RECONNAISSANCE REPORT ON GEOLOGY OF EKLUTNA LAKE DAM SITE AND CONDUIT ROUTE NEAR ANCHORAGE, ALASKA

By

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Summary and Recommendations

1. Eklutna Lake and Eklutna Creek lie in a wide, deep, glaciated, trough-like valley. Downstream from the lake, this valley is partially filled with unconsolidated glacial and alluvial deposits.

2. Eklutna Lake dam site, located about 400 feet below the lake outlet, is suitable for a low dam of flexible, earth-embankment type. Adequate control of the stream can be obtained by raising the lake level about 50 feet to altitude 910 feet, which will provide hold-over storage from wet years to dry years. Such a structure will have a crest length of about 1,950 feet.

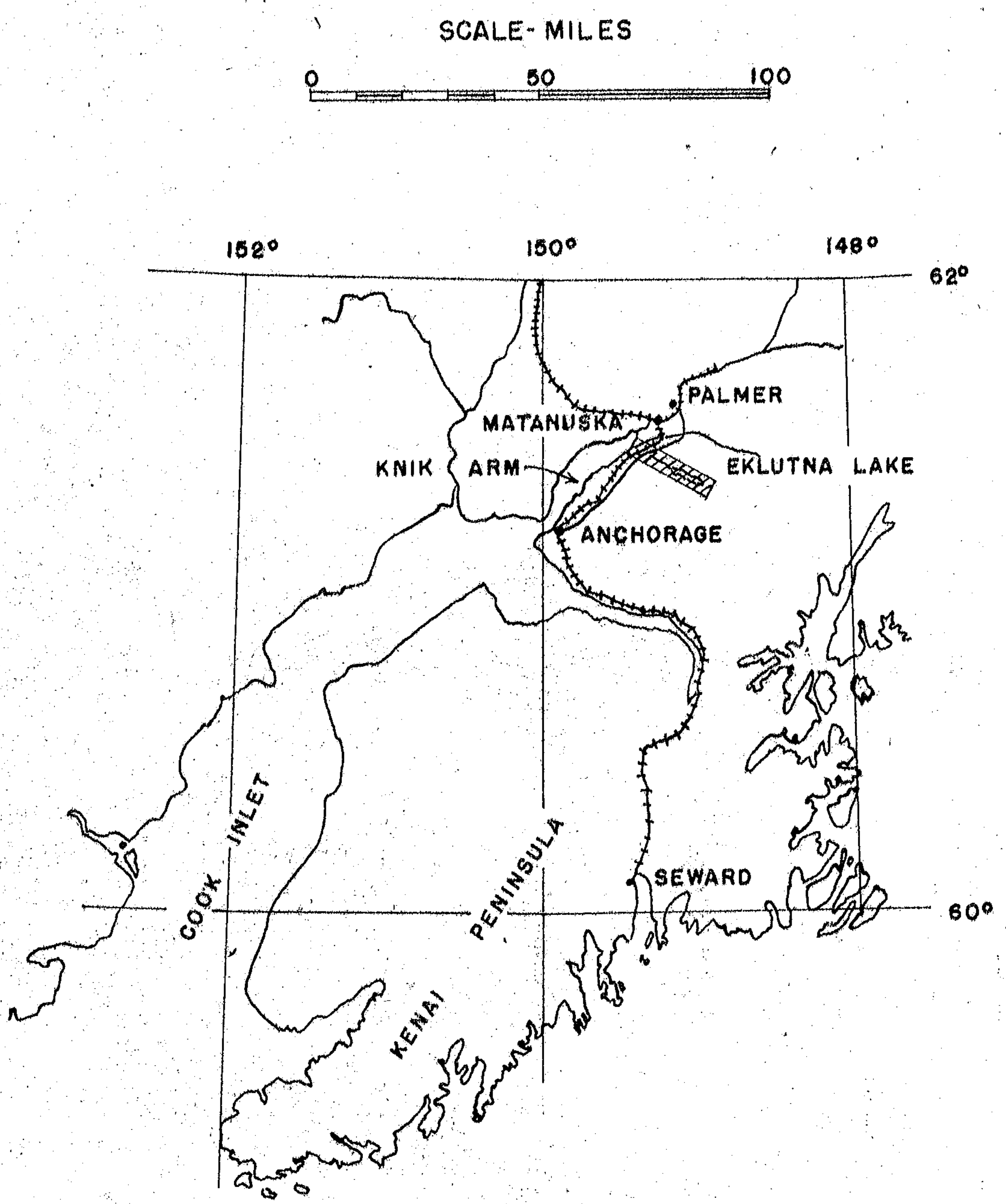
A. Bedrock is probably 200 to 475 feet below stream bed at the proposed axis. The dam will rest on glacial deposits of till, clay, sand and gravel, and on deposits of lake-shore and alluvial fan gravels.

B. Geologic conditions in the area of the right abutment, as yet imperfectly known, may make necessary a long, deep cutoff extending for an unknown distance beyond the north end of the dam.

C. A foundation exploration program is recommended that includes deepening test pit No. 1 and drill hole No. 2, and drilling 11 new holes. It is suggested that one drill hole near the center of the valley be taken to bedrock to give a complete picture of the fill materials underlying the foundation.

3. Delivery of water from the forebay of the reservoir to the powerhouse eight miles downvalley by means of a conduit is regarded as infeasible because: difficult terrain of the route will require earthwork more extensive than the volume of the dam; the route is subject to land slides, and will require expensive maintenance; it is more or less completely exposed to adverse winter conditions that may engender icing conditions; and it is easily subject to sabotage. It is recommended that the water be taken to the powerhouse through a rock tunnel.

FIGURE I



INDEX MAP SHOWING LOCATION OF
EKLUTNA LAKE, ALASKA

Introduction

Location: The proposed Eklutna Lake dam site is near the outlet of Eklutna Lake at latitude 61°23.5' N. and longitude 149°9.5' W., in a northwest trending valley on the west flank of the Chugach Mountains. The water surface of the lake stands at about altitude 862 feet. It is approximately 28 airline miles northeast of Anchorage, Alaska, and 10 miles from Knik Arm of Cook Inlet. The proposed conduit route extends from the dam site down the valley of Eklutna Creek for approximately eight miles. (See figs. 1 and 2.)

Accessibility: Eklutna Lake is accessible both by automobile road and by air. From the village of Eklutna, which is approximately 30 miles northeast of Anchorage via the Glenn Highway, a graveled road extends 10 miles up the valley of Eklutna Creek to the lake. A short (1,000 feet), "humpbacked," gravel surfaced runway has been constructed on the right bank of the stream about a quarter of a mile below the lake. It will accommodate only the lightest planes. Larger amphibious planes land on the lake.

The nearest rail point is at Eklutna village, a station on the Alaska Railroad.

Ocean-going ships dock at Anchorage. In the early days, shallow-draft steamships came up Knik Arm to Eklutna and other villages, but the channels are shallow, shifting, and little used at present. There are no pier or docking facilities.

Map references: The Eklutna quadrangle covers the dam site, most of the reservoir area, the proposed conduit alignment, and the proposed tunnel location. The remainder of the reservoir area is covered by the Metal Creek quadrangle. The drainage area is shown on Eklutna, Metal Creek, Raven Glacier, and Surprise Glacier quadrangles. All of these quadrangles were prepared and published by the Corps of Engineers, U. S. Army, on a scale of 1:62,500 and with a contour interval of 100 feet.

Purpose: Development of power is the sole purpose of the project. Power could be furnished to Anchorage, Palmer, and other communities, as well as to rural areas and the army installations at Fort Richardson. Possibilities for power development are discussed in detail in a companion report by Mr. Arthur Johnson, District Engineer, Water and Power Division, Conservation Branch, U. S. Geological Survey.1/

1/ Johnson, Arthur, Water power resources of Eklutna Creek, Alaska, U. S. Geological Survey, unpublished report, August 1947.

<u>Present development</u>: The Anchorage Department of Public Utilities now has a small hydroelectric plant near the village of Eklutna with an installed capacity of two 1,000 k.w. generators operating under a static head of 232 feet. Water is stored in Eklutna Lake. A small dam at the outlet of the lake provides some storage regulation. Maximum pool level is at altitude 868 feet, and the minimum draw down level is at 860 feet. The resulting usable water storage is slightly over 25,000 acre-feet. Under present conditions, no stream regulation is attempted during the spring and summer months, but late in the fall the reservoir is filled and water is withdrawn during the winter months when stream flow is at a minimum, in order to fulfill plant requirements.

Water released from the lake flows down Eklutna Creek for approximately 8 miles to the Eklutna Diversion Dam, where it is diverted through a short (1,800 feet) tunnel into the powerhouse penstocks. Top of the diversion dam is at altitude 258.6.

<u>Proposed development</u>: Full development of the potential water-power possibilities of Eklutna Creek presents two pertinent problems:

1. Runoff regulation.
2. Conduction of water from the reservoir to a suitable powerhouse site with minimum head loss.

<u>Runoff regulation</u>: From preliminary studies of the stream flow data available, Mr. Arthur Johnson has estimated that an average flow of 400 c.f.s. can be maintained throughout an average year by providing approximately 126,000 acre-feet of storage. In order to hold over water from wet years for use during dry years, the storage capacity should be in the neighborhood of 150,000 acre-feet.

Two schemes have been proposed to provide the necessary storage: (1) draw down of the present minimum lake level by tunnel or a combination tunnel and conduit. (2) raising the present high-water level by construction of an earth dam across Eklutna Creek near the lake outlet. Scheme (1) would require a tunnel intake at an elevation low enough to permit a minimum lake level of 815 feet. Scheme (2) would require a maximum pool level at an altitude of 900 feet.

<u>Conduction of water from reservoir to powerhouse</u>: To obtain a maximum difference in altitude between the reservoir and the generating units, the powerhouse site must be located in the Knik Valley. (See Eklutna quadrangle.) Two schemes have been suggested for conducting the water from the reservoir to the powerhouse site: (1), a tunnel from the lower end of Eklutna Lake northward through the mountain to the Knik Valley; (2), a conduit down Eklutna Valley, and possibly a short tunnel to a site near the powerhouse now in use. The proposed tunnel would be approximately 4½ miles long, and the proposed conduit would be about 7½ miles long.

<u>Previous investigations</u>: During January-February 1947, the Anchorage Department of Public Utilities made a series of soundings to determine the lake floor topography. Mr. Johnson took part in this work as a consultant.

<u>Present investigations</u>: The investigation of the Eklutna project was carried out during May, June, and July 1947 by engineers and geologists of the Geological Survey. In addition, the Anchorage Department of Public Utilities carried out an investigation program. Various phases of the investigation were:

1. <u>Topography</u>. - Topographic mapping was under the direction of Mr. Arthur Johnson, District Engineer, Water and Power Division, Conservation Branch. Maps made were as follows:

   a. Eklutna Lake Dam Site, on a scale of 1:4,800 and a contour interval of 10 feet, covers the dam site area to altitude 970. (Figure No. 2.)

   b. Eklutna Lake Reservoir Area, on a scale of 1:12,000 and a contour interval of 10 feet, covers the area around and upvalley from the lake to altitude 950.

   c. Eklutna Creek, on a scale of 1:24,000 and a contour interval of 20 feet, covers the stream valley to altitude 900 feet from the downstream edge of the dam site map to a point 4.2 miles below the lake outlet. (Figure No. 3.)

2. Proposed tunnel alignment: Dr. F. F. Barnes, geologist, Alaskan Division, Geologic Branch, made a reconnaissance survey of the geology along the proposed tunnel route and in the vicinity of the proposed powerhouse sites. It is discussed in a companion report.

3. Proposed dam site: A geologic map of the proposed dam site was made in the field by A. F. Bateman, Jr., geologist, Conservation Branch, between June 2, 1947 and July 4, 1947. The exploration program of the Anchorage Department of Public Utilities consisted of two drill holes, six test pits, and five side-hill trenches. Locations are shown on figure 2. The geologic materials exposed by these excavations were examined and logged by Bateman. Results are incorporated in this report and summary logs are included in appendices I and II.

4. Proposed conduit route: A reconnaissance of the geology along the route of the proposed conduit was made by A. F. Bateman, Jr., from June 2, 1947 to July 4, 1947.

Climate: The summary of climate that follows is based on the records 2/ of the United States Weather Bureau stations at Eklutna,

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2/ Climatological data, U. S. Department of Commerce, Weather Bureau, Alaska Section, annual summaries from 1915 to 1945 inclusive.

Matanuska, and Anchorage from the time of their establishment through 1945. Since these three stations lie at low altitudes near the sea, their records do not represent exactly the weather conditions at the dam site and in the reservoir and drainage areas, all of which are in the mountains at altitudes from 860 to 5,000 feet. However, these records do furnish the best information available. At Eklutna Lake and the headwaters of Eklutna Creek, precipitation is probably slightly greater, and temperatures somewhat lower.

Summary of climate at localities near Eklutna Lake

	Eklutna	Matanuska	Anchorage 5/
Latitude	61°27' 3/	61°34' 3/	61°13' 3/
Longitude	149°20' 3/	149°16' 3/	149°50' 3/
Altitude..........................feet	27	166	132
Length of record................years	4	28 4/	28 6/
Annual mean precipitation.......inches	18.57	15.90	14.56
Monthly mean precipitation......inches			
January	1.34	.86	.84
February	.59	.74	.67
March	.71	.58	.55
April	.24	.44	.41
May	.81	.72	.50
June	1.42 3/	1.22	.70
July	2.01 3/	1.98	1.63
August	3.85 3/	2.92	2.60
September	2.82 3/	2.66	2.58
October	1.40 3/	1.79	2.18
November	1.04 3/	.95	1.04
December	.73 3/	1.04	.86
Annual mean snowfall............inches	43.2	45.2 7/	58.0 7/
Annual mean temperature.........°F.	37.1	35.8	35.0
Monthly mean temperature........°F.			
January	16.3	13.8	11.6
February	25.3	19.4	18.6
March	25.4	24.3	23.7
April	36.8	36.5	35.4
May	48.2 3/	46.9	45.0
June	57.2 3/	54.4	53.5
July	58.8 3/	57.6	57.0
August	56.6 3/	55.6	55.6
September	49.0 3/	47.8	47.8
October	35.4 3/	36.4	36.0
November	19.1 3/	22.0	22.4
December	13.9 3/	14.0	13.3
Highest temperature.............°F.	90	84	92
Lowest temperature..............°F.	-35	-36	-36

3/ 5 year record.
4/ Records incomplete for 1932, 1933, 1934, 1935.
5/ Weather station moved from Ship Creek to Airfield in 1922.
6/ 30 year temperature record.
7/ No record for 1936.

When the soundings were made, there was a maximum thickness of 2.5 feet of ice over the water in the lake. Near shore where the ice extended to the bottom, a thickness of 3.5 feet was observed.

Although the Eklutna Lake area is not included in what is recognized as the permafrost region of Alaska 8/, in June 1947

8/ War Department technical bulletin, TB 5-255-3, Construction of runways, roads, and buildings on permanently frozen ground, January 1945.

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large areas of the dam site were underlain by a thin layer of frozen ground. This subject will be discussed in detail under the section on the dam site foundation.

Vegetation: Both at the dam site and in the reservoir area, the left side of the valley is forested by a thick stand of black spruce with birch, alder, aspen, and poplar in small scattered groves and along stream courses. The right side of the valley has been burned and is now covered with a dense growth of birch with scattered alder, poplar, and spruce.

Because their root systems spread at the base of the peat rather than penetrate the frozen ground, the high winds that frequently sweep the valley blow most trees down before they attain a size sufficient for cutting as timber. Few spruce or birch have a diameter of 12 inches. The spruce wood is hard because of its slow growth, and probably unsuited for pulp.

Acknowledgments: Field work was greatly facilitated by the many courtesies extended by various members of the Anchorage Department of Public Utilities. Thanks are especially due Mr. Emil Pfeil, member of the utilities board, Mr. C. A. Wilson, Superintendent, Department of Public Utilities, and Mr. Ray Henreichs, Superintendent of the power plant.

Mr. C. E. Erdmann, Regional Geologist, Mineral Classification Division, reviewed the manuscript and offered many helpful suggestions.

Plate I. View up Eklutna Valley from about a quarter of a mile above head of Eklutna Lake, showing surface of alluvium partially filling valley in this stretch. This is upper end of reservoir area for proposed dam. In center background are ice fields which feed main tributary to Eklutna Creek.

Plate II. View upvalley showing portion of Eklutna Lake from point on valley wall about a quarter of a mile downstream from right abutment and at about 1,500 feet altitude.

Plate III. View down Eklutna Valley from altitude 2,120 feet on hill south of dam site. Steep upper valley walls are bedrock. River occupies narrow inner gorge cut into glacial deposits filling valley to about 1,000 feet in altitude. Conduit route would be along gravel cliffs in center middle ground. Knik Arm in distance.

Plate IV. View up Eklutna Valley from point on rim of inner gorge 6½ miles by road below dam site and at 700 feet altitude. Top of glacial deposits filling valley which shows up as the nearly flat surface in middle ground is at about 1,000 feet altitude.

Topography and Drainage

Eklutna Creek: The source of the creek is the melt water discharging from the glacier that occupies the upper 7 miles of the valley. Four and three-fourths miles downstream from the snout of the glacier, the creek empties into Eklutna Lake, which is 7 miles long. Upstream from the lake, the flow is augmented by numerous small tributaries and by one main tributary that heads in a small glacierette or ice field about 3 miles east of the main glacier. (See Metal Creek and Surprise Glacier Quadrangles.) Below Eklutna Lake, the creek flows in a narrow inner gorge for most of its 10.5 miles to tidewater in Knik Arm.

Topography of Eklutna Valley: The present Eklutna Valley is a rather straight, steep-walled, trough-like valley from 1 to 1½ miles wide. Its walls have been smoothed and streamlined to altitudes of about 4,000 feet by one or more glaciers that moved down the valley, truncating the spurs between tributary streams, and planing off minor irregularities. With respect to the large Knik Valley, to which it is tributary, Eklutna Valley is a hanging valley because the huge Knik glacier was able to cut down more rapidly than the smaller Eklutna glacier. Above the level of the truncated spurs, sharp, rugged, alpine-sculptured peaks rise on either side to a maximum altitude of 7,785 feet.

Upper valley: Between the glacier and the head of Eklutna Lake, debris has partly filled the valley. The flat surface of the alluvium falls from 1,127 feet (barometer altitude) at the lower limit of the ice to 867 feet at the head of the lake. Over this surface, Eklutna Creek wanders in a mesh of continuously changing, braided channels. (See pl. I.) If the maximum lake level is raised to altitude 910 feet, the lower end of this stretch will be submerged.

Lake basin: Soundings show that the valley sides and the upper end of the lake basin descend at a steep angle below the lake surface to relatively flat bottom at a depth of about 200 feet. The lower end of the lake, however, is shallow for several hundred feet above the outlet. It then drops steeply to the general bottom level. (See pl. II.)

Lower valley: Downstream from Eklutna Lake, the valley has been filled with glacial debris and outwash to a general level at about altitude 1,000 feet. (See pls. III and IV.) These deposits extend up the right shore of the lake for at least 3 miles. Into this unconsolidated valley fill, Eklutna Creek has excavated a narrow inner gorge. Because the fill surface is nearly horizontal and Eklutna Creek has a steep gradient, this canyon increases in depth from 50 feet at the dam site to a maximum of over 500 feet about 5 miles downstream. Farther downstream the depth decreases because erosion has lowered the fill surface. In many places, the walls of this inner gorge are sheer cliffs of gravel, sometimes topped by till, which rise to heights of from 100 to more than 300 feet. Numerous short, deep, vertically walled side canyons are cut back into the valley fill, especially on the north side. Obviously, small land slides are very common.

Approximately 6.9 miles below the lake outlet, the creek has cut into bedrock underlying the fill materials at altitude 354 feet (barometer). (See fig. 3.) In the next mile, the bedrock surface gradually rises because the present stream cuts diagonally across the right wall of its enlarged preglacial channel along a superimposed course. In the vicinity of the diversion dam, the bedrock surface is at 595 feet, and the creek is actively cutting downward in a narrow slot already incised 400 feet into bedrock.

At the Anchorage-Palmer highway bridge, Eklutna Creek leaves its rock-walled canyon to flow over the alluvial flatlands bordering Knik Arm for 1.2 miles to the sea.

Benches: Three prominent spurs on the north side of the valley from 1 to 3 miles downstream from Eklutna Lake have comparatively flat tops about half a mile wide between 3,000 and 3,500 feet in altitude. These surfaces are underlain by bedrock.

A narrow, fragmentary, but prominent bench extends along the north valley wall from about 5 miles below the Lake to within 1½ miles of the present glacier. Less prominent remnants are also found on the south wall. This surface varies in altitude from 1,500 feet at the lower end, to 1,630 feet at the dam site, to 2,250 at the upper end. Above this level, the sides of tributary valleys appear considerably less steep than below. In other words, the present streams are flowing in narrow v-shaped valleys cut into the bottoms of broad v-shaped valleys. In most places, this bench is underlain by coarse stream gravels, but in at least two locations, it is cut into rock. Since greenstone cobbles in the gravels show slightly thicker weathered rinds than cobbles of similar material from the gravels filling the lower part of the valley, it is assumed that these bench gravels are older.

Numerous small benches were found both above and below this bench, but none of the others could be traced for more than a few hundred yards.

Above the right abutment of the dam site, there is a prominent bench remnant at altitude 1,190. At about 1,000 feet, a bench extends for at least 5 miles up the right side of the valley from the dam site. This bench appears to tie in with the general level to which the valley was filled.

Benches have also been observed along the shores of the lake at altitudes of 874, 906, 923, and 944 feet (barometer). Of these, the latter is the most noticeable. All of them seem to be related to former levels of the lake.

Alluvial fans: Upon the 1,000-foot fill surface, small tributary streams have built alluvial fans of large volume, especially on the north side of the valley. On some of these fans the apex is built up to altitudes of 1,300 feet. The streams are now actively trenching these fans.

Drainage area: Above the outlet of Eklutna Lake, the total drainage area is 119.2 square miles, which may be divided as follows:

Ice fields and glaciers	6.2 sq. miles
Surface Eklutna Lake	5.1 sq. miles
Mountain slopes and valleys	107.9 sq. miles

Discharge: The average rate of flow for Eklutna Creek over a period of 17 years during which records have been kept is 403 cubic feet per second. Monthly mean flows are as follows:

January	86 c.f.s.	July	1132 c.f.s.
February	75	August	1251
March	68	September	699
April	107	October	277
May	204	November	177
June	620	December	128

<u>Gradient</u>: Between the glacier and the upper end of the lake, Eklutna Creek carries a heavy load during the summer months and is aggrading its channel. Its gradient in this stretch is about 66 feet per mile. Below the lake, Eklutna Creek is incised in glacial deposits of gravel and till for a distance of 6.9 miles, through which it has a gradient of about 74 feet per mile. Through this stretch, the stream is actively eroding its channel. For the next 2.4 miles, the stream is cutting a narrow slot in bedrock and flows with a gradient of 116 feet per mile. After leaving the rock canyon, the stream has a gradient of approximately 63 feet per mile for 1.2 miles to the sea.

Geology

__Bedrock:__ Although solid rock crops out neither on the dam site nor along the route of the proposed conduit, it makes up both walls of the valley. In the vicinity of the dam site, the lowest rock in place on the right abutment is at altitude 1,340, and on the left abutment is at 1,015.

__Character:__ On the right abutment of the dam site, bedrock consists of a dense, fine-grained, medium-gray, fairly hard graywacke in beds from 1/2-to 6-inches thick, interbedded with dark-gray, thinly laminated argillite. From inspection with a hand lens, the graywacke seems to be made up of subangular grains of quartz, feldspar, a dark ferromagnesian mineral, and rock fragments cemented by silica. The argillite which makes up somewhat more than 50 percent of the rock, is very fine-grained, and splits into thin sheets. The exposure on the left abutment is small and consists chiefly of graywacke.

__Attitude:__ The beds dip approximately north at gradually increasing angles as one climbs the right wall of the valley. Determinations are as follows:

Altitude	Strike	Dip
1,340	N. 117° E.	33° to 49° N.
1,596	N. 87° E.	48° N.
1,990	N. 130° E.	56° N.

__Joints:__ Twelve determinations of the strike and dip of joints were made at four localities in the vicinity of the dam site. At each locality there were from two to four sets of joints. Classified on the basis of strike and dip, they fall into the following five groups, of which two stand out:

System	Number of determinations	Strike	Dip
1	4	N.87° to 130°E.	46° to 49° N.
2	4	N. 4° to 31°E.	61° W. to 90°
3	2	N.37° to 53°W.	52° to 58°SW.
4	1	N.47°E.	45°SE.
5	1	N.100°E.	76°N.

Most of the joints were clean, persistent, and at the surface were open from 1/32-to 1/16-inch, but some joints in systems 2, 3, and 5 were filled with silica. The spacing was somewhat greater in the graywacke than in the argillite. It varied from as much as 24 inches in the former down to 2 to 4 inches in the latter.

Character and depth of valley fill: Figures 4, 5, and 9 show the general relationship of the deposits filling the valley below the lake outlet. Detailed descriptions are given in summary geologic logs of drill holes and test pits, Appendix I, and in measured geologic sections, Appendix II.

Depth to bedrock: The bedrock valley floor can be seen about 8.8 miles below the lake outlet near the mouth of Thunder Bird Creek at an altitude of about 200 feet (barometer elevation). At the dam site, the depth to bedrock in the center of the valley is unknown. However, it seems reasonable that bedrock should not be expected at an altitude higher than that of the lake bottom at about 650 feet. On the other hand, if the bedrock surface is projected upstream from Thunder Bird Creek, at the rate of 20 feet per mile, an altitude of 375 is obtained. The actual bedrock surface is probably at some intermediate altitude.

Fill materials: Unconsolidated deposits of valley-fill make the foundations for the prospective dam and conduit. The partial, composite descriptive section that follows summarizes the lithology of the fill units and gives their general sequence upward from the lowest exposed. The detailed measured sections to which reference is made may be found in Appendix II.

1. Fine gravel. - A total thickness of 21.5 feet of clean, washed, fairly well graded, lenticular, highly cross-bedded, fine gravel and sand was observed in measured section No. 19.

2. Gravel. - Overlying bed No. 1 in measured section No. 19, there are about 8 feet of gravels, sands, and silts. At the base are many large boulders up to 4 feet in diameter.

3. Till. - In section No. 19, about 2 feet of light brownish-gray, compact till with a lean, silty, clay matrix overlies bed No. 2. It contains boulders up to 12 inches in diameter.

Plate V. Horizontally stratified deposits of gravel exposed in lower part of measured section No. 16.

Plate VI. Horizontally stratified gravel deposits about two miles down Eklutna Creek from the lake outlet.

Plate VII. Contact between light yellowish-brown, horizontally stratified gravel and overlying bluish-gray till. Man's band rests on boulder just below contact. Picture taken at measured section No. 13, altitude 884.

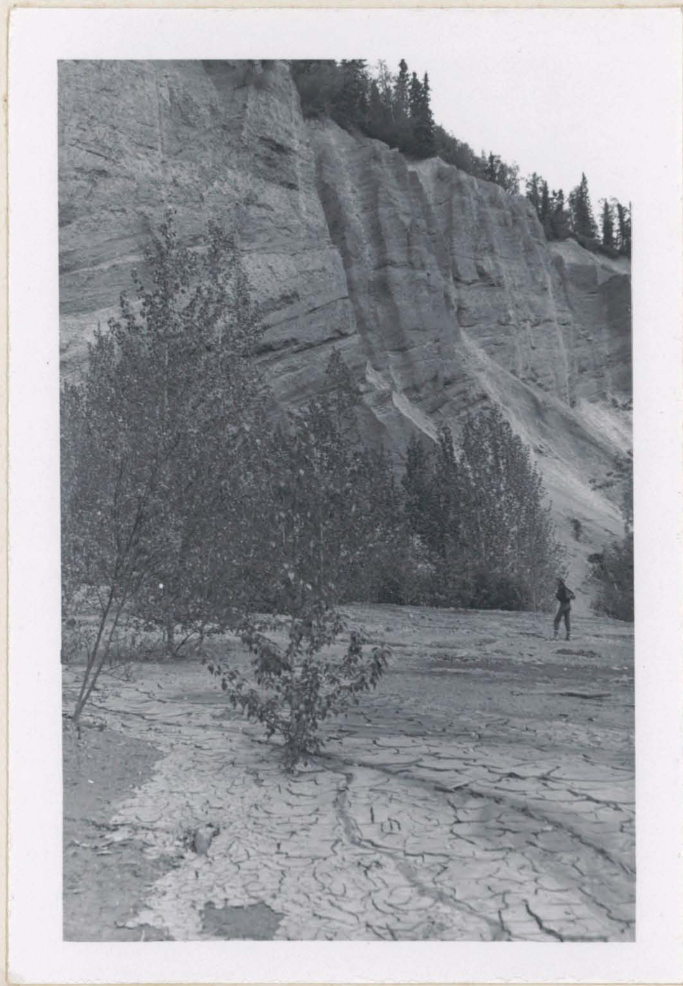


Plate VIII. Gravel deposits showing foreset cross-bedding dipping downstream at angle of about 20 degrees. Picture taken half a mile downstream from measured section No. 16.

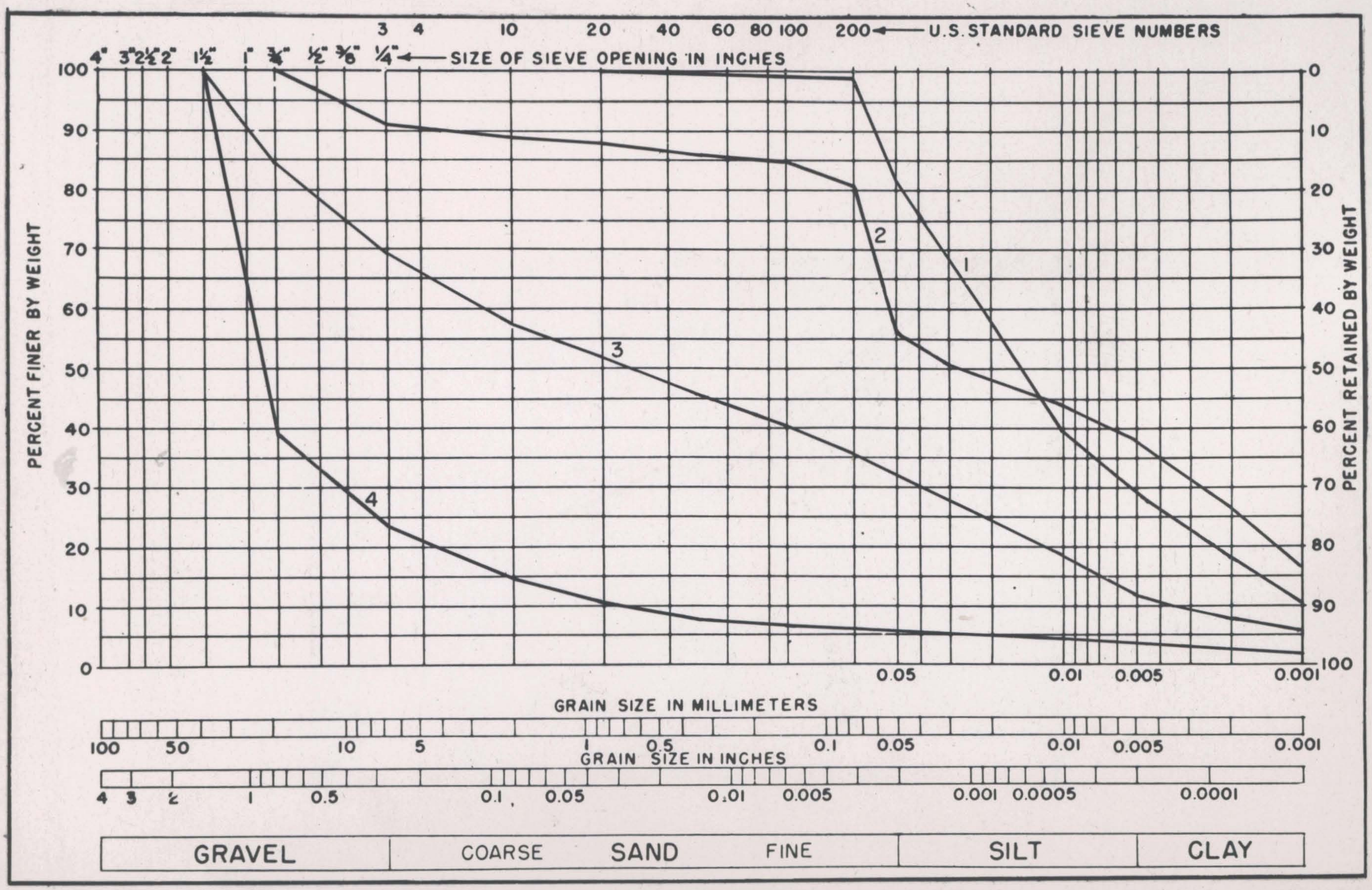


FIGURE 6

GRAIN SIZE DISTRIBUTION CURVES OF FILL MATERIALS

1. Thinly laminated clay, measured section no. 17, 43 to 127 feet
2. Massive clay, measured section no. 9, 33.4 to 42.9 feet
3. Till, measured section no. 2, 7 to 27 feet
4. Gravel, measured section no. 11, 17 to 68 feet

4. Horizontally stratified gravels. - Overlying the till in section No. 19 is a thick deposit of gravels that is remarkably uniform in composition and appearance, although it is made up of lenticular beds of the following materials: (1) light yellowish-gray, well-graded, slightly silty gravel and sand; (2) medium brownish-gray, well-graded, clean gravel and sand; (3) medium yellowish-gray, poorly graded, silty to clean sand that varies from fine to coarse. The gravels are coarse with occasional boulders up to 10 inches in diameter. On figure No. 6, a grain size distribution curve shows the gradation of the most common material listed above as (1). The entire series is very permeable, compact, resistant to erosion, and tends to stand in vertical cliffs which occur throughout the lower valley from section 10 to section 22. Stratification is well-developed and is either horizontal or dipping downvalley at angles from 1 to 5 degrees. The greatest observed thickness is 233 feet in section No. 19, the only locality where the base of the series was seen. Cobbles and pebbles of greenstone in these gravels show the effects of weathering in thin, discolored rinds from 1/8-to 5/16-inches thick. (See pls. V, VI, and VII.)

5. Intergravel zone. - In section 16 and 18, the gravels of bed 4 are overlain by about 12 feet of bluish-gray, compact, very hard, impervious, fairly well graded till with a lean, sandy, silty clay matrix. It contains striated cobbles and boulders up to 12 inches in diameter. Overlying the till in sections 16 and 18, and making up the entire zone in section 17, is from 2 to 7 feet of light yellowish-brown, thinly laminated, clean to slightly silty, fine-to-medium, even-grained, sand containing small lentils of coarse clean sand and fine gravel.

6. Cross-bedded gravels. - Occupying what appears to have been a channel cut into the horizontal gravel series are light yellowish-brown, well-graded, coarse, clean gravels and sands that are distinguished by highly-developed foreset cross-bedding on a large scale. (See pl. VIII.) Bed 5 may lie in the bottom of the channel. Contained in these gravels are many lenticular beds of medium brownish-gray, clean, coarse, cross-bedded sand with some fine gravel, small, scattered lenses of fine,

clean, even-grained sand, and small lenses of silt. These beds are permeable, fairly resistant to erosion, and tend to stand in vertical cliffs. The foreset beds dip downstream at an angle of about 20 degrees. As is shown in figure 4, these beds first appear between sections 15 and 16, thicken to 144 feet in section No. 17, and then thin to 74 feet in section 14. In section 20, they are replaced by a series of normally dipping, interbedded coarse gravels, sands, and silts about 35 feet thick and an overlying light yellowish-brown, horizontally stratified gravel 56 feet thick.

7. Blue-gray till and clays. - Overlying the cross-bedded gravels is a zone that is marked by its distinctive light blue-gray color. It usually consists of a bluish-gray, massive, compact, impervious till with a sandy, silty clay matrix and a high content of pebbles, cobbles, and boulders. However, in some places it either contains large masses of, or is entirely made up of, a massive lean silty clay with scattered pebbles and cobbles or a thinly laminated, fine, sandy silty clay. Grain size distribution curves for these materials are shown on figure No. 6. For example, in drill hole No. 1, this zone consists of 18 feet of clay overlying at least 14 feet of till; in section 16, it is entirely made up of massive clay; in section 17, it is a thinly laminated clay; and, in section 18, it is a massive till. This zone is thickest between sections 14 to 18 inclusive, with a maximum thickness of 149 feet. It was traced downstream as far as section No. 20. Pebbles and cobbles of greenstone from this zone have weathered rinds from 1/8-to 5/16-inches thick. Where these tills and clays underlie the 1,000-foot fill surface, they are oxidized and discolored to a light grayish-buff to a depth of about 4 feet.

8. Stratified drift. - Above the blue-gray zone and apparently interfingering with it in section Nos. 9 and 10 is a series of thin, discontinuous, lenticular beds of gravels, sands, silts, and silty clays containing masses of till varying from small lentils a few inches in maximum dimension to beds 16 feet thick.

This series has a general light yellow-brown color. The various strata are extremely variable in composition, degree of stratification, and thickness. Near the top of section Nos. 10, 13, and 17, is a light brownish-gray, compact, impervious, in places slightly stratified, till from 5 to 16 feet thick. As measured in section Nos. 9, 10, 12, 13, and 17, the total thickness of these deposits varies from 26 to 65 feet.

9. Lake gravels. - Much of the central part of the dam site area is covered with light yellowish-gray to buff, well-stratified, poorly graded to well-sorted, fine gravels composed mostly of flat pebbles and cobbles of argillite and shale coated with silty clay. (See pl. XII.) The maximum sized cobbles are 2 inches in the long dimension. Shingled structure in these beach gravels is well developed. The gravels dip toward Eklutna Lake at an angle of about 10 degrees, and closely resemble gravels on the present lake shore between high and low water levels. These gravels have a maximum thickness of 6.7 feet in test pit No. 5, where they are on the surface of the ground at altitude 883 feet. The top of these gravels rises to 889 feet in measured section No. 4, and to 888 feet in test pit No. 2.

10. Fan gravels. - The deposits in the alluvial fans built upon the 1,000-foot fill surface consist of coarse, clean, poorly-to fairly well-graded, loose, highly permeable gravels, with interbedded coarse, clean sands and thin layers of lean silty clay. A detailed description of these fan deposits is given in the summary log for test pit No. 1. The apex of the fan covering the north abutment of the dam is about altitude 1,300 feet, so the sediments of which it is composed may approach 300 feet in maximum thickness.

Hot spring deposits: High on the north wall of the valley above the dam site and reservoir area, there are at least six former hot springs with small deposits of calcareous tufa. The tufa consists of rounded to angular pebbles, cobbles, and fragments of graywacke, argillite, quartz, and rock fragments varying in size from that of fine sand to several inches in diameter, cemented by a calcareous matrix with a porous structure. In spots the matrix is banded. These spring deposits have been formed since the valley was glaciated, but in no way affect the dam site.

Earthquakes: The seismic history of Alaska is very incompletely known. From 1898 through 1934, Heck 9/ lists 21 earthquakes felt in

9/ Heck, N. H., Earthquake history of the United States, Part I, Continental United States and Alaska, U. S. Department of Commerce, Coast and Geodetic Survey, Serial No. 609, 1938.

the general region including Anchorage, the Matanuska Valley, and the Kenai peninsula, that equal or exceed intensity V on the modified Mercalli intensity scale. Of these, one on Sept. 11, 1911 of intensity IX broke cables and caused heavy rock slides. Numerous shocks broke plate glass windows, rattled dishes, and caused a slight amount of damage. On April 26, 1933, after a shock of intensity V to VI at Anchorage, telegraph lines were down for a distance of 50 miles from town. Beginning with 1935, complete records 10/ have been kept. In

10/ United States Earthquakes, 1935 to 1944, inclusive, published annually by the Coast and Geodetic Survey, U. S. Department of Commerce.

the Anchorage-Matanuska area from 1935 to 1944 inclusive, a total of 78 earthquakes have been noted that varied in frequency of occurrence from 3 to 28 per year. Most of these were light, but one was of intensity IV, and one of intensity VI. Three others were sufficiently intense to rattle dishes and crack windows. During field work for the present investigation, two shocks of intensity III to IV were felt.

Earthquake shocks will continue in this area, but even one of intensity IX or X would probably have but little effect on a low dam constructed of compacted earth. However, in the design of appurtenant structures such as the outlet conduit and spillway, due consideration should be given to the possibility of severe earthquake shocks, especially since these structures will be founded on valley fill materials rather than on bedrock. The same applies to a conduit down the valley with the added danger that a severe earthquake might start slides on the high vertical cliffs of fill materials.

Plate IX. View of dam site from altitude 2,120 on hill south of dam site. Present dam at outlet of Eklutna Lake in right foreground. Landing strip in center of middle ground.

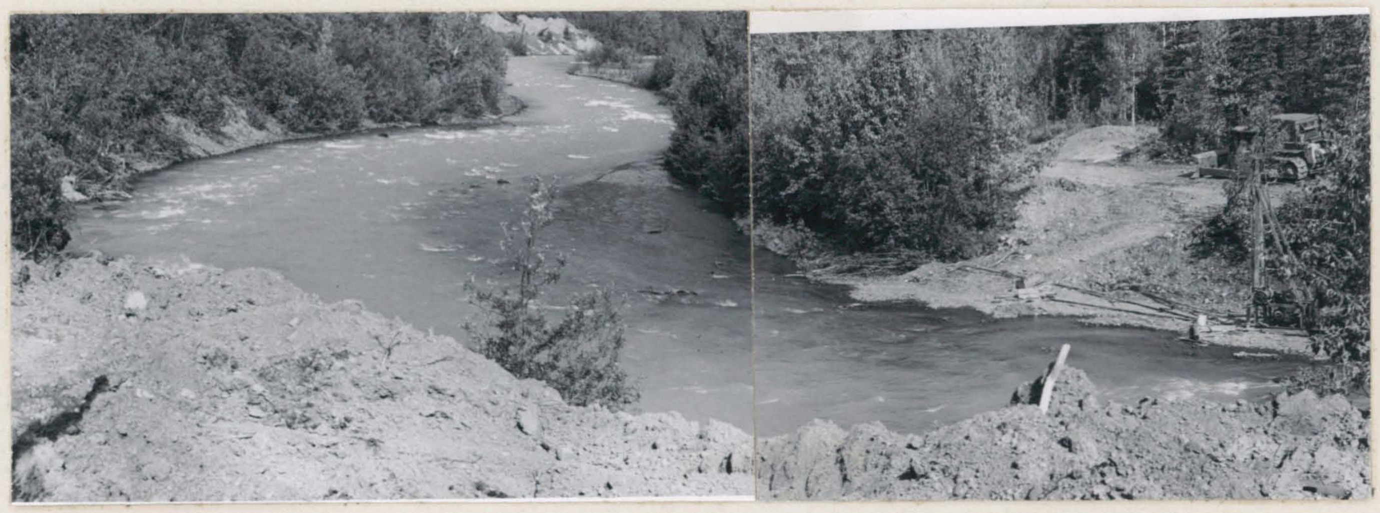


Plate X. View down Eklutna Creek at dam site, taken from measured section No. 2. Drill is set up on drill hole No. 2.

Plate XI. View of dam site from about three-quarters of a mile up left shore of Eklutna Lake.

Plate XII. View of gravel deposits exposed in test pit No. 5.

Dam site

(See pls. IX and X, and figs. 2, 4, 5, 7, and 8)

Location: The proposed location for the dam is on Eklutna Creek about 800 feet downstream from the outlet of Eklutna Lake.

Accessibility: A truck or car can be driven over truck trails from the Eklutna Lake road to within a few hundred yards of any point on the dam site to the right of Eklutna Creek. Vehicles can cross the creek over the present dam at the lake outlet, but can go no farther.

Valley profile: Figure 4 and plate XI show the valley profile at the dam site. A cross section of the bedrock surface is roughly parabolic in shape with a minor variation on the left wall because of a temporary glacial diversion channel cut into a bedrock spur. Glacial deposits fill the valley to about altitude 900 feet. Alluvial fan gravels cover the glacial deposits on the right half of the valley. Figure 7 shows an enlarged view of that small portion of the valley profile that will contain the embankment of the proposed dam.

Type and length of possible dam: Geologic conditions in the foundation limit the type of dam to flexible earth construction. Length of the dam will be 1,550 for a crest at altitude 910 feet, or 1,950 feet for crest at 920 feet.

Foundation: The proposed structure will rest on the unconsolidated glacial and alluvial deposits that have been described in the section on Fill materials. Figure 7 shows the writer's interpretation of the distribution of these deposits along the dam axis.

The bed of the river and probably the left abutment are underlain by an unknown thickness of compact stony till. This till was also found in drill hole No. 1 below altitude 848. Further exploration will be required to determine whether or not it extends under the right abutment to the north wall of the valley. In the center of the dam site area between drill hole No. 1 and measured section No. 4, the till is overlain by 18 to 20 feet of lean, silty clay that in the vicinity of section No. 4 contains many fragments of carbonized wood. Overlying the clay are from 3 to 7 feet of fine-to-medium, poorly sorted to even-grained, clean sand; then 3.5 to 6.5 feet of loose, clean, coarse gravel; and finally, 3 to 7 feet of the lake shore gravels. (See pl. XII.)

Almost the entire right half of the valley in the vicinity of the dam site is buried beneath the coarse gravels and sands of the alluvial fan built up by a small tributary stream. Since test pit No. 1 did not go through these gravels, the depth to the bottom of the fan is unknown. In test pit No. 2 near the toe of the fan, the lower limit is at an altitude of 888 feet.

Bearing capacity: The till, gravels, and the thin layer of sand in the dam site area have sufficient bearing capacity to withstand the loadings imposed by the proposed dam with but little consolidation. The clay, however, will suffer an appreciable amount of consolidation. Since coarse gravels underlie the till farther down the valley, the same condition probably exists under the dam site. Hence, foundation settlement will result primarily from consolidation of the 20-foot clay bed. The total settlement may amount to as much as one to two feet. However, a large part of this settlement will take place during construction of the earth embankment, and should have no effect on the dam itself. On the other hand, appurtenant structures with concentrated foundation loads, such as an outlet conduit, would very likely suffer damage from such a large amount of settlement and should be located so that they are not underlain by the clay bed.

Stability: In an engineering sense, tills, gravels, and sands, such as those in the dam foundation, have comparatively high resistance to shearing stress for unconsolidated materials. Clays, however, have low resistance, especially when saturated. The clay in place appears compact and firm, but there is a possibility that when loaded with embankment, it might squeeze out into the river channel or into the depression near measured section No. 4, especially during construction.

Permeability: The till and clay are relatively impermeable. Three water tests made in the till during drilling operations resulted in values of 0, 0, and 2.73×10^{-8} feet per second for the coefficient of permeability. The sand bed overlying the clay has about medium permeability. The gravels all have a rather loose structure and are highly permeable, especially the fan gravels.

To prevent seepage under the dam, some sort of cutoff must be provided, such as a trench excavated well into the till or clay, and backfilled with impervious material. This cutoff must be carried beyond the right abutment of the dam until impervious foundation material is found at an altitude of not less than 910 feet, or whatever maximum pool level is used.

__Frozen ground__: The foundation areas underlain by frozen ground in June 1947 are outlined on figure No. 2. Since embankment should not be placed on a foundation containing thin layers or kidneys of frozen ground, any contractor who anticipates submitting a bid for construction of the dam should be made aware of this condition so as to allow for it in his construction program.

The frozen zones varied in thickness from a few inches to four feet and were protected on the surface by a layer of moss from 6 to 24 inches thick underlain by from 6 to 18 inches of peat. Both are excellent insulating materials.

Between the peat and underlying frozen ground there was in most places either a layer of solid, clear ice from a fraction of an inch to 4 inches in thickness or else scattered ice crystals. At one locality on the dam site and at several localities in the reservoir area, the layer of clear ice was about 12 inches thick.

At a central location on the south abutment (see fig. 2), test pit No. 6 was dug through the frozen material. The air temperature varied gradually from 68° when the pit was started to 72° when it was completed. Results are summarized in the following table:

Depth feet	Material	Temperature Data: Depth to Measurement, feet	Temperature Data: Degrees F	Remarks
0 to 0.8	Moss	0.1	61	Sphagnum moss, spruce needles, roots, etc. Not frozen.
		0.8	32	
0.8 to 2.0	Peat			Thoroughly decayed moss, roots, spruce needles. Frozen. When thawed has light fluffy texture and is plastic.
		2.0	31	
2.0 to 4.6	Clay	2.7 4.0	32 32	Light olive-gray, lean, silty clay. Frozen to a depth of about 3.5 feet. Lower limit of frozen material is not distinct. Ice crystals are scattered through 3 to 4 inches of the unfrozen soil.
		4.6	35	
4.6 to 5.9	Till	5.0	35	Medium blue-gray. Top 12 inches weathered light olive-gray. Mixture of cobbles, fine gravel, and sand with a matrix of clay similar to that above.

In general, the ground is frozen to greater depths on the left abutment which is covered with a thick stand of spruce. Test pits Nos. 1 through 5, all on the right bank of Eklutna Creek were excavated to depths of about 10 feet with a dozer equipped D-8 Caterpillar tractor which had little trouble in breaking through the frozen ground. On the right bank, however, the dozer could not get through the frozen material. No doubt, parts of this frozen material never thaw during most summers.

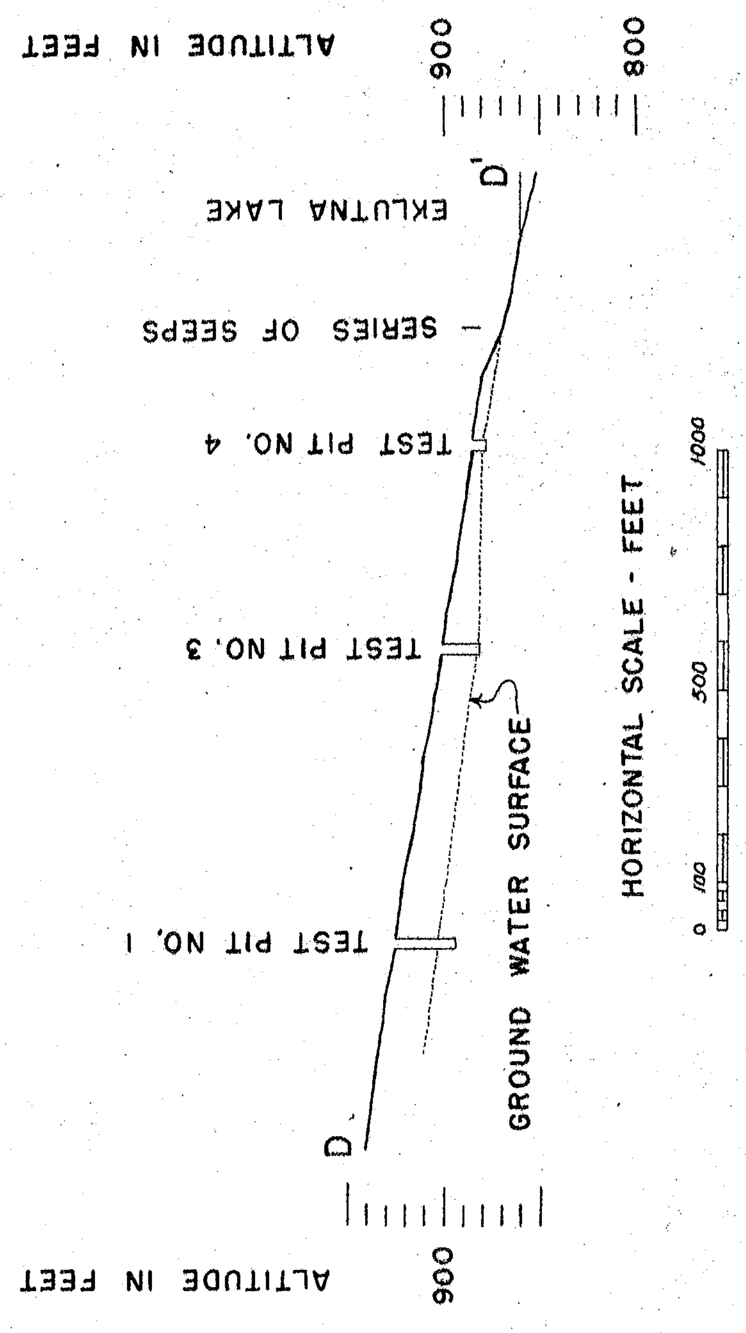
Areas from which the insulating moss and peat had been stripped were not underlain by frozen ground. Consequently, a contractor should plan to strip an area several weeks or months before excavating the underlying material.

Frozen ground tends to concentrate all rain water and melt water at the ground surface, and, hence, creates many drainage problems in connection with construction work.

Apparent possible height of dam: Stream regulation would require a maximum pool level at altitude 900. However, the most practical means of conducting water from the reservoir to a power plant in the Knik Valley appears to be by tunnel. If the portal at the Eklutna Lake end of the tunnel could be kept above lake level during construction, the need for a caisson would be eliminated and tunnel driving costs would be considerably lessened. This could be done by raising the ultimate minimum pool level from 860 to 870. As a result, the maximum pool level would have to be raised from 900 to about 910. The extra cost of a higher dam embankment would probably be much exceeded by the saving in tunnel driving costs. In addition, the net usable head for power generation would be increased by 10 feet. Since occasional high winds sweep down the valley raising large waves, a minimum of about 10 feet freeboard should be allowed. The crest of the dam would then be at altitude 920 or about 60 feet above the stream bed at the proposed axis. (See fig. Nos. 2 and 7.)

From our present knowledge of foundation conditions, it appears that seepage under or around the right abutment is the only factor that might interfere with construction of a dam to this height. Further exploration may show that impervious material does not reach an altitude of 910 feet at any point under the right abutment, or that it reaches this altitude at such a distance beyond the right end of the dam embankment that the cost of providing a cutoff would be prohibitive.

FIGURE 8



GROUND WATER PROFILE ALONG LINE D-D'

<u>Ground water conditions</u>: The ground-water level within the dam site appears to be related directly to an intake area about half a mile north where the discharge of a small tributary stream is absorbed by the gravels of the alluvial fan. The water then percolates on a fairly uniform gradient toward Eklutna Creek and Eklutna Lake. Along the lake shore it appears as a series of small seeps at an altitude of about 868. Profiles of the ground water surface in the dam site area to the right of Eklutna Creek are shown on figures 7 and 8. In drill hole No. 2, the till underlying the river bed was sufficiently impermeable so that no ground water was encountered.

In the valley downstream from the lake outlet, there was no evidence of seepage from the lake. All springs and seeps were from water moving down the side walls of the valley on top of clay or till.

<u>Choice of dam section</u>: The location of the dam could not be moved more than 50 to 100 feet from the tentative axis shown on figure 2, because (1) Eklutna Creek has a gradient of about 69 feet per mile for the first 4 miles below the lake outlet, thereby rapidly increasing the height of dam required to give the necessary storage; and (2) the topography is such that the cross sectional area of embankment is increased by moving the dam either upstream or downstream.

<u>Construction materials</u>: By selective excavation in the borrow pits, satisfactory embankment materials for the impervious, semi-pervious, and cobble sections of an earth dam can be obtained from the unconsolidated valley fill materials downstream from the dam. Average hauling distance should not exceed about 3,000 feet.

The most suitable rock for riprap would be the greenstones associated with the argillites and graywackes near the head of Eklutna Lake. At altitude 1,015 above the left abutment of the dam is a small exposure of rather massive graywacke which would probably prove satisfactory. Some prospecting will be required to determine whether or not enough massive material is available that will break into sufficiently large blocks.

Materials for concrete aggregate can be obtained from the large gravel banks downstream from the dam site. These gravels would probably require washing and selective screening to improve their gradation (see fig. 6). The fan gravels might also be used. They tend to be clean, but are usually lacking in fine sand and would need screening to improve gradation. Neither material will make first class concrete aggregate because of the rather large amounts of flat particles of slate and argillite.

Geology of the reservoir area: The reservoir area is long and narrow, and largely covered by Eklutna Lake. Little is known of its geology.

Bedrock in the valley walls consists of graywacke, argillites, and slates with interbedded greenstone sills or flows. One exposure occurs on the left (south) side of the lake 3.7 to 4 miles above the outlet. Elsewhere, the shores are veneered with gravels and other fill materials that are probably thin along the south shore and the upper end of the north shore. Along the north side for a distance of 5 miles above the dam site, however, there is a mass of fill materials between the lake and valley walls that is from 2,000 to 2,500 feet in width.

It is not known whether the lake bottom is on bedrock or valley fill. When the soundings were made it was observed that the bottom was covered with the glacial silts now being carried into the lake by Eklutna Creek.

Above the lake, the reservoir area is underlain by glacial outwash and debris that partially fills the valley.

Any leakage from the reservoir will be in the general area of the dam site, especially through the alluvial fan gravels covering the north side of the valley. This subject has been covered under the dam foundation.

Reservoir silting: During the summer months when melting of the glacier increases, the water in Eklutna Creek, especially above the lake, has a dirty milky appearance. Water samples were taken on June 29 following several cool days, and again on July 4 after several warm days. The total contained sediment in parts per million is:

June 29, 1947,	Inlet,	169 PPM
	Outlet,	17
July 4, 1947,	Inlet,	341
	Outlet,	21

While this evidence is inconclusive, it is all that is available, and may suggest the order of magnitude of the silting problem.

Summary: Foundation conditions at Eklutna Lake dam site are incompletely known, but geologic mapping and foundation studies to date indicate the following general conditions with respect to the dam site:

1. The dam must be founded on unconsolidated glacial sediments and alluvium that partially fill a wide, deep, glaciated valley. Bedrock is probably between 200 and 475 feet below stream bed at the proposed axis.

2. These sediments have adequate bearing capacity to support an earth fill dam of necessary height without suffering excessive consolidation accompanied by dangerous settlement.

3. Probably the greatest problem will be the prevention of seepage under and around the right abutment through gravels and sands of a large alluvial fan that covers the glacial sediments. Further exploration is necessary to establish a profile across the valley on top of impervious foundation material, so that some means can be devised to prevent such seepage.

Recommendations: Complete knowledge of the character, arrangement, and permeability of the glacial and alluvial deposits in the dam foundation should be obtained before a decision is made as to the maximum reservoir pool level, or work is started on preliminary design and cost estimates for an earth dam. To provide this knowledge, it is recommended that a series of drill holes be put down in the dam site area to depths of not less than 100 feet, and that one of the holes be taken to bedrock. Suggested locations are shown on figure 2, numbered from 2 to 13 inclusive, approximately in the order in which they should be drilled to obtain the most essential information first.

Location and drilling order of holes:

(1) Continue test pit No. 1 by drilling to determine the depth and thickness of any impervious material underlying the right abutment.

(2) Drill holes 3, 4, and 5 to determine the length of cutoff wall required beyond the end of the dam. If impervious material is not found above altitude 910 feet in these tests, another hole will be needed at a greater distance along the projected dam axis.

(3) Drill hole No. 6, and later, No. 12, to explore left abutment.

(4) Continue drill hole No. 1 to determine the thickness of till underlying the river bed and the character of the material under the till. Hole No. 10 to be drilled later for additional information.

(5) Hole No. 7, near the center of the valley, would be a good hole to drill to bedrock, thereby obtaining a complete section of the unconsolidated materials filling the valley.

(6) Drill holes 8 and 9 to give further information on conditions under the right abutment. In addition, they are located on what seems to be the logical route for a spillway.

(7) Drill hole 11 to obtain information with respect to changes in the character of the valley fill between the dam and the lake.

(8) Drill hole 13 to complete a cross section of materials in the foundation.

Logs of drill holes: Complete logs of each hole should be kept, in which is given:

(1) A description of the materials.

(2) Ground water conditions.

Samples: At intervals of not more than five feet, samples should be taken with a suitable sampling tube. These samples should be in as near their natural conditions as possible, and should not be chopped or washed. Glass jars with screw caps are satisfactory containers for preserving the samples. The labels should show the number of the hole, depth of sample, and any other pertinent information.

Water tests: In order to obtain permeability data on the various foundation materials, water tests should be made at depth intervals of not more than 10 feet. An approximate value of permeability can be obtained by the following procedure:

(1) Clean out the hole by washing or bailing to the bottom of the casing. Cleaning should be stopped as near the bottom of the casing as possible.

(2) Fill the casing with water either by hand or pump, maintaining a constant level of water at the top of the casing.

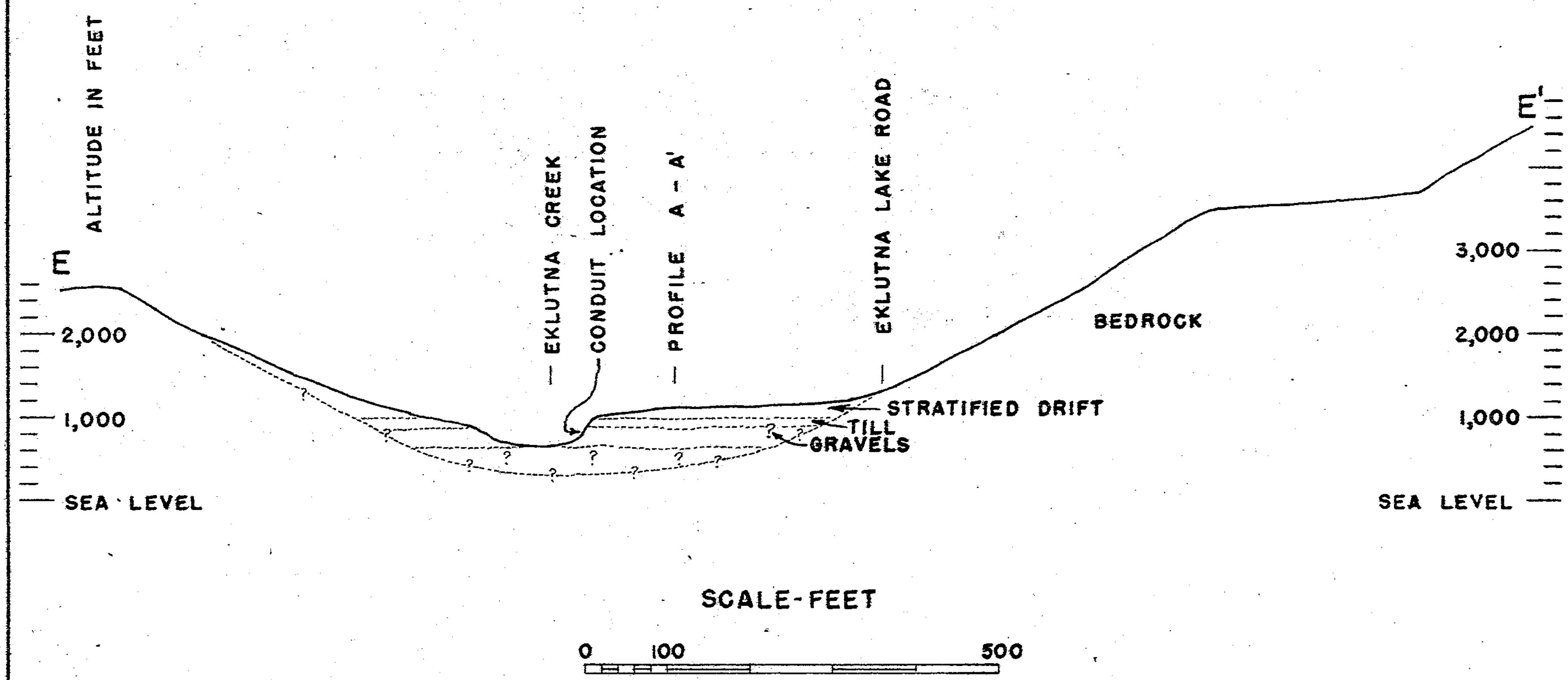
(3) Continue test for 30 minutes or more.

(4) Record the following data:

a. Depth of hole.
b. Depth to bottom of casing.
c. Inside diameter of casing.
d. Depth to ground water surface at start of shift.
e. Height from ground to top of casing.
f. Quantity of water required to maintain the water level.
g. Length of time test is continued.

Laboratory tests: It is recommended that a small laboratory be set up at the dam site to determine the engineering properties and strength characteristics of the fill materials in the dam foundation, especially those of the clay.

FIGURE 9



GEOLOGIC CROSS SECTION OF VALLEY SHOWING RELATIONSHIP OF CONDUIT TO INNER GORGE

Conduit route

<u>Conduit</u>: It is estimated that a conduit 8 feet in diameter and approximately 7½ miles long will be required. The conduit should be constructed with a gradient estimated at 15 feet per mile. At the dam, the top of the conduit would be about 870 feet in altitude.

<u>Location</u>: The conduit would extend from the dam site down Eklutna Creek valley to a powerhouse site situated in Knik Valley near the present powerhouse. The approximate route is shown on figure 3. For most of the distance, the route will lie part way up the steep, cliffy north bank of the inner gorge along cliffs from 50 to 350 feet in height. (See fig. 9.)

<u>Accessibility</u>: The conduit route is from half a mile to one mile from the Eklutna Lake road. Much of the intervening country is swampy and covered with muskeg. Access by truck will be difficult because of the swampy ground, and because the conduit would be part way down the extremely steep wall of the inner gorge.

<u>Foundation</u>: Throughout most of the route, the conduit will rest on either gravel or till. The gravel includes both the horizontally stratified gravels and the highly cross-bedded gravels. These deposits are described in the section on valley fill. Detailed measured geologic sections along the conduit route are described in Appendix II.

<u>Ground water conditions</u>: Because of their high permeability, the gravels are well drained. The overlying blue-grey till and associated clays are impervious. Ground water seeping down from the higher slopes tends to be retained on top of the till, and appears as seeps along the rim of the inner gorge.

<u>Slides</u>: Freezing and thawing produce a highly permeable, blocky, joint structure in the till and clays to depths of 3 to 4 feet below the ground surface. Whenever possible, ground water fills the joints, and as the till becomes saturated, its lateral support is gradually weakened until sliding occurs. After a slide starts in the till, the gravels also become involved, and as a result many of the slides involve hundreds and even thousands of cubic yards of material. Slides in the fill materials are common along almost the entire conduit route.

<u>Construction and maintenance problems</u>: A number of difficult problems will occur in connection with constructing and maintaining a conduit down Eklutna Valley:

(1) Transportation of materials to the conduit location.

(2) Construction of the conduit along the vertical cliffs of gravel and other unconsolidated fill materials.

(3) Crossing the numerous short but deep and steep-walled side canyons.

(4) Prevention of damage from slides.

In addition to these problems, other disadvantages are:

(5) Loss of about 120 feet of head.

(6) During cold winter weather, chilling of the water in the conduit may result in icing of the walls, thus reducing its capacity, and contribute to icing conditions at the power plant.

Appendix I

Summary geologic logs of drill holes and test pits.

Locations of drill holes and test pits were made with a plane table and telescopic alidade. They are shown on the geologic map of the dam site, figure 2.

Drill hole No. 1

Summary geologic log

Altitude top of ground 883.5

From Ft.	To Ft.	Thickness Ft.	Formation
Surface	10	10	Gravel, light yellowish-gray to brownish-gray, clean, coarse, poorly to fairly well-graded; contains little or no fine sand.
10	17	7	Sand, light bluish-gray, fine-to medium, poorly graded to even-grained, silty, fairly impervious. Maximum size 1 mm. Most grains under 0.25 mm.
17	35	18	Clay, light bluish-gray, lean, silty, very fine-grained, low plasticity, weak and friable at plastic limit.
35	48.5	13.5	Till, light bluish-gray, compact, hard. Mixture of cobbles, gravel, and sand with a matrix like the clay from 17 to 35 feet. In samples, there is too much matrix for material to be well-graded. Occasional boulders.

Hole abandoned at 48.5 feet.

Water first encountered at 7.6 feet.

Water test:

Depth of hole, 45 feet
Bottom of casing, 42.5 feet
Depth to water level before test, 40 feet
Casing, ID. - 4 inches
Casing filled to approximately 1 foot above ground surface at 3:20 p.m. No change in level between then and 7:30 a.m. on following morning.
k = 0 feet per second

Drill hole No. 2

Summary geologic log

Altitude top of ground: 859
Water surface in river: 859

From Ft.	To Ft.	Thickness Ft.	Formation
Surface	17	17	Till, light-gray, very hard, compact, stony. Mixture of boulders, cobbles, gravel, and sand with a very sandy clay matrix. Matrix lean, silty, very sandy clay with low plasticity. Slightly calcareous. From 14.9 feet to 17 feet, there were no boulders and few large cobbles.

Bottom hole July 4, 1947 at 17 feet.

Drillers reported that during drilling almost no water seeped into the hole.

Water test No. 1:

Depth of hole, 13 feet
Bottom of casing, 13 feet
Casing, ID. - 4 inches
Casing filled with water to 3.75 feet above ground.
No change in water level from 4:00 p.m. to 7:00 a.m. following morning.
k = 0 feet per second

Water test No. 2:

Depth of hole, 14.9 feet
Depth to bottom of casing, 12.4 feet
Casing, ID. - 4 inches
Hole bailed dry. In 16 hours 0.0217 cubic feet of water entered hole from lower 2.5 feet.

$k = 2.73 \times 10^{-8}$ feet per second

Test pit No. 1

Summary geologic log

Altitude top of ground: 925

From Ft.	to Ft.	Thickness Ft.	Formation
Surface	1.2	1.2	Moss, thick mat of moss, roots, twigs, leaves, etc. Lower part decayed to a spongy, plastic peat.
1.2	1.7	0.5	Clay, light yellowish-brown, lean, silty, loose texture, low plasticity, friable at plastic limit.
1.7	3.8	2.1	Gravel, light brownish-gray, loose, stratified, shingle structure, fairly well-graded, slightly dirty, maximum size cobbles 4 inches, low to medium permeability in place. Dip 4° N. 108° E. Frozen from 2.5 to 3.8 feet.
3.8	4.5	0.7	Clay, light brownish-gray, lean, silty, thinly-bedded, low plasticity, friable at plastic limit, low permeability. Frozen.
4.5	4.7	0.2	Sand, light reddish-brown, fine, even-grained, slightly silty, low permeability.
4.7	5.5	1.2	Gravel, light brownish-gray, fairly well-graded, fine, maximum size 1½ in., grains coated with silty clay, medium permeability.

5.5	5.7	0.2	Clay, light brownish-gray to black, lean, silty. Lower half mostly carbonaceous material. Impervious.
5.7	7.0	1.3	Gravel, same as from 4.7 to 5.5.
7.0	7.3	0.3	Clay, lean, silty.
7.3	9.5	2.2	Gravel, brownish-gray, coarse, fairly well-graded, voids filled with silty clay and sand. Low permeability. Contains striated boulders to 18 inches in size.
9.5	11.1	1.6	Clay, light yellowish-brown, lean, silty, low plasticity, with sandy lentils, impervious.
11.1	11.9	0.9	Gravel, light brownish-gray, fine, maximum size 1½ inches, fairly well-graded down through fine sand sizes, clean, medium-to high permeability.
11.9	13.0	1.1	Clay, as from 9.5 to 11.1.
13.0	13.3	0.3	Sand; and fine gravel, coarse, well-graded down through fine sand, maximum size 3/4 inch, loose structure, clean, high permeability.
13.3	15.3	3.0	Gravel, light brownish-gray, clean, well-graded down through fine sand, maximum size 3 inches, high permeability.
15.3	15.5	0.2	Clay, light yellowish-brown, lean, silty, with silt and fine, even-grained sand in top 1 inch, thinly laminated. Bottom half is ash-gray clay, more plastic, slightly tough at plastic limit, darker near bottom with many blebs of carbonaceous material; light spongy structure. Dip 5°, N. 158° E.

15.5	16.6	1.1	Sand, light reddish-brown, fine, even-grained, clean, with scattered pebbles and lenses of medium sand.
16.6	19.2	2.6	Alternating layers of sand and clay. Sand as from 15.5 to 16.6 in beds from 0.1 to 0.3 feet thick. Clay, light yellowish-brown, lean, silty, in beds from 0.1 to 0.2 feet thick, low permeability.
19.2	19.7	0.5	Sand and fine gravel, clean, with silty lentils, medium-to high permeability.
19.7	19.9	0.2	Clay, light-buff with ash-gray streaks.
19.9	20.6	0.7	Pebbles and some clean coarse sand, poorly graded, very pervious, thin layer clay coating pebbles near bottom. Water course.
20.6	25.2	4.6	Gravel, fine and coarse sand. Light brownish-gray, clean, compact, maximum size 3/4 inch, high permeability.
25.2	25.3	0.1	Pebbles and cobbles, rust coated. Estimated flow of about 2 gallons of water per minute from this stratum. Water course.
25.3	27.1	1.8	Sand, fine, even-grained, thinly stratified, clean, low-to medium permeability.
27.1	32.0	4.9	Gravel, light reddish-brown, coarse, maximum size 6 inches, well-graded down through fine sand.

Pit abandoned at 32 feet because crew was insufficient to maintain continuous pumping. No progress could be made against caving when pumping was continued during day shift only.

Ground water surface at 23.0 feet. Water in the pit rose to this level every night after pumping was stopped, and stayed at this level after hole was abandoned.

Water flow into test pit:

Depth	Rate of inflow
25.9 feet	4.2 gal. per minute
26.3	7.4
27.1	7.4
29.0	11.5

All tests were made after several hours of continuous pumping so that inflow had reached steady state. Size of shaft approximately 6 x 7 feet before timbering.

Test pit No. 2

Summary geologic log

Altitude top ground: 897

From Ft.	To Ft.	Thickness Ft.	Formation
Surface	0.5	0.5	Moss and peat.
0.5	2.5	2.0	Gravel, light brownish-gray, clean, well-graded through coarse sand, no fine sand, very pervious.
2.5	3.0	0.5	Sand, light brownish-gray, fine, uniform, silty, low permeability.
3.0	3.1	0.1	Peat, decayed moss, roots, twigs, etc., dark brown, plastic, highly pervious.
3.1	3.3	0.2	Silt, light yellowish-brown, contains much fine, even-grained sand, nonplastic.
3.3	6.6	3.3	Gravel, light brownish-gray, coarse, maximum size 4 inches, fairly well-graded down through coarse and medium sand, no fine sand, loose structure, very pervious, contains numerous lentils of rusty-gray to brownish-gray silt and fine, even-grained sand from 1 to 2 inches thick and 6 to 10 feet long, also contains lentils filled with small silt-coated pebbles.
6.6	8.3	1.7	Alternating layers of: (1) Clayey silt, light yellowish-brown, 1 to 2 inches thick; (2) carbonaceous material 1/4-to 1/2-inch thick; (3) sand, fine, poorly-

			graded, dirty, 2 to 3 inches thick.
8.3	9.2	0.9	Gravel, as from 3.3 to 6.6 feet.
9.2	11.0	1.8	Gravel, light yellowish-gray, fine, maximum size 1¼ inches, poorly graded, little sand, mostly flat silt-coated pebbles of slate and argillite, marked shingled structure. Dip 10°, N. 158° E. These are similar to gravels now found on lake shore between high and low levels.
11.0	16.8	5.8	Gravel, light-reddish, grayish-brown, coarse, maximum size 4 inches, poorly graded, too much matrix, very pervious. Matrix is fairly well-graded, fine to coarse, clean sand.

Ground water surface at 16.9 feet; no change.

Test pit No. 3

Summary geologic log

Altitude top of ground: 901.5

From Ft.	To Ft.	Thickness Ft.	Formation
Surface	0.7	0.7	Moss and peat
0.7	1.1	0.4	Soil, brownish-gray, fine, even-grained, silty sand with scattered pebbles.
1.1	1.8	0.7	Gravel, light yellowish-gray, fairly well-graded from 1½ inches down through fine sand, many flat pebbles of argillite and slate, some of larger pebbles coated with rock flour, otherwise clean, high permeability.
1.8	3.0	1.2	Sand, light brownish-gray, fine-to medium, poorly graded, slightly silty, many flat grains.
3.0	4.8	1.8	Gravel, light brownish-gray, stratified, fairly well-graded from 1½ inches down through fine sand, contains many flat particles of argillite and slate. Many lentils of silt and fine sand, 2 to 3 inches thick, 6 to 12 feet long. Medium to high permeability.
4.8	5.6	0.8	Silt, medium brownish-gray, with much fine, even-grained sand, and thin lentils of yellow-brown clay.

5.6	10.8	5.2	Heterogeneous arrangement of layers and lenses of: (1) Gravel, light brownish-gray, clean, fairly well-graded, maximum size 3/4 inch, loose structure, many flat particles. (2) Sand, fine, even-grained, rust colored in layers from 0.1 to 1.0 feet thick. (3) Silt, medium-gray, fine, sandy, slightly plastic.
10.8	12.5	1.7	Gravel, yellowish-and reddish-rust-brown, coarse, cobbles to 5 inches, fairly well-graded, very pervious.
12.5	13.5	1.0	Gravel, coarse, fairly well-graded down through fine sand, slightly silty, maximum size 5 inches, very pervious.
13.5	13.8	0.3	Cobbles and pebbles, iron-stained, extremely pervious.
13.8	20	6.2	Gravel, brownish-gray, stratified, clean, fairly well-graded, fine, maximum size 1 inch, few scattered cobbles to 3 inches.

Ground water surface at 19.5 feet; in 16 days rose to 18.3 feet.

Test pit No. 4

Summary geologic log

Altitude top ground: 883.9

From Ft.	To Ft.	Thickness Ft.	Formation
Surface	0.5	0.5	Moss and peat
0.5	1.5	1.0	Sand, dirty gray, fine, even-grained, silty, frozen.
1.5	2.1	0.6	Peat, thoroughly decomposed moss, roots, twigs, etc., plastic, loose, spongy texture. Frozen.
2.1	3.7	1.6	Sand, medium-olive gray, fine, even-grained, voids filled with slightly plastic clayey silt, rectangular blocky structure, probably the result of alternate freezing and thawing. Upper 0.4 feet frozen.
3.7	4.2	0.5	Pebble-clay, fine gravel with pebbles to 3/4 inch and a matrix of lean, silty clay. Dense, compact, blocky structure, many flat pebbles of argillite and slate.
4.2	7.5	3.3	Gravel, medium brownish-gray, poorly to fairly well-graded, maximum size 1½ inches, very little fine and medium sand, some silt, many flat particles of slate and argillite, has washed appearance, high permeability.

Ground water surface at 5.3 feet; in 19 days rose to 4.7 feet.

Test pit No. 5

Summary geologic log

Altitude top ground: 882.6

From Ft.	To Ft.	Thickness Ft.	Formation
Surface	6.7	6.7	Gravel, light yellowish-gray to buff, well stratified, sorted, maximum size 3 inches, pebbles flat, disc-shaped and coated with silty clay. Dip 10½°, N. 98° E. This deposit similar to gravels on lake shore and to gravel in test pit No. 2 from 9.2 to 11.0 feet.
6.7	10.2	3.5	Gravel, light brownish-gray, clean, poorly graded, contains too much sand to be well graded, stratified, cobbles to 6 inches, contains layers and lenses of medium-to fine-grained clean sand. Component dip 8½°, N. 86° E.
10.2	12.0	1.8	Sand, light brownish-gray, poorly sorted to even-grained, fine-to medium, clean, occasional flat argillite or slate pebble to 1/8-inch.
12.0	13.5	1.5	Sand, medium-gray, fine, even-grained, voids filled with gray, slightly clayey silt, more compact than overlying materials, low permeability.

Ground water surface at 9.8 feet; in 19 days rose to 8.5 feet.

Test pit No. 6

See page 24 for summary geologic log.

Appendix II

Summary of measured geologic sections.

The locations of sections 1 to 9 are shown on the geologic map of the dam site (fig. 2). A plane table and telescopic alidade was used to locate these sections on the dam site map and to establish the altitude given for each section. Measurements were made with a tape and hand level. Sections 3, 4, 6, 7, and 8 were measured in side hill trenches excavated by personnel of the Anchorage Department of Public Utilities.

The locations of sections 10 to 22 inclusive are shown on figure 3, Topography of valley showing country along which proposed conduit route would be located. These sections were located on the map by inspection. Altitudes were obtained by use of a Tycos surveying aneroid and hand level.

All sections are described from the top downward.

Measured geologic section No. 1

From Ft.	To Ft.	Thickness Ft.	Formation
0	1.1	1.1	Moss and peat
1.1	2.4	1.3	Silt, light brownish-gray or buff, clayey, slightly plastic, no evidence of stratification but may have been destroyed by alternate freezing and thawing, resulting in blocky structure.
2.4	3.0	0.6	Gravel, fine, maximum size ½-inch, with sand and some silt, well-stratified.
3.0	3.9	0.9	Till (?), gravel with somewhat more than enough sandy, clayey silt matrix to fill voids.
3.9	9.0	5.1	Gravel, light grayish-brown with rust-colored streaks, maximum size 2 inches but with scattered cobbles to 6 inches, fairly well-graded, compact, low permeability, pebbles coated with rock flour, numerous small silt lentils.
9.0	12.4	3.4	Sand, blue-gray, fine, even-grained, very silty, thinly-laminated with interbedded silt laminae and coarser rust-colored sand laminae, low permeability.
12.4	34.0	21.6	Obscured by slumping.
21.6			Water surface, Eklutna Creek, altitude 849.

Measured geologic section No. 2

Altitude at top 906.

From Ft.	To Ft.	Thickness Ft.	Formation
0	1.0	1.0	Moss and peat.
1.0	2.0	1.0	Gravel, light grayish-buff, fairly well-graded, pebbles mostly flat, argillite and shale, coated with rock flour, voids open.
2.0	7.0	5.0	Clay, light bluish-gray, weathers tan, lean, silty, non-stratified.
7.0	27.0	20.0	Till, light bluish-gray, upper 6 feet weathered light-yellowish-brown, very compact, boulders to 10 inches, poorly-graded mixture cobbles, pebbles, sand and lean silty clay matrix with low plasticity; too much matrix to be well-graded, resembles poor grade mass concrete in appearance. Cobbles appear slightly more weathered than in other deposits in dam site area; greenstones show weathered rind 1/8-to 5/16 inch thick.
27.0	47.0	20.0	Obscured by slumping.
47.0			Water surface, Eklutna Creek.

Measured geologic section No. 3

From Ft.	To Ft.	Thickness Ft.	Formation
0	1.3	1.3	Moss and peat.
1.3	5.3	4.0	Gravel, lake shore gravels, same as described in test pit No. 5 from surface to 6.7 feet.
5.3	6.8	1.5	Gravel, light reddish-brown, clean, too much fine sand to be well-graded, lacks coarse and fine gravel, boulders to 8 inches.
6.8	18.3	11.5	Till, light bluish-gray, top 5 inches weathered yellowish-gray, compact, impervious, cobbles to 4 inches, and gravel with considerably more than enough matrix to fill voids. Matrix is very lean, silty clay with low plasticity.
18.3			Water surface Eklutna Creek, altitude 860.

Measured geologic section No. 4

Altitude at top 891.8

From Ft.	To Ft.	Thickness Ft.	Formation
0	0.8	0.8	Moss and peat.
0.8	2.7	1.9	Clay, light yellow-brown, silty, contains some humus, low plasticity.
2.7	4.5	1.8	Gravel, lake shore gravels, same as described in test pit No. 5 from surface to 6.7 feet.
4.5	10.7	6.2	Gravel, light brownish-gray, coarse, contains no fine sand, fairly well-graded, maximum size 3 inches, trace of silt, loose structure, very pervious.
10.7	14.0	3.3	Sand, brownish-gray, fine-to medium, poorly graded, occasional pebble to ½-inch, many flaky grains of argillite and slate, fairly clean, loose structure, medium permeability.
14.0	34.5	20.5	Clay, light bluish-gray, surface weathered light grayish-tan to depth of 6 inches, lean, silty, low plasticity, slightly tough at plastic limit, compact, impervious, contains numerous scattered pebbles, lower part probably a till, from 28 to 34.5 feet and especially from 28 to 30 feet contains many macerated and carbonized fragments of reeds, wood, etc., and layers of greenish-to bluish-gray, fine, even-grained, dirty, compact sand.
34.5			Covered.

Entire slope frozen to depth of 18 to 24 inches.

Measured geologic section No. 5

From Ft.	To Ft.	Thickness Ft.	Formation
0	1.0	1.0	Moss and peat.
1.0	6.5	5.5	Gravel, light reddish-brown, clean, poorly-graded, maximum size 1½ inches, low on sand, many flat pebbles of argillite and slate, high permeability.
6.5	15.7	9.2	Till, light grayish-tan (weathered), mixture boulders and cobbles with a matrix of lean silty, sandy clay, compact, impervious.
15.7			Water surface in Eklutna Creek, altitude 850.

Measured geologic section No. 6

From Ft.	To Ft.	Thickness Ft.	Formation
0	1.2	1.2	Moss and peat.
1.2	2.1	0.9	Sand, fine, even-grained, dirty, scattered pebbles.
2.1	3.5	1.4	Clay, light bluish-gray, lean, silty, non-stratified, granular, blocky structure probably resulting from freezing and thawing.
3.5	6.6	3.1	Till, boulders, cobbles, pebbles, and sand with matrix of lean, silty clay similar to that from 2.1 to 3.5 feet, dense, compact, impervious, many striated pebbles.
6.6	9.5	2.9	Clay, light bluish-gray, lean, silty, impervious, indistinctly laminated, contains thin (1-inch) laminae of fine sand.
9.5	14.0	4.5	Sand, light grayish-tan, fine-to medium, uniform grain size, some laminae clean, others dirty, scattered lenses of silt, scattered lenses of pebbles up to 3/4-inch in size.
14.0	17.6	3.6	Sand, light yellowish-brown, clean, medium-to coarse, pebbles to ½-inch, very poorly-graded, grains subangular, high permeability.
17.6	18.8	1.2	Sand, light brownish-gray, coarse, with some fine gravel, poorly-graded, scattered cobbles to 3 inches, clean, high permeability.

18.8	35.0	16.2	Till, light bluish-gray, compact, impervious, scattered boulders to 10 inches, cobbles, gravel, and sand with a matrix of lean, silty clay with low plasticity. Poorly-graded, estimate 60-65 percent matrix by volume.
35.0			Covered below this point. Altitude 851.0

Measured geologic section No. 7

Altitude at top 933.

From Ft.	To Ft.	Thickness Ft.	Formation
0	0.4	0.4	Moss and peat.
0.4	1.0	0.6	Silt, medium brownish-gray, clayey, slightly plastic.
1.0	1.4	0.4	Sand, light-brown, fine, even-grained, slightly silty.
1.4	1.6	0.2	Silt, light brownish-yellow, sandy, trace of plasticity, light feathery structure, ash-gray layer ½-inch thick at top.
1.6	2.3	0.7	Sand, as from 1.0 to 1.4 feet.
2.3	6.0	3.7	Gravel, light-gray, fine, maximum size 2 inches, fairly well-graded, little fine sand, clean, many flat pebbles of argillite and slate, some pebbles mottled with patches of silty clay, medium-to high permeability.
6.0	8.2	2.2	Clay, light yellowish-brown, lean, silty, low plasticity, streaks of fine, even-grained sand up to 1-inch thick, low permeability.
8.2	10.1	1.9	Sand, light brownish-gray, medium-to coarse, trace silt, poorly-graded, scattered pebbles to 1½ inches, medium-to high permeability.
10.1	11.4	1.3	Gravel, light brownish-gray, fine, maximum size 1-inch, poorly-graded, over-sanded, clean, medium-to high permeability.

11.4	12.6	1.2	Sand, light-brown, fine, even-grained, voids filled with silt, lentils of coarser clean sand, layers of silty clay up to ½-inch thick, low permeability.
12.6	13.8	1.2	Gravel, as from 10.1 to 11.4 feet.
13.8	14.2	0.4	Sand, light-brown, fine, even-grained, voids filled with silt, low permeability.
14.2	15.7	1.5	Gravel, light brownish-gray, compact, firm, fine, occasional cobbles to 2 inches, well-graded, matrix slightly silty sand, high permeability.
15.7	18.4	2.7	Sand, light grayish-brown, fine, even-grained, silty, layers and lenses of gravel up to 2 inches thick.
18.4	21.2	2.8	Gravel, light-gray, clean, well-graded.
21.2	22.7	1.5	Clay, light yellowish-brown, lean, silty, low plasticity, low permeability, layers slightly more plastic, bluish-gray clay to ½-inch thick, layers fine, even-grained, rusty sand to 1-inch thick.
22.7	33.3	10.6	Gravel, light brownish-gray, poorly-graded, over-sanded, silty, cobbles to 3 inches, high permeability.
33.3	33.5	0.2	Clay, ash-gray and rust-colored, mottled, lean, silty, low plasticity.
33.5	37.4	3.9	Gravel, light brownish-gray, poorly-graded, over-sanded, slightly silty, cobbles to 3 inches, high permeability.
37.4	40.4	3.0	Covered.

Bottom of valley flat, swampy, probably near blue-gray till and associated clay found in sections No. 4 and No. 6.

Measured geologic section No. 8

Altitude at top 944.

From Ft.	To Ft.	Thickness Ft.	Formation
0	0.3	0.3	Moss and peat.
0.3	1.8	1.5	Silt, medium yellowish-brown, with some fine gravel, non-plastic.
1.8	1.9	0.1	Charcoal and silt, top half mostly small charcoal fragments; bottom half light ash-gray, non-plastic, silt, with much fine sand.
1.9	3.2	1.3	Silt, light yellowish-brown, non-plastic, with very fine, even-grained sand.
3.2	4.4	1.2	Gravel, light-gray, coarse, cobbles to 4 inches, little fine sand, fairly well-graded, clean except that many cobbles are veneered with silt, high permeability.
4.4	5.4	1.0	Clay, light yellowish-brown, lean, silty, low plasticity.
5.4	5.9	0.5	Gravel, light yellowish-brown, fine, pebbles to 3/4-inch, fairly well-graded, slightly dirty, high permeability.
5.9	7.1	1.2	Clay, as from 4.4 to 5.4 feet.
7.1	12.7	5.6	Gravel, light-brownish to pinkish-gray, coarse, cobbles to 6 inches, fairly well-graded down through fine sand, slightly dirty, high permeability.

12.7	17.3	4.6	Alternating layers: (1) gravel, in beds 3-to 9 inches thick, grayish-tan, fine, pebbles to 1-inch, fairly well-graded, slightly silty; (2) silt, in beds 3-to 5 inches thick, light yellowish-brown, much fine, even-grained sand.
17.3	21.5	4.2	Sand, light brownish-tan, fine, even-grained to poorly-graded, slightly silty, layers to 2 inches thick contain much clayey silt, and layers to 4 inches of yellowish-brown, lean, silty clay.
21.5	21.9	0.4	Gravel, light brownish-gray, fine, pebbles to 1-inch, well-graded, down through fine sand, clean, high permeability.
21.9	22.5	0.6	Sand, light brownish-gray, very fine, even-grained, slightly silty.
22.5	25.7	3.2	Gravel, light brownish-gray, cobbles to 4 inches, loose structure, low permeability, sandy silty clay matrix.
25.7	28.9	3.2	Covered.

Measured geologic section No. 9

From	To	Thickness	Formation
0	1.2	1.2	Moss, peat, and light sandy soil.
1.2	5.6	4.4	Interbedded strata of: (1) silt, light grayish-tan, thinly-laminated, cross-bedded, sandy, slightly clayey; (2) sand, rusty, fine, poorly-graded, in layers to 2 inches thick; (3) gravel, fine, fairly well-graded.
5.6	8.5	2.9	Gravels, light brownish-gray, fine, pebbles to 1¼ inches, poorly-graded, much coarse sand, clean, high permeability.
8.5	17.2	8.7	Interbedded strata similar to those from 1.2 to 5.6 feet.
17.2	20.6	3.4	Gravel, brownish-gray, fine, pebbles to 1-inch, much very coarse sand, even-grained to poorly-graded, grains coated with rock flour, but voids not filled, very pervious.
20.6	22.6	2.0	Gravel, medium brownish-gray, fine, pebbles to 3/4-inch, sandy, well-graded, clean, cross-bedded, high permeability.
22.6	33.4	10.8	Sand, light-to medium-gray with thin rust-brown layers, fine, poorly-graded, thinly-bedded, some layers clean, others silty, many thin layers and lentils of silt, medium-to low permeability.
33.4	42.9	9.5	Clay, light bluish-gray, very fine, powdery, lean, silty, impervious, nonstratified, contains 15 to 20 percent by volume pebbles and cobbles to a maximum size of 8 inches, scattered lenses of fine, dirty pea gravel and lenses of coarse sand.

42.9	43.4	0.5	Clay, light yellowish-gray to buff, very fine, silty, lean, friable, thinly-laminated, slightly contorted, no sand, impervious.
43.4	54.4	11.0	Gravel, light yellowish-brown, nonstratified, consists chiefly of pebbles from 1/8-to 1-inch, scattered cobbles to 3 inches, pebbles coated with lean, silty clay, voids partly filled, medium permeability.
54.4	60.4	6.0	Sand, light grayish-buff, fine, even-grained to poorly-sorted, mostly clean but with silty layers and silt partings, thinly-laminated, cross-bedded.
60.4	65.5	6.1	Till (?), medium-gray, compact, impervious, massive, nonstratified, lean, silty clay with about 25 percent by volume of scattered pebbles and cobbles.
65.5	81.0	14.5	Till, medium-gray, weathers light brownish-gray, compact, massive, impervious, poorly to fairly well-graded mixture of cobbles and gravel with about 25 percent lean silty clay matrix, cobbles to 6 inches, occasional boulders to 24 inches, cobbles highly striated.
81.0			Water level in Eklutna Creek, altitude 840.

Measured geologic section No. 10

Component dip of beds exposed - 3° , N. 95° E.

From Ft.	To Ft.	Thickness Ft.	Formation
0	1.5	1.5	Moss and peat.
1.5	2.7	1.2	Gravel, fine, clean, poorly-graded.
2.7	2.9	0.2	Silt, light-buff, nonplastic, bottom 1/8-inch lignite.
2.9	8.1	5.2	Till, light brownish-gray, compact, impervious, fairly well-graded; lean, sandy, very silty clay matrix, many striated boulders up to 24 inches in diameter.
8.1	9.1	1.0	Gravel, brownish-gray, fine, cobbles to 1½-inches, fairly well-graded, sandy, slightly silty, particles silt-coated, medium permeability.
9.1	10.6	1.5	Alternating series of beds grading from lean silty clay to silt to fine sand to coarse sand. Rust-colored sand about 2 inches thick both at top and bottom.
10.6	11.4	0.8	Gravel, fairly well-graded, sandy, slightly silty, maximum size 1½-inches, particles coated with rock flour, medium permeability. Series of faint water seeps along lower contact.
11.4	13.7	2.3	Till, light brownish-gray, compact, fairly well-graded, boulders to 18 inches, sandy silty clay matrix, impervious.

13.7	18.7	5.0	Alternating series of beds grading from lean silty clay to silt to fine sand to coarse sand. Series repeated 8 times. Sand strata are thickest, up to 5 inches. Series of small water seeps from lowermost sand.
18.7	19.1	0.4	Silt, light grayish-brown with rust-colored streaks of very fine sand, thinly-laminated.
19.1	21.1	2.0	Sand, coarse, and pea gravel, grayish to rusty-brown, poorly graded, slightly silty, high permeability, rust-colored layers. Series of small water seeps along lower contact.
21.1	25.1	4.0	Clay, pearl-gray to light blue-gray, thinly-laminated, very fine-grained, lean, silty, medium-low plasticity, impervious, ½-inch layer of ash, charcoal fragments, peaty material, and small shells about one foot from top.
25.1	25.2	0.1	Volcanic ash (?), light grayish-white, weathers yellow-brown, friable, nonplastic.
25.2	31.9	6.7	Sand, yellowish-rusty-brown, coarse, pebbles to ½-inch, thinly-bedded, highly cross-bedded, poorly-graded, clean, many flat argillite and slate particles. Very prominent series of water seeps along lower contact.

31.9	53.9	22.0	Till, medium-gray, top 14 inches weathered to a light yellowish-gray; mostly lean, silty clay matrix of low plasticity with an estimated 25 percent by volume of boulders, cobbles, and pebbles; impervious, most of bed is massive but there are traces of bedding in places. About 10 feet below top grades into a thinly laminated dark bluish-gray silty clay.
53.9	59.9	6.0	Obscured by sliding.
59.9	91.9	32.0	Gravel, medium grayish-brown, weathers light yellowish-brown, faintly stratified, well-graded mixture of boulders to 18 inches, cobbles, gravel, with a matrix of coarse to fine, slightly silty sand, low permeability, stands in cliffs.
91.9			Water surface in Eklutna Creek, altitude 834.

Measured geologic section No. 11

From Ft.	To Ft.	Thickness Ft.	Formation
0	10	10(est.)	Clay, light bluish-gray, thinly bedded, lean, silty. Thickness estimated, as exposure was on inaccessible cliff.
10	17	7(est.)	Till, medium-gray, fairly well-graded mixture of cobbles and pebbles, with a matrix of sandy, silty, lean clay. Impervious. Thickness estimated.
17	68	51	Gravel, light yellowish-buff, compact, massive to faintly stratified, well-graded, matrix of coarse to fine, slightly silty sand.
68			Water surface in Eklutna Creek, altitude 812.

Measured geologic section No. 12

From Ft.	To Ft.	Thickness Ft.	Formation
0	0.6	0.6	Moss and peat.
0.6	1.3	0.7	Silt, medium brownish-gray, with much fine, even-grained sand.
1.3	1.4	0.1	Silt, light ash-gray, nonplastic, loose, fluffy structure.
1.4	2.2	0.8	Gravel, light orange-brown, very loose structure, poorly-graded, cobbles to 6 inches, high percent sandy silt matrix, highly pervious.
2.2	4.7	2.5	Gravel, light brownish-gray, fine, poorly-graded, with layers of fine, even-grained sand, and layers of coarse, clean sand, medium-to high permeability.
4.7	13.2	8.5	Sand, light brownish-tan, thinly-laminated, highly cross-bedded; some layers and lenses fine, even-grained, both clean and silty; other layers and lenses medium-to coarse, clean; numerous small scattered lentils of till.
13.2	25.2	12.0	Gravel, light-brown, fairly well-graded from cobbles down through fine sand, loose pervious structure; many small lentils of fine sand and silt; numerous discontinuous masses of light brownish-gray, fairly compact till with cobbles to 3 inches and a sandy, slightly clayey silt matrix.

25.2	25.9	0.7	Gravel, light yellowish-brown, fairly well-graded, cobbles to 6 inches, pebbles coated and voids filled with lean silty clay.
25.9	42.4	16.5	Interbedded layers of: (1) Sand, light yellowish-brown, fine, even-grained, in layers to 24 inches thick, some layers clean, others silty; (2) Gravel, light yellowish-brown, stratified, cross-bedded, fairly well-graded, clean, pervious. Lower contact very pervious, site of line of water seeps.
42.4	56.2	13.8	Till, dark bluish-gray, weathers grayish-tan, massive, compact, hard, boulders to 10 inches, but most under 5 inches, poorly-graded sand and silt matrix with a trace of clay. Too much matrix for till to be well-graded.
56.2	90.2	34.0	Covered.
90.2	176.2	86.0	Gravel, light yellowish-brown, darker and more grayish on fresh exposure, stratified, well-graded, boulders to 18 inches, cobbles, and pebbles, with a matrix of coarse-to fine, slightly silty sand.
176.2			Water surface in Eklutna Creek, altitude 800.

Measured geologic section No. 13

From Ft.	To Ft.	Thickness Ft.	Formation
0	1.5	1.5	Moss and peat.
1.5	17.5	16.0(est.)	Stratified drift. Exposure on inaccessible cliff. Layers and lenticular masses of: till, light brownish-gray, fairly compact, cobbles and pebbles with sandy, slightly clayey silt matrix; gravel, light yellowish-brown, cobbles to 6 inches, most under 2 inches, sand matrix, slightly silty; sand, fine, poorly-graded, in lenses 2 to 4 inches thick, 1 to 3 feet long.
17.5	28.0	10.5	Interbedded layers of: gravel, light yellowish-gray, poorly-graded, clean; sand, brownish-gray, fine, even-grained, some clean, some silty.
28.0	73.0	45.0	Till, bluish-gray, weathers grayish-tan, massive, compact, boulders to 18 inches, cobbles, and pebbles with a matrix of sandy silty clay, poorly graded because of too much matrix, impervious.
73.0	164.0	91.0	Gravel, grayish-brown, weathers light yellowish-brown, stratified, well-graded, boulders to 12 inches, cobbles, pebbles, matrix of well-graded, coarse-to fine sand, with a trace of silt, medium permeability.

164.0	189.0	25.0	Covered.
189.0			Water surface in Eklutna Creek, altitude 768.

Measured geologic section No. 14

From Ft.	To Ft.	Thickness Ft.	Formation
0	1	1	Moss and peat.
1	81	80	Till (?), inaccessible cliff. Seems to be till similar to that described from 86 to 116 feet, but more yellowish in color.
81	86	5	Clay, light bluish-gray, lean, silty, thinly-laminated.
86	116	30	Till, medium-gray, massive, fairly well-graded, cobbles, pebbles in a matrix of lean, silty, sandy clay.
116	126	10	Sand, light yellowish-brown, fine, some layers even-grained, some poorly-graded, some layers clean, some silty.
126	150	24	Till, as from 86 to 116 feet. In lower 10 feet, there are many layers of finely-laminated, lean, silty clay 3 to 6 inches thick.
150	235	85	Gravel, grayish-brown, weathers to light yellowish-brown, stratified, well-graded, cobbles to 6 inches, well-graded sand matrix, some layers slightly silty, others clean.
235			Water surface in Eklutna Creek, altitude 750.

Measured geologic section No. 15

From Ft.	To Ft.	Thickness Ft.	Formation
0	1	1	Moss and peat.
1	48	47	Till, light grayish-buff, rather loose structure for till, fairly well-graded, cobbles to 3 inches, lean, silty, clay matrix, low permeability.
48	85	37	Covered.
85	170	85	Till, bluish-gray, compact, impervious, poorly-graded, too much matrix of lean, very silty clay. Bottom 12 feet is faintly stratified silty clay with scattered pebbles and cobbles.
170	283	113	Gravel, light yellowish-brown, well-stratified, coarse, well-graded, cobbles to 6 inches, matrix of well-graded coarse-to fine sand, some layers slightly silty, others clean, medium-to high permeability, stands in vertical banks.
283			Water surface in Eklutna Creek, altitude 712.

Measured geologic section No. 16

From Ft.	To Ft.	Thickness Ft.	Formation
0	1	1	Moss and peat.
1	32	31	Till, light bluish-gray, massive, impermeable, poorly-graded, mostly matrix with scattered pebbles and cobbles, matrix of lean, silty clay.
32	112	80	Gravel, light yellowish-brown, marked foreset cross-bedding dipping down valley at angles of about 20 degrees, well-graded, coarse, cobbles to 6 inches, matrix of clean sand, high permeability, stand in vertical cliffs; in top 40 feet, there are many lenticular beds of darker brownish-gray composed of fine gravel and clean, coarse, cross-bedded sand, scattered lenses of silt, and of clean, fine, even-grained sand.
112	114	2	Sand, light yellowish-brown, stratified, clean, medium, even-grained, some rusty grains, medium permeability.
114	126	12	Till, dark bluish-gray, top 6 inches weathered yellowish-to brownish-gray, very hard, compact, impervious, cobbles to 12 inches, cobbles striated, poorly graded, more than enough matrix to fill voids, matrix of sandy, silty, lean clay, low permeability.

126	232	106	Gravel, stands in vertical cliffs over 200 feet high, remarkably uniform; composed of following more or less lenticular strata: (1) gravel, light yellowish-gray, coarse, well-graded, matrix slightly silty sand; (2) gravel, light brownish-gray, coarse, well-graded, matrix clean sand; (3) sand, in small lentils, poorly-graded, coarse-to medium, some lentils clean, some silty, a few lentils of fine sand. Entire mass is compact, resistant, has high permeability. Dips downstream 3 to 5 degrees.
232			River surface in Eklutna Creek, altitude 677.

Measured geologic section No. 17

From Ft.	To Ft.	Thickness Ft.	Formation
0	1	1	Moss and peat.
1	16	15	Till, light brownish-gray, slightly stratified in places, compact, impervious, boulders to 10 inches, matrix of lean silty clay makes up estimated 40 percent, pebbles and cobbles scattered through.
16	43	27	Interbedded layers and lenticular masses of: (1) gravel, medium yellowish-brown, fairly well-graded, cobbles to 3 inches, matrix sand that is clean in some lenses, silty in others; (2) sand, clean, coarse, well-graded, or fine even-grained, both clean and silty. All lenses yellowish-brown in color; (3) silt, yellow-brown, sandy.
43	127	84	Clay, light blue-gray, thinly-laminated, strike N. 20° E., dip 3° W., lean, silty, fine-grained, impervious, scattered pebbles, thin sand partings, one massive bed 4 inches thick, impervious, occupies interval occupied by gray till in many localities.
127	271	144	Gravel, as described in section No. 16 from 32 to 112 feet. Dipping 20° downstream; high permeability.
271	278	7	Sand, light-tan, thinly laminated, highly cross-bedded, fine, even-grained, slightly silty, lenticular structure, encloses lenses of coarse, clean sand and of fine gravel.

278	367	89	Gravel, as described in section No. 16 from 126 to 232 feet. Top contact is irregular and channeled to depth of 3 feet.
367	393	26	Covered by alluvial fan.
393			Water surface in Eklutna Creek, altitude 649.

Measured geologic section No. 18

From Ft.	To Ft.	Thickness Ft.	Formation
0	1	1	Moss and peat.
1	115	114	Till, light blue-gray, massive, stony, hard, compact, impervious, boulders to 18 inches, fairly well-graded, pebbles and cobbles much striated, matrix of lean silty clay; scattered small lenses of silt; top 3 to 4 feet oxidized to a yellowish-gray.
115	226	111	Gravel, with foreset cross-bedding; as described in section No. 16 from 32 to 112 feet. Dipping downstream, high permeability.
226	232	6	Gravel, yellowish-brown, fine, scattered cobbles and boulders, poorly-graded, too much matrix of fine yellow sand, dense, compact, medium-to high permeability.
232	238	6	Sand, light yellowish-brown and grayish-brown, thinly-laminated, extremely fine, even-grained, silty.
238	250	12	Till, light bluish-gray, massive, compact, very hard, stony, boulders to 12 inches, matrix of lean silty clay, impervious.
250	387	137	Gravel, stratified, as described in section No. 16 from 126 to 232 feet.
387	486	99	Covered by alluvial fan.
486			Water surface in Eklutna Creek, altitude 532.

Measured geologic section No. 19

The entire section was well exposed in the vertical walls of a narrow side canyon. However, it was impossible to examine it above altitude 720 except by looking across from the opposite side, a distance of about 100 yards. Hence, it was impossible to determine if the horizontally stratified gravels and the steeply-dipping gravels were separated by thin strata of till and sand as in sections 16, 17, and 18. The light bluish-gray material above the steeply-dipping gravels could have been either till or clay, as both have occurred in this interval in other geologic sections. No stratification could be observed from a distance of about 300 yards. Above the bluish-gray bed are more than 100 feet of grayish-brown deposits, probably either gravels or till.

From Ft.	To Ft.	Thickness Ft.	Formation
		100/	Gravels or till, could not get close enough to determine.
0			Series of small water seeps.
0	28	28	Till or clay (?), light bluish-gray, appears massive from distance of about 100 yards.
28	102	74	Gravel, with foreset cross-bedding dipping downstream at an angle of about 20 degrees. As described in section No. 16 from 32 to 112 feet.
102	335	233	Gravel, light brownish-gray, horizontally stratified, fairly well-graded, cobbles to 8 inches, not much fine sand, trace of silt, lenticular structure but remarkably uniform over entire thickness, stands in vertical cliffs, same as gravel described in section No. 16 from 126 to 232 feet.

335	337.5	2.5	Till, light brownish-gray, compact, impervious, boulders to 12 inches, sandy silty clay matrix, fairly well-graded.
337.5	340	2.5	Interbedded strata of: (1) gravel, fine, with much coarse sand, pebbles coated with rock flour; (2) sand, brownish-gray, clean, scattered pebbles to 1 inch; (3) silt, light-buff, thinly-laminated, thin laminae of fine, even-grained sand, laminae made up of one thickness of pebbles up to 1/4-inch diameter.
340	345.5	5.5	Gravel, very coarse, fairly well-graded, matrix of sand with just a trace of clayey silt, boulders up to 4 feet.
345.5	367	21.5	Sand and fine gravel, lenticular structure, highly cross-bedded; (1) fine gravel with pebbles to 3/4-inch, coarse to fine sand, well-graded, clean. These lentils make up 75 percent of deposit; (2) sand in lenses up to 12 inches thick and 20 feet long, poorly-graded, clean.
367	372.5	5.5	Covered.
372.5			Water surface in Eklutna Creek, altitude 472.

Measured geologic section No. 20

From Ft.	To Ft.	Thickness Ft.	Formation
0	25	25(est.)	Till, inaccessible, light brownish-gray, appears massive, stony.
25	27	2	Clay, light brownish-gray, lean, silty, about horizontal, could not get to it for close examination.
27	83	56	Gravel, light yellowish-brown, poorly- to fairly well-graded, cobbles to 6 inches, sand matrix, looks like gravels described in section No. 16 from 32 to 112 feet.
83	118	35	Interbedded layers of: (1) gravel, light brownish-gray, coarse, clean, fairly well-graded, in beds up to 2 feet thick; (2) sand, light yellowish-to grayish-brown, fine, even-grained to poorly graded, both clean and silty, in beds up to 2 feet thick; (3) silt, light-buff, sandy, in beds up to 6 inches thick.
118	262	144	Gravel, light-to medium brownish-gray, horizontally stratified, fairly well-graded, coarse, cobbles to 6 inches, matrix of well-graded clean sand; similar to gravel described in section No. 16 from 126 to 232 feet.
262	394	132	Covered.
394			Water surface in Eklutna Creek, altitude 448.

Measured geologic section No. 21

From Ft.	To Ft.	Thickness Ft.	Formation
			Top part of section inaccessible, either gravel or till.
0	25	25(est.)	Interbedded layers of gravels, sands, and silts. Could not get to them for examination.
25	26.5	1.5	Till, light brownish-gray, compact, impervious, fairly well-graded, stony, cobbles to 6 inches.
26.5	28	1.5	Interbedded layers of light-buff sandy silt and fine, even-grained sand.
28	138	110	Gravel, grayish-brown, stratified, coarse, fairly well-graded, cobbles to 6 inches; matrix of clean sand.
138	167	29	Covered.
167			Water surface in Eklutna Creek, altitude 370.

Measured geologic section No. 22

From Ft.	To Ft.	Thickness Ft.	Formation
0	0.5	0.5	Moss and humus.
0.5	1.0	0.5	Silt, ash-gray with streaks of yellow, light fluffy structure, sandy, nonplastic.
1.0	2.0	1.0	Sand, light yellowish-brown, fine, even-grained, silty, non-stratified.
2	18	16	Gravel, brownish-gray, stratified, fairly well-graded, scattered boulders to 18 inches, matrix of fine-to coarse sand, small lentils of silt and sand.
18	38	20	Sand, light yellowish-brown, fine, even-grained, clean, with lentils and thin layers of buff, slightly clayey silt.
38	81	43	Till, light grayish-brown, compact, impervious, fairly well-graded, matrix of silty clay with medium-to low plasticity.
81	109	28	Gravel, brownish-gray, coarse, poorly-graded, silty, with lenses of coarse silty sand.
109	139	30	Gravel, light brownish-gray, coarse, clean, fairly well-graded, cobbles to 10 inches.
139	152	13	Interbedded layers and lenses of: (1) sand, light brownish-gray, fine, even-grained, both clean and silty; (2) sand, medium-gray, poorly-graded, coarse to fine, clean; (3) silt, light-buff, thinly-laminated, contorted, some laminae sandy, others clayey.

152	167	15	Covered.
167	183	16	Gravel, light-gray, fairly well-graded, cobbles to 8 inches, pebbles and cobbles coated with silty clay.
183	193	10	Till, light grayish-brown, compact, impervious, fairly well-graded, slightly too much matrix of lean silty clay.
193	208	15	Clay, light blue-gray, massive, lean, silty, scattered pebbles and cobbles.
208	258	50	Covered.
258	288	30	Gravel, light-gray, more yellowish on fresh surface, stratified, fairly well-graded, cobbles to 6 inches, matrix of fine sand with trace of silt.
288	356	68	Covered; on left bank of Eklutna Creek, this interval is a vertical bank of gravel similar to that from 233 to 263.
356			Water surface in Eklutna Creek, altitude 359.