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GEOLOGICAL SURVEY

Appraisal of Waterpower Potential and Land Classifications, Clackamas River Basin, Oregon

By

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CONVERSION FACTORS

Factors for converting English units to metric units are shown below.

English unit to convert	Multiply by	Metric unit to obtain
inches (in)	2.540	centimeters (cm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
acres	0.004047	square kilometers (km^2)
square miles (mi^2)	2.590	square kilometers (km^2)
acre-feet (acre-ft)	1234.	cubic meters (m^3)
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)

ABBREVIATIONS USED FREQUENTLY IN THIS REPORT

MSL:	mean sea level (used on profiles)
COE:	U.S. Army Corps of Engineers
BPA:	Bonneville Power Administration
FPC.	Federal Power Commission (now called Federal Energy Regulatory Commission, FERC)
KGRA:	Known Geothermal Resources Area
MW:	megawatt
SCS:	Soil Conservation Service
USGS:	U.S. Geological Survey

Appraisal of Waterpower Potential and Land Classifications, Clackamas River Basin, Oregon

By W. H. Lee and L. O. Moe

ABSTRACT

This report attempts to fulfill the U. S. Geological Survey's (USGS) responsiblity to classify Federal lands as to waterpower and water storage value. The report reviews one USGS waterpower designation, three USGS powersite reserves, three Federal Power Commission (FPC) projects that are in the Clackamas River basin, and one USGS powersite reserve adjacent to the basin boundary on the west. The area classified and withdrawn, after eliminating overlapping, is 14,462 acres, of which 5,680 is in USGS classifications and 8,781 acres is in FPC withdrawals. Of the total area reviewed, 2,257 acres in USGS classifications and 1,560 acres in FPC withdrawals were found to have negligible value for water resource development and will be recommended for revocation.

The four developed hydroelectric plants in the basin, having a total installation of 142.9 megawatts (MW), are owned and operated by Portland General Electric Company.

Development of the seven multipurpose conventional sites discussed herein would ease the expected growing needs in the basin and the nearby area.

The nonuniform demand for electrical power could be supplied best by pumped-storage developments. Five potential sites with a combined peaking generating potential of 20,840 MW are within the area of this report.

Approximately 26,459 acres of public domain lands not previously classified for their water resource values lie within the seven conventional sites and the five pumped-storage sites. Classification of these lands is desirable, and this report will contribute toward making that decision.

The Clackamas River basin is found in three physiographic provinces: the High Cascade Range, the Western Cascade Range and the Willamette Valley. Each province is characterized by a different suite of rocks. Rocks of the High Cascade Range province include andesite, basalt, and some gabbro, all of Pliocene to Pleistocene age. Rocks of the Western Cascade Range province are tuffs and andesite flows of the Oligocene to Miocene Little Butte Volcanic Series, basalts of the Columbia River Basalt Group of Miocene age, and pyroxene andesites and tuffs of the Sardine Formation of Miocene to Pliocene age. The Willamette Valley province includes the following rocks: tuffaceous sedimentary deposits of the Miocene Rhododendron Formation; mudstone and siltstone of the Pliocene Sandy River Mudstone; sandstone and conglomerate of the Pliocene Troutdale Formation; bouldery cobble gravel and mudstone of the Pleistocene Springwater, Gresham, and Estacada Formations; terrace deposits and alluvium of Holocene age.

The proposed waterpower and pumped-storage sites discussed in this report are appropriate for development geologically with one exception. The exception is the Elk Lake pumped-storage site. The problems with this site include highly fractured bedrock in the upper pool area, landslides in the penstock area, and a thick cover of glacial and stream deposits in the lower pool area.

INTRODUCTION

One of the primary responsibilities of the U. S. Geological Survey (USGS) is to classify the Federal lands as to waterpower and water storage value. These classifications neither commit the Government to construction nor prohibit private use for water resource development; however, they do serve to identify, protect, and forestall encumbrances of potential sites. Classification as a potential water development site does not constitute a "withdrawal" or "reserve" in the usual sense of these terms -- the lands remain under the supervision of the agencies administering them. Noninjurious uses may be allowed under provisions of Section 24 of the Federal Power Act of June 10, 1920, upon approval of the Federal Power Commision (FPC, now known as Federal Energy Regulatory Commission, FERC).

This review was based on investigations of the status of planning for future water resource developments in the basin by all known interested parties and the examinations of the most current topographic maps, water supply records, water rights, and reconnaissance field studies. Decisions relating to USGS classifications are based on tract-by-tract evaluation. Recommendations relating to Federal power project withdrawals are based on an evaluation of the purpose of each filing action.

The main stem of the Clackamas River originates near the summit of Olallie Butte in the Cascade Range The river pursues a northwesterly direction for about 84 mi and enters the right bank of the Willamette River at river mile 24.8 just south of the city of Gladstone 9 mi south of Portland (fig. 1). The river drains an area of about 937 sq mi and progresses from a narrow steep valley in the headwaters to

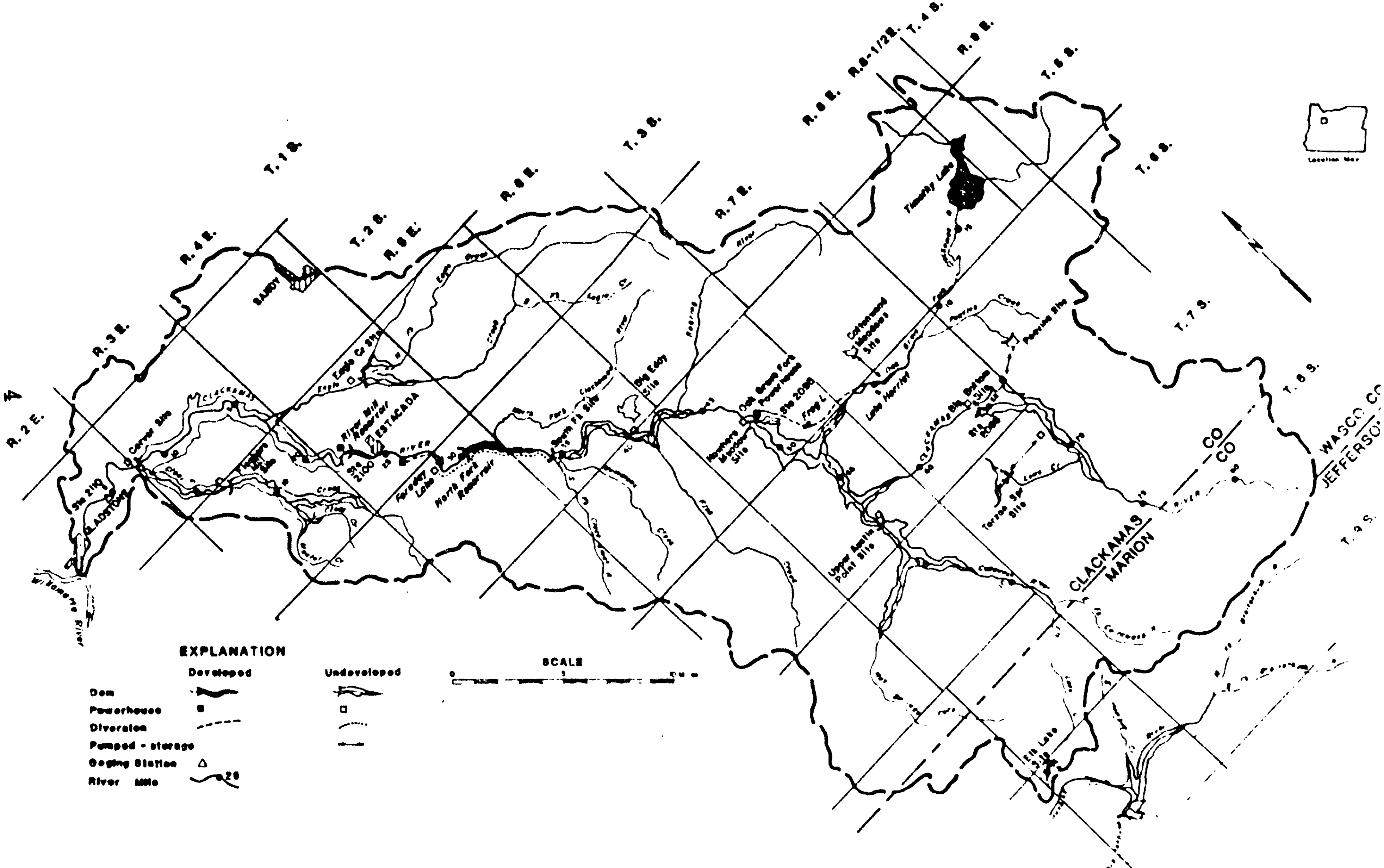

Figure I. -- Index map of developed and undeveloped sites, Clackamas River Basin broad flatlands near the confluence with the Willamette River. Oak Grove Fork and Collawash Rivers are two major tributaries heading slightly above 4,000 ft in the southeastern part of the basin on the west slope of the Cascade Range. Other tributaries originate below 4,000 ft in altitude. Most of these streams, including the main stem, flow in canyons 500 to 1,000 ft below the adjacent ridges for several miles in their headwaters or during their midcourses. Altitudes in the Clackamas River basin range from slightly more than 7,000 ft in the headwaters to 55 ft at the mouth. Olallie Butte is the highest point in the basin, with an altitude of 7,215 ft.

Most of the basin is covered with a dense evergreen forest of Douglas-fir, hemlock, and cedar. In the higher altitudes some virgin timber remains, but the forest in the lower parts of the basin is second growth or is industrial forest under intensive management. Most of the forest lands are in Federal ownership, a significant portion of which is in Mount Hood National Forest. The natural beauty of the basin, coupled with the closeness to the most populated city in the State, makes the area very popular with outdoor recreationists.

Estacada, population 1,550, is the only sizable community that is entirely within the study area. The towns of Sandy and Gladstone are on the drainage boundary line. A few other small farming settlements are scattered throughout the area below 1,000 ft in altitude. Timber and its related industries are the controlling economic factors of the basin. A great percentage of the residents are employed in manufacturing associated with the wood-utilization industry.

The basin is climatically typical of the northwest Pacific coast region west of the Cascade Range. Winters are mild and wet with considerable foggy weather, and summers are relatively dry. Very cold weather and hard rainstorms are rare, freezing temperatures are seldom observed in the lower lands, and the intensity of rainfall is usually light. The average annual precipitation is about 72 in. most of which occurs as rain at lower altitudes and snow on the higher levels. Temperature and precipitation vary greatly within the basin due to the wide difference in altitudes. Precipitation ranges from 45 in. near the mouth of the river to more than 100 in. on some mountain peaks.

Streamflow records indicate that the Clackamas River system has adequate water to meet present and foreseeable future needs. Streamflow is measured at stations maintained by the USGS. Five gaging stations were in operation in 1974 (U.S. Geological Survey, 1974, p.264-268). Station 14-2100, Clackamas River at Estacada, has the longest period of record (1908-74) and recorded an average discharge of 2,762 ft^3/s. The most downstream station is 14-2110, Clackamas River, with 12 years' average discharge of 3,849 ft^3/s (U. S. Geological Survey, 1974, p. 267 and 268).

Flooding occurs occasionally along the Clackamas River from Estacada to its mouth, especially during unusually heavy precipitation conditions. Some minor flood storage is provided by the two power-generating reservoirs, North Fork Reservoir and Timothy Lake.

As of January 1, 1974, the surface water rights in the Clackamas River basin totaled 9,823 ft^3/s (Oregon State Water Resources Board, 1974). About 95 percent, 9,302 ft^3/s, is for power. The Portland

General Electric Company has all the power rights, which are utilized in four power developments. The water used for power generation is considered to be nonconsumptive because it will become available for other uses at downstream locations.

The other major legal rights are municipal, 282 ft^3/s; fish life, 124 ft^3/s; and irrigation, 93 ft3/s. The rights for domestic, industrial, and wildlife total about 23 ft^3/s.

The Oregon State Legislature passed a bill, SB 956, establishing as a scenic waterway the stretch of Clackamas River from River Mill Dam downstream approximately 12 miles to the bridge at Carver. This legislative action would affect the sites within this stretch of the river discussed in this report, which identifies the potential sites. Although that portion of the river is classified as scenic waterway, the potential for waterpower development does exist.

The authors are grateful for assistance in the field by Frank W. Smith, Edward Mendez, and Jack Dugwyler.

DEVELOPED HYDROELECTRIC POWERPLANTS

While the area has tremendous value for watershed, recreation, fish and wildlife preservation and enhancement, it also has value for potential hydroelectric development.

The four existing hydroelectric developments in this basin are all owned and operated by Portland General Electric Company. These plants have a total installed capacity of 142.9 megawatts (MG) (Federal Power Commission, 1973a, p. 25). Power output from these plants is more than the total consumption in the basin; the plants produced 742 million kilowatt-hours, but consumption within the basin was about 234 million kilowatt-hours in the 12-month period through October 1970 (Federal Power Commission, 1973a, p. 22). The excess power is fed into the interconnection system to export to other parts of the region.

The four existing hydroelectric plants are under two FPC licenses. Three plants are licensed as parts of the North Fork Project (No. 2195) and the other as Oak Grove Project (No. 135). The four plants are grouped below according to their licences. Each plant is described in detail in the Federal Power Commission report (1973a).

Existing Hydroelectric Powerplants

Unit	Stream	Location sec.	Location T.	Location R.	Storage capacity (acre-ft)	Installed capacity (MW)
Oak Grove project, FPC license No. 135						
Timothy Meadow Storage	Oak Grove Fk.	27	5 S.	8 E.	65,800	0.025
Lake Harriet	Oak Grove Fk.	4	6 S.	7 E.	400	--
Frog Lake	offstream	35	5 S.	6 E.	400*	--
Oak Grove Powerhouse	Clackamas	21	5 S.	6 E.	--	51
North Fork project, FPC license No 2195						
North Fork	Clackamas	11	4 S.	4 E.	5,994*	38.4
Faraday Diversion Dam	Clackamas	3	4 S.	4 E.	--	--
Faraday Lake	offstream	33	3 S.	4 E.	550*	--
Faraday Powerhouse	Clackamas	33	3 S.	4 E.	--	34.4
River Mill	Clackamas	20	3 S.	4 E.	12,200	19.0

*Usable

POTENTIAL CONVENTIONAL HYDROELECTRIC SITES

The basin now consumes less electricity than it produces, and the excess power is exported. However, because of the expected economic and population growth within the basin and the nearby area, predictions are that the demand for electrical power will almost double every 10 years (Bonneville Power Administration, 1970, p. 6). Studies also indicate the need for flood storage, water-related recreation facilities, and future water supply.

The Clackamas River satisfies three basic factors that govern hydroelectric developments: (1) adequate volume of water available; (2) sufficient fall through which this water can be utilized; and (3) suitable market for the power when developed. A large number of potential sites in the basin have been selected and studied by various levels of government agencies and private parties. However, only a few of these sites would actually be developed, because of the need to reconcile hydroelectric development and other potential uses of the basin resources.

This report discusses only the seven sites that appear to have the most probable chance for future development (figs. 1 and 2). The maximum amount of power that could be produced from these sites is 278 MW. With the exception of the lands that were previously classified by the USGS and the FPC project withdrawals, there is a total of 15,600 acres of public lands that would be affected if all these sites were developed.

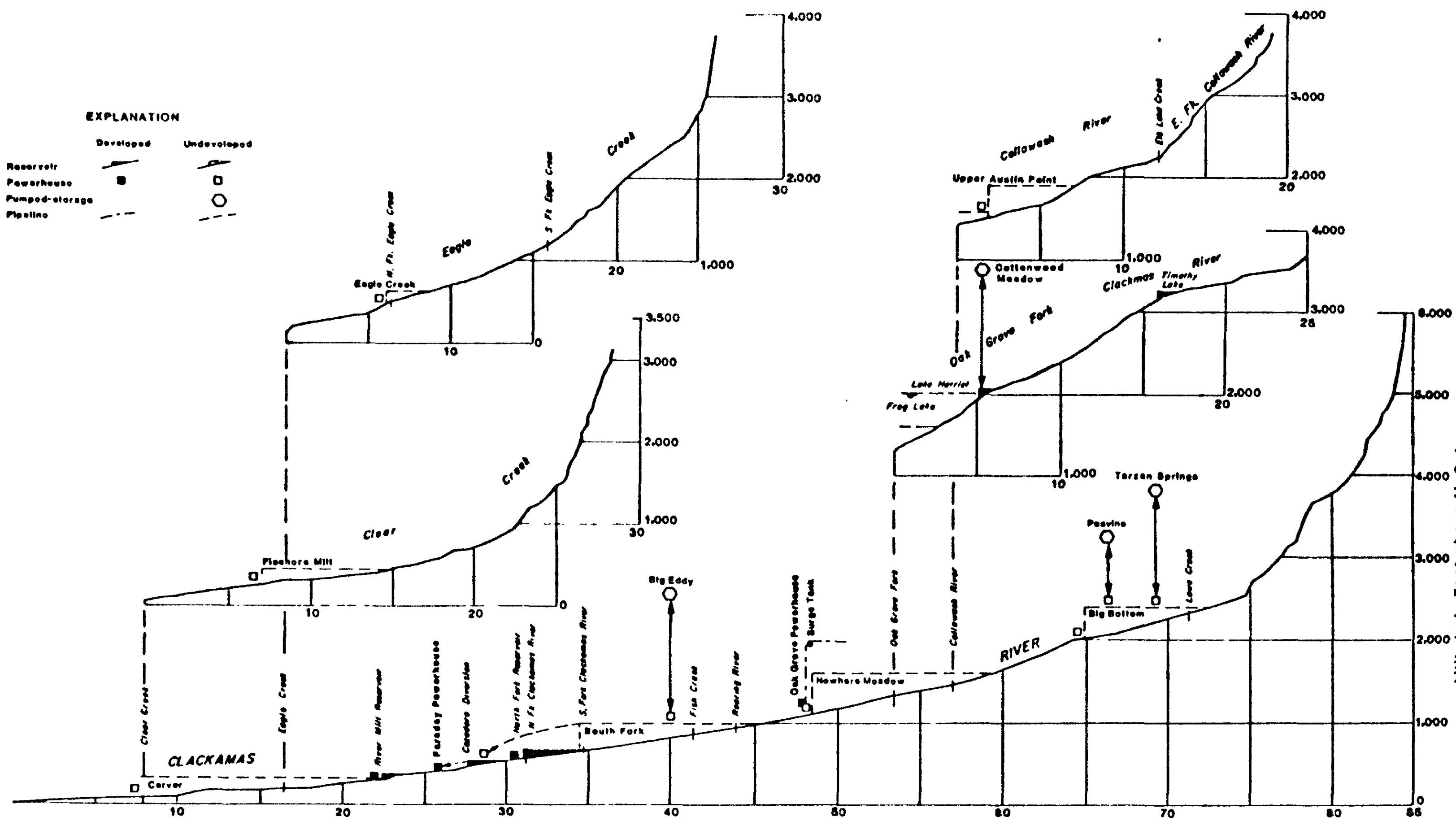

Figure 2.--Stream profile, Clackamas River Basin

BIG BOTTOM DAM AND RESERVOIR SITE

Power Potential

The Big Bottom site (fig. 1) is located on the Clackamas River in sec. 26, T. 6 S., R. 7 E., near river mile 65. A 355-foot-high and 1,400-foot-long dam would back water upstream about 7.5 mi and store 480,700 acre-ft of water between altitudes 2,045 and 2,400 ft. The development would provide storage for flood control, power, recreation, and water supply. Data from a discontinued USGS gaging station, 14-2080, about 0.25 mi upstream from the damsite, show that the average flow for the period from 1920 to 1970 was 477 ft^3/s. This flow and the gross head of 355 ft could produce 14.4 MW of gross theoretical power at 100-percent efficiency. The storage releases from this site not only would benefit the downstream hydroelectric developments, but also would improve the water quality and quantity downstream.

The Willamette Basin Comprehensive Study (Pacific Northwest River Basins Commission, 1969, Appendix J) suggested a 250-foot-high dam, from altitudes 2,045 to 2,295 ft at the same location for flood control and power. The total storage capacity provided by the lower dam would be 230,000 acre-ft. The gross theoretical power that could be produced from the lower head amounts to about 10 MW, with the average flow as stated.

A major physical impact of this project would be the flooding of the valley upstream from the dam. This flooding would destroy some excellent fish-spawning gravel beds, timber lands and consequently, some wildlife habitat. The area of the lands inundated would depend upon height of the dam to be built. A 355-foot-high dam would flood 2,950 acres. However, a 250-foot-high dam would flood only 1,900 acres.

Public Land Status

On July 15, 1921, the FPC withdrew about 2,040 acres of public land for FPC Project 234. On August 30, 1925, the project permit expired, but these lands remain withdrawn. Those lands of the expired permit are within this potential site area and should be retained for possible development of the Big Bottom site in the future. In addition to the stated FPC withdrawal, about 2,680 acres of public land, some unsurveyed, would be affected if this site were developed.

General Geology

The area of the proposed dam and the area of both reservoirs is covered by the USGS 15-minute High Rock and Breitenbush Hot Springs quadrangle maps at a scale of 1:62,500 and a contour interval of 80 ft. The dam and reservoir sites are accessible by a paved road along the Clackamas River.

The area of the Big Bottom dam and reservoir site has been mapped in part by Barnes and Butler (1930) and Peck and other (1964) (fig. 3). The boundaries of both geologic maps occur in the middle of the proposed reservoir site and leave part of the reservoir area unmapped. Available mapping shows the presence of the volcanic rocks of the High Cascades. Field investigations for this report have shown that the same rocks exist in the unmapped part of the reservoir area.

The Pliocene to Pleistocene volcanic rocks of the High Cascades are generally characterized by andesitic and basaltic lava flows with minor amounts of volcanic breccia and other pyroclastic rocks. These rocks are relatively undeformed and unaltered; only tilting and displacement are evident (Peck and others, 1964, p. 36). The most common rock type that occurs in the volcanic rocks of the High Cascades is a medium-gray porphyritic andesite lava (Barnes and Butler, 1930, p. 85-86). Aphyric olivine and olivine basalt are also quite common. The phenocrysts within the porphyritic andesites are either white feldspars, olivine, hornblende, or pyroxene.

Evidence of major faulting or folding in the area of the proposed reservoir has been found. However, a few minor faults with displacements of only a few feet were seen in the field investigation for this report. None of the observed faults should present much of a problem to development.

Geology of the Damsite

Current plans call for the construction of a dam either 250 ft or 355 ft high in the SW$\frac{1}{4}$ sec. 26, T. 6 S., R. 7 E. The dam will be founded on a hornblende andesite lava flow. This flow unit is porphyritic to aphanitic and fine-grained. The andesite seen in the right abutment area is nonporphyritic and appears to be incipiently fractured. It is difficult to determine the character of the fracturing because the steep hillside and most of the roadcut exposures are covered with thick soil and very heavy vegetation.

The left abutment is in the same rock unit as the right abutment but the rock at the left abutment is more porphyritic with phenocrysts of hornblende and occasional biotite as much as 2 mm across. The rock is better exposed here than at the right abutment. A joint pattern that breaks the andesite into subangular blocks is present. A thick soil profile has developed, allowing a heavy cover of vegetation. The jointing or fracturing of this rock seems minor in terms of strength characteristics, especially if bedrock will be shaped for the dam. Removal of the fractured and broken surface material should completely mitigate any problems.

Geology of the Reservoir Area

The proposed reservoir area for the Big Bottom damsite extends upstream from the dam in sec. 26 to either river mile 70 or river mile 73, depending upon how high the dam is built. The entire area of the proposed maximum reservoir lies in volcanic rocks of the High Cascades. These rocks are predominantly andesite and basalt flows but also include minor amounts of tuffs, agglomerates, and other pyroclastics. The portion of the valley that will contain most of the reservoir is a broad alluviated flat called Big Bottom. The Clackamas River at this point shows signs of reaching geomorphic maturity, with stretches exhibiting a braided stream pattern.

Inspection of outcrops near the upper reaches of the proposed reservoir near river mile 72 shows that this portion of the reservoir will be in basalt or basaltic andesite lava flows. This rock, fine-grained, aphanitic, and unweathered, is also highly fractured with two dominant joint sets at N. 55°E., dipping 82°S. and N. 40°E., dipping 85°S. Locally a thin, platy cleavage occurs.

Near river mile 68, a long, almost continuous, section of rock is exposed in the roadcut. Several types of rocks are exposed, along with three small faults. Aphanitic, porphyritic pyroxene andesite predominates; but light gray air-fall tuff exists in channels within the andesite. At least two andesite flows are present, separated by a baked, altered zone that may have been a paleosol (fig. 4). The lower flow rests unconformably on an agglomerate or debris flow. A series of springs issues from the contacts between the flows and air-fall tuff and the flows and agglomerate. Also visible is a tuffaceous siltstone unit of undeterminable stratigraphic relationship. It is blocky, fissile, and bedded. This rock has a very fine, homogeneous grain size.

The rock below the alluvium of Big Bottom and extending up to the area of the damsite is dark- to medium-gray andesite. This andesite is very fine-grained aphanitic with scattered quartz-lined vesicles. The unit is massive but with a joint trend N. 30° W., dipping 35° E. The andesite is very slightly magnetic in places. A few accumulations of hornblende phenocrysts occur but are not characteristic of this unit.

Construction Materials

Construction materials necessary for the building of a dam are readily available in the immediate vicinity. Riprap and concrete aggregate materials are available in many places in the proposed reservoir area. Quarries in the andesite lava flows could easily provide all of this kind of material needed. Pervious fill material can be screened and washed from the alluvium of Big Bottom. Impervious fill material can be derived from the thick soils in the area.

Figure 4.--Two andesite flows seperated by a baked (red) paleosol, Big Bottom reservoir site.

Conclusions and Recommendations

This brief reconnaissance disclosed no major geologic problems that would preclude the development of this site. However, further detailed geologic and geophysical examinations and studies would be necessary to confirm the suitability of the site. These studies should include physical property measurements on both foundation rocks and construction material, rock strength measurements, geophysical surveys to determine bedrock characteristics, and a drilling and (or) trenching program to gather samples for testing and to augment the surface geologic mapping.

UPPER AUSTIN POINT DAM AND RESERVOIR SITE

Power Potential

The upper Austin Point damsite (fig. 1) is 1.9 mi upstream from the mouth of the Collawash River. A dam, 405 ft high between altitudes 1,500 and 1,905 ft and 990 ft long across the Collawash River in sec. 27, T. 6 S., R. 6 E., would create a reservoir with a total storage capacity of 204,000 acre-ft. This site, with gross head and an estimated average flow of 540 ft^3/s (Lystrom, 1970, p. 11-15) could produce 18.6 MW of power at 100-percent efficiency. As studied by the U.S. Army Corps of Engineers (COE), this site would also provide flood storage and water supply for anticipated needs. The releases from this project also would benefit the existing hydroelectric plants and the future developments downstream on the Clackamas River. The dam would improve the water quality and quantity downstream during times of low-flow period and irrigation needs.

Public Land Status

Secs. 24, 25, and 36 of this township are classified as Carey Hot Springs Known Geothermal Resources Area (KGRA). Geothermal resources development in this area could utilize the water from the reservoir.

Development of this site would affect 3,598 acres of National forest lands by inundating valuable game-fish spawning beds and some wildlife habitat.

General Geology

The area of the proposed dam and reservoir site is within the USGS 15-minute Fish Creek Mountain and Battle Ax quadrangle maps at a scale of 1:62,500 and a contour interval of 80 ft. The damsite and reservoir areas are accessible by paved roads up the Collawash River and the Hot Springs Fork.

The geology of the proposed Upper Austin Point damsite and reservoir has been mapped in a reconnaissance manner by Barnes and Butler (1930), Callaghan and Buddington (1938), and Peck and others (1964) (fig. 5). The volcanic rocks of this area were originally named the Cascades Formation (Williams, 1916) and have been referred to as Cascade Formation, Cascade Andesite, and Cascade Volcanic Series by various authors (Beaulieu and others, 1974). Barnes and Butler (1930, p. 85-86) mapped the rocks of the area as the Cascade Andesite, a medium-gray porphyritic andesite. Callaghan and Buddington (1938, p. 11-12) mapped them as andesitic lavas and volcanic breccias of the Western Cascade volcanic rocks. This unit was characterized by light-gray, porphyritic calcic andesite. Peck and others (1964, p. 25) surveyed the older reports, and together with their own field mapping included these andesites in the vicinity of Austin Point as part of the lower sequence of the Little Butte Volcanic Series of Oligocene to early Miocene age. This was done because andesites located around Austin Point are petrographically similar to andesites occurring elsewhere in the lower part of the Little Butte Volcanic Series. No structures (faults, folds, etc.) except the Clackamas anticline (fig. 5) have been mapped in the area of this damsite and reservoir and none was observed during the fieldwork for this report. In the Collawash River and Clackamas River valleys, the andesite lava flows and andesitic ash-flow tuffs are as much as 1,500 ft thick (Peck and others, 1964, p. 15). These rocks have phenocrysts of pyroxene and hornblende.

Geology of the Damsite

The proposed Upper Austin Point dam is to be about 405 ft high and 990 ft long. The right abutment will be founded on the steep cliff of Austin Point proper, and the left abutment will be founded on the equally steep cliffs directly west of Austin Point and across the Collawash River (fig. 6). The andesite lava flows occur at both abutments and underlie the river for a considerable distance upstream and downstream. The flows are medium to dark gray, very hard, dense and aphanitic with an occasional phenocryst of hornblende. The rocks have a faint greenish tinge suggesting incipient chloritization. There are two joint sets (N. 76° E., 85° S.; N. 40° W., vertical), that give the flows an appearance of columnar jointing.

Figure 6.--Andesite lava exposed in left abutment, Upper Austin Point damsite (view upstream).

There are veins and fracture fillings of a pale-yellow to white zeolite mineral that X-ray determinations have identified as stilbite. Stilbite exists as vein fillings as much as 3/4 inch in thickness and as coatings on andesite fragments.

There are no cavities in the rock in which crystals can form, other than areas in the veins and fractures. Therefore, the bulk of the stilbite displays a flattened, radiating crystal habit rather than the customary bundle or tabular forms.

Flow banding and foliation are rare and chaotic. This condition could be due to the proximity of the andesite source. According to Barnes and Butler (1930, p. 90), the rocks in this area display evidence that Austin Point was a vent source for the Cascade Andesite (fig. 5).

Geology of the Reservoir Area

The proposed reservoir consists of two branches, the Collawash River and the Hot Springs Fork. The geology of the reservoir area is better exposed along the Hot Springs Fork. The rocks seen in outcrop in the reservoir area fit those that Peck and others (1964, p. 15) described for the lower sequence in the Little Butte Volcanic Series. Andesite flows, basaltic andesite flows, ash-flow tuffs, and volcanic agglomerates characterize the reservoir rocks.

An outcrop of indurated volcanic agglomerate occurs on the Hot Springs Fork near the confluence of the two rivers. This unit is very hard and consists of pieces of several different rocks types, principally basalt and andesite. This unit has an overall reddish color even though the lithic fragments have several colors. A very dark gray olivine andesite or basaltic andesite overlies the agglomerate unit. This flow unit is massive and displays two joint sets, N. 24° W., 73° W., and N. 34° E., 25° E. The agglomerate-andesite contact dips about 45° toward the river. There are areas of the andesite unit in which amorphous silica has filled available vesicles and otherwise locally silicified the rock.

All along the upper reaches of the Hot Springs Fork branch of the proposed reservoir are outcrops of altered and weathered ash-flow tuffs that range from competent to friable and incompetent. These tuffs have lithic fragments of pumiceous altered glass with lesser amounts of andesitic and basaltic lapilli. The tuffs also have phenocrysts of plagioclase and clear quartz.

A small landslide is located in the S½ sec. 7, T. 7 S., R. 6 E., just east of Pin Creek. This slide has moved downslope onto the roadway, which requires periodic clearing. In a wetted reservoir condition, this slide, as well as other areas, could become even more unstable and produce turbidity conditions in the reservoir, or, if movement were large and sudden, cause surge waves against the dam.

Because of the heavy vegetation, very few outcrops were seen along the Collawash River branch of the proposed reservoir. A quarry is located in the NE¼ sec. 10, T. 7 S., R. 6 E. This quarry was opened up in an andesite flow. In the vicinity of the quarry, several different andesite flows crop out. The exact relationships between these flows cannot be ascertained, owing to the poor exposure and thick cover. However, they are all medium-gray hornblende andesite. A prominent joint set is oriented N. 20° W., 80° W.

Construction Materials

Construction materials for an earthfill or concrete dam are readily available at many sites in the vicinity of Upper Austin Point. Any of the andesite flow units could furnish riprap and large and small crushed aggregate. Pervious material could be screened from stream alluvium and gravel deposits, and impervious fill material can be obtained from the soils in the reservoir area. Haulage costs would be minimal.

Conclusions and Recommendations

This brief reconnaissance disclosed no major geologic problems that would preclude the development of this site. However, further detailed geologic and geophysical examinations and studies would be necessary to confirm the suitability of the site. These studies should include physical property measurements on both foundation rocks and construction material, rock strength measurements, geophysical surveys to determine bedrock characteristics, and a drilling and (or) trenching program to gather samples for testing and to augment the surface geologic mapping.

NOWHERE MEADOW DAM AND RESERVOIR SITE

Power Potential

Nowhere Meadow site (fig. 1) has been studied for power purposes by various parties, government and private, and numerous plans have been considered. The various plans differ mainly in the height of the dam, but the locations of all the damsites are within half a stream mile on the Clackamas River.

One plan suggests a 240-ft-high dam in sec. 21, T. 5 S., R. 6 E., at river mile 48. This dam would create a capacity reservoir of 62,000 acre-ft. USGS gaging station, Clackamas River above Three Lynx Creek (14-2095), at the damsite, has a 55-year average discharge of 1,989 ft^3/s. This discharge and the gross head could produce 41 MW of power at 100-percent efficiency.

Another plan suggests building a dam at the same location, between altitudes 1,085 and 1,445 ft to store 191,000 acre-ft and to increase the gross head to 360 ft. The gross head and the average flow could produce 61 MW of theoretical power.

The damsite proposed under these two plans is about 1/4 mile upstream from the Oak Grove powerhouse. About 2-4 mi of highway would need relocation, depending upon the height of the dam that might be built.

Another plan being studied suggests building a dam about 500 ft upstream from the Oak Grove powerhouse. This site has been included in the basin summary of total potential power. A dam between altitudes 1,110 and 1,600 ft would develop a reservoir with a total storage capacity of 612,000 acre-ft and a surface area of 4,240 acres. The gross head of 490 ft and an estimated average flow of 1,500 ft^3/s would produce gross theoretical power of 62 MW. The dam would back water to the Upper Austin Point site on the Collawash River, and into the KGRA in secs. 24 and 25, T. 6 S., R. 6 E., adjacent to the Clackamas River. The possible geothermal development in the future in this area could obtain its water needs from this reservoir. This site, if developed, would inundate a sawmill and about 11 mi of medium-duty highway and some unpaved road.

Public Land Status

No land has been classified by the USGS in the damsite and the reservoir area. However, a total of 200 acres of Federal land withdrawn under FPC Project 135 would be affected if this site is developed. An additional 6,562 acres of National forest lands also would be required.

General Geology

The area of the proposed dam and reservoir is shown on the USGS 15-minute Fish Creek Mountain quadrangle map at a scale of 1:62,500 and a contour interval of 80 ft. Access to the dam and reservoir site is by a paved road along the Clackamas River and by numerous Forest Service logging roads.

The proposed Nowhere Meadow dam and reservoir will be located in lava flows and pyroclastic rocks of the Oligocene to Miocene Little Butte Volcanic Series. This particular area has been mapped in a reconnaissance manner by Peck and others (1964) and in part by Barnes and Butler (1930) (fig. 7). Basalt flows belonging to the Miocene Columbia River Basalt Group form the ridgetops and high ground around the area of the dam and reservoir site. The contact between the underlying Little Butte Volcanic Series and the Columbia River Basalt Group will be very near the top of the proposed dam, depending on the final design. Barnes and Butler (1930, p. 101-107) discussed the area of the reservoir in some detail in what they call the "Bull Creek sediments" problem. Their beds of Bull Creek are now considered to be part of the Little Butte Volcanic Series (Peck and others, 1964, p. 11). A broad structural fold, called the Clackamas anticline, has been mapped as passing through the proposed reservoir area (Peck and others, 1964, p. 42 and plate 1). This fold axis trends north-north east, and erosion of the crest of the anticline has exposed the upper units of the Little Butte Volcanic Series.

Geology of the Damsite

There are several alternate plans for the development of the Nowhere Meadow site and the exact location and height of the dam. For the purposes of this report, a site 500 ft upstream from the Oak Grove powerhouse was chosen. At this location, the abutments would be located against a steep hillside developed in a basaltic agglomerate. This agglomerate is indurated and contains well-cemented rounded clasts of vesicular basalt, aphanitic basalt, and reddish scoriaceous basalt (fig. 8).

The right, or east, abutment will be founded on a large, conical hill composed of the same agglomerate as seen in the left abutment (fig. 9) and capped by an outlier of the Columbia River Basalt Group. The basalt-agglomerate contact is very near the top of the dam and the proposed pool edge. The contact is unconformable. The basalt capping this hill is highly fractured, vesicular, and aphanitic. It is hard, dense, and dark-gray to black, and contains scattered olivine phenocrysts. The fracturing breaks the rock into fragments that are no larger than 12 in. The rock is difficult to break to a fresh surface due to its hardness and weathering along the extensive fracturing. The fractured basalt should present no construction problems because it will probably be above water level. The surge tank for the Oak Grove

Figure 8.--Agglomerate (above) - basalt (below) contact, Nowhere Meadow damsite.

Figure 9.--Left abutment area, Nowhere Meadow damsite (view downstream.

powerhouse is located atop this hill, with penstock running downhill to the powerhouse. Water is piped into the tank from Lake Harriet on the Oak Grove Fork of the Clackamas River.

Geology of the Reservoir Area

A dam constructed at the above-mentioned location and with a water level of about 1600 ft above mean sea level would back up a reservoir to the foot of the proposed Upper Austin Point dam on the Collawash River in sec. 27, T. 6 S., R. 6 E., and to the confluence of the Clackamas River and Switch Creek in sec. 25, T. 6 S., R. 6 E. The entire reservoir area is underlain by either alluvium or rock belonging to the Little Butte Volcanic Series (Peck and others, 1964, pl. 1). Barnes and Butler (1930, p. 101-107) discussed in great detail the volcaniclastic sediments north of the confluence of the Clackamas River and the Oak Grove Fork, which they called the beds of Bull Creek.

The basaltic agglomerate located at the abutment area of the proposed dam and discussed above extends upstream more than 1.2 mi. In fact, basaltic agglomerate very similar to the abutment rocks is found in many locations throughout the proposed reservoir area. In the vicinity of Alder Flat and Nowhere Meadow, Barnes and Butler (1930, p. 103) measured a section consisting of 103 ft of volcaniclastic sediments (beds of Bull Creek). These sediments consist of tuffaceous shale, tuffaceous sandstone, and reworked ashfall tuff.

A small landslide area is in the center of sec. 15, T. 6 S., R. 6 E., east of the river. The rock surrounding the landslide area is a severely weathered, extremely porphyritic andesite lava flow. The andesite has also been chloritized and is, in general, incompetent.

About 1,300 ft south of the landslide area, the andesite exhibits two color phases. In the gray phase, hornblende phenocrysts are weathered to hematite. In the reddish phase, the whole rock has been stained with hematite. The alteration seems to occur in blotches. Two sets of strong joints are also in this rock, N. 15° W., 85° W.; and N 57° W., 65° SW. These joints dip toward the river and downslope, thereby creating a potential landslide hazard.

On the Collawash River, upstream from the confluence with the Clackamas River, the rock is a highly fractured, intensely weathered andesite flow of medium gray color. Below this lava flow, the rock is an altered, weathered ash-flow tuff with a reddish baked zone at the contact. Farther upstream toward the location of the proposed Upper Austin Point damsite, the andesite becomes fresher in appearance and much more competent.

Upstream on the Clackamas River branch of the proposed reservoir, a very large exposure of volcanic breccia or agglomerate occurs overlain by a massive light-colored lava flow identified as a dacite. The dacite lava flow forms poorly developed columnar jointing.

The active Switch Creek landslide discussed by Beaulieu (1976, p. 68) (fig. 10) is located just upstream from the end of the reservoir area on the Clackamas River at the confluence with Switch Creek. Although not located where downslope movement would enter directly into the proposed reservoir, the landslide has the potential to block or partially obstruct the flow of the Clackamas River and also to threaten downstream water quality. With the proximity of the reservoir, future water saturation of the associated rocks could cause further weakening

Figure 10.--Main scarp and head of the Switch Creek landslide (view northwest).

and enlargement of the slide area.

Construction materials

Construction materials necessary for dam construction are available in the vicinity of the site. Riprap, crushed rock, and concrete aggregate can be obtained from any of the fresh, unaltered basalt or andesite lava flows in the area. Pervious fill and concrete aggregate can be screened and washed from alluvium along the Clackamas River in the reservoir area. Impervious fill material can be obtained from the soils in the reservoir area, but since the thicknesses of the soil profiles are unknown, the quantity of this material is unknown.

Conclusions and Recommendations

No major geologic conditions exist that would preclude the construction of a dam and the formation of a reservoir. However, the presence of active landslides such as the Switch Creek slide and soft, unconsolidated tuffaceous sediments may present problems such as siltation, water surges, and bank failure. Proper engineering techniques can be applied to mitigate these potential problems. Further detailed geologic investigations are needed before the construction phase. Physical property measurements of foundation rocks and all construction materials, rock strength measurements, geophysical surveys to determine bedrock characteristics, and a drilling and (or) trenching program are all needed as part of the geotechnical examination of this site.

SOUTH FORK DAM AND RESERVOIR SITE

Power Potential

The South Fork site (fig. 1), sometimes called the Cliff site, was considered by the COE for power and flood control purposes. The damsite is in sec. 29, T. 4 S., R. 5 E., on the Clackamas River at river mile 34.5. A 1,200-ft-long dam raising water from a streambed altitude of 635 to 995 ft would store 125,000 acre-ft. A gross head of 400 ft could be developed by conveying water downstream about 5 mi to a powerhouse that would be located in sec. 3, T. 4 S., R. 4 E., just upstream from Faraday Lake formed by the existing Cazadero division dam. The COE study indicated that with the reservoir storage and releases from Timothy Lake, plus possible future projects upstream from this site, 108 MW of hydroelectric power could be developed.

The storage releases from this site would benefit the existing Faraday and River Mill plants and any future projects downstream. The steep canyon walls that surrounds the reservoir area would limit the recreational value of the site.

Public Land Status

Within the project area, 480 acres of Federal lands have been classified by the USGS in Power Site Reserves 661 and 730. These lands, including those open to entry subject to the provisions of Section 24 of the Federal Power Act, should remain in the present status to protect the site for possible future development. An additional 2,681 acres of National forest lands in the damsite and reservoir area would be affected if this site is developed.

General Geology

The reservoir formed by this dam will be approximately 10 mi long and, because of the narrow canyon, will be confined to the Clackamas River valley with short arms extending up Fish Creek and South Fork. The area of the proposed dam and reservoir site is shown on the USGS 15-minute Fish Creek Mountain quadrangle map at a scale of 1:62,500 and a contour interval of 80 ft. The area of the dam and reservoir site is accessible by an all-weather, paved highway along the Clackamas River.

This area has been mapped in a reconnaissance manner by Peck and others (1964) (fig. 11). The South Fork dam and reservoir site will be developed and constructed within rocks belonging to the Columbia River Basalt Group. This unit is characterized by thick columnar-jointed, dense, fine-grained basalt flows. Just upstream from the proposed damsite, nine individual basalt flows are exposed at the face of Big Cliff (fig. 12). Overlying the basalts in this area is the Sardine Formation which is, in turn, overlain by andesite lava flows belonging to the volcanic rocks of the High Cascades.

The Columbia River Basalt Group in the area of Big Cliff is exposed as a series of flows that are 25 to 75 ft thick, and each flow contains one to three columnar joint sets. According to Peck and others (1964, p. 28), the basalt contains rare phenocrysts of feldspar, pyroxene, and olivine in a matrix of very small, randomly oriented plagioclase feldspar laths in a dusty glass matrix. The randomly oriented matrix components make the rock very hard and durable, and it breaks with a hackly fracture.

Figure 12.--Individual basalt flows exposed in the face of Big Cliff (view north).

The overlying Sardine Formation of middle Miocene to early Pliocene age is characterized by thin hypersthene andesite flows. The distal edges of the flows are exposed in the area of the proposed South Fork dam and reservoir site. The Sardine Formation has been deposited conformably over a surface of the Columbia River Basalt Group that apparently was of low relief.

Overlying the Sardine Formation on the north side of the proposed reservoir area is an elongated exposure of the volcanic rocks of the High Cascades (Peck and others, 1964, p. 36). Here it appears to be a channel-filling flow of andesitic to basaltic lava that, due to its relative resistance to erosion, forms the ridgetop. This unit has been dated as Pliocene to Pleistocene. The topographic surface developed on it is quite uniformly flat and tilted toward the west, probably representing an initial dip away from the source area.

Geology of the Damsite

The damsite will be located in rocks belonging to the Columbia River Basalt Group. At the proposed location of the right abutment, a thick cover of colluvium obscures the foundation rock. However, just upstream at Big Cliff, an excellent exposure of the rock is available in a sheer cliff. Nine individual basalt flows displaying one to three heating and cooling phases are each exposed, with minor ash interbeds also present. The rock exposed is quite hard and very competent. Fractures and joints are relatively minor. Most of the flows show columnar jointing at some stage of development.

The left abutment area has a thinner colluvial cover than the right abutment area, and at least three individual basalt flows are exposed.

The left abutment area has a thinner colluvial cover than the right abutment area, and at least three individual basalt flows are exposed. The left abutment area was inaccessible, but apparently the rocks are similar to those exposed in Big Cliff.

The valley floor at the site of the proposed dam is probably covered with no more than 20 ft of alluvium beneath the river. A slightly thicker sequence of alluvium exists at the river banks. Once this alluvium has been removed, very little bedrock shaping should be necessary.

Geology of the Reservoir Area

The entire reservoir will be developed within rocks of the Columbia River Basalt Group. There is a well-developed, narrow fluvial terrace present along this stretch of the Clackamas River. The canyon walls are steep and show few, isolated exposures of basalt. The reservoir, as proposed, will be only about 0.6 mi wide and extend approximately 10 mi.

A basalt quarry has been opened to furnish crushed rock and road metal near the confluence of Fish Creek and the Clackamas River in sec. 1, T. 5 S., R. 6 E. (fig. 13). The basalt exposed in both of these quarries is columnar-jointed, fine-grained and dense. Vesicles are present near the top of the columns in each of the four flows exposed. The rock is broken in large blocks by the quarry operation.

Other exposures of basalt show pillow structures indicating that at least a few of the flows were deposited in a water environment. These pillow basalts possibly are located near the bottom of the Columbia River Basalt Group. Palagonite is present around most of the

Figure 13.--Basalt quarry near confluence of Fish Creek and Clackamas River (view north).

pillow structures. A few of the pillows have vesicles that are partially filled with chloritic clay minerals. The overall appearance of the rock indicates a slight degree of chloritization. This alteration process has not noticeably affected the strength of the basalt. The rock is quite hard, dense, and fine-grained, and breaks with a subconchoidal fracture. There are a few prominent joint sets observable in outcrops, and they all trend northwest and dip to the south.

Construction Materials

Most of the necessary construction materials needed for dam construction are available nearby. Riprap, crushed rock, and concrete aggregate can be obtained from the existing quarries in the reservoir area mentioned earlier and from any flows along the proposed reservoir area. Pervious fill and concrete aggregate can be screened and washed from alluvium along the Clackamas River in the reservoir area. Impervious fill material is not readily available in large enough quantities for construction of an earthfilled dam. This material would have to be transported from downstream area, possibly the Willamette Valley.

Conclusions and Recommendations

No major geologic conditions exist that would preclude the construction of a dam and the formation of a reservoir. However, the steep canyon walls of the reservoir area represent potential landslide and rockfall hazards. The thin soil cover could easily slide when water saturated, thereby causing siltation, water surges, and bank failure. Proper engineering techniques can be applied to mitigate these potential problems.

Further detailed geologic investigations are needed before the design and construction phases. Physical property measurements of foundation rocks and all construction materials, rock strength measurements, geophysical surveys to determine bedrock characteristics, and a drilling and (or) trenching program are needed as part of the geotechnical examination of this site.

EAGLE CREEK DAM AND RESERVOIR SITE

Power potential

Eagle Creek damsite is located on Eagle Creek, about 6 mi upstream from the mouth, in sec. 10, T. 3 S., R. 4 E. Eagle Creek enters the Clackamas River near river mile 17. This site was considered by the COE and the USGS for power and flood control. Other functions such as water quality improvement, recreation, and water supply could be formulated into the plan when the need occurs and the plan comes under active consideration.

A dam 1,000 ft long, raising water from a streambed altitude of 480 ft to 640 ft, would store 22,000 acre-ft of water. The 79 sq mi of drainage area and the average annual precipitation of 75 in. could yield an estimated mean annual flow of 305 ft^3/s (Lystrom, 1970, p. 11-15). This flow and a gross head of 160 ft could produce 4.1 MW of power at 100-percent efficiency.

Eagle Creek enters the Clackamas River downstream from all the existing hydroelectric plants. However, it is upstream from the potential Carver site and its development would benefit the Carver site.

The existing State policy that requires different flows on Eagle

Creek above the mouth at various times of the year could dictate the development possibilities of this site.

Public Land Status

A total of 560 acres has been classified in the reservoir area in Power Site Reserve 661 since December 12, 1917. These lands should be retained in the present status to protect the value of the site. Aside from the private lands within the potential project boundary, an additional 39 acres of Oregon and California revested public land would be affected if this site is developed.

General Geology

A dam of this size will form a reservoir that will extend about 3 mi upstream on Eagle Creek and 2.1 mi upstream on the North Fork of Eagle Creek. The area of the proposed dam and reservoir is shown on the USGS 7½-minute Estacada quadrangle map at a scale of 1:24,000 and a contour interval of 10 ft. The dam and reservoir site is accessible by paved and unpaved roads thoughout the area.

The area of the proposed dam and reservoir was mapped by Trimble (1963) (fig. 14). The oldest unit exposed in the vicinity of the proposed Eagle Creek dam and reservoir is the Rhododendron Formation of late Miocene age. This unit in the Eagle Creek area is characterized by volcanic mudflow breccias, containing noncarbonized wood fragments. The top of the Rhododendron Formation has been deeply weathered and laterized with a laterite crust 8 to 10 ft thick (Trimble, 1963, p. 24).

Overlying the Rhododendron Formation is the Sandy River Mudstone of early Pliocene age. This unit is characterized by mudstone, siltstone, claystone, and sandstone. According to Trimble (1963, p 28), it is a lacustrine deposit as evidenced by the well-sorted, even beds, the fine grain size, the lack of marine fossils, and the presence of leaf fossils. The lacustrine sediments may represent a filling of a closed basin prior to development of a drainage outlet (Trimble 1963, p. 28).

In the area of the proposed dam and reservoir site, the Troutdale Formation of early Pliocene age conformably overlies the Sandy River Mudstone. This unit contains beds of conglomerate and sandstone. The conglomerate is a stratified quartzite pebble deposit (Trimble, 1963, p. 31). The sandstone contains abundant basaltic glass (sideromelane) fragments. Both the conglomerate and sandstone are commonly well-indurated with a clay mineral cement.

The Boring Lava of Pliocene to Pleistocene age overlies the Troutdale Formation in the Eagle Creek area. This lava is predominantly a light-gray to black olivine basalt. The unit is chiefly lava but locally contains tuff breccia, ash, tuff, cinders and scoriaceous phases (Trimble, 1963, p. 38-39). The Boring Lava just north of Eagle Creek represents a tongue of a flow that probably came from Lenhart Butte, a source area about 4 mi to the east (Trimble, 1963, p. 37). The top of this unit is deeply weathered.

The Springwater Formation of Pleistocene age is found overlying the Troutdale Formation south of the proposed dam and reservoir site and overlying the Sandy River Mudstone and Boring Lava north of the proposed site. This unit is characterized by alluvial gravels and mudflow deposits. The alluvial gravels are predominantly cobble gravel and bouldery cobble gravel of fluvial origins. Weathering of this unit has been severe and clay soil layers as much as 20 ft thick, locally, have been formed (Trimble, 1963, p. 48).

The youngest formation exposed in the vicinity of the proposed dam and reservoir site is the Estacada Formation of late (?) Pleistocene age. This unit is characterized by alluvial cobble gravels and small mudflow deposits and, in this area, is limited to the bottom of the Eagle Creek valley downstream from the damsite. This unit forms terraces along existing drainages and is distinguished from other alluvial gravel formations by intervening soil layers and stratigraphic position (Trimble, 1963, p. 58).

Geology of the Damsite

The proposed dam abutments will be in the E½ sec. 10, T. 3 S., R. 4 E. The abutments will be founded in rocks belonging to the Rhododendron Formation with the contact of the overlying Sandy River Mudstone very near the top of the right abutment.

The Rhododendron Formation in the vicinity of the abutments is a soft, pink to tan, unconsolidated accumulation of pyroclastic debris. There are angular to rounded lithic fragments of many different types of volcanics, mainly andesite. The formation is deeply weathered and incompetent at the surface. Even the lithic fragments are soft. The weathering of this unit may have produced a lateritic soil, but the mineralogy has not been determined.

There are local joint sets that appear to extend to a great depth. These joints dip toward the valley bottom, thereby causing a very great potential for landsliding of the soft, incompetent rock.

This same unit is exposed in the floor of the Eagle Creek valley but is indurated at the point where the creek traverses the falls. The rock is still a pyroclastic debris flow as it is at the abutment areas but the creek has removed the incompetent weathered material and exposes the more competent fresh rock. Excavation of the abutment areas down past the weathered zone would mitigate the potential geologic hazard of foundation leakage and failure, judged from the competency of the rock exposed in the creek bed.

The contact between the weathered pyroclastic debris of the Rhododendron Formation and the overlying Sandy River Mudstone is located near the top of the right abutment. The thick colluvial cover obscures the contact at the site, but, according to Trimble (1963, p. 28), the Sandy River Mudstone is disconformable on the Rhododendron Formation. The unit is susceptible to landsliding, adding to the potential geologic hazard at the damsite.

Geology of the Reservoir Area

A dam 160 ft high constructed at the aforementioned location would back up a reservoir that would extend into secs. 12 and 13, T. 3 S., R. 4 E. along the North Fork of Eagle Creek and into sec. 24 along Eagle Creek proper. Such a reservoir would be contained by rocks of the Rhododendron Formation.

The Rhododendron Formation in the reservoir area is chiefly mudflows and laterized agglomerate with minor andesite lava flows. Near the confluence of the North Fork of Eagle Creek and Eagle Creek proper a road cuts into an indurated, light-gray agglomerate and associated mudstone. The agglomerate has volcanic lithic fragments up to 2 in. in size. There is also a prominent joint system trending N. 44° W., dipping 87° S. at this location. This joint system dipping into the reservoir area may present a slope stability problem.

A dark-gray andesite lava flow is exposed near the upstream ends of the proposed reservoir on the North Fork of Eagle Creek. This rock is vesicular to porphyritic, with vesicles filled with earthy limonitic material and the pyroxene and plagioclase phenocrysts altered to clay or sericite. This unit is locally heavily indurated.

In the SE$\frac{1}{4}$ sec. 14, T. 3 S., R. 4 E., extensive laterization has taken place on an agglomerate bedrock. This unit is quite soft and punky and is susceptible to stability problems. The laterite zone is probably about 6.6 ft thick. This material may not be a laterite but a saprolite, depending upon the chemistry of the material. Both laterite and saprolite behave similarly in terms of poor drainage and poor slope stability.

Construction Materials

Just north of the proposed damsite lies a large mapped area of Boring Lava (fig. 14). This rock is an olivine basalt that has desirable qualities as a construction material. Quarries opened in this unit could provide sufficient amounts of riprap and crushed rock aggregate for dam construction. Pervious fill material may be derived from screening stream alluvium or breaking down the conglomeratic deposits of the nearby Troutdale and Springwater Formations. Impervious fill material possibly could be obtained from the thick saprolite and laterite deposits within the reservoir area. All construction materials needed for an earthfill type dam are located within short distances of the proposed damsite.

Conclusions and Recommendations

Because of the thick sequences of saprolites and laterites, slope instabilities and bank failures in the reservoir area are very likely. Wetting of a full-reservoir situation would greatly increase the potential instability. Bank failure would produce turbid conditions in the reservoir and could create large surges that could break a dam. The joints of rock units dipping into the reservoir would increase this problem.

The deeply weathered rock at the abutments would have to be removed down to competent bedrock. The material at the surface is certainly unsuitable for founding dam abutments.

A detailed drilling and (or) trenching program should be initiated in the dam site area to determine how much weathered material would have to be removed. Detailed geologic mapping of the reservoir area is needed to determine areas of unstable slope conditions. Once identified, these problem areas could be excavated to mitigate the hazard. Physical property determinations need to be made on all proposed construction materials to ascertain their suitabilities. Geophysical surveys could possibly aid in exploring for competent bedrock in both the dam area and the reservoir area.

FISCHERS MILL DAM AND RESERVOIR SITE

Power Potential

Clear Creek enters the Clackamas River on the left (south) bank at river mile 8 just upstream from the Carver site. The Fischers Mill site, sometimes called the Clear Creek site, is located on Clear Creek, about 7 mi upstream from the mouth, in sec. 4, T. 3 S., R. 3 E. The COE and the Soil Conservation Service (SCS) considered a dam 135 ft high and 500 ft long which would create a pool to an altitude of 395 ft containing 60,000 acre-ft of water. The reservoir would provide adequate storage to control a 100-year flood. This project could also be used for water supply, water quality improvement, and recreation.

The USGS studied a higher dam at the same location to develop 190 ft of head for power purposes. A dam 3,400 ft long between altitudes 260 and 450 ft would store 189,000 acre-ft of water. The gross head and an estimated average flow of 147 ft^3/s (Lystrom, 1970, p. 11-15) could produce 2.4 MW of power. The reservoir would have ample storage for municipal water supply, recreation, and flood control.

Here, too, the existing State policy could dictate the development possibilities of this site.

Either plan would inundate two small communities, Cedarhurst Park and Viola, a mill, and some homes scattered throughout the reservoir site. There are no public lands in the site area.

The geology of the Fischers Mill site was not examined.

CARVER DAM AND RESERVOIR SITE

Power Potential

The Carver site (fig. 1) is the farthest downstream on the Clackamas River. Because of the location, the development of this site would not benefit any existing or potential sites in the basin; however, through flow regulation provided by the dam, it would improve the water quality and quantity downstream during low flow periods. The dam would be located in sec. 18, T. 2 S., R. 3 E., at river mile 8 just upstream from the town of Carver. There are two alternative plans of development: one for a dam up to an altitude of 200 ft and the other for a dam to an altitude of 320 ft.

Under one plan, a dam 2,000 ft long and 120 ft high, between altitudes 80 and 200 ft, would create a reservoir with a surface area of 3,200 acres and a total storage capacity of 129,000 acre-ft. The reservoir would provide flood storage, power, recreation, water supply, and irrigation. An estimated 3,360 ft^3/s average flow from the drainage area of 906 sq mi through a gross head of 120 ft could produce 34.3 MW of power at 100-percent efficiency. The reservoir would flood about 4 mi of State Highway 211 and the residences below the flow line. A total of 14 acres of land in the reservoir area have been classified in Power Site Reserves 661 and 730. All the remaining lands in the site are patented.

Under the other plan that was studied, a higher dam across the river at the same location was suggested. A dam 240 ft high, between the altitudes of 80 and 320 ft, and 2,500 ft long would back water up to River Mill dam and up Clear Creek to Fischers Mill site. Total storage capacity of the reservoir would be 916,000 acre-ft. This also would be a multipurpose development. Obviously, the power from this higher dam would be 68.6 MW because the gross head is twice that of the low dam. The reservoir would flood about 7 mi of State Highway 211, the homes below the altitude of 320 ft, and the small community of Paradise Park. An additional 80 acres of land classified in Power

Site Reserve 661 lie in the larger reservoir area. The remaining lands are in private ownership.

The total of 94 acres in outstanding classifications, including those open to entry subject to the provision of Section 24 of the Federal Power Act, should be retained for protection of the two alternative sites.

The 1975 Oregon State Legislature Bill, SB 956, limits the development possibilities of this site.

General Geology

The area of the proposed dam and reservoir site is shown on the USGS 7½-minute Redland and Damascus quadrangle maps at a scale of 1:24,000 and a contour interval of 10 ft. Access to the dam and reservoir site is by paved highway Oregon 224 and by numerous public and private roads.

The area of the proposed Carver dam and reservoir site has been mapped in detail by Trimble (1963) (fig. 15). The oldest unit exposed in the vicinity of the proposed dam and reservoir site is the lower Pliocene Sandy River Mudstone. In this area, this unit crops out in a narrow band bordering both the Clackamas River and Clear Creek. The mudstone, siltstone, claystone, and sandstone of the Sandy River Mudstone are thought to be of lacustine origin because of the bedding, the high degree of sorting fine grain size, the lack of marine fossils, and the presence of fossil leaves (Trimble, 1963, p. 26, 28).

The Troutdale Formation overlies the Sandy River Mudstone in this area. The age of this unit is early Pliocene, based upon flora from the top of the underlying Sandy River. The principal lithologies of this formation are vitric sandstones and quartz-bearing conglomerates, but there are minor amounts of siltstone, claystone, and cobbly sandstone (Trimble, 1963, p. 32). This formation is usually well indurated and forms cliffs and scarps. The origin of the Troutdale Formation is probably fluvial as indicated by a coarse grain size and lenticular bedding (Trimble, 1963, p. 35).

A late Tertiary and early Quaternary volcanic vent just north of the proposed Carver damsite provided local accumulations of tuff breccia, ash, tuff, and basaltic lava known collectively as the Boring Lava (Trimble, 1963, p. 38-39). This vent was only one of many that provided material for this unit; however, the vent near Carver apparently was the only one displaying an explosive character. The basalt is light gray with olivine phenocrysts. According to Trimble (1963, p. 42), the Boring Lava from the Carver vent flowed into a Clackamas valley cut deeper than the late Pleistocene floor, thereby indicating the late Pliocene to late Pleistocene age of that rock unit.

The Pleistocene Springwater Formation is not found in the reservoir area but is found around the perimeter on the highlands. This formation is chiefly alluvial gravels and mudflow deposits and is of fluvial origin (Trimble, 1963, p. 46, 47).

Gravel and mudflow deposits forming remnants of older Clackamas terraces are called the Gresham Formation. South of the proposed reservoir site, this formation formed a Pleistocene flood plain (Trimble, 1963, p. 53). This unit is characterized by cobble gravels and bouldery cobble gravels with an occasional mudflow deposit.

Another group of gravels and mudflow deposits in the area of the proposed dam and reservoir site is the Estacada Formation of late Pleistocene age. This unit occurs on terraces that are lower than the previous terraces and is characterized by the presence of very fine sand and silt, along with the cobble gravels (Trimble, 1963, p. 58). Figure 16 (modified from Trimble, 1963, fig. 15) shows the general stratigraphic relationship between the Springwater, Troutdale, Gresham, and Estacada Formations.

Holocene terrace and landslide deposits and alluvium are the youngest mapping units in the vicinity of the proposed Carver dam and reservoir site.

Geology of the Damsite

The rock at road level at the right abutment site is tuffaceous sediment and pyroclastic debris belonging to the vent sequence of the Boring Lava. This rock is fairly competent, forming a steep cliff. Lithic fragments are predominantly scoriaceous basalt and scattered pumice fragments. The abutment area is almost obscured by heavy vegetation. Boring Lava caps the hill that forms the right abutment.

Boring Lava also caps the hill forming the left abutment. The lithology of the rocks of the left abutment is probably the same as in the right abutment, but exposures and access are poor. Scoriaceous lava and stratified tuffs are exposed near the present terrace level in both abutment areas.

The Sandy River Mudstone is present in the abutment area. At

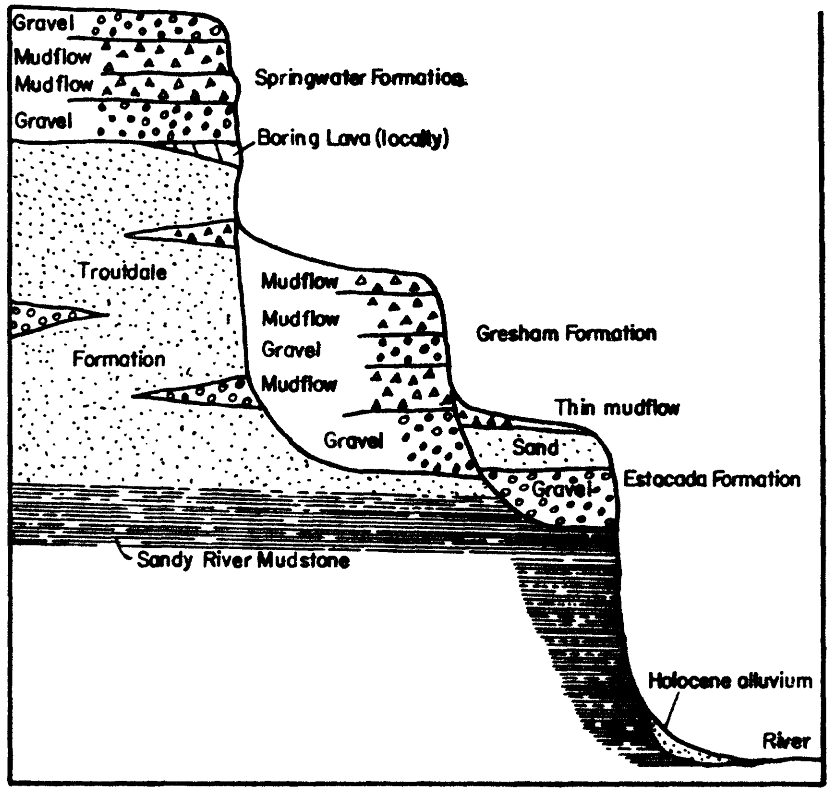

Figure 16.--Generalized section showing formational and terrace relationships (modified from Trimble, 1963, fig. 15).

this location it is chiefly composed of mudstone with some coarser material. Extensive slumping indicates that this unit is not very competent. Alluvium in the river bed is of an unknown thickness but probably not greater than 26 ft.

Geology of the Reservoir Area

The mapping units found in the proposed reservoir area have been subjected to extensive periods of weathering before burial. Trimble (1963, pg. 48, 55, 58) pointed out that the Springwater Formation has a maximum of 75 ft of saprolite and red soil developed at the top of the unit; the Gresham Formation has as much as 35 ft of saprolite and decomposed rock at its upper contact and the Estacada Formation has 10 ft of weathered rock at its upper contact. In general, these extensive weathered zones are unstable and susceptible to slumping and landsliding, especially when wetted by a reservoir.

Exposures in the reservoir area are quite poor, because of heavy vegetation cover and extensive agricultural activities. Access to most of the reservoir area is hampered by the large number of private roads and farms. Most of the outcrops examined were in roadcuts and stream bottoms. The extensive terrace and alluvial deposits are well exposed in the Clackamas River channel. These deposits are chiefly bouldery cobble gravels with occasional lenses of silt and sand. According to Trimble (1963, p. 72), the terrace deposits in the area of the proposed reservoir are less than 30 ft thick and are locally as thin as 6 to 8 ft. There has been no apparent folding or faulting of the rocks in the reservoir area.

Construction Materials

Construction materials of all types are located within short distances of the proposed Carver dam and reservoir site. Quarries already exist in the Boring Lava north of the damsite. An enlargement of the existing quarries could easily furnish all the riprap and coarse aggregate needed. Pervious fill material and concrete aggregate can be easily obtained from screening the Holocene terrace deposits and alluvium. Impervious fill material can be obtained from the extensive weathering profiles developed on the Springwater and Gresham Formations.

Conclusions and Recommendations

Most of the rocks that will contain the proposed reservoir are severely weathered. Because of this thick weathering profile and the relatively low level of induration, bank failure, slumping, and landslides are very real hazards to site development, especially under wetted reservoir conditions. Bank failure could cause turbid conditions in the reservoir and surges that could break the dam.

Extensive excavation at the damsite would be necessary to remove unstable material down to competent bedrock. Bedrock shaping would probably be necessary.

A detailed drilling and (or) trenching program should be initiated in the damsite area to determine the characteristics and suitability of the bedrock for the dam construction and also to determine how much weathered material would have to be removed. Detailed geologic mapping of the reservoir area is needed to determine areas of unstable slope conditions. Once identified, these problem areas could be excavated to mitigate the hazard. Physical property determinations need to be made on all proposed construction materials to ascertain their suitabilities. Geophysical surveys could possibly aid in exploring for competent bedrock in both the dam area and the reservoir area.

POTENTIAL PUMPED-STORAGE SITES

The demand for electrical power is by no means uniform. Pumped-storage generation is one of the most promising sources to meet this nonuniform demand, although the energy consumed by pumping is about one and one-half times the amount generated. Low-cost, off-peak energy is stored by pumping water from the lower reservoir to the upper reservoir. The water then is released through the turbines to generate power during peak-load periods when the power has greater economic value.

The operation and selection of sites have been studied by several Federal groups, particulary the COE and the FPC. The basic criteria for selection and operation of a pumped-storage site for this report are: (1) the site should be capable of at least 1,000 MW development; (2) the reservoir must have sufficient capacity to generate continuously for 14 hours at full capacity; (3) for plant size greater than 3,000 MW, the maximum allowable drawdown would be limited to 160 ft; (4) penstock diameter would range from 20 to 40 with maximum flow velocities of 16 to 20 ft per second; and (5) penstock length between upper and lower reservoirs should be not more than 15 times the head (U.S. Army Corps of Engineers, 1972, p. 14-19; Federal Power Commission, 1973b, p. 108).

This part of the report considers those sites that have a reasonable chance for future development. The technical and economical aspects of pumped storage will not be discussed, but the public lands involved, classified or otherwise, are shown here.

Ten potential pumped-storage sites in the Clackamas River basin were identified by the Willamette Basin Comprehensive Study and the U.S. Army Corps of Engineers (1972) report. Only five sites are discussed herein, and all but the Elk Lake site could utilize as lower reservoirs either the potential sites or the developed sites already discussed in this report. The Elk Lake site is included because it has a large storage capacity and is capable of generating up to 7,000 MW of power.

The following assumptions have been made relative to the pumped-storage sites. All sites operate on a weekly cycle with off-peak and weekend pumping sufficient to provide for short daily peaking operations; penstocks are underground; and off-peak pumping energy is available. Some of the data presented herein in the discussion of each site are slightly adjusted from the original sources by the authors for consistency of presentation.

TARZAN SPRINGS PUMPED-STORAGE SITE

Power Potential

The Tarzan Springs site, studied by the COE, is in the Mount Hood National Forest. The upper reservoir (fig. 1) would be on Lowe Creek, a tributary to the Clackamas River. A 320-ft dam across the creek about 3.7 mi upstream from the mouth, between the altitudes of

3,760 and 4,080 ft, in sec. 10, T. 7 S., R. 7 E., would develop a reservoir with 300 acres of surface area and a total capacity of 38,800 acre-ft.

A usable storage of 32,800 acre-ft and an average head of 1,475 ft could produce 3,500 MW of peaking power at 100-percent efficiency. Two 14,000-ft-long, 32-ft-diameter penstocks would be needed to discharge the storage and to remain within the velocity limitation of 18 ft^3/s. The lower reservoir would be on the Clackamas River. A 200-ft-high dam at river mile 70.1 in unsurveyed sec. 13, T. 7 S., R. 7 E., could store 62,600 acre-ft. Refilling the upper reservoir would require a 60-ft drawdown on this pool.

An alternative for the lower reservoir would be to use the Big Bottom site. In that event, only about 12,000 ft of penstock would be needed. The average head would be increased to 1,600 ft. This head and the usable storage in the upper reservoir could produce 3,800 MW of power at 100-percent efficiency. A 13-ft drawdown of the Big Bottom reservoir would be required to refill the upper pool.

Public Land Status

The USGS has not classified any lands in the area for water resource values. If this site is developed using the dam located at river mile 70.1, a total of 2,680 acres of unsurveyed National forest land in the two reservoirs and the penstock route area would be affected. However, if the Big Bottom site were used as the lower reservoir only 1,040 acres of unsurveyed land would be needed for the upper reservoir and the penstock route in addition to the lands required in the Big Bottom site.

General Geology

The area is shown on the USGS Breitenbush Hot Springs 15-minute quadrangle map at a scale of 1:62,500 with an 80-ft contour interval. Peck and others (1964) mapped the rocks in the vicinity of the proposed Tarzan Springs pumped-storage site as belonging to the Pliocene to Pleistocene volcanic rocks of the High Cascades (fig. 2). Barnes and Butler (1930) terminated their mapping just north of this site but indicated that the rocks are in the Cascade Formation, an earlier name for the High Cascade volcanic rocks. This mapping unit generally consists of basaltic andesite, olivine basalt, and pyroxene andesite flows with minor amounts of pyroclastic rocks. The flows are usually sparsely porphyritic with phenocrysts of altered olivine (Peck and others, 1964, p. 37).

Because of the few large, continuous outcrops and the dense vegetation coverage, the determination of existing structure in the area of the proposed pumped-storage site is very difficult. In the outcrops examined during the reconnaissance for this report, no evidence was found for any type of deformation of the rocks. Barnes and Butler (1930, p. 94-96) cited many places along the Clackamas River that have the High Cascade volcanic rocks exhibiting a smooth flow surface dipping gently to the west. Peck and others (1964) showed on their map that the volcanic rocks of the High Cascades mask the structure in the underlying rocks, and that no faults or fold axes were mapped in the unit.

Geology of the Upper Pool

The upper pool of the proposed Tarzan Springs pumped-storage site is located on Lowe Creek at an altitude of 4,080 ft (fig. 17). The entire area of the upper pool has been mapped as the volcanic rocks of the High Cascades by Peck and others (1964). Here these rocks are either medium-gray, aphanitic andesites, or extremely altered, soft, porphyritic andesite.

The location marked as a gravel pit at the end of the road is actually a quarry opened up in a fine-grained, aphanitic andesite. This rock has an occasional large (5mm) phenocryst of olivine that stands out against the light- to medium-gray matrix. The rock is hard and breaks with a conchoidal to subconchoidal fracture. It displays rounded or spheroidal weathering surfaces.

Elsewhere around the perimeter of the upper pool are outcrops of altered, whitish porphyritic andesite. Within the road cut below the dam for the upper pool are totally incompetent rock outcrops, apparently baked beyond recognition by overlying andesite flows. Originally, the rock was probably an andesite flow or ash-flow tuff. Relatively hard knots or lumps of rock occur within this unit.

The upper pool area is itself covered by an unknown thickness of alluvium with andesite float. The hill that separates the dam across Lowe Creek and the dike across the road is made of a sequence of andesite flows. They are hard, fine grained, nonporphyritic, and competent.

The occurrence of springs (Tarzan Springs and Saddle Springs) and the presence of the altered andesitic rocks are reason to be

Figure 17.--General view of the site of the upper pool, Tarzan Springs pumped-storage site (view south).

suspicious of the ability to contain a reservoir at this location. It is not known at this time what controls the location of the springs (faults ?) therefore, future investigations should be made.

Geology of the Penstock Area

The proposed plan for construction of the penstock calls for mining underground of the two 32-ft pipes from the upper pool to either of two locations along the Clackamas River. The first location for the lower part of the penstocks would be in a reservoir behind a dam at river mile 70.1. The penstock route would then roughly parallel the course of Low Creek. The second location for the penstocks would utilize the Big Bottom reservoir and would be located at about river mile 69. In both locations, rocks encountered during mining would probably be the same.

The penstocks would be mined through a sequence of competent andesite flows and altered, incompetent andesite flows and andesitic ash-flow tuffs. The competent andesite flows are medium-gray and fine-grained. The altered, incompetent flows are mainly light-colored, soft, with relict porphyritic minerals and feldspar grains altered to clay minerals. The altered ashflow tuffs are distinguished by included rock fragments, yellowish to reddish color, and spheroidal weathering habit.

Geology of the Lower Pool

The lower pool of the proposed Tarzan Springs pumped-storage site will be either the Big Bottom reservoir or a small reservoir with a dam on the Clackamas River at about river mile 70. For either location, the geology of the lower pool was discussed earlier in this report under the geology of the Big Bottom Reservoir. The only detail not covered earlier concerns the rock at the river mile 70 that might be used as abutments for a dam. This rock is fresh, unweathered, unaltered, medium-gray, massive porphyritic andesite.

Construction Materials

Construction materials are readily available in the vicinity of the proposed pumped-storage site. In the area of the upper pool, concrete aggregate and riprap can be crushed out of the existing "gravel quarry." Impervious fill is available from the abundant soil cover in the upper pool. Pervious fill material and gravel for aggregate use can be screened from the stream alluvium. Material derived from the mining of the penstocks may also prove to be useful in dam construction. If a dam is to be built at Clackamas River mile 70.1, andesite flows in the vicinity can be used for aggregate and riprap, and stream alluvium and soil for pervious and impervious fill.

Conclusions and Recommendations

The presence of springs in the area of the upper pool should be cause for further detailed investigations into the ability of the rock and overburden to contain water. Also of some concern is the narrow ridge or nose that will form the right abutment. Positioning the dam too high on this narrow ridge may lead to containment and construction problems. Further work in the upper pool area should include detailed geologic mapping to locate faults and other zones of weakness, geophysical surveys to determine bedrock characteristics, and physical property measurements of abutments, reservoir rock, and construction materials. Core drilling should be conducted in the area of the penstock to determine better the sequence of rock, the mining characteristics, and potential problems.

If another dam separate from the dam containing the proposed Big Bottom reservoir is to be constructed to form the lower pool of this proposed pumped-storage site, then further work similar to that outlined for the upper pool area will be needed to establish construction characteristics and outline potential problem areas.

PEAVINE PUMPED-STORAGE SITE

Power Potential

The Peavine site was studied by the COE. A dam 4,500-ft-long across an unnamed tributary to Peavine Creek and a 4,000-ft long dike could create a reservoir of 53,000 acre-ft storage capacity between altitudes 3,175 and 3,450 ft. This upper reservoir site, in an unsurveyed township, is crossed by a Bonneville Power Administration transmission line. A protraction of the land net indicates that the reservoir would be within secs. 19 and 20, T. 6 S., R. 8 E. A usable storage of 49,000 acre-ft and an average head of 1,240 ft could produce 4,440 MW of peaking power at 100-percent efficiency. Two penstocks, each 39 ft in diameter and 10,500 ft long, would be needed to remain within the velocity limitation of 18 ft/s (U.S. Army Corps of Engineers, 1972, p. 14-19).

The lower reservoir would be located at the Big Bottom site. The COE considered a 130-ft-high dam, between altitudes 2,045 and 2,175 ft to develop a reservoir of 60,000 acre-ft storage capacity. An 85-ft drawdown on this pool would be required to refill the upper reservoir. However, if the Big bottom site is built up to an altitude of 2,400 ft as proposed previously, the drawdown would amount to only 25 ft. The length of the penstocks would be about 8,500 ft, but only 980 ft of average head could be developed. The peaking power at 100-percent efficiency would be about 3,500 MW.

Public land Status

In addition to the lands that would be affected by the Big Bottom site, a total of 1,080 acres of unsurveyed National forest land would be affected by the upper reservoir and the penstock route.

Both the potential Tarzan Springs site and the Peavine site could utilize the Big Bottom site as the lower reservoir. All the data for the two sites as discussed are computed on the assumption that only one of the upper sites would be developed.

General Geology

The area of the proposed pumped-storage site is shown on the USGS 15-minute High Rock quadrangle map at a scale of 1:62,500 and a contour interval of 80 ft. Access to the site is by unimproved Forest Service logging roads.

The proposed site of the Peavine pumped-storage facility is unmapped geologically. The site lies just outside the boundaries of the geologic mapping by Barnes and Butler (1930) and Peck and others (1964). However, from their mapping certain inferences can be made concerning the general geologic conditions at this site. The rocks of this site belong to the Pliocene to Pleistocene volcanic rocks of the High Cascades (fig. 3). There are no faults or fold axes that can be projected into this area and, indeed, no tectonic features were found on the reconnaissance made for this report. The volcanic rocks of the High Cascades are characterized by sequences of basaltic andesite and olivine basalt flows, pyroclastic rocks, pyroxene andesites, and less abundant dacite flows. For the most part, these rocks are undeformed. The flows of andesite and basalt in this unit are usually aphyric; however, there are scattered occurrences of porphyritic rock with phenocrysts of plagioclase. The volcanic rocks of the High Cascades usually have a diktytaxitic texture; that is, an open network of feldspar laths enclosing abundant minute angular pores (Peck and others, 1964, p. 37).

Geology of the Upper Pool

The upper pool of the Peavine pumped-storage site will be located on an unnamed tributary to Peavine Creek, which is, in turn, a tributary to the Oak Grove Fork of the Clackamas River. In addition to a dam across this unnamed creek, a 4,000-ft dike will be required along the south edge of the pool.

The entire upper pool area is covered by alluvium and colluvium (fig. 18). There are no outcrops visible anywhere below the proposed waterline even though the area has been clearcut. Float boulders in the alluvial deposits indicate that the bedrock is probably andesite. The alluvial detritus consists of, in addition to andesitic float, small cobbles, sand, and silt. There was no clay seen in the upper pool area.

Figure 18.--Upper pool area of Peavine pumped-storage site.

There is one outcrop of rock along the logging road just east of the upper pool area and slightly above the proposed waterline. This rock is a hard, tough competent andesite, medium-grained and light to medium-gray. This rock contains scattered 1-2 mm phenocrysts of plagioclase and hornblende. With the presence of this outcrop and the andesitic float in the pool area, the inference can be made that this type of rock floors the upper pool area. If so, there should be no containment problems.

Geology of the Penstock Area

Development of the Peavine site as a pumped-storage facility calls for underground mining of the two 39-ft penstocks. The rocks to be encountered in the mining process belong to the volcanic rocks of the High Cascades. Outcrops near the penstock route indicate that the bulk of the rock to be mined will probably be a medium-gray, aphanitic, hard andesitic lava flow. For the most part, this rock displays a platy fracture habit that, if it extends to depth, could present hazardous mining conditions. The attitude of the fractures at the surface ranges from N. 35°E., 18°S. to N. 46°E., 11°W. Where the outcrops of this andesite are more massive and less fractured, spheroidal weathering is present.

Geology of the Lower Pool

The lower pool of the Peavine pumped-storage site will be the proposed Big Bottom reservoir. The geology of the proposed lower pool of the Peavine site was discussed earlier in this report under the section on geology of the proposed Big Bottom reservoir.

Construction Materials

Material for riprap, pervious fill, and concrete aggregate are in short supply in the immediate vicinity of the upper pool. There are no extensive exposures of rocks suitable for riprap and pervious fill. Perhaps the waste rock mined from the penstock tunnels could supply this type of material. Concrete aggregate could be screened from the alluvium that completely covers the upper pool area, but it is not known whether or not this would be a large enough source for this material. Impervious fill can be obtained from the alluvium of the upper pool in sufficient quantity for both the dam and the dike. Because suitable riprap, pervious fill, and concrete aggregate materials are in such short supply at this site, quarries would have to be developed elsewhere and these materials trucked to the site.

Conclusions and Recommendations

This pumped-storage site is questionable. The extensive alluvium and colluvium cover prevented a complete preliminary appraisal of this site. No apparent deleterious geologic conditions seem to exist, but until drilling and (or) trenching are conducted in the areas of the dam and the dike, no certainties concerning the geologic conditions can be made. Geophysical surveys in the dam and dike area could also provide more knowledge concerning the geologic conditions. The route of the penstock tunnel should be explored by a cored drill hole. Physical property measurements should be made on the penstock area cores, bedrock near the dam and dike, and all types of natural construction materials that will be used. These measurements, along with the drilling and (or) trenching information, would aid in assessing this site as a pumped-storage facility.

ELK LAKE PUMPED-STORAGE SITE

Power Potential

The Elk Lake site is near the headwaters of Elk Lake Creek, a tributary of the Collawash River. The existing lake is at a altitude of 3,370 ft as shown on the USGS Battle Ax 15-minute topographic quadrangle map and has a surface area of about 62 acres. The site is in a well-developed outdoor recreational area in the Mount Hood National Forest, and is accessible by a gravel road. A dam 233 ft high and about 3,500 ft long located in secs. 5 and 6, T. 9 S., R. 6 E., plus a 2,600-ft-long dike in sec. 6 of the same township, would increase the storage capacity of Elk Lake by 98,000 acre-ft. A peaking power of 7,000 MW could be produced by the average head of 1,830 ft and a usable storage of 52,000 acre-ft from a maximum drawdown of 160 ft. Two 40-ft-diameter penstocks would be required to discharge the amount of water and remain within the flow velocity limitation of 18 ft/s. The penstocks should be about 13,000 ft long, with the upper section underground and the lower section on the surface along Humbug Creek.

The lower reservoir would be on the Breitenbush River, a tributary of the North Santiam River in the adjacent Santiam drainage (fig. 1). A 320-ft-high dam in sec. 29, T. 9 S., R. 6 E., would raise the water from altitude 1,760 to 2,080 ft and store 161,000 acre-ft of water. A 50-ft drawdown on this lower pool would be required to refill the upper reservoir. The lower reservoir is in the Willamette National Forest and is in a popular recreational area. The wide fluctuation of water surface level would have a great impact on the recreational value. The record of a USGS gaging station downstream from the damsite indicates that this stream has adequate water to fill the reservoir. Once the reservoir is filled, the inflow will be used to maintain the desired reservoir water surface level, with the excess water being released downstream.

In late June 1973, the USGS completed a reconnaissance field study of this site and the Tumble Lake site in the Santiam River basin to determine the geologic and hydrologic feasibility of the dams, reservoirs and penstock areas. Preliminary results indicate some uncertainty about the geologic suitability of the Elk Lake site. In addition, the significant scenic and recreational value in the upper and lower reservoir area might outweigh the power value of the site.

Public Land Status

There is a total of 4,989 acres of public domain land that would be affected if this site were developed.

General Geology

Reconnaissance maps of the Elk Lake pumped-storage site area have been published by Peck and others (1964) and Thayer (1939) (fig. 19). The Little Butte Volcanic Series (Oligocene to early Miocene), the Sardine Formation (middle Miocene to early Pliocene), and the volcanic rocks of the High Cascade Range (Pliocene to Pleistocene) are exposed in the vicinity of the Elk Lake pumped-storage site. Glacial till deposits, morainal deposits, and alluvium are found in the lower elevations and in the valleys.

The Little Butte Volcanic Series consists generally of dacitic to andesitic tuff and olivine basalt, basaltic andesite and pyroxene andesite flows and breccias, dacitic and rhyodacitic flows and domes, and rhyodacitic tuff (Peck and others, 1964, p. 12). This unit averages 5,000 to 10,000 ft in thickness, but it is considerably thinner where it occupies the crest of the Breitenbush anticline. This unit includes rocks that Thayer (1939) had mapped as the Breitenbush Series.

The Sardine Formation consists of flows, flow breccia, lapilli tuff, and hypersthene andesite tuff. The flows are typically platy and porphyritic (Peck and others, 1964, p. 32). This unit averages about 3,000 ft in thickness but is probably much thicker in the vicinity of the Elk Lake pumped-storage site because many vent sources for the unit are nearby. Peck and others (1964, p. 30) included in the Sardine Formation units previously mapped by Thayer (1939, fig. 1) as the Fern Ridge tuffs and the upper part of the Breitenbush Series.

The volcanic rocks of the High Cascade Range are composed of flows and less abundant pyroclastic basaltic andesite and olivine basalt (Peck and others, 1964, p. 36). Thayer (1939, p. 11) had previously mapped these rocks as five different units - Outerson Volcanics, Minto lavas, Battle Ax lavas, Ollalie lavas, and Santiam basalts. The volcanic rocks of the High Cascades occur as the caprock on most of the high points around the upper pool (fig. 19).

The glacial drift in the valley of the Breitenbush River is probably of Wisconsin age, and along with the Quaternary alluvium, represents about 70 to 100 ft of unconsolidated material in the lower pool damsite area. The glacial moraine deposits in Elk Lake Valley also are of late Wisconsin age (Thayer, 1939, p. 26).

The Sardine syncline and the Breitenbush anticline are the only major structures mapped through the area of the pumped-storage site. Both folds plunge northward and are irregular and asymmetric (Peck and others, 1964, p. 42; Thayer, 1939, p. 19). The Breitenbush anticline has steeply dipping beds in the western limb (as much as 53°) and much gentler dips in the eastern limb (10°-15°) (Thayer, 1939, p. 19).

Geology of the Upper Pool

The upper pool will be an enlargement of the existing Elk Lake, a well-developed recreation site for fishing and camping. The natural lake occupies a small area in the floor of a large cirque or glacial amphitheater and is contained by glacial moraines on the valley floor. The lake is drained by Elk Lake Creek, a tributary to the Collawash-Clackamas drainage basin. The bulk of the cirque contains meadowlands and low, marshy areas (fig. 20).

Volcanic rocks of the High Cascade Range forming the south and west sides of the upper pool are principally a platy olivine-plagioclase basalt. This basalt is very hard, dense and is dark-gray to black in color and weathers to an orange color (fig. 21). The immediate sources for these rocks are the nearby vents at Battle Ax and Mt. Beachie. Because the sources for these rocks are so close, the flow banding and foliations are quite chaotic. Both Battle Ax and Mt. Beachie lie along the axis of the Sardine syncline, which has been called a zone of weakness allowing the ascension of magma (Peck and others, 1964, p. 51). The basalt in the vicinity of the proposed dike along the south edge of the upper pool is quite platy and broken

Figure 20.--Elk Lake cirque and area of the upper pool (view northeast from Mt. Beachie).

Figure 21.--Fractured olivine basalt near the south rim of the upper pool (N1/2 sec. 8, T. 9 S., R. 6 E., view north).

into small pieces (fig. 22). There is some evidence that the fracturing might continue to an appreciable depth.

Rocks of the Sardine Formation, chiefly hypersthene andesites, form the north side of the upper pool. These rocks are slightly less fractured than the volcanic rocks of the High Cascade Range of the west and south sides of the upper pool, but both units have been subjected to varying degrees of propylitic alteration, a hydrothermal process that changes pyroxene and olivine phenocrysts in the andesites and basalts to an assemblage of minerals including carbonates, epidote, quartz, and chlorite. At the upper pumped-storage site, the principal alteration mineral is chlorite, hence the overall greenish tint of most of the rocks.

The area of the dam for the upper pool is completely covered with heavy vegetation and thick soil and till. Because of this thick cover, it is difficult to assess the character of the rocks that will be encountered at the dam abutments. However, judged from exposures elsewhere, the rocks at the abutments will probably be fractured and chloritized. The contact between the Sardine Formation and the overlying volcanic rocks of the High Cascade Range may even be seen once the cover has been stripped away.

Geology of the Penstock Area

The proposed plan for construction of the penstock calls for driving the two 40-ft-diameter pipes underground through the upper part of the penstock route, a distance of approximately 5,000 ft. The lower part of the penstock pipes would be above ground and roughly follow the course of Humbug Creek downhill to the lower pool.

Figure 22.--Fractured, platy basalt in the vicinity of the proposed dike, south side of the upper pool (view from dike area to northeast).

The pipes would traverse the highly fractured olivine basalts of the volcanic rocks of the High Cascade Range. The intense fracturing could lead to tunnel containment problems. The rock at the surface breaks into pieces to 1 ft on a side and it is reasonable to assume that the fracturing extends to an appreciable depth.

The lower course of the penstock pipes follows the straight valley of Humbug Creek for aproximately 9,800 ft. This valley may be controlled by a linear fault or a strong regional joint system. Neither feature is observable on the ground, but a topographic lineation does exist (fig. 19). Streams do not normally show so pronounced a lineation without some type of structural control. Also seen in the route of the penstock is a recent landslide (fig. 23). This slide required rerouting the road up Humbug Creek. It was apparent that the Humbug Creek road was located originally on the west side of the creek but was closed because of the slide. The bridge over Humbug Creek was taken out by the slide and the lower part of the road that the map shows as being on the west side is now located on the east side with the road crossing the creek near the Breitenbush River. An old burn that removed the soil-retaining vegetation may have caused this landslide.

The rocks exposed in the valley of Humbug Creek are typical of the Sardine Formation--altered ash-flow tuffs, hypersthene andesite flows, and tuff breccia. The rocks, especially the flow rocks, are fractured but less than the volcanic rocks of the High Cascades Range.

Figure 23.--Active landslide in the route of the proposed penstock (W1/2 sec. 16, T. 9 S., R. 6 E., view northeast).

Geology of the Lower Pool

The lower pool of the Elk Lake pumped-storage site will be formed by building a dam across the Breitenbush River in the NE$\frac{1}{4}$ sec. 29, T. 9 S., R. 6 E. The south or left abutment will be founded in altered andesite lava flows that have blocky and platy fracture patterns (fig. 24). This combination of fractures breaks the rock into many pieces and may possibly extend to some depth. There are many thin flows of lava separated by thin, platy, lithic ash-flow tuffs. Both the lava flows and ash-flow tuffs have been chloritized. These rocks were mapped by Thayer (1939) as tuff units within the Breitenbush Series, but by Peck and others (1964, p. 30) as the Sardine Formation. The north or right abutment is located in a very thick alluvium and (or) glacial till deposit with a terrace developed about 80 to 100 ft above the level of the river. Considerable excavation would be required in the right abutment area to expose the bedrock.

The Breitenbush River, upstream from the proposed dam, flows through a broad, alluviated valley developed in the Sardine Formation. The alluvium and (or) glacial till is probably quite thick, but exact figures are not available. Outcrops and roadcuts throughout the area of the proposed reservoir indicate that the principal rocks are andesite flows and ash-flow tuffs. Near the confluence of Cultus Creek and the Breitenbush River (sec. 22, T. 9 S., R. 6 E), the rock is a much-fractured andesite lava flow. Microfractures and alteration along fractures make this rock incompetent. Near the confluence of Scorpion Creek and the Breitenbush River (NW$\frac{1}{4}$ sec. 24, T. 9 S., R. 6 E.), the lithic-rich ash-flow tuff is altered and highly jointed.

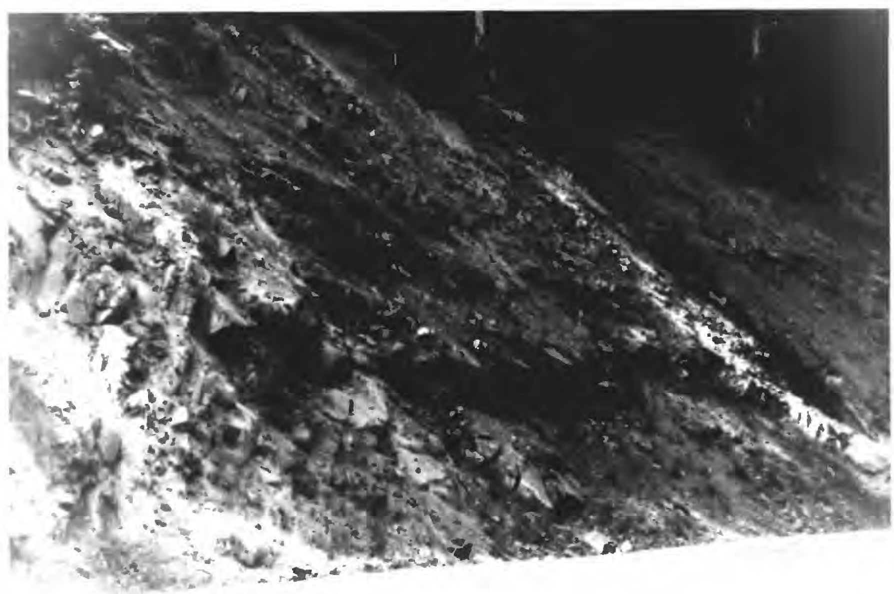

Figure 24.--Left abutment area of the lower pool on the Breitenbush River (NE1/4 sec. 29, T. 9 S., R. 6 E., view south).

The vertical and horizontal joint sets tend to break the rock into blocks that weather spheroidally. The two outcrops described above are fairly typical of the rock in the entire area of the proposed reservoir.

Construction Materials

Certain construction materials for the building of the pumped-storage site are readily available in the immediate vicinity. Riprap and concrete aggregate material are available all along Humbug Creek and would be available from excavation for the underground segment of the penstocks. Quarries in the andesite flows of the Sardine Formation or the basalts of the High Cascade Range could easily provide all material needed.

Sand, gravel, and earth-fill material could probably be obtained from the alluvium and till deposits along the Breitenbush River. The excavation of the right abutment of the lower pool damsite could provide the bulk of this material, given the proper sizing. Impervious fill material (clay, silt) is available only in very limited quantities and is derived mainly from soils in the upper pool area.

Conclusions and Recommendations

Several geologic conditions are unfavorable for development of Elk Lake as a pumped-storage site. Because of the highly fractured character of the rocks in both the upper and lower pools, an extremely large and expensive grouting program would probably be necessary before water could be contained in a reservoir. Fracturing of the rocks would make excavating the upper part of the penstock route risky, dangerous, and more expensive. Fractured rock would have no inherent strength, and tunneling would require sets and lagging. Additionally, the presence of an active landslide in the penstock route and favorable conditions for other slides elsewhere along the route would dictate against construction. Limited on-site or near-site supplies of impervious fill material would necessitate importing that material.

If the unfavorable geologic conditions are considered surmountable, certain further investigations are recommended. These new investigations should include detailed geologic mapping, drilling and trenching programs to ascertain depth to bedrock and bedrock configuration and charateristics, and an extensive sampling and analyses program. Physical property determinations should be made to permit judgments concerning porosity, permeability, density, and whole rock strength. Investigations should be made to find out how deep into the bedrock the prevalent fracturing extends and how best to overcome leakage along these planes of weakness. Physical property determination of on-site construction materials should be made to ascertain their suitability and available quantity as damsite material.

COTTONWOOD MEADOWS PUMPED-STORAGE SITE

Power Potential

The Cottonwood Meadows site is included in the Willamette Basin Comprehensive Study report for a long-range development plan. The upper reservoir would be on Cot Creek. The existing Lake Harriet would be enlarged to serve as the lower reservoir.

A 240-ft-high dam, between the altitudes of 4,000 and 4,240 ft, would develop a reservoir with a total storage capacity of 26,800 acre-ft with the allowable drawdown of 160 ft and average head of 2,020 ft could produce 3,500 MW of peaking power. One 11,000-ft-long, 36-ft-diameter penstock would be needed to discharge the amount of storage and remain within the velocity limitation of 20 ft/s.

The existing Lake Harriet is on Oak Grove Fork Clackamas River at river mile 5.2, and has a normal water surface altitude of 2,031 ft. If the Lake Harriet dam is built up to an altitude of 2,205 ft, the storage capacity of the lake would be increased by about 24,800 acre-ft. A 135-ft drawdown of this pool would be required to refill the upper reservoir.

Public Land Status

The USGS has not classified lands for water resource value in the site area. If this site is developed, a total of 1,310 acres of National forest land would be affected by the upper reservoir, the penstock route, and enlargement of the lower reservoir.

General Geology

The area of the proposed pumped-storage site is shown on the USGS High Rock 15-minute quadrangle map at a scale of 1:62,500 and a contour interval of 80 ft.

The area of the proposed Cottonwood Meadows pumped-storage site has been geologically mapped in a reconnaissance style by Barnes and Butler (1930) and Peck and other (1964). The two maps are different and for this report, the map by Peck and others is used (fig. 25). Field observations support this geologic map. The rocks of the area include the Miocene Columbia River Basalt Group, the Miocene to Pliocene

Sardine Formation, and the Pliocene to Pleistocene volcanic rocks of the High Cascades. Quaternary alluvium occurs in the creek and river beds.

The Columbia River Basalt Group consists of flows of very fine-grained dark-gray to black basalts. The flows are usually thick and display some stage of columnar jointing. This unit locally occurs downstream from the Lake Harriet dam. Barnes and Butler (1930, p. 37) described this particular occurrence as a dark-gray, fine- to medium-grained basalt with a few prominent feldspar phenocrysts.

The middle Miocene to early Pliocene Sardine Formation (fig. 25) consists of flows, breccias and tuff of hypersthene andesite (Peck and others, 1964, p. 30). In the area of the proposed Cottonwood Meadows pumped-storage site, this unit occurs only in a small area immediately upstream from Lake Harriet. Here the Sardine Formation conformably overlies the Columbia River Basalt Group along a surface of little relief (Peck and others, 1964, p. 31). The nearest source of the Sardine Formation is about 10 mi north-northwest of the proposed pumped-storage site. That source is at Squaw Mountain in T. 4 S., R. 6 E.

The volcanic rocks of the High Cascades, the Cascade Formation of Barnes and Butler (1930), consist chiefly of lava flows of Pliocene to Pleistocene age. The volcanic rocks of the High Cascades are principally light- to medium-gray and are characterized by vesicular, aphyric andesite and olivine basalt flows. These rocks unconformably overlie the Sardine Formation. In the area of the proposed site, the flows of this unit are generally flat-lying, and any dips present are probably initial dips around source vents (Peck and others, 1964, p. 36).

Peck and others (1964) mapped a fault 1.5 mi west of the dam that forms Lake Harriet. This sole structure near the proposed pumped-storage site will not affect development. Barnes and Butler (1930, p. 52) suggested that a fault forms the southern edge of Mt. Mitchell along the Oak Grove Fork. No supporting evidence for this idea has been presented, and Barnes and Butler's evidence suggests that the strong, uniform slope is a product of mass wasting.

Geology of the Upper Pool

The upper pool will be developed in the volcanic rocks of the High Cascades. Exposures of bedrock are rare in this area because of extensive surficial deposits. The abutment areas are covered by an unknown thickness of this surficial material, but it probably does not exceed 20 ft. The material ranges from fine sand and silt to boulders. An outcrop of bedrock in the vicinity of the right abutment is hard, dense, fine-grained light-gray pyroxene andesite with a platy fracture. Another outcrop, near the upper end of the proposed reservoir area, is dark- to medium-gray, medium-grained, flow-banded pyroxene andesite (fig. 26). The west and southwest walls of the valley in which the upper pool will be developed are covered by extensive talus piles composed of vesicular, aphanitic basalt or andesite, medium- to dark-gray in color (fig. 27). The vesicles have not been filled with secondary minerals. This may be an active talus accumulation, as most of the rocks appear freshly broken.

The basin that Cottonwood Meadows occupies was probably developed by either glacial scour or headward erosion of Cot Creek (fig. 28). No evidence of glaciation was observed during the reconnaissance fieldwork

Figure 26.---Flow-banded pyroxene andesite outcrop, upper pool area, Cottonwood Meadows pumped-storage site.

Figure 27.--Talus piles forming west and southwest walls of the upper pool area, Cottonwood Meadows pumped-storage site.

Figure 28.---General view of upper pool area, Cottonwood Meadows pumped-storage site

for this report, but an inspection of the topography lends credence to this mode of origin.

Geology of the Penstock Area

The penstock will be excavated underground through bedrock belonging to the volcanic rocks of the High Cascades. Depending upon the particular siting of the penstock, rocks belonging to the Columbia River Basalt Group and (or) Sardine Formation may be encountered at the lower end. The penstock will be beneath the talus-covered ridge discussed above. The rocks along the penstock route will be succession of basalt and (or) andesite flows that are dense, hard, and will require no support for mining. Minor thin interbeds of tuffaceous material may require support and may create water problems during tunneling. These beds are probably thin enough to present no serious problems. The slope immediately above Lake Harriet's north side is composed of vesicular, fine-grained andesite. A few of the vesicles in this rock are filled or lined with chabazite and mordenite, members of the zeolite group of minerals.

Geology of the Lower Pool

The lower pool of the proposed Cottonwood Meadows pumped-storage site will be made by enlarging the existing Lake Harriet. The rock that is exposed at the abutments is a dense, fine-grained, aphanitic basalt belonging to the Columbia River Basalt Group. The rock at the right abutment breaks up into "fist-sized" fragments. This fracturing may be some kind of pressure-release phenomenon because the same rock at the left abutment, which has been cleaned off, does not show jointing. The rock contains a few percent of grains of sideromelane (basaltic glass) and a few scattered 5-6 mm phenocrysts of pyroxene.

The reservoir will be developed in rocks mapped as the volcanic rocks of the High Cascades. The rocks are medium-gray, vesicular andesite lavas. No major jointing or fracturing of these rocks seems apparent. At the gaging station immediately east of river mile 6, an exposure of Sardine Formation bedded tuff was found. This tuff is of andesitic composition, and Peck and others (1964, pl. 1) mentioned a fossil flora collection from the area, but gave no details. On the highway due south of this point and across the river, a roadcut uncovers a contact between a tuffaceous unit and an overlying andesite flow sequence that may be the contact between the Sardine Formation and the overlying volcanic rocks of the High Cascades. The underlying tuff unit has been baked red by the overlying andesite flows. The attitude of the contact cannot be determined in this roadcut but appears to be nearly flay-lying.

No problems of reservoir containment are anticipated, because Lake Harriet has existed for some time without a failure. Some minor slope stability problems might develop as the sides of the enlarged reservoir are water-saturated.

Construction Materials

Construction materials are plentiful around the proposed pumped-storage site. Riprap and concrete aggregate can be obtained from the numerous flows of rocks in the vicinity and from the talus accumulations southwest of the upper pool. Concrete aggregate can also be obtained by screening stream gravels in the area. Impervious fill material can be obtained from the overburden in the upper pool area. Pervious fill can be obtained from screening and sizing the overburden and alluvium. Haulage would be minimal if the material is suitable for construction.

Conclusions and Recommendations

The geologic conditions at this proposed pumped-storage site seem favorable for construction. No fault or other deleterious geologic structures were seen during reconnaissance for this report. The rocks are dense and fine grained and should present no problems for reservoir containment. Construction materials are readily available. If this site is to be developed, then a more thorough investigation is called for which would include detailed geologic mapping, geophysical surveys, and sampling. Geophysical measurements would aid in determining depth to bedrock, bedrock characteristics, and some physical properties.

Sample analyses should be performed on the reservoir rock, abutment rock, and all construction materials to define accurately their characteristics. Drilling would aid in geologic mapping, sample gathering, and geophysical surveys.

BIG EDDY PUMPED-STORAGE SITE

Power Potential

The Big Eddy site (fig. 1) is located on the right bank of the Clackamas River on a plateau about 1,680 ft above the streambed in secs. 25, 26, 35, and 36, T. 4 S., R. 5 E., as studied by the COE. A continuous dike 13,500 ft long and 80 ft high, to the 2,560-ft altitude in sections 25 and 36 would form the upper reservoir. This reservoir would have a total storage capacity of 20,800 acre-ft and a surface area of 520 acres. An average head of 1,560 ft and a usable storage of 18,800 acre-ft with an 80-ft drawdown could produce 2,100 MW of peaking power at 100-percent efficiency. The penstock length would be about 3,200 ft. A 34-ft diameter penstock would stay within a flow velocity of 18 ft/s.

The South Fork site would serve as a lower reservoir. A 55-ft drawdown on this lower pool would be required to refill the upper reservoir.

Public Land Status

In the upper reservoir and penstock route area, a total of 323 acres of Federal land has been classified by USGS Power Site Reserve 730. These lands should remain in the present status to protect the site for possible future development. All the other lands within the upper reservoir boundary are in the Mount Hood National Forest. A total of 840 acres of unclassified Federal land would be affected if this site were developed.

General Geology

The area of the proposed pumped-storage site is shown on the USGS Fish Creek 15-minute quadrangle map at a scale of 1:62,500 and a contour interval of 80 ft. Access to the site is by unimproved Forest Service logging roads.

Peck and others (1964) mapped the area of the proposed Big Eddy pumped-storage site in a reconnaissance manner (fig. 11). Barnes and Butler (1930) mapped an area immediately adjacent to this site on the east. They infer that the canyon of the Clackamas River is incised into the Columbia River Basalt Group at this point and that the High Cascade Andesite forms the only caprock above the basalts. However, Peck and others (1964), in their more recent and detailed work, showed that a veneer of andesite belonging to the Pliocene to Pleistoene volcanic rocks of the High Cascades overlies a thinning pyroxene andesite lava flow unit of the Miocene to Pliocene Sardine Formation. The Sardine Formation in turn overlies the Miocene Columbia River Basalt Group. The dips of the various units are very shallow to horizontal. No geologic structures (folds, faults, etc.) have been mapped in the vicinity of the proposed pumped-storage site, and none were seen during our reconnaissance.

Geology of the Upper Pool

The upper pool will be created by an extensive dike built on the west, northwest, and northeast sides of a broad, slightly dipping, flat topographic area. In essence, the basin for the upper pool will be manmade and include a dike approximately 80 ft high. The area of the upper pool is very heavily forested with an accompanying thick soil cover. These two conditions preclude examining much of the bedrock. However, several small scattered bedrock outcrops occur along the unimproved Forest Service road that circles the site.

The rock in the scattered outcrops is a light-gray, highly weathered (altered?) andesite flow belonging to the volcanic rocks of the High Cascades. The matrix of the rock has been weathered away leaving a very distinctive skeletal framework of feldspar crystals. Where matrix remains, it is vitric in nature. The overall rock is coarse grained and very hard.

Geology of the Penstock Area

The penstock will be excavated underground through a thin flow of andesite belonging to the volcanic rocks of the High Cascades, a relatively thin pyroxene andesite flow belonging to the Sardine Formation, and a series of flows belonging to the Columbia River Basalt Group.

The volcanic rocks of the High Cascades that would be encountered in the excavation of the penstock will be vesicular light- to medium-gray andesite. This unit forms the caprock to the flat-topped ridge on the north side of the Clackamas River in T. 4 S., R. 5 E. Peck and others (1964, p. 36) called this particular andesite flow an inter-canyon flow; that is, a flow that filled an ancient canyon. As such, the flow unit is thin and irregular.

The Sardine Formation rocks that may be encountered in the mining of the penstock are thin pyroxene andesite lava flows. The rock is medium- to dark-gray and contains phenocrysts of feldspar and pyroxene in an aphanitic groundmass. These flows lie conformably on the Columbia River Basalt Group.

The Columbia River Basalt Group that will be encountered in mining is a series of dark-gray to black, fine-grained, hard basalt flows, which are competent despite some fracturing.

Away from weathering and alteration zones, each unit probably consists of hard, competent rock presenting few or no water containment problems. There may be paleosols (fossil soils) or altered, baked zones at the contacts between the volcanic rocks of the High Cascades and the underlying Columbia River Basalt Group. Thin inter-beds of tuffaceous material may be within each mapped unit. These possible areas of softer material represent zones of weakness and potential conduits for ground water and will probably have to be sealed off and contained in the mining process. Fracturing could be present in the Columbia River Basalt Group that would require special mining techniques. Generally speaking, the rocks should be competent enough to support mining of the penstock.

Geology of the Lower Pool

The lower pool of the Big Eddy pumped-storage site will be the proposed South Fork dam and reservoir on the Clackamas River. The geology of this site was discussed earlier in this report under the section on geology of the proposed South Fork damsite and reservoir.

Construction Materials

Materials needed for riprap, aggregate, and pervious fill are in short supply in the immediate vicinity of the upper pool. The extensive dikeworks will require a large amount of each material. Quarries in the Columbia River Basalt Group would have to be opened up to provide suitable material, and this would require extensive haulage. The rather thick soil profile in the area of the upper pool should be able to provide adequate amounts of impervious fill for the dikes. Waste rock derived from mining the underground penstock could provide some of the needed aggregate and pervious fill.

Conclusions and Recommendations

No obvious geologic problems were seen during the reconnaissance fieldwork done for this report. The site of the upper pool would not seem suitable from a topographic standpoint because of the lack of a depression to form a pool. The extensive dikework would necessarily be large and expensive. If construction is feasible, then further work needs to be done: drilling and (or) trenching to determine bedrock characteristics; core drilling in the mining area for the penstock; geophysical surveys to determine foundation suitabilities; and physical property measurements on the drill hole cores, bedrock, and all construction materials.

CONCLUSIONS AND RECOMMENDATIONS

As the result of this study, a total of 3,423 acres previously classified by the USGS as power or reservoir sites was determined to have sufficient value for potential development and should be retained in classified status. The study also revealed that 2,257 acres classified for potential development have negligible value for site development, are outside potential flow lines, or are along minor tributaries where developments are improbable; the classification affecting these lands will be recommended for revocation. After the 1970 elimination of the Big Bottom Diversion from the Oak Grove project, 1,560 acres of the total project withdrawn for the tunnel route are considered as having no power value. The USGS recommends that the project should be vacated insofar as it affects the land. Table 1 lists the acreage of classified and withdrawn land and categorizes them as to whether or not they have value for water resource development. Table 2 lists the lands by order that subdivides them into those "with power value" or those "with negligible power value." The proposed revocation of Geological Survey classifictions will in no way affect the withdrawals resulting from filings for preliminary permits or licenses under the

Federal Power Act.

This review disclosed that 26,459 acres of public lands within the potential sites discussed herein were not previously classified (table 3). The vacant lands should be classified to protect the resource value if geologic examinations are favorable.

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Table 1.--Audit of acreage review - Clackamas River basin

Order No.	Gross area (acres) in the order	Lands with power value (acres)	Lands with negligible power value (acres)
WP Des. 14	5,451.99	(1) 3,234.99	(2) 2,217.00
PSR 658	26.65	26.65	---
PSR 661	1,526.77	(3) 1,249.66	277.11
PSR 664	200.00	160.00	40.00
PSR 730	3,887.49	(3) 1,987.02	1,900.47
FPP 135	6,699.55	5,139.55	1,560.00
FPP 234	2,040.00	2,040.00	---
FPP 2195	137.18	137.18	---
Grand totals	19,969.63	13,975.05	5,994.58
USGS classifications	(4)5,680.33	(4)3,423.33	(4)2,257.00
FPC project withdrawals	(4)8,781.39	(4)7,221.39	(4)1,560.00
Net totals (4)	14,461.72	10,644.72	3,817.00

(1) Total of 1,249.66 acres overlaps PSR 661, and 1,985.33 acres overlaps PSR 730.
(2) Total of 227.11 acres overlaps PSR 661, and 1,900.47 acres overlaps PSR 730.
(3) Approximately 95.34 acres are overlapped in WP Des. 14, PSR's 661, 730, or FPP 135.
(4) After eliminating overlapping withdrawals.

Table 2.--Disposition of classified and withdrawn lands - Clackamas River basin

Land with power value	Land with negligible power value
Waterpower Designation 14 -- 12/12/17	
T. 2 S., R. 3 E., (12.41 acres) sec. 21, lot 5; sec. 23, lots 6, 8, and 12.	
T. 3 S., R. 3 E., (80.24 acres) sec. 1, lot 3; sec. 13, lot 5.	
T. 3 S., R. 4 E., (560 acres) sec. 11, NE¼, N½NW¼, SE¼NW¼, NE¼SW¼, S½SW¼, and SE¼.	
T. 3 S., R. 5 E., (477.01 acres) sec. 19, lot 4; sec. 27, NE¼NE¼, S½NE¼, N½SW¼, and NW¼SE¼; sec. 29, N½SW¼, SE¼SW¼, and S½SE¼.	T. 3 S., R. 5 E., (197.11 acres) sec. 19, lot 3, and SE¼SW¼; sec. 27, S½SW¼, and NE¼SE¼.
T. 4 S., R. 4 E., (120 acres) sec. 13, N½NE¼, and SE¼NE¼.	T. 4 S., R. 4 E., (80 acres) sec. 13, E½SE¼.
T. 4 S., R. 5 E., (1,922.29 acres) sec. 7, lots 2, 3, 4, NE¼, E½NW¼, and NE¼SW¼; sec. 17, E½NE¼, NW¼NE¼, and W½SE¼; sec. 19, E½NE¼, and NW¼NE¼; sec. 21, N½N½; sec. 23, NW¼NE¼, S½NE¼, NW¼, NE¼SW¼, and SE¼; sec. 27, SW¼NE¼; sec. 29, S½NE¼, NW¼NW¼, and S½NW¼; sec. 35, lots 3, 4, N½SE¼, and NE¼.	T. 4 S., R. 5 E., (1,692.44 acres) sec. 7, lot 1, SE¼SW¼, and SE¼; sec. 17, SW¼NE¼, and E½SE¼; sec. 19, lot 1, SW¼NE¼, and NE¼NW¼; sec. 21, S½N½, and S½; sec. 23, N½NE¼, and SE¼NE¼; sec. 27, N½NE¼, and SE¼NE¼; sec. 31, lots 5, 6, 7, NE¼, SE¼NW¼, NE¼SW¼, and N½SE¼.
T. 4 S., R. 6 E., (63.04 acres) sec. 33, lots 1 and 2.	T. 4 S., R. 6 E., (247.45 acres) sec. 27, S½NW¼; sec. 31, lots 4 and 5; sec. 33, N½SW¼.
Total - 3,234.99 acres	Total - 2,217.00 acres

Land with power value	Land with negligible power value
Power Site Reserve 658 - 11/14/17	
T. 3 S., R. 3 E., (26.65 acres) sec. 29, lot 4;	
Total - 26.65 acres	
Power Site Reserve 661 - 12/12/17	
T. 2 S., R. 3 E., (12.41 acres) sec. 21, lot 5; sec. 23, lots 6, 8, and 12.	
T. 3 S., R. 3 E., (80.24 acres) sec. 1, lot 3; sec. 13, lot 5.	
T. 3 S., R. 4 E., (560 acres) sec. 11, NE¼, N½NW¼, SE¼NW¼, NE¼SW¼, S½SW¼, and SE¼.	
T. 3 S., R. 5 E., (477.01 acres) sec. 19, lot 4; sec. 27, NE¼NE¼, S½NE¼, N½SW¼, and NW¼SE¼, sec. 29, N½SW¼, SE¼SW¼, and S½SE¼.	T. 3 S., R. 5 E., (197.11 acres) sec. 19, lot 3 and SE¼SW¼; sec. 27, S½SW¼ and NE¼SE¼.
T. 4 S., R. 4 E., (120 acres) sec. 13, N½NE¼ and SE¼NE¼.	T. 4 S., R. 4 E., (80 acres) sec. 13, E½SE¼.
Total - 1,249.66 acres	Total - 277.11 acres

Land with power value	Land with negligible power value
Power Site Reserve 664 - 12/12/17	
T. 3 S., R. 5 E., (160 acres) sec. 26, $NE\frac{1}{4}NW\frac{1}{4}$ sec. 28, $NE\frac{1}{4}SW\frac{1}{4}$ and $N\frac{1}{2}SE\frac{1}{4}$.	T. 3 S., R. 5 E., (40 acres) sec. 28, $NW\frac{1}{4}SW\frac{1}{4}$.
Total - 160.00 acres	Total - 40.00 acres
Power Site Reserve 730 - 2/19/20	
T. 2 S., R. 3 E., (1.69 acres) sec. 25, lots 7 and 8.	
T. 4 S., R. 5 E., (1,922.29 acres) sec. 7, lots 2, 3, 4, $NE\frac{1}{4}$, $E\frac{1}{2}NW\frac{1}{4}$, and $NE\frac{1}{4}SW\frac{1}{4}$; sec. 17, $E\frac{1}{2}NE\frac{1}{4}$, $NW\frac{1}{4}NE\frac{1}{4}$, and $W\frac{1}{2}SE\frac{1}{4}$; sec. 19, $E\frac{1}{2}NE\frac{1}{4}$ and $NW\frac{1}{4}NE\frac{1}{4}$; sec. 21, $N\frac{1}{2}N\frac{1}{2}$; sec. 23, $NW\frac{1}{4}NE\frac{1}{4}$, $S\frac{1}{2}NE\frac{1}{4}$, $NW\frac{1}{4}$, $NE\frac{1}{4}SW\frac{1}{4}$, and $SE\frac{1}{4}$; sec. 27, $SW\frac{1}{4}NE\frac{1}{4}$; sec. 29, $S\frac{1}{2}NE\frac{1}{4}$, $NW\frac{1}{4}NW\frac{1}{4}$, and $S\frac{1}{2}NW\frac{1}{4}$; sec. 35, lots 3, 4, $N\frac{1}{2}SE\frac{1}{4}$, and $NE\frac{1}{4}$.	T. 4 S., R. 5 E., (1,653.02 acres) sec. 7, lot 1, $SE\frac{1}{4}SW\frac{1}{4}$, and $SE\frac{1}{4}$; sec. 17, $SW\frac{1}{4}NE\frac{1}{4}$ and $E\frac{1}{2}SE\frac{1}{4}$; sec. 19, $SW\frac{1}{4}NE\frac{1}{4}$ and $NE\frac{1}{4}NW\frac{1}{4}$; sec. 21, $S\frac{1}{2}N\frac{1}{2}$ and $S\frac{1}{2}$; sec. 23, $NE\frac{1}{4}NE\frac{1}{4}$, $NW\frac{1}{4}SW\frac{1}{4}$, and $S\frac{1}{2}SW\frac{1}{4}$; sec. 27, $N\frac{1}{2}NE\frac{1}{4}$ and $SE\frac{1}{4}NE\frac{1}{4}$; sec. 31, lots 5, 6, 7, $NE\frac{1}{4}$, $SE\frac{1}{4}NW\frac{1}{4}$, $NE\frac{1}{4}SW\frac{1}{4}$, and $N\frac{1}{2}SE\frac{1}{4}$.
T. 4 S., R. 6 E., (63.04 acres) sec. 33, lots 1 and 2.	T. 4 S., R. 6 E., (247.45 acres) sec. 27, $S\frac{1}{2}NW\frac{1}{4}$; sec. 31, lots 4 and 5; sec. 33, $N\frac{1}{2}SW\frac{1}{4}$;
Total - 1,987.02 acres	Total - 1,900.47 acres

Land with power value	Land with negligible power value
Federal Power Project 135 - August 23, 1922 withdrawal (3740 acres)	

T. 5 S., R. 6 E.,
sec. 15, $S\frac{1}{2}SW\frac{1}{4}$;
sec. 16, $SE\frac{1}{4}SE\frac{1}{4}$;
sec. 22, $NW\frac{1}{4}$, $NE\frac{1}{4}SW\frac{1}{4}$, and $SE\frac{1}{4}$;
sec. 23, $W\frac{1}{2}SW\frac{1}{4}$;
sec. 26, $SW\frac{1}{4}NW\frac{1}{4}$, $NW\frac{1}{4}SW\frac{1}{4}$, $N\frac{1}{2}SW\frac{1}{4}SW\frac{1}{4}$, and $SE\frac{1}{4}SW\frac{1}{4}SW\frac{1}{4}$;
sec. 27, $N\frac{1}{2}NE\frac{1}{4}$, $SE\frac{1}{4}NE\frac{1}{4}$, and $NE\frac{1}{4}SE\frac{1}{4}$;
sec. 35, $NE\frac{1}{4}NW\frac{1}{4}$, $NE\frac{1}{4}NW\frac{1}{4}NW\frac{1}{4}$, $S\frac{1}{2}NW\frac{1}{4}NW\frac{1}{4}$, $S\frac{1}{2}NW\frac{1}{4}$, $NE\frac{1}{4}SW\frac{1}{4}$, and $SE\frac{1}{4}$;
sec. 36, $SW\frac{1}{4}$, $N\frac{1}{2}SE\frac{1}{4}$, and $SE\frac{1}{4}SE\frac{1}{4}$.

T. 5 S., R. 7 E.,
sec. 31, $SW\frac{1}{4}$ and $S\frac{1}{2}SE\frac{1}{4}$;
sec. 32, $SW\frac{1}{4}SW\frac{1}{4}$.

T. 6 S., R. 7 E.,
sec. 4, $SW\frac{1}{4}NW\frac{1}{4}$ and $SW\frac{1}{4}$;
sec. 5, $NE\frac{1}{4}$, $N\frac{1}{2}NW\frac{1}{4}$, and $NE\frac{1}{4}SE\frac{1}{4}$;
sec. 6, $NE\frac{1}{4}NE\frac{1}{4}$;
sec. 9, $W\frac{1}{2}NE\frac{1}{4}$, $W\frac{1}{2}$, and $SE\frac{1}{4}$;
sec. 15, $W\frac{1}{2}NW\frac{1}{4}$, $N\frac{1}{2}SW\frac{1}{4}$, $SE\frac{1}{4}SW\frac{1}{4}$, and $SW\frac{1}{4}SE\frac{1}{4}$;
sec. 16, $E\frac{1}{2}W\frac{1}{2}$;
sec. 21, $E\frac{1}{2}W\frac{1}{2}$ and $W\frac{1}{2}SE\frac{1}{4}$;
sec. 22, $NW\frac{1}{4}NE\frac{1}{4}$, $S\frac{1}{2}NE\frac{1}{4}$, $NE\frac{1}{4}NW\frac{1}{4}$, and $E\frac{1}{2}SE\frac{1}{4}$;
sec. 26, $N\frac{1}{2}NW\frac{1}{4}$ and $SW\frac{1}{4}NW\frac{1}{4}$;
sec. 27, $N\frac{1}{2}N\frac{1}{2}$;
sec. 28, $N\frac{1}{2}NE\frac{1}{4}$.

Land with power value	Land with negligible power value

Federal Power Project 135 - August 21, 1922 Withdrawal (644 acres) Con't.)

All portions of the following described land lying within 200 feet of the center line of the transmission line location shown on maps designated "Exhibit K", "Exhibit K-1", "Exhibit K-2" and entitled "Map of Proposed Primary Transmission Line and Wagon Road, Oak Grove Project, situated in Clackamas County, Oregon, Portland Railway Light and Power Company, Portland, Oregon" filed in the office of Federal Power Commission on August 21, 1922:

T. 4 S., R. 4 E.,
sec. 13, E½NE¼.

T. 4 S., R. 5 E.,
sec. 19, N½NE¼ and SE¼NE¼;
sec. 26, SW¼SW¼;
sec. 27, SW¼NE¼ and SE¼;
sec. 29, NW¼NW¼ and SW¼NE¼;
sec. 34, NE¼ and NE¼SE¼;
sec. 35, W½NW¼ and SW¼.

T. 5 S., R. 5 E.,
sec. 1, NE¼NE¼, S½NE¼, SE¼NW¼, SW¼, and NW¼SE¼;
sec. 2, NW¼NE¼, S½NE¼, NE¼NW¼, and NE¼SE¼.

T. 5 S., R. 6 E.,
sec. 6, NW¼NW¼, S½NW¼, E½SW¼, and S½SE¼;
sec. 7, N½NE¼ and SE¼NE¼;
sec. 8, S½NW¼, N½S½, SE¼SE¼, and NW¼NW¼;
sec. 9, SW¼SW¼;
sec. 16, N½NW¼, SE¼NW¼, NE¼SW¼, and W½SE¼;
sec. 21, W½NE¼.

Land with power value	Land with negligible power value
Federal Power Project 135, September 19, 1922 Withdrawal (120 acres) (Con't.)	
T. 5 S., R. 6 E., sec. 22, NW$\frac{1}{4}$SW$\frac{1}{4}$ and SE$\frac{1}{4}$SW$\frac{1}{4}$; sec. 27, SW$\frac{1}{4}$NE$\frac{1}{4}$.	
Federal Power Project 135, May 12, 1926 Withdrawal (400 acres) (Con't.)	
T. 5 S., R. 6 E., sec. 36, SW$\frac{1}{4}$SE$\frac{1}{4}$.	
T. 6 S., R. 7 E., sec. 4, SE$\frac{1}{4}$; sec. 9, E$\frac{1}{2}$NE$\frac{1}{4}$; sec. 10, W$\frac{1}{2}$SW$\frac{1}{4}$; sec. 15, SE$\frac{1}{4}$NW$\frac{1}{4}$.	

The February 9, 1933 adjustment on the August 23, 1922 withdrawal. The land should be described as follows: increase of 138 acres

T. 6 S., R. 7 E.,
sec. 4, lot 12 and SW$\frac{1}{4}$;
sec. 5, lots 1 thru 10 and NE$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 6, lots 1 and 8.

Land with power value	Land with negligible power value
Federal Power Project 135 - April 4, 1957 Withdrawal (1637.55 acres) (Con't.)	
All portions of the following subdivisions lying within the project boundaries are delineated on revised map designated "Exhibit K-1-B (FPC 138-89)" entitled "Project Area and Project Boundary, Frog Lake Reservoir" and filed in the office of the Commission April 4, 1957:	
T. 5 S., R. 6 E., sec. 34, $E\frac{1}{2}SE\frac{1}{4}$; sec. 35, $S\frac{1}{2}NE\frac{1}{4}$, $SW\frac{1}{4}$, and $W\frac{1}{2}SE\frac{1}{4}$.	
All portions of the following subdivision lying within the project boundaries as delineated on revised map "Exhibit K-1-B, K-2-B and K-3-B (FPC 135-90-91 and 92 respectively)" entitled, "Project Area and Project Boundary, Timothy Meadows Reservoir" and filed in the office of the Commission April 4, 1957: The area of this withdrawal is 1,656.15 acres. Approximately 18.6 acres has been withdrawn in connection with earlier application for this project:	
T. 6 S., R. 7 E., sec. 17, $SW\frac{1}{4}NW\frac{1}{4}$.	
T. 5 S., R. 8 E., sec. 12, $S\frac{1}{2}SE\frac{1}{4}$; sec. 13, $NE\frac{1}{4}$, $NE\frac{1}{4}SW\frac{1}{4}$, $S\frac{1}{2}SW\frac{1}{4}$, $N\frac{1}{2}SE\frac{1}{4}$, and $SW\frac{1}{4}SE\frac{1}{4}$; sec. 14, $S\frac{1}{2}SE\frac{1}{4}$; sec. 22, $SE\frac{1}{4}NE\frac{1}{4}$ and $E\frac{1}{2}SE\frac{1}{4}$; sec. 23, all; sec. 24, $W\frac{1}{2}NE\frac{1}{4}$, $NW\frac{1}{4}$, and $S\frac{1}{2}$; sec. 25, $N\frac{1}{2}NE\frac{1}{4}$ and $NW\frac{1}{4}$; sec. 26, $N\frac{1}{2}$ and $NE\frac{1}{4}SE\frac{1}{4}$; sec. 27, $N\frac{1}{2}NE\frac{1}{4}$.	

Land with power value	Land with negligible power value
Federal Power Project 135 - April 4, 1957 Withdrawal (con't.)	
T. 5 S., R. 8½ E., sec. 11, S½SW¼; sec. 14, N½NW¼; sec. 23, SW¼SW¼.	
	(Big Bottom diversion route) T. 6 S., R. 7 E., (1,560 acres) sec. 9, all; sec. 10, W½SW¼; sec. 15, NW¼NW¼, S½NW¼, N½SW¼, SE¼SW¼; and SW¼SE¼; sec. 16, E½W½; sec. 21, E½NW¼, NE¼SW¼, and NW¼SE¼; sec. 22, NW¼NE¼, S½NE¼, NE¼NW¼, and E½SE¼.

The total area of this project withdrawal is 6,699.55 acres of which 5,139.55 acres have power value.

Land with power value	Land with negligible power value
Federal Power Project 234 - July 15, 1921 Withdrawal (2,040 acres)	
T. 6 S., R. 7 E., sec. 25, SW¼, S½SE¼; sec. 26, S½SE¼, SE¼NW¼, E½SW¼, and SE¼; sec. 35, N½NE¼ and SE¼NE¼; sec. 36, E½, NW¼, N½SW¼, and SE¼SW¼.	
T. 7 S., R. 7 E., (unsurveyed) sec. 1, NE¼, NE¼NW¼, N½SE¼, and SE¼SE¼.	
T. 6 S., R. 8 E., (unsurveyed) sec. 31, SW¼NW¼ and W½SW¼.	
T. 7 S., R. 8 E., (unsurveyed) sec. 6, W½NW¼ and SW¼; sec. 7, NW¼NW¼.	

Land with power value	Land with negligible power value
Federal Power Project 2195 - January 18, 1957 Withdrawal (137.18 acres)	
All portions of the following described subdivisions lying within the dam and reservoir areas as delineated on map Exhibit "K" sheets 1 to 5 inclusive (FPC 2195-32 to 36 inclusive) T. 4 S., R. 4 E., sec. 13, $N\frac{1}{2}NE\frac{1}{4}$ and $SE\frac{1}{4}NE\frac{1}{4}$. T. 4 S., R. 5 E., sec. 7, lots 2 and 3; sec. 19, $N\frac{1}{2}NE\frac{1}{4}$ and $SE\frac{1}{4}NE\frac{1}{4}$; sec. 20, $W\frac{1}{2}W\frac{1}{2}$; sec. 29, $W\frac{1}{2}NW\frac{1}{4}$. Also all portions of the following described subdivision lying within 50 feet, on either side of center line survey of project transmission line location as delineated on map Exhibit "K" sheets 6 to 11 inclusive, (FPC 2195-37 to 42 inclusive) T. 3 S., R. 4 E., sec. 31, lot 5. The area of this withdrawal is approximately 137.18 acres of which approximately 95.34 acres are overlapped in WP Des. 14, PSRs 661, 730 or FPP 135.	

Table 3.—Unclassified public lands affected by potential sites.

Big Bottom Site - 2,680.00 acres

T. 6 S., R. 7 E.,
sec. 25, $S\frac{1}{2}NW\frac{1}{4}$ and $N\frac{1}{2}SE\frac{1}{4}$;
sec. 26, $W\frac{1}{2}SW\frac{1}{4}$;
sec. 35, $E\frac{1}{2}NW\frac{1}{4}$.

T. 6 S., R. 8 E., (unsurveyed)
sec. 30, $SW\frac{1}{4}SW\frac{1}{4}$;
sec. 31, $N\frac{1}{2}NW\frac{1}{4}$, $SE\frac{1}{4}NW\frac{1}{4}$, and $E\frac{1}{2}SW\frac{1}{4}$.

T. 7 S., R. 7 E., (unsurveyed)
sec. 1, $SE\frac{1}{4}NW\frac{1}{4}$ and $SW\frac{1}{4}SE\frac{1}{4}$;
sec. 12, $E\frac{1}{2}$;
sec. 24, $E\frac{1}{2}NE\frac{1}{4}$, $SW\frac{1}{4}NE\frac{1}{4}$, and $W\frac{1}{2}SE\frac{1}{4}$.

T. 7 S., R. 8 E., (unsurveyed)
sec. 6, $E\frac{1}{2}NW\frac{1}{4}$ and $SW\frac{1}{4}NE\frac{1}{4}$;
sec. 7, $W\frac{1}{2}NE\frac{1}{4}$, $E\frac{1}{2}NW\frac{1}{4}$, $SW\frac{1}{4}NW\frac{1}{4}$, $SW\frac{1}{4}$, and $SE\frac{1}{4}$;
sec. 18, $W\frac{1}{2}NE\frac{1}{4}$, $W\frac{1}{2}NW\frac{1}{4}$, and $SW\frac{1}{4}SW\frac{1}{4}$;
sec. 19, $W\frac{1}{2}W\frac{1}{2}$.

Upper Austin Point Site - 3,597.95 acres

T. 6 S., R. 6 E.,
sec. 27, $SE\frac{1}{4}SW\frac{1}{4}$ and $S\frac{1}{2}SE\frac{1}{4}$;
sec. 34, $NE\frac{1}{4}$, $E\frac{1}{2}NW\frac{1}{4}$, $SW\frac{1}{4}$, and $SE\frac{1}{4}$;
sec. 35, $W\frac{1}{2}NW\frac{1}{4}$.

T. 7 S., R. 6 E.,
sec. 3, lots 1 through 4, $SW\frac{1}{4}NE\frac{1}{4}$, $SE\frac{1}{4}NE\frac{1}{4}$, $SW\frac{1}{4}NW\frac{1}{4}$, $SE\frac{1}{4}NW\frac{1}{4}$, $SW\frac{1}{4}$, and $SE\frac{1}{4}$;
sec. 4, lot 1, $SE\frac{1}{4}NE\frac{1}{4}$, $SE\frac{1}{4}SW\frac{1}{4}$, $E\frac{1}{2}SE\frac{1}{4}$, and $SW\frac{1}{4}SE\frac{1}{4}$;
sec. 7, lot 4, $SE\frac{1}{4}SW\frac{1}{4}$, and $S\frac{1}{2}SE\frac{1}{4}$;
sec. 8, $SW\frac{1}{4}NE\frac{1}{4}$, $E\frac{1}{2}NE\frac{1}{4}$, $SE\frac{1}{4}NW\frac{1}{4}$, $SW\frac{1}{4}$, and $N\frac{1}{2}SE\frac{1}{4}$;
sec. 9, $N\frac{1}{2}NE\frac{1}{4}$ and $NW\frac{1}{4}$;
sec. 10, $NE\frac{1}{4}$, $NW\frac{1}{4}$, $NE\frac{1}{4}SW\frac{1}{4}$, and $SE\frac{1}{4}$;
sec. 11, $SE\frac{1}{4}SW\frac{1}{4}$;
sec. 14, $W\frac{1}{2}NE\frac{1}{4}$, $N\frac{1}{2}NW\frac{1}{4}$, $SE\frac{1}{4}NW\frac{1}{4}$, and $W\frac{1}{2}SW\frac{1}{4}$;
sec. 15, $NE\frac{1}{4}$;
sec. 18, $N\frac{1}{2}N\frac{1}{2}$.

Table 3 - (con't.)

Nowhere Meadow Site - 6,561.64 acres

T. 5 S., R. 6 E.,
sec. 21, SE$\frac{1}{4}$;
sec. 22, SW$\frac{1}{4}$SW$\frac{1}{4}$;
sec. 27, NW$\frac{1}{4}$, N$\frac{1}{2}$SW$\frac{1}{4}$, and SW$\frac{1}{4}$SW$\frac{1}{4}$;
sec. 28, E$\frac{1}{2}$, SE$\frac{1}{4}$NW$\frac{1}{4}$, and E$\frac{1}{2}$SW$\frac{1}{4}$;
sec. 33, E$\frac{1}{2}$, NE$\frac{1}{4}$NW$\frac{1}{4}$, and SE$\frac{1}{4}$SW$\frac{1}{4}$;
sec. 34, SW$\frac{1}{4}$NE$\frac{1}{4}$, NW$\frac{1}{4}$, SW$\frac{1}{4}$, and SE$\frac{1}{4}$.

T. 6 S., R. 6 E.,
sec. 1, lots 1 through 4, SW$\frac{1}{4}$NE$\frac{1}{4}$ and S$\frac{1}{2}$NW$\frac{1}{4}$;
sec. 2, lots 1 through 4, S$\frac{1}{2}$N$\frac{1}{2}$, SW$\frac{1}{4}$, and NE$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 3, all;
sec. 4, lot 1;
sec. 10, E$\frac{1}{2}$, E$\frac{1}{2}$NW$\frac{1}{4}$, SW$\frac{1}{4}$NW$\frac{1}{4}$, N$\frac{1}{2}$SW$\frac{1}{4}$, and SE$\frac{1}{4}$SW$\frac{1}{4}$;
sec. 11, W$\frac{1}{2}$ and SW$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 14, NW$\frac{1}{4}$NE$\frac{1}{4}$, N$\frac{1}{2}$NW$\frac{1}{4}$, and SW$\frac{1}{4}$NW$\frac{1}{4}$;
sec. 15, NE$\frac{1}{4}$, E$\frac{1}{2}$NW$\frac{1}{4}$, E$\frac{1}{2}$SW$\frac{1}{4}$, SW$\frac{1}{4}$SW$\frac{1}{4}$, N$\frac{1}{2}$SE$\frac{1}{4}$, and SW$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 21, NE$\frac{1}{4}$NE$\frac{1}{4}$;
sec. 22, NW$\frac{1}{4}$NE$\frac{1}{4}$, S$\frac{1}{2}$NE$\frac{1}{4}$, NW$\frac{1}{4}$, SW$\frac{1}{4}$, and SE$\frac{1}{4}$;
sec. 23, N$\frac{1}{2}$SW$\frac{1}{4}$ and SE$\frac{1}{4}$;
sec. 24, S$\frac{1}{2}$SW$\frac{1}{4}$ and SW$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 25, NW$\frac{1}{4}$NE$\frac{1}{4}$;
sec. 27, NW$\frac{1}{4}$ and N$\frac{1}{2}$SW$\frac{1}{4}$.

T. 6 S., R. 7 E.,
sec. 6, lots 4 and 5.

South Fork Site - 2,681.1 acres

T. 4 S., R. 5 E.,
sec. 26, W$\frac{1}{2}$SW$\frac{1}{4}$;
sec. 27, NW$\frac{1}{4}$, N$\frac{1}{2}$SW$\frac{1}{4}$, and SE$\frac{1}{4}$;
sec. 28, S$\frac{1}{2}$NE$\frac{1}{4}$, SW$\frac{1}{4}$, N$\frac{1}{2}$SE$\frac{1}{4}$, and SW$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 29, N$\frac{1}{2}$SE$\frac{1}{4}$ and SE$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 34, NE$\frac{1}{4}$ and NE$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 35, lots 1, 2, W$\frac{1}{2}$NW$\frac{1}{4}$, and N$\frac{1}{2}$SW$\frac{1}{4}$.

T. 5 S., R. 5 E.,
sec. 1, lot 1, S$\frac{1}{2}$NE$\frac{1}{4}$, S$\frac{1}{2}$NW$\frac{1}{4}$, SW$\frac{1}{4}$, and NW$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 2, lots 1, 2, 3, S$\frac{1}{2}$NE$\frac{1}{4}$, SE$\frac{1}{4}$NW$\frac{1}{4}$, and E$\frac{1}{2}$SE$\frac{1}{4}$;
sec. 11, E$\frac{1}{2}$NE$\frac{1}{4}$ and NE$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 12, NW$\frac{1}{4}$NW$\frac{1}{4}$.

Table 3 - (con't.)

South Fork Site - con't

T. 5 S., R. 6 E.,
sec. 6, Lots 4, 5, SE$\frac{1}{4}$NW$\frac{1}{4}$, E$\frac{1}{2}$SW$\frac{1}{4}$, and SW$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 7, N$\frac{1}{2}$NE$\frac{1}{4}$;
sec. 8, W$\frac{1}{2}$NW$\frac{1}{4}$.

Eagle Creek Site - 38.89 acres

T. 3 S., R. 4 E.,
sec. 13, lot 4.

Tarzan Springs pumped-storage site - 2,680.00 acres

T. 7 S., R. 7 E., (unsurveyed)
sec. 9, S$\frac{1}{2}$NE$\frac{1}{4}$, NE$\frac{1}{4}$NE$\frac{1}{4}$, SE$\frac{1}{4}$NW$\frac{1}{4}$, SW$\frac{1}{4}$, N$\frac{1}{2}$SE$\frac{1}{4}$, and SE$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 10, W$\frac{1}{2}$NW$\frac{1}{4}$, SE$\frac{1}{4}$NW$\frac{1}{4}$, SW$\frac{1}{4}$, and SW$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 13, E$\frac{1}{2}$SW$\frac{1}{4}$, SW$\frac{1}{4}$SW$\frac{1}{4}$, and SE$\frac{1}{4}$;
sec. 14, W$\frac{1}{2}$NW$\frac{1}{4}$, SE$\frac{1}{4}$NE$\frac{1}{4}$, NE$\frac{1}{4}$SW$\frac{1}{4}$, N$\frac{1}{2}$SE$\frac{1}{4}$, and SE$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 15, N$\frac{1}{2}$NE$\frac{1}{4}$;
sec. 24, E$\frac{1}{2}$, N$\frac{1}{2}$NW$\frac{1}{4}$, and SE$\frac{1}{4}$NW$\frac{1}{4}$;
sec. 25, E$\frac{1}{2}$ and NE$\frac{1}{4}$NW$\frac{1}{4}$;
sec. 36, NE$\frac{1}{4}$ and NE$\frac{1}{4}$SE$\frac{1}{4}$.

T. 7 S., R. 8 E., (unsurveyed)
sec. 18, W$\frac{1}{2}$SW$\frac{1}{4}$ and SE$\frac{1}{4}$SW$\frac{1}{4}$;
sec. 19, W$\frac{1}{2}$W$\frac{1}{2}$.

Peavine pumped-storage site - 1,080.00 acres

T. 6 S., R. 8 E., (unsurveyed)
sec. 18, SE$\frac{1}{4}$SE$\frac{1}{4}$;
sec. 19, N$\frac{1}{2}$NE$\frac{1}{4}$, SE$\frac{1}{4}$NE$\frac{1}{4}$, NE$\frac{1}{4}$SE$\frac{1}{4}$, and S$\frac{1}{2}$SE$\frac{1}{4}$;
sec. 20, W$\frac{1}{2}$NE$\frac{1}{4}$, SE$\frac{1}{4}$NE$\frac{1}{4}$, NW$\frac{1}{4}$, SW$\frac{1}{4}$, and SE$\frac{1}{4}$;
sec. 30, NW$\frac{1}{4}$NE$\frac{1}{4}$ and NW$\frac{1}{4}$.

Table 3 - (con't.)

Elk Lake pumped-storage site - 4,989.32 acres

T. 9 S., R. 5 E.,
sec. 1, $SE\frac{1}{4}NE\frac{1}{4}$, $E\frac{1}{2}SW\frac{1}{4}$, and $SE\frac{1}{4}$;
sec. 12, $N\frac{1}{2}NE\frac{1}{4}$ and $NE\frac{1}{4}NW\frac{1}{2}$.

T. 9 S., R. 6 E.,
sec. 5, $SW\frac{1}{4}NE\frac{1}{4}$ and $W\frac{1}{2}SW\frac{1}{4}$;
sec. 6, lots 1 through 7, $S\frac{1}{2}NE\frac{1}{4}$, $SE\frac{1}{4}NW\frac{1}{4}$, $E\frac{1}{2}SW\frac{1}{4}$, and $SE\frac{1}{4}$;
sec. 7, lot 1;
sec. 8, $SW\frac{1}{4}NE\frac{1}{4}$, $N\frac{1}{2}NW\frac{1}{4}$, $SE\frac{1}{4}NW\frac{1}{4}$, $NE\frac{1}{4}SW\frac{1}{4}$, $W\frac{1}{2}SE\frac{1}{4}$, and $SE\frac{1}{4}SE\frac{1}{4}$;
sec. 10, $SW\frac{1}{4}SE\frac{1}{4}$;
sec. 15, $W\frac{1}{2}NE\frac{1}{4}$, $E\frac{1}{2}NW\frac{1}{4}$, $SW\frac{1}{4}$, and $W\frac{1}{2}SE\frac{1}{4}$;
sec. 16, $W\frac{1}{2}NW\frac{1}{4}$, $N\frac{1}{2}SW\frac{1}{4}$, $SE\frac{1}{4}SW\frac{1}{4}$, and $SW\frac{1}{4}SE\frac{1}{4}$;
sec. 17, $NE\frac{1}{4}NE\frac{1}{4}$;
sec. 21, $NE\frac{1}{4}$, $NE\frac{1}{4}NW\frac{1}{4}$, $S\frac{1}{2}SW\frac{1}{4}$, and $SE\frac{1}{4}$;
sec. 21, all;
sec. 23, $NE\frac{1}{4}$ and $NW\frac{1}{4}$;
sec. 24, $S\frac{1}{2}NE\frac{1}{4}$, $NW\frac{1}{4}$, and $NE\frac{1}{4}SE\frac{1}{4}$;
sec. 27, $N\frac{1}{2}NE\frac{1}{4}$, $NW\frac{1}{4}NW\frac{1}{4}$, and $NW\frac{1}{4}SW\frac{1}{4}$;
sec. 28, $NE\frac{1}{4}$, $NW\frac{1}{4}$, $SW\frac{1}{4}$, and $N\frac{1}{2}SE\frac{1}{4}$;
sec. 29, $NE\frac{1}{4}$ and $NE\frac{1}{4}SE\frac{1}{4}$;
sec. 33, $N\frac{1}{2}NW\frac{1}{4}$.

T. 9 S., R. 7 E., (unsurveyed)
sec. 19, $SW\frac{1}{4}NW\frac{1}{4}$ and $NW\frac{1}{4}SW\frac{1}{4}$.

Cottonwood Meadows pumped-storage site - 1,310.1 acres

T. 5 S., R. 7 E.,
sec. 28, $SW\frac{1}{4}NE\frac{1}{4}$, $NW\frac{1}{4}$, $SW\frac{1}{4}$, and $W\frac{1}{2}SE\frac{1}{4}$;
sec. 29, $E\frac{1}{2}SE\frac{1}{4}$;
sec. 33, lot 1, $W\frac{1}{2}NW\frac{1}{4}$, and $NW\frac{1}{4}SW\frac{1}{4}$.

T. 6 S., R. 7 E.,
sec. 2, $SW\frac{1}{4}NE\frac{1}{4}$, $S\frac{1}{2}NW\frac{1}{4}$, and $N\frac{1}{2}SW\frac{1}{4}$;
sec. 3, $S\frac{1}{2}$;
sec. 4, lots 3, 6, and 11.

Big Eddy pumped-storage site - 840.00 acres

T. 4 S., R. 5 E.,
sec. 25, $SW\frac{1}{4}NW\frac{1}{4}$, $SW\frac{1}{4}$, $W\frac{1}{2}SE\frac{1}{4}$, and $SE\frac{1}{4}SE\frac{1}{4}$;
sec. 26, $SE\frac{1}{4}NE\frac{1}{4}$, $SE\frac{1}{4}SW\frac{1}{4}$, and $SE\frac{1}{4}$;
sec. 36, $NW\frac{1}{4}NE\frac{1}{4}$, $NW\frac{1}{4}$, and $W\frac{1}{2}SW\frac{1}{4}$.