UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Evaluation of Three Potential Pumped-Storage Sites, Mokelumne River Basin, California

By

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Open File Report 79-1678

1979

This report has not been edited for conformity
with U.S. Geological Survey editorial standards

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CONVERSION FACTORS

English units are used in this report. For the benefit of readers who prefer metric units, the conversion factors for the terms used herein are listed below:

Multiply English unit	By	To obtain metric units
Inches (in.)	2.540	Centimeters (cm)
Feet (ft)	0.305	Meters (m)
Miles (mi)	1.609	Kilometers (km)
Acres	0.405	Hectares (ha)
Square miles (mi^2)	2.590	Square kilometers (km^2)
Acre-feet (acre-ft)	0.001233	Cubic meters (m^3)
Feet per second (ft/s)	0.305	Meters per second (m/s)
Cubic feet per second (ft^3/s)	0.0283	Cubic meters per second (m^3/s)
Degrees Fahrenheit (°F)	0.555 (°F-32)	Degrees Celsius (°C)

EVALUATION OF THREE POTENTIAL PUMPED-STORAGE SITES, MOKELUMNE RIVER BASIN, CALIFORNIA

By David E. Wilson and Frank W. Smith

INTRODUCTION

The demand for electric energy varies over any period of time. If large quantities of electric energy could be stored, the variation in demand placed on generating equipment could be reduced. However, suitable methods of storing large quantities of electric energy have not been developed. An alternative method to storing electric energy is to convert the electric energy into a form of potential energy that can be stored. Hydro pumped-storage provides a method of storing potential energy. During periods of low electric-energy demand, electric energy is used to pump water from a lower elevation to a higher elevation for storage as potential energy. When a period of high electric-energy demand occurs, the stored potential energy is converted to electric energy by releasing water from the higher elevation to the lower elevation through a water turbine driving an electric generator. Although the electric energy consumed by pumping is about one and one-half times the amount generated, hydro pumped-storage electric energy is justified by the high-economic value of peak electric energy versus low-cost, off-peak electric energy.

The principal operating cycles for pumped-storage projects are daily, weekly, and seasonal or a combination. The cycle adopted for a project depends on the type of load to be served and the availability of off-peak pumping energy. The sites identified in this report are assumed to operate on a weekly cycle with readily available low-cost, off-peak electric energy. Weekly cycle plants generate for 6 to 8 hours each weekday and partially replenish upper reservoir storage during the night. Because of the limited time available for pumping each night, it is impossible to replenish all of the upper reservoir storage used in the previous day's generating phase. Accumulated losses in the upper reservoir can be made up by pumping on weekends. The weekly cycle also allows a certain amount of flexibility in operation because generating or pumping requirements vary from day to day.

A primary responsibility of the U.S. Geological Survey (USGS) is the classification of Federal lands for waterpower and water-storage value. These classifications neither commit the Federal Government to construction nor prohibit private use for water resource development; however, they do identify, protect, and forestall encumbrances of potential sites. Noninjurious uses may be allowed under provisions of Section 24 of the Federal Power Act of June 10, 1920, upon approval of the Federal Energy Regulatory Commission.

This report will be used to determine if classification of the Federal land affected by the Cole Creek No. 1, Cole Creek No. 2, and Moore Creek pumped-storage sites is justified.

Cole Creek No. 1, Cole Creek No. 2, and Moore Creek pumped-storage sites are identified in the Federal Power Commission's 1975 report on "Potential Pumped Storage Projects in the Pacific Southwest." These sites are tentatively named for the North Fork Mokelumne River tributaries on which the upper reservoirs would be located. Pacific Gas and Electric Company's existing Salt Springs Reservoir would be the common lower reservoir for the projects. The three developments would operate at heads of more than 2,000 feet and have a total generating capacity of 11,300 MW.

DESCRIPTION OF THE MOKELUMNE RIVER BASIN

The Mokelumne River originates in the barren snowfields of the west slopes of the Sierra Nevada, at altitudes above 8,000 feet. Beginning in Alpine County, the river flows westward along the boundary between Amador and Calaveras Counties, through San Joaquin County, discharging into the tidal channels of the San Joaquin-Sacramento delta region 158 miles away from the headwaters (fig. 1). The Mokelumne River is joined by the Cosumnes River near the town of Thornton. Although the Cosumnes River is a tributary to the Mokelumne River, the Mokelumne River basin as discussed in this report does not include the Cosumnes River basin. The Mokelumne River basin area is 700 square miles, 584 square miles of which is mountain and foothill area. The North Fork is the main branch of the Mokelumne River. Approximately 35 miles west of its source, the North Fork is joined by the Bear River, which drains an area of 50 square miles. Fifteen miles west of the Bear River junction, the North Fork is joined by the South and Middle Forks, which drain an area of 150 square miles.

The most striking characteristic of the Mokelumne River basin is its long narrow shape. For 18 miles below the confluence of the North and South Forks, the basin is only 2 to 4 miles wide. Above the confluence, the basin is 10 to 12 miles wide and 40 miles long with the three forks occupying rugged canyons 1,000 to 4,000 feet deep.

Above the foothills a large part of the basin is covered with dense conifer forests. In the higher altitudes there are large areas of bare granite and scattered alpine vegetation. Numerous natural lakes are located in the canyons and gorges of the headwaters. These lakes are a legacy of the ice age, filling low areas excavated by glaciers.

The pumped-storage sites investigated for this report are located on Cole and Moore Creeks, tributaries to the North Fork Mokelumne River (fig. 1). Cole Creek originates at an altitude above 8,500 feet in Amador County and flows in a southwesterly direction 15 miles to its confluence with the North Fork. Moore Creek originates at an altitude above 7,500 feet in Calaveras County and flows in a northwesterly direction 8 miles to its confluence with the North Fork.

CLIMATE

The climate in the Mokelumne River basin varies with altitude and location within the basin (table 1). In the surrounding mountains temperatures below 0°F are common during the winter and rarely exceed 90°F during the summer. The average annual temperature at the Salt Springs Powerhouse climatological station at an altitude of 3,700 feet is 58°F. In the lower basin the winters are less severe and summer temperatures often exceed 90°F, averaging 59°F, at the Lodi climatological station at an altitude of 40 feet.

Table 1.--Average annual precipitation and temperature, Mokelumne River basin

[Data from National Oceanic and Atmospheric Administration, 1977. PH, powerhouse]

Station	Altitude (ft) 1/	Temperature (°F)	Precipitation (in.)
Lodi	40	59.3	16.3
Elliott	92	--	17.5
Camp Pardee	658	61.1	20.9
Electra PH	715	60.7	30.2
Tiger Creek PH	2,355	57.1	46.9
Salt Springs PH	3,700	57.6	45.4
Twin Lakes 2/	7,829	39.2	51.1

1/ Datum is mean sea level.

2/ This station is located in the American River basin, but is considered to represent conditions similar to those in the upper Mokelumne River basin.

The wet season usually begins in October or November and continues until the following May. About 90 percent of the annual precipitation occurs in this period. Winter storms blowing from the Pacific Ocean are deflected upward by the Sierra Nevada; in passing over them the air is chilled and so most of the storm's moisture is dropped as rain or snow on the west slope of the Sierra Nevada. Above 5,000 feet the precipitation is usually in the form of snow. The average annual precipitation is about 16 inches on the San Joaquin Valley floor, and the amount gradually increases toward the headwaters of the Mokelumne River. The average annual precipitation is about 45 inches in the vicinity of Salt Springs Reservoir at an altitude of 3,700 feet.

WATER RIGHTS

Adequate appropriative water rights are a necessary prerequisite to the construction of any water development project involving a storage or direct diversion of surface water for use on nonriparian land. Water rights would be needed to appropriate water for the initial filling of the upper reservoirs for Cole Creek No. 1, Cole Creek No. 2, and Moore Creek pumped-storage projects and to replace evaporation and seepage losses. There is now a minimum year-round flow-release requirement in Cole Creek below the Cole Creek diversion dam of 2 ft^3/s or the natural streamflow, whichever is less, for fishery purposes. Moore Creek has no minimum flow-release requirement. (Pacific Gas and Electric Company, 1972.)

Major appropriators of water in the Mokelumne River basin are Pacific Gas and Electric Company (PG&E) and East Bay Municipal Utility District (EBMUD). The combined water rights of these agencies could effectively preclude any further large development on the Mokelumne River. This possibility should not affect the potential pumped-storage projects, inasmuch as the only major appropriation of water would be for the initial filling of the upper reservoirs.

Water rights to divert water from Cole Creek are held by PG&E under licensed Applications 2548 and 6032 (Pacific Gas and Electric Company, 1972). Application 2548 is for a direct diversion of 20 ft^3/s from Cole Creek into the Tiger Creek Conduit for use at Tiger Creek Powerhouse. Under Application 6032 an appropriation of 200 ft^3/s can be made from either Lower Bear River Reservoir or Cole Creek (or both) for diversion to Salt Springs Powerhouse via Bear River Tunnel. Water from Salt Springs Powerhouse is discharged into either the North Fork Mokelumne River or Tiger Creek Conduit. The only appropriative water right on Moore Creek is for a diversion of 0.168 ft^3/s for mining and domestic purposes.

WATER SUPPLY

The flow of the Mokelumne River has been under continuous study since 1905 when a gaging station was established near Clements (fig. 1). Fourteen continuous gaging stations in the Mokelumne River basin are reported by the U.S. Geological Survey (1977). Data from some of these stations are summarized in table 2. Intermittent gaging stations are operated at many other locations in the basin.

Because the melting of the accumulated snowpack in the Sierra Nevada provides the major part of the water supply in the Mokelumne River basin, the largest runoff occurs during May, June, and July. The upper watershed is not sufficiently elevated to sustain perpetual snowfields, and so there is a pronounced annual freshet in the river and a high sustained flow far into the summer. By late summer and early fall discharge becomes very small.

Table 2.--Summary of hydrologic data, Mokelumne River basin

[Data from U.S. Geological Survey Water Data-Report CA-76-3]

Gaging station	Location[1/]			Drainage area (mi^2)	Period of record	Average annual discharge (acre-ft)	Extreme discharges (ft^3/s) for record period	
	T.N.	R.E.	Sec.				Maximum	Minimum
North Fork Mokelumne River below Salt Springs Dam ----------	7	16	4	170	1926-76	340,500	16,000	0.3
Cole Creek near Salt Springs Dam -----	8	16	28	21	1927-76	46,440	6,140	0
Bear River near Salt Springs Dam-------------------	7	15	2	48	1951-76	38,620	11,000	1.0
Middle Fork Mokelumne River at West Point---	6	13	10	68	1911-76	44,050	4,320	0
South Fork Mokelumne River near West Point-	6	13	16	75	1933-76	59,770	6,920	0
Mokelumne River near Mokelumne Hill-------	5	11	1	544	1927-76	704,200	33,700	16
below Camanche Dam---	4	9	7	627	1929-76	591,200	28,800	0
at Woodbridge--------	4	6	34	661	1929-76	434,700	27,000	1.4

1/ Mount Diablo Meridian.

Above Pardee Reservoir, at the U.S. Geological Survey gaging station near Mokelumne Hill for the period 1927-76, the average annual discharge of the Mokelumne River was 704,200 acre-feet. Extremes of runoff for this period are represented by a high flow of 33,700 ft^3/s on December 3, 1950, and a low flow of 16 ft^3/s for several days in November 1929. Hydrologic data for selected locations in the Mokelumne River basin are given in table 2. Streamflow data for Moore Creek are not available. The average annual precipitation on the Moore Creek and Cole Creek basins should be similar. The runoff from the smaller Moore Creek basin, therefore, should be less than the 46,440-acre-foot average annual discharge from Cole Creek basin

EXISTING WATER RESOURCES DEVELOPMENT

Development of the Mokelumne River for water and power dates back to the gold rush days. The miners built flumes and ditches to supply waterpower to their placer and quartz claims. This water-resources development became the nucleus of today's maze of conduits for the water-powered generation of electricity. Existing water resources developments in the Mokelumne River basin (California Department of Water Resources, 1963, p. 88) are shown on figures 1 and 2. Stream profiles for the Mokelumne River, upstream from State Highway 88 bridge, and for Cole Creek and Moore Creek are shown on figures 2, 3, and 4.

The hydroelectric power potential of the North Fork Mokelumne River is extensively developed by PG&E under licensed Federal Power Project No. 137. Project works consists of the following major units. In the upper reaches of the North Fork water is impounded in Twin Lake, Upper and Lower Blue Lakes, Meadow Lake, Upper and Lower Bear River Reservoirs, and Salt Springs Reservoir. Water is conveyed from Lower Bear River Reservoir and Salt Springs Reservoir

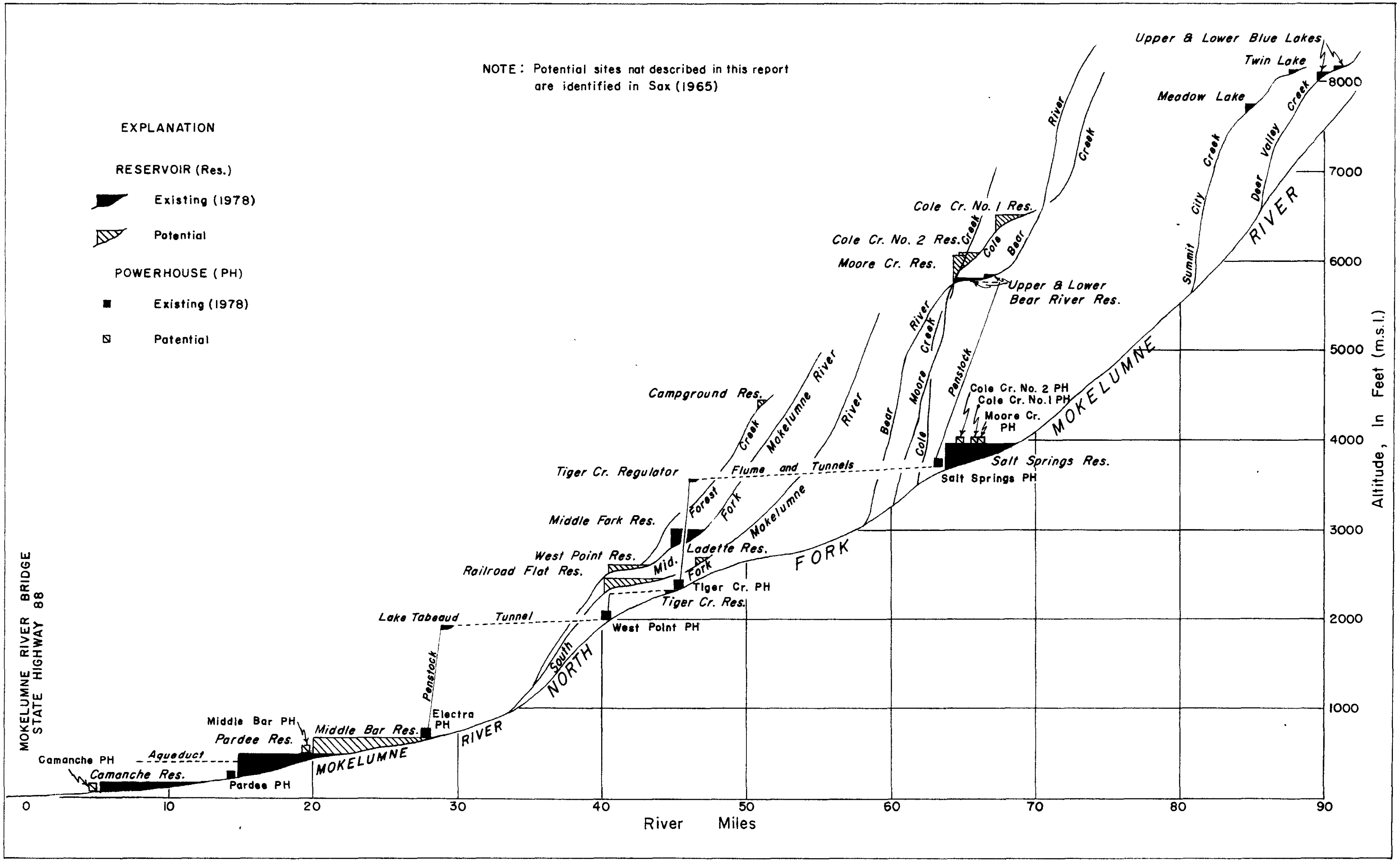

Figure 2.-- Stream profile, Mokelumne River, California (upstream from State Highway 88 bridge).

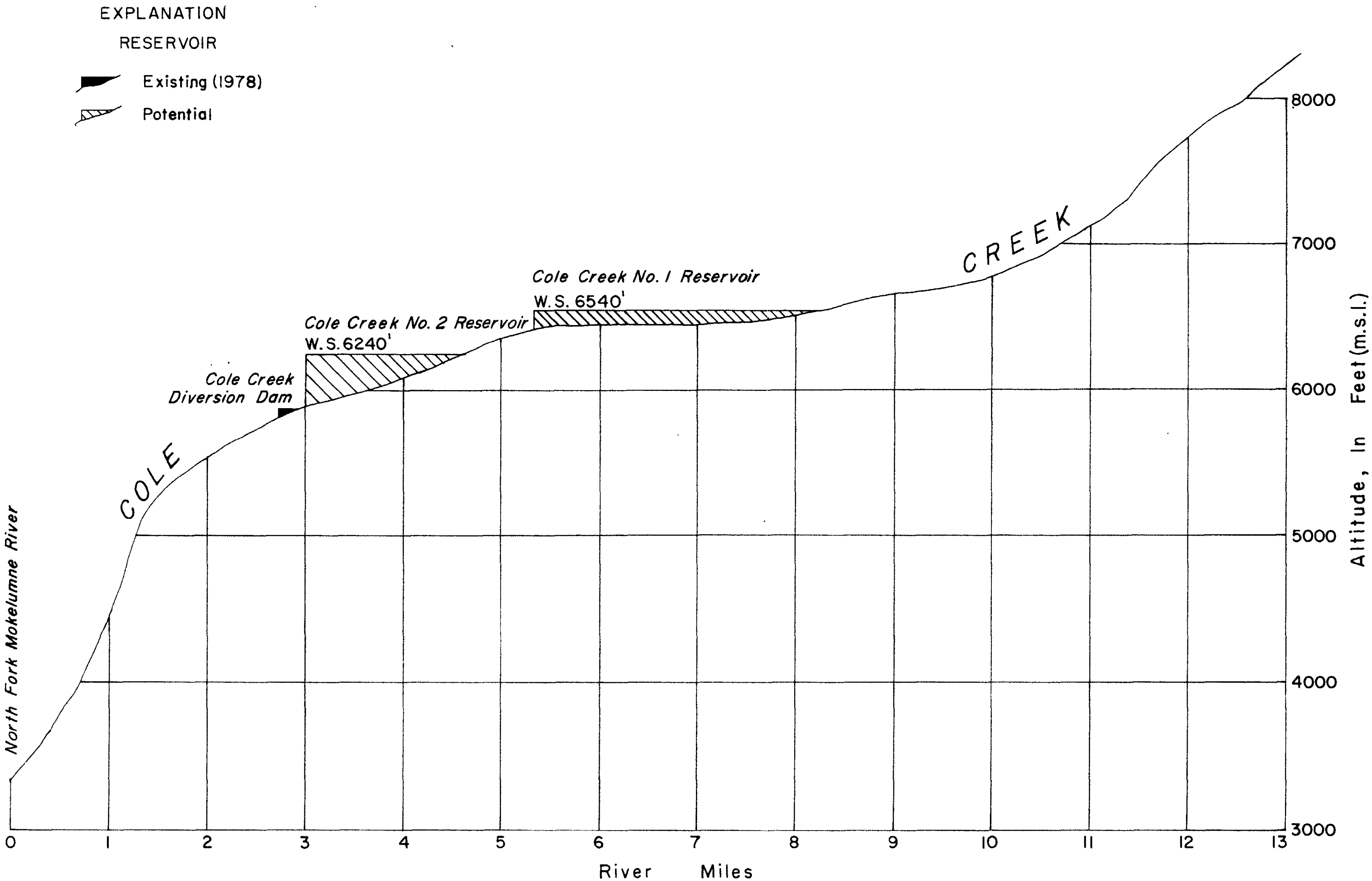

Figure 3. —— Stream profile, Cole Creek, California.

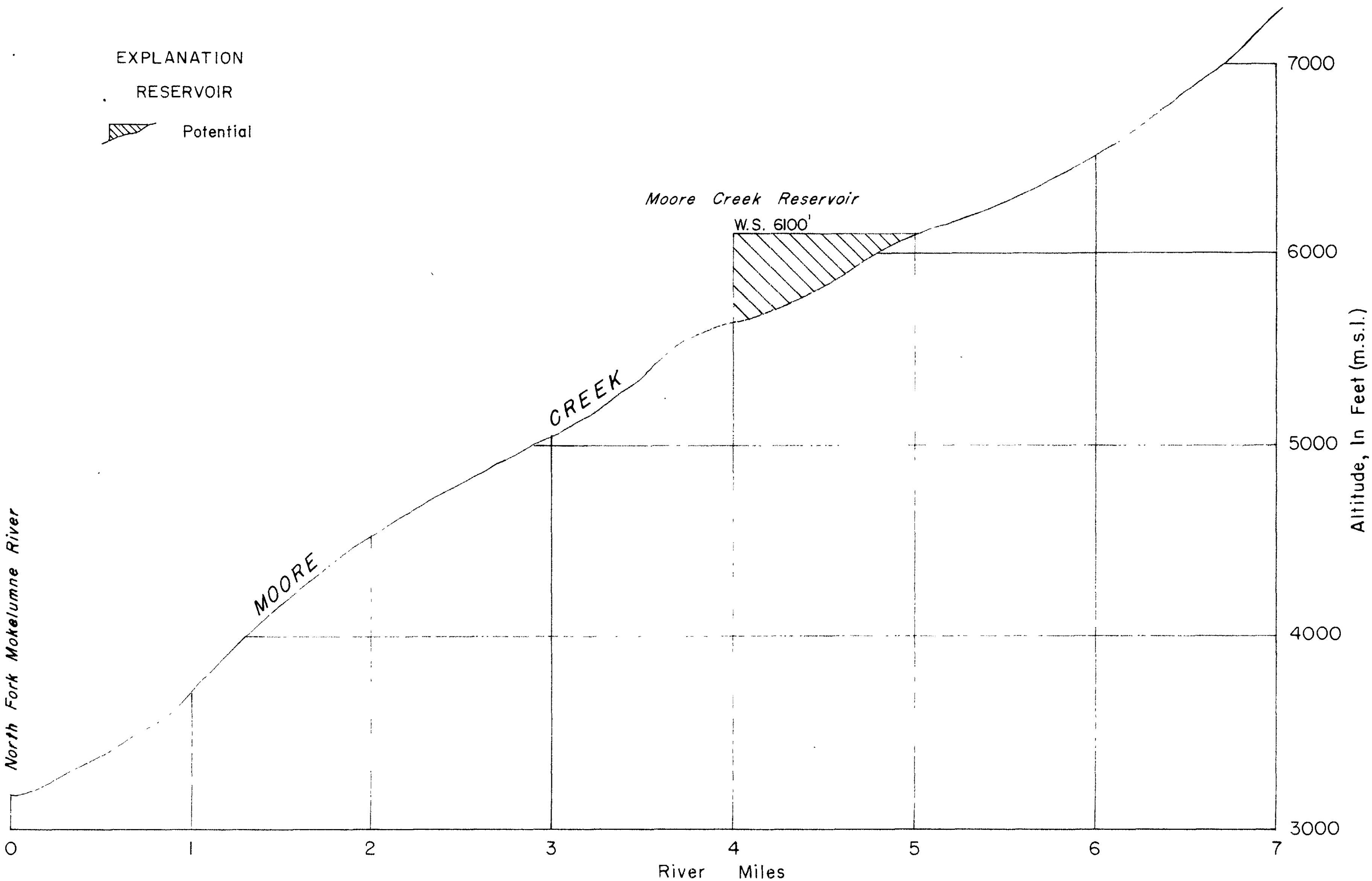

Figure 4.—— Stream profile, Moore Creek, California.

to Salt Springs Powerhouse. From Salt Springs Powerhouse the water is conveyed through Tiger Creek Powerhouse to West Point Powerhouse, and from West Point Powerhouse to Electra Powerhouse located on the main stem of the Mokelumne River. Between Salt Springs and Tiger Creek Powerhouses the water is carried by a concrete bench flume that intercepts water from several small streams enroute. Tunnels convey water between the other powerhouses.

PG&E also operates Amador Canal, which diverts water from Lake Tabeaud for domestic and irrigation uses in Amador County. Lake Tabeaud acts as the forebay to Electra Powerhouse. Annual diversion through Amador Canal of 15,000 acre-feet at a rate not to exceed 30 ft^3/s is authorized. Except for this diversion, all water utilized by the foregoing PG&E system is returned to the Mokelumne River.

Since the early 1900's the Mokelumne River has been the principal source of water supply for the metropolitan area bordering the east shore of San Francisco Bay. This area is served by EBMUD. Under existing permits and agreements the public utility is able to divert 504 ft^3/s or 364,000 acre-feet annually from the river. Three underground aqueducts transport water from the tailrace of Pardee Powerhouse at the base of Pardee Dam to Walnut Creek Pumping Plant in the East Bay area. Camanche Reservoir, with a capacity of 431,500 acre-feet, was completed in 1964 by EBMUD. This reservoir, located downstream from Pardee Reservoir, controls excess flow and permits full use of water rights at Pardee. A substantial portion of Camanche storage is allotted to flood control.

The only significant development of Mokelumne River water for use in Calaveras County is that of the Calaveras Public Utility District. This organization furnishes water to domestic and industrial users in and near the towns of Mokelumne Hill and San Andreas. The Public

Utility District operates under an agreement with EBMUD, which specifies that 9,000 acre-feet of water per season may be diverted at a maximum rate of 15 ft^3/s. The water is diverted from the South Fork Mokelumne River, about 2 miles above its confluence with the Middle Fork, into the Mokelumne Hill Ditch. The water available at the headgate of Mokelumne Hill Ditch is the natural flow of the South Fork augmented by diversion from the Middle Fork Mokelumne River about 1.5 miles below Middle Fork (Schaad) Reservoir. This diverted water is conveyed through Middle Fork Ditch to the Licking Fork, a tributary of the South Fork Mokelumne River.

Calaveras County Water District owns and operates a small reservoir on Bear Creek, tributary to the Middle Fork. Less than 400 acre-feet is diverted annually through natural stream channels and by pipeline to a second small reservoir near West Point from which the water is distributed for domestic use.

Woodbridge Irrigation District diverts more than 99,000 acre-feet of water annually from Woodbridge Reservoir into Woodbridge Canal. This water is conveyed to a system of canals and ditches in the San Joaquin Delta.

POTENTIAL PUMPED-STORAGE PROJECTS

The method and criteria used to analyze the potential Cole Creek No. 1, Cole Creek No. 2, and Moore Creek pumped-storage projects were developed by the North Pacific Division, Corps of Engineers (U.S. Army, Corps of Engineers, 1976). Each pumped-storage project meets the following basic criteria: (1) development capability of at least 1,000 MW at 85-percent efficiency; (2) sufficient reservoir storage to generate continually for 14 hours at full capacity; (3) maximum allowable drawdown limited to 180 feet: (4) maximum flow velocity limited to 20 ft/s at a maximum penstock diameter of 40 feet; and (5) penstock length limited to less than 3 miles. Developments operating at heads higher than 2,000 feet are assumed to require separate pumps and turbines.

The existing Salt Springs Reservoir (fig. 5) can be used as the lower reservoir for each of the three pumped-storage projects. Salt Springs Reservoir has a storage capacity of 139,400 acre-feet at a water surface altitude of 3,959 feet (fig. 7). Salt Springs Reservoir is now serving 9,350 kW and 29,700 kW generating units. The power generated by the three pumped-storage projects could be fed into the existing transmission facilities at Salt Springs Powerhouse for use in northern and central California.

The three pumped-storage projects were analyzed as individual units and not as a system working in conjunction with each other. A more detailed study would be necessary to determine specific operating criteria with the three projects working as a system and to determine the impact on the existing generating facilities at Salt Springs Powerhouse.

The geographic relationship between Salt Springs Reservoir and the potential Cole Creek No. 1, Cole Creek No. 2, and Moore Creek pumped-storage projects is shown on figure 8.

Cole Creek No. 1

Cole Creek No. 1 upper reservoir would be located on Cole Creek in T. 8 N., Rs. 16 and 17 E., M.D.M. A 140-foot-high dam in secs. 14 and 23, T. 8 N., R. 16 E., (fig. 6) would create a 21,000-acre-foot reservoir at a water surface altitude of 6,540 feet (fig. 9).

Figure 5.-- Salt Springs Reservoir (view east).

Figure 6.-- Cole Creek No. 1 damsite located in center of picture (view downstream).

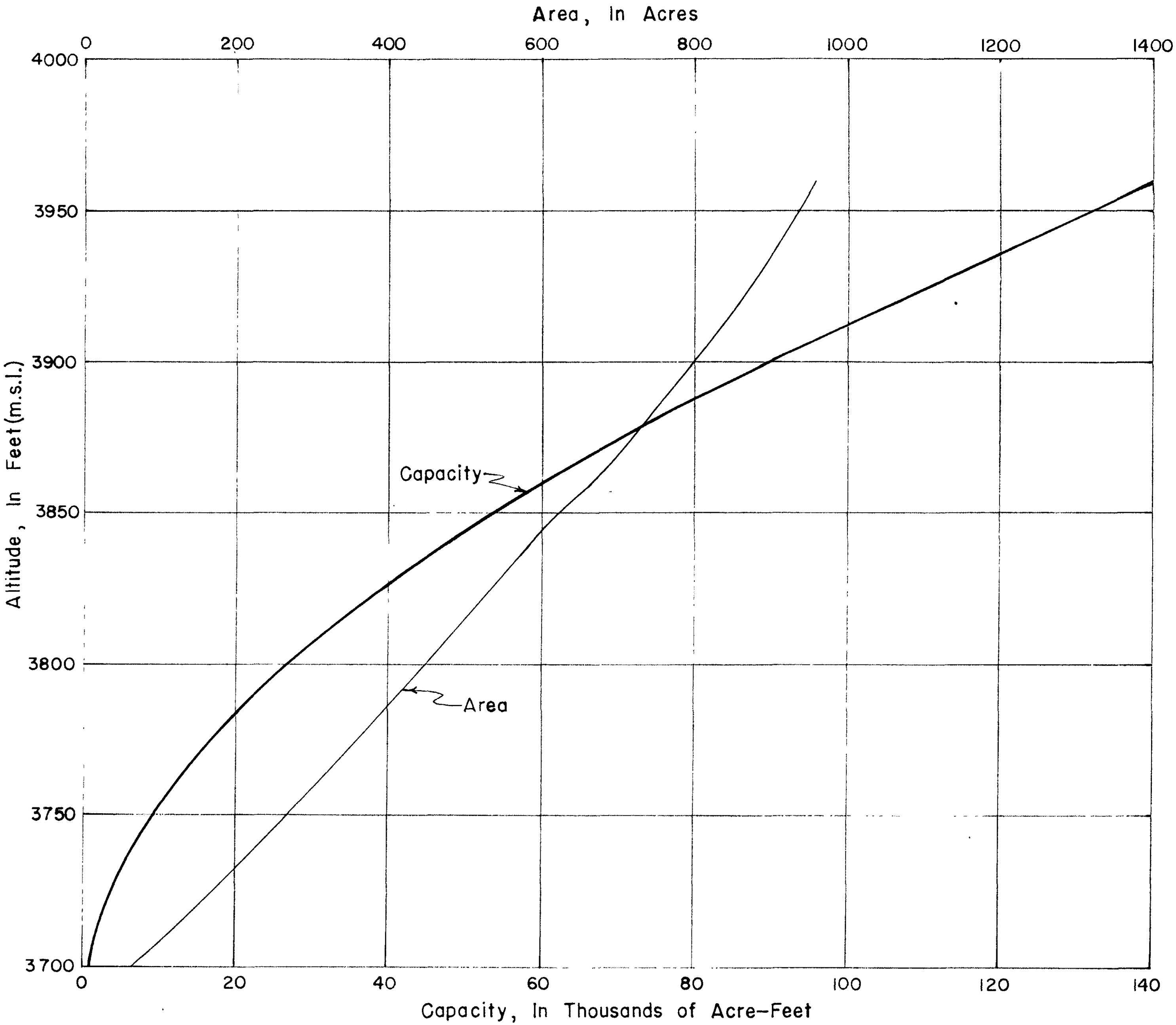

Figure 7. — Area and capacity of Salt Springs Reservoir.

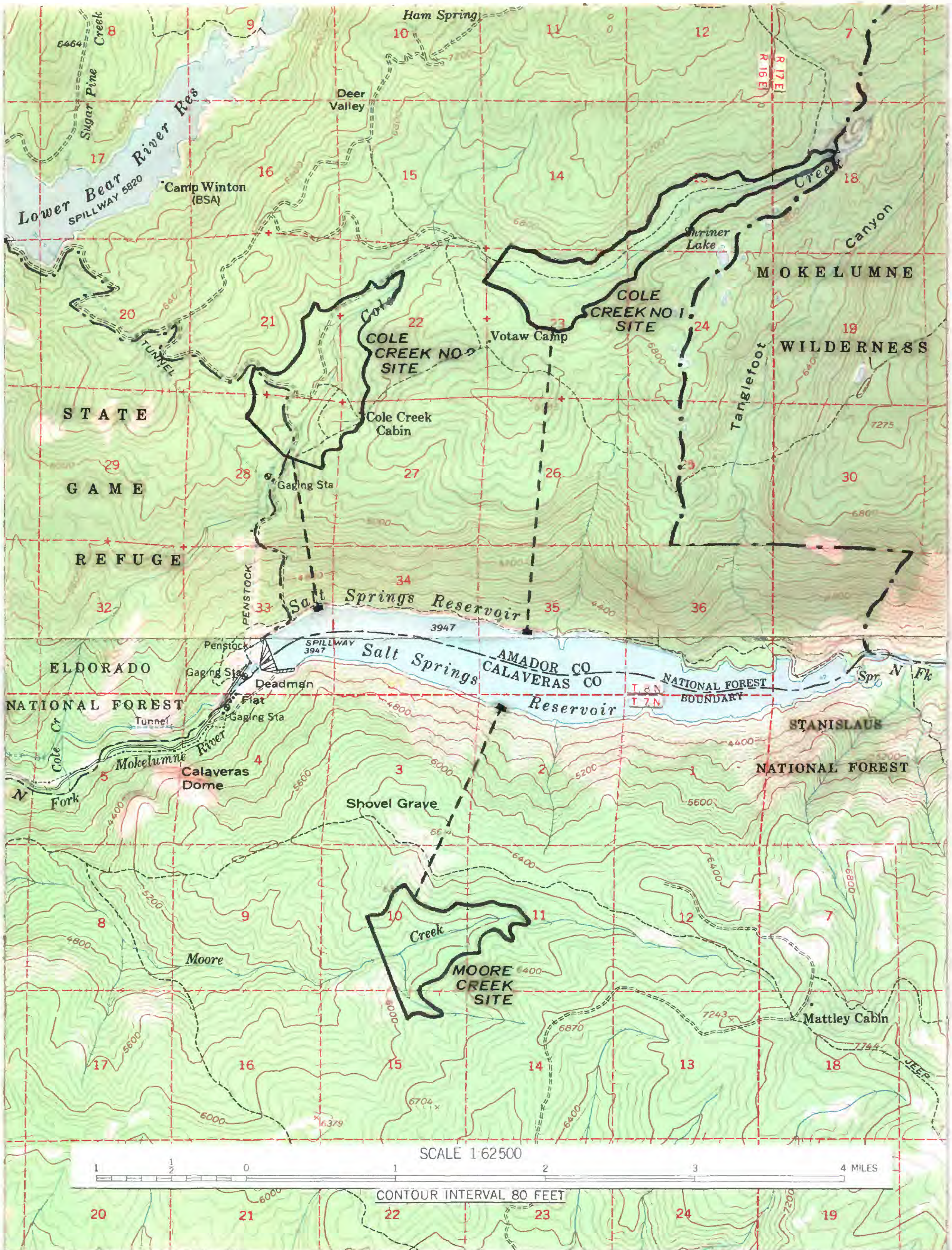

Figure 8.-- Existing Salt Springs Reservoir and potential pumped-storage development, Big Meadow and Silver Lake quadrangles, California.

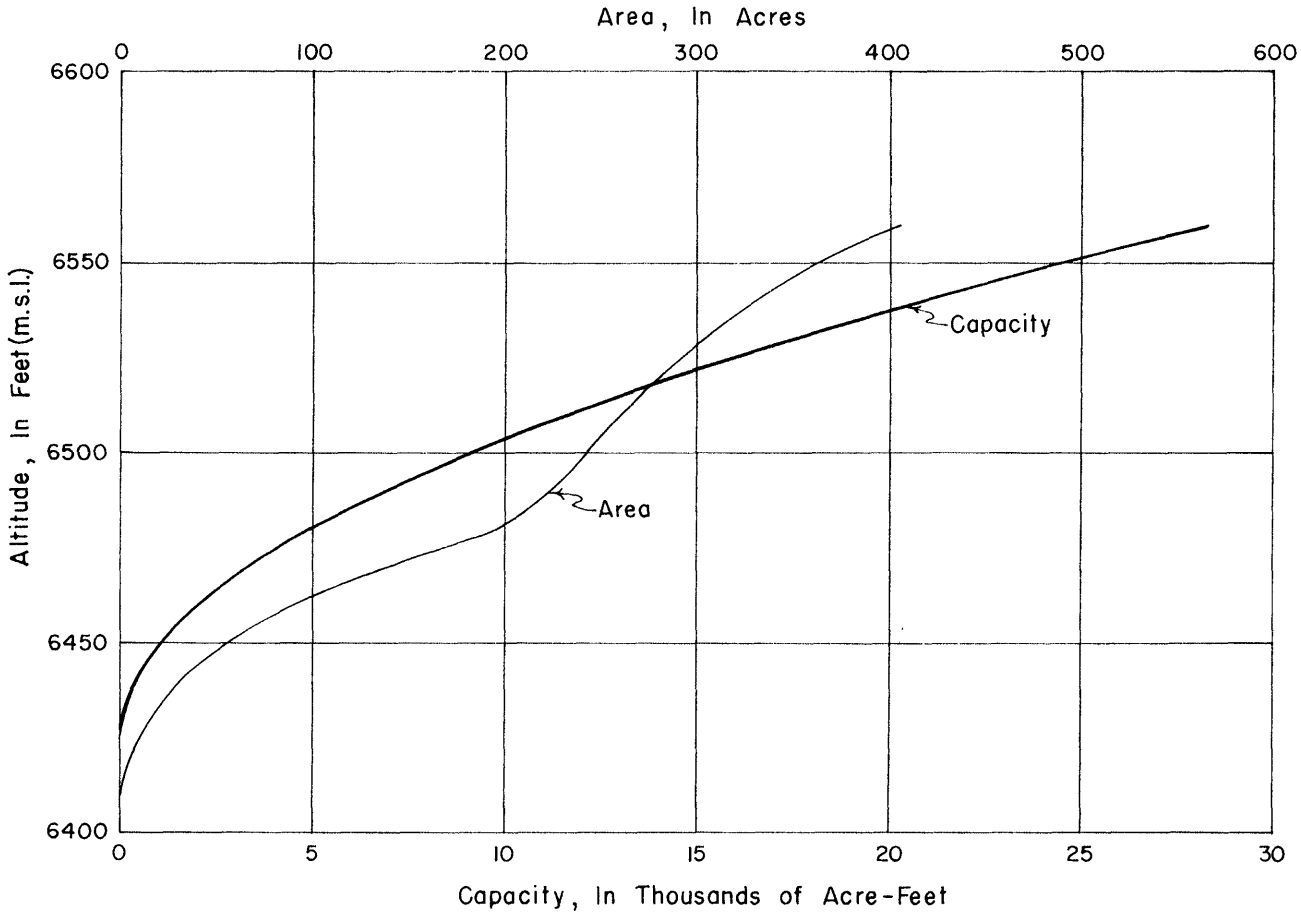

Figure 9. -- Area and capacity of Cole Creek No. I site (upper reservoir).

The usable storage capacity would be 19,200 acre-feet. With an average head of 2,580 feet, 3,000 MW of power could be produced in a continuous 14-hour generating period at 85-percent efficiency. One 32.2-foot-diameter tunnel penstock would connect the upper reservoir with the powerhouse located on the north side of Salt Springs Reservoir, approximately 1.8 miles east of Salt Springs Dam. The penstock would be 13,250 feet long. The powerhouse would consist of 9 units of 333 MW each. The maximum operational draw-down would be 82 feet and 25 feet, respectively, for the upper and lower reservoirs.

Initial filling of the upper reservoir would probably be achieved during a period of high streamflow on Cole Creek or by pumping from Salt Springs Reservoir. After the initial filling the only additional water needed would be to replace evaporation and seepage losses. Evaporation losses at Cole Creek No. 1 upper reservoir are estimated to be 1,700 acre-feet per year.

Cole Creek No. 2

Cole Creek No. 2 upper reservoir site is located on Cole Creek in T. 8 N., R. 16 E., M.D.M., about 1 mile downstream from the Cole Creek No. 1 damsite. A 370-foot-high dam located in sec. 28 (fig. 10) would create a 41,300-acre-foot reservoir at a water surface altitude of 6,240 feet (fig. 12). With a usable-storage capacity of 37,000 acre-feet and an average head of 2,280 feet, this site is capable of producing 5,100 MW of power at 85-percent efficiency for 14 hours of continuous operation. The powerhouse, with 14 units of 364 MW each, would be located on the north side of Salt Springs Reservoir, about 0.5 mile east of Salt Springs Dam. Two 31.0-foot-diameter tunnel-penstocks, each 6,800 feet in length, would connect the upper and lower reservoirs. Maximum operational draw-down for the upper and lower reservoirs would be 180 feet and 47 feet, respectively.

Water to initially fill the upper reservoir would probably come from Cole Creek during a period of high streamflow or by pumping from Salt Springs Reservoir. Additional water would be needed to replace evaporation and seepage losses. Evaporation losses at Cole Creek No. 2 upper reservoir are estimated to be 1,500 acre-feet per year.

Moore Creek

The Moore Creek upper-reservoir site is located in T. 7 N., R. 16 E., M.D.M. A 370-foot-high dam, in secs. 10 and 15 (fig. 11), would create a reservoir with a total storage capacity of 28,800 acre-feet at a water surface altitude of 6,100 feet (fig. 13). The usable storage capacity would be 24,700 acre-feet. The project would have an average head of 2,140 feet and could produce 3,200 MW of power at 85-percent efficiency in a continuous 14-hour generating period. Two 25.0-foot-diameter tunnel-penstocks, each 8,900 feet in length, would connect the upper and lower reservoirs. The powerhouse, consisting of 9 units of 356 MW each, would be located on the south side of Salt Springs Reservoir, approximately 2 miles east of Salt Springs Dam. The maximum operational drawdown would be 180 feet and 30 feet, respectively, for the upper and lower reservoirs.

Initial filling of the upper reservoir would probably be accomplished by pumping water from Salt Springs Reservoir. Additional water would be needed to replace the estimated average annual evaporation loss of 1,000 acre-feet and any seepage losses from the upper reservoir.

GEOLOGY

The Sierra Nevada in the vicinity of the Cole Creek No. 1, Cole Creek No. 2, and Moore Creek pumped-storage sites has received little geologic study since the late 1800's. At that time, the U.S.

Figure 10.-- Cole Creek No. 2 damsite (view from left abutment location).

Figure 11.-- Moore Creek damsite (view from right abutment location).

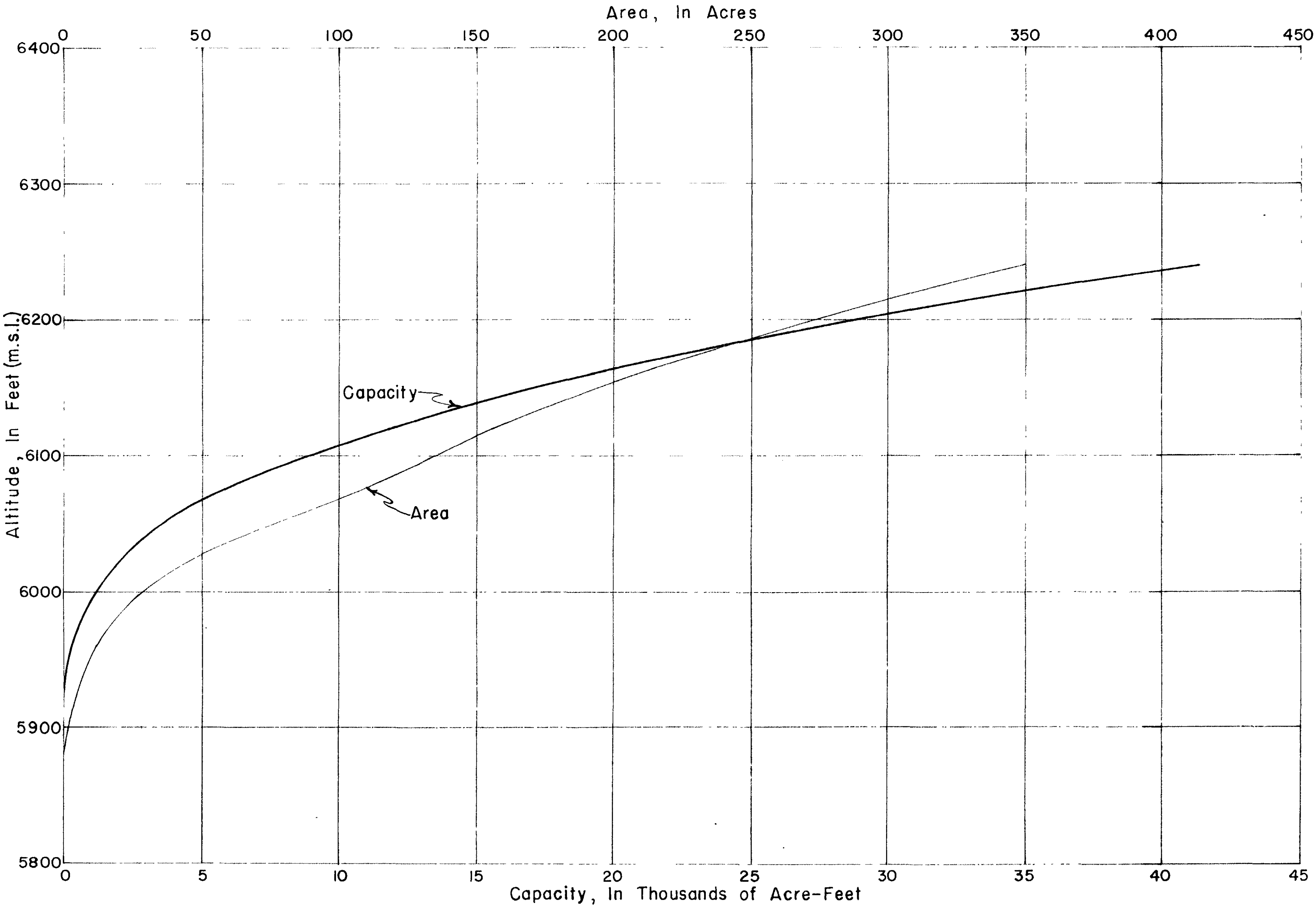

Figure 12.— — Area and capacity of Cole Creek No. 2 site (upper reservoir).

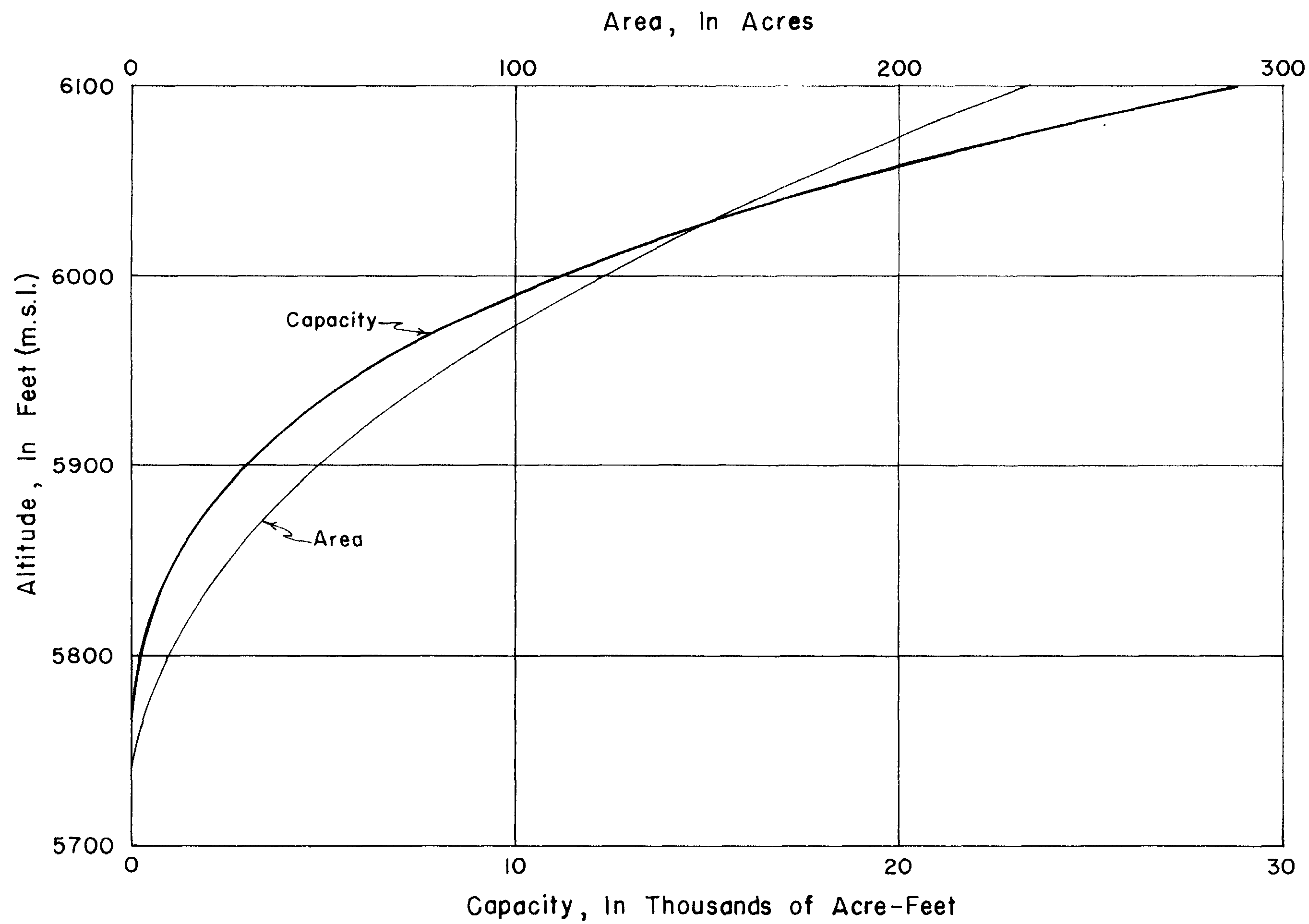

Figure 13. -- Area and capacity of Moore Creek site (upper reservoir).

Geological Survey published information pertinent to this locality as the Pyramid Peak (Lindgren and Hoover, 1896) and the Big Trees (Turner and Ransome, 1898) Folios of the Geologic Atlas of the United States. The results of these early investigations, the work of Mayo (1937) and Bateman and Wahrhaftig (1966), and F. W. Smith's field observations form the basis for the following geologic description. Figure 14 shows the areal distributions of rock types.

The predominant rock type underlying the three pumped-storage sites is granitic in appearance and texture. Because of its mineral composition it more properly can be classified as quartz monzonite or granodiorite. It is medium- to coarse-grained, has a light-gray color, and contains fine- to medium-grained inclusions that are believed to be xenoliths. The xenoliths may be remnants of the preexisting country rock that were torn off but not melted when the igneous, granitic pluton intruded the Earth's crust during the Jurassic and Cretaceous Periods about 120 to 140 million years ago. These fragments are usually elongate and vary in size from 1 by 3 in. to less elongate, larger masses up to 8 by 12 in. They are alined in a north-northwest to south-southwest direction and are believed to parallel the contact with the preexisting rock.

The granitic rocks compose the Sierra Nevada batholith which is part of a belt of plutonic rocks extending from Baja California northward through the Peninsular Ranges and the Mojave Desert, through the Sierra Nevada at an acute angle to the long axis of the range, and into western Nevada. The bulk of the batholith consists of discrete masses, or plutons, which are contiguous or are separated by thin units of metamorphic or mafic (iron and magnesium rich) igneous rocks. The individual plutons have different ages, sizes, shapes, and chemical compositions. Major plutions in the western part of the batholith are generally older than those along the crest of the range.

The regional joint patterns of the batholith are reflected in those observed at the pumped-storage site locations. Two predominant sets of joints are considered to be typical throughout the Sierra. One set strikes N 30°-50°W and the other strikes N 30°-50°E. Both have near vertical dips. Locally, in the vicinity of the pumped-storage sites, joints are widely spaced and tight. Filling of joints by secondary minerals (quartz, epidote, and minor amounts of sulfides) has been reported in other parts of the batholith. A more detailed study might reveal filling of joints by secondary minerals at the pumped-storage sites also. The granitic rocks appear in outcrop as dense, smooth, well-rounded masses. Because of this type of weathered surface, determining local attitudes of joints is often difficult.

Cole Creek No. 1

Cole Creek No. 1 upper reservoir site is located in a relatively broad, U-shaped valley containing abundant, dense vegetation. The valley walls slope gently upward to the bordering ridges. The valley floor is covered by at least 10 feet of glacial deposits composed of medium to coarse sand. There is no obvious evidence of past or potential sliding, slumping, faulting, or other types of damaging earth movement.

The right abutment, the valley floor, and part of the left abutment of the damsite are covered with vegetation and large boulders of granite and volcanic rocks. A bedrock exposure along the left abutment indicates that the bedrock underlying the damsite is composed of competent, dense granitic rocks of the Sierra Nevada batholith. A more detailed investigation would be necessary to determine the exact type and physical characteristics of the bedrock.

Materials necessary for construction of a dam and roads are locally available. The alluvium and glacial deposits could furnish an abundant source of well-sorted sand for pervious fill and concrete. Riprap and aggregate for concrete can be derived from the bouldery material near the damsite or from quarries in the granitic bedrock. The same quarries can provide crushed rock for road surfaces and subgrades.

Cole Creek No. 2

The valley walls at the Cole Creek No. 2 upper reservoir site are steeper than at the Cole Creek No. 1 upper reservoir site. The reservoir area is covered with dense vegetation and large granitic rock outcrops. There is no evidence of past or potential sliding, slumping, faulting, or other types of damaging earth movement.

The gradient of Cole Creek increases at the damsite so, during periods of high streamflow, the streambed has been scoured clean of all but the largest cobbles and boulders. Outcrops indicate that the abutments are underlain by competent, dense granitic rocks of the Sierra Nevada batholith. A more detailed investigation of joint patterns and possible fault locations would be needed to determine the exact nature of the underlying bedrock. Higher on the valley walls the abutments are covered with dense vegetation.

Construction materials for the dam and roads are locally available. In the alluvium farther upstream where the gradient flattens out there is an abundant source of well-sorted sand for pervious fill and concrete. Quarries in the granitic bedrock would provide riprap, aggregate for concrete, and crushed rock for road surfaces and subgrades. Riprap and aggregate can also be derived from nearby bouldery deposits.

Moore Creek

The Moore Creek upper reservoir site is underlain by granitic rock of the Sierra Nevada batholith and by volcanic breccia composed of angular rock fragments varying in diameter from 0.5 to 18 in. In outcrop the breccia has a weathered, crumbly matrix and contains a variety of volcanic fragments, mostly andesite, vesicular andesite, and pumice. One outcrop on the northern side of the site is extensively fractured into small, angular fragments measuring 1 to 3 in. on each side. These rocks are believed to have been deposited during an episode of intense volcanic activity spanning the latter part of the Tertiary Period, about 2 to 10 million years ago. At that time, lava flows were extruded along the crest of the mountain range and flowed down the ancient river channels.

The bed of Moore Creek is composed of boulders ranging in diameter from a few inches to several feet. Most of the reservoir area is densely vegetated with underbrush and large trees. This dense vegetation prohibits both a satisfactory view of the valley floor's shape and an investigation of the underlying bedrock. There is no evidence of past or potential sliding, slumping, faulting, or other types of damaging earth movement. The steep slopes underlain by volcanic rocks may be somewhat unstable, owing to deep weathering and fracturing. Those areas would require subsurface investigation to determine the depth of weathering.

There are no rock outcrops at the abutment sites. The nearest outcrops to the abutments consist of granitic rocks, which appear to be only slightly weathered. Subsurface investigations will be necessary to determine the thickness of surficial material and the physical characteristics of the underlying bedrock.

Materials necessary for construction of a dam and roads are locally available. Riprap and aggregate for concrete can be derived from the bouldery valley fill underlying the reservoir site or from quarries in the granitic and volcanic bedrock. The quarries can also provide crushed rock for road surfaces and subgrades. Further investigation may reveal the existence of deposits of deeply weathered volcanic rock that, after processing, would serve as impervious core material for the dam.

COST ANALYSIS

The method used to analyze the cost of the three potential pumped-storage projects discussed in this report was developed by the North Pacific Division, Corps of Engineers using January 1971 cost levels. The costs obtained using the Corps procedure can be directly updated by using the engineering cost index from "Engineering News-Record" magazine (1979). The Corps tested their cost-estimating method by comparing costs of recently built or planned pumped-storage projects with costs developed, for the same projects, using the Corps method. Values were comparable in nearly all cases considered.

Cost estimates were prepared for the following physical items: (1) embankment (dams and dikes), (2) relocation, (3) penstock, and (4) powerhouse and equipment. The embankment cost provides for minimal outlet or spillway works. The total investment cost included all these items and an additional amount for contingencies, engineering and overhead, and interest during construction. The annual capacity cost was determined by applying interest and amortization to the investment cost and adding the cost of operation, maintenance, and replacement. The annual capacity cost does not include the cost of pumping energy and should not be directly compared with capacity costs for alternative peaking sources without the addition of a pumping-energy cost. The pumping-energy cost is dependent upon the portion of the peak load to be carried by the pumped-storage project and by the source of the pumping energy. The investment cost and annual capacity cost for each of the three pumped-storage projects is shown in table 3. All costs are based on 6 7/8 percent interest rate and January 1979 cost level.

Table 3.--Capacity costs

	Investment cost		Annual capacity cost 1/	
	Total	$/kW	Total	$/kW-yr
Cole Creek No. 1----	$554,000,000	184.7	$46,100,000	15.4
Cole Creek No. 2----	952,200,000	186.7	79,200,000	15.5
Moore Creek---------	645,900,000	201.8	53,600,000	16.8

1/ Does not include pumping costs.

In the Corps' 1976 report on potential pumped-storage sites in the Pacific Northwest all projects having an investment cost higher than an arbitrary value of $240 per kilowatt (July 1975 cost level) were eliminated from further consideration. Revised to January 1979 cost levels, the upper limit is $298 per kilowatt. The pumped-storage sites analyzed in this report are less than the upper limit.

ENVIRONMENTAL CONSIDERATIONS

The environmental impact of the three pumped-storage projects warrants close consideration. The large drawdowns would limit recreational activities at Salt Springs Reservoir [illegible] alter existing recreational activities at Salt Springs Reservoir. The Mokelumne Wilderness area is located immediately upstream from the

Cole Creek No. 1 upper reservoir site. Part of the Cole Creek No. 2 upper reservoir and dam would be located in State Game Refuge 1-J, but the impact would probably be negligible, because of the small area involved. Wildlife habitat would be reduced and several acres of valuable timberland would be lost in the upper reservoir areas. The impact on the fishery resource would involve the change from strictly stream fishing to stream and reservoir fishing on Cole and Moore Creeks. This would probably be an enhancement because the fishery resource of Cole and Moore Creeks is limited by stream size and streamflow. The impact from transmission lines could be minimized by using the existing facilities from Salt Springs Reservoir.

Assessing all environmental impacts would require the more detailed studies called for by State and Federal laws.

LAND AFFECTED BY THE POTENTIAL PROJECTS

Approximately 4,160 acres of land would be affected by the three pumped-storage projects. The affected land comprises 2,820 acres of Federal land, 500 acres of Federal land withdrawn under Federal Power Project 137, and 840 acres of private land. The division of land at each of the three pumped-storage sites is given in table 4.

Table 4.--Acreage affected

Site	Federal land	Federal land withdrawn under Federal Power Project 137	Private land
Cole Creek No. 1---	1/ 800	1/ 40	800
Cole Creek No. 2---	1/ 700	1/ 420	40
Moore Creek--------	2/ 1,320	2/ 40	0
Total------	2,820	500	840

1/ Eldorado National Forest land.

2/ Stanislaus National Forest land.

The 2,820 acres of Federal land not withdrawn for waterpower or reservoir site purposes is described below.

Mount Diablo Meridian, California

Amador and Calaveras Counties

	Acres
T. 7 N., R. 16 E.,	
sec. 2, $SW\frac{1}{4}NW\frac{1}{4}$ and $NW\frac{1}{4}SW\frac{1}{4}$;	80
sec. 3, $SE\frac{1}{4}NE\frac{1}{4}$ and $E\frac{1}{2}SE\frac{1}{4}$;	120
sec. 10;	640
sec. 11, $S\frac{1}{2}NW\frac{1}{4}$, $N\frac{1}{2}SW\frac{1}{4}$, and $SW\frac{1}{4}SW\frac{1}{4}$;	200
sec. 15, $NE\frac{1}{4}$, $N\frac{1}{2}NW\frac{1}{4}$, and $SE\frac{1}{4}NW\frac{1}{4}$.	280
T. 8 N., R. 16 E.,	
sec. 13, $SE\frac{1}{4}NW\frac{1}{4}$;	40
sec. 14, $N\frac{1}{2}SW\frac{1}{4}$;	80
sec. 21, $SE\frac{1}{4}NE\frac{1}{4}$, $N\frac{1}{2}SE\frac{1}{4}$, and $SE\frac{1}{4}SE\frac{1}{4}$;	160
sec. 22, $NE\frac{1}{4}NE\frac{1}{4}$, $S\frac{1}{2}NE\frac{1}{4}$, $S\frac{1}{2}NW\frac{1}{4}$, and $W\frac{1}{2}SW\frac{1}{4}$;	280
sec. 23, $S\frac{1}{2}N\frac{1}{2}$, $SE\frac{1}{4}SW\frac{1}{4}$, and $NW\frac{1}{4}SE\frac{1}{4}$;	240
sec. 26, $E\frac{1}{2}W\frac{1}{2}$;	160
sec. 27, $W\frac{1}{2}NW\frac{1}{4}$ and $NW\frac{1}{4}SW\frac{1}{4}$;	120
sec. 28, $E\frac{1}{2}E\frac{1}{2}$ and $NE\frac{1}{4}NW\frac{1}{4}$;	200
sec. 33, $NE\frac{1}{4}NE\frac{1}{4}$ and $N\frac{1}{2}SE\frac{1}{4}NE\frac{1}{4}$;	60
sec. 35, $E\frac{1}{2}NW\frac{1}{4}$.	80
T. 8 N., R. 17 E.,	
sec. 18, $SW\frac{1}{4}NW\frac{1}{4}$ (lot 2).	40

All portions of the following described land lying outside the Mokelumne Wilderness aggregate approximately 40 acres:

T. 8 N., R. 17 E.,	
sec. 18, $SE\frac{1}{4}NW\frac{1}{4}$ and $NW\frac{1}{4}SW\frac{1}{4}$ (lot 3).	40
Total	2,820

CONCLUSIONS AND RECOMMENDATIONS

The primary advantage associated with development of the Cole Creek No. 1, Cole Creek No. 2, and Moore Creek pumped-storage sites is the use of the existing Salt Springs Reservoir as the lower reservoir. This use would reduce the time required to complete the projects. Depending on the construction schedule, some of the water needed initially to fill the Cole Creek No. 1 and No. 2 upper reservoirs could come from natural streamflow during periods of high flow. Otherwise, the upper reservoirs would be filled by pumping from Salt Springs Reservoir. Evaporation and seepage losses could be replaced from natural streamflow throughout most of the year. Water to fill the Moore Creek upper reservoir would be pumped from Salt Springs Reservoir. Evaporation and seepage losses could be partly replaced by the natural streamflow of Moore Creek.

On the basis of a reconnaissance study, the upper reservoir and penstock areas for the pumped-storage sites appear to be geologically suitable for development. No evidence exists of past or potential sliding, slumping, faulting, or any other types of damaging earth movement. The damsites appear to be underlain by granitic rocks of the Sierra Nevada batholith. The bedrock is relatively joint-free and the joints that do exist are widely spaced and tight. Small outcrops of volcanic breccia were found in the Moore Creek upper reservoir site. The steep slopes underlain by the volcanic material could be unstable as a result of deep weathering and fracturing. Subsurface investigation would be necessary to determine the depth of weathering. Loss of water from the upper reservoirs by seepage would probably be minimal, because of the strong character of the underlying bedrock. Materials for construction of dams and roads are locally available.

Physical property measurements and rock strength measurements of foundation rocks and all construction materials should be made to determine suitability of use. Geophysical surveys to determine bedrock characteristics in the upper reservoir and penstock areas would also be needed. A systematic core drilling and trenching program must precede any engineering design work, to determine bedrock character information and depth of soil cover. More thorough geologic mapping should be done to pinpoint specific problem areas and outline source areas for construction material.

The investment cost for each of the three pumped-storage projects is less than the upper limit of $298 per kilowatt used by the North Pacific Division, Corps of Engineers as a cutoff point for further investigation. Project justification would depend on the annual capacity cost including the cost for pumping energy. Pumping-energy cost is dependent upon the source of the pumping energy and the plant operation. The determination of plant operation is beyond the scope of this investigation.

The information presented in this report illustrates that the Cole Creek No. 1, Cole Creek No. 2, and Moore Creek pumped-storage sites have potential for waterpower development. Land-management agencies should consider this resource value when making land use decisions or developing any plans affecting the 2,820 acres of Federal land located within the potential sites not withdrawn for waterpower or reservoir site purposes.

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