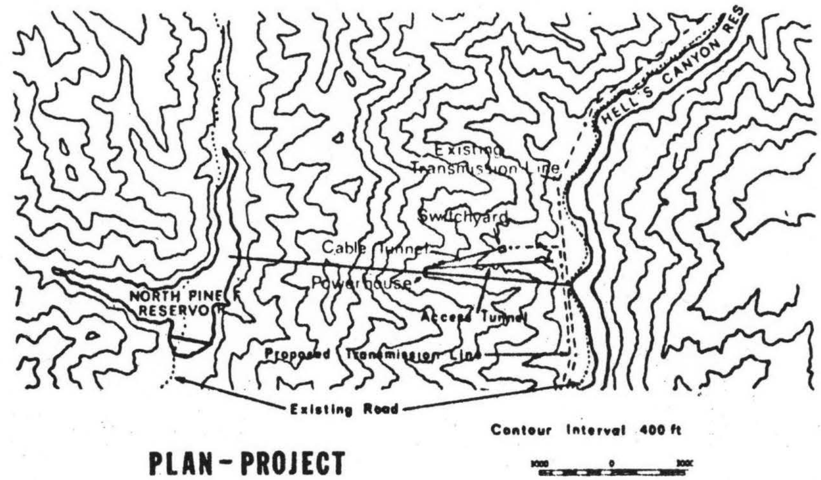
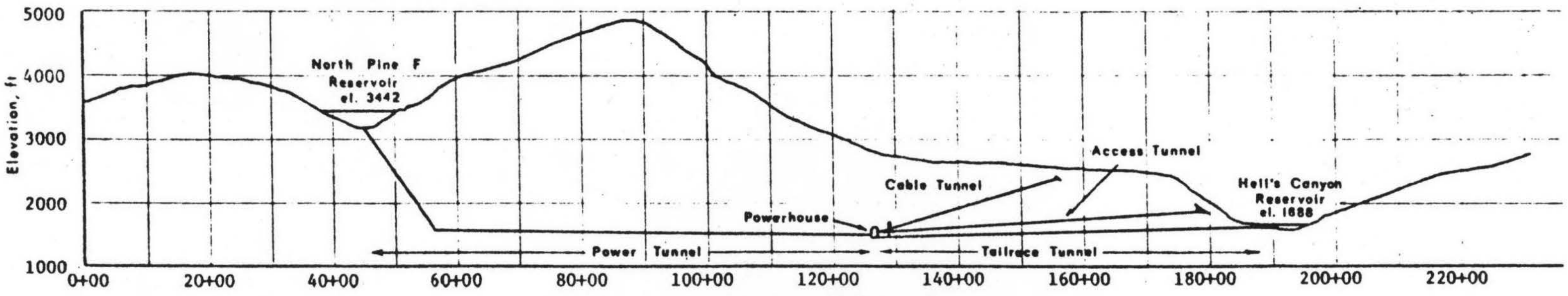


PLAN - PROJECT

DESIGN FEATURES,
FIGURE 5-13. NORTH PINE F
PUMPED STORAGE SITE



PROFILE ALONG WATERWAY

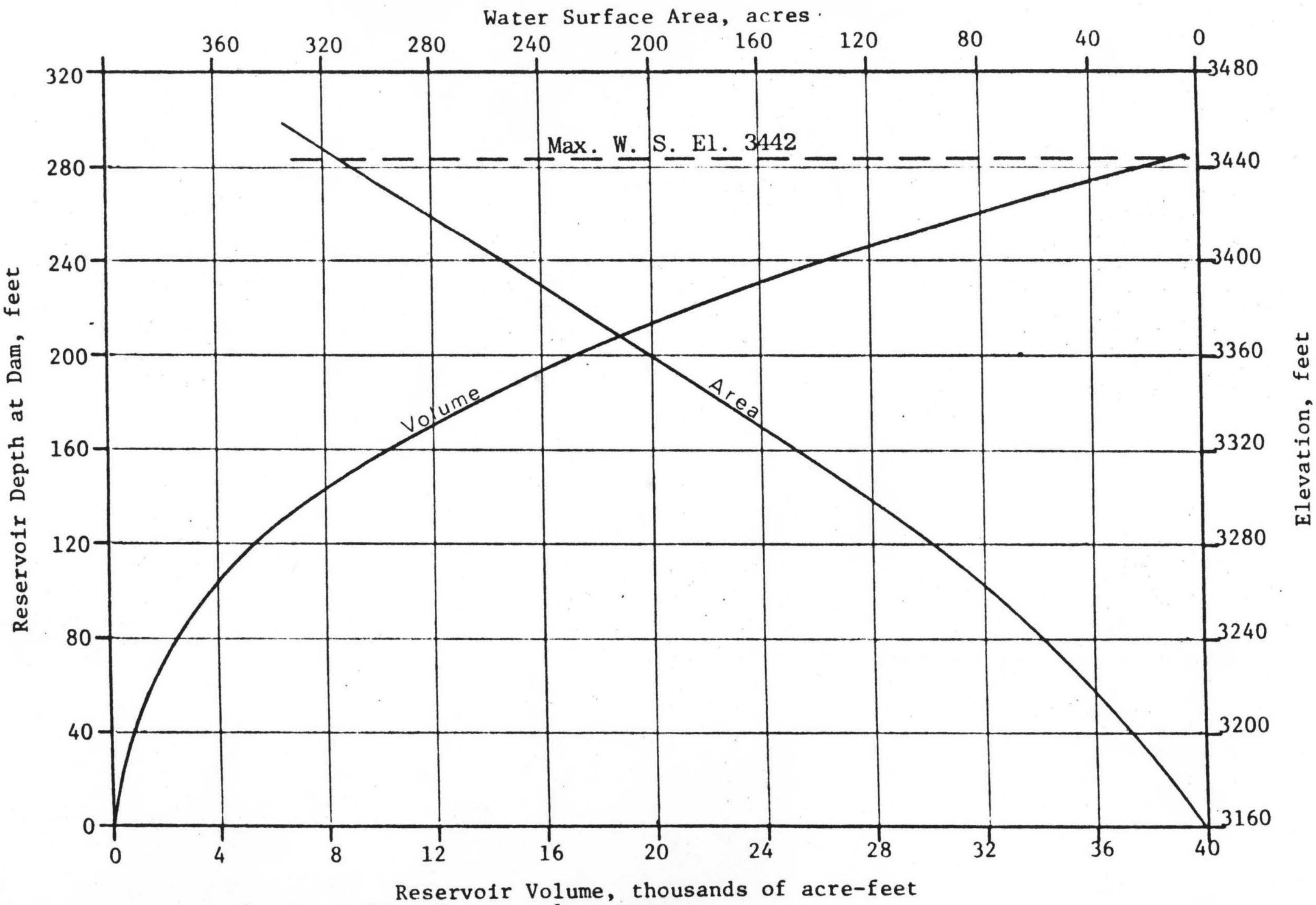


Figure 5-14.--North Pine F area-volume curve.

lower reservoir is Hell's Canyon reservoir.

The site's head of approximately 1,730 feet is less than the head for the other two sites. More storage is therefore needed for the same plant size. The head is definitely suitable for Francis-type pump-turbines, though. The 1,000 MW powerhouse would contain four 250 MW units at an estimated submergence of 180 feet.

Paved highways lead to both the upper and lower work areas, so access would not be a problem. The highway in the upper reservoir area would need to be relocated, and a proposed route is shown.

The powerhouse is located by the same rationale used for the Indian Creek site; that is, to minimize the amount of transmission line and to provide adequate rock cover for the power tunnel.

The land in the upper reservoir area is all publicly owned, and a Forest Service campground would be inundated. Figure 5-12 is a photograph of the upper reservoir area. The site is within the National Recreation Area, however, so development would be difficult.

This site is somewhat similar to the Corps Homestead #2. However, the Homestead #2 site is farther upstream on North Pine Creek, and does not use the storage provided by the Lake Fork Creek valley.

TABULAR PRESENTATION OF DETAILS ON THE THREE SELECTED SITES

The following table presents details of the three sites described briefly above. Refer to the previous drawings for illustration of the quantities presented in the table. Reservoir levels and fluctuations are covered more fully in the next chapter.

Table 5-1.--Engineering features - three selected sites.

Item	Barber Flat	Indian Creek	North Pine F
<u>Location</u>			
Upper reservoir	N44° 56.5' W116° 46.2'	N45° 4.3' W116° 43.6'	N45° 5.3' W116° 54.6'
Lower intake	N44° 51.2' W116° 49.8'	N45° 4.6' W116° 46.8'	N45° 7.1' W116° 50.8'
<u>Upper Reservoir Features</u>			
Maximum dam height, ft	80	220	292
Dam crest length, ft	4,700	1,700	2,000
Dam volume, cu yds	450,000	4,300,000	8,300,000
Maximum water surface elevation, ft	4,300	4,210	3,442
Reservoir storage at max. W.S. elevation, ac-ft	21,700	22,100	37,500
Reservoir surface area at max. W.S. elevation, ac	670	295	315
Volume required for 14 hr operation, ac-ft	6,450	6,400	9,200
W.S. elevation @ 14 hr drawdown, ft	4,288.6	4,184.1	3,409.0
Volume required for 40 hr operation, ac-ft	18,500	18,500	26,800
W.S. elevation @ 40 hr drawdown, ft	4,253.5	4,094.5	3,323
Drainage area at the damsite, sq mi	3	22	60

(Table 5-1 continued)

Item	Barber Flat	Indian Creek	North Pine F
<u>Lower Reservoir Features</u>			
Existing reservoir used	Oxbow	HC	HC
Maximum water surface elevation, ft	1,805	1,688	1,688
Total storage, ac-ft	58,200	168,800	168,800
Existing min. W.S. elevation, ft	1,800	1,683	1,683
Existing active storage, ac-ft	5,500	12,000	12,000
Min. W.S. elevation, with pumped storage (existing minimum minus 14 hrs of storage), ft	1,794	1,680	1,679
<u>Heads and Flows</u>			
Static head, ft			
Maximum	2,506	2,530	1,763
Median (14 hr)	2,494	2,515	1,744
Minimum	2,448	2,406	1,635
Median flows @ 1,000 MW, cfs			
Turbine mode	5,570	5,530	7,970
Pump mode	3,710	3,680	5,310
Estimated friction losses, ft			
Turbine mode	100	100	60
Pump mode	50	50	30
<u>Powerhouse and Waterway Features</u>			
Number of units and rating, MW	3 @ 333.3	3 @ 333.3	4 @ 250
Estimated submergence, ft	220	220	180
Elevation of distributor, ft	1,574	1,460	1,500

(Table 5-1 continued)

Item	Barber Flat	Indian Creek	North Pine F
Powerhouse and Waterway Features (continued)			
Estimated powerhouse dimensions, ft	70x150x 250	70x150x 250	80x175x 400
Length of power tunnel, ft	5,700	9,500	9,000
Diameter of power tunnel, ft	17	17	22.5
Velocity in power tunnel @ median turbine flow, fps	24.5	24.4	20.0
Length of tailrace tunnel, ft	9,900	5,900	6,200
Diameter of tailrace tunnel, ft	18	18	23
Velocity in tailrace @ median turbine flow, fps	21.9	21.7	19.2
Length of access tunnel, ft	5,700	4,900	5,300
Access tunnel dimensions (horseshoe section), ft	24x28	24x28	24x28
Cable shaft length, ft	2,200	3,000	3,200
Diameter of cable shaft, ft	20	20	20
Access Road Features			
Length of road needing improvement, mi	20	0	0
Length of road needing relocation, mi	2	5	4
Transmission Features			
Length of new 345 KV transmission line to Brownlee substation, mi	11	21	15
Length of new 345 KV transmission line, Brownlee to Boise and McNary, mi	250	250	250

CHAPTER 6

RESERVOIR FLUCTUATIONS AND SYSTEM OPERATION - THREE SELECTED SITES

Water level fluctuations are a major aspect of a pumped storage project, particularly when an existing reservoir is used. The fluctuations are important for several reasons. Recreational use is hampered by muddy, unsightly, and unpleasant beaches exposed by drawdowns. Fish and insect production areas may be dewatered and destroyed. Serious bank erosion and slumping may be induced. Of special importance in the case of hydroelectric complexes, such as the three Hell's Canyon dams, is the effect on power production. The operation of the complex must be modified in some way to accommodate the inclusion of pumped storage. This modification may cause a loss in power from the existing system.

An optimization study would need to be done to find the best manner of adjusting the existing system for the pumped storage. The system could be operated by appropriate releases so that any reservoir could supply the required storage space, regardless of where the pumped storage plant is connected. The most straightforward manner of regulation is to provide the space at the reservoir on which the pumped storage plant is connected. This method is assumed for this analysis. Space could be provided by either increasing the dam height or drawing down the lower reservoir prior to the pumped storage generation. The possibility of raising the height of Oxbow or Hell's Canyon dams has not been investigated.

The flow from a pumped storage installation is, of course, highly variable. In the case of the Hell's Canyon complex, these variations should be smoothed out and not transferred to the flowing river below Hell's Canyon Dam. Thus, some reservoir space must be allocated in the system for regulating the pumped storage flows.

License provisions require that outflow from Hell's Canyon Dam be regulated to a 1 ft/hr maximum fluctuation at Johnson's Bar and a 5,000 cfs minimum flow (U. S. Army Corps of Engineers 1961). The 1 ft/hr restriction corresponds to about 3,000 cfs/hr. These flow requirements lessen the peaking capability of Hell's Canyon Dam relative to the other two dams. This disparity in operations requires use of some storage in Hell's Canyon reservoir for regulating the flows.

RESERVOIR SIMULATION

As an attempt to analyze the fluctuation effects, a computer simulation of the system has been developed. Documentation of the computer program is contained in the Appendix. Hourly increments are used for the analysis.

Three low flow periods are studied; one-week periods in the winter and summer, and a three-week period in the winter. Low flow conditions are analyzed because the peaking would be most extreme at these times. The inflow rate and release pattern will determine the amount of reservoir space required for regulation. However, two opposing forces are at work. As the average flow decreases, peaking <u>flows</u> will become more variable, requiring more regulation storage; on the other hand, there is less <u>volume</u> to regulate, and so less storage is needed. Because of the above opposing forces, extremely low flows (say a 1 percent occurrence) will require less regulation storage than less severe conditions (say a 5 percent occurrence). As the conditions become less severe, less peaking would be needed and fluctuations would decrease. Therefore, maximum fluctuations will occur at moderately severe low flow conditions. A 5 percent nonexceedence frequency (found by standard graphical techniques) was chosen to reflect this moderately severe condition. The three test periods are chosen to reflect the potential for meeting West Group and Idaho Power loads. All three periods are analyzed for each of the three pumped storage sites.

A simple method of analysis is used. First, operating patterns are developed for the dams and pumped storage installation. The derivation of the operating patterns is explained later in this chapter. Four runs are made for each test period. One run is conducted without any pumped storage plant operating. This is to simulate the present or "base" condition. Then a run is made for each of the three pumped storage sites. By this procedure, the differences attributable to the pumped storage can be found. The objective of each run is to maximize the power output without altering the preset patterns of operation (no spill or unplanned flow through the turbines).

For ease in calculation, several mathematical simplifications are used in the program; the major simplifications are discussed here. The operating patterns are rather simple geometrical approximations for typical hydroelectric operations. Elevation-storage relationships for the reservoirs are approximated by parabolic sections for the active ranges of drawdowns and storages. Tailwater curves are approximated by parabolas and straight lines. Efficiencies are estimated as 85 percent generating and 78.4 percent pumping for the pump-turbines, and 90 percent for the Snake dam turbines.

DERIVATION OF OPERATING PATTERNS

The operating patterns for the dams are based on the flow into the system rather than load conditions. The general procedure used is to multiply the average period inflow to Brownlee reservoir by a factor which is a function of time (time of day and day of week). The pumped storage flow is based on operating at a time dependent fraction of the maximum plant output (1,000 MW). The pumped storage flow is then a function of time and head.

The patterns are basically water balances over a week's period, with most of the output during the weekdays and reduced output during weekends. Because the test periods are low flow condition, rather extreme peaking operations are assumed. The reservoirs end at the same levels at which they began, except in two cases. These exceptions are Brownlee reservoir in the winter periods and the pumped storage upper reservoir during the three-week winter period. During the winter, Brownlee Dam releases water from storage for flood control and power purposes. This extra release is assumed to be 3,600 cfs as estimated from a power rule curve from the Brownlee, Oxbow, and Hell's Canyon projects reservoir regulation manual (U. S. Army Corps of Engineers 1961). This 3,600 cfs is added to the Brownlee average inflow for adjustment and release. The three-week winter period is designed to be an emergency or critical period. The pumped storage plant would generate as much as possible, with refill occurring later when power is available. In the analysis, the extra storage water released from the pumped storage reservoir is averaged as a constant flow over the three-week period.

The winter operating patterns for the dams have been developed with reference to a power pondage study by the Corps of Engineers (U. S. Army Corps of Engineers 1972). This study is based on West Group load conditions for historical flow periods. The winter pumped storage patterns are based primarily on load studies for the Antilon Lake project in Washington (Williamson 1974).

The summer period dam pattern is based on the Corps power pondage study and on some limited flow records of the river below Hell's Canyon Dam. The pumped storage pattern is based on the Antilon Lake studies.

The summer peaks are not as variable as the winter peaks. The summer peaks are generally from irrigation pumping, and the winter peaks from heating. Therefore, the summer pattern is a single daily peak at less than full plant capability. The summer and winter week periods use 14 hours of storage and the winter three week period uses 40 hours.

The operating patterns used for the three test periods are shown in Figures 6-1, 6-2, and 6-3. Hell's Canyon Dam is reduced in peaking to comply with the license provisions.

PRESENTATION AND DISCUSSION OF SIMULATION RESULTS

The results of the computer study are presented in Figures 6-4 through 6-10 and Table 6-1. Only upper reservoir drawdown curves are

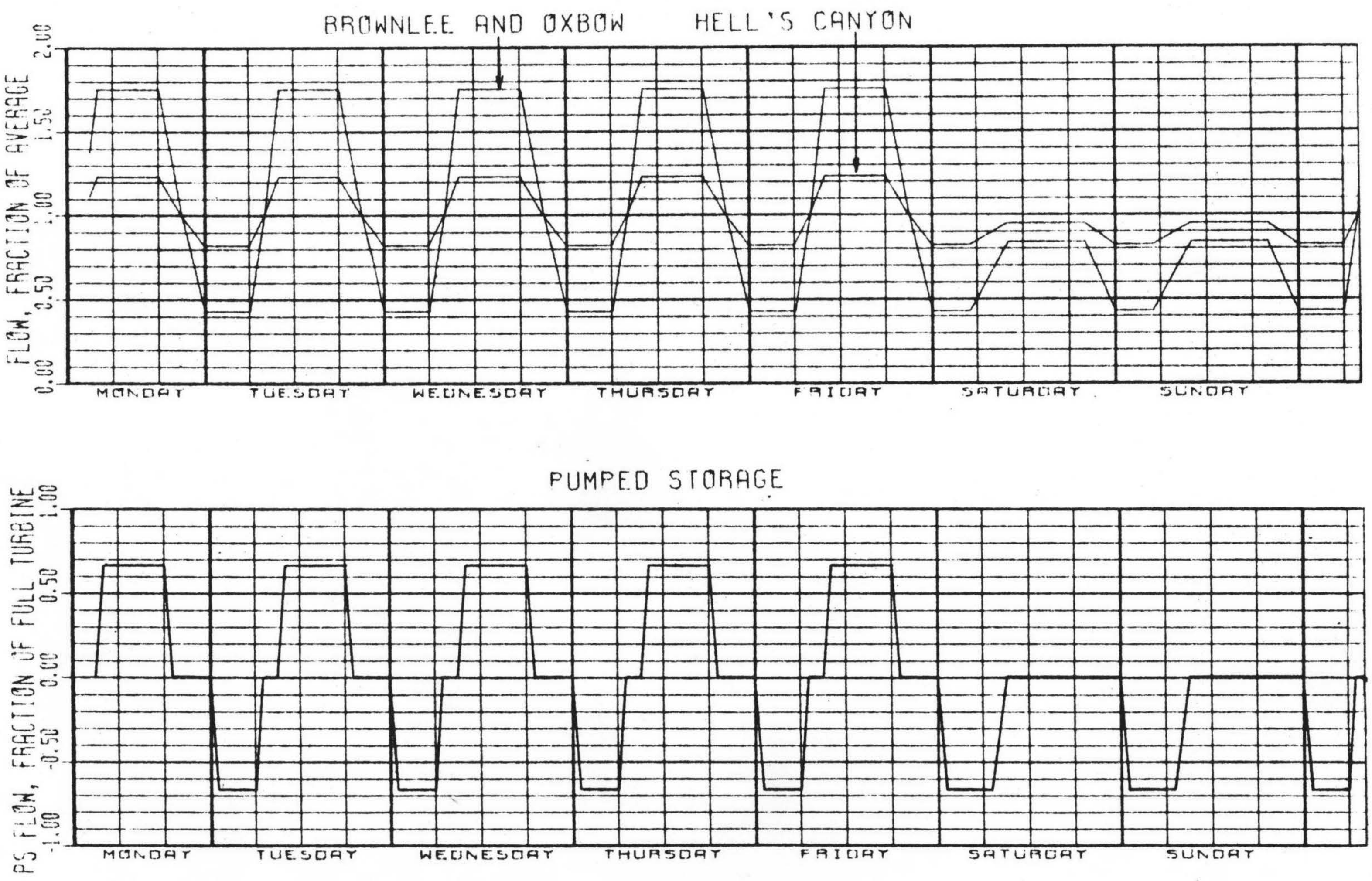


Figure 6-1.--Summer week operating patterns.

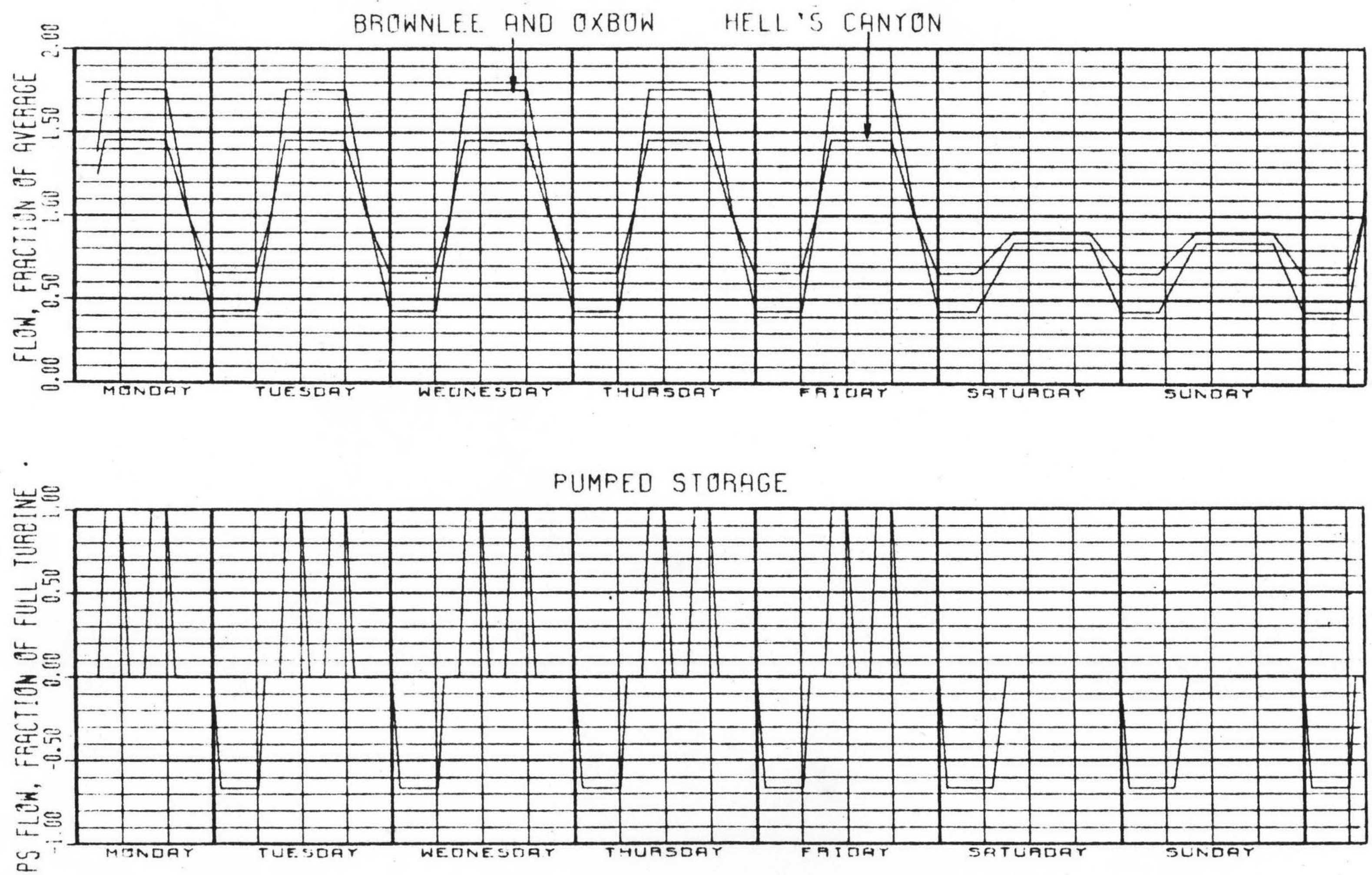


Figure 6-2.--Winter week operating patterns.

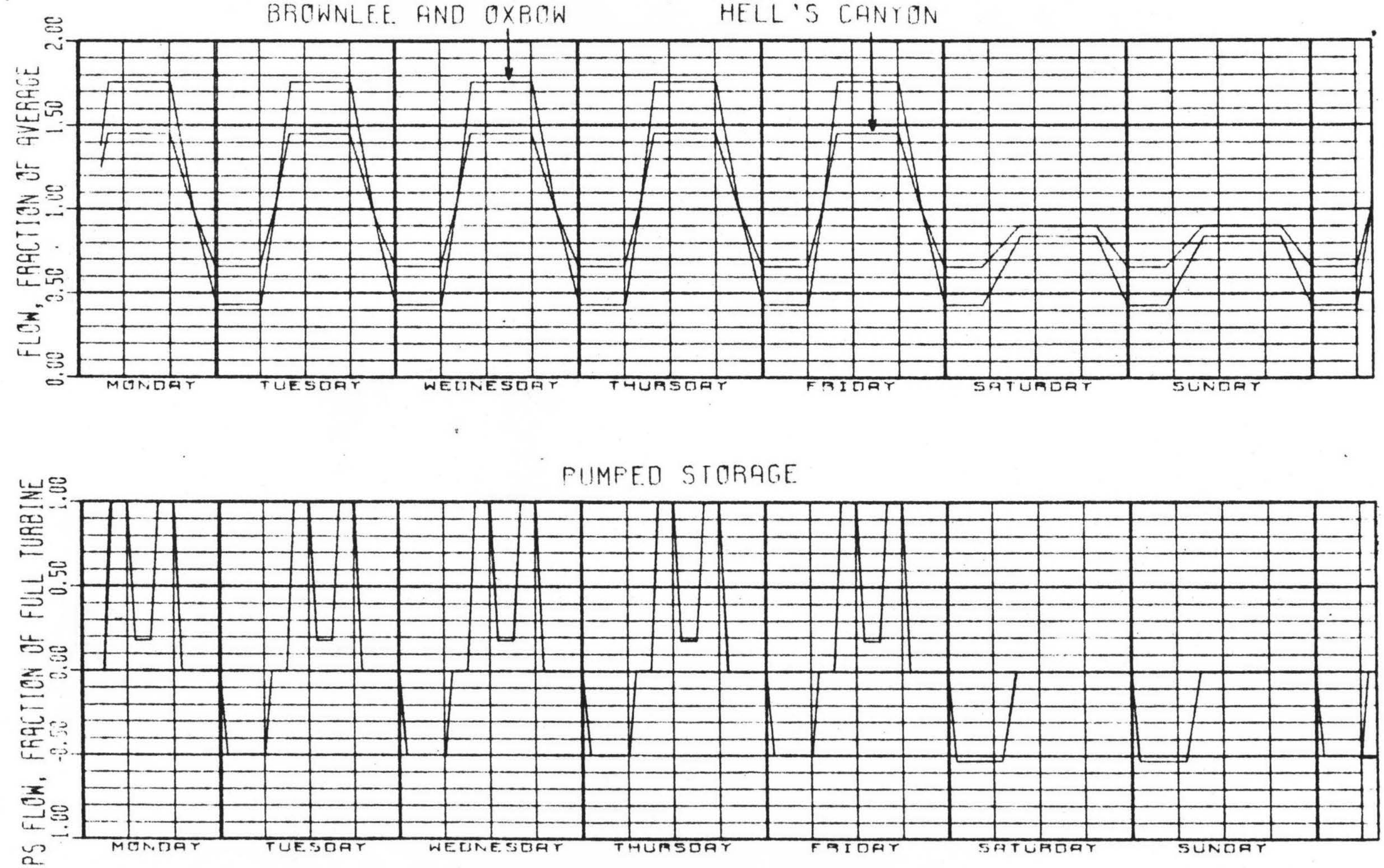


Figure 6-3.--Winter three-week operating patterns.

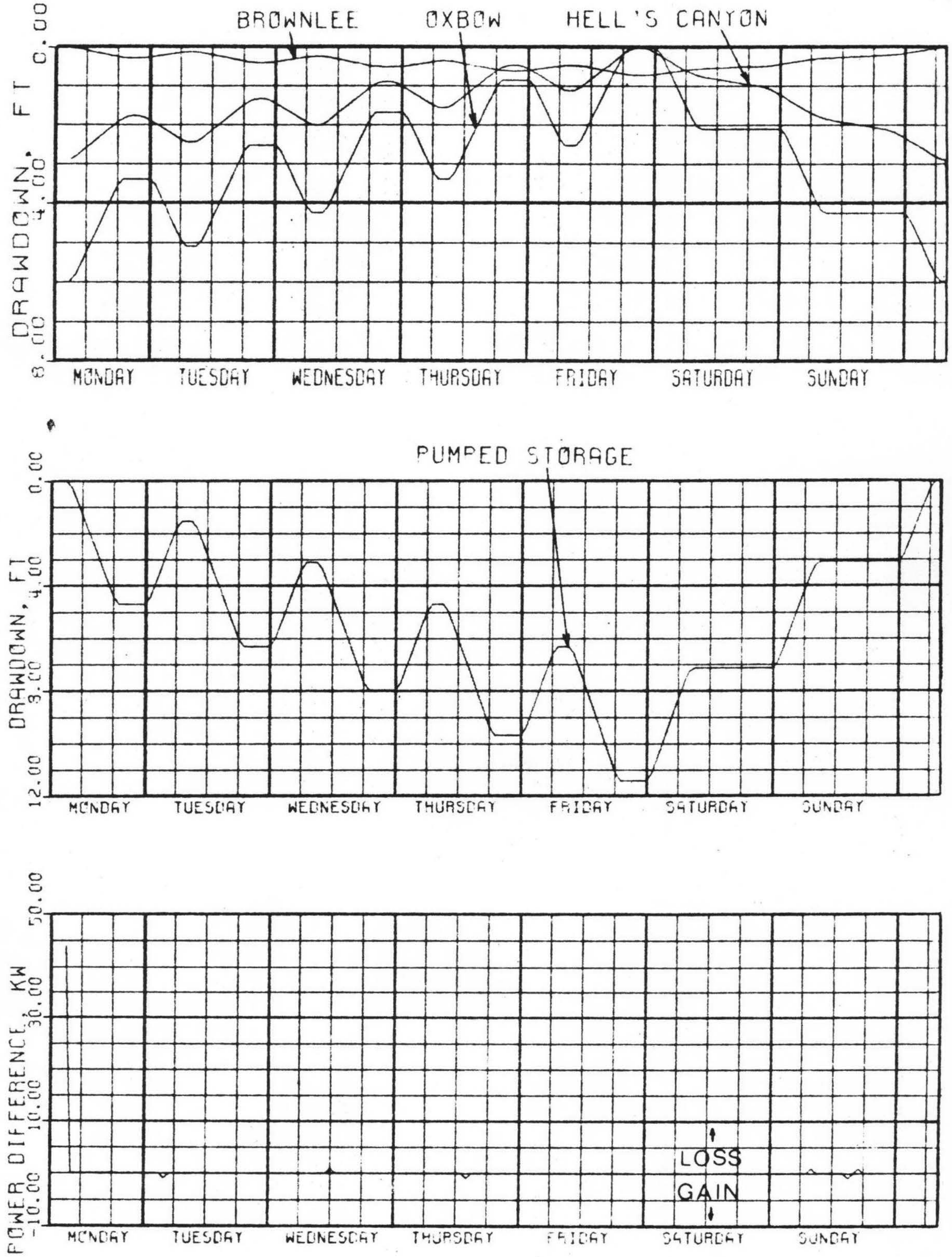


Figure 6-4.--Barber Flat summer week drawdown and power loss curyes.

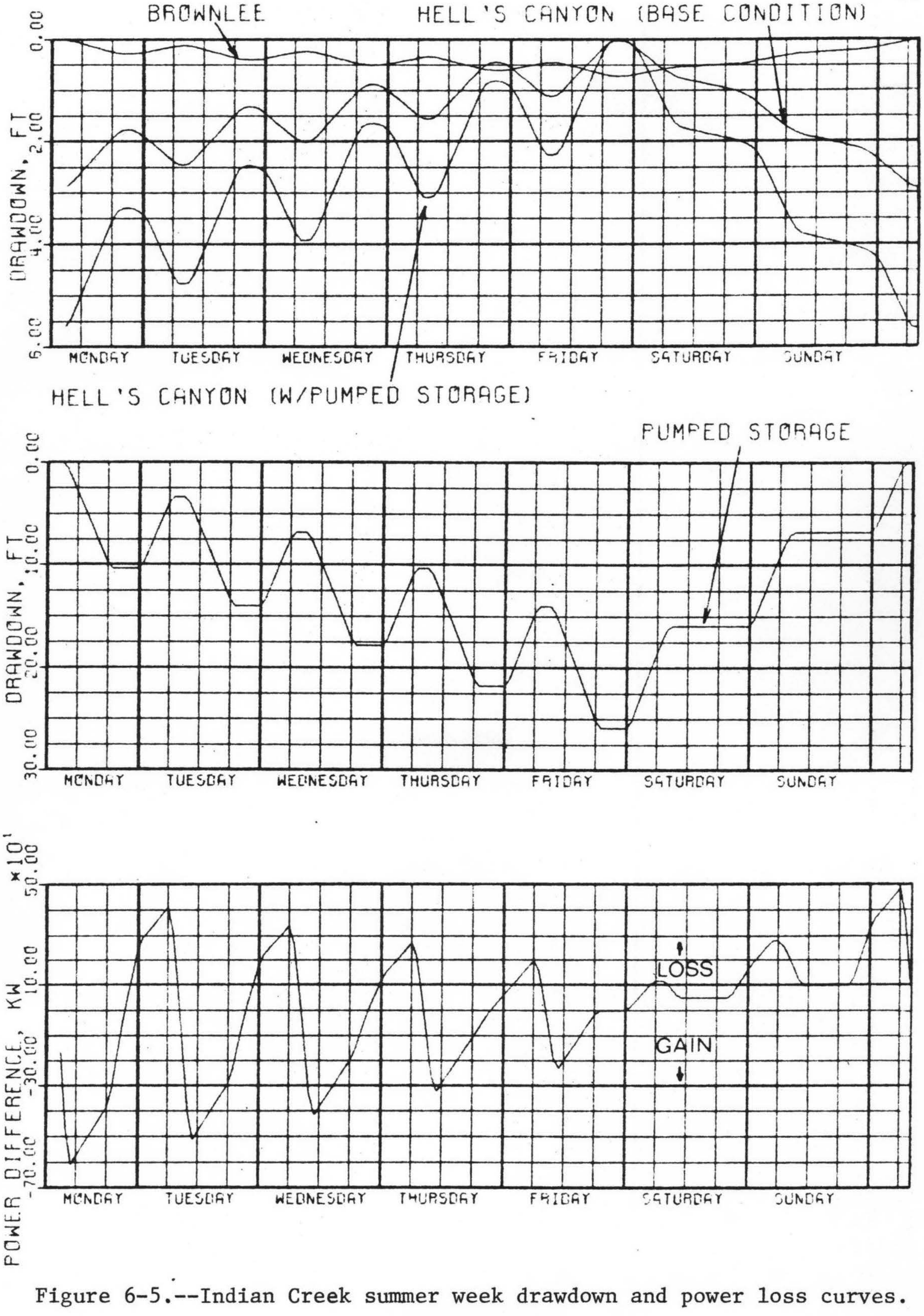


Figure 6-5.--Indian Creek summer week drawdown and power loss curves.

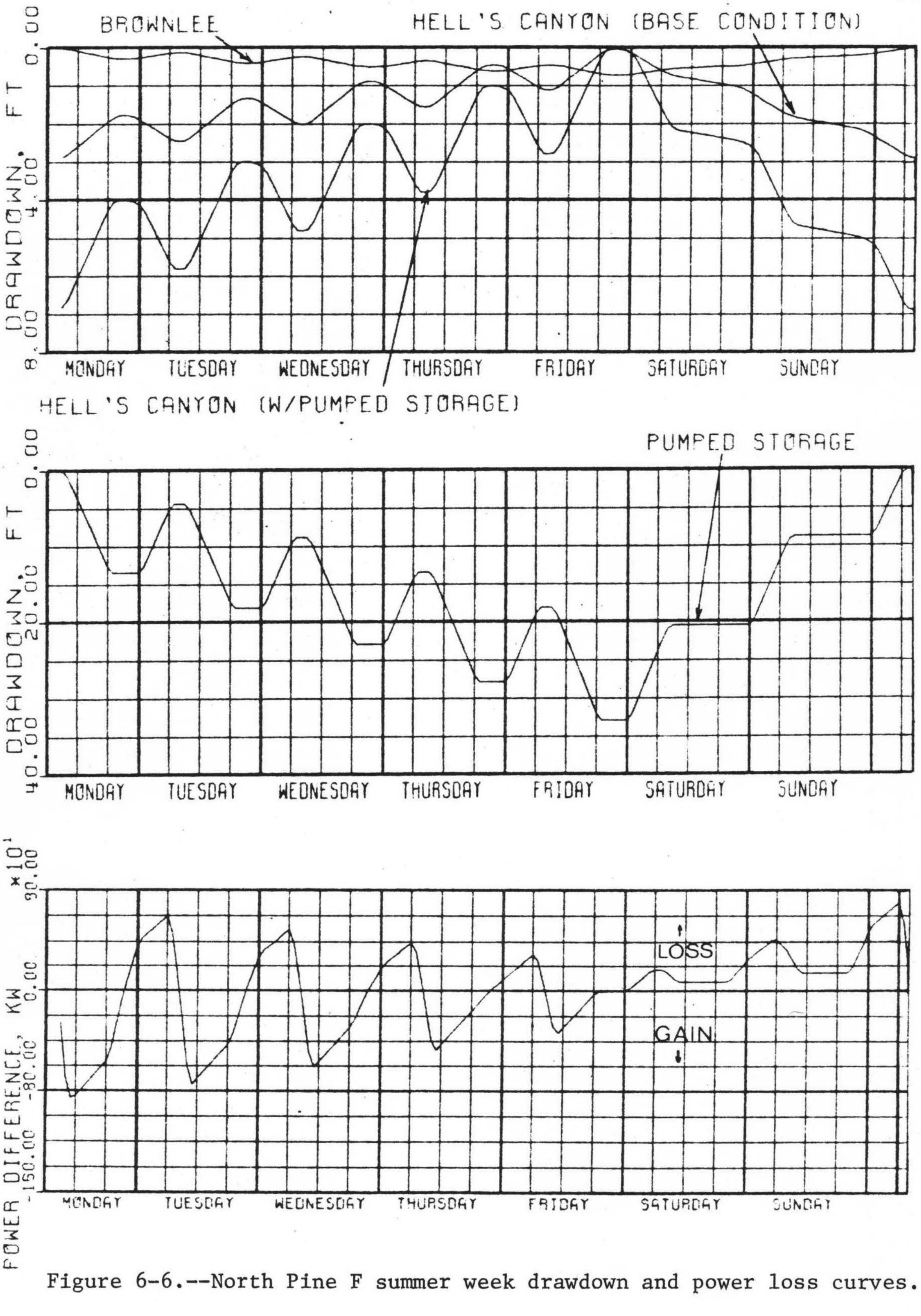


Figure 6-6.--North Pine F summer week drawdown and power loss curves.

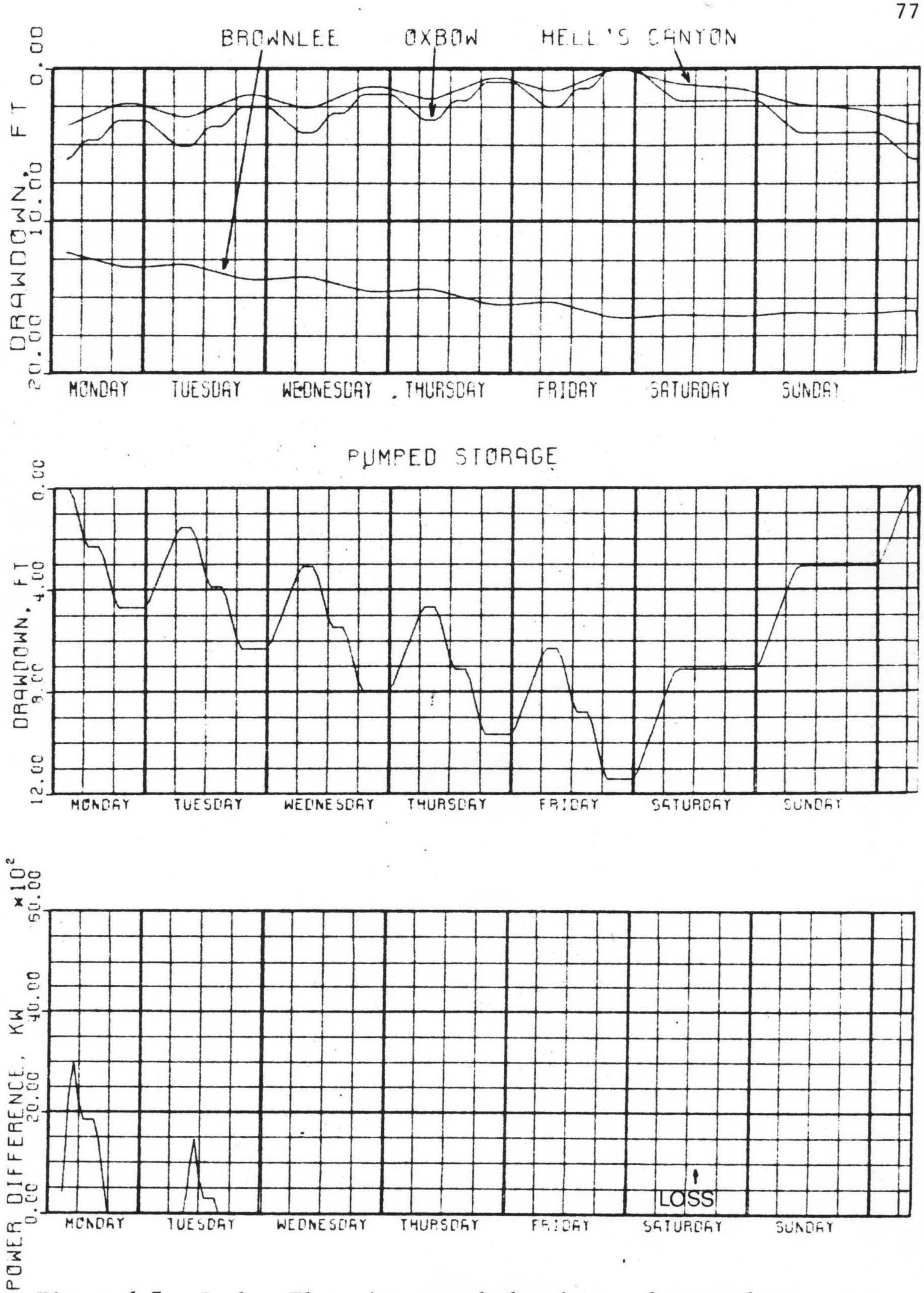


Figure 6-7.--Barber Flat winter week drawdown and power loss curves.

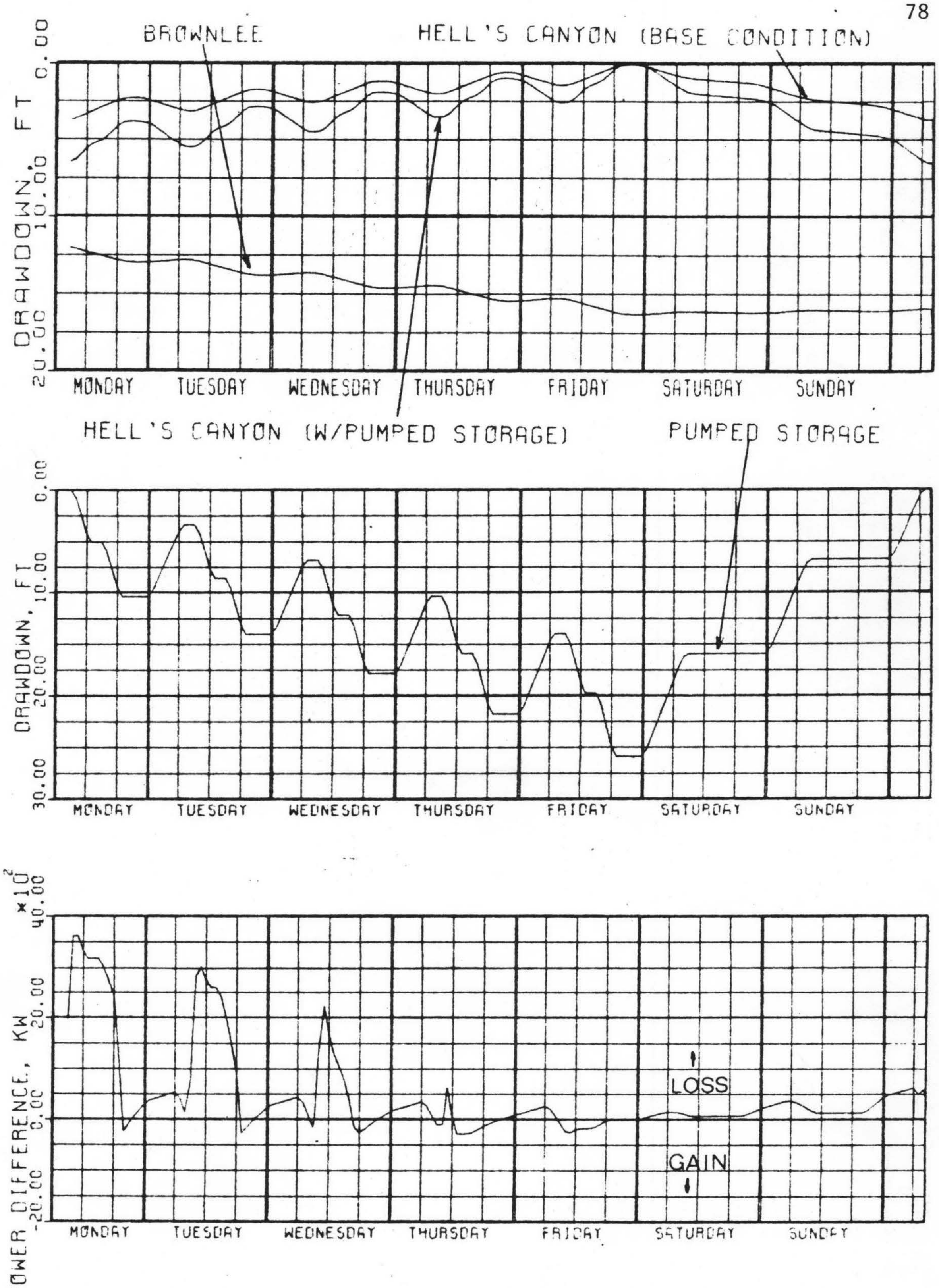


Figure 6-8.--Indian Creek winter week drawdown and power loss curves.

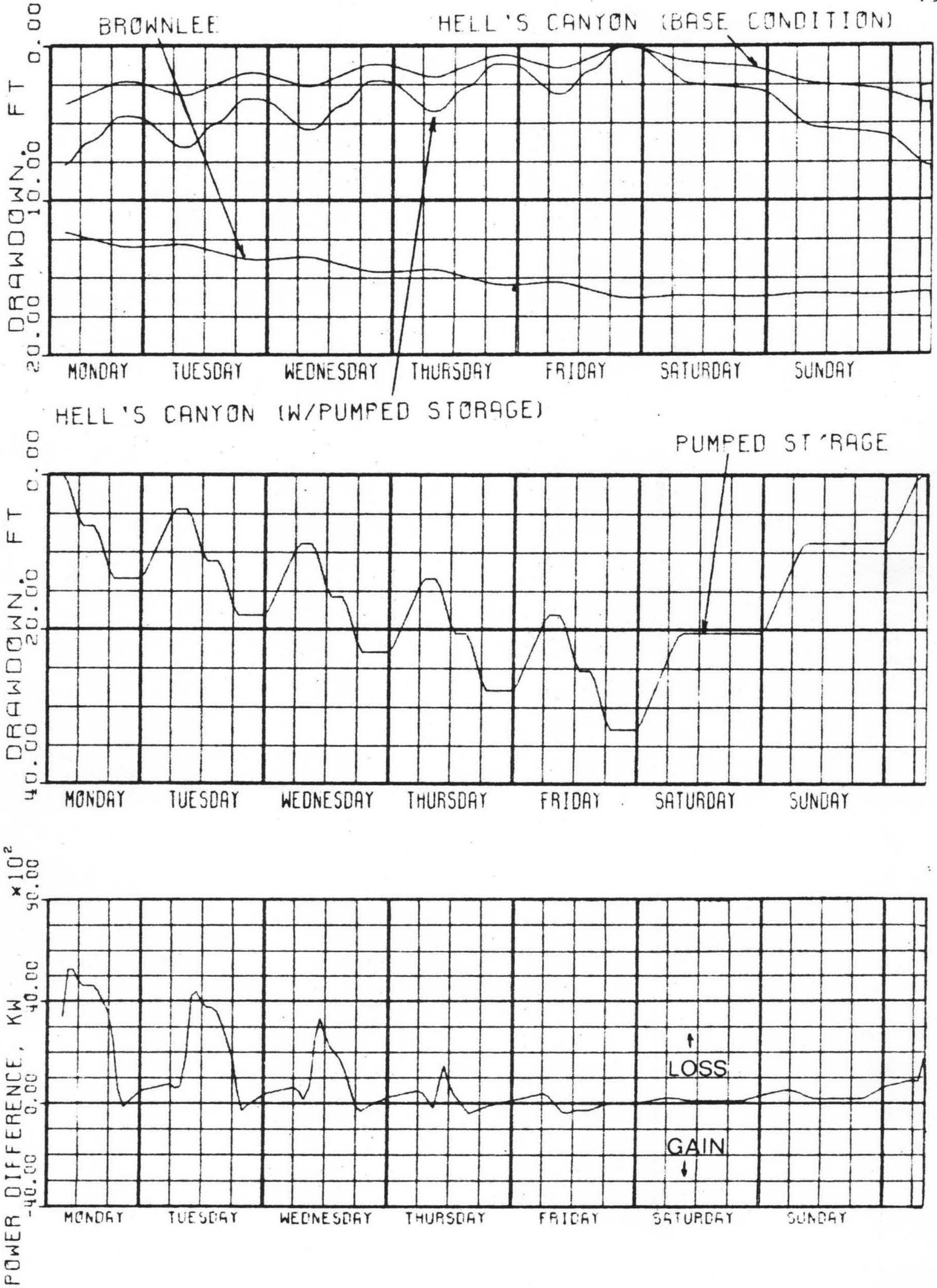


Figure 6-9.--North Pine F winter week drawdown and power loss curves.

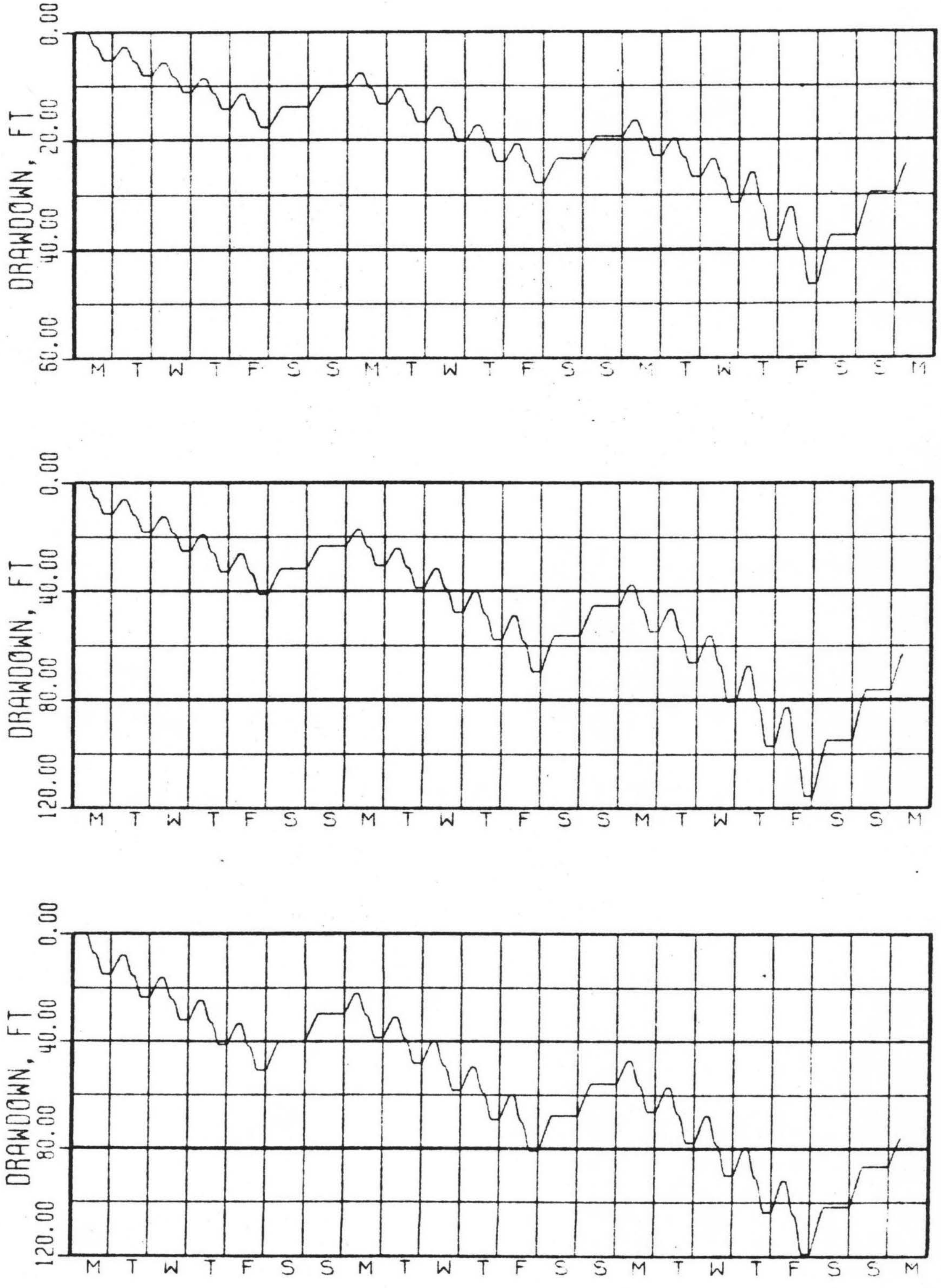


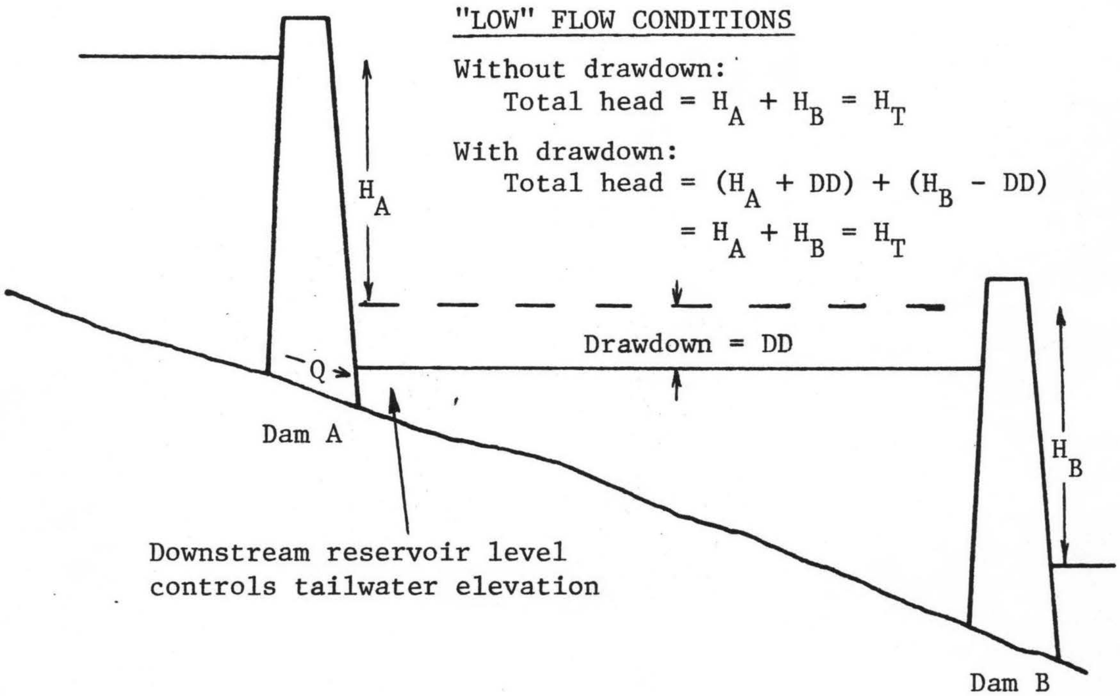
Figure 6-10.--Winter three-week upper reservoir drawdown curves.

presented for the winter three-week period, as the Snake dam results are similar to a series of one-week winter periods.

Two factors are important when considering the energy loss data. First is the physical interrelationships of the Snake dams and reservoirs, as illustrated in Figure 6-11. In this series of dams, each downstream reservoir overlaps the tailwater of the upstream dam by a considerable amount. Thus, the drawdown of a downstream reservoir may not mean a loss in total head for the system, because the upstream dam may experience a gain in head. However, this drawdown head may not be totally recovered due to the tailwater effect at the upstream dam. At sufficiently high flows, the tailwater elevation for the upstream dam can be above the downstream reservoir level. This tailwater effect is amplified by the extra drawdown required for pumped storage.

This point explains why the energy loss for the winter week period is greater than for the summer week. For one reason, the peaking flow cycle has greater amplitude for the winter week period. Thus, the outflow will control the tailwater more often in the winter period than in the summer. Also, in the case of the Indian Creek and North Pine F sites, Hell's Canyon reservoir must be drawn down more in the winter period, as there is more peaking to regulate.

This brings up the second factor: Hell's Canyon is not peaked as much as the other two dams so as to comply with the operating license provisions. This fact causes some interesting results for the Indian Creek and North Pine F sites. Although over the total period some energy is lost, for very low flow conditions such as the summer week period, the pumped storage actually helps distribute the generation



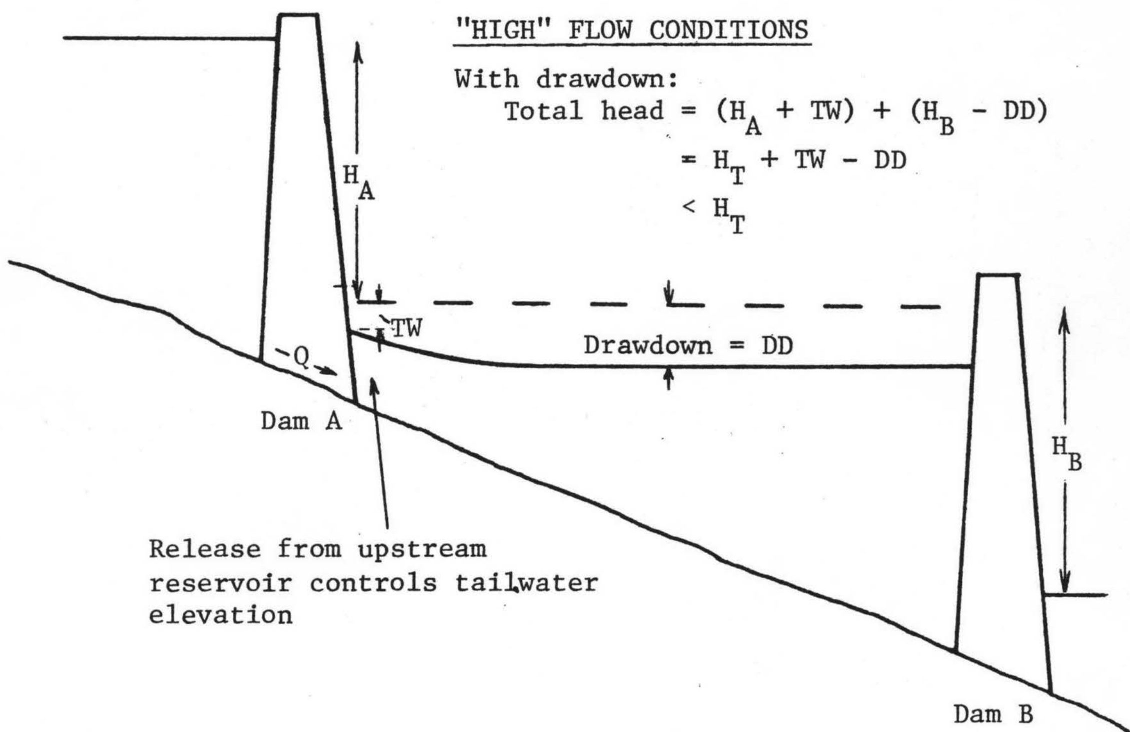


Figure 6-11.--Tailwater effect illustration.

Table 6-1.--Reservoir fluctuations.

Item	Barber Flat	Indian Creek	North Pine F
Summer Week			
Average inflow to Brownlee, cfs	6,100	6,100	6,100
Storage used, hrs	14	14	14
Storage used, ac-ft	6,450	6,380	9,200
Upper reservoir max. drawdown, ft	11.43	25.93	32.96
Upper reservoir max. drawdown rate, ft/hr	0.75	1.82	2.24
Change in upper reservoir surface area, ac	140	69	51
Lower reservoir max. drawdown-base condition, ft	0.00	2.91	2.91
Lower reservoir max. drawdown-w/pumped storage, ft	5.96	5.83	7.17
Lower reservoir max. drawdown due to pumped storage, ft	5.96	2.92	4.26
Lower reservoir max. drawdown rate-base condition, ft/hr	0.00	0.11	0.11
Lower reservoir max. drawdown rate-w/pumped storage, ft/hr	0.38	0.28	0.36
Lower reservoir max. drawdown rate due to pumped storage, ft/hr	0.38	0.17	0.25
Loss of energy from Snake dams due to pumped storage, KW-hrs	Negl.	600.	1,400.
Loss of energy from Snake dams due to pumped storage, as a percent of total produced	Negl.	Negl.	Negl.

(Table 6-1 continued)

Item	Barber Flat	Indian Creek	North Pine F
Winter Week			
Average inflow to Brownlee	9,900	9,900	9,900
Storage used, hrs	14	14	14
Storage used, ac-ft	6,900	6,840	9,860
Upper reservoir max. drawdown, ft	11.43	25.93	32.96
Upper reservoir max. drawdown rate, ft/hr	0.87	2.06	2.54
Change in upper reservoir surface area, ac	140	69	51
Lower reservoir max. drawdown-base condition, ft	0.00	3.75	3.75
Lower reservoir max. drawdown-w/pumped storage, ft	5.96	6.48	7.72
Lower reservoir max. drawdown due to pumped storage, ft	5.96	2.73	3.97
Lower reservoir max. drawdown rate-base condition, ft/hr	0.00	0.14	0.14
Lower reservoir max. drawdown rate-w/pumped storage, ft/hr	0.43	0.35	0.43
Lower reservoir max. drawdown rate due to pumped storage, ft/hr	0.43	0.11	0.29
Loss of energy from Snake dams due to pumped storage, KW-hrs	19,800	79,600	130,600
Loss of energy from Snake dams due to pumped storage, as a percent of total produced	0.02	0.08	0.13

(Table 6-1 continued)

Item	Barber Flat	Indian Creek	North Pine F
Winter Three Week			
Storage used, hrs	40	40	40
Storage used, ac-ft	21,700	22,100	37,500
Upper reservoir max. drawdown, ft	46.46	115.38	118.84
Upper reservoir max. drawdown rate, ft/hr	2.55	5.48	4.55
Change in upper reservoir surface area, ac	415	222	165

more advantageously. This occurs because the additional pumped storage drawdown of Hell's Canyon reservoir increases the head at the Oxbow plant. Because the flow during peak generating periods from Oxbow is more than from Hell's Canyon, there is a gain in energy over the base condition. This gain is offset by the reverse situation during the night hours, when Hell's Canyon is releasing more than Oxbow. This effect can also be seen during the winter period, but the gains are almost totally offset by the tailwater effect discussed earlier. The advantageous peaking distribution is not realized with the Barber Flat site because Brownlee and Oxbow release at the same rate.

Another point to consider is timing of the energy losses. For the higher flows, the greatest losses occur in the first part of the week, decreasing until the reservoirs fill on Friday night. This conflicts with what is often the load situation (highest loads occur early in the week). For the summer low flows, the reverse situation exists for the Indian Creek and North Pine F sites, i.e., the greatest gain (as discussed earlier) coincides with the greatest load.

CHAPTER 7

ECONOMIC ANALYSIS - THREE SELECTED SITES

At this level of study, only very approximate cost estimates can be made. The Corps of Engineers has developed estimating procedures for both investment and annual costs. This analysis is based on those procedures.

The Corps 1976 inventory study presented cost estimates for sites similar to the three analyzed here. However, there are significant differences, and these differences will be reflected in the cost estimates. The major differences are: (1) required storage (40 hours for this study, 14 hours for the Corps); (2) dam locations; (3) waterway routes; and (4) powerhouse locations (underground for this study, surface for the Corps). The Corps basic procedure is outlined below. Additions and refinements to their procedure as used for this study are also discussed.

COST ESTIMATING PROCEDURE

The Corps investment cost calculation is based on cost estimates for relocations, embankments, powerhouses, and penstocks. Costs are for July 1975 conditions. The cost of new transmission line and access road is not considered. The embankment cost is found by assuming a cost per unit volume of embankment. The powerhouse cost is found from an experience curve relating the powerhouse unit cost ($/KW) to the head and generator rating. Adjustments are made for high head installations and for economies of scale in the number of machines. Penstock costs are based on curves relating the total penstock cost to the head, tunnel diameter, and length. The subtotal of these costs is then increased by a factor to account for contingencies (25 percent), engineering (6 percent), overhead (6 percent), and interest during construction (6-1/8 percent over 4 years).

The annual cost is determined by amortizing the investment cost over a 100-year life, and then adding a yearly pumping cost and an operation, maintenance, and replacement cost. The pumping cost is based on a 10 percent plant factor (generating) and an energy cost of 4.5 mils per kilowatt-hour.

The Corps also calculates a benefit-cost ratio, the benefits assumed to be the alternative cost of thermal peaking (combustion turbines). This alternative cost was calculated to be $41.50 per kilowatt-year (based on Federal Power Commission data and federal financing).

The use of a large contingency allowance (25 percent) poses a problem when trying to make estimates with more precise data. An estimate based on precise design quantities should theoretically decrease the contingency factor. The 25 percent factor may be large enough to cover costs of items such as access roads and transmission lines. To reconcile this conflict, two cost estimates are presented; one using the Corps basic procedure and the other using the more refined data developed in the site designs. The 25 percent contingency factor is used in both cases.

MODIFICATIONS, REFINEMENTS, AND ADDITIONS TO BASIC PROCEDURE

The major refinement possible with the design data concerns the waterway (penstock) cost. Also, the use of a different dam cross-section and volume calculation procedure will lead to a different embankment cost estimate.

The use of underground powerhouses generally results in significant cost savings, but the Corps procedure is based on surface powerhouses. In comparing the Brown's Canyon study (Bechtel, Inc. 1975) to the Corps estimates for the Brown's Canyon site, the savings from an underground design appear to be mainly in the cost of the powerhouse works (about a one-third savings). An increase in cost (about two-thirds) occurs for the waterway. For the Antilon Lake project, the Corps and design estimates correspond reasonably closely, however. Based on these studies, the Hell's Canyon site costs are estimated by decreasing the Corps powerhouse cost by 20 percent and increasing the cost of the waterway by 50 percent. The cost of the access tunnel is estimated from the Brown's Canyon study as one and a third million dollars per thousand feet.

A factor of major importance for the Hell's Canyon sites is the need for additional transmission lines. A cost estimate of $90,000 per mile for 345 KV line is applicable for the area (Idaho Power Company 1976).

Other minor costs considered are for road improvement and the loss of energy from the Idaho Power Company dams. A cost of $100,000 per mile of dirt road needing improvement is assumed, based on the Corps of Engineers relocation unit costs. The loss of energy cost is estimated by assuming the winter week period is an "average" generation period for the year (at higher flows, less peaking is needed). The value of the lost energy could be as high as the 15 mils per kilowatt-hour credited to the energy from the Barber Dam Rehabilitation Project near Boise (Idaho Water Resources Board 1976). Assuming this value and a 10 percent plant factor, the cost of the lost energy is very minor. The gain in peaking capability from the pumped storage would justify the loss.

PRESENTATION OF ECONOMIC ANALYSIS

Economic benefit and cost estimates for the Hell's Canyon pumped storage sites are presented in Table 7-1. Both the Corps and modified estimates are given.

In comparing the cost estimates, one point deserves emphasizing: the transmission line cost increases the overall cost significantly. This is a measure of the disadvantage of being remote from any major load region. If transmission lines are built to transmit other power as has been proposed (e.g., from Wyoming coal-fired plants), the possibility of siting pumped storage in the area would be enhanced.

Table 7-1.--Economics of three selected pumped storage sites. (Figures in millions of dollars excepted as noted, July 1975 estimates.)

Item	Barber Flat	Indian Creek	North Pine F
BASIC CORPS OF ENGINEERS PROCEDURE			
Investment Cost			
Cost of embankments	2.8	26.8	51.8
Cost of relocations	0.3	0.8	1.2
Cost of powerhouse	79.0	79.0	62.5
Cost of waterway	36.3	38.2	48.7
Subtotal	118.4	120.8	164.2
Contingencies (25%)	29.6	30.2	41.0
Engineering and overhead (12%)	17.8	18.1	24.6
Interest during construction	20.3	20.7	28.2
Total investment cost	186.1	189.8	258.0
Investment cost, $/KW	186	190	258
Annual Cost			
Amortized investment cost (100-year life), $\$x10^6$/yr	11.4	11.7	15.8
O, M, & R cost, $\$x10^6$/yr	0.6	0.6	0.7
Pumping cost, $\$x10^6$/yr	5.9	5.9	5.9
Total annual cost, $/KW-yr	17.9	18.2	22.4
Annual Benefit, $/KW-yr	41.5	41.5	41.5
Benefit-Cost Ratio	2.3	2.3	1.8

(Table 7-1 continued)

Item	Barber Flat	Indian Creek	North Pine F
MODIFIED PROCEDURE			
Investment Cost			
Cost of embankments	2.8	26.8	51.8
Cost of relocations	0.3	0.3	1.2
Cost of road improvement	6.0	0.0	0.0
Cost of powerhouse	63.2	63.2	50.0
Cost of waterway	36.3	36.2	50.5
Cost of access tunnel	7.6	6.5	7.1
Cost of transmission line	23.5	24.4	23.9
Subtotal	139.7	157.4	184.5
Contingencies	34.9	39.4	46.1
Engineering and overhead (12%)	20.9	23.6	27.7
Interest during construction	24.0	27.0	31.6
Total investment cost	219.5	247.4	289.9
Investment cost, \$/KW	220	247	290
Annual Cost			
Amortized investment (100-yr life), $\$x10^6$/yr	13.5	15.2	17.8
O, M, & R cost, $\$x10^6$/yr	0.6	0.6	0.7
Pumping cost, $\$x10^6$/yr	5.9	5.9	5.9
Loss of energy cost, $\$x10^6$/yr	0.001	0.003	0.005
Total annual cost, \$/KW-yr	20.0	21.7	24.4
Annual Benefit, \$/KW-hr	41.5	41.5	41.5
Benefit-Cost Ratio	2.1	1.9	1.7

CHAPTER 8

SOCIAL AND ENVIRONMENTAL FACTORS - THREE SELECTED SITES

Only limited comment can be made concerning social and environmental factors relating to the sites. These factors would play a very important role in any actual development, and so some major apparent effects should be noted. This coverage is not meant to be complete or authoritative. Analysis criteria are taken primarily from an energy plant siting methodology study for Idaho (Warnick 1976).

SOCIAL FACTORS

The area is sparsely populated, and construction at any of the sites would not cause major disruption. Construction of a pumped storage project would have social consequences similar to any hydroelectric project, i.e., a brief boom period in the nearby communities. The communities in the Hell's Canyon area have experienced this effect before from the construction of the Snake dams. It is unknown whether this experience would be welcomed again. Few long term social changes would be induced.

Dislocation of people because of the upper reservoir would only be a factor at the Indian Creek site. This would be limited to only a few people. A loss of grazing land would occur at the Barber Flat and Indian Creek sites.

The most important social aspect of development would be the loss in recreational capacity. A campground would be flooded by the North

Pine F reservoir. Recreational use of the upper reservoirs would be unlikely because of the extreme drawdowns. At the lower reservoirs, the drawdowns would decrease the existing recreational use, although no quantities can be estimated here. In 1970, Idaho Power Company estimated an annual recreational use of 250,000 visitors at the Middle Snake reservoirs (Idaho Power Company 1970). The majority of these visitations probably occurred at the readily accessible Brownlee reservoir. Of the other two reservoirs, Hell's Canyon is probably visited more as it is more scenic and better developed. This would indicate that the Barber Flat site would cause the least recreational loss of the three.

ENVIRONMENTAL FACTORS

The three sites would cause varying impacts on open space and natural beauty. The remote and dry Barber Flat site would cause little impact because it is rarely visited. Development of the Indian Creek site, on the other hand, would destroy a particularly scenic and rustic valley. Even though the North Pine F site is in the National Recreation Area, it has a scenic value intermediate of the other two. The unsightly beaches exposed by drawdowns would be detrimental at any of the sites. New transmission line would also detract from scenic values.

All sites would have impact on animal life. Deer were observed in the vicinity of all three upper reservoir sites during a field reconnaissance trip in June 1976. These animals may depend on the water supplies existing at the upper reservoir sites. To avoid stranding and entrapment of wildlife in the upper reservoirs, the sites might have to be fenced. If so, then some loss in wildlife would occur because of water supply loss. Domestic stock would be displaced at the Barber Flat and Indian Creek sites. To protect against loss of aquatic life from passage through the plant, intake facilities can be adequately screened. Estimates of the losses due to drawdown cannot be made here.

The preceding discussion of social and environmental factors is at best limited. Further study by qualified persons should be conducted for a proper analysis of the sites.

CHAPTER 9

COMPARISON OF THE THREE SELECTED SITES

The following comparison of the Barber Flat, Indian Creek, and North Pine F pumped storage sites is based on the information developed in the preceding four chapters. Before any definite conclusions can be drawn concerning these sites, they must be compared with other alternatives.

Each site has good and bad points. Table 9-1 summaries the major advantages and disadvantages for each site. The preliminary nature of the analysis must be stressed, particularly with regards to the environmental and social factors.

Table 9-1 indicates that with all factors considered, the Barber Flat site is probably the best of the three. It is interesting to note that the remoteness of the Barber Flat site is a physical disadvantage but a major environmental advantage. The Indian Creek and North Pine F sites seem to have serious environmental drawbacks.

Table 9-1.--Site comparison - major aspects.

Item	Barber Flat	Indian Creek	North Pine F
Physical Aspects	A - Large upper reservoir storage capacity	D - Limited upper reservoir capacity	D - Limited upper reservoir capacity
	D - Possibly too high head	D - Possibly too high head	A - Acceptable head
	D - Difficult access		A - Good access
	D - Large lower reservoir drawdown	A - Least lower reservoir drawdown	D - Large lower reservoir drawdown
Economic Aspects	A - Least cost site		D - Highest cost
Social and Environmental Aspects	A - Remote and less attractive upper reservoir site	D - Very scenic valley for upper reservoir site	D - In the National Recreation Area
	A - Uses Oxbow as lower reservoir (less recreational use than Hell's Canyon)	D - Uses Hell's Canyon reservoir	D - Uses Hell's Canyon reservoir

A = relative advantage D = relative disadvantage

CHAPTER 10

ALTERNATIVE USES FOR PUMPED STORAGE IN THE HELL'S CANYON AREA

The preceding analysis deals with single-purpose pumped storage only. Two supplemental purposes might be possible with sites in the Hell's Canyon area: (1) the relief of Hell's Canyon dam of objectionable peaking duties; and (2) the cooling of nuclear power plants. These topics are briefly discussed below.

PEAKING RELIEF OF HELL'S CANYON DAM

When Hell's Canyon Dam was being planned, it was believed another reservoir would eventually be built downstream. Thus, it was natural to build Hell's Canyon as a peaking facility. Now that additional dams have been restricted from the remaining river, the peaking causes serious conflicts with downstream recreational use.

Two main problems occur. The 5,000 cfs minimum flow now provided is too low for safe navigational usage of the river. Actions have been taken to force an increase in the minimum flow to about 9,500 cfs. So far these efforts have been unsuccessful, as an increase could cause a serious loss in power and a summer drawdown of Brownlee reservoir (U. S. Army Corps of Engineers 1972).

The second problem is related to the fluctuation in river level caused by the peaking at Hell's Canyon Dam. Although efforts are made to give advance notice of the release schedule, the water level occasionally changes unexpectedly. Such occurrences hamper recreational use, e.g., beached boats can be stranded or floated without warning. Any further restriction on the peaking from Hell's Canyon Dam would be a serious loss for Idaho Power Company.

Pumped storage could help alleviate these problems. By restricting the peaking at Hell's Canyon Dam, the 5,000 cfs flow would not be reached as often, and the water levels would not fluctuate as much downstream. The excess energy generated at Hell's Canyon Dam during the off-peak hours could be stored by the pumped storage and later released to make up for the loss in peaking. Adverse consequences of this system would be (1) increased fluctuation in the upstream reservoir levels, and (2) more costly power, as only about two-thirds of the excess energy could be stored. Actually it would not be necessary for the pumped storage to be located in the Hell's Canyon area for this relief role to be possible. Transmission losses would be minimized if it were.

NUCLEAR POWER PLANT COOLING

Idaho Power Company and Utah Power and Light Company have proposed to study the joint construction of a nuclear power plant to meet their future load requirements (Lewiston Morning Tribune February 25, 1977). The advantages of locating nuclear and pumped storage together have been briefly mentioned earlier. They are: (1) a pumped storage reservoir can be used as a cooling pond for the nuclear plant; and (2) the nuclear plant can supply the off-peak pumping power with minimum transmission losses.

The location of a nuclear/pumped storage complex in the Hell's Canyon area would have advantages and disadvantages. The site would be located reasonably close to Idaho Power and West Group loads, but distant from Utah Power and Light loads. The low population of the area would minimize fears concerning the nuclear plant's safety. On the other hand, the remoteness would increase the cost of construction and operation. Living facilities would have to be built and maintained for plant personnel.

For economic reasons, a nuclear power plant must have a large generating capacity; projects are commonly greater than 1,000 MW. The pond size and consumptive water use with a pond cooling system are dependent upon the meteorological characteristics of the site. Average values for water use at a 1,000 MW plant are 18 cfs consumptive use and 1.5 acres per MW cooling pond size (Heitz 1975). Two pumped storage sites in the Hell's Canyon area deserve mention as possible nuclear generation sites.

Barber Flat

The upper reservoir of the Barber Flat site can be increased up to a maximum surface area of about 1,200 acres. Thus, it is incapable of handling a 1,000 MW plant by pond cooling alone. Spray cooling units could be installed to make up for the lack in pond surface area, but at higher cost. However, a critical drawback for the site is the lack of evaporation makeup water. It is uneconomical to pump the water 2,500 feet from the Snake River, and other sources of water are probably not sufficient to supply 18 cfs on a continuous basis. Storage of spring runoff of nearby creeks might be a source of cooling makeup water, but this would require the construction of another reservoir. Nuclear plant cooling therefore seems infeasible at the Barber Flat site.

Bear Creek #1

The Bear Creek #1 site is located in Idaho, approximately 7 miles east of the Oxbow (Figure 10-1). The reservoir can store a large volume of water, but the long tunnels required make the site uncompetitive for single-purpose pumped storage operation. When combined with a nuclear plant, the combination may become practical. Storage benefits could also be achieved.

An area-volume curve for the site is shown in Figure 10-2. The greatest part of the dam would be located in a narrow canyon, and a composite concrete-earthfill dam might be practical.

At a water surface elevation of 4,400 feet, the dam would be about 400 feet high. The reservoir would have a surface area of about 3,800 acres, and a storage of 330,000 acre-feet. Approximately 200,000 acre-feet of reservoir space could be used for storing excess energy and water during spring runoff, assuming that 2,000 acres would be needed for thermal cooling (2 acres per MW, a conservative estimate). At 2,700 feet of head, this represents a considerable amount of energy stored (around a third of a billion kilowatt-hours). Some recreational benefits might also be possible.

Evaporation makeup water for a nuclear power plant could come from stored runoff of Bear Creek. Possible nuclear plant sites are noted in Figure 10-1.

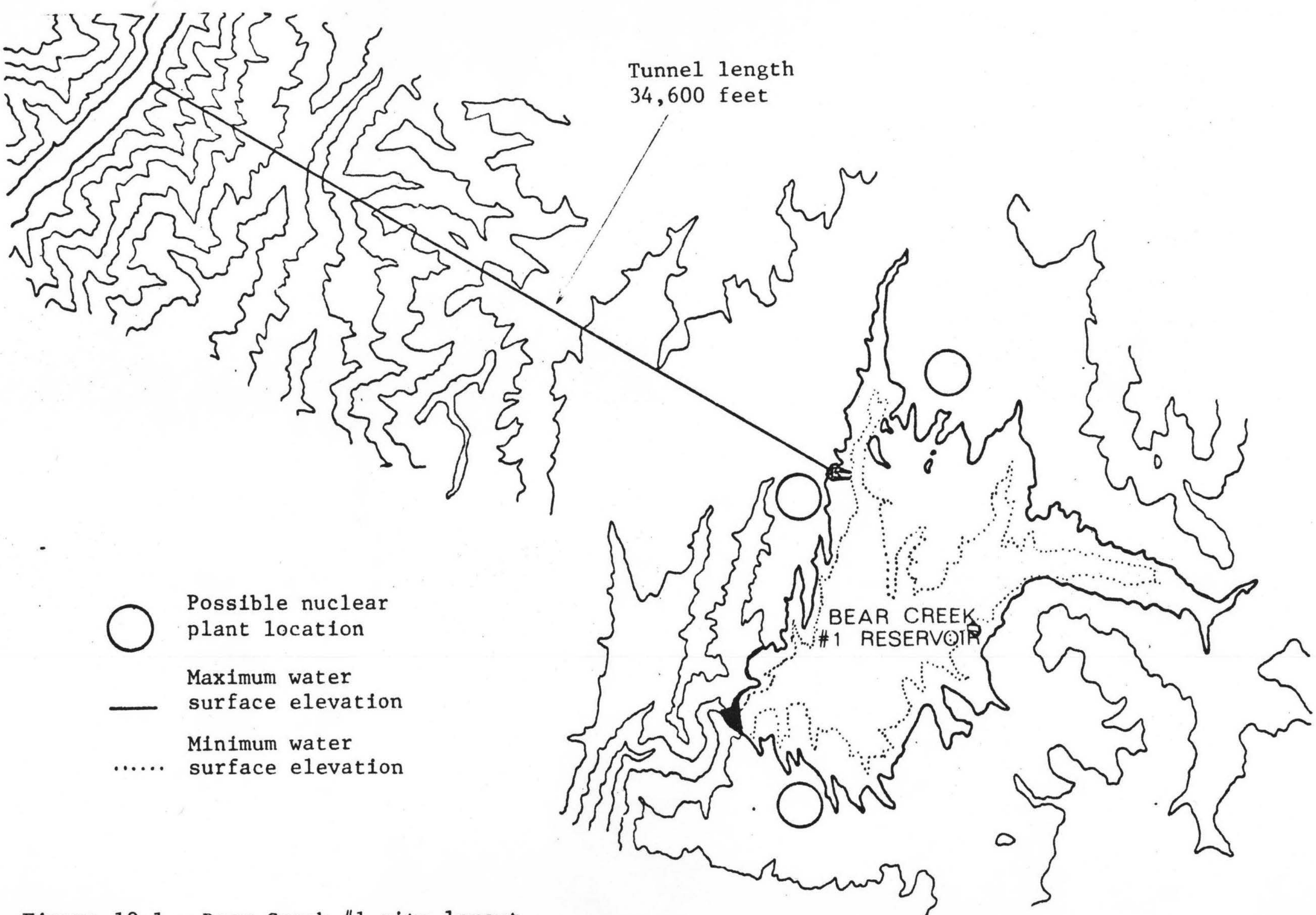


Figure 10-1.--Bear Creek #1 site layout.

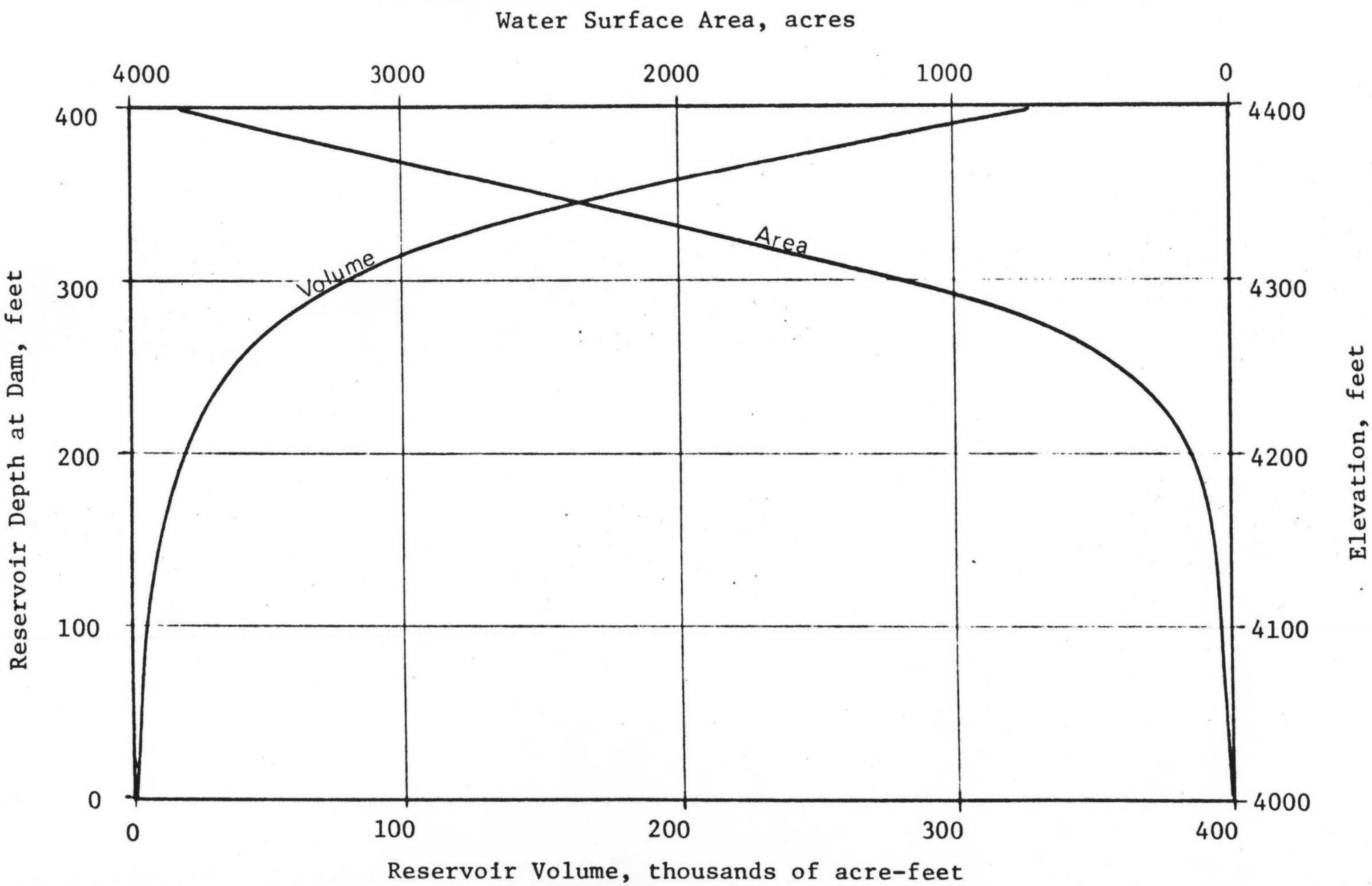


Figure 10-2.--Bear Creek #1 area-volume curve.

The land for the upper reservoir is now privately owned and probably used for grazing. Several ranches, the town of Bear, and many miles of dirt road would be inundated.

Table 10-1 presents a brief economic analysis of this site. The pumped storage portion of the costs are figured using the Corps of Engineers procedure. The storage costs are based on pumping 2,700 feet at 80 percent efficiency with 5 mil power. Benefits are based on generating over 3,200 feet (2,700 plus 500 at downstream dams) at 85 percent efficiency and 12 mil power. This procedure assumes that about half the water would have been spilled at downstream dams if not stored. The benefit for nuclear cooling would be the foregone cost of building the cooling pond. It is assumed that the cost of building the pond is half the cooling system cost, which is estimated at $10 per kilowatt (Pacific Northwest Environmental Research Lab 1973). The additional site induced cost for the nuclear cooling would be the cost of building in a remote area; this has been estimated as 10 percent of the total cost (Idaho Power Company 1976). Assuming a 1 billion dollar plant, this cost is then 100 million dollars. As can be seen from Table 10-1, the Bear Creek #1 site appears to be marginally feasible as a nuclear/pumped storage generation complex.

The preceding analysis is very approximate, and further study would be valuable. The environmental aspects of the sites have not been mentioned at all. The hydrology of creeks in the area and the cooling ability of the reservoirs also deserve much more study.

Table 10-1.--Economics of the Bear Creek #1 site.

Investment cost, with 1,000 MW pumped storage installation	$390,000,000
Annual cost, weekly pumped storage operation	30,900,000
Annual benefit from weekly pumped storage operation (cost of thermal alternative)	40,500,000
Annual supplemental storage cost, pumping 200,000 acre-feet at 2,700 feet head, 5 mils/KW-hr	3,500,000
Annual supplemental storage benefit, generate 200,000 acre-feet at 3,200 feet head, 12 mils/KW-hr	4,900,000
Annual nuclear cooling cost	6,200,000
Annual nuclear cooling benefit	300,000
Total annual costs	40,600,000
Total annual benefits	45,700,000
Net annual benefits	5,100,000
Benefit-cost ratio	1.1

CHAPTER 11

CONCLUSIONS AND RECOMMENDATIONS

Study of the potential for pumped storage development in the Hell's Canyon area has revealed that it is a possibility worth considering. At a time of increasing costs and shortages of energy, all power resources should be examined.

Pumped storage is a practical method of meeting the Pacific Northwest's peaking requirements. A large number of potential sites exist, and some development is likely to occur. However, as Chapter 2 relates, it is not certain when pumped storage will become needed and feasible.

The Hell's Canyon area is well suited for pumped storage development, as evidenced by the 18 sites of 1,000 MW or greater capacity listed in Table 4-1. The area is also a magnificent recreational resource, and the recent creation of the Hell's Canyon National Recreation Area has precluded the development of many pumped storage sites. Nevertheless, some of the best sites are outside the NRA boundaries and appear to be still possible for development. Indeed, pumped storage could possibly help with the existing minimum flow and river fluctuation problems in the canyon, as pointed out in Chapter 10.

The location of the Hell's Canyon area is both detrimental and advantageous for pumped storage siting. The area is centrally located, and thus use by several utilities and load regions might be possible. However, as Chapter 7 determines, the distance from any major load center makes pumped storage development quite expensive. It is therefore concluded that the Hell's Canyon area may not be a practical region for siting pumped storage until load growth occurs closer to the site or transmission lines are built for other purposes.

A pumped storage project in the area would likely use one of the existing reservoirs on the Snake River. The computer operations study, developed for this thesis and reported in Chapter 6, shows that the pumped storage would cause only minor loss in energy from the existing dams, but the reservoir levels would be fluctuated much more severely than they now are.

Of the three sites studied in greater detail (Barber Flat, Indian Creek, and North Pine F), the Barber Flat site is probably the best. This is evidenced by the details of the site comparison presented in Chapter 9. The social and environmental aspects of the sites cannot be properly evaluated here, but would be significant and important. Some possible effects, such as scenic values and recreational loss at the existing reservoirs, are noted in Chapter 8.

Based on this study, the following recommendations are offered:

(1) The Barber Flat site warrants further consideration in future pumped storage planning.

(2) The Bear Creek #1 site briefly presented in Chapter 10 should be investigated in greater detail as a site for a nuclear/pumped storage power complex.

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APPENDIX

RESERVOIR OPERATIONS PROGRAM

DOCUMENTATION

RESERVOIR OPERATIONS PROGRAM DOCUMENTATION

The reservoir operations program developed for this study is written in FORTRAN IV language and used on an IBM 370 computer. The program was originally written for terminal use, but later transferred to a card mode because of the lengthy output.

This documentation consists of five parts: (1) an explanation of the purpose, basic procedures, and simplifications of the program; (2) a list of the program; (3) a detailed explanation of the program operation; (4) input and output formats; and (5) actual input used for the analysis presented in Chapter 6.

PURPOSE, PROCEDURE, AND SIMPLIFICATIONS OF THE PROGRAM

The purpose of the program is to simulate the hydraulic operations of the Hell's Canyon complex of dams in conjunction with any of three pumped storage sites in the area. The output consists of values for the reservoir levels, flows, and energy production from the complex.

The program is essentially a basic reservoir operations procedure, i.e., an expansion of the continuity equation. The inflows and releases are determined by preset patterns of operation as explained in Chapter 6. These patterns determine factors by which the average inflow to Brownlee reservoir is multiplied (in the case of the Snake dams), or by which the maximum plant output is multiplied (for the pumped storage). The amplitude of peaking cycle can be modified by proper program input.

The main use of this capability is to keep Hell's Canyon Dam within its flow limitations. If the net inflow to a reservoir causes the storage capacity to be exceeded, the program releases the extra water through the turbines if possible. Spill occurs when the hydraulic capacity is exceeded.

The program analyzes three periods of operation: a three-week winter period and one week periods in the winter and summer. Certain modifications are required in the program for each period. Because the winter three-week program is the longest and most complex, this version is listed. The modifications required for the summer and winter week periods are also explained.

The basic procedure of the program is to first determine the total release for Brownlee Dam (desired turbine flow + excess turbine flow + spill). This release is the inflow to the Oxbow reservoir. The Oxbow release is then figured (as a function of the Brownlee inflow). Hell's Canyon Dam is analyzed similarly. When a pumped storage plant is operating, its release (positive or negative) is added to the inflow to the lower reservoir.

Flow calculations are made at the beginning of each hour. The reported value for a flow variable is the average of the values at the beginning and end of each hour. For example, suppose Q(8:00) = 10,000 cfs and Q(9:00) = 12,000 cfs. The value of Q for the hour from 8:00 to 9:00 is reported at 9:00 and is Q(9:00) = 11,000 cfs. Storage, spill, and energy calculations are based on the average flow values.

The model departs from reality at mainly three points. First, the operating patterns are based on flow into the system rather than on load conditions. In reality, the operating pattern for each day would be unique, rather than the identical patterns assumed in the program. Second, flows are not routed from dam to dam because routing would require a variable time factor, which would be a severe complication to the program. The neglection of a routing procedure in effect causes the program to ignore small water level fluctuations which in reality would occur. Third, this operation neglects the ability to use the Brownlee storage for power purposes. It assumes a pondage-type operation.

The elevation-reservoir volume relationships for the reservoirs are approximated by parabolic sections. These relations are listed below (volumes in thousands of acre-feet, elevation in feet):

Brownlee: $\text{Volume} = 1079.254 + 11.57861X + 0.04745X^2$

where X = elevation - 2050.

Oxbow: $\text{Volume} = 24.20972 + 0.83907X + 0.00381X^2$

where X = elevation - 1770.

Hell's Canyon: $\text{Volume} = 77.27588 + 1.35287X + 0.01155X^2$

where X = elevation - 1640.

Barber Flat: $\text{Volume} = 0.6853 + 0.23518X + 0.00372X^2$

for $X>20$, where X = elevation - 4250.

$\text{Volume} = 2.6 + 0.172X + 0.0021X^2$

for $X<20$.

Indian Creek: $\text{Volume} = 6.00908 + 0.08335X + 0.00106X^2$

for $X>20$, where X = elevation - 4120.

$\text{Volume} = 6.0 + 0.099833X + 0.000258X^2$

for $X<20$.

North Pine F: Volume = $5.34029 + 0.09634X + 0.00063X^2$

where $X = \text{elevation} - 3280$.

Tailwater curves for the three Snake dams are approximated by parabolic and linear curves, as follows (Q (flow) in thousands of cfs, elevation in feet):

Brownlee: for $Q \leq 15$, elevation = $0.264Q + 1795.1$

for $Q \geq 15$, elevation = $0.264(Q-15) + 1799.06$

Oxbow: for $Q<15$, elevation = $-0.01Q^2 + 0.568Q + 1676.76$

for $Q>15$, elevation = $0.292(Q-15) + 1683.03$

Hell's Canyon: for $Q<15$, elevation = $0.384Q + 1465.78$

for $Q>15$, elevation = $0.311(Q-15) + 1471.54$

The above relationships were developed from curves in the Brownlee, Oxbow, Hell's Canyon regulation manual (U. S. Army Corps of Engineers 1961), except for the Oxbow tailwater equations which were developed from a tailwater curve supplied by Idaho Power Company.

The drawdown and energy loss curves presented in Chapter 6 were made with a Calcomp plotter, using data punched on cards by the operations program. A more efficient system would have been to store the data in temporary files rather than punching on cards. Anyone considering the use of this program should modify it to avoid punching so many cards. A listing of the program is contained in the next section.

PROGRAM LISTING

```
C
C      THE PURPOSE OF THIS PROGRAM IS THE SIMULATION OF THE OPERATION
C OF THE HELL'S CANYON COMPLEX OF DAMS IN CONJUNCTION WITH ANY OF THREE
C PUMPED STORAGE SITES IN THE AREA.  THE THREE PUMPED STORAGE SITES ARE
C BARBER FLAT, INDIAN CREEK, AND NORTH PINE F.  HOURLY RUNS ARE MADE
C OVER A ONE WEEK PERIOD STARTING AT 8 AM MONDAY.
C
C      RESERVOIR CAPACITY CURVES ARE APPROXIMATED BY PARABOLAS FOR THE
C ACTIVE RANGE OF ELEVATIONS AND STORAGES.
C
C      DATA IS ENTERED IN THE ORDER OF:
C    CARD 1--COL 1-6, THE WEEK'S AVERAGE INFLOW TO BROWNLEE, IN CFS
C    CARD 2-- BEGINNING RESERVOIR ELEVATIONS:
C                 COL 1-6   BROWNLEE
C                 COL 7-12  OXBOW
C                 COL 13-18  HELL'S CANYON
C    CARD 3-- THE FRACTION OF THE MAXIMUM PEAKING AT EACH INSTALLATION:
C                 COL 1-4   BROWNLEE
C                 COL 5-8   OXBOW
C                 COL 9-12  HELL'S CANYON
C                 COL 13-16  PUMPED STORAGE
C    CARD 4--PUMPED STORAGE INFORMATION:
C                 COL 1-ENTER 1 FOR BARBER FLAT, 2 FOR INDIAN CREEK, 3 FOR
C                       NORTH PINE F
C                 COL 2-9   SIZE OF INSTALLATION, IN KW
C                 COL 10-14 UPPER RESERVOIR BEGINNING ELEVATION
C                 COL 15   ENTER 1 IF ANOTHER RUN FOLLOWS, 0 IF ITS THE LAST
C
C
C
      DIMENSION T(504),Y1(504),Y2(504),Y3(504),Y4(504),Y5(504)
      DIMENSION Y6(168),Y7(168),Y8(168)
      DIMENSION OPPAT(3),AVEIN(8),FLOWIN(4,24),OUT(3),TUROUT(4),STRMAX(3
     *),PERIN(3),CPMOD(3),E1(5),E2(5),E3(5),E4(5),
     *RESLEV(5),TURMAX(3),NAME(7,3),FLUC(4),STOR(4),DSTOR(4),HEAD(4),SPI
     *LL(4),ENERGY(4),HOLD(4)
      DIMENSION HTURB(3),TURB(3)
      DIMENSION DESTUR(3),CONSPL(3),EXCSPL(3)
      DIMENSION PERPK(3)
      DIMENSION PP(3),PL(3),PM(3)
      DIMENSION TW(3),TWA(3),TWB(3),TWC(3),TWD(3),TWE(3)
      DATA TWA,TWB,TWC,TWD,TWE/0.0,-0.01,0.0,.264,.568,.384,1795.1,1676.
     *76,1465.78,.264,.292,.311,1799.06,1683.03,1471.54/
      DATA NAME/'BROW','OXBO','HELL','PUMP','BARB','INDI','N. P','NLEE',
     *'W   ','S CA','-STO','ER F','AN C','INE ','    ',
     *'    ','NYON','RAGE','LAT ','REEK','F   '/
      DATA TURMAX,STRMAX/33750.,25000.,31000.,1426467.,58244.,168824./
      DATA HOLD/2077.,1805.,1698.,0./
C
C    ENTER AND INITIALIZE SNAKE DAM COMPLEX INFORMATION
C
 1000 READ(5,603) AVEWK
  603 FORMAT(F6.0)
      READ(5,800) (RESLEV(I),I=1,3)
  800 FORMAT(3F7.2)
      RESLEV(4)=1468.
      READ(5,1) (PERPK(I),I=1,3),PRPKPS
    1 FORMAT(4F4.0)
      DO 105 K=1,3
      PL(K)=.57*PERPK(K)/100.
      PP(K)=(7939./10500.)*PERPK(K)/100.
      PM(K)=.16*PERPK(K)/100.
  105 CONTINUE
      AVEIN(8)=AVEWK
      DATA E1,E2,E3,E4/1079.254,24.20972,77.27588,0.,0.,11.57861,.83907,
     *1.35287,0.,0.,.04745,.00381,.01155,0.,0.,2050.,1770.,1640.,0.,0./
      DO 111 I=1,3
      HTURB(I)=AVEWK+3600.
      Z=RESLEV(I)-E4(I)
  111 STOR(I)=1000.*(E1(I)+E2(I)*Z+E3(I)*Z**2)
C
C    ENTER AND INITIALIZE PUMPED STORAGE INFORMATION
C
      READ(5,602) JPS,PSPOW,RESLEV(5),IGIN
      READ(5,1631) IPLOT,IPRINT
 1631 FORMAT(2I1)
  602 FORMAT(I1,F8.0,F5.0,I1)
      IF(JPS.EQ.0) GO TO 1001
      IF(JPS-2) 401,402,403
  401 E1(4)=.6853
      HOLD(4)=RESLEV(5)
      E2(4)=.23518
      E3(4)=.00372
      E4(4)=4250.
      IPS=2
      HOLD(4)=4300.
      QWTW=311.
      E3(5)=.0021
      E2(5)=.172
      E1(5)=2.6
      GO TO 404
  402 E1(4)=6.30908
      E2(4)=.03335
      E3(4)=.00106
      E4(4)=4120
      IPS=3
      HOLD(4)=4210.
      E3(5)=.000258
      E2(5)=.099833
      E1(5)=6.
      QWTW=311.
      GO TO 404
  403 E1(4)=5.34029
      E2(4)=.09534
      E3(4)=.00063
```

```
      E4(4)=3280.
      IPS=3
      HOLD(4)=3442.
      QWTW=452.
      E3(5)=E3(4)
      E2(5)=E2(4)
      E1(5)=E1(4)
      GO TO 404
 1001 CONTINUE
      QWTW=0.
      HOLD(4)=0.
      IPS=0.
  404 STOR(4)=1000.*(E1(4)+E2(4)*(RESLEV(5)-E4(4))+E3(4)*(RESLEV(5)-E4(4
     *))**2)
      NPS=JPS+4
      PSCK=E4(4)+20.
C
C     WRITE HEADINGS
C
      WRITE(6,701) AVEWK,(PERPK(I),I=1,3),PRPKPS
  701 FORMAT('1IN THE TIME COLUMN 1 IS MONDAY, 7 IS SUNDAY'//'0THE AVERA
     *GE WEEKLY INFLOW IS ',F6.0,' CFS'//'0THE PERCENT OF MAXIMUM PEAKIN
     *G AT EACH DAM IS:'/' ',10X,'BROWNLEE--',F4.0/' ',10X,'OXBOW--',F4.
     *0/' ',10X,'HELLS CANYON--',F4.0/' ',10X,'PUMPED STORAGE--',F4.0)
      WRITE(6,2) (NAME(NPS,II),II=1,3),PSPOW
    2 FORMAT     ('0THE PUMPED STORAGE PROJECT IS ',3A4,', ',F8.0,' KW'//
     *//' ',T40,'DESIRED',T52,'EXCESS'/' ',T29,'RIVER',T40,'TURBINE',
     *T52,'TURBINE',T76,'W.S. ELEVATION',T99,'W.S.',T119,
     *'ENERGY'/'    TIME',T13,'INSTALLATION',T28,'INFLOW',T41,'FLOW',
     *T53,'FLOW',T64,'SPILL',T75,'UPPER',T87,'LOWER',T97,'DRAWDOWN',
     *T110,'HEAD',T118,'PRODUCED'/' (DAY,HR)',T29,'(CFS)',T41,'(CFS)',
     *T53,'(CFS)',T64,'(CFS)',T75,'(FT)',T87,'(FT)',T99,'(FT)',T110,
     *'(FT)',T119,'(KW-HR)'/'+','________________________________________
     *________________________________________________________________
     *______________________')
      TOTENG=0.
      AVEWK=AVEWK+3600.
C
C     BEGINNING OF CALCULATIONS--INITIALIZE AT 8 AM MONDAY
C
      DO 907 IWP=1,3
      DO 802 IZ=1,7
      ID=IZ
      EGTT=0.
      DO 102 IK=1,24
      L=IK+24*(IZ-1)+168*(IWP-1)
      IH=IK+8
      IF(IH.LE.24) GO TO 702
      IH=IH-24
      IF(IH.GT.1) GO TO 702
      ID=ID+1
  702 CONTINUE
      IX=ID
      FLOWIN(1,IH)=AVEWK-3600.
      DO 100 I=1,3
      IF(ID.EQ.8) GO TO 810
      IF(ID.GE.6) GO TO 200
      GO TO 1725
C
C     DETERMINATION OF SNAKE COMPLEX'S RELEASE
C
C     WEEKDAY
C
  810 IX=1
 1725 IF(IH.GE.21) GO TO 201
      IF(IH.GE.18) GO TO 202
      IF(IH.GE.10) GO TO 203
      IF(IH.GE.8) GO TO 204
      IF(IH.GE.6) GO TO 208
      PERIN(I)=1.-PL(I)
      GO TO 211
  201 PERIN(I)=1.-(IH-21)*PL(I)/3.
      GO TO 211
  202 PERIN(I)=1.+PP(I)-(IH-18)*PP(I)/3.
      GO TO 211
  203 PERIN(I)=1.+PP(I)
      GO TO 211
  204 PERIN(I)=1.+(IH-8)*PP(I)/2.
      GO TO 211
  208 PERIN(I)=1.+(IH-6)*PL(I)/2.-PL(I)
      GO TO 211
C
C     WEEKEND
C
  200 IF(IH.GE.20) GO TO 205
      IF(IH.GE.10) GO TO 206
      IF(IH.GE.5) GO TO 207
      PERIN(I)=1.-PL(I)
      GO TO 211
  205 PERIN(I)=1.-PM(I)-(IH-20)*(PL(I)-PM(I))/4.
      GO TO 211
  206 PERIN(I)=1.-PM(I)
      GO TO 211
  207 PERIN(I)=1.-PL(I)+(IH-5)*(PL(I)-PM(I))/5.
  211 TURB(I)=PERIN(I)*AVEWK
      TUROUT(I)=(TURB(I)+HTURB(I))/2.
      IF(I.GE.IPS) TUROUT(I)=TUROUT(I)+QWTW
  501 IF(I.EQ.IPS) GO TO 227
      GO TO 236
C
C     DETERMINATION OF PUMPED STORAGE'S RELEASE
C
  227 PSHEAD=RESLEV(5)-RESLEV(IPS)
      QTUR=PSPOW*550./(.746*62.4*PSHEAD*.85)
      QTUR=QTUR*PRPKPS/100.
      QTURH=QTUR
      IF(IH.NE.9) GO TO 500
      IF(ID.EQ.1) CPSC=0.
```

```
      500 CONTINUE
          IF(ID.EQ.8) GO TO 811
          IF(ID.GE.6) GO TO 220
C
C     WEEKDAY
C
      811 IF(IH.GE.19) GO TO 221
          IF(IH.GE.16) GO TO 222
          IF(IH.GE.13) GO TO 223
          IF(IH.GE.10) GO TO 224
          IF(IH.GE.7) GO TO 225
          QPS=-.5*QTUR
          GO TO 235
      221 QPS=0.
          GO TO 235
      222 QPS=QTUR
          GO TO 235
      223 QPS=8.*QTUR/45.
          GO TO 235
      224 QPS=QTUR
          GO TO 235
      225 QPS=0.
          GO TO 235
C
C     WEEKEND
C
      220 IF(IH.GE.9) GO TO 226
          IF(IH.GE.7) GO TO 230
          QPS=-8.*QTUR/15.
          GO TO 235
      226 QPS=0.
          GO TO 235
      230 QPS=-8./15.*QTUR*(1.-(IH-7)/2.)
      235 QPS=QPS*PRPKPS/100.
          QPSA=(QPS+QPSO)/2.
          QPSO=QPS
          QPS=QPSA
          FLOWIN(IPS,IH)=FLOWIN(IPS,IH)+QPS
C
C     DETERMINATION OF NEW RESERVOIR LEVELS
C
          IF(RESLEV(5).GT.PSCK) GO TO 1313
          E1(4)=E1(5)
          E2(4)=E2(5)
          E3(4)=E3(5)
     1313 A=1000.*E3(4)
          STOR(4)=STOR(4)-QPS*3600./43560.
          B=1000.*E2(4)
          C=1000.*E1(4)-STOR(4)
          X=(SQRT(B**2-4.*A*C)-B)/(2.*A)
          RESLEV(5)=X+E4(4)
          IF(RESLEV(5).GT.HOLD(4)) RESLEV(5)=HOLD(4)
          FLUC(4)=HOLD(4)-RESLEV(5)
C
C     CHECK FLOW AGAINST LIMITATIONS
C
      236 IF(TUROUT(I).GT.TURMAX(I)) TUROUT(I)=TURMAX(I)
          IF(I.NE.3) GO TO 237
          IF(TUROUT(I).LE.5000.) TUROUT(I)=5000.
      237 DESTUR(I)=TUROUT(I)
C
C     DETERMINATION OF STORAGES AND SPILLS
C
          DSTOR(I)=(FLOWIN(I,IH)-TUROUT(I))*3600./43560.
          STOR(I)=STOR(I)+DSTOR(I)
          IF(STOR(I).LE.STRMAX(I)) GO TO 301
          CONSPL(I)=(STOR(I)-STRMAX(I))*43560./3600.
          CHEKSP=TUROUT(I)+CONSPL(I)
          IF(CHEKSP.GT.TURMAX(I)) GO TO 1511
          TUROUT(I)=CHEKSP
          EXCSPL(I)=CONSPL(I)
          STOR(I)=STRMAX(I)
          GO TO 1512
     1511 SPILL(I)=CHEKSP-TURMAX(I)
          EXCSPL(I)=TURMAX(I)-TUROUT(I)
          TUROUT(I)=TURMAX(I)
          STOR(I)=STRMAX(I)
          GO TO 400
      301 EXCSPL(I)=0.
     1512 SPILL(I)=0.
      400 A=1000.*E3(I)
          B=1000.*E2(I)
          C=1000.*E1(I)-STOR(I)
          X=(SQRT(B**2-4.*A*C)-B)/(2.*A)
          RESLEV(I)=X+E4(I)
          FLUC(I)=HOLD(I)-RESLEV(I)
          OUT(I)=TUROUT(I)+SPILL(I)
          HTURB(I)=TURB(I)
          Q=OUT(I)/1000.
          IF(Q.GT.15.) GO TO 1688
          TW(I)=TWA(I)*Q**2+TWB(I)*Q+TWC(I)
          GO TO 1689
     1688 TW(I)=TWD(I)*(Q-15.)+TWE(I)
     1689 CONTINUE
          IF(I.LE.2) GO TO 302
          GO TO 100
      302 FLOWIN(I+1,IH)=OUT(I)
      100 CONTINUE
          ENGTOT=0.
          DO 1652 I=1,3
     1651 IF(RESLEV(I+1).GT.TW(I)) TW(I)=RESLEV(I+1)
     1652 CONTINUE
C
C     CALCULATION OF ENERGY PRODUCED AT THE SNAKE DAM COMPLEX
C
          IF(IPS.EQ.0) QWTW=0.
          DO 103 I=1,3
          TUROUT(I)=TUROUT(I)-QWTW
```

```
              HEAD(I)=RESLEV(I)-TW(I)
              ENERGY(I)=TURDUT(I)*HEAD(I)*62.4*.9*.746/550.
              TURDUT(I)=TURDUT(I)-QWTW
              ENGTOT=ENGTOT+ENERGY(I)
         103 CONTINUE
      C
      C     PRINT DATA
      C
              IF(IPRINT.EQ.1) GO TO 1407
              WRITE(6,3) ID,IH,((NAME(I,J),J=1,3),FLOWIN(I,IH),DESTUR(I),
             *EXCSPL(I),SPILL(I),RESLEV(I),TW(I),FLUC(I),HEAD(I),ENERGY(I
             *),I=1,3),(NAME(4,J),J=1,3),QPS,RESLEV(5),RESLEV(IPS),FLUC(4),
             *PSHEAD,ENGTOT
            3 FORMAT('0',T4,I2,',',I2,3(T13,3A4,T28,F7.0,T40,F7.0,T52,F7.0,T62,
             *F7.0,T73,F7.2,T85,F7.2,T98,F6.2,T108,F6.1,T118,F10.0/),T13,3A4,
             *T4),F7.0,T73,F7.2,T85,F7.2,T98,F6.2,T108,F6.1,T118,F10.0,'-TOT')
         1407 CONTINUE
              EGTT=EGTT+ENGTOT
              Y1(L)=FLUC(1)
              Y2(L)=FLUC(2)
              Y3(L)=FLUC(3)
              Y4(L)=FLUC(4)
              Y5(L)=ENGTOT
              IF(L.GE.169) GO TO 102
              Y6(L)=PERIN(1)
              Y7(L)=PERIN(3)
              Y8(L)=QPSO/QTURH
          102 CONTINUE
              TOTENG=TOTENG+EGTT
          802 CONTINUE
          907 CONTINUE
              WRITE(6,804) TOTENG
          804 FORMAT('/','TOTAL ENERGY FOR THIS WEEK (EXCLUDING SPILL) IS ',F12.
             *0)
              IF(IPLOT.EQ.1) GO TO 1637
              IF(JPS-1) 1408,1409,1410
         1408 CONTINUE
              GO TO 1637
         1409 CONTINUE
              WRITE(7,1635) (Y6(I),I=1,168)
              WRITE(7,1635) (Y7(I),I=1,168)
              WRITE(7,1635) (Y8(I),I=1,168)
         1410 CONTINUE
              WRITE(7,1638) (Y4(I),I=1,504)
         1635 FORMAT(10(16F5.3/),8F5.3)
         1638 FORMAT(31(16F5.1/),8F5.1)
         1637 IF(IGIN.GE.1) GO TO 1000
              STOP
              END
```

PROGRAM VARIATIONS

To change from the winter three-week program to the winter week program, do the following:

Remove cards 84, 96, 132, 228, 230, 233, 253

Add the following card after card 138:

```
QPUMP=-2*QTUR/3.
```

Substitute the following cards:

```
 89        L=IK+24*(I2-1)
149        QPS=QPUMP
155    223 QPS=0.
163        QPS=QPUMP
167    230 QPS=QPUMP*(1.-(IH-7)/2.)
```

To change from the winter week program to the summer week program, do the following:

Remove card 83

Substitute the following cards:

```
 28        HTURB(I)=AVEWK
 97        FLOWIN(1,IH)=AVEWK
```

Add the following card in front of card 139:

```
QTUR=2.*QTUR/3.
```

Substitute the block of cards shown on the next page for cards 144 through 167.

```
  811 IF(IH.CE.19) GC TO 221
      IF(IH.GE.1)) GO TC 222
      IF(IH.GE.7) GO TO 223
      CPS=QPUMP
      GO TO 235
  221 QPS=0.
      GO TO 235
  222 QPS=QTUR
      GO TO 235
  223 QPS=J.
      GO TO 235
C
C  WEEKEND
C
  220 IF(IH.GE.9) GO TC 226
      IF(IH.GE.7) GO TC 230
  229 QPS=QPUMP
      GO TO 235
  226 QPS=0.
      GO TO 235
  230 QPS=QPUMP*(1.-(IH-7)/2.)
```

PROGRAM EXPLANATION

Cards	Function
1-8	Dimension subscripted variables
9-12	Define constant values--tailwater curve coefficients, names, hydraulic capacities, maximum storages, and maximum reservoir levels
13-14	Read average inflow to Brownlee
15-17	Read initial reservoir levels for Brownlee, Oxbow, and Hell's Canyon
18-19	Read fraction of "normal" operation for Brownlee, Oxbow, Hell's Canyon, and pumped storage
20-24	Determine Snake dams pattern factors
25	Set second Monday inflow to the average inflow
26	Define reservoir curve constants
27-30	Determine initial Snake dams storages
31,34	Read pumped storage information--project, size, initial reservoir level, and if another run follows
32-33	Read print and punch control variables
35-74	Define pumped storage constants--volume curve coefficients, maximum reservoir levels, extra winter three-week release
75-77	Determine initial pumped storage reservoir volume
78-81	Write headings
82	Define total energy variable
83	Add Brownlee flood control release to inflow
84-88	Start loops for week, day, and hour

Cards	Function
89	Determine consecutive hour from beginning (for use by the plotter)
90	Start operation at 8:00 a.m. Monday
91-97	Compensate counting variables for starting at 8:00 a.m.
98	Start loop for series of dams--determine release in the order Brownlee, Oxbow, and Hell's Canyon
99-129	Determine dam release factor for day and hour
130	Determine dam release
131	Determine average release for the hour
132	Add extra winter three-week release
133-138	Determine pumped storage head and maximum release
139-168	Determine pumped storage release for the hour
169-171	Determine average pumped storage release for the hour
172	Add pumped storage release to the lower reservoir inflow
173-176	Determine proper upper reservoir equation
177-184	Determine new upper reservoir level and drawdown
185	Check Snake dam turbine flow against hydraulic capacity
186-187	Check Hell's Canyon Dam for 5,000 cfs minimum flow
188-190	Determine new storages for Snake reservoirs
191	Check Snake reservoir storage against maximum
192	Determine excess storage (if any)
193-198	Determine volume of excess whhich can go through turbines (if any)
199-205	Determine spill (if any)
206-211	Determine new Snake reservoir levels and drawdowns

Cards	Function
212-213	Determine total release (turbine plus spill)
214-219	Determine tailwater elevation due to release
220-222	Set outflow of upstream dam as inflow to downstream dam
223	End of dam series loop
224	Initialize daily energy variable
225-227	Determine tailwater elevation (whether due to release or downstream reservoir level)
228-235	Determine energy produced at Snake dams (extra pumped storage release not included so comparison is possible with base run)
236	Check if printing of data is desired
237-239	Print results
240-249	Prepare data for punching
250	End of hour loop
251	Summation of daily hourly energy figures
252-253	End of day and week loops
254-255	Write total energy produced value
256-267	Punch data (if desired), cards variable depending on what wanted punched
268	Return to start for another run (if desired)
269-270	Finish

INPUT AND OUTPUT FORMATS

Five cards are read for each run (runs can be stacked). These cards are explained below.

Card 1: 1 value - the average inflow to Brownlee reservoir (Weiser gage) for the period. Format F6.0.

Card 2: 3 values - initial reservoir levels for the three Snake dams. Format 3F7.2. In the order Brownlee, Oxbow, Hell's Canyon.

Card 3: 4 values - percent of "normal" peaking operation for the three Snake dams and the pumped storage. Format 4F4.0. In the order Brownlee, Oxbow, Hell's Canyon, pumped storage. For the three dams, the values can be greater or less than 100, but cannot be greater than 100 for the pumped storage.

Card 4: 4 values - the pumped storage project (1=Barber Flat, 2= Indian Creek, 3=North Pine F), the size of the pumped storage project in kilowatts, the initial reservoir level for the pumped storage upper reservoir, and a repeat control value (1 if another run follows, 0 if this is the last run). Format I1, F8.0, F5.0, I1.

Card 5: 2 values - punching (1 if no punching desired, 0 if punching desired) and printing (1 if no printing desired, 0 if printing desired) instructions. Format 2I1.

Sample printed output is shown on the next page.

IN THE TIME COLUMN 1 IS MONDAY, 7 IS SUNDAY.

THE AVERAGE WEEKLY INFLOW IS 9900. CFS

THE PERCENT OF MAXIMUM PEAKING AT EACH DAM IS:
BROWNLEE--100.
OXBOW--100.
HELLS CANYON-- 60.
PUMPED STORAGE--100.

THE PUMPED STORAGE PROJECT IS BARBER FLAT , 1000000. KW

TIME (DAY.HR)	INSTALLATION	RIVER INFLOW (CFS)	DESIRED TURBINE FLOW (CFS)	EXCESS TURBINE FLOW (CFS)	SPILL (CFS)	W.S. ELEVATION UPPER (FT)	W.S. ELEVATION LOWER (FT)	W.S. DRAWDOWN (FT)	HEAD (FT)	ENERGY PRODUCED (KW-HR)
1. 9	BROWNLEE	9900.	16052.	0.	0.	2064.96	1799.34	12.04	265.6	[illegible]
	OXBOW	16052.	16363.	0.	0.	1798.79	1694.29	6.21	114.5	145001.
	HELLS CANYON	16363.	15342.	0.	0.	1684.29	1471.65	3.71	212.6	243465.
	PUMP-STORAGE		0.			4300.00	1798.79	0.00	2501.2	701957.-TOT
1.10	BROWNLEE	9900.	21155.	0.	0.	2064.89	1800.68	12.11	264.2	419501.
	OXBOW	23934.	21466.	0.	0.	1798.98	1684.92	6.02	114.1	[illegible]
	HELLS CANYON	21466.	18404.	0.	0.	1684.39	1472.60	3.61	211.8	[illegible]
	PUMP-STORAGE		2779.			4299.62	1798.98	0.38	2501.2	895206.-TOT
1.11	BROWNLEE	9900.	23707.	0.	0.	2064.80	1801.36	12.20	263.4	[illegible]
	OXBOW	29265.	24018.	0.	0.	1799.39	1685.66	5.61	113.7	[illegible]
	HELLS CANYON	24018.	19935.	0.	0.	1684.53	1473.07	3.47	211.5	316100.
	PUMP-STORAGE		5558.			4298.86	1799.39	1.14	2500.6	990969.-TOT
1.12	BROWNLEE	9900.	23707.	0.	0.	2064.71	1801.36	12.29	263.4	469343.
	OXBOW	29267.	24018.	0.	0.	1799.79	1685.66	5.21	114.1	[illegible]
	HELLS CANYON	24018.	19935.	0.	0.	1684.68	1473.07	3.32	211.6	316312.
	PUMP-STORAGE		5560.			4298.09	1799.79	1.91	2499.5	991760.-TOT
1.13	BROWNLEE	9900.	23707.	0.	0.	2064.63	1801.36	12.38	263.3	469186.
	OXBOW	26982.	24018.	0.	0.	1800.02	1685.66	4.98	114.4	206519.
	HELLS CANYON	24018.	19935.	0.	0.	1684.82	1473.07	3.18	211.7	316523.
	PUMP-STORAGE		3275.			4297.63	1800.02	2.38	2498.3	992228.-TOT
1.14	BROWNLEE	9900.	23707.	0.	0.	2064.54	1801.36	12.46	263.2	469029.
	OXBOW	24697.	24018.	0.	0.	1800.08	1685.66	4.92	114.4	206614.
	HELLS CANYON	24018.	19935.	0.	0.	1684.96	1473.07	3.04	211.9	316734.
	PUMP-STORAGE		989.			4297.49	1800.08	2.51	2497.6	992378.-TOT
1.15	BROWNLEE	9900.	23707.	0.	0.	2064.45	1801.36	12.55	263.1	468872.
	OXBOW	24697.	24018.	0.	0.	1800.13	1685.66	4.87	114.5	[illegible]
	HELLS CANYON	24018.	19935.	0.	0.	1685.10	1473.07	2.90	212.0	316945.
	PUMP-STORAGE		989.			4297.35	1800.13	2.65	2497.4	992526.-TOT
1.16	BROWNLEE	9900.	23707.	0.	0.	2064.36	1801.36	12.64	263.0	468715.
	OXBOW	26985.	24018.	0.	0.	1800.36	1685.66	4.64	114.7	207123.
	HELLS CANYON	24018.	19935.	0.	0.	1685.24	1473.07	2.76	212.2	317156.
	PUMP-STORAGE		3278.			4296.89	1800.36	3.11	2497.2	992993.-TOT
1.17	BROWNLEE	9900.	23707.	0.	0.	2064.27	1801.36	12.73	262.9	468558.
	OXBOW	29274.	24018.	0.	0.	1800.76	1685.66	4.24	115.1	207855.
	HELLS CANYON	24018.	19935.	0.	0.	1685.38	1473.07	2.62	212.3	317366.
	PUMP-STORAGE		5567.			4296.09	1800.76	3.91	2496.5	993778.-TOT
1.18	BROWNLEE	9900.	23707.	0.	0.	2064.18	1801.36	12.82	262.8	[illegible]
	OXBOW	29276.	24018.	0.	0.	1801.17	1685.66	3.83	115.5	[illegible]
	HELLS CANYON	24018.	19935.	0.	0.	1685.52	1473.07	2.48	212.4	317576.
	PUMP-STORAGE		5560.			4295.29	1801.17	4.71	2495.3	994561.-TOT
1.19	BROWNLEE	9900.	22006.	0.	0.	2064.11	1801.36	12.89	262.7	434216.
	OXBOW	24701.	22317.	0.	0.	1801.36	1685.64	3.64	115.7	[illegible]
	HELLS CANYON	22317.	18915.	0.	0.	1685.64	1472.76	2.36	212.9	301673.
	PUMP-STORAGE		2785.			4294.89	1801.36	5.11	2494.1	929866.-TOT

Final runs will involve knowing the proper initial reservoir levels (8:00 Monday morning conditions). The easiest way to find these levels is to make a trial run with the levels set at their maximums (2077 for Brownlee, 1805 for Oxbow, 1688 for Hell's Canyon). A lot of water will spill or go undesired through the turbines during the week for this trial run. The reservoir levels at the last hour of the trial run are then the ones to use in the final runs. This is because the objective of the final run is to maximize the head without spilling or letting extra flow through the turbines. Because the preset patterns are water balances, using the above determined reservoir levels will just fill the reservoirs during the week, but not spill, thus maximizing the head.

ACTUAL INPUT USED IN CHAPTER 6

The first four of the five input cards are listed below for each final run of each test period.

Summer week

Base run	6100.
	2077. 1805. 1685.09
	100.100. 31.
	1
Barber Flat	6100.
	2077. 1799.041685.09
	100.100. 31.100.
	11000000.4300.1

Indian Creek	6100.	
	2077. 1805. 1682.38	
	100.100. 31.100.	
	21000000.4210.1	
North Pine F	6100.	
	2077. 1805. 1681.15	
	100.100. 31.100.	
	31000000.3442.0	

Winter week

Base run	9900.
	2065. 1805. 1684.25
	100.100. 60.
	1
Barber Flat	9900.
	2065. 1799.041684.25
	100.100. 60.100.
	11000000.4300.1
Indian Creek	9900.
	2065. 1805. 1681.52
	100.100. 60.100.
	21000000.4210.1
North Pine F	9900.
	2065. 1805. 1680.28
	100.100. 60.100.
	31000000.3442.0

Winter three-week

Base run	9900.	
	2065. 1805. 1684.25	
	100.100. 60.	
	1	
Barber Flat	9900.	
	2065. 1798.811684.25	
	100.100. 60.100.	
	11000000.4300.1	
Indian Creek	9900.	
	2065. 1805. 1681.39	
	100.100. 60.100.	
	21000000.4210.1	
North Pine F	9900.	
	2065. 1805. 1680.03	
	100.100. 60.100.	
	31000000.3442.0	