HYDROLOGIC CONDITIONS AND LOW-FLOW INVESTIGATIONS OF THE LOWER BRADLEY RIVER NEAR HOMER, ALASKA OCTOBER 1991 TO FEBRUARY 1992

By Ronald L. Rickman

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CONVERSION FACTORS, ABBREVIATED WATER QUALITY UNIT, AND VERTICAL DATUM

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)

Abbreviated water-quality unit used in report:

μS/cm, microsiemen per centimeter

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929–a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Construction of the dam at Bradley Lake near Homer, Alaska, and the resulting flow regulation have lessened the variation in seasonal streamflow in the lower Bradley River. Streamflow records prior to dam construction indicated that the lower Bradley River was occasionally a losing reach at medium and medium-high discharges. Following completion of the dam, there were concerns that the lower Bradley River might be a losing reach during the winter and that a streamflow loss would dewater critical salmon spawning gravels, violating Federal Energy Regulatory Commission minimum flow requirements. A low-flow investigation was made on the lower Bradley River from October 1991 to February 1992 to determine if a gain or loss in streamflow occurred between the bypass outlet at the dam and the U.S. Geological Survey's (USGS) gaging station, Bradley River near tidewater. Streamflow measurements were made at four sites on the lower Bradley River in October and December 1991 and February 1992. Water temperature and specific conductance measurements were also made in river cross sections at these sites to gain insights into ground-water contributions. Low-flow study results indicated that no discharge losses or gains occurred until February, when the downstream part of lower Bradley River showed a significant increase in flow. This increase is probably caused by ground-water inflow. The river channel at the USGS gaging station, Bradley River below dam, remained ice free during most of the study period, whereas the river channel at the Bradley River near tidewater site was affected by ice during much of the winter period.

INTRODUCTION

The Alaska Energy Authority (AEA) completed construction and began operation of the Bradley Lake hydroelectric power plant near Homer, Alaska in 1991. The main dam was built on the outlet to Bradley Lake, and smaller dams were built on the Upper Nuka River, Battle Creek, and the Middle Fork of the Bradley River to divert water into Bradley Lake (fig. 1). A bypass system at the dam is used to maintain legally required flows for fish in lower Bradley River. As part of the AEA/U.S. Geological Survey (USGS) cooperative hydrologic study program, the USGS began to collect streamflow data in the Bradley River basin in 1979.

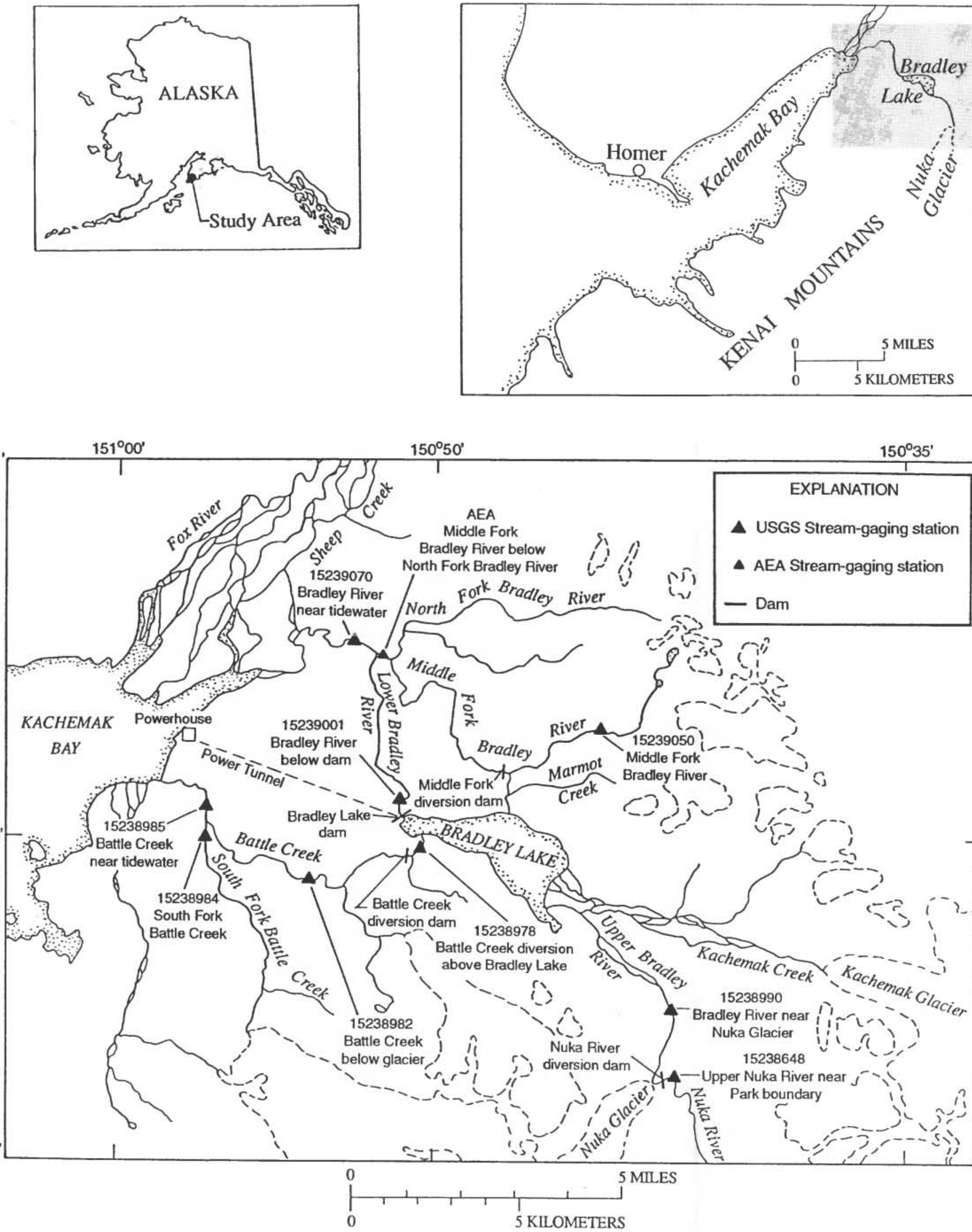

Figure 1. Location of the Bradley Lake Hydroelectric Project area.

Federal Energy Regulatory Commission (FERC) licensing requirements for the Bradley Electric Hydroelectric Project include maintenance of the following minimum flows in lower Bradley River:

Date	Flow regulation
May 12 to September 14	100 ft^3/s
September 15-23	Decrease flow 5 ft^3/s per day to 50 ft^3/s
September 24 to October 31	50 ft^3/s
November 1	Decrease flow 5 ft^3/s per day to 40 ft^3/s
November 2 to April 30	40 ft^3/s
May 1-11	Increase flow 5 ft^3/s to 100 ft^3/s

These discharges are measured at the USGS gaging station, Bradley River near tidewater, which is referenced as "Tree Bar Reach" in several publications (Alaska Power Authority, 1984, v. 2, chap. 3, p. 3.2-3.23). Severe channel icing at this site adversely affects the stage/discharge relation used to obtain real-time discharge information. The USGS gaging station, Bradley River below dam, is located directly downstream from the dam and remains ice free most of the winter. Therefore discharge data from this gaging station could be used to predict discharge at the downstream gaging station, Bradley River near tidewater. However, the discharge variations between these two gaging stations must be better understood.

Purpose

The purpose of this report is to determine streamflow gains or losses in the lower Bradley River and their variations through the winter, and to describe the characteristics and ice conditions of the channels. This report briefly describes the water diversion facilities, hydrologic conditions of the lower Bradley River, and low-flow study methods and results.

Location and Site Description

Bradley River originates in the Kenai Mountains east of Homer and flows into Bradley Lake (fig. 1). The two major inflow sources are Kachemak Creek, which begins at Kachemak Glacier, and an unnamed tributary (called "upper Bradley River" in this report), which begins at Nuka Glacier. Bradley River flows northward from Bradley Lake for about 5 mi to Kachemak Bay. The Middle and North Forks of Bradley River flow into the main stem of Bradley River 3.3 mi downstream from Bradley Lake outlet. The most downstream mile-long reach of Bradley River provides habitat for five species of Pacific salmon (Rundquist and others, 1985, p. 78).

The main dam located at the outlet to Bradley Lake impounds water from the upper basin and is used for power generation. Smaller dams on Battle Creek, upper Nuka River, and Middle Fork Bradley River divert water into Bradley Lake. A fish-water bypass (fig. 2), consisting of two pipes with motor-driven valves at the outlets, are installed parallel to the dam diversion tunnel to deliver water to the lower river to meet minimum release requirements.

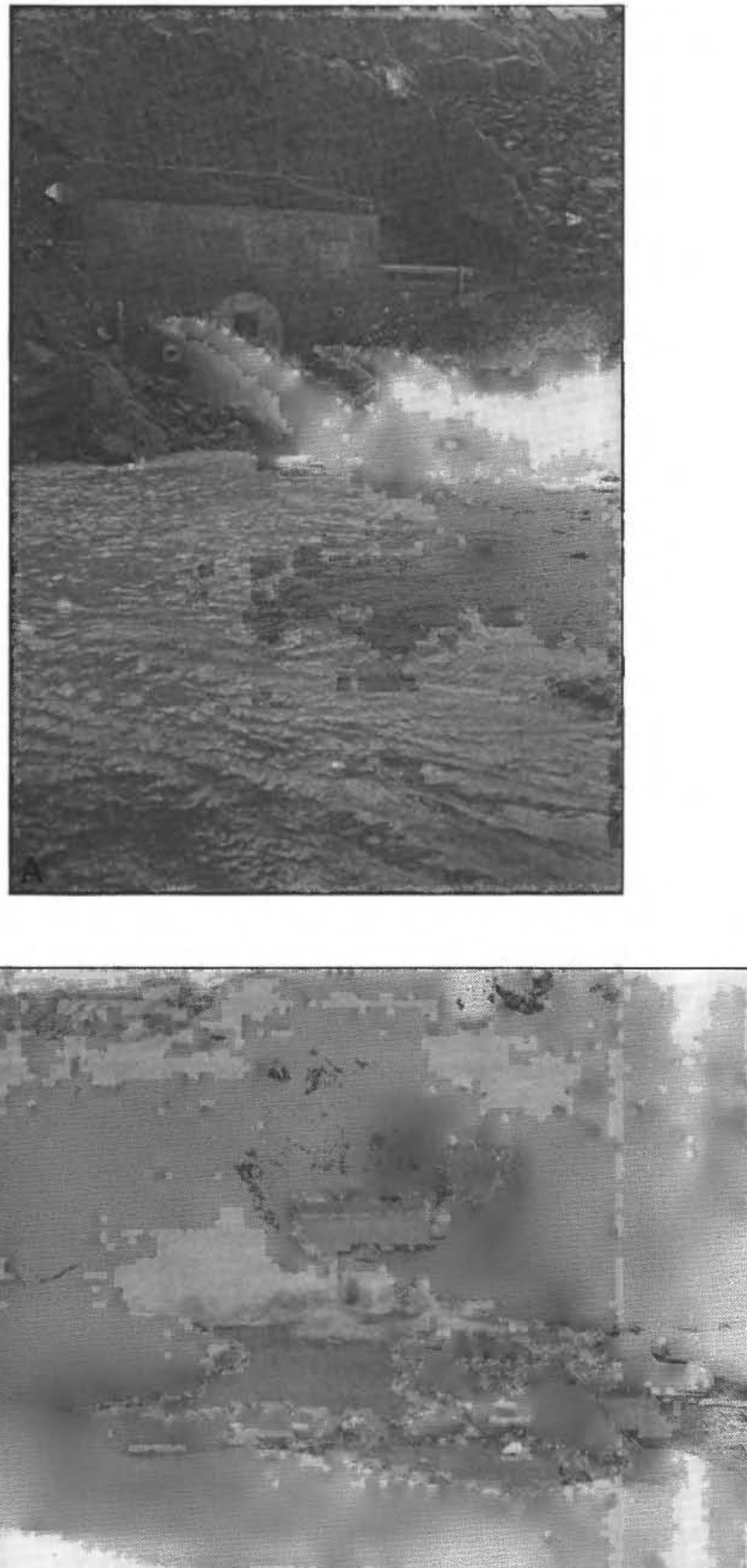

Figure 2. Fish-water bypass outlets at Bradley River below dam: A, summer (August 1992); B, winter (February 1992).

Previous Studies and Data Collection Activities

The USGS collected daily streamflow data at the Bradley Lake outlet in July and August 1955 and from October 1957 to the present (U.S. Geological Survey, 1958-92). In 1979 and 1980, the USGS began collecting daily streamflow data on the upper Nuka, Middle Fork Bradley, and upper Bradley Rivers to determine the inflow into Bradley Lake before and after construction of the diversion dams (U.S. Geological Survey, 1979-91). The USGS began daily streamflow data collection on lower Bradley River in 1983 to determine the natural discharges into Kachemak Bay; these data were used to assess fisheries habitat needs (U.S. Geological Survey, 1984-92). Data were also collected by USGS on Battle Creek in 1991 and 1992, to obtain information needed to assess possible stream-water diversions into Bradley Lake.

HYDROLOGIC CONDITIONS

Prior to dam construction and streamflow regulation, discharges to the lower Bradley River varied greatly on a seasonal basis. Daily mean discharges at the gaging station Bradley River near Homer (No. 15239000)[1] at the Bradley Lake outlet, commonly ranged from 700 to 1,500 ft^3/s during the summer, and peak flows resulting from rainstorms were as high as 8,800 ft^3/s (U.S. Geological Survey, 1958-88). Daily mean discharges at the gaging station Bradley River near tidewater (No. 15239070) commonly ranged from 800 to 2,000 ft^3/s during the summer, and storms produced peak discharges as high as 11,000 ft^3/s (U.S. Geological Survey, 1984-88). Water from North and Middle Forks of Bradley River accounted for most of the additional flow at the tidewater gaging station. Daily mean discharges during the winter ranged from about 10 to 100 ft^3/s at the lake outlet and from 17 to 110 ft^3/s at tidewater (U.S. Geological Survey, 1958-88).

After completion of the dam, water storage in the Bradley Lake reservoir and diversion of Middle Fork into Bradley Lake greatly reduced the streamflow to lower Bradley River during the summer. Water released through the fish-water bypass has increased the flow above natural quantities during the winter. Hydrographs showing the daily mean discharges of the lower Bradley River before and after flow regulation and dam completion are shown on figure 3.

Daily discharge records indicated occasional loss of flow in the lower Bradley River from 1985 to 1990. These losses were determined by comparing the combined daily mean discharges from the gaging stations, Bradley River near Homer and Middle Fork Bradley River (called "Bradley River tributary near Homer" before 1990), with those from the gaging station, Bradley River near tidewater; the losses were verified by discharge measurements. Additional inflow from the North Fork Bradley River was not accounted for in the comparisons. The apparent loss of surface water occurred most often at medium to medium-high discharges (400 to 1,700 ft^3/s), but not during low flow (less than 400 ft^3/s) or high flow (more than 1,700 ft^3/s). Losses from the system occurred most frequently during periods having only gradual or minor changes in streamflow. The reasons for this loss are not understood. Following completion of the dam, there was concern that lower Bradley River might be a losing reach during the winter. This streamflow loss would dewater critical salmon spawning gravels and also would violate FERC minimum flow requirements.

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[1] Gaging station Bradley River near Homer (15239000) was replaced by Bradley River below dam (15239001) in 1990. Discharges prior to 1990 are for unregulated, natural flows; discharge after 1990 is regulated: it is controlled by the fish-water bypass and dam spillway, and is decreased by the flow through the diversion tunnel to the powerhouse.

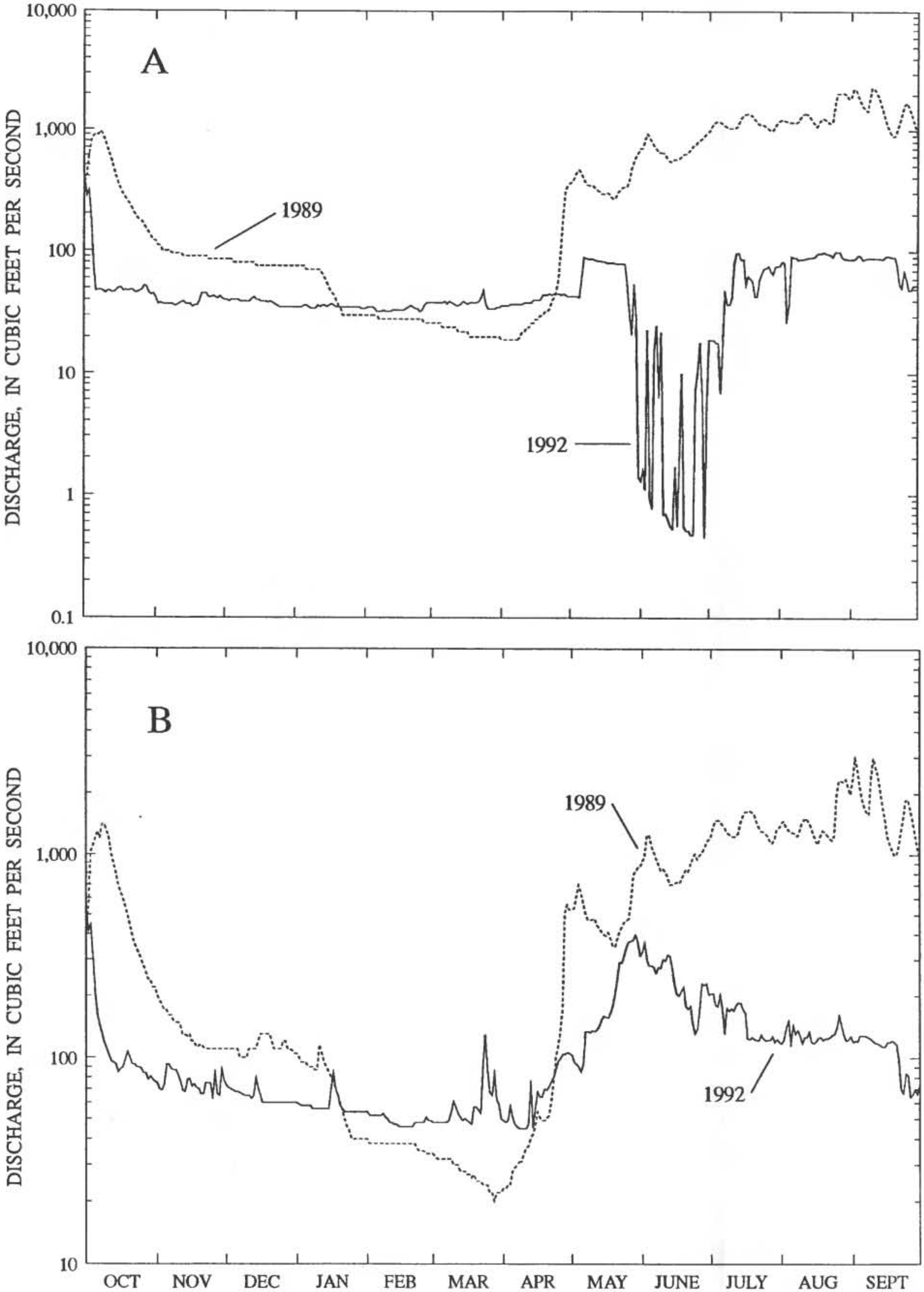

Figure 3. Daily mean discharge of: A, Bradley River near Homer, 1989 water year and Bradley River below dam, 1992 water year; B, Bradley River near tidewater, 1989 and 1992 water years.

Bradley River below the lake outlet remains mostly ice free during the winter. Thus, the stage/discharge relation used to calculate daily mean discharge is effective year around. (This condition was not changed by installation of the dam or regulation of discharge to the river.) The exception was during the 1990-91 winter, when severe cold and heavy snows led to extensive ice formation in the river at the gaging station below the dam. Historically, shore ice has formed on the downstream reach of lower Bradley River and adversely affects the stage/discharge relation at the Bradley River near tidewater gaging station. As a result, most of the daily mean discharge values are estimated during the winter, and real-time gage-height data are affected by ice.

LOW-FLOW INVESTIGATIONS

A low-flow investigation was made on lower Bradley River during the winter of 1991-92, to determine the extent of gains or losses of flow between the gaging stations Bradley River below dam and Bradley River near tidewater (table 1 and fig. 4). Discharge was measured at each site using standard procedures (Buchanan and Sommers, 1969). Discharge measurements were made as closely as possible to each other in time to minimize the effects of diurnal fluctuations and changes in the rate of water release from the reservoir. Also, measurements were made only during extended periods of fair weather to ensure that the river was in a steady-state condition. Gage height was recorded at the gaging stations. Stream-water temperature and specific conductance were measured using standard approved methods (Hem, 1985) to help gain insight into ground-water contributions to streamflow (Riggs, 1972, p.12; Stevens and others, 1975; Miller and others, 1988). Observations of channel and ice conditions were also recorded. Additional low-flow measurements had been planned at sites located 1.5 mi below the dam and 0.5 mi below the tidewater gaging station, but the measurements at these sites were canceled because of severe avalanche danger and unsafe ice conditions at the time of the study.

Bradley River below Dam
(USGS Gaging Station No. 15239001)

A USGS water-stage recorder at this site is located on the right bank, approximately 250 ft downstream from the confluence of the spillway and fish-water bypass (figs. 4 and 5). The channel bottom consists of bedrock, small boulders, and cobble. Both streambanks are armored with large boulder riprap. The channel remained free of ice and snow during most of the low-flow study. Low-flow discharge measurement error for this study was estimated to be between 5 and 8 percent. Stream-water temperature data were collected at 1-hour recording intervals. Recorded data were checked using calibrated field thermometers. Cross-sectional water temperature distribution was measured periodically to verify the accuracy of the recorded data (Stevens and others, 1975, p. 33).

Table 1. Bradley Lake Hydroelectric Project gaging station network and low-flow study sites

[L, Low-flow study data-collection site; --, no data; see figure 1 for site locations]

USGS station number	Station name	Location		Altitude of gage (feet)	Period of continuous record	
		Latitude	Longitude		Streamflow	Water temperature
15238648	Upper Nuka River near park boundary	59°41'04"	150°42'12"	1,300	1984-present	–
15238978	Battle Creek diversion above Bradley Lake	59°44'45"	150°50'22"	1,350	1992-present	–
15238982	Battle Creek below glacier	59°44'19"	150°53'49"	780	1991-present	–
15238984	South Fork Battle Creek	59°45'10"	150°57'14"	100	1991-present	–
15238985	Battle Creek near tidewater	59°45'20"	150°57'12"	90	1991-present	–
15238990	Upper Bradley River near Nuka Glacier	59°42'02"	150°42'19"	1,250	1979-present	1980-90
15239001	Bradley River below dam (L)	59°45'30"	150°51'02"	1,054	[3]1955; 1957-present	[3]1979-present
15239050	Middle Fork Bradley River	59°46'42"	150°45'15"	2,300	1979-present	–
(1)	Middle Fork Bradley River below North Fork Bradley River (L)	59°47'54"	150°51'48"	130	(1)	–
(2)	Bradley River above slough at canyon mouth (L)	59°48'00"	150°52'12"	75	(2)	–
15239070	Bradley River near tidewater (L)	59°48'06"	150°52'58"	25	1983-present	[4]1986-present

[1]Station operated by Alaska Energy Authority. Gage-height only; discharge is not computed
[2]Miscellaneous measurement site
[3]Includes data collected at and published for gaging station No. 15239000, Bradley River near Homer, through water year 1989
[4]Stream and intragravel water temperature

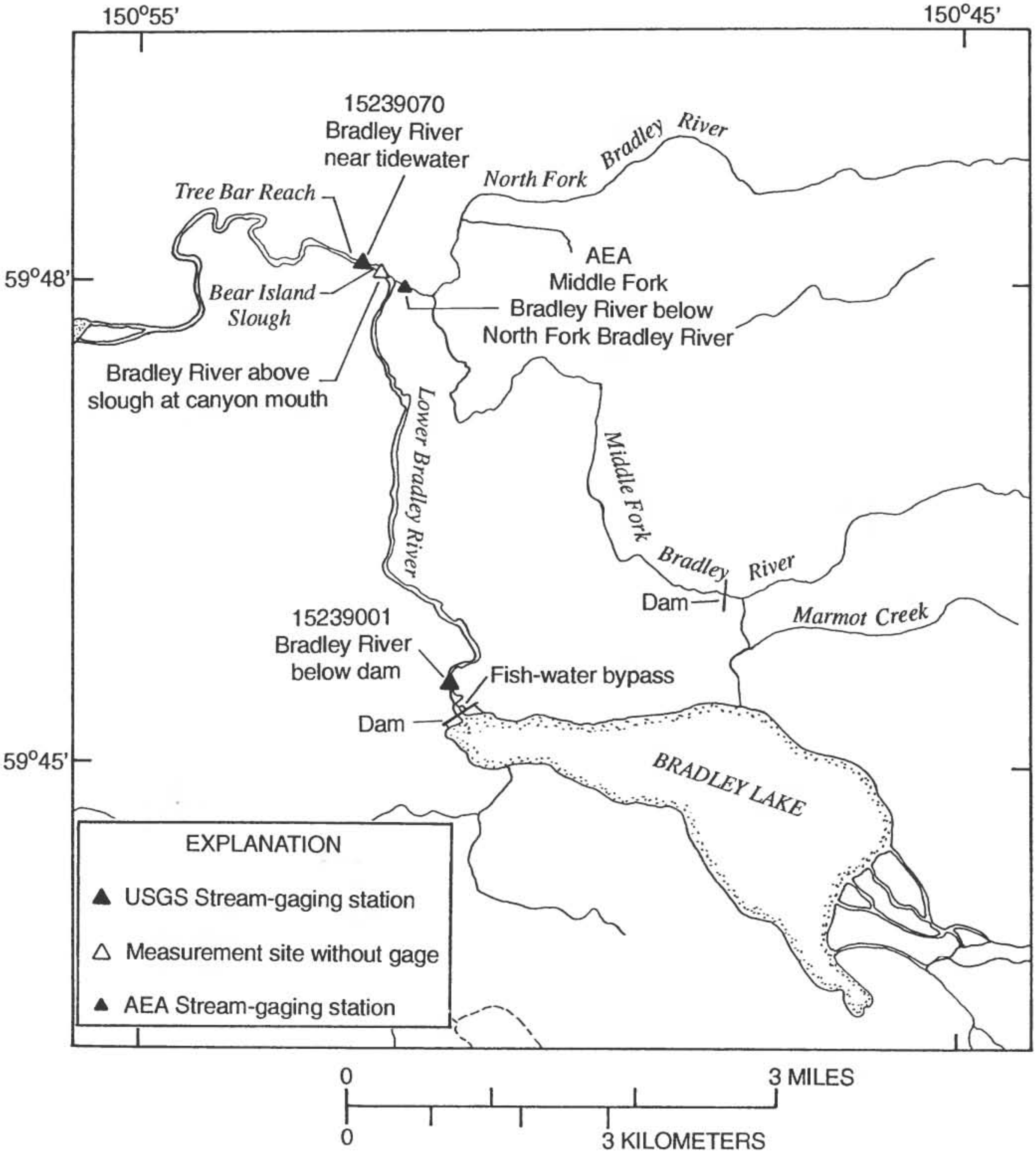

Figure 4. Lower Bradley River study area.

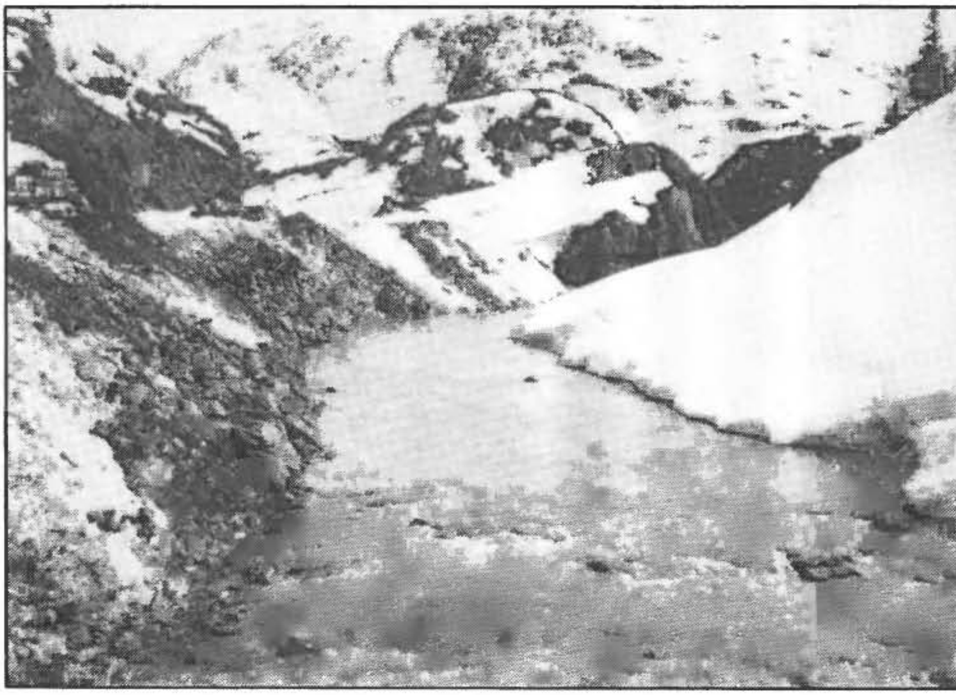

Figure 5. Bradley River below dam showing low-flow study reach, looking upstream toward Bradley Lake.

Middle Fork Bradley River below North Fork Bradley River

An AEA water-stage recorder at this site is located on the left bank, approximately 200 ft upstream from the confluence with the main stem of Bradley River (fig. 4). The river channel cuts through a deep narrow canyon and consists of small pools connected by steep riffles and small waterfalls (fig. 6). The channel bottom and banks are mostly bedrock with scattered boulders. Discharge measurements were made at the gage pool outlet. The pool outlet was ice free during the December field visit, and had about 5 ft of shore ice during the February visit. Discharge measurements were estimated to be accurate to within 5 percent.

Bradley River above Slough at Canyon Mouth

This site (fig. 4) is located at the break between the steep gradient of the bedrock channel and the moderate gradient of the alluvial channel downstream. This site also defines the uppermost end of the Bradley River fisheries (Woodward-Clyde, 1983, p. 32). The channel consists of cobble and gravel with some small boulders (fig. 7). There is no recording gage at this site. Discharge measurements were made at a shallow pool outlet and were estimated to be accurate to within 5 percent. The site was ice free during the October visit and had only moderate shore ice in December. A discharge measurement was not made during the February 8 visit because of severe icing and backwater conditions.

Figure 6. Middle Fork Bradley River below North Fork Bradley River, looking upstream at Alaska Energy Authority gaging station pool.

Bradley River near Tidewater
(USGS Stream Gaging Station No. 15239070)

A USGS water-stage recorder at this site is located on the right bank, 0.8 mi downstream from Middle Fork Bradley River, and 4.3 mi downstream from the dam on Bradley Lake (fig. 4). The channel bed consists of gravel and cobble: the left bank is a large cobble and gravel bar that was deposited during the flood of October 1986, and the right bank is made up of cobble overlain by vegetation and shallow soil. Discharge measurements were made at the gage pool outlet or at a riffle 150 ft below the gage, depending on ice conditions. Channel conditions ranged from ice free in October to moderate ice formation in mid-winter (fig. 8). Shore ice was significant enough to adversely affect the stage/discharge relation, but not the quality of the discharge measurements. Discharge measurement error was estimated to be within 5 percent.

Surface-water temperatures were also recorded at 1-hour intervals. Recorded data were verified using calibrated field thermometers (Stevens and others, 1975, p. 30). Cross-sectional water temperature distribution was measured periodically to verify the accuracy of the recorded data.

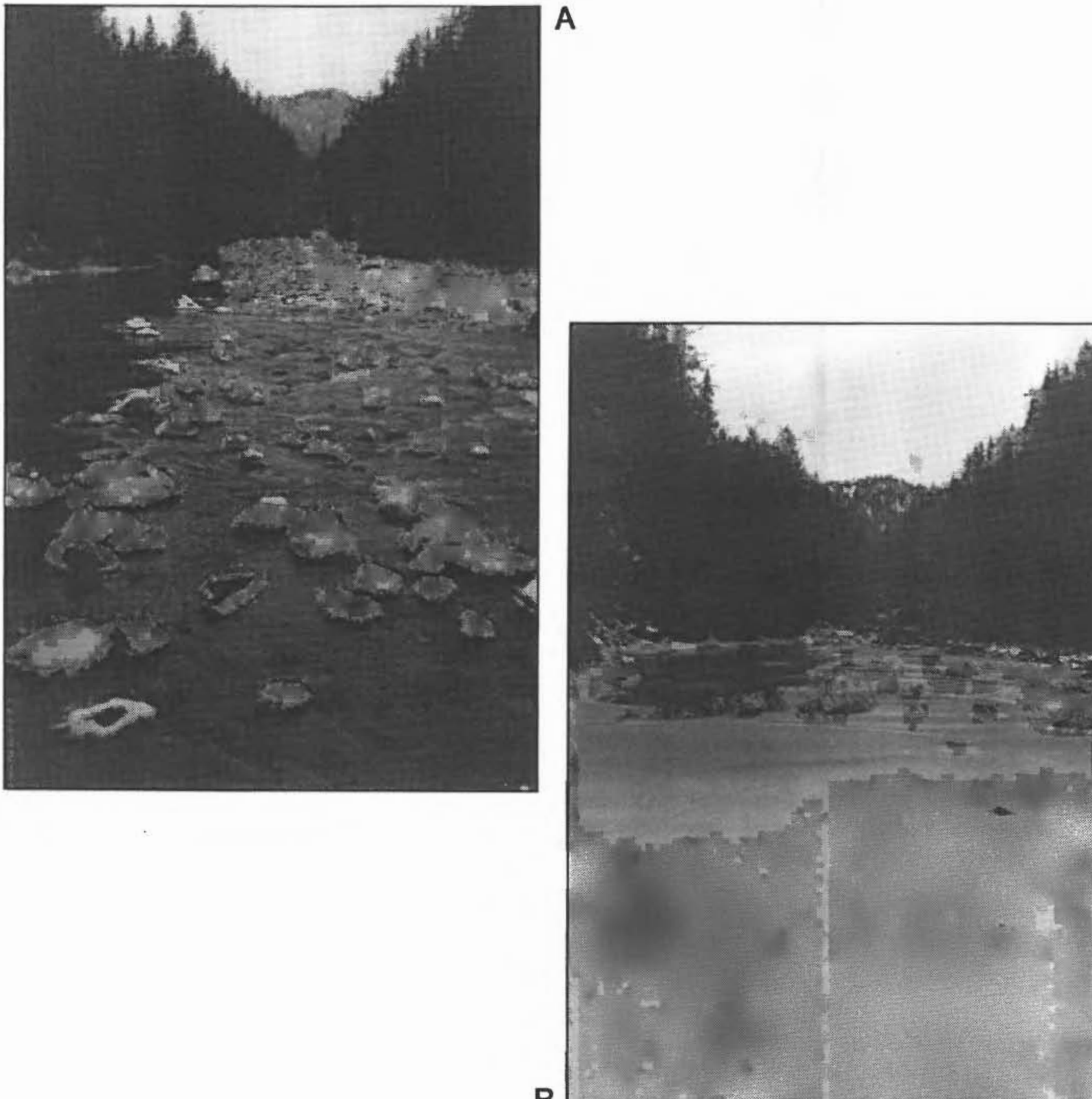

Figure 7. Bradley River above slough showing low-flow study reach, looking upstream from Bear Island: A, early winter; B, mid-winter.

A

B

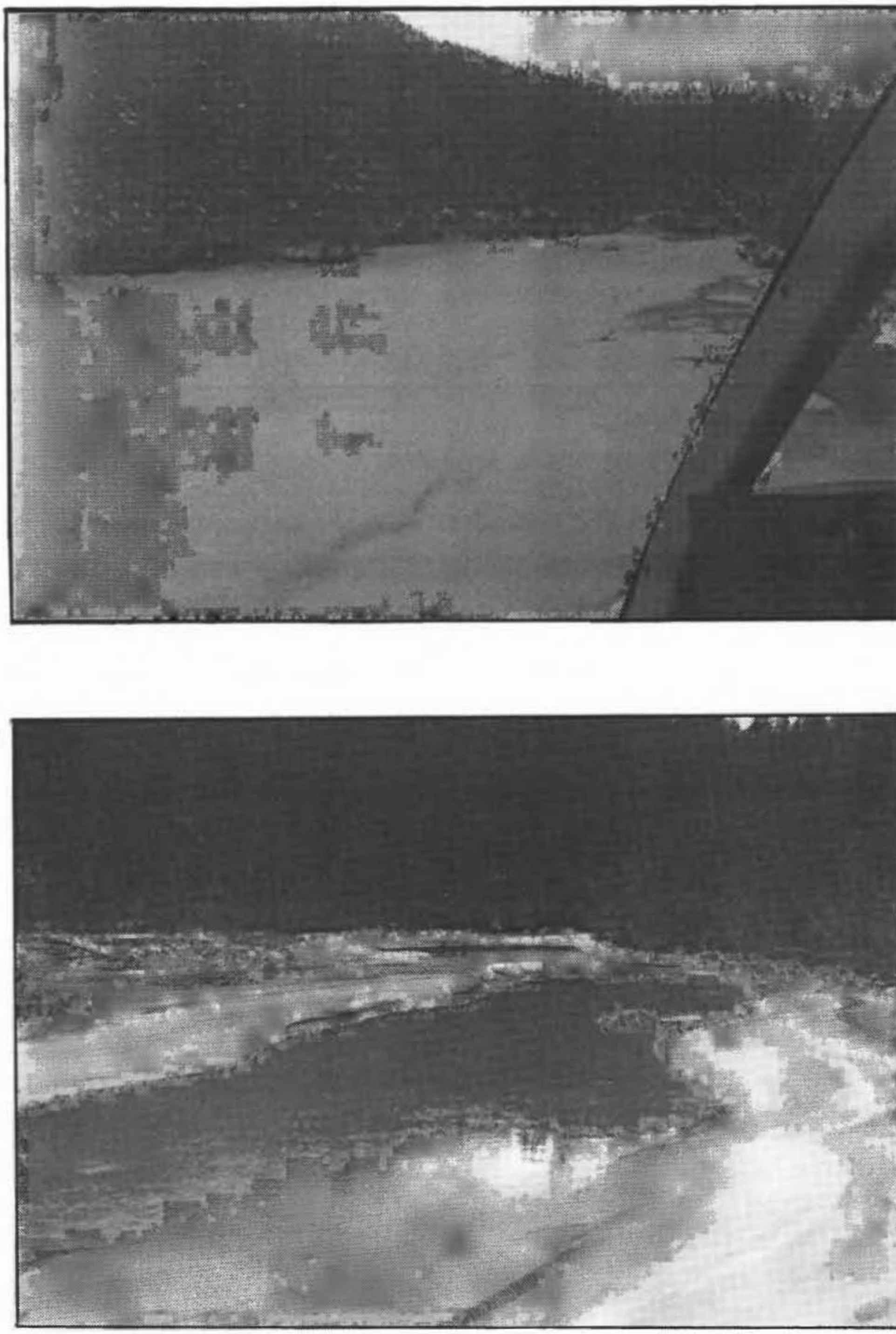

Figure 8. Moderate ice formation on Bradley River near tidewater, looking downstream from Bear Island: A, February 1992; B, January 1993.

Intragravel water temperature data were collected at 1-hour recording intervals at the lower end of Tree Bar Reach, 250 ft downstream from the USGS stage gage. This temperature sensor is housed in a steel gravel point, driven vertically to a depth of 1.0 ft into the streambed gravels. No method is available to field calibrate the sensor while it is in place, but the sensor was checked for calibration immediately prior to gravel point installation.

Results and Discussion

Discharge measurements made on October 28, 1991 above the slough at the canyon mouth and at the tidewater gaging station were nearly identical (table 2). This uniformity of measured discharge indicated no gain or loss in streamflow in the upper alluvial channel. However, conclusions cannot be drawn concerning gains or losses in streamflow between the dam and the combined flow of Middle Fork Bradley River and the main stem of Bradley River, because high winds prevented collection of data at Middle Fork Bradley River below the North Fork. A slight increase in specific conductance and a significant decrease in water temperature were noted between water released at the dam and water at the tidewater gaging station (table 2).

Discharge measurements made during the December 18, 1991 visit show no significant gains or losses in streamflow between the upper part of the study reach (using the combined discharges of Bradley River below dam and the Middle Fork below North Fork Bradley River) and the lower river reach. As with the October visit, specific conductance values were slightly elevated in the lower river and water temperature was significantly decreased (table 2).

Data from the final round of low-flow measurements collected on February 8, 1992 show a 27 percent increase in discharge at Bradley River near tidewater (52.4 ft^3/s) compared with the combined discharges of Bradley River below dam and the Middle Fork below North Fork Bradley River (41.2 ft^3/s) (table 2). The source of this additional water may be from ground-water discharging from the alluvial gravels downstream from the canyon mouth. This ground-water discharge was verified by field observations in April 1988, when supercooling caused the formation of anchor ice over most of the lower river, except for numerous small areas (2 to 4 ft in diameter) where clear water could be seen flowing from the river bed gravels. Ground-water discharge has also been documented at Bear Island Slough and Tree Bar Reach (Woodward-Clyde, 1983, p. 23). Severe icing at the canyon mouth site during the February 8 visit prevented field personnel from making a discharge measurement to confirm the source of the additional water in the lower river. Specific conductance values were higher in the lower river with the highest (94 µS/cm) found on the Middle Fork (table 2). Stream-water temperature was the same at all measurement sites.

Another round of low-flow measurements scheduled for March 1992 was canceled because of unsteady-state river conditions caused by snow melting in the lower part of the study reach.

Table 2. Low-flow discharge, water temperature, specific conductance, and channel conditions for the lower Bradley River

[ft^3/s, cubic foot per second; °C, degree Celsius; µS/cm, microsiemens per centimeter; --, no data; see figure 4 for site locations]

Channel conditions

C, clear channel; no ice

M, moderate ice formation; 5 to 10 ft shore ice on each bank; moderate backwater condition

S, severe channel icing; not possible to make accurate discharge measurement; severe backwater condition

USGS station number	Station name	October 28, 1991				December 18, 1991				February 8, 1992			
		Discharge (ft^3/s)	Water temperature (°C)	Specific. conductance (µS/cm)	Channel condition	Discharge (ft^3/s)	Water temperature (°C)	Specific conductance (µS/cm)	Channel condition	Discharge (ft^3/s)	Water temperature (°C)	Specific conductance (µS/cm)	Channel condition
15239001	Bradley River below dam	51.9	5.5	54	C	39.1	1.0	56	C	32.5	0.5	46	C
----	Middle Fork Bradley River below North Fork Bradley River	(1)	(1)	(1)	(1)	18.0	0.0	55	C	8.72	0.5	94	M
Total discharge[2]		--				57.1				41.2			
----	Bradley River above slough at canyon mouth	81.3	3.5	69	C	59.5	0.0	65	M	--	--	--	S
15239070	Bradley River near tidewater	80.1	3.5	68	C	59.5	0.0	69	M	52.4	0.5	67	M

[1]Unable to access with helicopter because of high winds

[2]Combined discharges from Middle Fork Bradley River below North Fork Bradley River and Bradley River below dam

SUMMARY

Streamflow variation in lower Bradley River has decreased since regulation began at the dam in 1991. Regulated stream-water discharges are lower in summer and higher in winter than were natural flows prior to dam construction. Streamflow data on lower Bradley River prior to the dam construction indicated that it was a losing reach at medium and medium-high discharges (400 to 1,700 ft^3/s), but not at low discharges (less than 400 ft^3/s) or at high discharges (more than 1,700 ft^3/s). Streamflow losses usually occurred during periods of relatively stable discharge. Since the dam's completion, discharges have not been within the range that previously showed losses in this reach.

The upper part of the study reach, at the Bradley River below dam gaging station, usually remains ice free through most of the winter, whereas the lower reach, in the vicinity of the Bradley River near tidewater gaging station, is affected by ice most of the winter. Accurate, real-time streamflow data can be obtained only where the river remains ice free. Discharges can be estimated at Bradley River near tidewater on the basis of discharge data from the Bradley River below dam gaging station, and estimated discharges for Middle Fork Bradley River below North Fork Bradley River.

Low-flow study results indicated no losses of water in the lower Bradley River during the winter of 1991-92. Stream-water discharges in the upper study reach were the same as those in the lower study reach through December. Data from February showed significant additional inflow (27 percent) into Bradley River at the lower part of the study reach. Ground-water inflow is the likely source of this additional stream water.

REFERENCES CITED

Alaska Power Authority, 1984, Bradley Lake hydroelectric project, Bradley River, Kenai Peninsula Alaska--Application for license for major unconstructed project before the Federal Energy Regulatory Commission: Anchorage, Alaska, Alaska Power Authority, 10 volumes.

Buchanan, T.J., and Sommers, W.P., 1969, Discharge measurements at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A8, 65 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Miller, R.L., Bradford, W.L., and Peters, N.E., 1988, Specific conductance--Theoretical considerations and applications to analytical quality control: U.S. Geological Survey Water-Supply Paper 2311, 16 p.

Riggs, H.C., 1972, Low-flow investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. B1, 18 p.

Rundquist, L.A., Baldrige, J.E., and Joyce, M.R., 1985, Lower Bradley River flow regime and its relation to fish, *in* "Resolving Alaska's water resources conflicts," Proceedings, Alaska Section, American Water Resources Association: Fairbanks, University of Alaska, Institute of Water Resources Report IWR-108, p. 77-88.

Stevens, H.H., Jr., Ficke, J.F., and Smoot, G.F., 1975, Water temperature--Influential factors, field measurements, and data presentation: U.S. Geological Survey Techniques of Water-Resources Investigations, book 1, chap. D1, 65 p.

U.S. Geological Survey, 1958-62, Quantity and quality of surface waters of Alaska, 1953-60, Annual reports as follows: U.S. Geological Survey Water-Supply Papers 1486, 1500, 1570, 1640, and 1720.

______1971 and 1976, Surface water supply of the United States, 1961-70, Parts 15, Alaska: U.S. Geological Survey Water-Supply Papers 1936 and 2136.

_____1972-92, Water resources data for Alaska, water years 1971-91: U.S. Geological Survey Water-Data Reports AK- 71-1 to AK-91-1 (published annually).

Woodward-Clyde Consultants, 1983, Bradley River instream flow studies: 75 p. [available from Stone and Webster Engineering Corporation, Anchorage, Alaska].