Waterpower Resources of the Bradley River Basin Kenai Peninsula Alaska

By F. A. JOHNSON

WATERPOWER RESOURCES OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1610-A

Potential power of Bradley Lake and related geographic, climatic, and hydrologic factors

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UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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By F. A. Johnson

ABSTRACT

A survey of Bradley Lake and the Bradley River, including underwater contouring at the lake, was made in 1955 for use in studying possible plans of waterpower development. The survey was supplemented by surface geologic examinations. Illustrative plans of development in accord with the topography and geology are described in this report, and used with runoff records and estimates to compute the potential waterpower. Runoff records available in 1960 covered only two complete water years, October 1957 to September 1959. These were supplemented by estimates of monthly runoff from October 1949 to September 1957 based on a relationship with the runoff of the nearby Kasilof River and records for that stream. The runoff at the outlet of Bradley Lake was thus determined to have been about 334 cfs (cubic feet per second), or 84 inches per year on the drainage area of 54 square miles, from 1949 to 1959.

Runoff from an additional area of 14 square miles could readily be diverted into the Bradley Lake basin to increase the water supply about 26 percent, and the waterpower estimates were made accordingly. It was determined that a usable storage capacity of 300,000 acre-feet would have provided for substantially complete control in the 10-year period, 1949–59, with uniform release of 421 cfs. Development through a mean gross head of 1,131 feet to a powerhouse at tidewater some three and a half miles from the lake would provide for generation of 32,400 kw (kilowatts) continuously. The storage capacity could be obtained by a dam at the lake outlet to raise the surface 104 feet, or alternatively by a lower dam and a tunnel to tap the lake at depth.

The runoff from 1949 to 1959 is estimated to have been about 90 percent of that during the 40-year period prior to 1960. A lesser degree of development corresponding to control and utilization of about 80 percent of the 40-year mean runoff also was considered. This would have required about 171,000 acre-feet of capacity for uniform release of 375 cfs. Development through a mean gross head of 1,110 feet would provide for generation of 28,300 kw continuously. The storage capacity could be obtained by a dam at the lake outlet to raise the surface 68 feet, or by a combination of damming and lake drawdown.

Water could be conveyed from the lake to a powerhouse at tidewater by means of tunnels and pipelines along several alternative routes. It would be possible also to convey it along the Bradley River for development in two nearly equal stages at powerhouses located on the river.

Geographic, climatic, and hydrologic features of the Kenai Peninsula are discussed briefly. The runoff of the Bradley River is consistent with a mean annual precipitation of about 100 inches; whereas precipitation is less than 20 inches a short distance to the north in the rain shadow of the Kenai Mountains.

INTRODUCTION

PURPOSE AND SCOPE

The purpose of this report is to present an evaluation of the potential waterpower in the Bradley River basin as a basis for classifying the public lands with respect to their values for waterpower purposes. Possible plans of development, based on topography, geology, streamflow, climate and related information are outlined as a means of estimating the potential waterpower.

Records of the flow of the Bradley River that are available at the time of this report (1960) cover only two complete water years, 1957–1958 and 1958–1959. Figures of monthly runoff for the seasons 1949–1950 to 1956–1957 were estimated from the records of the nearby Kasilof River near Kasilof and used with the two-year record in reservoir operation schedules for given degrees of regulation.

Since the runoff may be considerably affected by changes of natural storage in snow or glacier ice, the climatic factors that determine such changes are discussed.

The utilization of a substantial part of the potential power of Bradley Lake probably will depend on the creation of new industries. Normal needs of farms and the small communities of the Kenai Peninsula would not absorb much of the Bradley Lake potential in the foreseeable future. A need may develop for some of the power at Anchorage through future growth of that city. A hydroelectric plant at Bradley Lake could be interconnected with a plant under construction at Cooper Lake (1960), and with other hydroelectric plants which may be constructed on the Kenai Peninsula, for joint transmission of power to the Anchorage area. The transmission distance from Bradley Lake to the vicinity of the Cooper Lake plant, near the lower end of Kenai Lake, is roughly 90 miles, and to Anchorage roughly 155 miles over a circuitous route, some of which is near existing highways.

OTHER INVESTIGATIONS

The Alaska District, U.S. Army Corps of Engineers, made a reconnaissance investigation of the Bradley Lake site in September 1954. A report based on this investigation and other available information was compiled by the Corps of Engineers (1955) at the request of the Governor of Alaska. 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 diverted to Bradley Lake. 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.

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 outside the scope of the present report, also were discussed.

In October 1959 geologists and engineers from the office of the Alaska District, Corps of Engineers, made several field reconnaissances of the Bradley Lake power site; two core holes were drilled in the channel of the Bradley River near the lake outlet; and a test pit was dug in the saddle on the right abutment. It was concluded that the site is highly satisfactory for any type of dam, that rock available at the site is not suitable for coarse concrete aggregate, but that it has been found suitable for use in a rockfill dam.

ACKNOWLEDGMENTS

Information concerning recent investigations of the Corps of Engineers was supplied by the office of the District Engineer, U.S. Army Engineer District, Anchorage, Alaska.

GEOGRAPHY

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 the 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. (See fig. 1.) 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. The head of Kachemak Bay is featured by an extensive tidal mud flat, but the water deepens abruptly to 60 feet or more in and near Bear Cove, 4 miles southwest from the head of the bay.

The Bradley Lake basin is characterized by glaciers, extensive exposures of bare rock, and relatively little soil cover. (See fig. 2.) The basin is uninhabited and entirely undeveloped. Some occupation by settlers has taken place along the north side of the Fox River valley and northwest of the head of Kachemak Bay within 10 miles of Bradley Lake. If such settlement increases sufficiently a road presumably may be extended to this area from Homer.

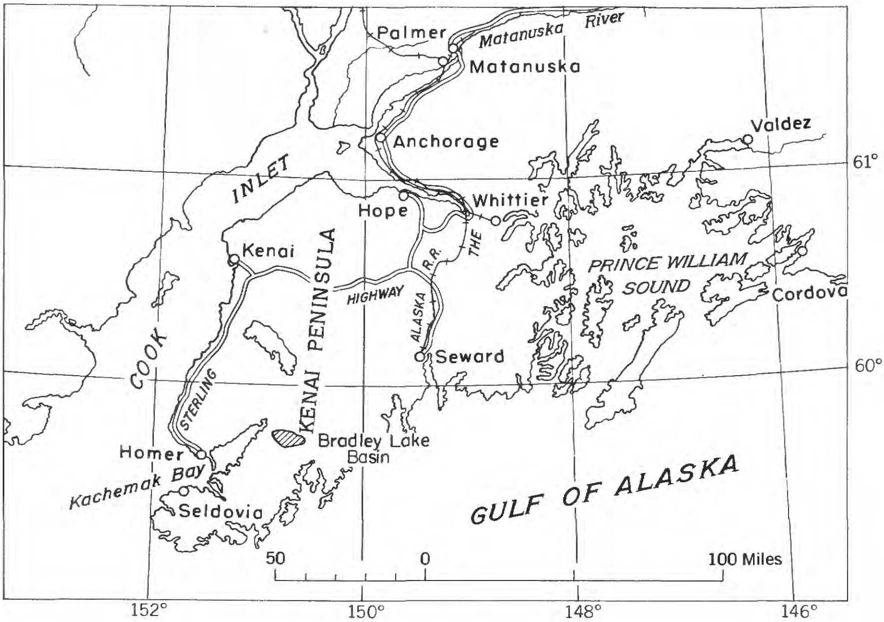

FIGURE 1—Index map of Kenai Peninsula, Alaska, showing location of Bradley Lake.

FIGURE 2—Bradley Lake looking southeast from right abutment at the damsite toward the headwaters of the basin. Kachemak Glacier in background, right of center, July 1955.

Areas above selected altitudes in the Bradley Lake basin and in nearby basins are listed in table 1.

TABLE 1—*Drainage areas in square miles above selected altitudes in Bradley Lake basin and adjacent basins*

Altitude (feet)	Bradley Lake basin		Nuka River diversion area		Diversion area north of lake		Lake basin plus diversion areas	
	Area	Percent of total	Area	Percent of total	Area	Percent of total	Area	Percent of total
1,000	54.0	100	4.1	100	10.2	100	68.3	100
2,000	36.3	67	3.6	88	10.1	99	50.0	73
2,500	31.3	58	3.3	81	9.6	94	44.2	65
3,000	25.5	47	2.5	61	8.3	81	36.3	53
4,000	8.4	16	0.8	20	4.1	40	13.3	19

Homer, the nearest town, is on the north side of Kachemak Bay about 25 miles to the southwest of Bradley Lake, at the end of the Sterling Highway. 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 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 437 in the 1950 census.

The principal industries at these places are fishing, and processing and canning fish. A number of homesteads have been established in the region near Homer, and to the north, and farming may increase in importance. Recently there have been extensive investigations of petroleum possibilities, and some discoveries have been made. Discovery of substantial reserves might 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. Manufacturing by electro-metallurgical or electro-chemical processes may offer the best possibilities. Lumbering and related activities will have little importance since forest growth in the region is scanty.

ACCESSIBILITY

At present the only practicable access to Bradley Lake is by float planes or small land planes. Development of the site for waterpower would necessitate construction of a road. This might be located from the region of deep water at Bear Cove along the hills bordering the south side of Kachemak Bay to the vicinity of Battle Creek on the Bradley River and thence southeastward to the lake, or from the north side of Kachemak Bay, connecting with a road from

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Homer, and extending around the head of Kachemak Bay to the Bradley River or Battle Creek. Possible routes up the mountainside to Bradley Lake are in rugged terrain, and considerable rock excavation would be required for road construction. (See figs. 3 and 4.)

FIGURE 3—Bradley Lake outlet and river downstream. The Bradley River at the bend in left foreground is 200 feet lower than the lake.

MAPS AND PHOTOGRAPHS

A map entitled "Plan and Profile, Bradley River and Bradley Lake, Alaska, Dam Sites" was published by the Geological Survey in 1956. The scale of the plan map is 1:24,000 and the contour interval is 20 feet. The topography is shown to about 200 feet above and to 250 feet below the lake surface. In addition, an area on a tributary of the Bradley River is shown at scale 1:24,000 and with a contour interval of 10 feet. (Works could be constructed there for diverting the stream into Bradley Lake.) A damsite at the outlet of Bradley Lake and one at mile 6.7 on the Bradley River are shown at a scale of 1:2,400 and with a contour interval of 10 feet.

FIGURE 4—Lower canyon of the Bradley River. Mile 6.7 damsite at point indicated by arrow.

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

Seldovia: Reconnaissance series, scale 1:250,000, contour intervals 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.

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, Colo.

GEOLOGY

The geology of the Bradley Lake powersite is described briefly in the report of the Corps of Engineers (1955), and in more detail by

Soward.[1] Some of Soward's findings are summarized briefly in the discussions of damsites and diversion routes given further on in this report.

CLIMATE

GENERAL

Most of the climatic records are for coastal points on the Kenai Peninsula, and none have been obtained in mountain regions near Bradley Lake.

Records of runoff and precipitation for several stations from Seward to Kenai show 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. Precipitation records indicate that the average annual precipitation at Kenai, Naptowne, and Kasilof probably is less than 20 inches, whereas it was about 66 inches at Seward during 39 years of record to 1959. The average annual runoff of the Snow River of the Kenai River basin (see fig. 1) is estimated to have been in excess of 90 inches, 1920 to 1959. This is from a basin of 166 square miles, ranging in altitude from 436 feet to more than 5,000 feet. The estimated runoff probably corresponds to a mean annual precipitation of roughly 100 inches. It is probable that precipitation in the headwaters area of the basin is considerably greater.

There is a marked decrease in winter temperatures northward from Seward to Naptowne, although summer temperatures are comparable at the two stations. Monthly mean temperatures 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 by Johnson (1955). Climatic data for the Kenai Peninsula are published in "Summaries of Climatological Data" (U.S. Weather Bureau).

The general distribution of precipitation and temperature across the Kenai Peninsula in the vicinity of Bradley Lake probably is somewhat similar to that between Seward and Naptowne. The average annual precipitation at Kasilof is about 18 inches, as estimated on the basis of a relatively short record, and this is 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

[1] Report in preparation, 1961.

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 because 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 recorded at Homer, probably as a result of the factors 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 nearly continuous records were kept. 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. Precipitation such as that recorded at Kasilof may be expected to result in runoff, especially snow runoff, 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° F at Kasilof and 25.9° F at Homer, and average January temperatures are 13.3° F and 22.6° F respectively. Minimum temperatures as low as −30° F to −40° F are not uncommon at Kasilof; whereas temperatures below −15° F are unusual at Homer. During the period, April to October, monthly temperatures are about the same at both places; 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 it is only about 20 miles northwest of the Gulf of Alaska, and is subject to the weather patterns of the Gulf of Alaska.

CLIMATE AT BRADLEY LAKE

The Bradley Lake basin is near the crest of the mountains and, as indicated by glaciers, and by the two years of runoff records, receives heavy precipitation. The runoff of the Bradley River at Bradley Lake for the water years ending September 30, 1958 and 1959, was recorded as 121 inches and 74 inches respectively. From comparisons of these figures with other runoff records and long-term precipitation records the mean annual runoff during the past 40 years is estimated to have been about 92 inches, which probably corresponds with a mean annual precipitation of about 100 inches.

Winter temperatures at the lake probably are lower than at Homer, since the altitude is a thousand feet higher. It is probable also that winter temperatures at sea level near the head of Kachemak Bay are lower than at Homer, since the region 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 report the occurrence of williwaws at the head of the bay when the air is fairly calm at Homer.

In 1955 ice on Bradley Lake prevented landing by float plane until after July 1. Temperatures in May and June 1955 were below normal, and the lake reportedly is usually open by about the middle of June. It was observed to have been free of ice June 4, 1958 and June 12, 1959, at times of visits to the streamgaging station.

Strong winds occur frequently at the lake. During the course of the survey in July and August, 1955, there were 12 days in a 31-day period when 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.

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. The average of precipitation recorded at Seward and Homer may be closely representative of the year-to-year distribution at Bradley Lake. Continuous records have been published for both stations from 1940 through 1959, and rounded figures for the water years ending September 30 are listed in table 2.

The average of the indices for the period 1950 to 1959 is 89 percent of the 20-year mean, and the 20-year mean in turn is about the same as an average (partly estimated) for 39 years at the Seward station. The lowest water year of record occurred in 1952, both during the 20-year record for the two stations; and at Seward during 39 water years of fairly complete records. The year 1951 also was relatively dry, but 1953 was one of the two wettest years of record.

Records of monthly and annual precipitation for Seward and Homer, 1940–59, are given in tables 3 and 4, and records of monthly and annual mean temperature for Homer are listed in table 5.

TABLE 2.—*Precipitation, in inches and percent of mean, at Homer and Seward*

Water Year	Homer		Seward		Mean, columns 3 and 5, percent
	Precipitation	Percent of mean	Precipitation	Percent of mean	
1940	31.4	130	87.1	131	130
1941	38.3	158	88.8	134	146
1942	24.0	99	73.8	111	105
1943	17.2	71	52.7	79	75
1944	33.6	139	101.1	152	146
1945	33.5	138	74.2	112	125
1946	27.0	112	58.0	87	100
1947	22.8	94	64.9	98	96
1948	22.8	94	67.6	102	98
1949	21.4	88	58.2	88	88
1950	19.5	81	66.2	100	90
1951	16.2	67	47.0	71	69
1952	11.9	49	42.8	64	56
1953	35.3	146	101.3	153	150
1954	20.7	86	51.6	78	82
1955	22.9	95	63.1	95	95
1956	17.6	73	48.0	72	72
1957	17.6	73	45.0	68	70
1958	28.8	119	87.4	132	126
1959	21.9	90	49.3	74	82
Mean	24.2	----------	66.4	----------	----------

TABLE 3.—*Monthly and annual precipitation, in inches, Seward, Alaska*

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year
1940	6.9	5.6	9.8	12.0	2.8	5.6	8.6	3.0	1.3	2.1	10.7	18.7	87.1
1941	14.9	6.4	5.9	2.4	14.6	12.1	13.9	4.6	3.0	5.5	.8	4.7	88.8
1942	3.4	2.2	11.1	8.2	10.4	6.6	5.0	1.1	3.8	3.6	10.5	7.9	73.8
1943	7.1	.9	1.0	2.7	6.8	1.7	4.5	2.2	3.4	3.6	3.6	15.2	52.7
1944	11.3	18.3	18.2	11.3	6.1	2.0	1.1	7.0	1.6	4.8	11.4	8.0	101.1
1945	12.2	7.4	6.2	12.1	11.0	3.0	1.3	2.2	1.9	2.2	8.1	6.6	74.2
1946	15.8	2.1	4.8	5.6	6.2	3.2	3.4	4.9	1.2	.8	4.6	5.4	58.0
1947	11.7	4.3	2.9	3.0	6.4	7.1	1.8	6.7	2.9	2.3	5.0	10.8	64.9
1948	7.7	12.6	8.7	12.5	4.8	1.3	0	3.7	1.5	4.3	1.0	9.5	67.6
1949	13.5	4.4	1.6	4.7	.6	6.1	3.7	1.8	2.0	1.0	5.6	13.2	58.2
1950	8.1	10.9	4.7	1.2	.9	3.0	6.1	5.5	3.8	1.4	4.8	15.8	66.2
1951	4.0	.3	6.1	3.3	3.8	2.6	4.7	2.6	2.9	.9	3.0	12.8	47.0
1952	5.1	4.9	2.6	1.8	3.8	3.1	4.7	1.7	1.4	5.3	4.4	4.0	42.8
1953	21.7	19.2	15.1	2.6	16.0	2.1	7.6	.8	.6	1.1	5.6	8.9	101.3
1954	10.1	6.4	7.8	4.9	3.5	5.8	.4	2.4	.7	4.0	2.7	2.9	51.6
1955	10.6	8.8	2.8	10.8	2.6	3.5	3.2	4.4	2.4	3.6	4.5	5.9	63.1
1956	7.3	.8	7.1	2.0	4.2	2.3	4.1	7.7	.3	1.2	7.3	3.7	48.0
1957	3.0	7.7	2.0	2.3	2.1	3.3	.6	1.2	.1	1.5	5.1	16.1	45.0
1958	13.4	15.7	4.8	8.7	3.1	2.7	2.8	5.1	4.6	10.3	8.2	8.0	87.4
1959	6.0	7.0	2.4	1.3	3.6	.3	8.6	2.5	.3	6.2	1.8	9.3	49.3
Mean	9.7	7.3	6.3	5.7	5.6	3.8	4.3	3.5	2.0	3.3	5.4	9.4	66.4
Percent of mean annual	14.6	11.0	9.4	8.6	8.6	5.7	6.5	5.3	3.0	5.0	8.1	14.2	100.0

TABLE 4.—*Monthly and annual precipitation, in inches, Homer FAA, Alaska*

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year
1940	3.4	1.7	8.0	3.8	0.2	2.2	1.2	0.7	0.3	2.1	3.2	4.6	31.4
1941	7.8	2.3	3.8	2.8	5.3	3.9	2.8	1.5	3.4	1.7	1.4	1.6	38.3
1942	1.4	1.1	4.4	1.3	2.4	2.1	2.4	.7	1.0	1.6	2.7	2.9	24.0
1943	2.3	.2	.9	1.1	1.7	.5	.9	1.3	.7	1.6	2.3	3.7	17.2
1944	2.5	7.3	5.0	3.8	1.1	1.5	.2	1.9	1.5	3.0	3.6	2.2	33.6
1945	3.3	4.0	1.8	4.9	4.0	3.8	.3	.4	.4	1.4	5.3	3.9	33.5
1946	6.3	2.9	1.3	3.3	2.3	1.3	1.2	2.0	.4	1.4	2.0	2.6	27.0
1947	6.8	1.4	1.3	.9	1.2	1.5	.7	.8	.3	2.1	2.2	3.6	22.8
1948	3.8	2.8	2.8	2.4	.6	.5	0	.7	.6	3.8	2.4	2.4	22.8
1949	3.5	1.0	.5	3.9	.4	2.3	.9	.5	2.2	1.4	1.3	3.5	21.4
1950	2.6	3.1	2.2	.7	.2	1.1	2.8	.5	1.4	1.0	1.3	2.6	19.5
1951	2.4	.1	1.4	1.5	.9	.4	1.4	.2	2.1	.7	2.1	3.0	16.2
1952	1.4	1.1	.3	.7	.8	.3	.6	.3	.5	1.7	2.0	2.2	11.9
1953	4.6	8.6	5.7	1.0	3.6	.2	1.5	2.0	.7	.2	4.8	2.4	35.3
1954	3.8	2.7	2.2	1.1	.8	1.9	0	.4	.3	1.9	4.1	1.5	20.7
1955	4.6	2.4	1.3	2.1	1.0	.4	1.1	.4	2.8	.9	4.0	1.9	22.9
1956	3.7	.1	2.6	1.0	.9	.7	1.5	1.2	.5	1.4	2.2	1.8	17.6
1957	1.4	3.0	.2	.9	.8	.4	.8	.4	.1	2.3	3.0	4.3	17.6
1958	3.6	6.0	2.4	3.7	.5	1.7	.9	1.1	1.1	2.5	2.9	2.4	28.8
1959	2.1	4.7	1.1	.8	1.8	.6	3.5	.6	.1	3.3	1.6	1.7	21.9
Mean	3.6	2.8	2.5	2.1	1.5	1.4	1.2	.9	1.0	1.8	2.7	2.7	24.2
Percent of mean annual	14.8	11.6	10.3	8.7	6.2	5.8	5.0	3.7	4.1	7.4	11.2	11.2	100.0

TABLE 5.—*Average monthly and annual temperatures, degrees Fahrenheit Homer FAA, Alaska*

Water year[1]	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year
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
1941	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
1942	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
1943	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
1944	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
1946	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
1947	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
1948	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
1949	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
1951	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
1952	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
1953	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
1954	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	29.5	32.0	41.5	46.5	51.5	51.6	45.2	36.6
1956	35.0	22.3	15.0	14.1	17.4	22.8	34.1	41.4	46.7	51.5	51.5	44.9	33.1
1957	32.3	23.6	14.7	24.0	20.5	32.5	36.7	43.1	50.6	52.9	53.6	48.6	36.1
1958	41.4	37.5	18.7	26.7	29.1	33.2	38.4	44.4	50.5	53.6	42.7	45.4	39.3
1959	34.0	26.7	24.9	19.6	29.1	17.7	33.8	42.9	49.5	52.0	52.4	46.5	35.8
Mean	37.7	28.4	21.9	22.1	25.3	27.8	35.4	42.4	48.8	52.4	52.5	47.0	36.8

[1] Year ending Sept. 30.

GLACIERS AND SNOW ACCUMULATIONS

As interpreted from aerial photographs taken in 1950, glaciers in the Bradley Lake basin and in the nearby areas that can be made tributary to Bradley Lake cover about a third of the entire area. The distribution is as follows:

Drainage area	Area, square miles		Glacier area percent of total
	Total	Glacier	
Bradley Lake basin	54. 0	16. 9	31. 2
Upper Nuka R. basin	4. 1	3. 2	78. 0
Tributary to Bradley R.	10. 2	2. 8	27. 4
Total	68. 3	22. 9	33. 6

The largest is the Kachemak Glacier, the main body of which is below an altitude of about 3,600 feet, starting on a pass 10 miles southeast of Bradley Lake. This and a glacier which drains both into Bradley Lake and the Nuka River extend as valley glaciers down to altitudes of about 1,500 feet. The others are cirque glaciers generally above altitudes of 3,000 feet.

The substantial extent of the glaciers indicates that the snow packs must be relatively great, so that in the wetter and colder years it is to be expected that a substantial amount of water would be stored as transient snow to appear as runoff in subsequent drier or warmer years.

FACTORS THAT WOULD AFFECT THE DESIGN AND 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. 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. It was also observed that some silt or rock flour was held in suspension in Bradley Lake. This, no doubt, decreases during periods of low inflow and it seems quite probable that the lake water will be fairly clear during the winter months.

If a reservoir were created at Bradley Lake, sediment 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. 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 during filling of the reservoir in spring months. 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.

If storage capacity were created at the lake by drawdown through a tunnel outlet or by combined drawdown and damming instead of damming alone this would introduce another kind of sedimentation (written communication, K. S. Soward, 1956). With reservoir levels below the natural lake surface, inflow at the head of the lake would erode the delta and start a new cycle of erosion in the channels upstream. A large amount of debris thus might be moved into the reservoir in a relatively short time. It seems doubtful, however, that such movement of material would seriously affect the useful life of the reservoir. To some extent a balancing effect is introduced, as the space formerly occupied by material carried into the lake at low stages would be available for storage at higher stages.

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 EFFECTS

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.

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 after melting of the ice, 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 because of the prevailing downstream winds. Such accumulation was observed early in July 1955.

WATER SUPPLY

TRIBUTARY TO BRADLEY LAKE

Continuous records of streamflow have been collected at the outlet of Bradley Lake since October 1, 1957. The figures of monthly runoff had about the same relationship to those of the Kasilof River during each of the two water years ending September 30, 1958 and

September 30, 1959. The relationship varies greatly in different seasons of the year because of widely different conditions for natural storage in the two basins but may be fairly stable from year to year. The Bradley River runoff in percentage of the Kasilof River runoff for the two years was as follows:

Water year	Oct..	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1958	11.3	13.5	6.0	6.8	5.8	5.7	12.5	59.6	61.4	20.4	13.5	5.7
1959	7.9	7.2	7.1	8.0	8.2	7.8	6.9	43.1	52.3	18.3	12.3	5.4
Mean	9.6	10.4	6.6	7.4	7.0	6.8	9.7	51.4	56.8	19.4	12.9	5.6

Continuous streamflow records have been collected on the Kasilof River since July 1949. Estimates of the monthly runoff of the Bradley River were computed from the recorded monthly runoff of the Kasilof River by using the foregoing relationship, and are shown with the two years of record in table 6. As shown in table 4 the mean annual runoff for the period 1950–59 was 242 thousand acre-feet, which is equivalent to a mean flow of 334 cfs. The runoff record for the Kasilof River near Kasilof is listed in rounded figures in table 7.

TABLE 6.—*Monthly and annual runoff, in thousands of acre-feet, Bradley River near Homer, Alaska*

[Estimated October 1949 to September 1957; provisional records rounded to nearest thousand, October 1957 to September 1959]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1950	24	13	4	3	2	2	4	21	40	45	52	23	233
1951	22	10	4	2	1	1	3	22	46	54	57	28	250
1952	26	12	5	4	2	2	3	18	28	35	53	17	205
1953	25	17	8	5	3	3	4	24	61	58	62	23	293
1954	22	11	4	2	1	1	3	22	47	42	51	20	226
1955	22	13	4	3	2	2	3	18	28	32	43	19	189
1956	17	7	2	1	1	1	3	24	34	29	50	22	191
1957	20	9	3	2	2	2	2	20	60	58	52	36	266
1958	41	30	7	5	2	2	4	24	66	69	79	21	350
1959	14	6	4	2	1	1	2	19	49	48	48	18	212
Mean	23	13	4	3	2	2	3	21	46	47	55	23	242

The total estimated and recorded runoff of the Bradley River for the 10-year period was 2,420 thousand acre-feet, or 840 inches. This is approximately 14.0 percent of that of the Kasilof River for the corresponding period, although the Bradley River drainage area is only 7.3 percent of that of the Kasilof River. Half of the Kasilof River basin lies below an altitude of a thousand feet in a rain shadow northwest of the Kenai Mountains. The bulk of the runoff must come from the upper half of the basin which extends up to altitudes above 6,000 feet, and about half of which is covered by glaciers. It

TABLE 7.—*Monthly and annual runoff, in thousands of acre-feet, Kasilof River near Kasilof, Alaska*

[From published records, 1950–57; provisional records, 1958–59, rounded to thousands]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1950	255	125	62	46	31	33	39	41	70	233	400	405	1,740
1951	230	98	55	33	20	18	27	43	81	281	445	484	1,815
1952	267	120	76	51	33	28	34	36	49	178	407	296	1,575
1953	260	160	116	67	49	49	40	47	108	301	480	384	2,061
1954	224	104	55	34	21	17	26	43	83	216	394	337	1,554
1955	225	122	50	37	30	30	30	34	50	165	331	331	1,435
1956	174	69	22	18	16	17	27	46	60	151	389	386	1,375
1957	204	86	45	28	22	20	25	38	106	298	407	624	1,909
1958	362	220	113	70	40	35	35	40	108	339	582	369	2,313
1959	182	85	52	25	17	18	29	44	93	265	389	339	1,538
Mean	238	119	65	41	28	27	31	41	81	243	422	396	1,732

is to be expected from the proportionately larger area of glaciers in the productive portion of the basin that snow carryover would have a substantially greater equalizing effect in the Kasilof basin than in the Bradley basin. The annual figures of runoff listed in tables 4 and 5 verify this expectation. The standard deviation of the Kasilof River runoff is 16 percent of the mean compared with 20 percent for the Bradley River; and the ranges are 54 percent and 64 percent respectively.

The Bradley Lake basin is similar to the Snow River basin in altitude, glacier cover, and location with respect to the Gulf of Alaska. The Snow River basin is in the Kenai Mountains, about 75 miles northeast of Bradley Lake, and drains into the upper end of Kenai Lake. Estimates of its monthly runoff have been made by deducting from the recorded runoff of the Kenai River the recorded runoff of tributaries intermediate to the Snow River plus estimates for ungaged areas. The runoff, 1950–59, thus estimated was 816 inches, or not significantly different from the 840 inches estimated for the Bradley River. The standard deviation of the annual figures of runoff, 1950–59, for both basins also is approximately the same, 20 percent of the mean.

SUPPLEMENTAL WATER SUPPLY

The foregoing discussion has considered only the runoff from the area tributary to Bradley Lake. The flow from Bradley Lake could be appreciably increased by the diversion of the runoff from three adjacent basins into the lake.

DIVERSION FROM UPPER NUKA RIVER

The Nuka River originates in a large glacier about 5 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 with a 10-foot contour interval on the published map of Bradley River and Bradley Lake. 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 be difficult 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, the increase in water supply by diversion of the upper Nuka River into Bradley Lake would be proportionately greater than the increase in the apparent drainage area would indicate, particularly since the glacier extends back to one of the highest and probably one of the wettest parts of the region.

DIVERSION FROM BRADLEY RIVER TRIBUTARY

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 the published map of Bradley River and Bradley Lake.

A diversion from the stream 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 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 magnitude 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.

DIVERSION FROM BATTLE CREEK

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 power estimates of this report.

The diversions from the upper Nuka River and the Bradley Lake tributary would increase the drainage area tributary to the lake from 54 to 68 square miles or an increase of 26 percent. Assuming that this additional area would have the same runoff characteristics as the area directly tributary to the lake, the mean annual discharge would be increased from 334 cfs to 421 cfs.

STREAM REGULATION

In the two years for which runoff records are available the runoff of the Bradley River was largely concentrated in the six-month period, May to October, about 90 percent of the total occurring then. This seasonal distribution is closely similar to that found in a number of basins in Alaska at similar altitude for which records are available.

Since a demand for industrial or municipal power would be fairly uniform, the power possibilities of the Bradley Lake site were estimated only on the basis of regulated flow. It was judged from characteristics of the reservoir site that it would be impracticable to provide enough storage capacity for substantially complete control of the runoff, and that the maximum to be considered probably would be for control of 90 percent of the runoff during the past 40 years. This would correspond approximately to complete control during the relatively dry period, 1950–59.

The amount of storage capacity required during this period was computed by first estimating the monthly runoff of the Bradley River from the recorded runoff of the Kasilof River, 1950–57, and the average relationships that existed between the two streams during the period of overlapping records, 1958 and 1959. Reservoir operation schedules then were computed for the 10 years of estimates and records. A storage capacity equal to about 93 percent of the estimated mean annual runoff of the past 40 years would have been required for 90 percent utilization on a schedule of uniform monthly releases. This is about twice as much storage as for a corresponding degree of control in southeastern Alaska. The difference evidently is due to the greater variability of annual precipitation and runoff on the Kenai Peninsula. During the period 1950–59 annual indices of wetness for the Seward-Homer area had a range of −43 to +49 percent and a standard deviation of 27 percent, whereas the annual precipitation recorded at Juneau in southeastern Alaska had a range of −23 to +21 percent and a standard deviation of only 15 percent during the same period.

RESERVOIR SITES

Bradley Lake provides a favorable opportunity for the development of the required storage for adequate stream regulation. It is 3½ miles from tidewater at the head of Kachemak Bay, at an altitude of 1,090 feet, and 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 for a mile and a half upstream from the lake has a comparatively flat gradient and is filled with glacial deposits, terminating in a delta about a mile wide. 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 about a mile above the lake. 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 transverse profile.

Bradley Lake is drained by the Bradley River, which flows northward three miles through a very rugged canyon down to an alittude 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 an altitude of about 1,200 feet, or 110 feet above the lake surface. However, there is a saddle northeast of the right abutment, at an altitude a little above 1,150 feet, and another saddle west of the left abutment, at an altitude a little above 1,170 feet. Dams would be required in these saddles for reservoir flow lines above their controlling altitudes. At a lake stage of 1,090 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.

Soward [2] 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.

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 or 125 feet below its natural surface. A study of the underwater contours shows that 965 feet is about the lowest altitude to which the lake can be drawn down. 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.

TABLE 8.—*Area and capacity of Bradley Lake reservoir site*

Altitude (feet)	Area (acres)	Capacity (acre-feet)		Altitude (feet)	Area (acres)	Capacity (acre-feet)	
		Below lake surface	Above lake surface			Below lake surface	Above lake surface
960	1, 050	169, 000		1, 100	1, 990		17, 800
980	1, 140	147, 000		1, 120	2, 460		62, 300
1, 000	1, 220	123, 000		1, 140	2, 950		116, 000
1, 020	1, 290	97, 900		1, 160	3, 340		179, 000
1, 040	1, 340	71, 600		1, 180	3, 660		249, 000
1, 060	1, 410	44, 100		1, 200	4, 010		326, 000
1, 080	1, 480	15, 200		1, 220	4, 300		409, 000
1, 090 [1]	1, 570		0	1, 240	4, 600		498, 000

[1] Lake surface

[2] Report in preparation, 1961.

The power possibilities of Bradley Lake were considered for two degrees of regulation that would provide for about 90 percent and 80 percent utilization, respectively, of the long-term mean discharge. They were estimated on the assumption that runoff from 64 square miles of drainage area or a mean discharge of 461 cfs could be available for regulation. For a controlled flow of 421 cfs, equal to the estimated mean for the period, 1950–59, or roughly 90 percent of the long-term mean, 300,000 acre-feet of capacity would be required. This could be provided by a dam at the lake outlet raising the lake level 104 feet to an altitude of 1,194 feet. A storage capacity of 171,000 acre-feet would have been required for 80 percent utilization and this could be provided by raising the lake surface 68 feet to an altitude of 1,194 feet.

The width across the river canyon at an altitude of 1,194 feet is 375 feet and at an altitude of 1,150 feet it is 275 feet. Storage to the higher level would necessitate construction of two saddle dams; one about 700 feet west of the left abutment, and the other 300 feet northeast of the right abutment. Soward[3] estimated that rock under the first saddle probably is at an altitude of 1,165 to 1,170 feet beneath 10 to 15 feet of fill; and that it may be at an altitude of 1,100 to 1,120 feet under 30 to 50 feet of fill at the saddle near the right abutment. The widths of the saddles at an altitude of 1,194 feet are 80 feet and 240 feet respectively. An auxiliary dam or core wall probably would be required at the right-bank saddle to seal this for storage to an altitude of 1,150 feet.

Development of storage by damming alone would have the considerable advantage of leaving the entire underwater capacity of the lake in dead storage to serve as a sediment catchment, and also the advantage that it would not result in a change in stream regimen upstream from the reservoir. It would also provide a greater head for power development.

The underwater topography is reasonably favorable for development of storage by a tunnel outlet for drawdown to an altitude of about 960 feet. This would necessitate tapping the lake at a point about 700 feet southeastward from the lake outlet. The nature of the lake bottom could not be judged closely from soundings at the time of the 1955 survey, and the water was too murky for visual examination. The possibility of development by drawdown alone, or by combined drawdown and damming may be seriously considered if further investigations show that conditions for dam construction are unfavorable.

The maximum discharge recorded at Bradley Lake during the two years of record was 3,470 cfs, August 13, 1958. This occurred at a time of general rainfall on the Kenai Peninsula and evidently was

[3] Report in preparation, 1961.

due both to rain runoff and snow melt. The discharge was equivalent to 64 cfs per square mile—not an unusually high rate. If a dam were constructed at Bradley Lake a spillway capacity at least five times that amount probably would be considered.

POWER DEVELOPMENT SCHEMES

The development of power from Bradley Lake can be accomplished by either of two general plans, both of which would utilize the lake as a reservoir to regulate the flow. In one plan the entire head from Bradley Lake to tidewater would be developed in one stage with the powerhouse at one of several possible locations near the shore of Kachemak Bay. In the other plan the head would be developed in two stages with one powerhouse at mile 8.2 on the river and the second powerhouse near mile 5.0 on the river. Water would be conveyed from the lake to the powerhouse at mile 8.2. The flow from this powerhouse would be diverted by a dam on the river at mile 6.7 and conveyed to a powerhouse near mile 5.0.

In the mile and a half reach downstream from the above mentioned powerhouse site, mile 8.2 to 6.7, the river drops only about 75 feet, or to an altitute of about 525 feet; and from mile 6.7 to 5.5 it drops 500 feet or to an altitude of 25 feet.

SINGLE-STAGE DEVELOPMENT

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 (called Route "A"). Alternative pipeline 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 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. (See fig. 5)

Conditions for tunnel construction along the general routes westward or southwestward from Bradley Lake were described by Soward.[4] Conditions along alternative routes to the northwest of Bradley Lake, leading to a powerhouse site on lower Bradley River also were discussed. Routes to the northwest could be followed by various combinations of tunnels and pipes. One possibility would involve about 2.2 miles 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

[4] Report in preparation, 1961.

route probably would cross one large fault, and that a tunnel along Route "A" of the Corps of Engineers report westward to the Battle Creek site probably would cross two large faults, and encounter massive graywacke, chert beds, and interbedded graywacke and chert beds. Routes to the northwest would be in similar rock formations. A tunnel southwestward from the lake, as in Route "B" of the Corps of Engineers report, would be in massive graywacke for its entire length.

The lengths of the waterways to the west or northwest were measured from the damsite 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.

TWO-STAGE DEVELOPMENT

Bradley River drops to an altitude of 600 feet at a point about 1.2 miles northwest of 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 a short penstock to the powerhouse on the left bank of the river. The tunnel route would cross a sharp ravine, considered by Soward [5] to be in a probable fault zone. The tunnel could be terminated at this point, about a 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. In either event the powerhouse would be located at mile 8.2 on the Bradley River. In view of the extremely rugged terrain it might be advisable to place the generating equipment in a cave excavated in the canyon wall rather than in the more conventional powerhouse in the open.

The topography at mile 6.7 and immediate vicinity 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. The altitude of the river surface at this site is about 525 feet. A possible by-pass area in a saddle 2,000 feet northeast of the damsite 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 on

[5] Report in preparation, 1961.

the Bradley River at mile 6.7, with a crest at an altitude of about 550 feet may be considered.

Water from the diversion dam could be conveyed to the northwest about 3,600 feet by tunnel, and thence to a powerhouse at the point where Bradley River emerges from its canyon; a distance of about 2,400 feet by penstock. This site is near mile 5.0 on the river, where the water surface is at an altitude of about 10 feet.

The conditions at the damsite, in the saddle area, and along the conduit route were discussed by Soward.[6]

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 damsite 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.

The two foregoing sites are described 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 costs for a 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 lengths for each of the two plants are less than half the length required for single-stage development, the overall length of tunnels and penstocks being about 2.5 miles. Storage requirements would be the same, but powerhouse and equipment costs per kilowatt of capacity would be increased because of the smaller installations and lower heads.

POTENTIAL POWER

The potential power, and related data, is shown in table 9 for the single-stage and two-stage plan of development. For the single stage plan two possibilities are shown, one with all of the storage developed above the normal lake level, and one with a combination of dam and drawdown. In the latter case half of the storage would be above and half below the normal lake level.

In the two-stage plan the data shown for stage one is for storage above the normal lake level. If a combination of dam and drawdown were used the head and resulting power would be decreased 8 percent and 5 percent, respectively for 90 percent and 80 percent degrees of regulation. The head and resulting power for stage two would be

[6] Report in preparation, 1961.

the same regardless of which plan is followed for the development of storage.

The power as shown in table 9 was computed from the formula $P=0.068QH$ in which P=power in kilowatts; Q, flow in cubic feet per second; and H, head in feet. This formula assumes an overall efficiency of 80 percent

TABLE 9.—*Estimated potential power and related data for Bradley Lake and Bradley River power sites.*

	Single-stage development—Storage				Two-stage development			
	Dam only		Combination of dam and drawdown [1]		Stage 1 [2]		Stage 2 [3]	
Height of dam (feet)	[4] 104	[4] 68	[4] 61	[4] 40	[4] 104	[4] 68	[5] 25	[5] 25
Storage capacity (acre-feet)	300,000	171,000	300,000	171,000	300,000	171,000	([6])	([6])
Altitude of reservoir (feet):								
Maximum	1,194	1,158	1,151	1,130	1,194	1,158	([6])	([6])
Minimum	1,090	1,090	976	1,029	1,090	1,090	-----	-----
Mean head (feet)	1,131	1,110	1,070	1,070	551	530	540	540
Controlled flow								
Percent of mean	90	80	90	80	90	80	90	80
Flow in cfs	421	375	421	375	421	375	421	375
Continuous power (kw)	32,400	28,300	30,600	27,300	15,800	13,500	15,500	13,800

1 Storage capacity half above and half below normal lake level
2 Power plant near mile 8.2 on Bradley River with diversion from lake
3 Power plant near mile 5.0 on Bradley River with diversion by dam at mile 6.7
4 Above normal lake surface
5 Above river surface
6 Stage 2 would follow stage 1 and would utilize the same storage and flow as stage 1.

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