Geologic Reconnaissance of a Proposed Powersite at Lake Grace, Revillagigedo Island, Southeastern Alaska

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By ALEXANDER A. WANEK *and* JAMES E. CALLAHAN

GEOLOGY OF WATERPOWER SITES IN ALASKA

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A feasibility study of geologic conditions at a proposed powersite

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By Alexander A. Wanek and James E. Callahan

ABSTRACT

The proposed Lake Grace powersite is 32 miles northeast of Ketchikan on the east side of Revillagigedo Island, Alaska. The region is mountainous and glaciated and lies within the Coastal Foothills section of the Coast Mountains province. It is accessible only by float plane, helicopter, or foot travel.

The powersite is underlain by a complex zone of intrusive and metamorphic rocks that border the composite Coast Range batholith. This group of rocks is a part of the Wrangell-Revillagigedo metamorphic belt, which is intruded by masses of quartz diorite. Quartz diorite and diorite gneiss and lesser amounts of diorite and granodiorite are exposed at the powersite. Almost all the igneous activity in southeastern Alaska is considered Jurassic or Cretaceous in age. Later igneous activity is represented at the east end of Lake Grace by a plug of basaltic breccia intruded into diorite gneiss. The hill north of the left abutment of the damsite is capped by a sequence of basalt flows and interbedded tuff. The volcanic rocks are late Cenozoic in age.

Deposits of marine fossiliferous laminated and crossbedded gravel and sand occur in high-level terraces along Trail and Grace Creeks. Field relations indicate that these deposits are prevolcanic and may be Quaternary in age. The terrace gravels and the alluvium at the head of Lake Grace and on Grace Cove are potential sources of aggregate.

The many large lineaments that trend north or northwest through the Alexander Archipelago indicate major shear zones or faults. The Coast Range lineament borders the east side of Revillagigedo Island and passes under Behm Canal; the Clarence Strait and Chatham Strait lineaments, which trend northwest, indicate a continuation of the Denali fault. Small linear features within the powersite, traceable on the aerial photographs and possibly related to the large lineaments, may be interpreted as faults or joints.

The proposed damsite is in the canyon of Grace Creek 0.5 mile below the outlet of Lake Grace. The abutments at the damsite are competent diorite gneiss and are capable of taking the thrust of the arch dam proposed for the site. The proposed tunnel route, which is 3,500 feet long, will penetrate diorite gneiss.

Some concrete lining may be required in zones of broken rock. The proposed penstock alinement is on a steep colluvial slope from the tunnel outlet to the powerhouse; penstock anchors will require footing excavated into bedrock.

The powerhouse area is underlain by diorite gneiss above Grace Creek. The site must be chosen carefully because of the potential hazard of slides from the volcanic flows capping the hill.

Leakage from the damsite should be negligible. More exploratory drilling will be required to determine the extent of the zones of broken rock beneath the foundation and their relation to the linear features in the powersite. Also, a seismic survey and several deep drill holes are required in the damsite to determine whether the basalt actually extends to depth and overlies diorite gneiss or if there may be some unconsolidated material at depth. The tunnel route will also require additional exploration. The landsliding that will occur with the rise of the water level in Lake Grace should not create a hazard. However, a potential hazard may be the gravity movement of large cueva-type volcanic blocks into the narrow canyon above the damsite. These factors must be considered in the design of the dam.

INTRODUCTION

This report is based on the geologic reconnaissance of a proposed powersite at Lake Grace on the east side of Revillagigedo Island, 32 air miles northeast of Ketchikan, southeastern Alaska. The field investigation was made in June 1964 at the request of the Branch of Waterpower Classification, Conservation Division, to furnish geologic information for use in evaluating some of the waterpower resources of southeastern Alaska.

The authors wish to acknowledge the logistic support provided by Gordon C. Giles, Regional Hydraulic Engineer, U.S. Geological Survey.

GEOGRAPHY

Revillagigedo Island in the Alexander Archipelago (fig. 1) between lat 55°00′ and 56°00′ N. and long 131°00′ and 132°00′ W. is 55 miles long and about 35 miles wide. It is separated from the mainland by Behm Canal, which borders the island on the east, west, and north. The island is rugged and mountainous. The few roads and trails are mainly in the vicinity of Ketchikan in the southwestern part of the island. The interior of the island is accessible by float plane or by boat along the waterways which penetrate deeply inland.

Transportation to Revillagigedo Island is by airplane or boat. Commercial airlines have scheduled flights to Annette Island, the airport for Ketchikan, and charter flights to other points of the island. Air charter service is also available from air taxi operators based at Ketchikan, Juneau, and Petersburg. The State of Alaska ferry system maintains weekly transportation between Seattle and Ketchikan and other points in southeastern Alaska. The Alaska Steamship Co. furnishes commercial freight transportation between Seattle and Ketchikan and other ports along the Alaska coastline.

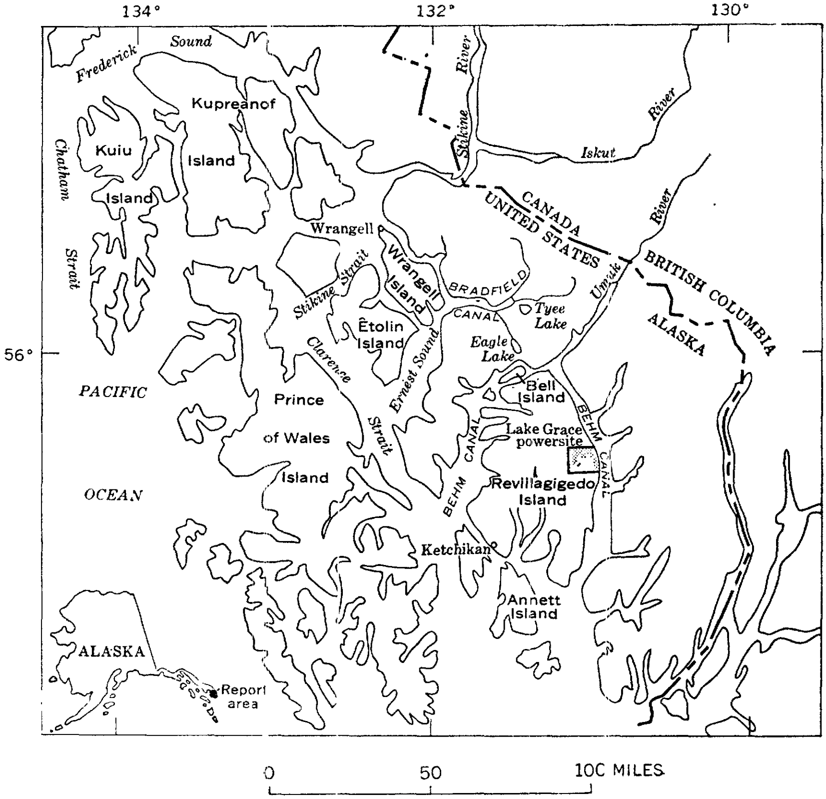

FIGURE 1.—Location of the Lake Grace powersite.

The population of Revillagigedo Island is concentrated along the southern coastline. Ketchikan, the largest city, had a population in 1960 of 6,483 and an additional 5,500 people within its trading area. Metlakatla on Annette Island had a population in 1960 of 1,466. Other small settlements such as Mountain Point, Saxman, and Ward Cove are fishing centers. Fishing and lumbering are the main industries in this part of Alaska.

CLIMATE AND VEGETATION

The climate of this area is typical of southeastern Alaska. The region has mild winters, cool summers, and heavy precipitation. The amount of precipitation increases progressively from June, one of the drier months, to a peak in November. According to the U.S. Weather Bureau (1965), the annual precipitation at Ketchikan averaged 154.01 inches from 1951 to 1960. At Bell Island, immediately north of

Revillagigedo Island, the annual precipitation averaged 108.67 inches for the period 1929–52 (U.S. Weather Bureau, 1958).

The mean annual minimum and maximum temperatures at Ketchikan from 1951 to 1960 were 35.1°F. and 58.9°F., respectively. The mean annual minimum and maximum temperatures at Bell Island from 1922 to 1952 were 29.6°F. and 58.8°F.

For the period 1951–60, the mean annual snowfall for Ketchikan was 32.9 inches; for the period 1922–52, the mean annual snowfall for Bell Island was 116.00 inches. The greatest amount occurs during December, January, and February (U.S. Weather Bureau, 1958). The snow cover is generally gone by June at lower altitudes and by August on most of the ridges. Lakes in deep basins are usually covered by ice until mid-July. Some lakes at higher altitudes are not free from ice until mid-August.

A heavy growth of vegetation covers much of the area. Hemlock, Sitka spruce, and cedar are the most abundant of the conifers and usually grow in dense stands. Alder, devilsclub, and berry bushes form thick, almost impenetrable undergrowth on steep slopes, alluvial fans, and landslide areas. Small peat bogs and mudflows are in undrained depressions on bedrock. Timberline is generally at about 2,000 feet, and above this altitude the bedrock is covered by a growth of grass, lichen, and heather. The entire island is a part of the Tongass National Forest.

TOPOGRAPHY AND DRAINAGE

Revillagigedo Island, which is within the Coastal Foothills section of the Coast Mountains province (Wahrhaftig, 1965), contains rugged mountains ranging from 1,000 to 4,500 feet in altitude. Those mountains less than 3,500 feet high were glacially overriden and have rounded hummocky summits; higher mountains are generally sharp crested. Most valleys are flat floored and steep walled, and the drowning of the lower parts of the valleys forms inlets and harbors. The interior of the island contains many lakes in rock basins; the largest are Manzanita Lake, Lake Grace, Swan Lake, and Mirror Lake, all of which are near the central and eastern part of the area of highest mountains. Few streams are more than 10 miles long. This part of the Coastal Foothills section has no glaciers at this time. There is no permafrost.

The indented coastline and the deep lake-filled valleys of Revillagigedo Island show a strikingly similar parallel linear orientation, a pronounced north and east to northeast trend that may reflect a conjugate set of joints or shears. Twenhofel and Sainsbury (1958) believed that many of these linear features are faults or shear zones.

Brew, Loney, Pomeroy, and Muffler (1963) concluded from their geologic investigations on Baranof Island that a conjugate system of joints and foliation form some linear features in that part of Alaska.

PREVIOUS INVESTIGATIONS

Some of the earliest reconnaissance studies of the geology and mineral resources of southeastern Alaska were made by Blake (1868), who in 1863 accompanied a Russian expedition sent to the Stikine River to establish the boundary between Russian and English possessions. Dall (1896) and Becker (1898) studied the gold and coal resources of southern Alaska and visited localities in the Alexander Archipelago and on the adjacent mainland. The geology and the ore deposits of the Ketchikan mining district were described by Brewer (1901) and Brooks (1902, p. 107–109). F. E. and C. W. Wright (1908) made geologic investigations of the Ketchikan and Wrangell mining districts and structural studies of the Coast Range. Knopf (1910, 1912) made detailed geologic investigations of the Eagle River region and visited mining localities in the Ketchikan district. Mertie and Canfield (1921) made a reconnaissance of geologic and mineral resources in the Glacier Bay and Lynn Canal regions and visited all the producing mines in the Juneau and Ketchikan districts. Buddington and Chapin (1929) made comprehensive reconnaissance geologic studies in southeastern Alaska. Dort (1924) investigated the power potential and possible waterpower development of the lakes in southeastern Alaska. The general plans for waterpower development in this area were described in the report by the Federal Power Commission and U.S. Forest Service (1947). Twenhofel and Sainsbury (1958) studied fault patterns and their relation to ore deposits in southeastern Alaska. Callahan and Wanek (1969) made reconnaissance geologic studies of proposed powersites at Tyee, Eagle, and Spur Mountain Lakes.

PRESENT INVESTIGATION

The present investigation consisted of field examination of the proposed damsite and reservoir area at Lake Grace, a possible tunnel and penstock route, and several powerhouse sites along Grace Creek. Geologic mapping at the damsite, along the tunnel route, and at the powerhouse sites was by foot traverse, and data were plotted on aerial photographs and on river survey topographic maps. Lake Grace is shown on the U.S. Geological Survey Ketchikan 1:250,000-scale reconnaissance topographic quadrangle maps. The damsite is also shown on the Lake Grace 1:24,000- and 1:2,400-scale river survey maps. The areas are included in the U.S. Navy aerial photographs SEA 110–017 through 019, SEA 112–119 through 121, and SEA 112–019 through 021, taken August 1948, scale approximately 1:40,000 at sea level. Aerial photographs were used to determine the general structural features in the map area and the adjacent areas. Many observations were made at the abutments of the damsite and along the reservoir, and samples of the bedrock were taken for petrographic and chemical analyses. A light fiber-glass motorboat was used in the geologic mapping along the shores of the lake.

REGIONAL GEOLOGY

The powersite lies in the Wrangell-Revillagigedo belt of metamorphic rocks and the associated bordering intrusive bodies of the Alexander Archipelago and the Glacier Bay region of southeastern Alaska (Buddington and Chapin, 1929). The Wrangell-Revillagigedo metamorphic belt trends northwest across Revillagigedo Island and is bordered on the east by the Coast Range batholith. The metamorphic belt consists of injection gneiss, crystalline schist, marble, phyllite, and highly schistose greenstone, and intermingled intrusive masses of quartz diorite. Much of the western boundary of the metamorphic belt is formed by the resistant Mesozoic greenstone, which is generally found along the west side of Revillagigedo Island.

Rocks of Carboniferous and Triassic age constitute a large part of the Wrangell-Revillagigedo metamorphic belt, and beds of possible Cretaceous and Ordovician age may be included. Quartz diorite, the predominant igneous rock, is common elsewhere in the Alexander Archipelago; the quartz diorite grades into granodiorite toward the mainland (Buddington and Chapin, 1929). The intensity of metamorphism appears to increase from west to east toward the core of the batholith. Buddington and Chapin (1929) considered most igneous activity in southeastern Alaska as Jurassic or Cretaceous in age, and most recent studies of field relations in northern southeastern Alaska have suggested a Cretaceous age (Lathram and others, 1959; Loney, 1964). Recently determined lead-alpha and potassium-argon ages of rocks in the northern part of the Alexander Archipelago indicate that some plutons may be as young as Eocene in age (Loney and others, 1967).

Major Mesozoic structures such as the Coast Mountains geanticline on the mainland, the Seymour geosyncline, and the Prince of Wales geanticline extend through this part of southeastern Alaska (Buddington and Chapin, 1929; Payne, 1955). The folding of bedrock in southeastern Alaska in positive and negative tracts was contemporaneous with folding in mid-Mesozoic time in other places in Alaska. Igneous granitic rocks of Jurassic and Cretaceous age predominate in the Coast Mountains geanticline and were probably a source of sediments deposited in the adjacent Seymour geosyncline. The Seymour geosyncline, which extends south from Juneau, is composed of metamorphosed Triassic and Jurassic slate, graywacke, and other marine sedimentary rocks interbedded with Jurassic and Cretaceous volcanic rocks and Lower Cretaceous marine clastics and impure limestone. The Prince of Wales geanticline extends along Prince of Wales Island and includes all the Alexander Archipelago to the west; it is composed chiefly of marine sedimentary rocks of Paleozoic age that are intruded by large bodies of igneous rocks.

Many large linear features that trend north or northwest through the Alexander Archipelago indicate major shear zones or faults. The major faults or lineaments such as the Clarence Strait fault and the Chatham Strait fault are west of the damsite and trend north along the outer edge of the Alexander Archipelago. The Coast Range lineament extends along the southwest border of the Coast Range batholith and has been traced for at least 370 miles (Twenhofel and Sainsbury, 1958). Many other large linear features on the mainland and the islands could be the trace of faults. The Clarence Strait and Chatham Strait lineaments trend northwest and indicate a continuation of the Denali fault, which extends from Bristol Bay along the front of the Alaska Range through Canada to the head of Lynn Canal. St. Amand (1957) inferred right-lateral movement of as much as 150 miles along part of the Denali fault. Lathram (1964) suggested right-lateral movement of about 120 miles along the Chatham Strait and Clarence Strait lineaments or faults. The observations were based on apparent displacement of major geologic features on opposite sides of the faults. Many smaller linear features, traceable on aerial photographs, can be interpreted as faults, or they may be joint controlled (Brew and others, 1963).

SEISMIC ACTIVITY

The damsite is in an area of only moderate seismic activity. Between 1843 and 1956, 17 earthquakes of moderate to severe intensity were reported in Juneau and Sitka in southeastern Alaska (Heck, 1958). Many epicenters of shallow earthquakes have been recorded along the great north-trending fault west of the Alexander Archipelago. The presence of large faults within areas of recorded seismic activity makes it imperative that the location of dams and appurtenant works be chosen carefully. The region appears to be subject to crustal unrest as shown by post-Pleistocene uplift of recent deposits along Grace Creek, near Hyder east of Behm Canal, and in other parts of southeastern Alaska (Twenhofel, 1952). Post-Pleistocene uplift, however, may have been due to either glacial rebound or to tectonic disturbances and may or may not have been accompanied by seismic shocks.

GLACIATION

Most of the mountains and all the valleys of both the mainland and the islands were buried under an ice sheet that extended across southeastern Alaska during the Pleistocene Epoch (Buddington and Chapin, 1929). The height of the surface of the ice field was not everywhere the same; the ice may have been in excess of 5,000 feet thick on the mainland and between 4,000 and 5,000 feet thick along the east side of Revillagigedo Island during the period of maximum glaciation (Coulter and others, 1965). The ice sheet covered the mountains on Revillagigedo Island to at least an altitude of 3,500 feet, as evidenced by glacial smoothing of the peaks and rounding of valleys and ridges. Subsequent alpine glaciation in late Pleistocene and Holocene time resulted in the present sculpturing of the landscape. Many of the cirques lie below the maximum surface level of the immense ice sheet that once covered the island. On Revillagigedo Island the floors of the cirques are at altitudes of 1,000–2,500 feet, and the basins either are empty or are lakes. None of the high valleys or cirques contain glaciers.

Postglacial changes in the former land level are also evident: U-shaped valleys become V-shaped at their mouths. Streams emptying from these valleys have cut deep canyons and in places flow at steep gradient or drop in spectacular falls to sea level. The fiords which intersect the coastline are former river valleys that were deepened by the ice. The submergence of the region by rise of the sea level and recession of the ice has formed picturesque channels, straits, and embayments.

The basin of Lake Grace was carved out of bedrock by a large valley glacier that flowed east to Behm Canal. The ice gouged more deeply into bedrock at the head of the valley than in the lower part and cut two deep basins, one of which extends nearly to sea level. The steep gradient of the ice flowing from the summit area probably resulted in the plucking and scouring of bedrock in the lower and less steep valley floor. The lake is impounded behind a transverse ridge, or rock lip, that separates it from Behm Canal. The most pronounced glacial erosion was due to the Cordilleran ice sheet which in Pleistocene time probably flowed southwest from centers on the mainland east of Behm Canal (Coulter and others, 1965).

Postglacial change in sea level is evident in the lower part of Lake Grace glacial valley. Terraces underlying gravel and sand beds containing marine fossils denote postglacial uplift in the lower 1½ miles of the valley. The basic evidence in this region indicates that relative postglacial uplift has probably been at least 150 feet to as much as 300 feet at Grace Creek and possibly as much as 450 feet in the Hyder district east of Behm Canal.

LAKE GRACE POWERSITE

WATERPOWER DEVELOPMENT

The general plan for waterpower development is described in a report by the Alaska Power Administration (written commun., 1968). The development plan includes a dam with an ungated spillway, a tunnel, a penstock, a powerplant, transmission lines, an unloading dock, access roads, and an artificial spawning channel for salmon. The drainage area of the Lake Grace basin above the proposed damsite is estimated at 29.2 square miles. The surface area of Lake Grace is approximately 1,650 acres at the normal lake altitude of 430 feet. The surface area of the reservoir would be 2,585 acres at the altitude of 500 feet. A proposed operating range would be from 431 to 500 feet. Storage capacity for the reservoir is estimated at 148,900 acre-feet.

The average runoff above the Grace Creek gaging station for the 11 years of record (Oct. 1927–Sept. 1939) was 309,700 acre-feet per year. The two high streamflow periods are during the rainy fall months and the spring snow melt. Inflow into the Lake Grace reservoir is computed to be 92.4 percent of the recorded runoff at Grace Creek gaging station. The estimated average annual inflow to the reservoir during the period 1928–64 was 281,000 acre-feet. The maximum and the minimum annual inflows were, respectively, 347,900 acre-feet (1931) and 205,900 acre-feet (1941).

A double-curvature thin arch dam 148 feet high about half a mile below the lake outlet is proposed. The dam would raise the water surface to the crest altitude of 500 feet. The reservoir would have a delivery capacity of 16,000 cubic feet per second at the maximum water-surface altitude of 508.25 feet. Discharge from the outlet pipe would be at the rate of 388 cubic feet per second, the average annual flow of Grace Creek at the water-surface altitude of 431 feet.

A 9-foot-diameter pressure tunnel 3,400 feet long would carry water from Lake Grace to a powerplant site on Grace Creek. The intake 50 feet upstream from the damsite would be at an altitude of 410 feet, and the tunnel would drop to an altitude of 357 feet at the outlet. A steel penstock 875 feet long and 78 inches in diameter would carry the water from the outlet to the powerplant. The powerplant would have an installed capacity of 20,000 kilowatts operating at an average annual factor of 55 percent and through a net head of 415 feet. A 115,000-volt transmission line about 39 miles long would deliver project power to a substation at Ward Cove for delivery to Ketchikan.

TOPOGRAPHY

Lake Grace (pl. 1) is about 4.7 miles long and 0.8 mile wide; the narrowest part at the constriction near the lower end of the lake is about 500 feet wide. Soundings made by the U.S. Geological Survey indicate that the lake bottom is separated into two basins by a transverse submarine ridge. The upper basin is approximately 425 feet deep, and the bottom is about 5 feet above sea level; the lower basin is approximately 220 feet deep, and the bottom is about 210 feet above sea level. The altitude of the lake surface was measured at 342 feet on June 23, 1963.

The valley above Lake Grace is flat floored, U shaped, and steep walled. Grace Creek above the lake meanders over a swampy alluviated plain. Another large stream drains a narrow basin 4 miles long on the northwest side of the lake. These streams provide the main recharge to Lake Grace. Both streams head in rugged mountains which rise to altitudes ranging from 3,400 to 4,110 feet along the divide. Eastward toward the proposed damsite, the mountains range from 500 to 2,800 feet in altitude. Lake Grace is retained behind a bedrock ridge which rises to an altitude of about 600 feet.

Grace Creek flows east from the lake outlet through a narrow gorge to Behm Canal. The gradient of the stream channel of Grace Creek is about 74 feet in a distance of 0.5 mile from the lake outlet to the damsite. Below the damsite the stream flows over several waterfalls which prevent the migration of salmon upstream from the coast. At the proposed damsite the canyon walls rise in vertical cliffs 100–150 feet high. The canyon widens below the confluence of Grace Creek and Trail Creek, is less rugged, and opens into Grace Cove.

The saddle, or notch, north of the northeast end of Lake Grace and at the head of Trail Creek is at the approximate altitude of 700 feet. The saddle was probably cut by meltwater flowing from the glacier which once occupied the basin or by drainage from a former lake which at one time filled the basin to this altitude. The erosion of the bedrock along the saddle was controlled by joints and by the weathering of bedrock of different lithologies. Another saddle about 3,000 feet northeast at approximately the same altitude is cut in homogeneous rocks and is probably joint controlled.

GEOLOGY

METAMORPHIC AND IGNEOUS ROCKS

Quartz diorite gneiss and quartz diorite underlie the Lake Grace powersite. Quartz diorite gneiss is exposed in the eastern third of the reservoir and in the valley walls all the way to Behm Canal; quartz diorite is exposed in the western part of the map area.

Immediately east of Lake Grace, a plug of basalt breccia is intruded into quartz diorite gneiss, and basalt flows overlie an area east of the volcanic plug. Outcrops of the basalt breccia occur at places along Grace Creek upstream from the proposed damsite; a sequence of the basalt flows and intercalated tuff beds cap the hill north of the left abutment of the damsite.

QUARTZ DIORITE GNEISS

Quartz diorite gneiss is the predominant metamorphic rock exposed at the powersite. Associated with the quartz diorite gneiss are small masses of diorite, granodiorite, and, commonly, inclusions of amphibolite. In most outcrops the rock is gneissic. In the western part of the map area the diorite gneiss is greenish gray and medium grained and grades into hornblende-biotite diorite and granodiorite; foliation or schistosity is not distinct. Segregation layering is not conspicuous, but hornblende prisms and biotite show some orientation. At the damsite the quartz diorite gneiss is intercalated with greenish-gray amphibolite interlayered with light-colored quartz diorite that is very siliceous and cut by many quartz stringers. Segregation layering is conspicuous, and the mafic minerals show a preferred orientation. The diorite gneiss is fine grained. It is well foliated or schistose and locally shows contortion; foliation layering ranges from a few inches to as much as several feet in thickness. Weathering of the rock is generally moderate, but severe weathering is apparent along highly micaceous zones.

The amphibolite is dark greenish gray, fine grained, and schistose; it is conspicuously interlayered with diorite gneiss in bands from a few inches to as much as several hundred feet thick. The amphibolite is composed chiefly of hornblende and plagioclase and may be representative of an amphibolite facies formed by regional metamorphism.

QUARTZ DIORITE

The quartz diorite is fine to medium grained and generally predominantly light gray to white, mottled black and white. Black prismatic crystals of hornblende are common, and biotite occurs in hexogonal flakes and chunky crystals as much as 1–2 mm long. The ferromagnesian minerals may be separate and oriented or segregated in small patches or narrow lenticles ranging from a fraction of an inch to as much as 1 foot in thickness.

The average mineral composition of representative types of quartz diorite from the mainland batholith (Buddington and Chapin, 1929) is given in table 1. The average mineral composition of samples collected in the powersite indicates that zoned andesine and oligoclase are the predominant minerals and make up 40–50 percent of the rock. Hornblende and biotite form about 20–30 percent of the rock, and usually hornblende predominates over biotite. Quartz is common as interstitial material, and in samples taken from fracture zones there may be as much as 20 percent quartz. Orthoclase is rare or absent. Some calcite is present along fractures, and biotite shows some alteration to chlorite. The accessory minerals include garnet, sphene, apatite, and zircon, in that order of abundance, and amount to about 2 percent. Some rutile needles are present in the quartz grains. Chemical analyses of five samples collected in the powersite are given in table 2.

TABLE 1.—*Average mineral composition of the Coast Range batholith*

[After Buddington and Chapin, 1929, p. 209]

	Percent		*Percent*
Quartz	19. 4	Titanite	1. 3
Orthoclase	6. 6	Epidote	3. 5
Andesine ($Ab_{56}An_{44}$)	47. 4	Chlorite	. 1
Hornblende	7. 6	Calcite	. 1
Biotite	11. 6	Kaolin and muscovite	. 8
Apatite	. 6		
Magnetite	. 9		100. 0
Pyrite	. 1		

BASALT

Volcanic rock north of the lake outlet is a basaltic breccia. The relationship of the basalt to the quartz diorite gneiss indicates that the volcanic rock is intruded into the gneiss and is younger. The basalt is dark brown to greenish brown and ranges in texture from fine to coarse. The breccia is composed of inhomogeneous small to large fragments of dark-gray basalt in a matrix of palagonite tuff. Small masses of basalt are in the breccia. At places where volcanic rock is dominantly breccia and is silicified, it weathers into prominent spires. Much of the breccia along the east end of the lake and along Grace Creek upstream from the damsite is tuffaceous, and weathering produces large voids as much as 10 feet in diameter. The tuff contains abundant glassy grains of palagonite, which are generally yellow or light brown. Palagonite is believed to be formed during volcanic eruptions onto or beneath glaciers or in regions of copious ground water (Williams and others, 1954).

TABLE 2.—*Chemical composition, in percent, of five rock samples from the Lake Grace powersite*

[Analysts: P. Elmore, S. Botts, and L. Artis, U.S. Geol. Survey]

	G-1	G-2	G-3	G-4	G-5
SiO_2	44.8	72.1	73.7	43.0	43.5
Al_2O_3	16.6	15.2	14.8	16.4	17.6
Fe_2O_3	4.9	.52	.17	6.4	4.7
FeO	8.4	1.8	.94	6.5	8.2
MgO	8.5	.4	.4	4.8	8.9
CaO	6.6	3.0	3.1	6.9	13.0
Na_2O	2.4	4.4	4.9	2.3	1.1
K_2O	.97	1.1	.65	1.1	.27
H_2O^-	3.4	.11	.02	4.4	.07
H_2O^+	2.7	.67	.59	3.5	1.7
TiO_2	3.8	.23	.11	3.7	.54
P_2O_5	.62	.21	.35	.81	.15
MnO	.16	.07	.06	.16	.30
CO_2	.11	.10	.11	.14	.09
Total	103.96	99.91	99.90	99.91	100.12

Locality

G-1. Basaltic breccia sampled in SW¼NW¼ sec. 10, T. 72 S., R. 94 E., Copper River meridian. Intrusive plug at east end of Lake Grace; plug is probably conduit for lava flows north of damsite.
G-2. Quartz diorite gneiss sampled in NE¼NE¼ sec. 10, T. 72 S., R. 94 E., Copper River meridian. Medium grained, light gray; greater amounts of biotite than hornblende; rock has well-defined foliation.
G-3. Quartz diorite gneiss sampled in NE¼NE¼ sec. 9, T. 72 S., R. 94 E., Copper River meridian. Medium grained, light gray; hornblende exceeds biotite; rock is highly siliceous.
G-4. Basaltic breccia sampled in NE¼NE¼ sec. 9, T. 72 S., R. 94 E., Copper River meridian. Volcanic plug and source for flows northeast of damsite. Palagonite tuff common in plug.
G-5. Amphibolite sampled in NW¼NW¼ sec. 10, T. 72 S., R. 94 E., Copper River meridian. Coarse grained, dark gray; composed largely of hornblende that shows well-defined orientation; interbedded with quartz diorite.

The brecciated character of the volcanic rock indicates that it may be a diatreme, or volcanic pipe, and the source for the basalt flows above the left abutment. The flows are a sequence of lapilli tuff beds and basalt flows about 100 feet thick which cap the hill. The tuff is vesicular to frothy and contains an abundance of dark-brown palagonite. Iron ore is common and occurs in grains and oxidation rims about the vesicles. The base of the basalt flows rests unconformably on quartz diorite gneiss. Large landslide blocks are common below the flows along Grace Creek above and below the damsite. The chemical composition of two samples of volcanic rocks is given in table 2.

The age of the volcanic rocks based on field relations indicates that the volcanism probably occurred late in the Pleistocene or in the Holocene Epoch. The breccia is younger than the diorite gneiss which it intrudes, and the basalt flows overlie unconsolidated glacial-fluvial sand and silt probably correlative with the fossiliferous marine deposit of possible Pleistocene or Holocene age. Basaltic lava and tuff of Quaternary age occur at many places along the mainland and on Revillagigedo Island (Buddington and Chapin, 1929). The abundance of palagonite tuff also indicates that the material that forms the volcanic rocks was extruded in late Pleistocene or Holocene time.

SURFICIAL DEPOSITS

Quaternary marine stratified gravel, sand, and silt deposits underlie the high-level terraces along the lower part of Trail Creek and Grace Creek. The sand and gravel beds occur up to an altitude of 200 feet, are unconsolidated, and are composed of laminated silt intercalated with crossbedded fine- to medium-grained grayish-orange sand beds that contain abundant pebbles and coarse gravel lenses. The deposits exceed 100 feet in thickness and rest unconformably on quartz diorite gneiss; shells of gastropods and small pelecypods are abundant.

U.S. Bureau of Reclamation geologists (written commun., 1967) reported similar unconsolidated stratified deposits of glacial-fluvial sands and silt at an altitude of about 300 feet near the east end of the basalt flows. The sand and silt beds appear to rest unconformably upon diorite gneiss, which is exposed above the powerhouse site, and are unconformably overlain by the volcanic rocks. These deposits are probably correlative with the fossiliferous marine deposits along the lower part of Trail and Grace Creeks.

In the Hyder district across Behm Canal, marine interlaminated clay, sand, and gravel beds occur up to altitudes of 450 feet near Elevenmile on Salmon River at the head of Portland Canal and were reported by Hanson (1923) at similar altitudes on Bear River. These marine deposits have been elevated by glacial rebound due to land emergence after Pleistocene glaciation and were considered by Buddington and Chapin (1929) to be Quaternary in age. Many occurrences of marine Quaternary deposits have been reported at places in southeastern Alaska at altitudes of as much as 600 feet (Buddington and Chapin, 1929). The age of the sand and gravel deposits along the lower part of Trail and Grace Creeks may be early Quaternary, and field relations indicate that the gravels were deposited prior to the emplacement of volcanic rock. No volcanic material was observed in the marine deposits.

Other unconsolidated deposits in the powersite include talus, alluvium, and colluvium. The largest area of alluvium is in the flood plain of the stream flowing into the upper end of Lake Grace. Glacial-fluvial material ranging in size from silt and sand to coarse gravel and cobbles underlies the delta and the stream channel. The coarsest fraction contains scattered boulders as much as 1 foot in diameter. The delta clastics are fine and show stratification. The texture of the sediments appears to coarsen upstream and also toward the sides of the valley where landslide detritus coalesces with the alluvium. The clastic materials are homogeneous and consist chiefly of quartz diorite and diorite gneiss.

A large area of alluvial deposits is along Grace Cove at the mouth of Grace Creek. The estuary is a wide tidal flat underlain by mud, silt, sand, and coarse clastics; the gravel becomes more coarse landward. The channel in Grace Creek is underlain chiefly by subrounded to rounded cobbles, boulders, and coarse gravels of quartz diorite, diorite gneiss, and basalt which can be excavated at low-water stages. Estimates indicate that the deposits contain 5–10 percent boulders greater than 8 inches in diameter, 60 percent cobbles 3–8 inches in diameter, and 30 percent sand and gravel.

A bench on the right abutment of the damsite at about 490 feet and a saddle south of a small knob that rises to 560 feet are underlain by soil, mudflows, gravel, and talus. The depth of this overburden is uncertain, and the site will require exploratory drilling to determine the bedrock surface. Bedrock appears to be at shallow depth because there are many outcrops of diorite gneiss among the bogs and glades.

Colluvium was mapped to include small landslide blocks, talus, mudflows, and soil. Much of this material is deposited by mass gravity movement and appears to have stabilized in areas of heavy timber growth. The largest deposits are peripheral to the volcanic outcrops along Trail and Grace Creeks. Some of the talus blocks are as much as 100 feet in size.

Landslide blocks of greater dimensions were mapped as separate units. The large volcanic block upstream from the proposed damsite appears stabilized and should not be a hazard to the dam. However, geologic evidence indicates that landslide blocks in volcanic terrain always present a potential hazard. Two landslides are present along the valley at the head of Lake Grace. They are chiefly talus and coarse detritus. These slides are in part stabilized where heavy growth of brush and timber occur. The slides appear to encroach upon the flood plain, and a raise in the water surface level of the lake may undercut the slides and accelerate gravity movement. The landslides should not create a hazard to the reservoir or the dam.

STRUCTURE

Large positive and negative features underlie Revillagigedo Island. Within the powersite, quartz diorite is emplaced along the western margin of the Coast Mountains geanticline (Buddington and Chapin, 1929).

Twenhofel and Sainsbury (1958) interpreted several of the prominent lineaments in and adjacent to the powersite as faults or shear zones. The Coast Range lineament trends north beneath Behm Canal and has been identified where mapped in the area between Petersburg and Juneau as a major thrust fault. Another large lineament that is conspicuous on the aerial photographs extends from Manzanita Lake north across the powersite and parallels Grace Creek about 3,000 feet upstream from the powerhouse site to the mouth of the creek. It can be projected across Behm Canal into the mainland north of Walker Cove. Twenhofel and Sainsbury (1958) interpreted this linear feature as a shear zone or fault. The volcanic plug that is east of Lake Grace is probably emplaced along the fault that Twenhofel and Sainsbury (1958) showed branching north along Fromholtz Creek from the large lineament that crosses the east end of Lake Grace. The relation of the volcanic rock to the quartz diorite indicates that faulting may have caused the thinning of the volcanic breccia to the southwest. The fault appears to intersect the large lineament in the upper part of the Fromholtz Creek drainage area in the SE¼SE¼ sec. 9; the amount of displacement on the fault has not been determined. Quartz diorite gneiss exposed at this locality appears to be shattered, and the fractures are filled with quartz; some of the silicified fractures show mineralization.

The regional strike of foliation within the quartz diorite gneiss is generally north to northeast and the dip is nearly vertical in the proximity of the damsite; west of the lake outlet the strike of foliation is north to northwest and the dip ranges from 30° to 55° E. At the powersite the strike of the foliation ranges from N. 85° E. to N. 70° W. and dips range from 50° SE. to vertical. The wide range of attitudes may indicate folding, faulting, or plastic flow of the molten rock. Two major joint sets appear to control drainage; one set strikes N. 50° E. and is nearly vertical, and the other strikes N. 15° E. and dips 55° E. Minor joint sets cut the bedrock; their strikes range from N. 15° to 18° W., and their dips range from 71° to vertical.

Many short lineaments conspicuous on the aerial photographs and identified on the ground in the reservoir may be joints. The quartz diorite contains many fractures and joint surfaces filled with quartz. These silicified zones may be the result of movement along joints, or they may be faults.

DAMSITE

The proposed damsite is on Grace Creek 0.5 mile below the outlet of the lake. The site is at a constriction in the canyon where Grace Creek has cut a narrow gorge through bedrock (pl. 1). Quartz diorite gneiss is well exposed in both abutments.

The left abutment rises in an almost vertical cliff about 140 feet above the river bed. The abutment is bifurcate where it is cut by a small southwest-trending gulch. Above the left abutment, the ground surface rises less abruptly to the top of a broad ridge at an altitude of about 530 feet. The ground surface in the north and east side of the ridge drops abruptly into a small northwest-trending valley that is a tributary to Grace Creek, then rises steeply to an altitude of more than 700 feet to a broad flat area that is underlain by volcanic rocks. Much of this slope is covered by colluvium and landslide detritus of undetermined thickness. The landslide blocks range from a few feet to 100 or more feet in size and are derived from the volcanic flows. The volcanic rock is composed of basalt flows and palagonite tuff beds which crop out in cliffs or ledges that are 30–50 feet high.

The right abutment is less steep and the top is lower than the left abutment. The ground surface rises in a steep cliff about 100 feet above the river bed and culminates in a small knob at an altitude of about 490 feet. South of the knob the ground surface dips into a shallow saddle and then rises gradually to a broad north-trending ridge at an altitude of about 560 feet.

At the damsite the foliation in the quartz diorite gneiss strikes about N. 25°–30° E. and the dip is 75°–80° E. The foliation is normal to the stream channel; so water leakage would be minimal. The major joint set strikes N. 40° W. and is vertical, and a well-defined minor joint set strikes N. 70° E. and dips 45° S. The partings in the bedrock are from a few inches to as much as several feet apart. Joints or sheeting are normal to the foliation and not well defined. The bedrock is moderately weathered and ironstained at the surface; more severe weathering is apparent along the highly micaceous zones.

The foundation in Grace Creek should require minimum excavation. Bedrock extends out from each side of the canyon toward the center of the stream for a distance of 8 or more feet, and there is probably less than 10 feet of overburden in the stream channel. The overburden consists of detritus such as boulders and cobbles and very coarse gravel. Immediately downstream from the damsite, a deposit of gravel underlies the low terrace on the bend in the left side of the river channel. The deposit would require processing to be made suitable for construction material.

The Bureau of Reclamation engineers drilled several holes in the powersite. Hole DH–1 was drilled at an angle of 45°, N. 80° W. on the right abutment to determine if a small north-trending draw is fault controlled. The drill hole penetrated 126 feet of hard, dense diorite gneiss. Some minor soft layers about 1 inch thick were present and may represent weathered rocks along joints or gouge along minor faults.

Hole DH-2 was drilled on the base of the right abutment under the stream channel into the left abutment at an angle of 45°, N. 50° E. The drill hole penetrated 150 feet of hard massive diorite gneiss. Two zones of broken rock that may represent faults or shear zones were found at depths 122-125 feet and 130-138 feet. The water losses in the holes were minimal even in the zones of broken rock, indicating that there may not be any serious structural defects in the foundation. However, faulting may be indicated by the presence of the large lineations that parallel Grace and Fromholtz Creeks and the linear feature that crosses the outlet of the lake.

Two axes are possible at the damsite (pl. 1). Axis A-A′ is 40 feet downstream from the southwest-trending gulch which cuts the left abutment. The canyon section of this alinement is about 220 feet long, and the overall length of the dam to the altitude of 510 feet is about 500 feet. The dam would be about 150 feet high and would raise the water surface level of Lake Grace 68 feet. Bedrock underlies the damsite; the foundation appears on the basis of exploratory drilling to require minimal excavation. Axis line B-B′ is located approximately 165 feet upstream from line A-A′; it is underlain by bedrock. The canyon section of the dam is about 140 feet long, and the overall length of the alinement is considered more favorable for a damsite than line A-A′ because the canyon section is narrower. The abutment would give better support than that in the damsite farther downstream.

RESERVOIR SITE

The reservoir area is underlain by bedrock. Most of the rock that crops out along Lake Grace is hornblende-biotite-quartz diorite gneiss. Locally there are variations in composition, texture, and degree of metamorphism. At places in the western part of Lake Grace basin, the rock appears as interlayered dark amphibolite gneiss and light-colored quartz diorite. Foliation is generally distinct, but where the rock is massive and coarse grained it is not well defined. The strike of the foliation ranges from N. 85° E. to N. 70° W. and dips range from 55° E. to vertical. The wide range of attitudes may indicate considerable folding during emplacement of the batholith or plastic flow of the molten rock. Two major joint sets appear to control drainage in the area; one set strikes N. 50° E. and is nearly vertical; the other strikes N. 15° E. and dips 55° E. Several minor joint sets that have strikes N. 15°-18° W. and dips ranging from 71° E. to vertical were measured in diorite gneiss along Grace Creek channel above the damsite and the eastern part of the reservoir.

The volcanic rock at the east end of Lake Grace is soft and decomposes easily. A raise in the lake level will undoubtedly undercut the soft rock in this area and cause landsliding. Surficial slide scars are evident, but they seem to be due to shallow surface soil creep in the weathered rock. The operating level in the reservoir and the amount of drawdown will significantly affect this undercutting. One slide area at the north side of the outlet is very unstable, and gravity mass movement may increase appreciably with fluctuating water levels.

A large mass of volcanic rock in the stream channel and on the north valley wall of the creek from 160 to 900 feet upstream from axis line B–B′ is interpreted by us to be a large landslide block, but U.S. Bureau of Reclamation geologists believe it to be flows formed in place and associated with those in Grace Creek valley east of the intrusive rock. In holes DH–3, DH–4, and DH–5, the rock is very broken, and the core recovery was poor. No voids or caverns were encountered, and water losses were small to moderate. Interpretation of the results of the drilling by the Bureau of Reclamation is that the base of the volcanic rocks slopes down and away from the stream channel filling an older canyon of Grace Creek. Grace Creek is downcutting along the contact of these rocks in this part of its course. Our evidence for landsliding is based on the crushed and broken rock found in the drill holes and on outcrops of diorite gneiss that are between the volcanic rock in the stream channel and the overlying flows on the bench to the north.

Many other large basalt blocks rest precariously on the steep north valley wall. Although a heavy growth of timber is on the steep slope, earthquakes can accelerate gravity movements of the blocks and create a hazardous situation in which the blocks slide either onto the dam or into the reservoir to produce a large wave that might momentarily overtop the dam.

The presence of the volcanic rock at the east end of the basin is of concern because of the possibility that it may provide a zone of leakage from the reservoir. However, an examination of the drainage in the saddle at the head of Trail Creek does not show any line of springs that would indicate high permeability of the rock. The voids and caverns observed in the outcrops of basaltic rock may be the result of weathering of small masses of tuff in the inhomogeneous material in the conduit. Further exploratory drilling will be necessary to determine the depth of the water table.

It is also possible that the area of the valley was eroded by the glacier as deeply as the east end of Lake Grace basin and then partly filled with a mass of outwash material from the retreating glacier before being covered by pyroclastic rocks, flows, or basalt breccia. The damsite should be investigated by seismic survey to check if the basalt actually extends to depth and overlies diorite gneiss or if there may be some unconsolidated material at depth. A deep drill hole to the gneiss or to a depth of 100 feet below lake level in a location about 1,000 feet north of the south line and 500 feet west of the east line of sec. 4, T. 72 S., R. 94 E., would be worthwhile.

TUNNEL ROUTE

The inlet portal is in diorite gneiss. It is concluded from reconnaissance that the conduit will penetrate competent massive diorite gneiss over most of its length and that it will be at least 100–200 feet below the base of the volcanic flows. However, near the outlet the tunnel may penetrate a thick overburden of volcanic detritus and would require lining.

The tunnel route may require additional exploration. Although the portal is in diorite gneiss, this may be a ridge between Grace Creek and a glacially eroded basin north of the creek that may be filled with terrace gravel, pyroclastic rocks, and volcanic flows. The reported presence of terrace deposits at about an altitude of 300 feet at the east end of the area of flows may indicate that the flows overlie the terrace deposits near the tunnel outlet and that the marine gravels could extend a considerable distance southwest beneath them. The tunnel route should be checked by a seismic survey and possibly two or three drill holes along its length in the area of the flows. If it is determined that the tunnel would be in the flows, a drill hole at the northeast end of the tunnel route should be carried to the gneiss.

Faulting along the tunnel route was not observed on the ground or in the aerial photographs. Exploratory drilling at the damsite indicated that minor zones of crushed rock are present in the diorite gneiss. The evidence suggests possible fault or shear zones. Where the tunnel traverses such zones, concrete lining would be required to prevent leakage.

The penstock would be on a steep colluvial slope from the tunnel to the powerhouse on Grace Creek. Exploratory drilling along the penstock route will be necessary to determine the position of the bedrock surface. Penstock anchors will require footing excavated in competent bedrock.

POWERHOUSE SITE

The powerhouse site is on diorite gneiss. The rock appears deeply weathered along micaceous zones but not decomposed. Attitudes in the foliation in the bedrock range from N. 70° W., dips 50° S., to N. 85° E., dips 61° W. The range in attitudes indicates proximity to possible shear or fault zones, or it may be due to other deformation. The powerhouse site is on or near a linear topographic feature that may be a possible shear or fault zone (Twenhofel and Sainsbury, 1958).

The linear feature has been delineated in the aerial photographs but has not been identified on the ground.

Because of the steepness of the slope above the powerhouse site, landsliding is common in the basalt flows and tuff beds capping the mesa. The location of the powerhouse site should be chosen carefully to eliminate the hazard from landslides. Also, the powerhouse installations should be designed to give maximum protection against earthquakes.

CONSTRUCTION MATERIAL

Deposits of sand and gravel, landslide material, colluvium, and alluvium occur at the powersite. Alluvium in the river channel and the delta at the upper end of Lake Grace could be a major source of concrete aggregate. The glacial-fluvial deposits consist of silt, sand, and gravel which ranges in size from pebbles to boulders. The gravel is chiefly granitic rock but would require processing.

Another source of material might be the deposits underlying the mudflats at the mouth of Grace Creek. The deposits are composed of sand, gravel, and cobbles but contain much organic impurities. Tidal action within the basin might make this deposit difficult to excavate.

Probably the best source of construction material is the deposit at the confluence of Grace Creek and Trail Creek. Silt, sand, and gravel underlie the terraces south of Grace Creek where at least 50 feet is exposed. The unconsolidated material consists of stratified beds of coarse gravel and cobbles interbedded with conglomeratic sands. The coarse constituents are homogeneous and are principally diorite gneiss and quartz diorite. The abundance of calcium carbonate in shell fragments may preclude the use of these materials as a source of concrete aggregate. The deposit appears to have lateral extent within the valley of Trail Creek and possibly of Grace Creek, but the boundaries could not be determined because of overburden.

CONCLUSIONS

The proposed damsite is feasible for a concrete arch dam. Both abutments appear capable of taking the thrust of an arch dam, and the choice of either axis is dependent on economic factors. Axis *B–B′* appears more favorable than axis *A–A′* because of a narrow section and a larger rock sidewall in the left abutment to give more support to take the thrust. Minor faults or shear zones may be present along Grace Creek above and below the damsite. The zones of broken rock encountered in the drill hole along the axis of the dam may be interpreted as minor faults, shear zones, or closely spaced joints. More exploratory drilling will be required to determine magnitude, trend, and relation of these zones to the larger linear features.

The foliation is parallel to the axis of the damsite, and leakage should be negligible. Some water loss may occur along the joints and crush zones, but only minor water losses in the exploratory drill hole under the damsite were reported. Cement grouting should reduce any loss to minimal amounts.

The saddle 300 feet south of the right abutment between the knob and the broad ridge will require exploratory drilling to determine whether this topographic feature is fault or joint controlled. The depth of surficial cover must also be determined.

The saddle area at the head of Trail Creek is at the approximate altitude of 700 feet and may have been a meltwater channel when the former lake or glacier was at this altitude. It does not appear likely that surficial deposits occupy this saddle to a depth which would cause leakage from the reservoir. However, a seismic survey will be necessary to check if the basalt actually extends to depth and overlies diorite gneiss or if there may be some unconsolidated material at depth. A drill hole should also be drilled to the gneiss or to a depth below lake level to verify how watertight the basalt breccia is at depth.

The tunnel route will require additional exploration by seismic survey and drilling to determine the position of the top of the diorite gneiss. If the tunnel should pass into basalt or terrace gravel near the outlet, the tunnel may have to be lined for a considerable part of its length.

Exploratory drilling will be required to determine the depth of the water table and to test the permeability of the volcanic rock at the east end of the lake and in the saddle. The contact with the gneiss is an intrusive contact, and the former channel was cut along the boundary between the volcanic rock and the quartz diorite gneiss. The lack of zones of springs at the head of Trail Creek indicates that water loss is minimal, and a raise in water level of the reservoir should not appreciably increase the water loss in the volcanic rocks.

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