UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Preliminary report

WATERPOWER POSSIBILITIES OF BRADLEY LAKE, ALASKA

by F. A. Johnson
January 1956

with a chapter on

TENTATIVE GEOLOGIC CONCLUSIONS ON BRADLEY LAKE POWER SITE

by Kenneth S. Soward
January 1956

U S GEOLOGICAL SURVEY

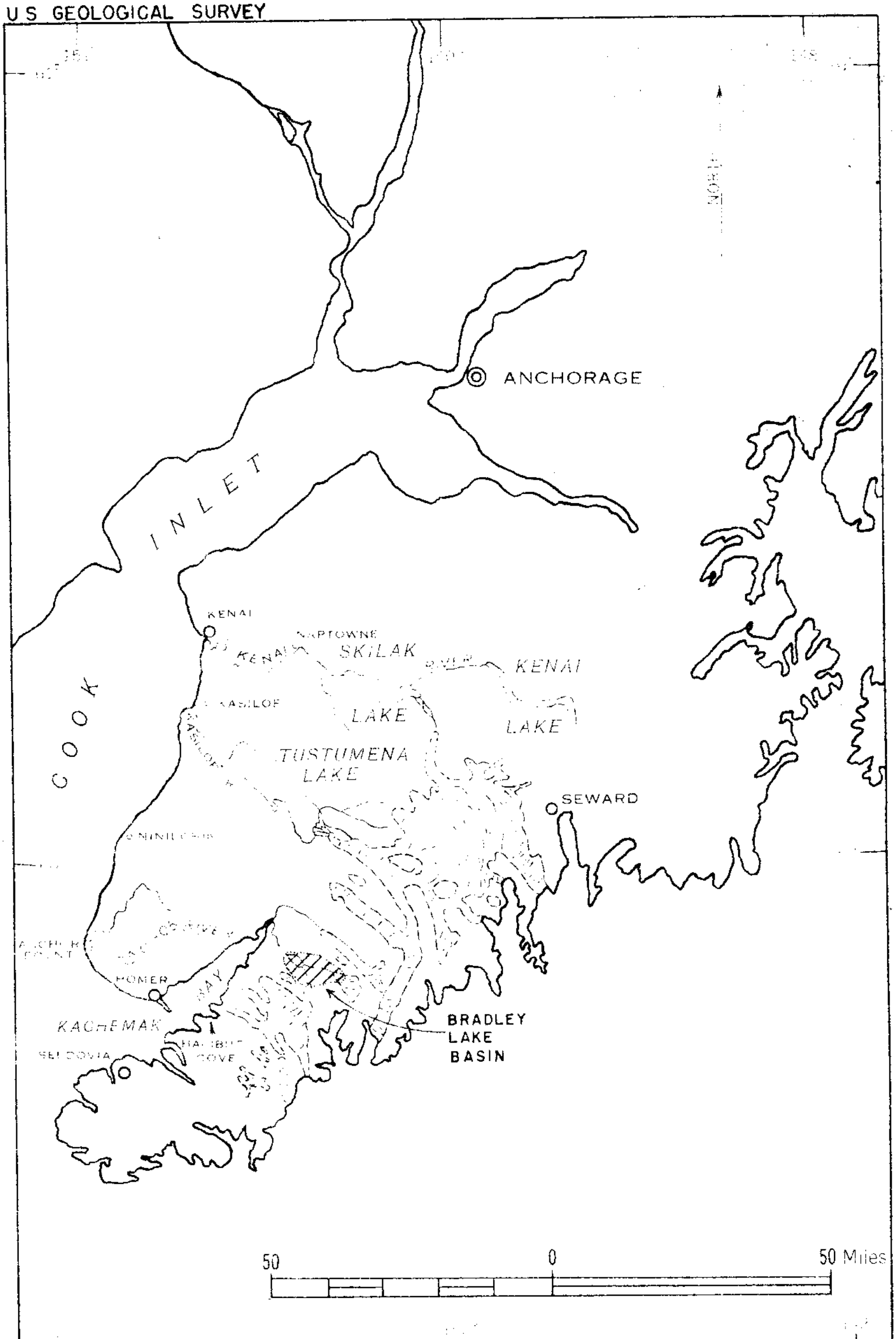

FIG.1 INDEX MAP OF KENAI PENINSULA, ALASKA, SHOWING LOCATION OF BRADLEY LAKE

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by F. A. Johnson

INTRODUCTION

Purpose of report, and general conclusions

The purpose of this report is to give a preliminary estimate of the power possibilities of Bradley Lake, Alaska, and to describe outstanding hydrologic, geologic and topographic features that might determine the character of development. Bradley Lake lies in the Kenai Mountains near the southwestern end of the Kenai Peninsula. It is at an altitude of 1,090 feet, at a point about 25 miles northeast of the town of Homer, and about 3 miles southward from the head of Kachemak Bay.

A survey of Bradley Lake and Bradley River made in July and August 1955 provides a basis for computing the potential storage capacity at the lake, and for studying the possibilities for diversion of two nearby streams into the lake basin. Geologic examinations of different features of the power site were made concurrently with the topographic surveys, and the tentative geologic conclusions are presented in a section with this report. The geologist, Kenneth S. Soward, has in preparation a more detailed report, which will include geologic maps and cross sections.

Climatic records, streamflow records, topographic maps, and reports of previous investigations that were used for the waterpower studies are listed in following section of this report. The runoff at Bradley Lake has not yet been recorded under the regular gaging program of the Geological Survey, but a brief record was obtained at the time of the topographic surveys in 1955. From July 13 to August 5, 1955 the stage of Bradley Lake was recorded twice-daily by members of the survey crew. Discharge measurements were made at the outlet of the lake on July 13 and August 2, and provided a basis for computing the runoff for the period of gage-height records.[1/]

1/ Slaughter, Marvin J., Measurements and computations, Engineer-in-charge, Palmer, Alaska, Surface Water Branch, Water Resources Division, U. S. Geol. Survey.

This record is summarized on page 38 of this report.

The available information does not justify more than a rough estimate of the average runoff, from the lake basin and nearby areas, but it seems likely that this may be about 5.5 cubic feet per second, per square mile, during periods such as the past 30 years. The total area, including that of the two tributaries that could readily be diverted into the lake basin, is 68.3 square miles. Thus the average discharge, directly and indirectly available for control at Bradley Lake, may be roughly 375 cubic feet per second.

The storage capacity required for power regulation depends not only on the average water supply, but also on the character of its seasonal and annual variation. The year-to-year variations depend partly on the departures of annual precipitation from average, and records show that these are relatively large on the Kenai Peninsula. On the other hand, glaciers in the vicinity of Bradley Lake cover about a third of the drainage area, and undoubtedly tend to equalize the annual runoff. Since there is little basis for estimating the quantitative effect of the glaciers, streamflow records over a period of many years would be needed both for a close estimate of the average water supply and of the nature of its distribution. Lacking such information, plans for power development probably should be based on conservative estimates of the average supplies, and on liberal estimates of the storage required for regulation.

The potential storage capacity that could be developed at Bradley Lake is enough for complete control of the runoff, although further investigation probably will show that a lesser degree of regulation would be preferable. It is estimated that storage capacity in the order of 500,000 acre-feet might be required for substantially complete control of the estimated runoff, but that a capacity of only 250,000 acre-feet probably would be adequate for utilization of about 90 percent of that amount for power generation. These capacities could be obtained by damming the lake outlet to raise the surface 150 feet for the larger amount or 90 feet for the smaller. Alternatively, they could be obtained by various combinations of damming and drawdown. With storage developed by damming, and with a powerhouse located near tidewater of Kachemak Bay, the average gross heads that could be utilized would be roughly 1,150 and 1,120 feet respectively, and the corresponding power available 100 percent of the time would be 29,000 kw and 25,500 kw respectively.

At present there are no large communities or industries in the probable service area. Development of the Bradley Lake site therefore will depend on creation of new industries such as the manufacture of products by electro-chemical or electromettalurgical processes. The manufacture of ammonimum nitrate has been suggested as a possibility. Lumbering and related activities will have a very limited field since forest growth in the region is scanty.

Previous investigations and reports

The Alaska District, Corps of Engineers, U. S. Army made a reconnaissance investigation of the Bradley Lake site in September 1953. A report based on this investigation and other available information was compiled by the Corps of Engineers at the request of the Governor of Alaska.[2/] It was estimated that an average discharge of 320 cfs would be available from about 54 square miles of drainage area directly tributary to the lake, plus about 4 square miles of the adjacent Nuka River basin that could readily be tapped. (Some comparisons described herein led to about the same estimate of average water supplies per unit area). It was further estimated that this supply could be completely regulated for generation of 23,000 kw of prime power, with 325,000 acre-feet of storage capacity at the lake.

2/Bradley Lake project - A reconnaissance report on potential power developments together with auxiliary possibilities, Corps of Engineers, U. S. Army, Office of the District Engineer, Alaska District, March 1955

Several possibilities were described for auxiliary development of run-of-the-river power in the lower Bradley River basin and on nearby Battle Creek. It was pointed out that this seasonal power could be firmed up by providing additional storage and plant capacity in the Bradley Lake project.

The report of the Corps of Engineers includes descriptions of possible industrial sites at Homer, at Halibut Cove across the bay from Homer, and at Kasilof. Construction details and possible costs of power development ; - subjects which are outside of the scope of the present report, also were discussed.

Maps and aerial photographs

The drainage basin of Bradley Lake and nearby regions are shown on the quadrangle maps:

Seldovia: Reconnaissance series, scale 1:250,000
Contour interval 200 and 1,000 feet.

Seldovia: C-2, C-3, C-4, C-5, D-2, D-3, D-4, D-5,
Scale 1:63,360, contour interval 100 feet.

The Bradley Lake basin is included in the quadrangles: Seldovia C-2, C-3, D-2 and D-3. The other quadrangles include regions in the vicinity of Kachemak Bay.

Maps are in preparation for Bradley Lake and Bradley River on a scale of 1:24,000, generally with 20-foot contour interval on land and underwater, and with 5-foot contour interval on stream surfaces. The map will include a possible diversion area on the divide between Bradley River basin and Nuka River basin, and another possible diversion site on a tributary of Bradley River just north of Bradley Lake. A map of a dam site at the outlet of Bradley Lake is being prepared on scale of 1:2,400 (1 inch = 200 feet) and with contour interval of 10 feet. A map of a site for a possible diversion dam on Bradley River, at an altitude of about 520 feet, is being prepared on scale of 1:2,400 and with contour interval of 10 feet. A detail map of the diversion site north of Bradley Lake also is being prepared at this same scale and contour interval. Advance sheets for these maps are included as Plates I and II in the pocket at the back of this report.

Soundings in Kachemak Bay are shown on Charts 8531 and 8554 of the U. S. Coast and Geodetic Survey. Chart 8531 is on a scale of 1:82,662 and Chart 8554 on a scale of 1:200,000. The soundings are shown in fathoms.

Aerial photographs used in compilation of the topographic maps are on file with the Geological Survey, Denver Federal Center, Denver, Colorado.

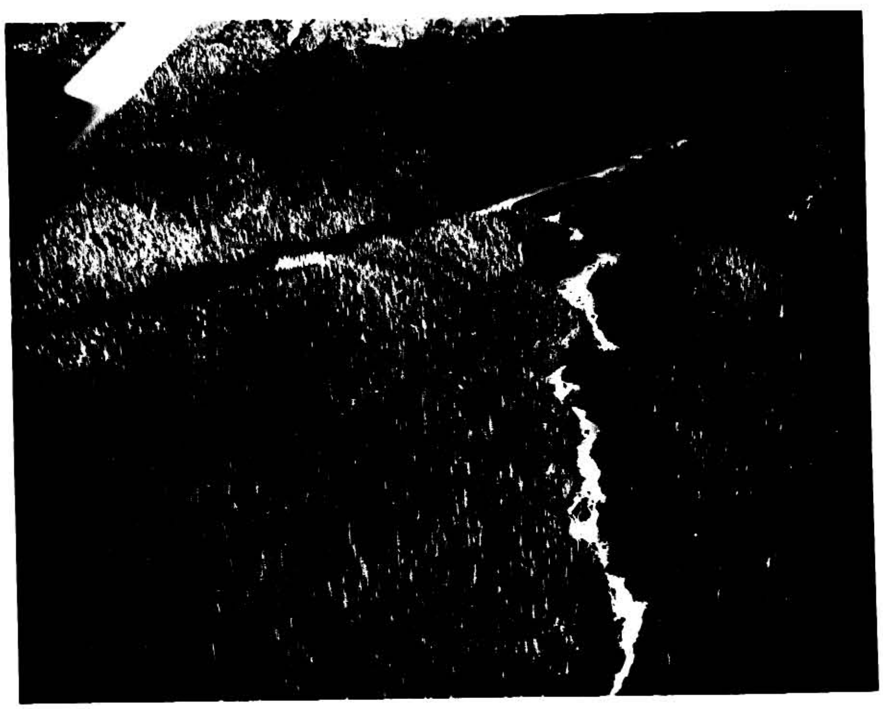
GEOGRAPHIC AND TOPOGRAPHIC FEATURES

General description

Bradley Lake basin lies in the Kenai Mountains, which extend from southwest to northeast along the Kenai Peninsula. The lake is drained by Bradley River, which flows in a northward direction about 3 miles through a very rugged canyon, and thence 3 miles westward to the head of Kachemak Bay, an arm of Cook Inlet. The reach below the canyon is across the side of a wide delta formed by deposits from Bradley River and two glacial streams flowing southward to the bay; Fox River and Sheep Creek. There is an extensive mud flat at the head of Kachemak Bay, but the water deepens abruptly to 60 feet or more in and near Bear Cove, 4 miles southwest from the head of the bay.

There are no inhabitants in the Bradley River area, and there are no roads nearby. However, there are a number of settlers along the hills bordering Fox River, and north of the head of Kachemak Bay. Access to this locality is by boats or small planes. At present the only practicable access to Bradley Lake is by float planes or small land planes and development of the site for waterpower would necessitate

Bradley Lake outlet



Lower canyon of Bradley River

Bradley Lake

Bradley River near Kachemak Bay

construction of an access road. This might be located from a terminus at Bear Cove accessible to deep-draft vessels, along the hills bordering the south side of Kachemak Bay to the vicinity of Battle Creek or Bradley River and thence southeastward to the lake. Alternatively, it might be possible to locate a road eastward from Bear Cove across Martin River and along the upper course of Battle Creek; but this would not reach the powerhouse site. In either case construction would involve several stream crossings and considerable rock excavation.

The nearest settlement to Bradley Lake is the town of Homer, on the north side of Kachemak Bay about 25 miles to the southwest. It is at the end of the Sterling Highway, which joins a surfaced highway between Anchorage and Seward at Kenai Lake. There is a road from Homer to a point some 7 miles to the northeast, and extension to Bradley Lake would necessitate 25 or 30 miles of construction, following a route around the head of Kachemak Bay across the Fox River Delta.

The population of Homer, according to the 1950 census, was 307. The Homer District which includes the villages of Anchor Point and Ninilchik (about 30 miles north) had a population of 907. The town of Seldovia on the south side of Kachemak Bay, 15 miles southwest of Homer (but outside of the Homer recording district), had a population of 437 in the 1950 census. The principal industry at these places is fishing, and processing and canning fish. A number of homesteads have been established in the vicinity of Homer, and to the north, and farming may become of increasing importance. In recent years several oil companies have been carrying on extensive investigations in an effort to determine the petroleum possibilities of the Kenai lowlands. Location of significant reserves would have a considerable effect on development of the region. It appears, however, that demand for the substantial amount of power that could be generated at Bradley Lake will depend mainly on the creation of other industries.

Features affecting runoff from Bradley Lake basin

The Bradley Lake basin and adjacent areas are located near the crest of the Kenai Mountains, which in this part of the Kenai Peninsula extend up to altitudes above 5,000 feet. The drainage is to the northwest, and may be considered as on the lee-ward side of the mountains since the heaviest precipitation probably results from flows of moist air from the Gulf of Alaska, south of the Kenai Peninsula.

It seems likely, however, that the numerous high points bounding the basin on three sides tend to keep the air currents at high levels over much of the basin, and that the "rain-shadow" effect usually found on the leeward side of high mountains is relatively minor within the basin. The general occurrence of fairly heavy precipitation is indicated by the existence of glaciers distributed at the higher levels throughout the basin. The precipitation at low elevations on the northwest side of the Kenai Peninsula, however, is notably light.

The glaciers of the Bradley Lake basin, and of nearby areas which may be made tributary to Bradley Lake, cover about a third of the entire area. (See Plate 3 in pocket at back of report). The distribution is as follows:

Drainage	Area, sq. mi. Basin	Area, sq. mi. Glacier	Glacier area, % of basin
Bradley Lake basin	54.0	16.9	31.2
Upper Nuka R. area	4.1	3.2	78.0
Area north of lake	10.2	2.8	27.4
Total	68.3	22.9	33.6

Runoff records for other basins having a comparable amount of glacier area indicate that the ice and snow storage in the Bradley Lake basin undoubtedly has a substantial equalizing effect on the annual runoff.

The Bradley Lake basin is characterized not only by glaciers but also by extensive exposures of bare rock and relatively little soil cover. With these characteristics, and the low winter temperatures prevalent at northern latitudes and at high altitudes, it is to be expected that runoff in winter months would be very small, since there can be little groundwater storage, snow or ice melt, or rain runoff.

The low temperature, impervious nature of the terrain, and the scanty amount of vegetation, would serve also to minimize evapotranspiration. It is estimated that the annual water losses are in the order of 10 inches on the basin, or even less.

CLIMATE

General characteristics of the Kenai Peninsula

Most of the climatic records published by the U. S. Weather Bureau are for coastal points on the Kenai Peninsula, and none have been obtained in the mountains near Bradley Lake.

Records of runoff and precipitation for various points from Seward to Kenai indicate that precipitation in some parts of the mountains is greater than at Seward and very much greater than in lowlands or at coastal points on the northwest side of the Kenai Peninsula. Records indicate that the average annual precipitation at Kenai, Naptowne and Kasilof probably is less than 20 inches, whereas it was about 69 inches at Seward for some 30 years of record.

There is marked decrease in winter temperatures northward from Seward to Naptowne, although summer temperatures are somewhat comparable at the two stations. Monthly mean temperature at Naptowne from November to February may be 15°F to 20°F lower than at Seward and extremes may be even lower. Minimums of -40°F to -50°F apparently are not unusual at Naptowne and in the vicinity of Kenai Lake (at altitude about 500 feet), whereas those at Seward generally are about -10°F or higher. Records of runoff, precipitation, temperatures and snowfall for this region are summarized in a recent report issued by the Geological Survey. 3/ The climatic data were summarized from publications of the U. S. Weather Bureau, and data for this and other regions of the Kenai Peninsula are

3/ Johnson, Arthur, 1955, The potential waterpower of Grant, Ptarmigan, Cooper, and Crescent Lakes on the Kenai Peninsula near Seward, Alaska, (Open file release).

available in Summaries of Climatological Data prepared by that agency.

The general distribution of precipitation and temperature between Seward and Naptowne probably is somewhat similar to that across the Kenai Peninsula in the vicinity of Bradley Lake. The average annual precipitation at Kasilof is about 18 inches, (estimated on basis of a relatively short record), and this may be of about the same order of magnitude as that at Naptowne. Temperatures at Kasilof are somewhat higher than at Naptowne, and there probably is a gradual increase in precipitation and winter temperature around the coast to Homer, and beyond, where there is greater exposure to southerly winds from the Gulf of Alaska. The average annual precipitation at Homer is 25 inches, and the monthly temperatures generally are only a few degrees lower than at Seward. The deficiency in precipitation and the cold winters on the northwestern side of the Kenai Peninsula reportedly are due to the "rain-shadow" effect of the Kenai Mountains, and the circumstance that the region is exposed to dry, north winds from the interior of Alaska.

The seasonal distribution of precipitation recorded at Kasilof differs greatly from that of precipitation recorded at Homer, possibly as a result of the circumstances just noted. The totals were computed for the two periods October to April and May to September, for the calendar years, 1940 to 1947, when there were nearly continuous records. During the first period the catch at Kasilof was less than half that at Homer, being 72.0 inches as against 145.1 inches for the 8 seasons. However, during the second period, May to September, precipitation recorded at Kasilof was more than at Homer, being 91.5 inches as compared with 79.7 inches. With precipitation like that recorded at Kasilof it is to be expected that runoff, and especially snow runoff, would be much less than at Homer.

Temperatures at Kasilof and Homer also differ greatly in the winter period, November to March. The mean for that period is 19.5° at Kasilof and 25.9° at Homer, and average January temperatures are 13.3° and 22.6° respectively. Minimum temperatures as low as -30° to -40° are not uncommon at Kasilof; whereas temperatures below -15° are unusual at Homer. During the period, April to October, monthly temperatures are about the same at both places, and the mean for the period is about 46°F.

The seasonal distribution of precipitation and temperature at Bradley Lake possibly resembles the pattern at Homer, or at stations on the southeast side of the Kenai Peninsula since the lake basin is only about 20 miles northwest of the Gulf of Alaska, and has relatively great exposure to southerly winds.

Special characteristics in the vicinity of Bradley Lake

The Bradley Lake basin is near the crest of the mountains and, as evidenced by the glaciers, and by the summer runoff in 1955, receives fairly heavy precipitation. Winter temperatures at the lake probably are considerably lower than at Homer, since the altitude is 1,090 feet. It is probable also that winter temperatures at sea level near the head of Kachemak Bay are lower than at Homer, since that locality is somewhat less shielded from north winds, and less exposed to southerly winds. Ice forms in a so-called "fresh-water" area at the head of the bay, but the bay reportedly is always open as far as Bear Cove. Local residents also describe the occurrence of williwaws at the head of the bay when the air is fairly calm at Homer.

Ice on Bradley Lake prevented landing by float plane until after July 1, 1955. Temperatures in May and June 1955 were below normal, and the lake reportedly is usually open by about the middle of June. During the course of the surveys in July and August 1955 strong winds frequently were observed at the lake; - during 12 days of 31 the wind was so strong that a small boat could not be operated. These winds generally were from east to west along the length of the lake. The shape of trees near the outlet of the lake and the absence of limbs on the eastward side indicate that this is the prevailing direction of strong winds. This circumstance possibly may be due to flows of cold air down-slope, and to southerly, storm winds modified in direction by the local configuration of the mountains.

Distribution of annual precipitation

The magnitude of precipitation on the Bradley Lake basin cannot be estimated directly from precipitation records at other places, since none have been obtained at comparable, mountain localities. It is reasonable to assume, however, that the year-to-year distribution of precipitation is roughly the same throughout a considerable area, both in the mountains and at coastal points. Precipitation indices thus may serve as measures of the wetness of given years or periods at Bradley Lake, in relation to the average for longer periods.

Some idea of the order of magnitude of runoff from the Bradley Lake basin may be gained from analysis of Kasilof River records, as is discussed further on in the section on Water Supply. The upper part of the Kasilof River basin lies about 25 miles northeast of Bradley Lake basin, and the two areas have some similar characteristics. The Kasilof runoff records are available for the water years ending September 30, from 1950 to 1955, and precipitation indices based on reasonably continuous observations can be computed from the precipitation recorded at Homer and Seward, Alaska for the water years, 1940 to 1955.

According to summaries of climatological data published by the U. S. Weather Bureau there were several changes in altitude of the precipitation gages both at Homer and Seward since 1940, which may have been due to changes in location, and which may have resulted in some differences in measuring conditions. Comparisons indicate that Seward records are reasonably consistent for the period 1940 to 1955, but that Homer records from 1947 to 1955 probably are on a somewhat different basis than that for the earlier period. The precipitation recorded at Seward from 1940 to 1946 was 2.62 times that recorded at Homer; whereas the catch from 1947 to 1955 was 2.92 times that at Homer. As indicated in Table 1, following this page, Homer records from 1940 to 1946 were adjusted accordingly; and precipitation indices were computed from the two records as is explained in that table. These may be representative of the variations in precipitation on the mountains midway between Seward and Homer, in the vicinity of Bradley Lake and the upper Kasilof River. (Precipitation at Juneau, Alaska is included in Table 1 for comparative purposes, and it evidently had a more uniform annual distribution).

The average of the indices for the period 1950 to 1955 is about 90 percent of the 16-year mean, and the 16-year mean in turn is the same as an average (partly estimated) for 35 years at the Seward station. The lowest water year of record occurred in 1952, both on the basis of the 16-year record for the two stations; and at Seward during 35 water years of fairly complete records. 1951 also was a relatively dry year, but 1953 was one of the two wettest years of record.

Table 1

Indices of wetness for the vicinity of Bradley Lake
and upper Kasilof River; and precipitation at Juneau, Alaska

Water Year 1/	Homer Precipitation in inches: Recorded	Homer Precipitation in inches: Adjusted 2/	Homer Precipitation in inches: Adjusted 3/	Seward: Recorded	Indices of wetness: Inches 4/	Indices of wetness: % of mean	Juneau precipitation: Inches	Juneau precipitation: % of mean
1940	31.2	28.0	81.9	87.2	84.6	123	93.7	104
41	38.2	34.3	100.0	88.8	94.4	137	65.1	72
42	24.2	21.8	63.5	74.1	68.8	100	93.2	103
43	17.1	15.4	44.9	52.7	48.8	71	98.2	109
44	33.5	30.1	88.0	101.4	94.7	137	96.7	107
1945	33.4	30.0	87.6	74.5	81.1	118	97.3	108
46	27.1	24.4	71.0	58.2	64.6	94	77.7	86
47	22.7	22.7	66.3	65.0	65.6	95	103.4	115
48	22.7	22.7	66.3	67.9	67.1	97	90.0	100
49	21.3	21.3	62.2	58.3	60.2	87	111.3	124
1950	19.5	19.5	57.0	63.3	60.2	87	78.0	87
51	16.2	16.2	47.3	47.0	47.2	68	65.2	72
52	11.9	11.9	34.8	42.8	38.8	56	84.7	94
53	35.3	35.3	103.0	100.8	101.9	148	99.1	110
54	20.8	20.8	60.8	51.7	56.2	82	86.3	96
1955	23.4	23.4	68.3	63.3	65.8	95	101.0	112
Mean	25.0	23.6	69.0	69.0	69.0	100	90.1	100

1/ Year ending September 30.

2/ Recorded figures multiplied by the factor 0.898, 1940-46, to adjust for an apparent inconsistency following a change in gage location between 1946 and 1947.

3/ Figures in column 3 multiplied by factor 2.92 to convert to same basis as Seward precipitation for purpose of averaging.

4/ Arithmetical averages of figures in columns 4 and 5. Recorded figures of precipitation were rounded to nearest tenths.

Records of monthly and annual precipitation for Seward and Homer, 1940-55, are given in Tables 2 and 3, pages 24 and 25 and records of monthly and annual mean temperature for Homer are listed in Table 4, page 26.

WATER SUPPLY

Runoff records

Records of runoff at stations on the Kenai Peninsula that were considered in preparation of this report are as follows:

Station	Drainage area Sq. Mi.	Period of record
Kasilof River near Kasilof	738	July 1949 to 9/1955
Anchor River near Anchor Point	226	July 1953 to 9/1955
Cooper Creek near Cooper Landing	31.8	Aug. 1949 to 9/1955
Crescent Creek near Cooper Landing	31.7	Aug. 1949 to 9/1955
Grant Creek near Moose Landing	44.2	Oct. 1947 to 9/1955

Two discharge measurements were made at the outlet of Bradley Lake during the summer of 1955. The results are as follows:

Date	Discharge, cfs.
July 13, 1955	1,320
August 2, 1955	997

Table 2

Monthly and annual precipitation in inches,
Seward, Alaska

Water Year 1/	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1940	6.87	5.57	9.81	12.07	2.83	5.54	8.62	3.02	1.31	2.14	10.71	18.69	87.18
41	14.85	6.43	5.86	2.48	14.55	12.12	13.91	4.60	2.98	5.50	0.78	4.70	88.76
42	3.47	2.27	11.17	8.22	10.40	6.64	5.00	1.12	3.83	3.61	10.49	7.91	74.13
43	7.18	0.94	1.01	2.68	6.77	1.68	4.49	2.22	3.38	3.58	3.62	15.19	52.74
44	11.34	18.33	18.25	11.33	6.18	1.97	1.09	7.00	1.58	4.83	11.44	8.05	101.39
1945	12.20	7.43	6.25	12.13	10.99	3.07	1.38	2.24	1.93	2.23	8.13	6.55	74.53
46	15.81	2.17	4.78	5.59	6.20	3.23	3.40	4.87	1.25	0.88	4.62	5.42	58.22
47	11.73	4.37	2.93	3.01	6.40	7.16	1.79	6.64	2.87	2.38	4.95	10.77	65.00
48	7.73	12.61	8.73	12.52	4.83	1.38	0.00	3.72	1.5 2/	4.36	1.05	9.49	67.9
49	13.48	4.46	1.61	4.66	0.64	6.10	3.67	1.78	2.05	1.04	5.61	13.21	58.31
1950	8.13	10.90	4.65	1.18	0.92	3.03	6.1 2/	5.54	3.77	1.38	4.82	15.83	66.3
51	3.96	0.32	6.12	3.27	3.81	2.63	4.66	2.60	2.87	0.88	3.02	12.82	46.96
52	5.12	4.88	2.57	1.76	3.77	3.13	4.74	1.74	1.41	5.28	4.44	3.96	42.80
53	21.65	19.23	15.08	2.16	15.97	2.08	7.63	0.80	0.60	1.12	5.64	8.87	100.83
54	10.13	6.40	7.76	4.92	3.54	5.81	0.40	2.45	0.71	4.02	2.73	2.86	51.73
1955	10.62	8.83	2.80	10.77	2.62	3.54	3.26	4.43	2.43	3.61	4.53	5.86	63.30
Mean	10.27	7.20	6.84	6.17	6.28	4.32	4.38	3.42	2.15	2.93	5.41	9.39	68.76
Percent of mean annual	14.9	10.5	9.9	9.0	9.1	6.3	6.4	5.0	3.1	4.3	7.9	13.6	100.0

1/ Year ending Sept. 30
2/ Estimated

Table 3

Monthly and annual precipitation in inches,
Homer CAA, Alaska

Water Year 1/	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1940	3.40	1.73	8.01	3.78	0.23	2.22	1.21	0.66	0.33	2.12	3.21	4.58	31.48
41	7.82	2.35	3.76	2.76	5.25	3.87	2.83	1.47	3.37	1.70	1.45	1.62	38.25
42	1.44	1.07	4.41	1.32	2.45	2.05	2.45	0.70	1.00	1.59	2.74	2.93	24.15
43	2.29	0.22	0.92	1.08	1.67	0.47	0.90	1.26	0.71	1.58	2.33	3.67	17.10
44	2.53	7.25	5.01	3.80	1.12	1.46	0.19	1.88	1.48	2.99	3.56	2.21	33.48
1945	3.30	4.00	1.80	4.85	3.97	3.78	0.33	0.42	0.36	1.44	5.30	3.87	33.42
46	6.32	2.92	1.30	3.37	2.26	1.34	1.20	1.96	0.39	1.44	2.04	2.60	27.14
47	6.80	1.38	1.31	0.86	1.19	1.53	0.69	0.76	0.30	2.11	2.16	3.64	22.73
48	3.81	2.84	2.78	2.41	0.62	0.46	0.00	0.70	0.62	3.79	2.38	2.40	22.81
49	3.46	0.95	0.51	3.88	0.40	2.30	0.90	0.48	2.21	1.45	1.34	3.46	21.34
1950	2.64	3.13	2.16	0.71	0.16	1.08	2.75	0.50	1.40	1.02	1.34	2.63	19.52
51	2.36	0.08	1.44	1.49	0.90	0.36	1.42	0.16	2.08	0.72	2.14	3.01	16.16
52	1.40	1.14	0.28	0.69	0.78	0.34	0.64	0.27	0.48	1.69	1.99	2.16	11.86
53	4.59	8.59	5.65	0.98	3.57	0.21	1.49	2.04	0.74	0.16	4.81	2.43	35.26
54	3.82	2.74	2.20	1.12	0.76	1.93	0.01	0.43	0.26	1.90	4.13	1.47	20.77
1955	4.63	2.44	1.34	2.09	1.04	0.44	1.10	0.36	2.76	0.92	4.02	1.94	23.08
Mean	3.79	2.67	2.68	2.20	1.65	1.49	1.13	0.88	1.16	1.66	2.81	2.79	24.91
Percent of mean annual	15.3	10.7	10.8	8.8	6.6	6.0	4.5	3.5	4.6	6.7	11.3	11.2	100.0

1/ Year ending Sept. 30

Table 4

Average monthly and annual temperatures, °F
Homer CAA, Alaska

Water Year 1/	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1940	34.8	27.8	27.6	31.1	33.0	29.5	41.6	44.4	49.3	53.8	53.8	48.4	39.6
41	39.2	31.4	30.8	23.9	33.2	35.4	40.2	43.1	50.6	53.0	54.4	47.3	40.2
42	38.9	25.9	27.6	33.3	36.4	29.7	38.6	47.7	50.9	53.9	54.7	52.4	40.8
43	41.5	26.4	11.2	16.1	26.2	29.8	36.4	42.2	49.4	52.4	51.4	45.6	35.7
44	40.1	33.4	29.9	25.3	34.4	28.4	34.8	44.4	50.9	54.2	55.5	47.4	39.9
1945	39.6	30.8	27.9	33.2	29.9	27.6	33.1	41.6	49.8	53.5	53.0	46.4	38.9
46	37.6	20.8	22.9	24.7	24.2	21.1	33.6	42.0	47.4	51.7	50.8	46.0	35.2
47	38.8	26.2	12.9	9.4	26.4	31.1	36.2	42.3	47.4	51.7	50.8	45.8	34.9
48	37.4	32.8	28.2	25.1	21.0	25.2	31.9	42.2	48.1	50.4	49.4	44.0	36.3
49	38.2	21.5	17.7	20.1	16.0	32.0	32.0	39.2	46.9	50.4	51.4	47.6	34.4
1950	37.5	32.5	17.9	20.1	16.0	32.8	34.9	40.2	47.2	50.6	52.8	47.2	35.8
51	36.2	20.7	20.4	16.4	23.1	18.5	36.4	41.7	48.2	52.2	52.8	47.5	34.5
52	35.3	30.1	21.3	14.4	26.5	27.0	33.2	38.6	45.3	52.0	52.5	46.8	35.2
53	39.9	35.2	25.6	19.0	26.4	26.5	37.1	42.1	52.2	53.9	53.3	47.2	38.2
54	35.8	29.2	27.5	18.3	14.1	26.5	32.7	43.6	49.2	52.8	52.4	48.5	35.9
1955	41.1	32.9	14.6	27.8	23.5	29.6	32.0	41.5	46.5	51.5	51.6	46.2	36.6
Mean	38.2	28.6	22.8	22.4	25.6	28.2	35.3	42.3	48.7	52.4	52.5	47.2	37.0

1/ Year ending Sept. 30.

It was reported that there was very little fluctuation of lake level on those dates, but that a strong downstream wind on July 13 may have affected the measurement. (This could have increased the stage somewhat at the downstream end of the lake). The lake stages were recorded by the survey crew from July 13 to August 5, 1955 by twice-daily readings on temporary staff gages. The daily discharges were computed for this period on the basis of the gage-height record and the two discharge measurements, and are summarized on page 38.

The monthly and annual figures of runoff for the Kasilof River, Anchor River, and Grant Creek are given in Table 5, following this page. The figures of annual runoff for the 5 streams during the period, 1950-55, are listed herewith for comparison.

Runoff in thousands of acre-feet

Water years ending Sept. 30	Kasilof R.	Anchor R.	Cooper Creek 1/	Crescent Creek 1/	Grant Creek
1950	1,737	-	63.6	49.2	149.6
1951	1,815	-	47.5	37.8	126.1
1952	1,577	-	43.9	36.8	112.6
1953	2,062	-	109.5	90.2	223.1
1954	1,555	175.5	58.3	42.7	126.0
1955	1,434	244.9	62.7	59.4	130.7
Mean	1,697	-	64.2	53.7	144.7

1/ Recorded figures rounded to nearest tenth. Records after 1950 may be subject to review, but probably are substantially correct.

Table 5

Monthly and annual runoff in thousands of acre-feet,
Kasilof River near Kasilof, Alaska

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1949										210	317	414	-
1950	255	125	62	46	31	33	39	41	70	233	400	403	1,737
51	230	98	55	33	20	18	27	43	81	281	445	484	1,815
52	267	120	76	51	33	28	34	36	49	178	407	296	1,577
53	260	160	116	67	49	49	40	47	108	301	480	384	2,062
54	224	104	55	34	21	17	26	43	83	216	394	337	1,555
1955	225	122	50	37	30	30	30	34	50	165	331	331	1,434

Figures were rounded to nearest unit.

Anchor River near Anchor Point, Alaska

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1953										5.1	11.2	16.9	-
54	20.5	9.8	6.2	3.1	2.8	4.9	13.3	62.4	12.3	8.3	20.6	11.5	175.5
1955	25.5	16.5	6.8	7.4	6.7	7.4	8.3	68.6	48.1	15.5	14.7	19.5	244.9

Figures were rounded to nearest tenth.

Grant Creek near Moose Pass, Alaska

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1948	16.1	11.9	7.2	2.0	1.4	1.0	1.6	15.0	29.3	34.2	23.7	9.6	153.0
49	16.0	5.3	1.6	0.9	0.7	0.9	1.0	8.4	24.3	29.2	20.0	26.5	134.9
1950	11.9	11.7	4.4	2.3	1.2	1.1	1.6	7.2	26.6	32.0	29.6	20.1	149.6
51	6.2	2.0	1.3	1.2	0.9	0.8	1.6	7.6	19.4	31.9	23.1	30.0	126.1
52	5.4	3.1	1.9	1.1	0.9	1.0	0.9	4.1	22.3	33.2	23.3	15.4	112.6
53	20.1	15.2	8.5	3.5	2.5	1.9	3.8	18.5	54.9	43.3	31.4	19.5	223.1
54	15.8	4.1	2.4	2.0	1.8	1.7	1.8	10.6	24.3	25.8	23.6	12.0	126.0
1955	10.3	8.6	3.2	2.6	1.3	1.1	1.1	4.4	17.3	39.5	25.0	16.2	130.7

Monthly figures were rounded to nearest tenth.

Estimates of average runoff at Bradley Lake

The annual runoff figures for the Kasilof River and Anchor River are discussed in detail in the following paragraphs, because they afford a basis for estimating the average runoff from the upper mountainous part of the Kasilof basin, during the period 1950 to 1955. This estimate in turn provides an indication of the probable order of magnitude of runoff in the Bradley Lake basin, which has some similar characteristics. The Kasilof basin may be classified in two parts having widely different characteristics. The lower part, taken as an area of 378 square miles, lies northwest of the steeper slopes of the Kenai Mountains, mainly below an altitude of 1,000 feet. Tustumena Lake, at an altitude of 113 feet, covers 114 square miles, or nearly a third of this portion, and has a substantial regulating effect on monthly flows. The upper part of the basin, 360 square miles, is generally in steep rugged terrain extending in places to altitudes above 6,000 feet, and about half of the area is covered by glaciers. The pronounced equalizing effect of the glaciers on the year-to-year distribution of runoff is reflected in the figures of runoff for the Kasilof River, 1950 to 1955, as shown in the foregoing tabulation. Although changes in ground-water storage and changes in Tustumena Lake may have provided for some year-to-year regulation, this probably was minor in relation to changes in storage as ice or snow.

Estimated runoff from lower Kasilof basin

It is provisionally assumed that the runoff per unit area from the lower portion of the Kasilof basin may be of the same order of magnitude as that from the Anchor River basin, a drainage area of 226 square miles, some 30 miles to the southwest of Tustumena Lake. The Anchor River basin extends from near sea level at the gage to a maximum altitude of about 2,000 feet. The runoff of Anchor River and from the lower Kasilof area probably has relatively large year-to-year variations since changes in natural storage probably are small in relation to changes in glacier storage, and since the annual water losses must be fairly large relative to the annual precipitation. The runoff of Anchor River, 1950 to 1955, probably had at least as much annual variation as that of runoff from the Cooper and Crescent Creek basins, which are in an area of relatively low precipitation near Kenai Lake. A provisional estimate of the distribution, computed on that basis, and without allowance for possible differences in natural storage would be as follows:

Water year	Runoff, thousands of acre-feet: Cooper Creek plus Crescent Creek	Anchor R.
1950	113	214 1/
1951	85	161 1/
1952	81	153 1/
1953	200	378 1/
1954	101	176
1955	122	245
Mean	117	221

1/ Anchor River runoff estimated as 1.89 times that of Cooper plus Crescent runoff; the ratio between the runoff figures for the 2-year period, 1954 and 1955. Records of runoff after 1950 may be subject to revision. Figures of runoff were rounded to the nearest thousand acre-feet.

Since the unit runoff from the Anchor River basin is much less than from the creek basins, it is possible, however, that there were even greater year-to-year variations. During the two water years, 1954 and 1955, the runoff of the two creeks was 66.5 inches on the basins, and that of Anchor River was only 34.8 inches. It is estimated that water losses in the Anchor River basin are about 15 inches a year, and the precipitation on the basin during the two-year period accordingly is estimated as about 65 inches. This is 1.47 times the amount recorded at Homer, and it is to be expected that the amounts of precipitation in other periods would be in roughly the same relation. (The ratio in 1954 was 1.41; that in 1955 was 1.51). On this assumption, the precipitation on the Anchor

River basin from 1950 to 1953 is estimated as 122 inches. In 1951 precipitation on parts of the basin must have been insufficient to provide for evapotranspiration of 15 inches; the loss that year accordingly is estimated as only 10 inches, and the loss for the 4-year period is estimated as about 55 inches. The remainder, 67 inches, corresponds to a runoff of about 800,000 acre-feet. Together with the 420,000 acre-feet recorded in 1954 and 1955, this results in an average of about 203,000 acre-feet per year for the 6-year period, 1950-55, or 8 percent less than that estimated according to the foregoing tabulation. Estimates of this kind for individual years of course would be subject to greater error, but it seems possible that the runoff of Anchor River in 1953 was more than 400,000 acre-feet and in 1951 less than 100,000 acre-feet, unless natural regulation due to changes in ground water was very great.

If the runoff per square mile from the lower part of the Kasilof River basin was the same as from Anchor River basin the total would be estimated according to the drainage area ratio, 378/226. This would make the average for the 6-year period 340 thousand acre-feet or about 17 inches per year.

Since the mean annual precipitation at Kasilof and Naptowne is about 7 inches less than at Homer, it seems probable, however, that the precipitation on the lower Kasilof basin may be correspondingly less than on the Anchor River basin. The average runoff from the lower Kasilof area from 1950 to 1955 therefore may have been only about 12 inches per year. This rough estimate is based on the assumption that in the region of lesser precipitation natural water losses would have been reduced in many years because of lack of enough precipitation to provide for normal or potential evapotranspiration. Thus a reduction of 7 inches in mean precipitation might correspond to a reduction of about 5 inches in annual runoff.

Estimated runoff from upper Kasilof basin

If the average runoff from the lower part of the Kasilof basin was 340 thousand acre-feet per year from 1950 to 1955, the remainder from the upper part was 1,697-340, or 1,357 thousand acre-feet. This is equivalent to an average of 71 inches per year on the area of 360 square miles. If the lower Kasilof runoff during this period averaged only 240 thousand acre-feet per year, or 12 inches instead of 17 inches, that from the upper part of the basin averaged 76 inches per year. This is accepted here as probably the more accurate estimate for the period 1950 to 1955.

According to the indices of wetness listed in Table 1, the average annual precipitation from 1950 to 1955 was only about 90 percent of the 16-year mean, which also probably is the mean for more than 30 years of record at Seward. Runoff in the Kasilof basin for the 6-year period may not have had the same relation as precipitation to the long-time mean, since there may have been a considerable change in storage as ice or snow. Lacking any other basis for judgment, it is assumed, however, that the mean annual runoff from the upper Kasilof area may be about 10 percent more than the 6-year average, or about 84 inches.

Bradley River runoff estimated from that of upper Kasilof

The Bradley Lake basin and vicinity has a lower mean altitude than the upper Kasilof basin, and proportionately a smaller part of its area above an altitude of 4,000 feet and a larger part below an altitude of 2,000 feet. (See Table 6 following this page). This distribution of areas may largely account for the difference in extent of the glaciers, - 34 percent of the total area near Bradley Lake, as

Table 6

Drainage areas in square miles above given altitudes in Bradley Lake basin and adjacent areas, and in upper Kasilof River basin.

Altitude (feet)	Upper Kasilof 1/		Bradley Lake 2/		Bradley plus diversions 3/		Diversion No. 1 4/		Diversion No. 2 5/	
	Area	% of total	Area	% of total	Area	% of total	Area	% of total	Area	% of total
1,000	360	100	54.0	100	68.3	100	4.1	100	10.2	100
2,000	311	86	36.3	67	50.0	73	3.6	88	10.1	99
2,500	271	75	31.3	58	44.2	65	3.3	81	9.6	94
3,000	236	65	25.5	47	36.3	53	2.5	61	8.3	81
4,000	148	41	8.4	16	13.3	19	0.8	20	4.1	40

1/ Kasilof River basin above base of Kenai Mountains.
2/ Bradley Lake at outlet.
3/ Bradley Lake basin plus drainage areas for Diversion Nos. 1 and 2.
4/ Upper Nuka River basin.
5/ Diversion area north of Bradley Lake.

The mean altitude of the upper Kasilof River basin is about 3,550 feet; that of the Bradley Lake basin plus diversion areas is about 3,000 feet.

compared with about 50 percent in the upper Kasilof basin. The lesser proportion of glaciers near Bradley Lake therefore does not necessarily indicate lesser precipitation. Furthermore, a considerable part of the upper Kasilof River basin lies more than 10 miles northwest of the crest of the Kenai Mountains, on the leeward side where precipitation may be relatively low. The Bradley Lake basin, and nearby areas that may be tapped, lie within 10 miles of the crest, and have relatively large exposure to southerly winds. It seems possible, therefore, that precipitation and run-off in the Bradley Lake basin and adjacent areas may be as great as the average for the upper 360 square miles of the Kasilof River basin; - in the order of 84 inches per year, or even more. However, since the basis for comparison is speculative, the figure 75 inches per year is adopted here as a safer estimate of the average annual runoff near Bradley Lake.

Estimated Bradley River runoff compared with that of Grant Creek

Grant Creek near Moose Pass, had an annual runoff of 65.6 inches in the water year 1948 when there was somewhat less than average precipitation. The mean annual runoff there during the past 16 years as well as the past 30 years probably was about 70 inches, as estimated from 8 years of record and the corresponding indices of wetness. Both the Bradley Lake basin and Grant Creek basins have a similar distribution of areas between given altitudes and have about the same mean altitude. The greater extent of glaciers in the Bradley Lake basin, 34 percent of the total area as compared with only 12 percent in the Grant Creek basin, therefore may indicate that there is more precipitation and runoff at Bradley Lake, and that runoff of 75 inches may be a conservative estimate. (This evidence is not conclusive, however, since snow accumulation and growth of glaciers may be influenced by many, complicated factors).

Mean discharge of Bradley River estimated from the recorded runoff during a summer period in 1955.

The water-surface elevations of Bradley Lake were recorded by the survey party during the period July 13 to August 5, 1955, from readings on temporary staff gages in the morning and evening of each day. The discharge measurements of July 13 and August 2 serve to define an approximate stage-discharge relation for the period, and the average of the twice-daily readings approximate the mean daily gage heights. (Diurnal fluctuations were relatively small, possibly because of the regulating effect of Bradley Lake). Daily discharges were computed in the Palmer office of the Geological Survey from these gage heights and the approximate stage-discharge relation, and it was found that the mean discharge for the 24-day period was 1,070 cfs. (The maximum daily discharge was 1,330 cfs and the minimum, 820 cfs). The corresponding runoff for the period was 51,000 acre-feet.

During this same period the runoff of Grant Creek near Moose Pass was 29,500 acre-feet, or 22.6 percent of the total during the water year 1955. Because of the similarity in the range of altitude in the Bradley Lake and Grant Creek basins, and the probability that precipitation is of roughly the same order of magnitude, it seems unlikely that the distribution of snow runoff would differ greatly. It is estimated accordingly that the runoff of 51,000 acre-feet from July 13 to August 5 constituted not more than a quarter of the total, making this not less than 204,000 acre-feet for the water year 1955. This corresponds to 71 inches on the drainage area of 54.0 square miles.

Although the amount of precipitation during the water year 1955 was nearly average, runoff of streams affected by much snow carryover and storage as ice was much below average. The runoff of Grant Creek was only about 80 percent of its estimated average during the past 16 years. If that of the Bradley River was correspondingly low, the mean annual runoff may be as much as 88 inches; or 17 percent greater than the 75 inches previously estimated. These figures perhaps represent about the maximum and minimum amounts that could reasonably be estimated on the basis of the available data. A mean annual runoff of 75 inches is used in computations of this report because it probably is a conservative estimate.

Annual variation of runoff

The figures of annual runoff for Kasilof River, from 1950 to 1955, range from 85 percent to 122 percent of the mean for that period, whereas precipitation ranged from 61 percent to 165 percent of its corresponding mean. Annual runoff, particularly from the upper part of the basin, apparently has little or no direct relation to the amount of annual precipitation. For example, runoff from upper Kasilof basin in the wettest year of record, 1953, possibly was about 1,700 thousand acre-feet and may have been exceeded in the relatively dry year, 1951. The lowest annual runoff during the 6-year period, possibly about 1,150 thousand acre-feet, occurred in 1955, a year of nearly normal precipitation.

During the wet years, such as 1953, a considerable amount of water probably is held in storage as snow throughout the summer. Moreover, the snow packs of such years, being heavier than in dry years, generally have greater duration, and hence are more effective as insulation on the glaciers to prevent melting. In years such as 1955, cool, cloudy weather in spring and summer months tends to inhibit melting of snow and ice and thus to increase the amount of water that is carried over as snow or ice into other years.

Because of the altitude characteristics and lesser extent of glaciers in the Bradley Lake basin it is to be expected that the annual runoff would have a larger range of variation than in the Kasilof basin. The annual variation, however, probably would be less than that of precipitation, which in 1952 and 1953 was from 56 to 148 percent of the mean. Without natural storage and with annual losses of 10 inches on the Bradley Lake basin this would have resulted in a range of annual runoff of from about 50 to 153 percent of the mean. Because of the considerable area of glaciers in the Bradley Lake basin, and the equalizing effect of ice and snow storage, it is tentatively assumed that the extreme range may be as little as from about 75 to 125 percent of the mean, but that it probably is somewhat greater. This range is about the same as that of annual runoff from some basins in Southeastern Alaska where the range in annual precipitation is proportionately less, but where glaciers and snow accumulations may not have quite as much equalizing effect. The range in annual runoff of Grant Creek near Moose Pass between 1948 and 1955 was from roughly 70 percent to 140 percent of the estimated long-time average, and the period includes extremely dry and extremely wet years. The greater amount of ice and snow storage in the Bradley Lake basin probably resulted in a somewhat more uniform distribution of annual runoff than that of Grant Creek.

Seasonal variation of runoff

The seasonal distribution of runoff from the Bradley Lake basin probably is roughly similar to that of runoff from mountain areas near Kenai Lake. It undoubtedly differs substantially from the monthly distribution of Kasilof River runoff, as recorded at the gage downstream from Tustumena Lake. This difference is shown by the two discharge measurements made at the outlet of Bradley Lake, on July 13 and August 2, 1955. The results of these measurements were 1,320 cfs and 997 cfs respectively, whereas the daily discharges of the Kasilof River on the same dates were 2,260 cfs and 4,590 cfs respectively. Between these two dates the stage of the Kasilof River at the gage increased 1.30 feet. If there was a similar rise at the outlet of the lake, storage in the lake increased about 100,000 acre-feet and outflow from the lake was roughly only 60 percent of inflow during the period July 13 to August 2, 1955. (Storage in the lake during the early snow-runoff period may partly account for the fact that outflow in May of 1954 and 1955 actually was less than the discharge of the Anchor River, from a much smaller drainage area).

The monthly distribution of flow at Bradley Lake probably is somewhat similar to that from the Grant Lake basin near Moose Pass, an area that includes some glaciers, and which receives fairly heavy precipitation. The seasonal distribution of runoff of Grant Creek, Cooper and Crescent Creeks, and that of two glacial streams near Juneau, Alaska is listed in Table 7, following this page, for comparison.

The seasonal runoff distribution, both in mountain basins of the Kenai Peninsula and near Juneau, is characterized by a period of heavy runoff from snow melt, with maximum discharge in July or August. Fairly high flows generally continue through September to November, being sustained by heavy fall rains in both regions. During the winter period, December to April, runoff is very low and must result mainly from a little return from ground water, and occasional small amounts of snow melt or rain. The seasonal distribution of flow at Bradley Lake probably does not differ greatly from that of Grant Creek near Moose Pass or of Crater Creek near Juneau; and as a guide to storage requirements for seasonal regulation, the records for those streams probably afford an adequate model. (It is possible, however, that the year-to-year distribution may differ substantially).

FACTORS THAT WOULD AFFECT THE OPERATION OF POWER PLANTS

Sedimentation

During the period of the surveys, June to August 1955, it was observed that Bradley River below the lake, and the main tributaries upstream, carried a considerable amount of dark sediment in suspension.

Table 7

The average seasonal distribution of runoff from some Alaskan basins.

Percentage of annual runoff

Stream	Oct.	Nov.	Dec. to Apr.	May	June	July	Aug.	Sept.	Annual
Cooper Creek + Crescent Creek near Cooper Landing	10.9	8.7	11.9	7.9	20.3	18.2	11.4	10.7	100.0
Grant Creek near Moose Pass	8.1	4.9	7.1	6.6	20.2	21.9	17.9	13.3	100.0
Dorothy Creek near Juneau	12.5	8.4	7.1	5.5	14.0	18.9	16.5	17.1	100.0
Crater Creek near Juneau 1/	12.6	6.0	7.0	6.1	13.8	18.5	19.3	16.6	100.0

1/ Excepting Crater Creek, the average figures were computed from the recorded runoff, October 1949 to September 1954.

The figures for Crater Creek are the averages for 31 years of recorded and estimated runoff between 1916 and 1953; the estimates being based on the relation of monthly runoff.

The Crater Creek basin has a range of altitude of from 1,022 feet to about 5,000 feet; that of Dorothy Creek has a similar range of altitude. The area of glaciers in each basin is about a quarter of the total.

This material evidently is largely the result of glacial erosion. The delta at the upper end of the lake, and the valley bottom just upstream is composed of sand and mud. The material farther upstream at the glaciers includes gravel and boulders, grading into the finer materials downstream. Some silt or rock flour is held in suspension throughout Bradley Lake.

If a reservoir were created at Bradley Lake, material undoubtedly would be deposited at the upper end during periods of high streamflow, and there probably would be some gradual impairment of the usable capacity from the outset. Since the period of substantial drawdown of the reservoir generally would coincide with periods of low inflow much of the material deposited in this way probably would remain in place. There is no basis for estimating the rate of sedimentation, since it would depend on the average sediment load of streams entering the reservoir, the amount that would accumulate in the active zone of the reservoir, and the amount that would be carried through or deposited in deeper parts of the reservoir below the level of drawdown. Allowance for sedimentation may depend on a somewhat arbitrary provision of extra storage capacity at the outset, as a safety factor, or on a provision for enlargement of the reservoir at some future time when the rate of sedimentation can be estimated from reservoir surveys.

Fine materials carried through the reservoir and power plant might cause some wear or impairment of gates, waterways and turbines, but the trouble probably would be relatively minor.

Ice on reservoir

Ice would form on the surface of the reservoir during winter months, which would be the period of drawdown. Spill probably would not occur except in late summer of the wettest years, if storage for a high degree of regulation is provided. Control of ice probably would have to be considered for protection of the dam and intake structure. At the time of the spring break-up large quantities of the ice accumulate at the downstream end of the lake due to the prevailing downstream winds. Such accumulation was observed early in July 1955.

Low temperatures

Winter temperatures at Bradley Lake, and along waterway and transmission routes probably are lower than at Homer, but may not be as low as at Kasilof where minimums of -40°F to -50°F have been observed at times. However, structures such as pipelines and transmission lines would have to be designed for a fairly severe winter climate.

BRADLEY LAKE RESERVOIR SITE

General description

Bradley Lake is 3½ miles from tidewater at the head of Kachemak Bay, and is at an altitude of 1,090 feet. It is the only place in the region that is suitable for development of a substantial amount of storage capacity. The lake is about 3 miles long (in an east-west direction) and has a surface area of 1,566 acres. Except at the upper end, it is bounded by steep, rocky slopes which generally extend underwater for about 200 feet. The valley upstream from the lake is filled with glacial deposits, which form a delta about a mile wide at the head of the lake, and flat, bottom terrain of about the same width for a mile and a half upstream. Tributary valleys from Kachemak Glacier to the east, and from the divide between the Bradley Lake and Nuka River to the south, join the wide valley at that point. A considerable part of the potential storage capacity of the site is in the wide valleys upstream from the lake, since they have a relatively flat gradient. (See Plate I in pocket).

Bradley Lake is drained by Bradley River, which flows northward 3 miles through a very rugged canyon down to an altitude near tidewater in the flat area above the head of Kachemak Bay. The channel at the lake outlet is about 150 feet wide, divided by a small rock island near the center.

The sides of the Bradley River canyon near the lake outlet are topographically suitable as abutments for a dam to about an altitude of 1,200 feet, or 110 feet above the lake surface. The width of the canyon at that altitude is 500 feet, and it is about 260 feet at an altitude of 1,150 feet. However, there is a saddle 350 feet northeast of the right abutment, at an altitude a little above 1,150 feet, that would constitute a by-pass area unless dammed. The width across this saddle area at an altitude of 1,200 feet is about 250 feet. Also, there is another saddle about 800 feet west of the left abutment, at an altitude a little above 1,170 feet. The width there at the 1,200-foot level is about 100 feet.

At a lake stage of 1089.6 feet, the river drops only a foot in a distance of 300 feet below the island, and the canyon widens abruptly about 400 feet downstream from the island.

It was found that rock in the foundation and both abutments is mainly of massive graywacke, and is of good quality for a dam site. In the saddle area, northeast of the right abutment, this rock may be at considerable depth under a cover of gravel and talus. Descriptions of these and other geologic features are given further on in the section on geologic conclusions.

The topography near the lake outlet also appears to be reasonably favorable for development of storage capacity by tapping the lake with a tunnel outlet and drawing it down to a depth as low as 965 feet. A considerable amount of capacity thus could be obtained by damming the lake outlet, by drawdown, or by a combination of the two methods. The potential capacities and corresponding surface areas are listed in Table 8, following this page.

Inflow

The average annual inflow to Bradley Lake is about 216,000 acre-feet, if it is equivalent to 75 inches on the drainage area of 54.0 square miles, as previously estimated. This could be increased about 25 percent, or to 273,000 acre-feet, by diversion of upper Nuka River water and water from a stream north

Table 8

Bradley Lake Reservoir Site

Altitude (feet)	Area (acres)	Capacity (acre-feet)
960	1,047	168,700
980	1,145	146,800
1,000	1,223	123,100
1,020	1,292	97,960
1,040	1,342	71,600
1,060	1,409	44,100
1,080	1,479	15,200
1,090 1/	1,566	0
1,100	1,992	17,800
1,120	2,463	62,300
1,140	2,948	116,400
1,160	3,341	179,300
1,180	3,657	249,300
1,200	4,009	326,000
1,220	4,297	409,000
1,240	4,588	498,000

1/ Lake surface

of Bradley Lake into the lake basin. Since these diversions probably would entail relatively little construction, it seems probable that they will be favorably considered when need for Bradley Lake power becomes apparent. Preliminary estimates of this report therefore are based on a long-time average water supply of 273,000 acre-feet per year.

Effect of evaporation from reservoir

Damming of the lake outlet to provide storage capacity would increase the surface area very considerably, and for full control of the runoff the increase possibly would be from the natural area, 1,566 acres, to a maximum of about 4,600 acres. The average surface area during summer months then might be roughly 3,500 acres, or about 2,000 acres more than the natural lake surface. Because of prevalent high winds at Bradley Lake, evaporation perhaps might be as much as 24 inches a year, so there might be an increase from roughly 3,000 acre-feet a year to a total of 7,000 acre-feet a year, or about 2.5 percent of the average annual runoff. Since the water supply as estimated herein may be subject to error of that much or more, an allowance for evaporation loss was not made. It should be kept in mind, however, that evaporation at that rate during several seasons of holdover operation would result in an appreciable reduction in storage.

Storage requirements and illustrative reservoirs

As shown by the indices of wetness of Table 1, page 28 precipitation on the Kenai Peninsula was substantially below normal in 5 years of 7 after 1948. Storage requirements at Bradley Lake therefore were estimated on basis of the record of runoff of Grant Creek near Moose Pass for the 8-year period, 1948 to 1955. A storage capacity of 155,000 acre-feet would have been required on that stream to provide for a uniform monthly draft of 12,000 acre-feet. This draft corresponds to about 87 percent of the average discharge, as estimated for the period 1940 to 1955, and the capacity is 94 percent of the estimated average annual runoff for the same period. The reservoir would have been full and spilling in October 1947, August 1948, August 1953; and almost full in September 1955. The same degree of regulation could be obtained at Bradley Lake with proportionately less capacity, if runoff during the critical period, October 1953 to September 1955, was increased substantially by return from ice and snow storage, as may have happened. Lacking definite information, however, it is estimated that as much as 250,000 acre-feet of capacity would be required at Bradley Lake for a regulated flow of 338 cfs, or 90 percent of the estimated average inflow.

On Grant Creek, about 310,000 acre-feet of storage would have been required for a regulated flow equal to the average discharge from 1940 to 1955, with reservoir full in October 1948 and half empty in September 1955. On the same basis, a capacity of about 500,000 acre-feet would have been required at Bradley Lake for a regulated flow of 375 cfs. This includes no allowance for evaporation from the reservoir, which over the 7-year period at Bradley Lake might have been roughly 50,000 acre-feet.

Unless there is a very considerable contribution from glacier storage at Bradley Lake during periods such as 1948 to 1955, regulation for full control of the long-time runoff probably would require a larger reservoir than could be justified by the increase in power possibilities.

Usable storage of these amounts could be obtained by damming the outlet of Bradley Lake or by various combinations of damming and drawdown. Several illustrative possibilities are summarized as follows:

Bradley Lake Reservoir

Plan	Capacity, acre-feet	Range of stage altitude, feet	Mean surface altitude, feet
A	500,000	1090-1240	1,170 1/
A	500,000	965-1200	1,130 1/
B	250,000	1090-1180	1,140
B	250,000	1000-1140	1,090
C	168,000	965-1090 2/	1,035

Plan A: 100 percent regulation of assumed runoff.
Plan B: 90 percent regulation.
Plan C: Storage developed entirely by drawdown.

1/: Roughly estimated for long period of holdover storage.
2/: 965 feet is assumed to be the lower limit of feasible drawdown. There is an underwater saddle, 4,000 feet from the lake outlet at an altitude of 957 feet.

Spillway

If a dam were constructed at the outlet of Bradley Lake, a spillway would have to be provided for passing the maximum discharge that might occur. At Crater Lake near Juneau, which may be roughly comparable, the maximum discharges usually occur in the wet months, September or October. The highest of record was 3,100 cfs in September 1927, corresponding to the relatively high unit rate of 260 cfs a square mile; and this may have been the highest in the 42-year period 1913-54. The maximum probably was largely due to intense rainfall, added to some snow and ice melt. If a similar storm occurred on the Bradley Lake basin, the discharge per square mile probably would be substantially less because of its much larger drainage area. (The Crater Lake basin has a drainage area of 11.4 square miles, and the mean annual precipitation is more than 200 inches).

DIVERSION POSSIBILITIES

Upper Nuka River

The Nuka River originates in a large glacier about 3 miles southeast of Bradley Lake, and flows southward into an arm of the Gulf of Alaska. Some drainage from the glacier also flows northward into the Bradley Lake basin. The glacier extends from its highest point at a ridge 4 miles to the southwest and terminates at the edge of a wide valley, at the place where there is a low divide between the Nuka River and Bradley Lake basins. The topography in this region is shown at 10-foot contour interval on Plate I of this report (in pocket). Diversion of all of the glacier drainage into Bradley Lake basin could be accomplished by construction of a short dike across the Nuka River channel, at a channel altitude of about 1,285 feet, and by excavation of a channel for a distance of about 2,000 feet to the north, largely or entirely through deposits of glacial debris. The highest ground along this route is just a little above an altitude of 1,300 feet. (Construction equipment probably would have to be conveyed by barge from the lower to the upper end of Bradley Lake).

Maintenance of the diversion works probably would not require much work under normal conditions. Intense, warm rainfall on the glacier conceivably might scour quantities of ice into the channel and cause temporary damming and damage, but this possibility seems unlikely. The surface of the glacier is fairly clean, so that abnormal quantities of debris are not to be expected. It appears that the only possibility for major trouble might be an advance of the glacier across the valley, such as might occur after a substantial and prolonged change in climatic conditions.

During the river survey, at about the end of August 1955, the flow of Nuka River at this place was estimated as several hundred cubic feet per second, and it appeared to be several times greater than the amount that drains toward Bradley Lake from the same glacier. It seems likely, therefore, that much of the runoff from the entire glacier region flows in channels under the glacier into the Nuka River, instead of dividing in accordance with the surface boundaries of the drainage basins. If that is the case, diversion of the upper Nuka River into Bradley Lake might increase the tributary area about 15 percent, from roughly 50 square miles to 57 square miles, and the increase in water supplies probably would be proportionately even greater, since the glacier extends up to one of the highest and probably one of the wettest parts of the region.

Bradley River tributary, north of Bradley Lake

Water from a tributary of the Bradley River could be diverted from that stream at a point about a mile north of Bradley Lake, into the nearby drainage area of another stream which flows directly into Bradley Lake. This diversion would tap a basin of 10.2 square miles, and increase the water supply perhaps 20 percent over that directly tributary to the lake. The topography of the diversion area is shown in detail on Plate II, in the pocket at the back of this report.

A diversion from the creek could be made at an altitude of about 2,180 or 2,190 feet, by means of a conduit or an excavated channel along the hillside to a point about 500 feet to the southwest. A small diversion dam at a channel altitude of about 2,180 feet probably would be required. A dike or training wall also would be required at a point 800 feet southwest of the creek, on a divide between the creek and lake basins.

It is estimated that the maximum discharge at the diversion point generally would be in the order of 500 cfs or less, but that extreme discharges of several times that amount might occur. This possibility should be taken into account in the design of the diversion works. At the time of the survey, July 25, 1955, the flow was estimated to be at least 200 cfs, and it was noted that there was a fairly heavy load of dark sediment, similar to that of the Nuka River.

One of the major costs of construction might be for transport of equipment and materials to the site. The hillside north of Bradley Lake extends up to an altitude of 1,900 feet on a slope of about 1 in 2.

Other diversion possibilities

Some water from the headwaters of Battle Creek in a region extending 2 miles south of the outlet of Bradley Lake could be diverted northward to the lake. Several diversion dams and conduits, and a short tunnel through the divide just south of Bradley Lake outlet, would be required for this purpose. The drainage area that could be tapped in this way is roughly 10 square miles, including 3 square miles of glacier area. The amount of required construction can be judged only roughly from the topography shown on the quadrangle maps, but the scheme appears to be relatively complicated, and perhaps of marginal feasibility. Potential water supplies from this source were not considered in the estimates of potential power made herein.

There is also the possibility of diverting a larger portion of runoff in the Nuka River basin northward to Bradley Lake, by construction of a high dam on the Nuka River at a gorge section about 3 miles south of proposed diversion point near the glacier. A dam about 270 feet high would back water to the low divide between the Nuka River and Bradley Lake, creating a sizable reservoir. Water could be conveyed thence through the divide, by a diversion channel, as previously described. Additional water could be conveyed into this reservoir by a system of diversion dams and conduits extending about $2\frac{1}{2}$ miles to the southeast of the dam. It would thus be possible to divert runoff from an additional 18 square miles of drainage area into Bradley Lake, increasing the area previously considered about 25 percent, from 68.3 to about 86 square miles. Kenneth S. Soward, Geologist, described this possibility on the basis of topography shown on the map of Seldovia C-2, although it is not covered in his report on geologic conclusions, page 73 . He pointed out that his field examinations did not cover this dam site, but that the topographic map indicates that it may be in rock. The scheme probably is of doubtful economic feasibility at this time, and is mentioned here only as a remote possibility for additional power development in the Bradley Lake Project at some future time.

If further investigations should indicate that these diversions may sometime become feasible and desirable, design of the initial power plant at Bradley Lake might depend somewhat on this possibility of future enlargement. There is enough potential capacity in the Bradley Lake reservoir site for substantial control of a much larger water supply than is considered herein.

BRADLEY LAKE POWER SITE

Illustrative plans for single-stage development

Power plant

Water could be conveyed from the Bradley Lake reservoir almost due west about 3.7 miles, by way of tunnels, pipes and a penstock to a powerhouse on Battle Creek near Kachemak Bay. This is a route suggested in the reconnaissance report of the Corps of Engineers. Alternative pipe-line and tunnel routes to the same powerhouse site and to a possible site on lower Bradley River also were discussed. Conveyance route "B" of that report would include a 4,000 foot tunnel leading to the southwest from the reservoir into the upper Battle Creek drainage. Water would be conveyed thence by pipe and penstock roughly 4 miles along the hillside north and east of Battle Creek, to the powerhouse site on lower Battle Creek.

Conditions for tunnel construction along the general routes westward or southwestward from Bradley Lake are described further on in this report in the section on Geology. Conditions along alternative routes to the northwest of Bradley Lake, leading to a powerhouse site on lower Bradley River also are discussed. Routes to the northwest could be followed by various combinations of tunnels and pipes. One possibility would involve about 2.2 mile of tunnel and 1.0 mile of pipe and penstock, with a total length of 3.2 miles. This is the shortest of several routes under consideration. It was found that a tunnel along this route probably would cross one large fault, and that a tunnel along the route westward to the Battle Creek site probably would cross two large faults. A tunnel southwestward from the lake, as in Plan "B" of the Corps of Engineers, would be in massive graywacke for its entire length.

The lengths of the waterways to the west or northwest were measured from the dam site at the outlet of Bradley Lake. If storage capacity were developed there by drawdown of the lake surface, or by combined damming and drawdown, it would be necessary to locate the tunnel intake in the lake at a point as much as 700 feet southeastward from the lake outlet. However, drawdown of at least 100 feet could be obtained with, underwater diversion only 200 feet from the left bank at the lake outlet. (See dam site map on Plate I, in pocket).

It would be possible to construct a temporary diversion tunnel, about 2,000 feet in length, extending under the right abutment of the dam site, to the river channel downstream and drain the lake down to an altitude of 980 feet or lower during construction of the dam and main tunnel.

The nature of the lake bottom in the outlet region could not be judged closely by the soundings used for the survey, except in shallow regions near the shore. Here there evidently were boulders or large rock fragments, possibly fallen from nearby hillsides. The water was too murky for visual examination of the bottom.

Estimated power

For estimating the potential power it is assumed that the average gross heads that can be developed below the reservoir will be 20 feet less than the mean surface altitudes at the reservoir, as listed on page 54. (This provides for location of impulse wheels well above high water). It is further assumed that power can be generated at an over-all efficiency of 80 percent. The power in kilowatts then is given by the relation: $P = 0.068\ QH$, where Q is the regulated flow in cubic feet per second, and H is the mean head in feet, without allowance for friction losses in the conduit.

Under Plan A, for complete control of the runoff, and with a storage capacity of about 500,000 acre-feet created by a dam, the average gross head would be approximately 1,150 feet, and the regulated flow would be 375 cfs. This would provide for generation of about 29,000 kw, 100 percent of the time, or a dependable production of about 250 million kilowatt-hours of energy per year.

Under Plan B, for 90 percent regulation, and with a storage capacity of about 250,000 acre-feet created by a dam, the average gross head would be approximately 1,120 feet, and the regulated flow would be 338 cfs. This would provide for generation of about 25,500 kw, 100 percent of the time, or a dependable production of about 225 million kilowatt-hours of energy per year.

Under Plan C, with storage developed entirely by drawdown, the limited capacity might provide for a dependable flow of only about 300 cfs. If utilized through an average head of 1,015 feet, this would provide for generation of about 20,500 kilowatts continuously, or about 180 million kilowatt-hours per year.

A reservoir created entirely by drawdown probably would have a relatively short life, because sedimentation might be very rapid. Kenneth S. Soward has pointed out that drawdown would lead to immediate erosion of the delta by inflow at the head of the lake. This, in turn would start a new cycle of erosion in the channels upstream, and a very large amount of debris thus might be moved into the reservoir in a relatively short time. The material would form a new delta farther out in the lake, and then encroach on the active capacity of the reservoir.

This trouble would not occur to the same extent with combined damming and drawdown, since the reservoir level would be above the delta and part of the valley floor during much of the periods of high inflow. Deposition in the valley portion at the upper end of the reservoir then might be offset by scour of some delta material into deep parts of the lake below the minimum reservoir level.

Illustrative plan for two-stage development

Power plants

Bradley River drops to an altitude of 600 feet at a point about 1.2 miles from the lake outlet. Routes to this site have not been investigated closely in the field, but it may be found possible to convey water by way of a tunnel about 1.3 miles along the west side of the river, and thence by short, underground penstock to the powerhouse on the left bank of the river. The tunnel route would cross a sharp ravine, considered to be in a probable fault zone. The tunnel could be terminated at this point, about 1.0 mile from the lake, and a penstock placed down the ravine to the powerhouse, but conditions for anchoring the penstock and protecting it from possible snow or rock slides may be unfavorable. Investigation may show that a somewhat longer tunnel route along the east side of the river would be preferable. A powerhouse, located either near the left or right bank of the river possibly would have to be excavated from rock of the hillside for protection from snow or rock slides. The suggested powerhouse sites are near Mile 8.25 of the river survey.

In the reach for a mile and a half downstream the river drops only about 75 feet, or to an altitude of about 525 feet. The region is shown on the map of the dam site at Mile 6.7 (See Plate 2 in pocket). The topography is suitable for building a diversion dam to a crest altitude of at least 580 feet, and at this level the width of the canyon is 150 feet. There is a possible by-pass area in a saddle 3,000 feet northeast of the dam site that might be a controlling feature. The saddle is at an altitude of about 600 feet, and foundation conditions for an auxiliary dam are unfavorable. For power estimates of this report it is assumed that only a low dam may be considered with a crest at an altitude of about 550 feet.

Water from the diversion dam could be conveyed to the northwest about 4,200 feet by tunnel, and thence to a powerhouse at the point were Bradley River emerges from its canyon; a distance of about 3,200 feet by penstock. This site is at Mile 5.0 of the river survey, where the water surface is at an altitude of about 10 feet.

The conditions at the dam site; in the saddle area; and along the conduit route are discussed in the section on geology.

Access to the upper powerhouse site would be difficult because of the rugged terrain, and it might be necessary to use a tramway or cableway from high ground for access down into the canyon. Access to the diversion dam site at Mile 6.7 also would be difficult, although a road probably could be constructed to a point near the river about 2,000 feet downstream.

Both of these sites are mentioned because they afford a means of developing the bulk of the potential power of the Bradley Lake site in two stages, of roughly equal size. Although the capital cost and operation costs for two plants probably would be greater than the same costs for single-stage development, it is conceivable that a market for all of the power may not be found in the near future. If a lesser development should prove to be economically feasible, and if a demand should develop for only about half of the total power at the outset, the possibility would be worth considering.

The waterway distances for each of the two plants are less than half the distance required for single-stage development. Storage requirements would be the same, but the storage cost probably would not be a major part of the total. Powerhouse and equipment costs per kilowatt of capacity would be increased, because of the smaller installations and because of the lower heads.

Estimated power

For estimating the potential power, it is assumed that the heads would be utilized down to tailrace level, by means of reaction turbines and draft tubes. The average power drop thus would be from the mean reservoir surface down to the river surface at the powerhouse.

Under limited plans of initial development, it is possible that the reservoir would be designed for limited regulation, and with provision for future enlargement. A capacity in the order of 150,000 acre-feet probably would provide for a regulated flow of 300 cfs. This capacity might be obtained, for example, by lowering the lake surface 70 feet, and raising it 25 feet. The mean reservoir surface then would be 1,075 feet, initially, and about 1,105 feet ultimately, if the dam were raised in the future to provide a capacity of 250,000 acre-feet.

The average gross head at the upper plant thus would be 475 feet initially, and with the regulated flow of 300 cfs, 9,700 kilowatts could be generated continuously. With regulation for 338 cfs, and with an average head of 505 feet, the generation could be increased to 11,600 kilowatts.

At the lower plant, the average gross head would be 540 feet, initially and ultimately. This corresponds to an output of 11,000 kilowatts with a regulated flow of 300 cfs, or 12,400 kilowatts with a regulated flow of 338 cfs.

The total power that could be generated at the two plants is 24,000 kilowatts or about 94 percent of that possible with single-stage development, and with the same degree of regulation. If the scheme should be found feasible and desirable; the more economical of the two plants would be constructed first. Provision for its ultimate waterway and plant capacity should be made at the outset. Further investigation may show that a higher dam would be feasible at the Mile 6.7 site in which case nearly all of the potential head below Bradley Lake could be utilized in the two-stage development.

INDUSTRIAL SITES AND RELATED POSSIBILITIES

It is beyond the scope of this report to discuss industrial sites and transmission routes, except in a general way. Several possibilities were described in the reconnaissance report of the Corps of Engineers, in 1955.

Halibut Cove, across the bay from Homer, was suggested as one possibility because it is within a transmission distance of only 16 miles from the proposed powerhouse on Battle Creek, for the Bradley Lake development. It was pointed out that docking facilities could be provided; and that there is about 100 acres of land available near the mouth of Halibut Creek, with a possibility for considerable expansion on a large expanse of delta terrain 2 miles to the north. The possibility of a nearby power development on Halibut Creek also was suggested on the basis of an air reconnaissance. There is a very narrow gorge not far above the mouth of Halibut Creek, which appeared to be a possible site for a high storage dam.

A survey was made of this dam site at the end of June 1955, during an interim when the survey of Bradley Lake was postponed because of ice conditions. The survey revealed that the gorge is less than 150 feet wide at an altitude of 400 feet, but widens abruptly above that altitude. The width is less than 100 feet at an altitude of 350 feet, and is about 30 feet at an estimated altitude of 125 feet, at the stream surface. (The flow was high at the time of the survey, and the gorge could not be traversed.) A brief description of the rock formation is given further on in the section on geologic conclusions.

The topography at the gorge and upstream is shown on the quadrangle map of Seldovia C-3 and C-4. The configuration of the gorge section and valley immediately upstream is not shown closely, but it appears that very little storage capacity could be developed below an altitude of 400 feet. The site may be suitable only as a possibility for development of seasonal power.

An alternative possibility for an industrial site is Homer Spit near Homer, which is shown on the map of Seldovia, C-4. Transmission distance around the head of Kachemak Bay to this site, from the proposed powerhouse site on Battle Creek, was estimated as 44 miles. An underwater crossing by cable from the south shore of Kachemak Bay about 3½ miles to Homer Spit, as an extension of a line by way of Halibut Cove, was considered to be of doubtful feasibility.

Investigation may show that some terrain near Bear Cove or nearby Martin River may be suitable for limited industrial development.

Tentative geologic conclusions
on Bradley Lake power site

by Kenneth S. Soward

Bradley Lake dam site

The proposed dam site is located immediately downstream from the lake outlet where for about 350 feet the river flows between two rock knobs.

The dam site and the hills to the west and southwest have been glaciated by a large mountain glacier that carved the lake basin and the wide, U-shaped valley to the east-southeast.

The rock in the foundation and both abutments is a dark greenish-gray and dark-gray, massive, fresh, strong, slightly metamorphosed, very fine- to medium-grained graywacke of very good quality for a dam site. No bedding could be found in the massive graywacke, but at a few places in the left abutment lenses of hard, grayish-black shale with smaller lentils of graywacke and chert are exposed. Alignment of the graywacke lentils in the shale suggests that the strike of the beds varies from N. 5° to 25°W., and the dip varies from 69° to 81° SW.

One minor fault with 1 to 15 inches of crushed rock and gouge is present about 200 feet west of the left abutment. A few narrow slips with friction breccia along them are exposed at the site.

The rock on both sides is cut by a number of joint sets; and many large angular blocks, some up to 12 feet through, have broken loose from the steep sidehill northeast of the site. A number of the joints are open at the surface, especially on the left abutment, but they appear to narrow quickly and probably are tight at shallow depths.

In the low saddle about 300 feet northeast of the right abutment, the rock surface may extend almost to the level of the lake. Gravel and talus fill the deep narrow gap; with rock of very good quality suitable as a foundation for any type of structure in the side walls. The small saddle about 800 feet west of the left abutment probably is underlain by rock of good quality at an estimated depth of 10 to 15 feet.

The right abutment appears suitable for any type of dam. However, if an arch or gravity-arch dam is considered for the site, the left abutment should be investigated more fully. The rock there is cut by a number of joints, and is in smaller blocks than in the right abutment. Also, the canyon immediately downstream from the small island flares or widens so that there may not be a sufficient mass of rock to take the thrust of an arch dam.

An alternative dam site suitable for a gravity dam is present about 500 feet downstream from the lake outlet.

Diversion routes to powerhouse

Geology. - The shortest distance to where a powerhouse can be located on the tidal flats is on a line between N. 37° to 45° W., from the dam site. See Seldovia (D-3), Alaska quadrangle. Actually, however, there are a number of possible routes, depending upon the type of conduit, either steel pipe or tunnel, that is considered most desirable to use.

Massive graywacke is exposed for about 2,500 feet west and 3,000 feet northwest of the dam site. It is overlain by a thick sequence of chert beds with a shaly or argillaceous matrix in which the chert particles vary from only a few percent to an estimated 80-90 percent of the rock. The outcrop of these chert beds is about 1,500 to 2,000 feet wide. The strike of these beds trends north-northeast and the course of Bradley River from 1½ to 3½ miles below the lake outlet appears to be controlled by this softer rock. Overlying this unit and exposed to the west is a thick sequence of interbedded graywacke and chert beds.

Two large faults appear to be present between the dam and powerhouse sites. Based on topographic evidence, a fault may be in the chert beds in the prominent draw one mile northwest of the site and in the channel of Bradley River. Its southwest projection would cross any tunnel line selected. The second fault is in the sharp, steep draw of the small creek that flows by the cabins north of the proposed powerhouse site area. Any tunnel line whose bearing would fall between N. 55° W. and west would intersect the southwest projection of this fault about 10,000 to 12,000 feet from the lake.

For construction purposes the quality of the rock will vary from fair to possibly excellent. A tunnel in the graywacke will not require support while being driven; in fact, the massiveness and strength of this rock may be high enough that a concrete lining would not be required. The only structural defect noted in this rock is the jointing, but a shear zone or lens of cherty shale may be encountered. If they are encountered, a concrete lining would be necessary to prevent caving.

The section of the tunnel in the chert beds probably would require support over seventy-five percent of its length. Extremely difficult conditions for tunneling will exist where the faults believed to be present would cut the line. The entire section of the tunnel in this rock would require a concrete lining.

In the interbedded graywacke and chert beds to the west, probably only short lengths of the tunnel would require light support during construction. This section of the tunnel probably would have to be lined with concrete.

Proposed conduit lines. - A conduit line with a general bearing of N. 37° W. from the dam site would allow a number of opportunities for a choice of either tunnel or steel pipe sections. A bore on this bearing at altitude 1,100 feet would daylight in the steep draw about 4,800 feet from the dam site and possibly in the small cirque about 8,000 feet from the dam site. However, slight shifts in its bearing would place it beneath cover at both places. The conduit would be about 16,900 feet long and consist of the following elements: a 400-foot steel pipe from the dam to the intake portal; 11,400 feet of tunnel, if the route stays underground; another 700-foot length of steel pipe from the discharge portal to the surge tank; and a penstock about 4,400 feet long to the powerhouse. The first 3,300 feet of this tunnel would be in massive graywacke; the next 2,400 feet in the chert beds; and the last 3,400 feet in the interbedded graywacke and chert beds.

If a steel pipe conduit is sufficiently cheaper to justify its use, the tunnel section could be shortened to 6,700 feet. Under this plan, a pipe section 1,600 feet long would be needed from the dam to the intake portal. From here a tunnel bearing N. 55° W. would extend 3,400 feet to an angle point beneath the deep draw where a bore bearing N. 43° W would extend 3,300 feet to daylight in the small cirque. A steel pipe about 6,000 feet long would be required to convey the water to the surge tank and penstock. The approximate length of this line would be 18,700 feet. From the portal to about 2,400 feet, the tunnel would be in massive graywacke; from 2,400 to 4,600 feet in the chert beds; and from 4,600 to 6,700 feet in the interbedded graywacke and chert beds.

The tunnel line proposed by the Corps of Engineers [1/] under their basic scheme, and alternative

1/ Bradley Lake project - A reconnaissance report on potential power developments together with auxiliary possibilities, Corps of Engineers, U. S. Army, Office of the District Engineer, Alaska District, March 1955.

tunnel A, would be in massive graywacke from the portal to 2,400 feet; in chert beds from 2,400 to 4,100 feet; and in interbedded graywacke and chert beds from 4,100 feet to the discharge portals. Alternative tunnel B would be in massive graywacke for its entire length of approximately 4,000 feet.

The proposed penstock line was not examined. Preliminary exploration of the project should include work to determine if excessive rock creep or solifluction has taken place in the hillside above the powerhouse site. Permafrost may occur where there is a heavy soil cover.

Powerhouse site

The powerhouse site on the N. 37° W. conduit line is on argillite. The rock in the vicinity of the site appeared to be of good quality for a powerhouse foundation.

Nuka River diversion

No geologic problems appear to be involved in this diversion. The preferred location is on the north side of the valley just east of the divide.

Here the Nuka River swings around a small morainal ridge that dams the valley and forces the melt water from the glacier to cross to the north side before the stream turns to the east.

The moraine appears to be composed of till, and the shallow cut required to divert the water should be in gravels or possibly in till. If a cut deeper than 25 feet is necessary, tests should be made to determine if bedrock would be encountered.

Diversion of Bradley River tributary into Bradley Lake

About 2¼ miles west and one mile north of Bradley Lake outlet, a tributary of Bradley River can be diverted into the lake. A low dam possibly 10 feet high and a canal about 450 feet long with a maximum cut of about 20 feet will divert the stream. Rock appears to be present at shallow depth at the dam site, but the diversion canal will be in pervious gravel possibly with a short section in rock.

Construction Materials

Some small exposures of gravel were noted along the North Fork of Battle Creek and gravel probably underlies the grassy meadows for about 0.6 of a mile downstream from the small lake that is 0.5

of a mile S. 10° W. of Bradley Lake dam site. See Seldovia (C-3), Alaska quaddangle. However, the gravel appeared deficient in sand, and the volume of the deposits is small.

An adequate supply of sand and gravel is available at the upper end of Bradley Lake.

Dam site at Mile 6.7, conduit line, and related possibilities

This dam site is just upstream from a 35 to 40 feet high falls formed by a thick resistant quartzite bed that crosses the river channel at a right angle. The bed dips 71°E., and appears to be overturned to the west compared to beds just upstream that dip at a high angle to the northwest. The foundation and abutments of the site are in an argillite bed in which numerous sand and pebble-sized pieces of quartzite are embedded. The rock is closely jointed, and breaks into small blocks.

The site appears feasible for a small arch dam that topographically is limited to a maximum height of 60 to 70 feet with a crest line at altitude 590 to 600 feet. The canyon is 160 feet wide at altitude 590 feet.

The tunnel line to the northwest will be in argillite, cherty shale, and quartzite beds. The strike of the beds is approximately at right angles to the tunnel line, and the dip of the beds is at a high angle mainly to the northwest.

Only light support will be required at a few places during construction, but the tunnel probably will have to be lined.

A reservoir to altitude 600 feet would overflow through a gap 2,400 feet north of the dam site. Rock crops out in places across the gap, but a large fault, with a probable bearing of S. 35° W., 65° SE. exposed in the right creek bank to the north of the gap, would be in the foundation. Marshy ground in the gap may contain lenses of permafrost. The poor foundation conditions require investigation by core drilling, but a small retaining dam probably could be built here.

CONCLUSIONS

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Topographic and geologic conditions are favorable for creation of a large reservoir at Bradley Lake with a dam of moderate height. Considerable storage also can be obtained by drawdown of the lake surface, or by combined damming and drawdown. A head of about 1,100 feet can be utilized below the reservoir with several miles of waterway leading to a powerhouse at tidewater of Kachemak Bay, and several alternative routes and powerhouse sites are available. Further investigations, such as stream gagings and sub-surface geologic examination, would be needed to determine the optimimum plan of development.

The area tributary to Bradley Lake can be increased about 25 percent by diversions from two nearby areas that could be tapped with relatively minor construction. The total water supplies thus available can be estimated only roughly from information now available. It seems likely, however, that the average flow, including the proposed diversions, was as much as 375 cfs during the past 30 years, and possibly was 10 or 15 percent more. The power possibilities are estimated accordingly as 25,500 kilowatts, 100 percent of the time with utilization of 90 percent of the estimated discharge; or 29,000 kilowatts, 100 percent of the time, with full utilization.

It is provisionally estimated that a reservoir with a capacity of 250,000 acre-feet would be adequate to provide a uniform power flow of 338 cfs, equal to 90 percent of the average discharge. Utilization of much more than this amount on a uniform basis may not be practicable because of the considerable duration of dry and wet periods on the Kenai Peninsula. A reservoir with a capacity of 500,000 acre-feet, or more, might be required at Bradley Lake for a uniform monthly draft equivalent to 375 cfs, if that is the average for many years.

An uncertain factor in these estimates is the effect of the extensive glaciers on the amount of runoff during periods of abnormal precipitation, which may last for 7 years or longer. Ice and snow storage undoubtedly has a considerable effect on the runoff from year to year, and it may have an appreciable equalizing effect on the averages for wet and dry periods of several years. If this effect is found to be relatively large in the Bradley Lake basin, the estimated requirements for artifical storage might be reduced substantially.

Runoff records are a primary requirement for close determination of the potential power, and for closer determination of reservoir and plant capacities needed for a given degree of utilization. Records for only a few years, if carefully interpreted, probably would lead to a much more reliable estimate of the amount of runoff and of the character of its variation. If a gaging station cannot be established on Bradley River in the near future, a series of discharge measurements made systematically throughout the months of heavy runoff would provide valuable information in the meantime, and would constitute a useful supplement to a future record.

The potential power of the Bradley Lake site is much more than could be used by existing communities and industries in the probable service area, but it may be considered for use in new industries. Further investigations, such as a stream-gaging program, seem well justified.