Hydrologic and Water-Quality Data For the Lower Bradley River, Alaska March 1993 to April 1994

U.S. GEOLOGICAL SURVEY

Open-File Report 95-338

Prepared in cooperation with the

ALASKA ENERGY AUTHORITY

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By Ronald. L. Rickman

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1995

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square foot (ft^2)	0.0929	square meter
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.028317	cubic meter per second

Water temperature:

Water temperature is expressed in degrees Celsius. The following equation can be used to convert to degrees Fahrenheit:

$$^{\circ}F = 1.8\,(^{\circ}C) + 32$$

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.

Abbreviated water-quality units used in report:

mm, millimeter
mL, milliliter
mg/L, milligram per liter
µS/cm, microsiemen per centimeter at 25 degrees Celsius

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Abstract

A dam constructed at the outlet of Bradley Lake near Homer, Alaska has blocked natural flows to the lower Bradley River. To protect salmon egg incubation habitat during the period November 2 to April 30, a fish-water bypass was incorporated into the design of the dam to ensure a minimum discharge of 40 cubic feet per second in the lower river. This minimum flow determination was based on an open-water instream flow study that did not take into account effects of ice formation. A study was begun in March 1993 to determine winter flow conditions in the lower Bradley River. As a part of this study, data were collected at sites in the lower Bradley River to measure discharge, wetted perimeter, cross-sectional area, water depth, flow velocity, and specific conductance, as well as temperature and dissolved oxygen from both surface water and intragravel water. Discharge and specific conductance in the Middle Fork Bradley River below North Fork Bradley River were also measured. This report presents data collected between March 1993 and April 1994.

INTRODUCTION

The Alaska Energy Authority (AEA) began operation of the Bradley Lake Hydroelectric Project near Homer, Alaska in 1991 (fig. 1).The dam, which was constructed at the Bradley Lake outlet, incorporated a fish-water bypass system to maintain flows required for fish habitat enhancement in the lower Bradley River. Federal Energy Regulatory Commission (FERC) licensing requirements for the Bradley Lake Hydroelectric Project require maintenance of a minimum flow of 40 ft^3/s from November 2 to April 30, measured at the U.S. Geological Survey (USGS) streamgaging station Bradley River near Tidewater (station no. 15239070). This discharge of 40 ft^3/s is based on an open-water instream flow study (Woodward-Clyde Consultants, 1983). The study did not account for the effects of river ice formation, which is common in the lower Bradley River during the winter months. Many studies have developed suitability criteria for salmon spawning habitats, but few have addressed salmon egg incubation habitats in ice-covered streams (Morsell, 1994).

It is not practical to obtain a record of continuous river discharge directly. Instead, instruments are installed to continuously measure river stage. Numerous discharge measurements are made at various stages to define the correlation between stage and discharge. Once the stage-discharge relation has been defined, periodic discharge measurements are made to ensure that the relation remains valid. The stability of the stage-discharge relation is dependent on the stability of the river channel. If channel geometry changes because of either scour or fill, so does the stage-discharge relation. In a regulated channel, such as the lower Bradley River, changes caused by scour or fill are usually gradual, and adjustments can be applied to the stage-discharge rating as needed. Channel geometry is also changed during periods of ice formation in the river. These changes are usually rapid and highly variable, rendering the stage-discharge relation useless.

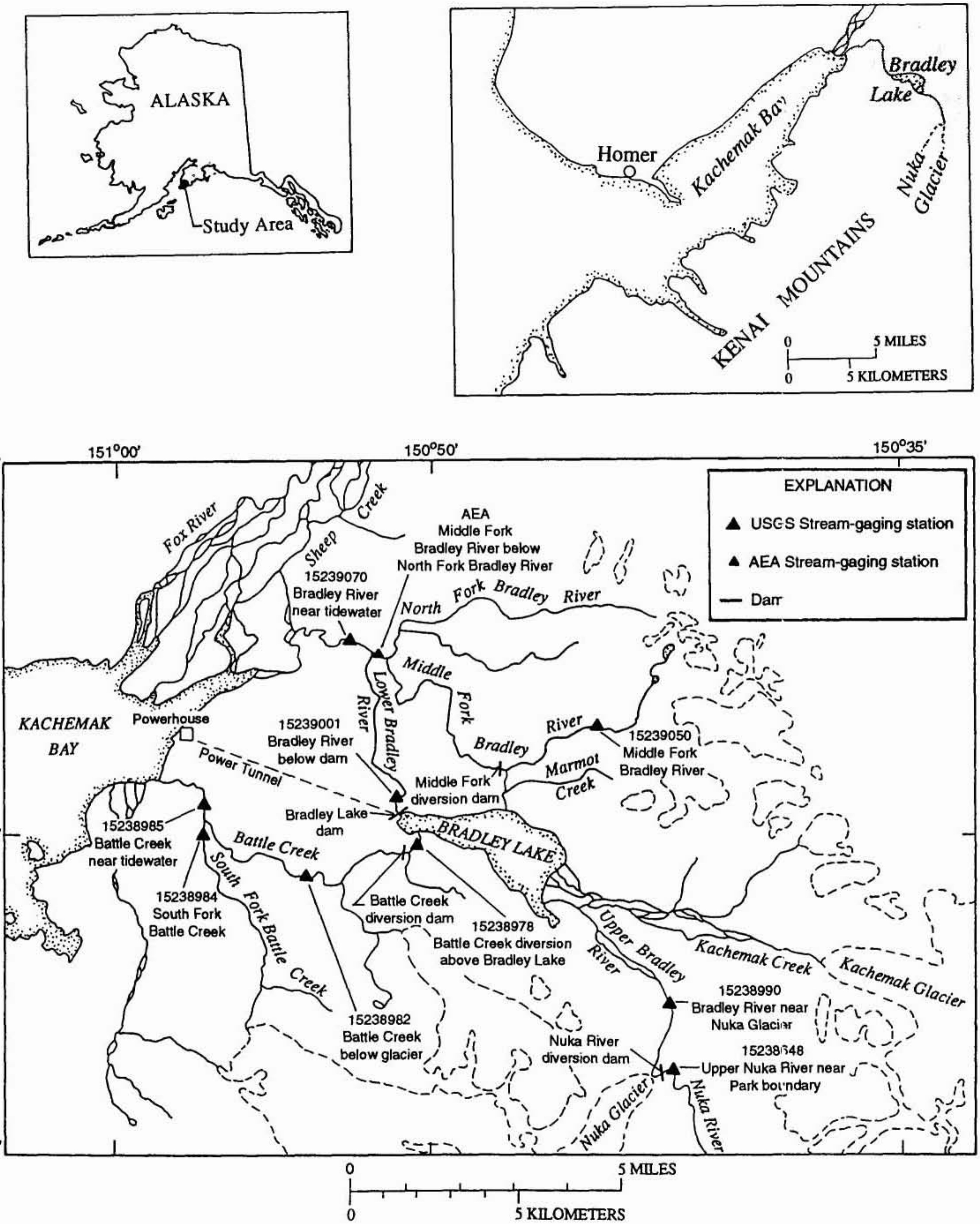

Figure 1. Location of the Bradley Lake Hydroelectric Project area.

Operators of the Bradley Lake Hydroelectric Project have released flows of 40 ft^3/s at the fish-water bypass (measured at the USGS gaging station Bradley River below Dam, which generally remains ice free) to ensure maintenance of a flow of 40 ft^3/s in the lower Bradley River. However, actual flows in the lower Bradley River have been above the required minimum because the Middle and North Fork Bradley Rivers contribute inflow that has not been adequately quantified. This additional flow could be used for power generation if the flow contributions of Middle and North Fork Bradley River were better understood.

In March 1993, under a cooperative agreement with the Alaska Energy Authority, the USGS began a study of winter flow conditions in the lower Bradley River. The objectives of this study are to: (1) determine the discharges that must be released at the fish-water bypass to maintain a flow of 40 ft^3/s in the lower Bradley River, (2) determine whether a flow of less than 40 ft^3/s might also provide adequate protection, and (3) gain insight into the minimum limits of flow that would provide some assurance of egg protection in the event of unexpected decreases in flow. This report summarizes data collected between March 1993 to April 1994 at selected sites in the lower Bradley River. A previous report (Rickman, 1993) summarizes flow losses and gains between the fish-water bypass and the USGS gaging station, Bradley River near Tidewater.

DISCHARGE

The USGS has operated daily streamflow stations on the Bradley River below the dam since 1989 and near tidewater since 1983. Daily mean discharge data at both stations from March 1 to April 30, 1993, and November 1 to April 30, 1994 are shown in figure 2. Discharge data are presented through April 1994 to show complete period of icing, even though field sampling ended in late February. Streamflow that was estimated because of ice effect is shown using dashed lines. Very few days were ice affected at the Bradley River below Dam gaging station, whereas several days were ice affected at the Bradley River near Tidewater gaging station. Three distinct icing periods occurred between November 1, 1993 and April 30, 1994. Daily mean discharge for the study period ranged from 0.35 to 69 ft^3/s at the Bradley River below Dam stream-gaging station, and from 46 to 356 ft^3/s at the Bradley River near Tidewater stream-gaging station. Streamflow greater than 80 ft^3/s at the tidewater stream-gaging station was caused by snowmelt and (or) rainfall in the lower Bradley River basin.

Discharge measurements were made at the Middle Fork Bradley River below North Fork Bradley River on March 10 and December 2, 1993 and March 31, 1994. Measured discharges were 10.2, 25.2, and 7.86 ft^3/s, respectively. Discharge measurements were also made at six locations in the lower Bradley River from Bear Island to Lower Riffle Reach (fig. 3) where most spawning activity occurs (Morsell, 1993, p. 12). Measured discharge ranged from 54 ft^3/s on March 12, 1993 to 73 ft^3/s on December 2, 1993 (table 1). Both extremes occurred at the Bradley River at Bear Island gaging station and are considered accurate to 5 percent. These measured discharges ranged between 35 and 82 percent higher than the target flow of 40 ft^3/s.

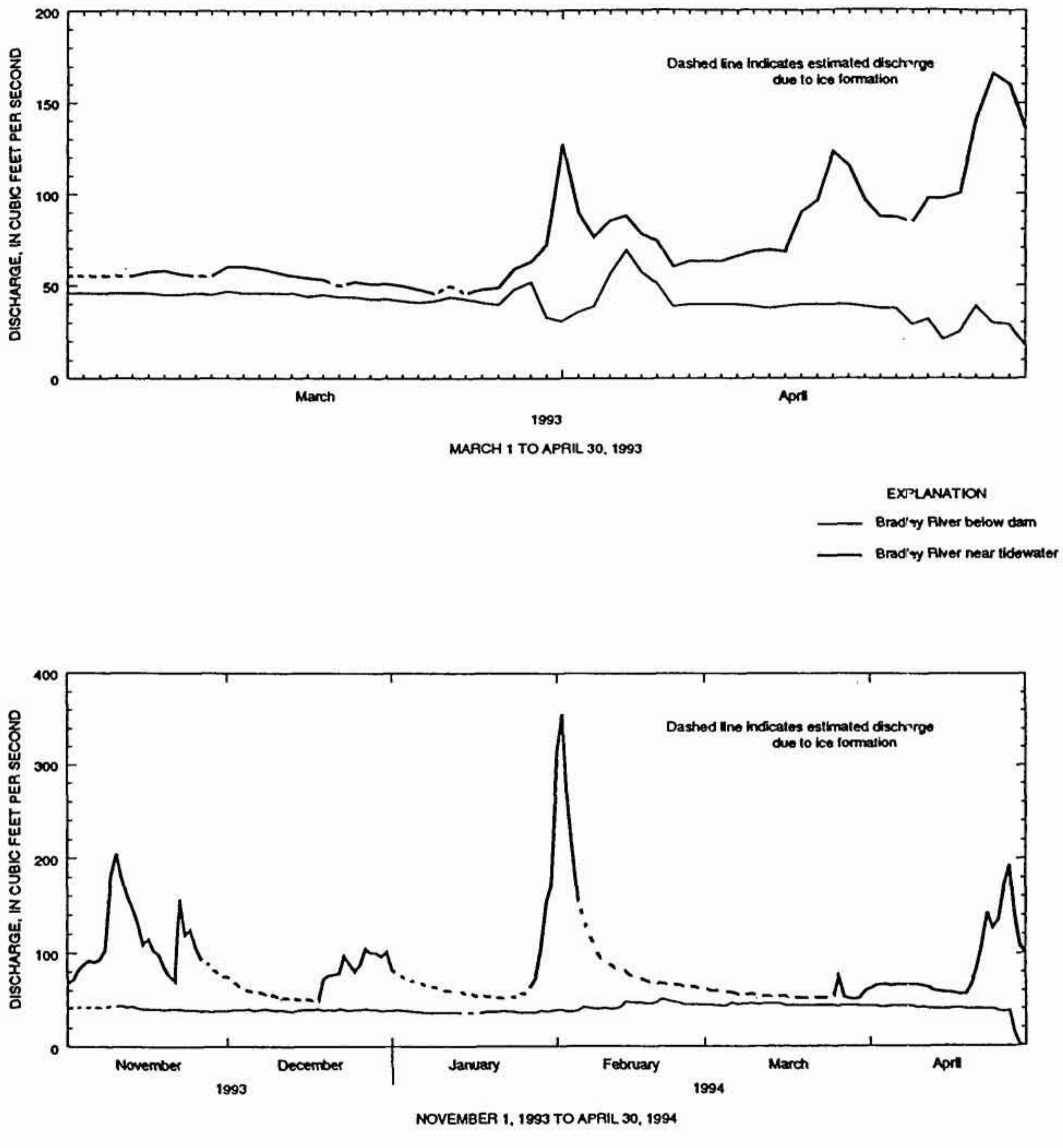

Figure 2. Daily mean discharges of Bradley River below dam and Bradley River near tidewater.

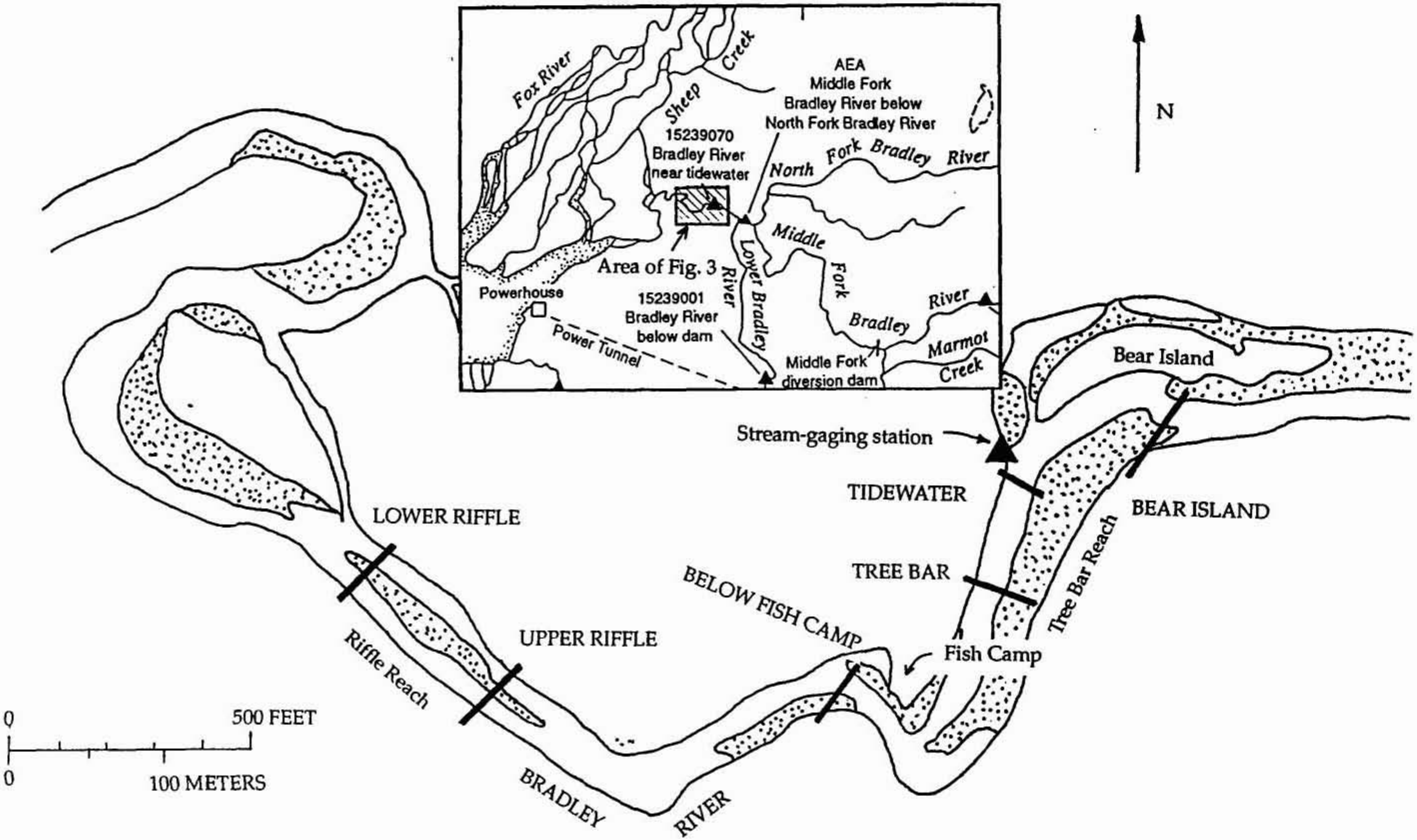

Figure 3. Lower Bradley River study cross section locations (modified from Morsell, 1994, fig. 1)

Table 1. Selected hydraulic properties for the lower Bradley River

[ft, foot; ft², square foot; ft/s; foot per second; ft³/s, cubic foot per second; <, less than; >, more than]

Cross-section site (fig. 3)	Date	Ice cover (percent)	Streamflow			Cross section			
			Discharge (ft^3/s)	Discharge accuracy (percent)	Mean velocity (ft/s)	Top width (ft)	Area (ft^2)	Wetted perimeter (ft)	Hydraulic radius (ft)
Bear Island	3-12-93	<20	54	8	0.81	101.6	67.1	101.9	0.66
	12-02-93	<10	73	5	1.01	92.0	72.2	92.4	.78
	2-24-94	100	65	>8	.64	109.0	102	109.4	.93
Near Tide-water	3-11-93	<10	56	5	1.46	35.0	38.6	35.6	1.09
	12-03-93	<10	65	8	1.48	43.3	44.1	43.8	1.01
	2-24-94	100	66	>8	1.30	43.0	50.4	43.7	1.15
Tree Bar Reach	3-11-93	<20	56	5	1.13	64.4	49.5	64.6	.77
	12-02-93	<25	71	5	1.43	69.0	49.6	69.2	.72
	2-23-94	100	70	>8	.65	101.0	108	101.4	1.07
Below Fish Camp	3-11-93	<10	57	5	.95	49.4	59.6	49.7	1.20
	12-02-93	<20	72	5	.93	57.6	77.5	58.4	1.33
	2-23-94	100	65	>8	1.00	50.9	64.8	51.2	1.27
Upper Riffle Reach	3-11-93	<10	60	5	.76	81.4	78.6	82.2	.95
	12-03-93	<15	60	8	.68	83.7	88.6	84.9	1.04
	2-24-94	100	65	>8	.90	78.0	72.3	79.1	.91
Lower Riffle Reach	3-11-93	<10	59	5	1.21	71.0	48.9	71.4	.68
	12-03-93	0	55	>8	1.02	82.9	53.8	83.3	.65
	2-24-94	100	62	>8	1.12	75.0	55.6	75.4	.74

SURVEY AND CROSS-SECTIONAL DATA

Cross-sectional profiles of the lower Bradley River were surveyed in March, June, and December 1993 and in February 1994 at six locations (fig. 3). At each location, steel markers were established to define cross-section end points. Standard survey techniques were used to tie all the cross sections to the same datum. An arbitrary datum was used and was not tied to the National Geodetic Vertical Datum (NGVD) of 1929. The June 1993 survey was made to establish baseline channel geometry at each cross section for comparison against ice-affected cross sections. Discharge during the June 1993 survey was 130 ft^3/s, which is two to three times larger than observed winter discharges, and is not useful for comparison purposes.

Differences between the baseline cross sections measured in June 1993 and the cross sections measured three times during the winter (figs. 4-9)[1] are attributed to channel fill or scour, anchor ice formation, and survey limitations relating to streambed roughness. The most significant change in cross sections occurred at Bradley River below Fish Camp (fig. 7), where the channel scoured, and at Bradley River near Tidewater on February 24 (fig. 5), when anchor ice covered much of the streambed.

HYDRAULIC DATA

Water-depth and flow-velocity data were also collected at each of the six cross sections three times between March 1993 and February 1994. These properties were measured at several points across each section using the procedures described by Buchanan and Sommers (1969). Wetted perimeter, cross-sectional area, and hydraulic radius were computed for each section (table 1).

Complete ice cover resulted in a significant increase in cross-sectional area and decrease in water velocity at the Bear Island, Tidewater, and Tree Bar reach cross sections. These changes are evident even though the data were obtained at varying stream discharges. The most significant increase in area, wetted perimeter, and hydraulic radius, and decrease in velocity, occurred at Tree Bar Reach on February 23, 1994 during a period of complete ice cover. Comparing these data to those of the same site at a similar discharge during nearly ice-free conditions shows a 117 percent increase in area, 46 percent increase in wetted perimeter, 49 percent increase in hydraulic radius, and 55 percent decrease in velocity. These changes were caused by an ice jam downstream from the cross section. The effect of complete ice cover on hydraulic properties at the lower three cross sections (Bradley River below Fish Camp, Upper Riffle Reach, and Lower Riffle Reach) were not readily apparent, given the small size of the data set.

Water velocity distribution within each section varied significantly with ice formation at the upper three cross sections (figs. 4-6). The most striking examples are at Bradley River at Bear Island (fig. 4) and Bradley River at Tree Bar Reach (fig. 6). Complete ice cover has forced most of the flow into narrow parts of the channels. Water velocity distribution did not vary significantly with ice formation at the Fish Camp (fig. 7), Upper Riffle (fig. 8), and Lower Riffle (fig. 9) cross sections.

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[1]Note: Figures 4-10 are at the end of the report, starting on p. 11.

FIELD WATER-QUALITY DATA

Temperature

The USGS has operated daily surface-water and intragravel-water temperature stations on the lower Bradley River since 1986. The surface-water temperature station is located at the Bradley River near Tidewater gaging station, and the intragravel water-temperature station is located downstream from the gaging station near the Tree Bar Reach cross section (published as Bradley River near Tidewater, U.S. Geological Survey, 1987-95). The intragravel water-temperature probe is buried in the gravels to a depth of approximately 1 ft, and is in an area of known ground-water discharge. Both surface-water and intragravel-water temperatures are recorded at 1-hour intervals. Recorded data were verified using calibrated field thermometers (Stevens and others, 1975, p. 30) and are rounded to the nearest 0.5 °C.

Surface-water temperature fluctuates more than intragravel water temperature (fig. 10), is generally colder than intragravel water during cold weather periods, and is warmer than intragravel water during warm weather periods. Extended periods of 0 °C surface-water temperature are common. Intragravel-water temperature occasionally drops to 0 °C, but for a shorter time. Surface-water temperature measurements were made at each cross section concurrently with discharge measurements. Temperatures were relatively constant between cross sections for each sample period (table 2). Temperature measurements were made at several points across each cross section in March 1993. Water temperature did not vary within the cross sections.

Dissolved Oxygen

Dissolved-oxygen samples of surface water and intragravel water were collected at each cross section concurrently with discharge measurements. Surface-water dip samples were collected by gently filling 300 mL glass biological oxygen demand (BOD) bottles which were then immediately fixed and analyzed using the Azide modification of the Winkler method (American Public Health Association and others, 1989, p. 4-152). Water temperature and barometric pressure were also measured to calculate the percent oxygen saturation (table 2).

Dissolved-oxygen samples of intragravel-water were collected at each cross section by inserting a stainless-steel tube with an inside diameter of 3/16 in. into the streambed to a depth of 1 ft. The lower 0.4 ft of the sample tube was perforated with 1/16-inch-diameter holes. Water was pumped at a rate of 10 to 15 mL per minute into a 60-mL BOD bottle. The slow pump rate was necessary to prevent surface-water intrusion (Hoffman, 1986, p. 446). A total of three sample volumes were pumped through the bottles, and the samples were fixed and analyzed using the azide modification of the Winkler method. Intragravel water temperature was not measured during sample collection, so percent saturation is not calculated except at Tree Bar Reach (table 2), where the intragravel-water temperature station is located. Intragravel dissolved-oxygen data collected in March 1993 were discarded because of errors associated with the sample-collection method.

Dissolved-oxygen concentrations of surface water ranged from 98 to 104 percent of saturation (table 2). Intragravel-water dissolved-oxygen concentrations were 0.8 to 2.9 mg/L lower than those of the surface water.

Table 2. Selected water-quality data and site characteristics for the lower Bradley River

[mm Hg, millimeter of mercury; °C, degree Celsius; mg/L, milligram per liter; µs/cm, microsiemens per centimeter; ft, foot; ft/s, foot per second; N/A, not applicable; --, no data]

Cross-section site (fig. 3)	Date	Barometric pressure (mm Hg)	Surface water				Intragravel water		Intragravel sample location	
			Temperature (°C)	Dissolved oxygen (mg/L)	Dissolved oxygen percent saturation	Specific conductance (µs/cm)	Temperature (°C)	Dissolved oxygen (mg/L)	Depth of water above streambed (ft)	Surface-water velocity (ft/s)
Bear Island	3-12-93	750	1.0	14.3	102	68	--	--	--	--
	12-02-93	745	1.5	14.0	102	66	--	12.5	0.88	0.56
	2-24-94	771	.5	14.6	100	63	--	12.2	1.4	.75
Near Tide-water	3-11-93	750	1.0	14.4	103	71	--	--	--	--
	12-03-93	752	.5	14.5	102	67	--	13.1	1.2	2.05
	2-24-94	771	.0	14.5	98	60	--	13.0	.0	N/A
Tree Bar Reach	3-11-93	750	.5	14.7	104	62	1.0	--	--	--
	12-02-93	745	1.5	13.9	101	65	2.0	--	--	--
	2-23-94	775	.0	14.8	100	65	.5	14.0	2.2	.53
Below Fish Camp	3-11-93	750	1.0	14.3	102	69	--	--	--	--
	12-02-93	746	1.5	14.1	103	65	--	13.3	1.28	0.97
	2-23-94	775	.0	14.8	100	63	--	13.6	.8	.61
Upper Riffle Reach	3-11-93	750	1.0	14.4	103	72	--	--	--	--
	12-03-93	752	.0	14.2	98	67	--	11.3	1.22	.90
	2-24-94	773	.0	14.6	99	65	--	13.6	0.75	.77
Lower Riffle Reach	3-11-93	750	1.0	14.6	104	73	--	--	--	--
	12-03-93	752	.0	14.6	101	66	--	13.8	1.18	.75
	2-24-94	773	.5	14.4	98	65	--	13.6	.7	1.64

Specific Conductance

Surface-water dip samples were collected concurrently with discharge measurements and analyzed for specific conductance (Hem, 1985). Specific conductance was measured to gain insight into ground-water contributions (Riggs, 1972, p. 12; Miller and others, 1988) and possible salt-water intrusion from high tides.

Specific conductance values ranged from 60 to73 µS/cm and did not vary significantly between cross sections or between field visits (table 2). Specific conductance does not appear to be related to flow, nor is there evidence that salt-water intrusion occurred at any of the six cross sections during the field visits.

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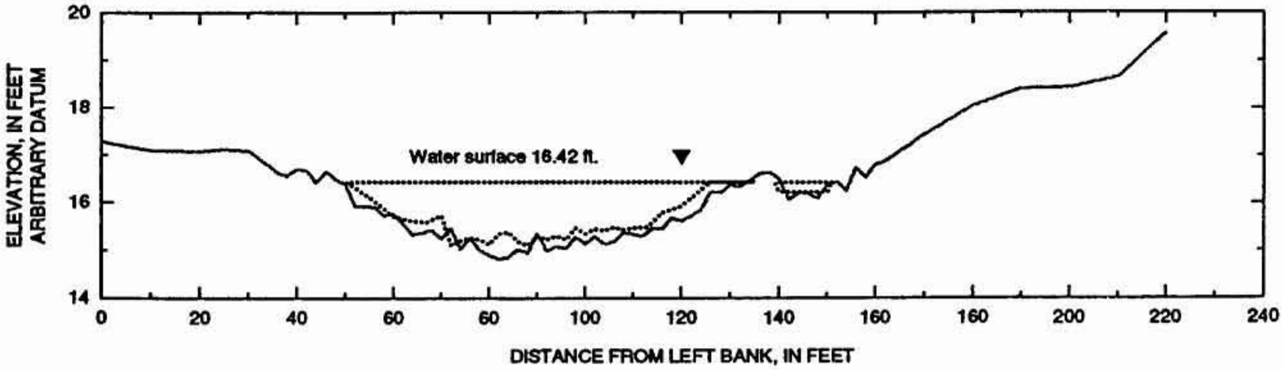
FIGURES 4-10

BRADLEY RIVER AT BEAR ISLAND

CROSS SECTION

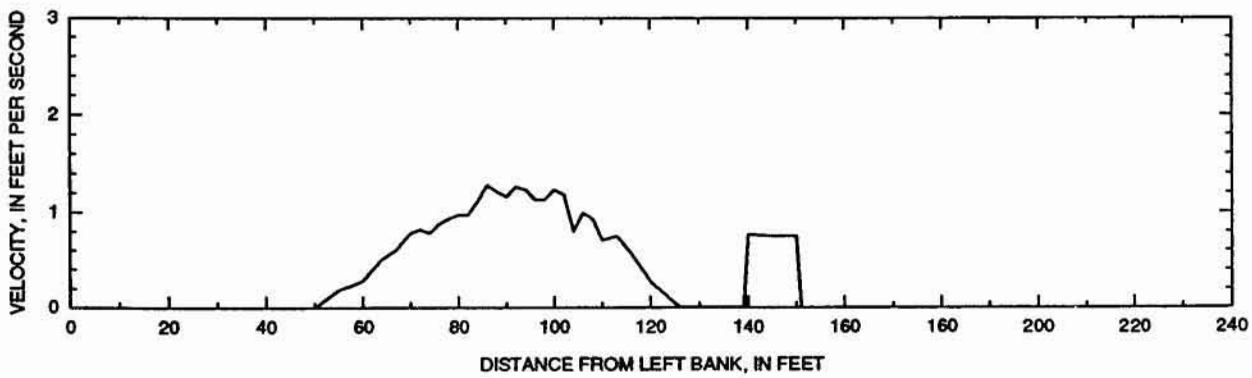


Date of survey, ice conditions, and discharge

—— June 29, 1993, open-water baseline

.... March 12, 1993, minor shore ice
Discharge, 54.4 cubic feet per second

VELOCITY PROFILE

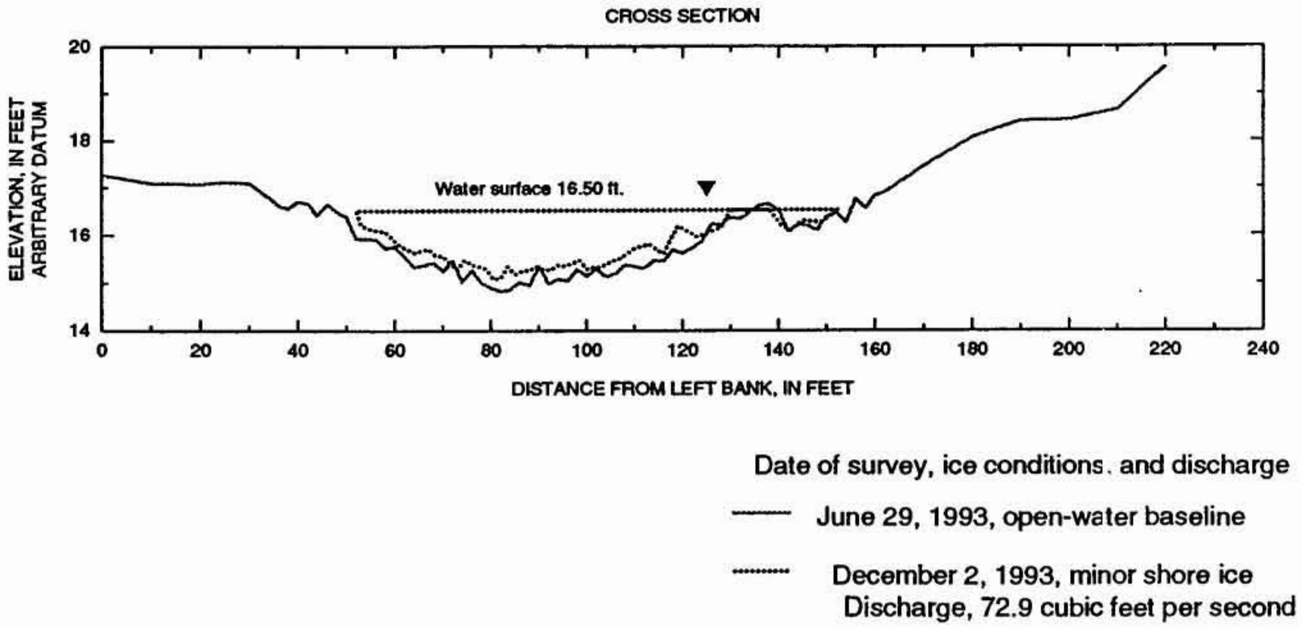


Date of survey, ice conditions, and discharge

—— March 12, 1993, minor shore ice,
Discharge, 54.4 cubic feet per second

Figure 4. Cross section and velocity distribution of the lower Bradley River at Bear Island (see figure 3 for cross section location).

BRADLEY RIVER AT BEAR ISLAND



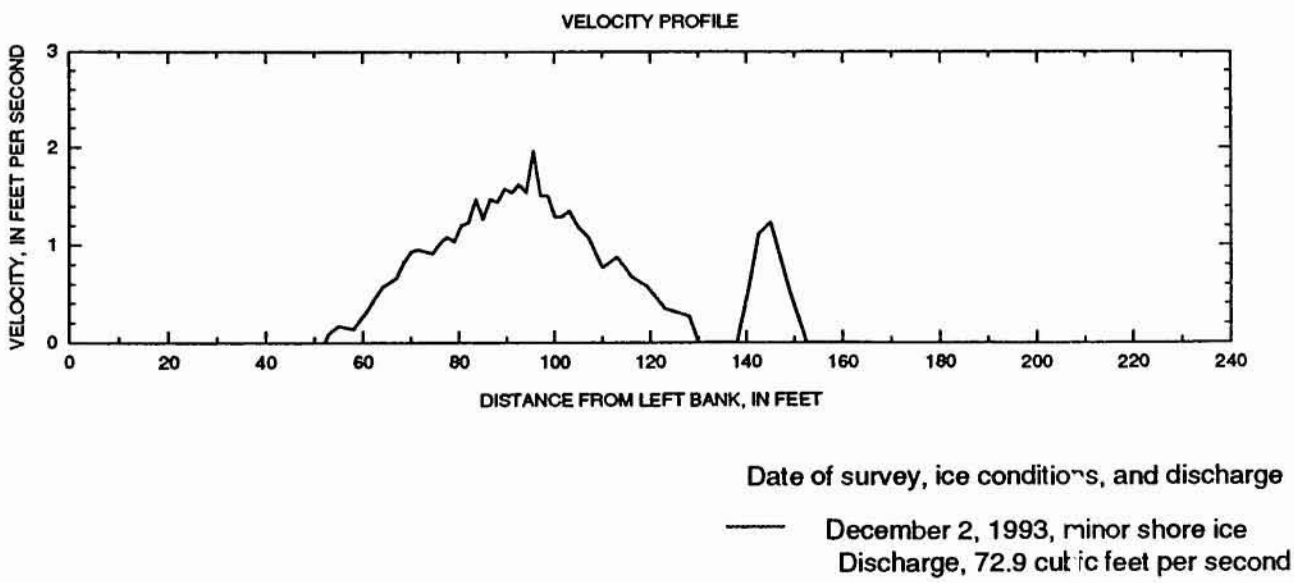
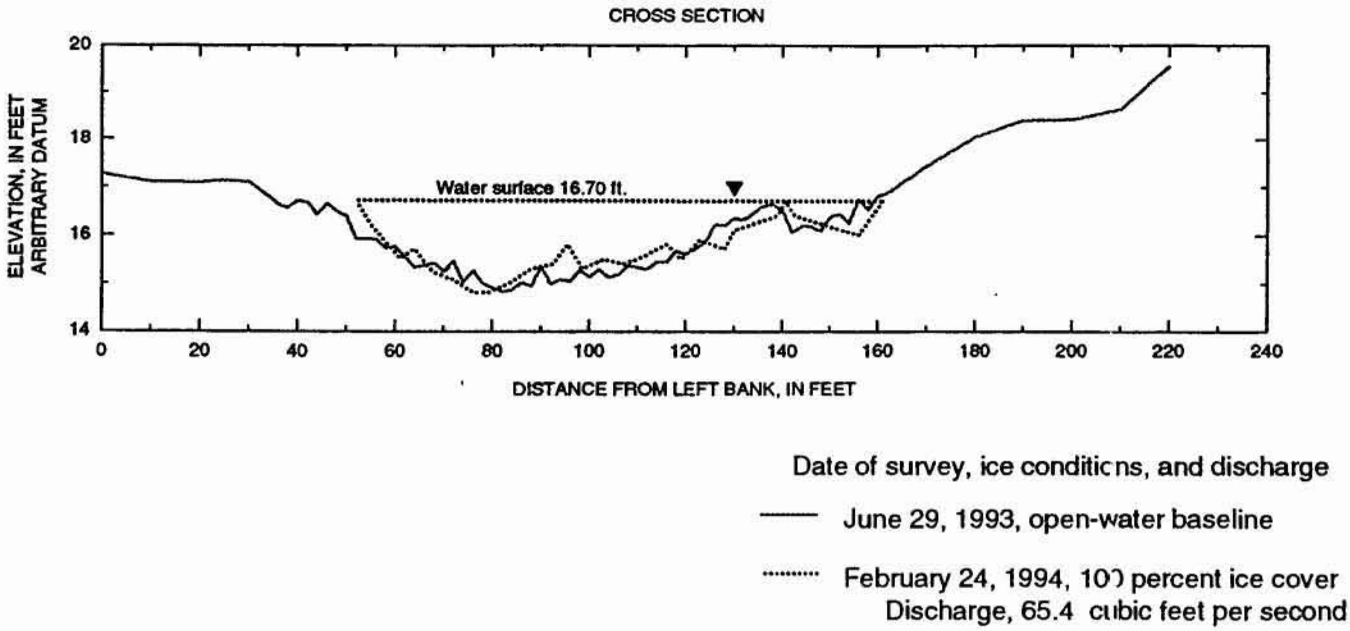


Figure 4. Continued.



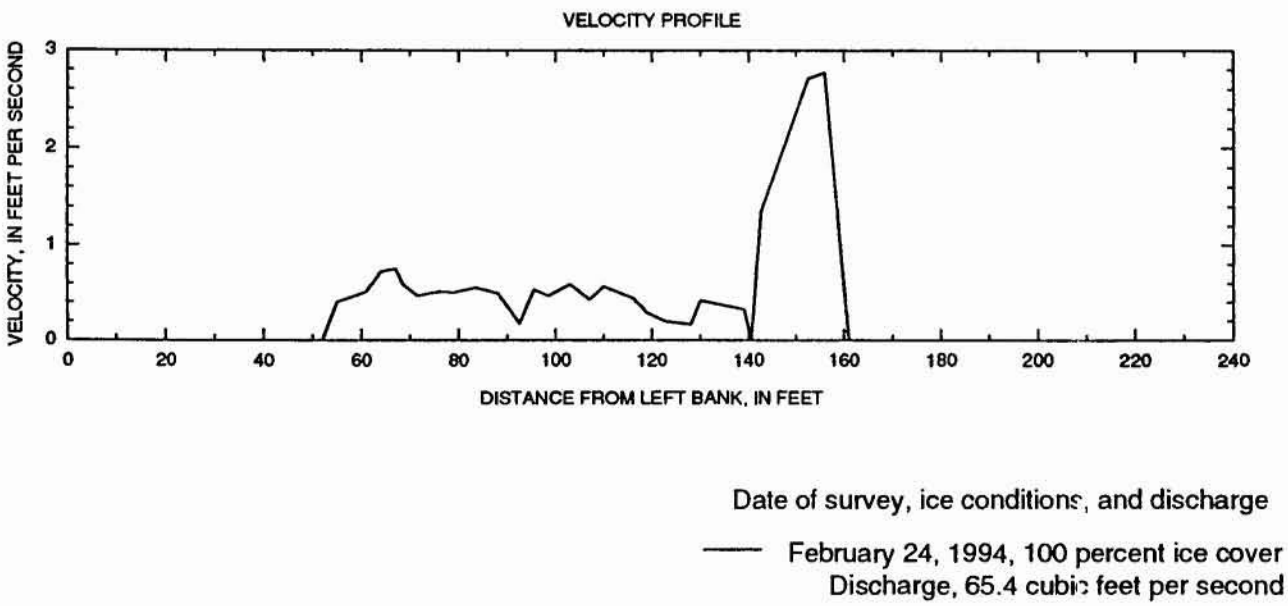
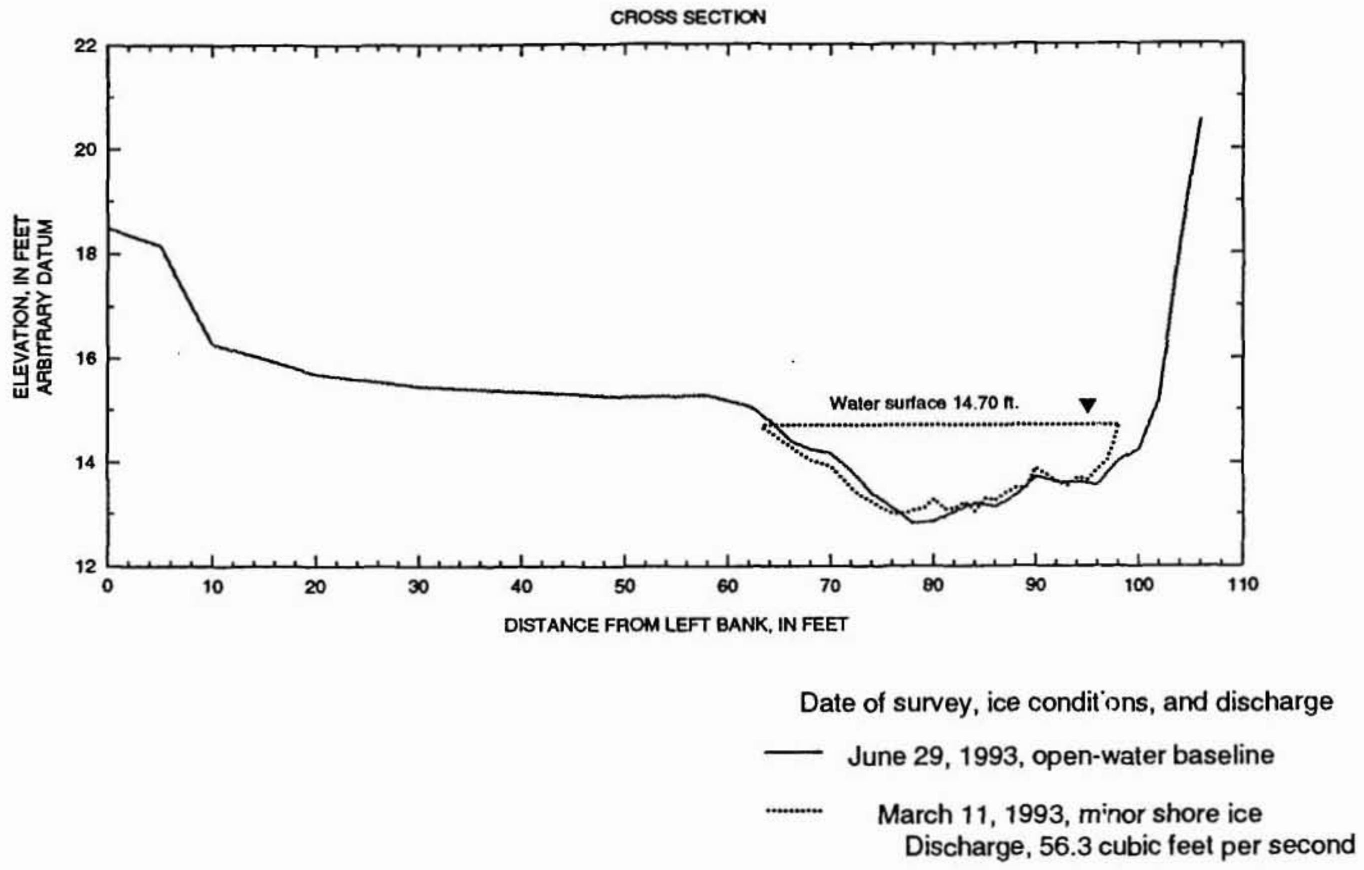


Figure 4. Continued.



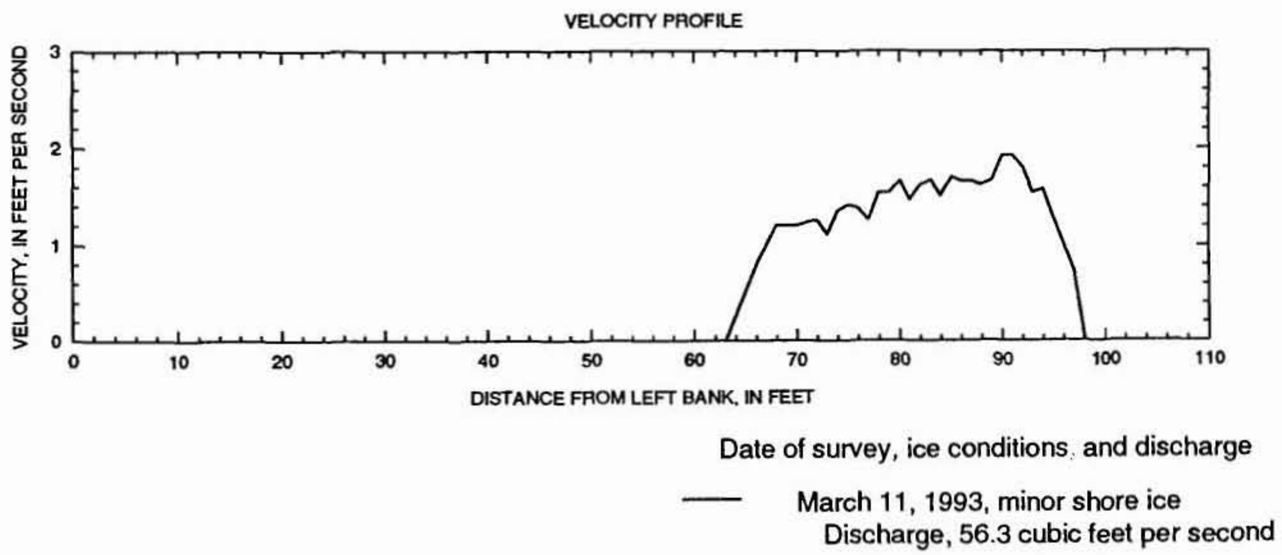
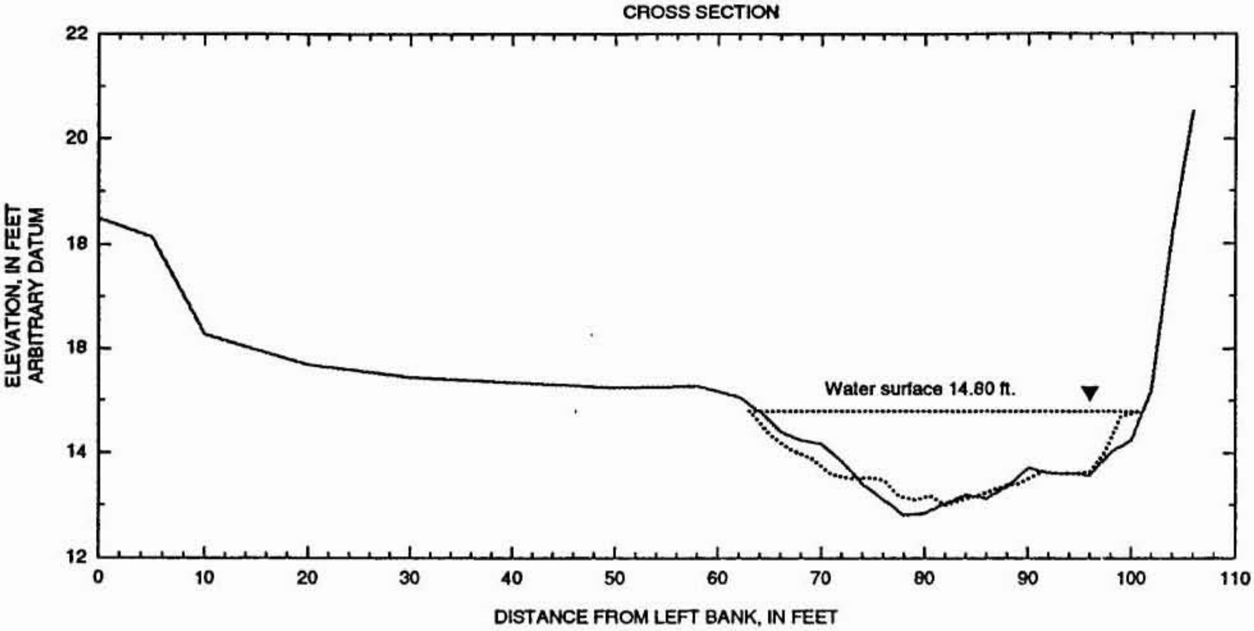


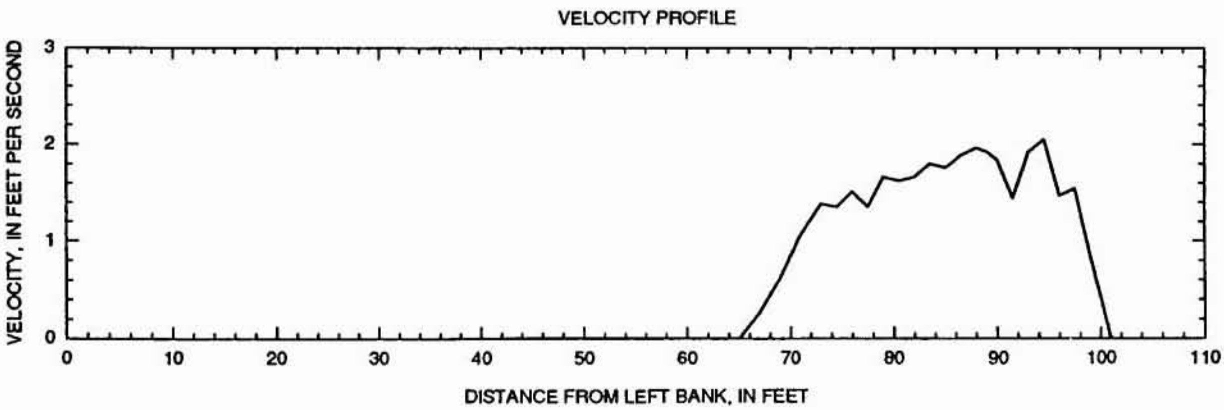
Figure 5. Cross section and velocity distribution of the lower Bradley River near Tidewater. (see figure 3 for cross section location).



Date of survey, ice conditions, and discharge

June 29, 1993, open-water baseline

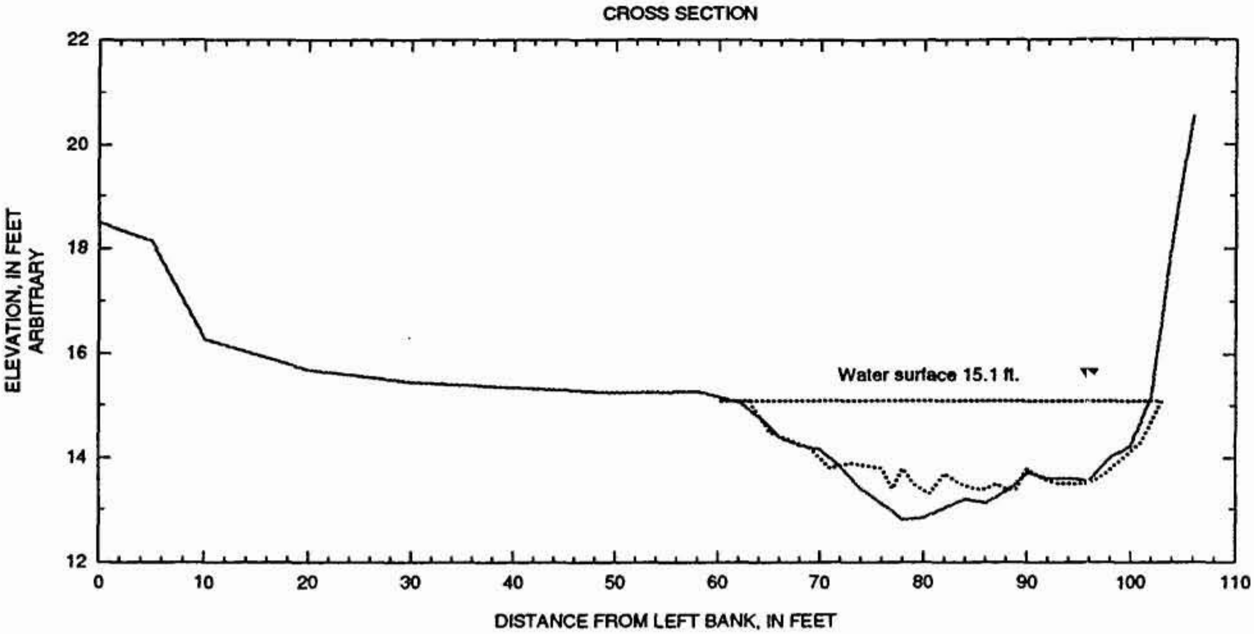
December 3, 1993, minor shore ice
Discharge, 65.2 cubic feet per second



Date of survey, ice conditions and discharge

December 3, 1993, minor shore ice
Discharge, 65.2 cubic feet per second

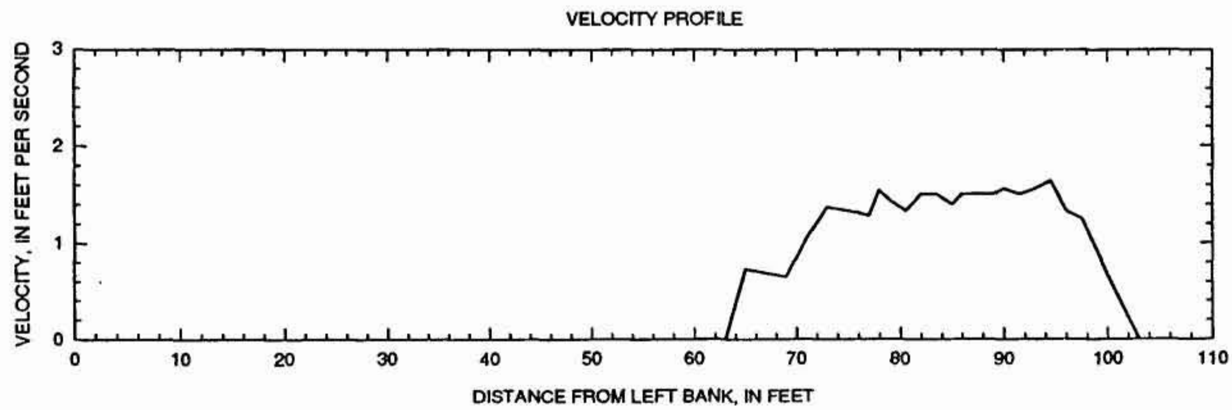
Figure 5. Continued.



Date of survey, ice conditions, and discharge

—— June 29, 1993, open-water baseline

········ February 24, 1994, 100 percent ice cover
Discharge, 65.7 cubic feet per second



Date of survey, ice conditions, and discharge

—— February 24, 1994, 100 percent ice cover
Discharge, 65.7 cubic feet per second

Figure 5. Continued.

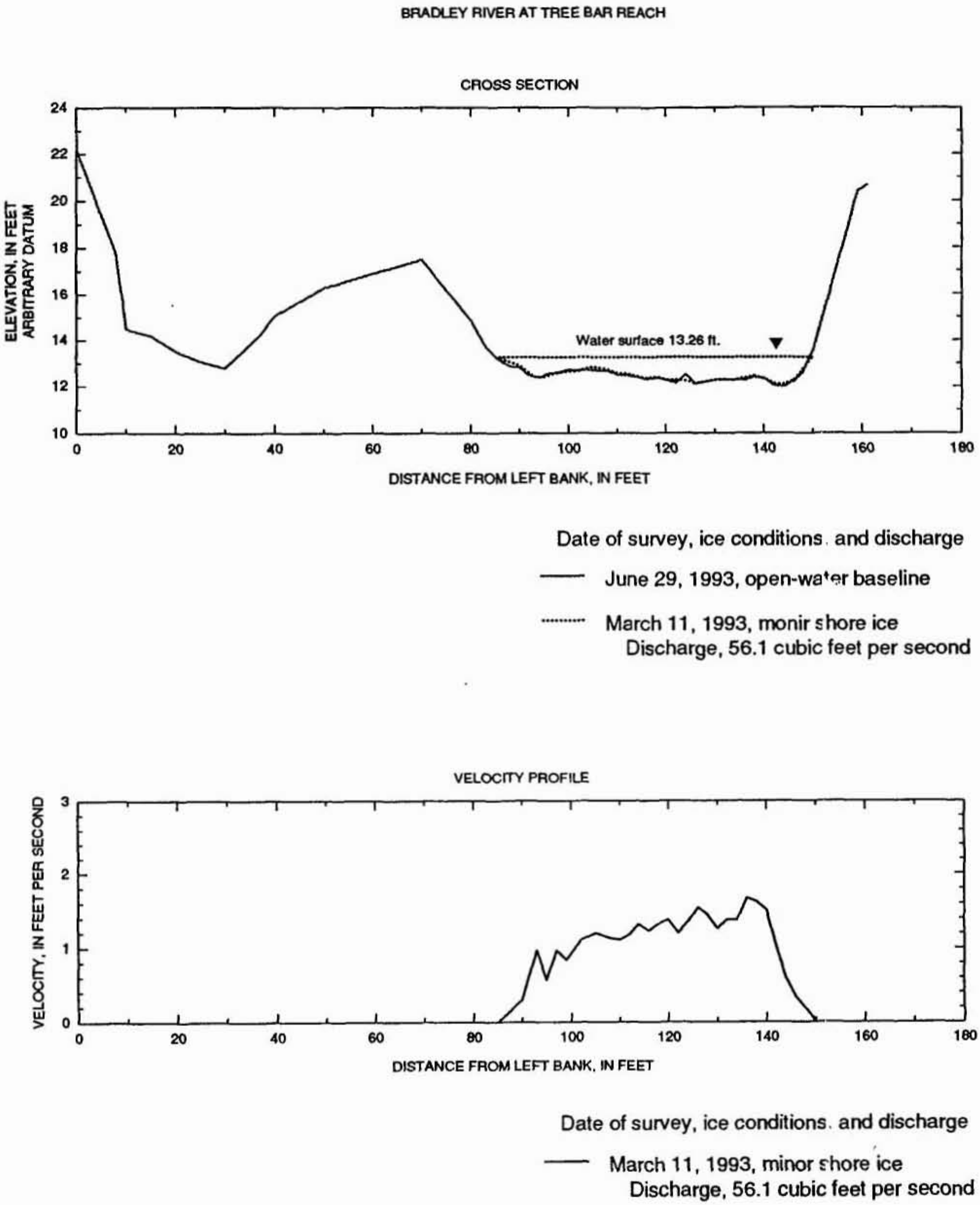
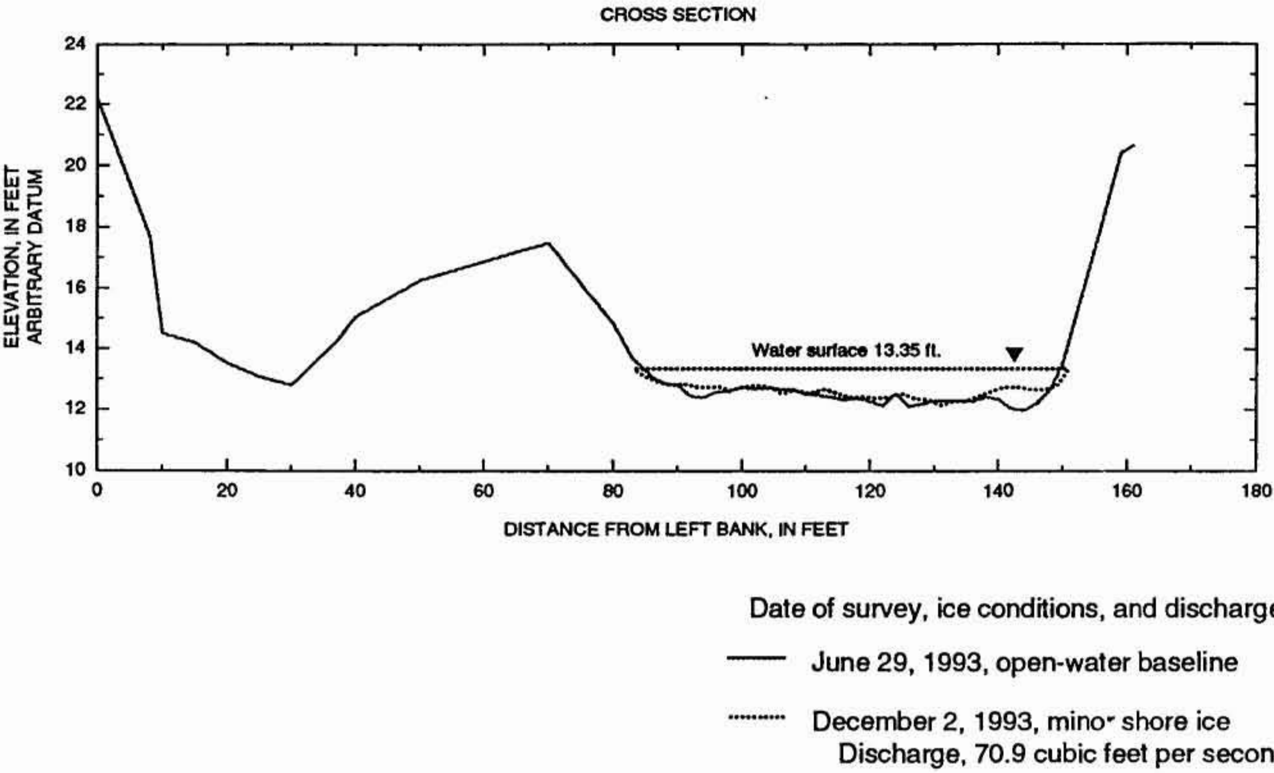


Figure 6. Cross section and velocity distribution of the lower Bradley River at Tree Bar Reach (see figure 3 for cross section location).

BRADLEY RIVER AT TREE BAR REACH



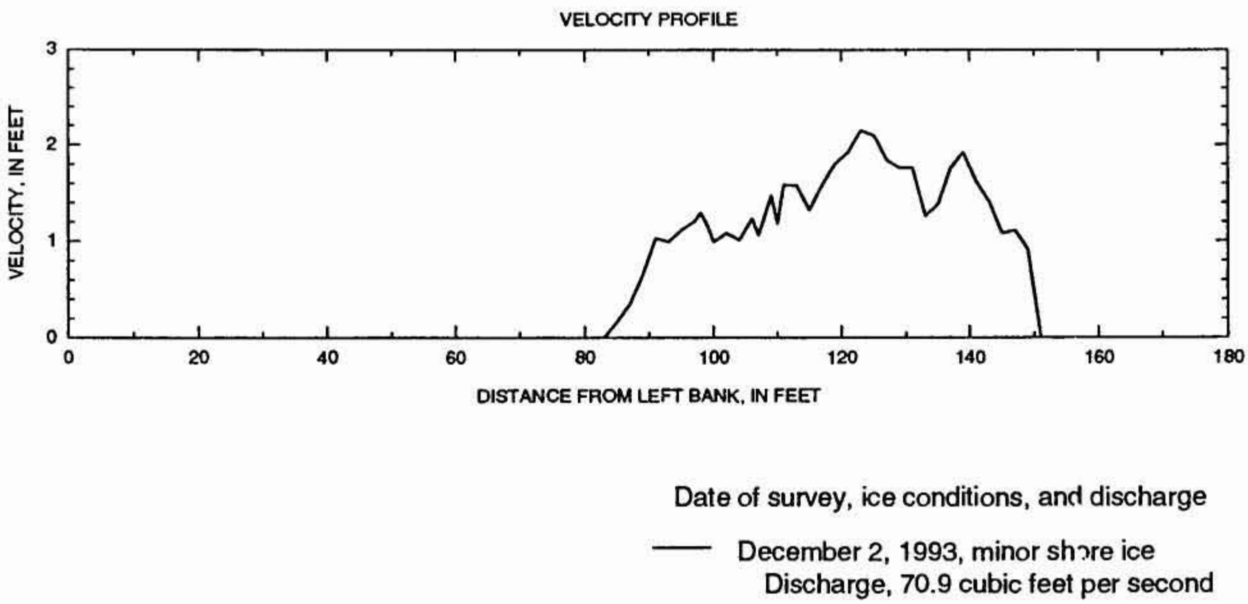
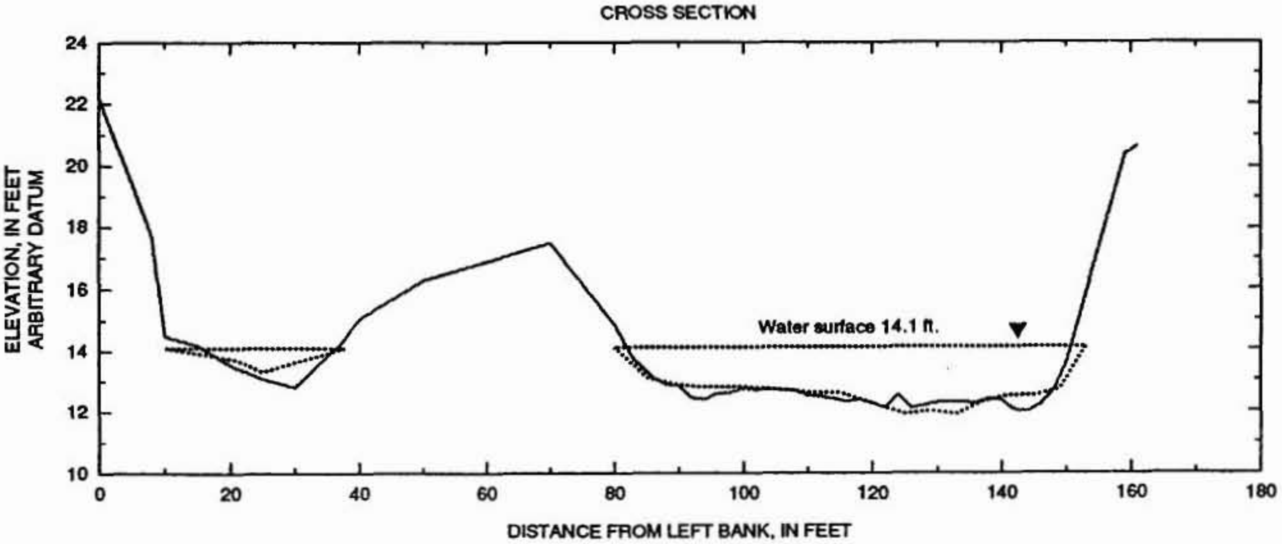


Figure 6. Continued.

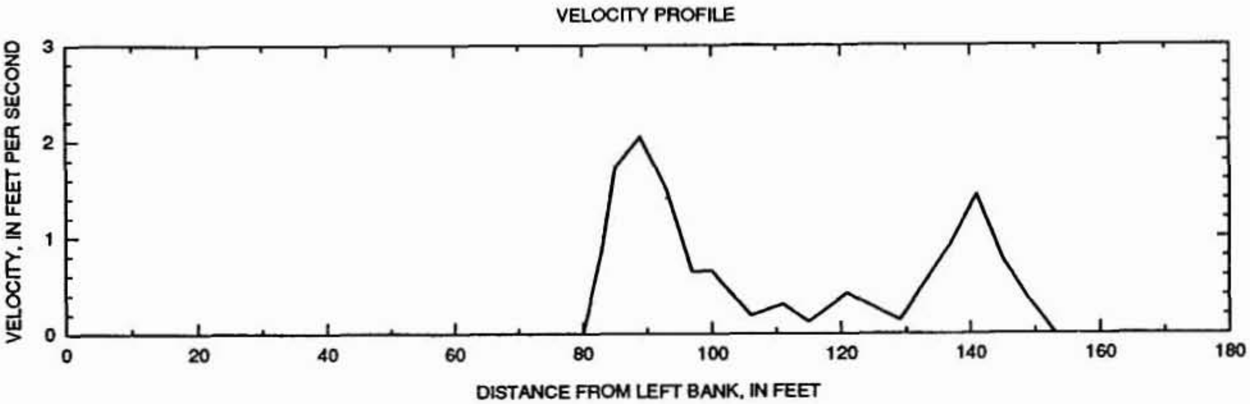
BRADLEY RIVER AT TREE BAR REACH



Date of survey, ice conditions, and discharge

—— June 29, 1993, open-water baseline

········ February 23, 1994, 100 percent ice cover
Discharge, 69.9 cubic feet per second

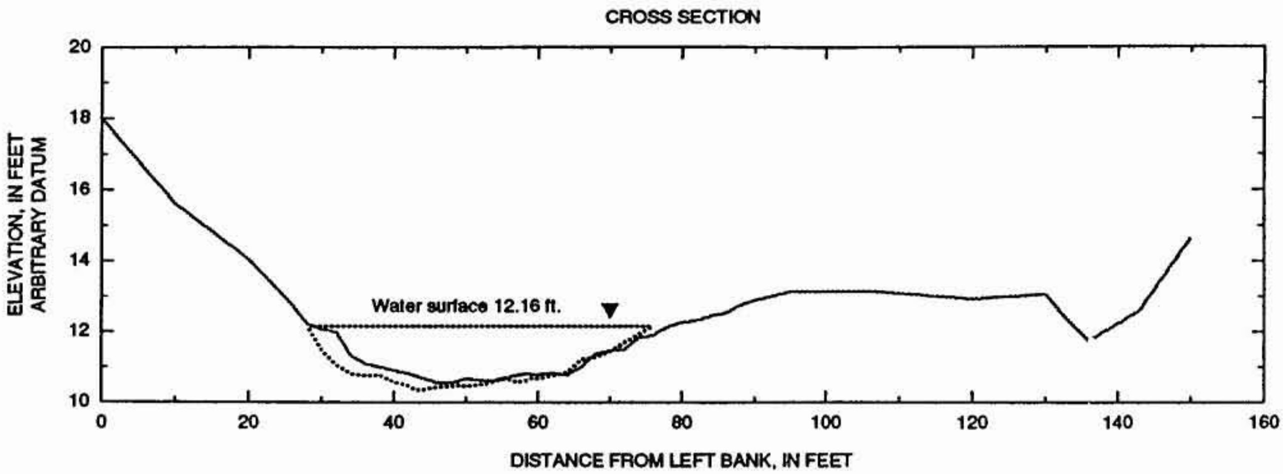


Date of survey, ice conditions, and discharge

—— February 23, 1994, 100 percent ice cover
Discharge, 69.9 cubic feet per second

Figure 6. Continued.

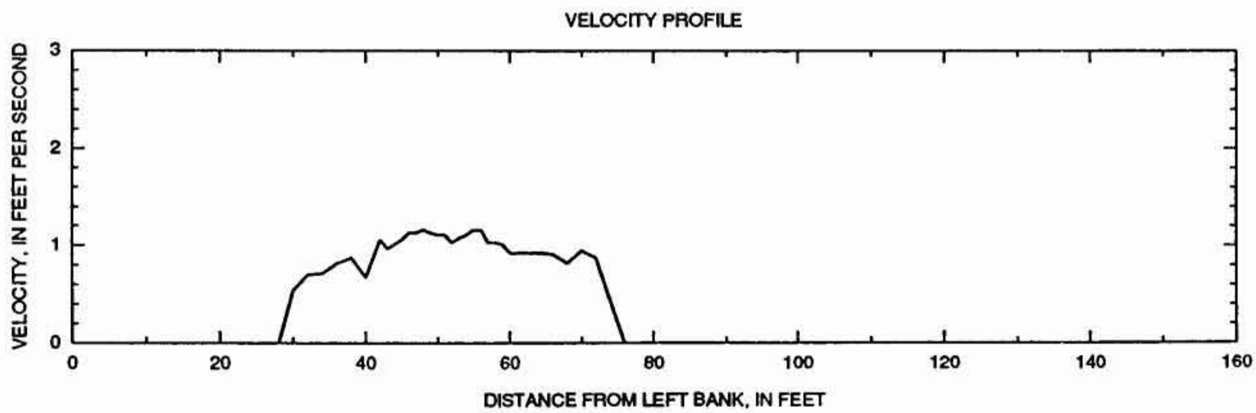
BRADLEY RIVER BELOW FISH CAMP



Date of survey, ice conditions, and discharge

——— June 29, 1993, open-water baseline

········ March 11, 1993, minor shore ice
Discharge, 56.9 cubic feet per second

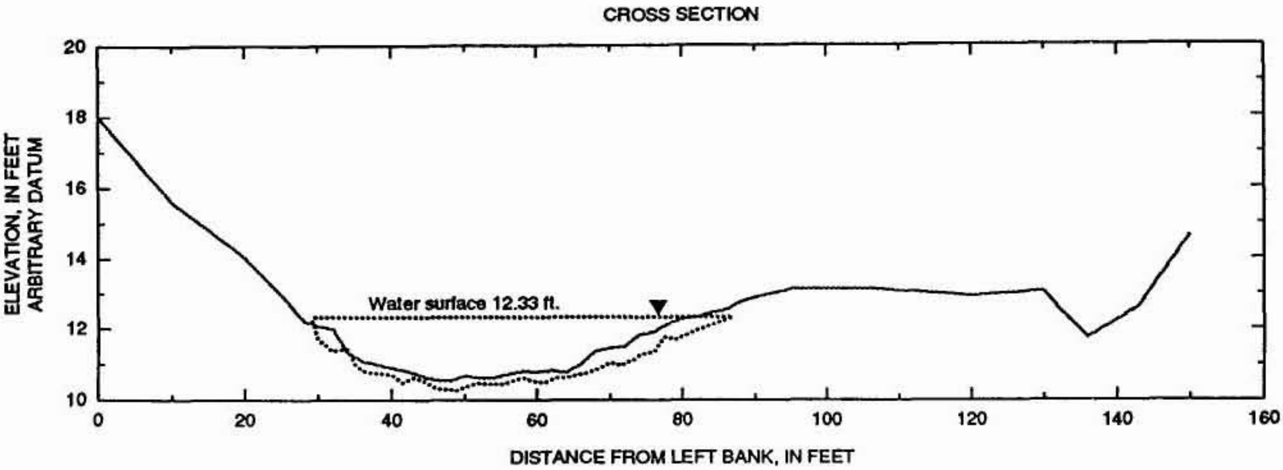


Date of survey, ice conditions and discharge

——— March 11,1993, minor shore ice
Discharge, 56.9 cubic feet per second

Figure 7. Cross section and velocity distribution of the lower Bradley River below Fish Camp (see figure 3 for cross section location).

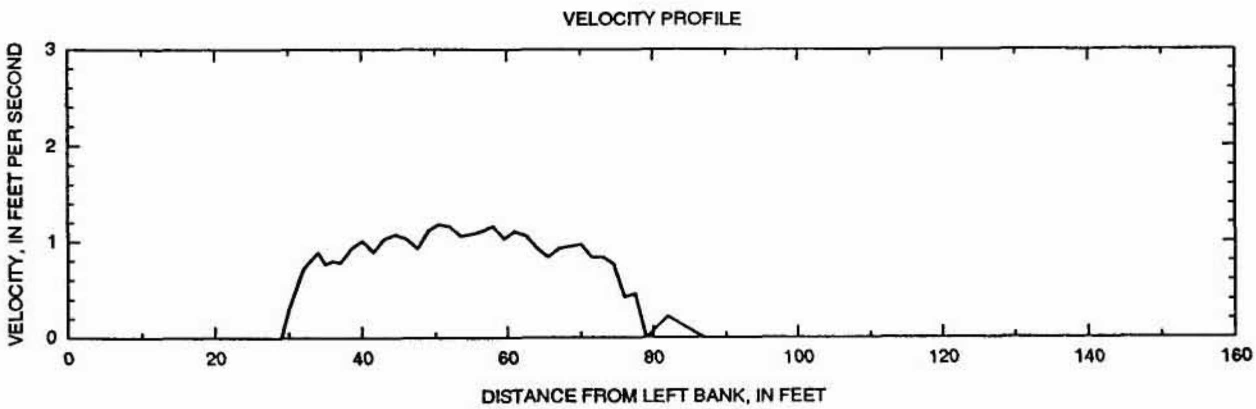
BRADLEY RIVER BELOW FISH CAMP



Date of survey, ice conditions, and discharge

—— June 29, 1993

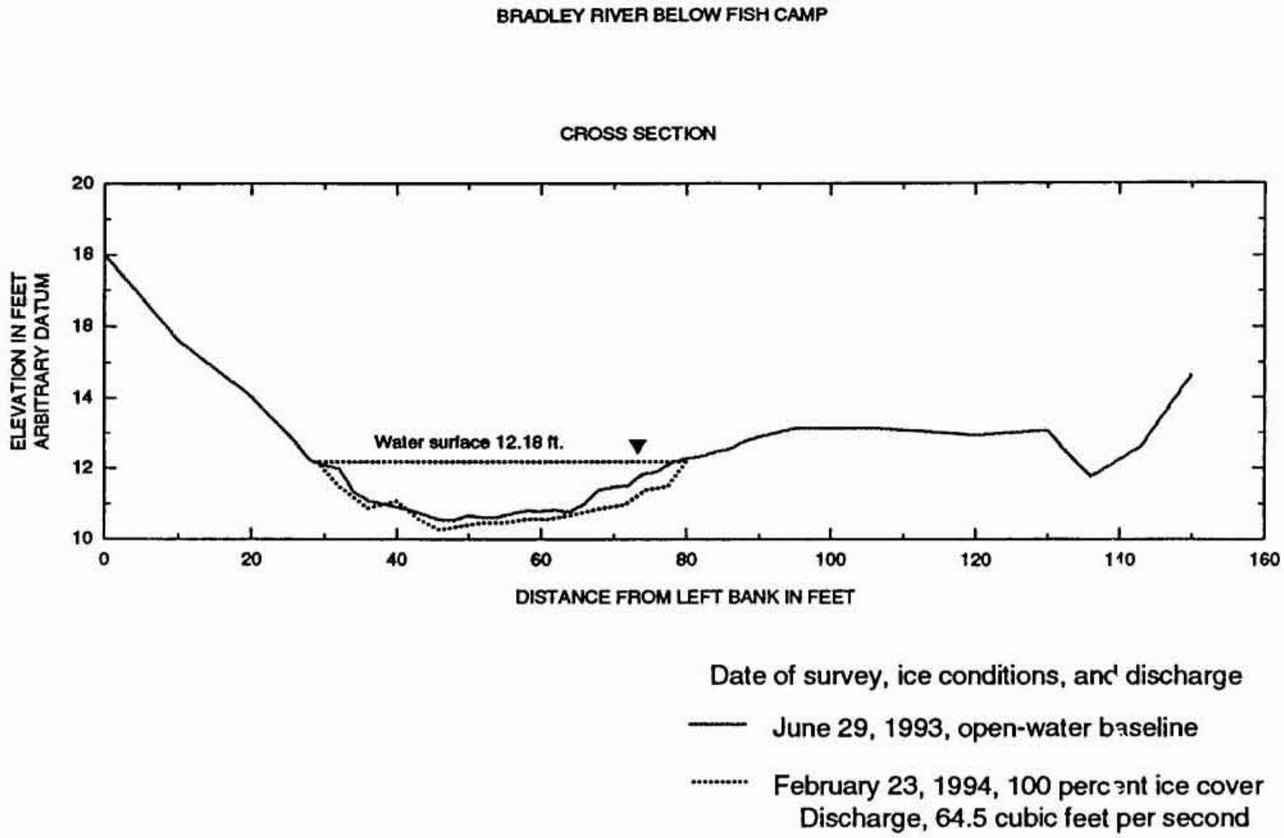
········ December 2, 1993, minor shore ice
Discharge, 71.9 cubic feet per second



Date of survey, ice conditions, and discharge

—— December 2, 1993, minor shore ice
Discharge, 71.9 cubic feet per second

Figure 7. Continued.



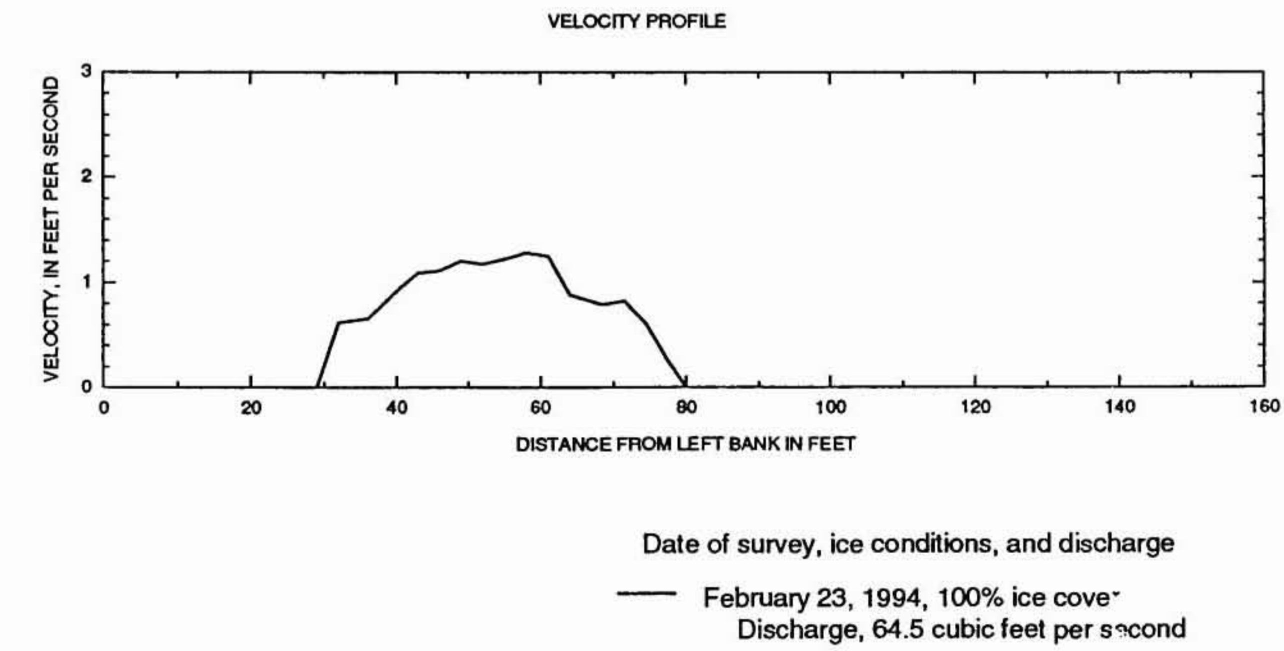


Figure 7. Continued.

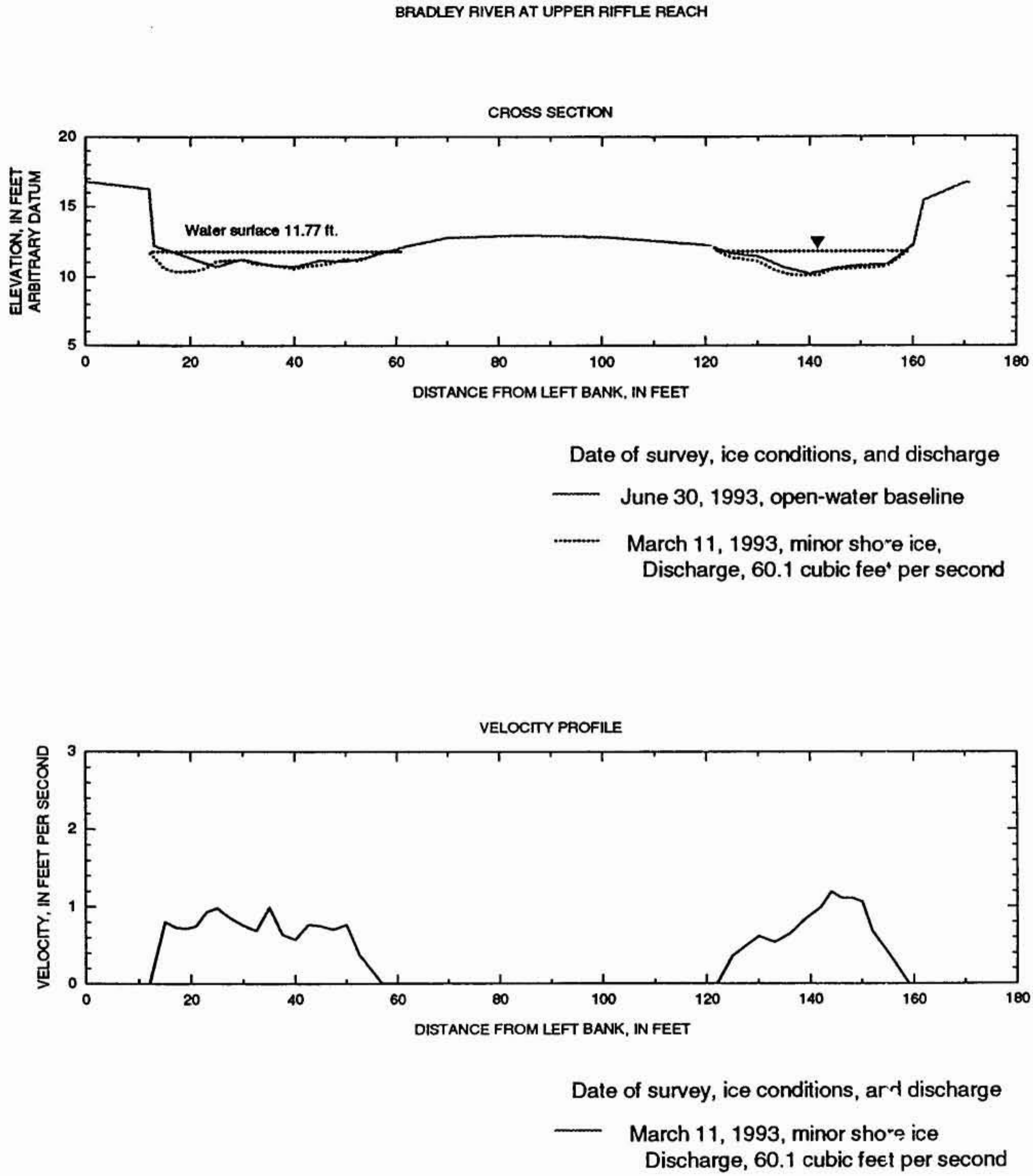
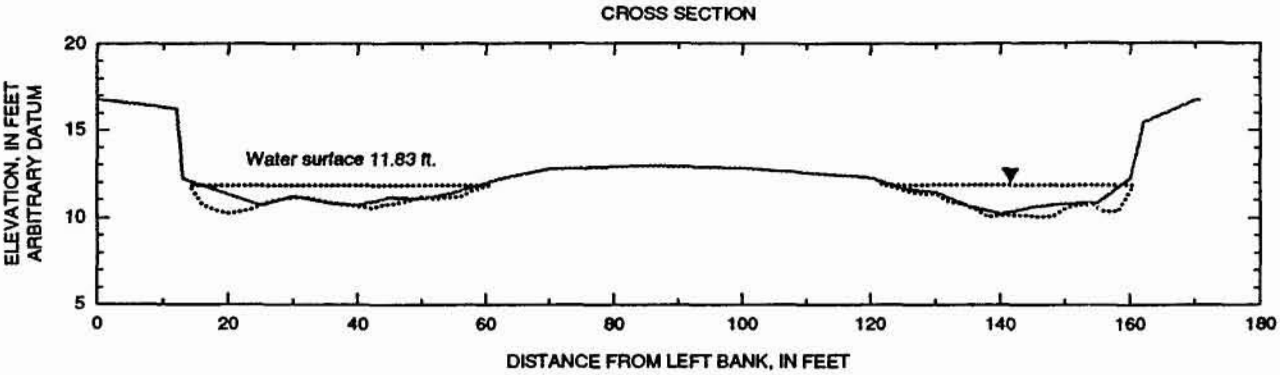


Figure 8. Cross section and velocity distribution of the lower Bradley River at Upper Riffle Reach (see figure 3 for cross section location).

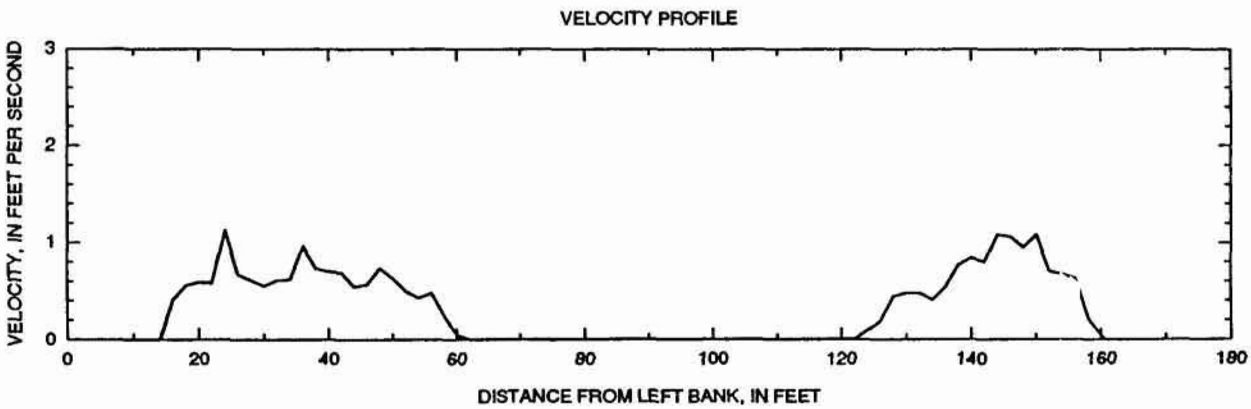
BRADLEY RIVER AT UPPER RIFFLE REACH



Date of survey, ice conditions, and discharge

—— June 30, 1993, open-water baseline

········ December 3, 1993, minor shore ice
Discharge, 60.0 cubic feet per second

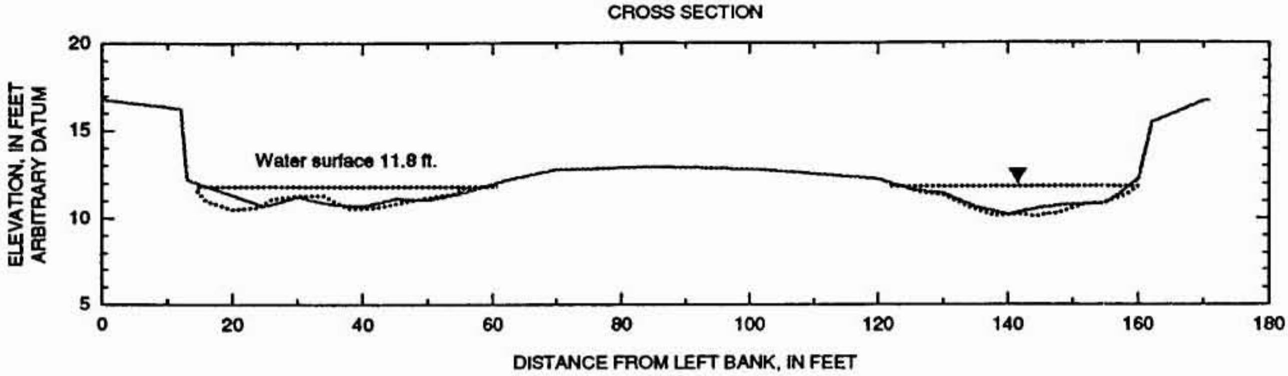


Date of survey, ice conditions, and discharge

—— December 3, 1993, minor shore ice
Discharge, 60.0 cubic feet per second

Figure 8. Continued.

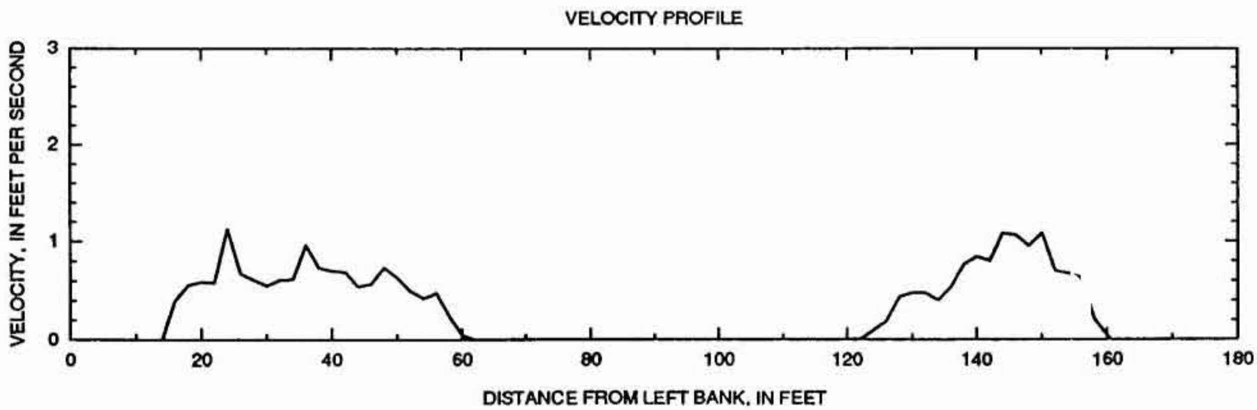
BRADLEY RIVER AT UPPER RIFFLE REACH



Date of survey, ice conditions, and discharge

June 30, 1993, open-water baseline

February 24, 1994, percent ice cover
Discharge 65 2 cubic feet per second



Date of survey, ice conditions, and discharge

February 24, 1994, 100 percent ice cover
Discharge, 65.2 cubic feet per second

Figure 8. Continued.

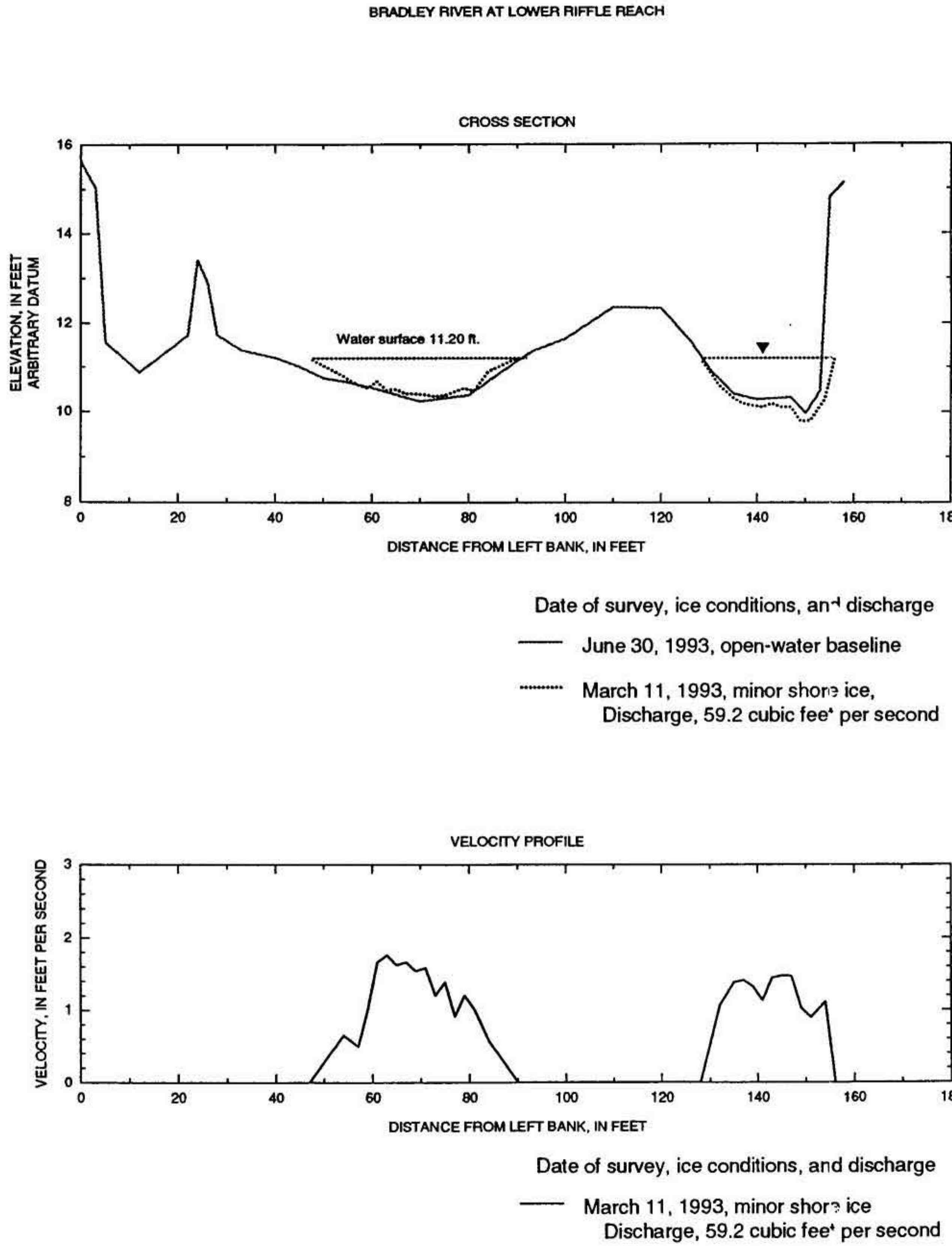
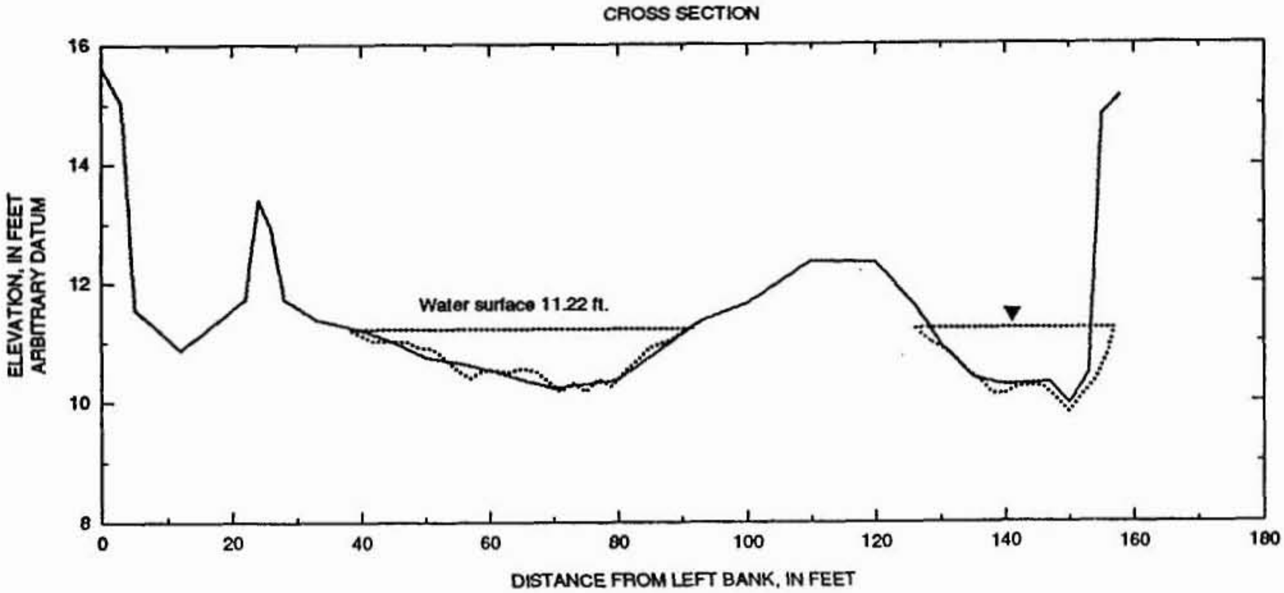


Figure 9. Cross section and velocity distribution of the lower Bradley River at Lower Riffle Reach (see figure 3 for cross section location).

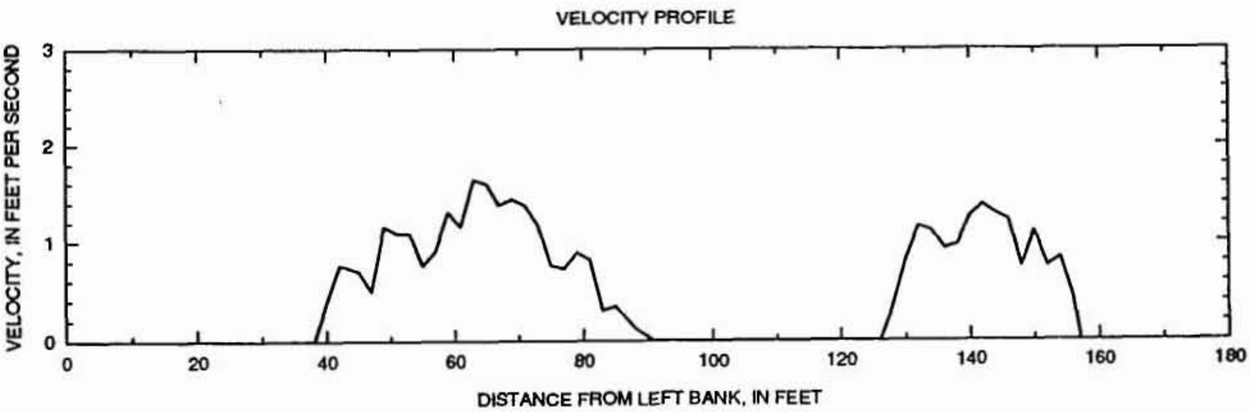
BRADLEY RIVER AT LOWER RIFFLE REACH



Date of survey, ice conditions, and discharge

—— June 30, 1993, open-water baseline

········ December 3, 1993, minor shore ice
Discharge, 54.8 cubic feet per inch

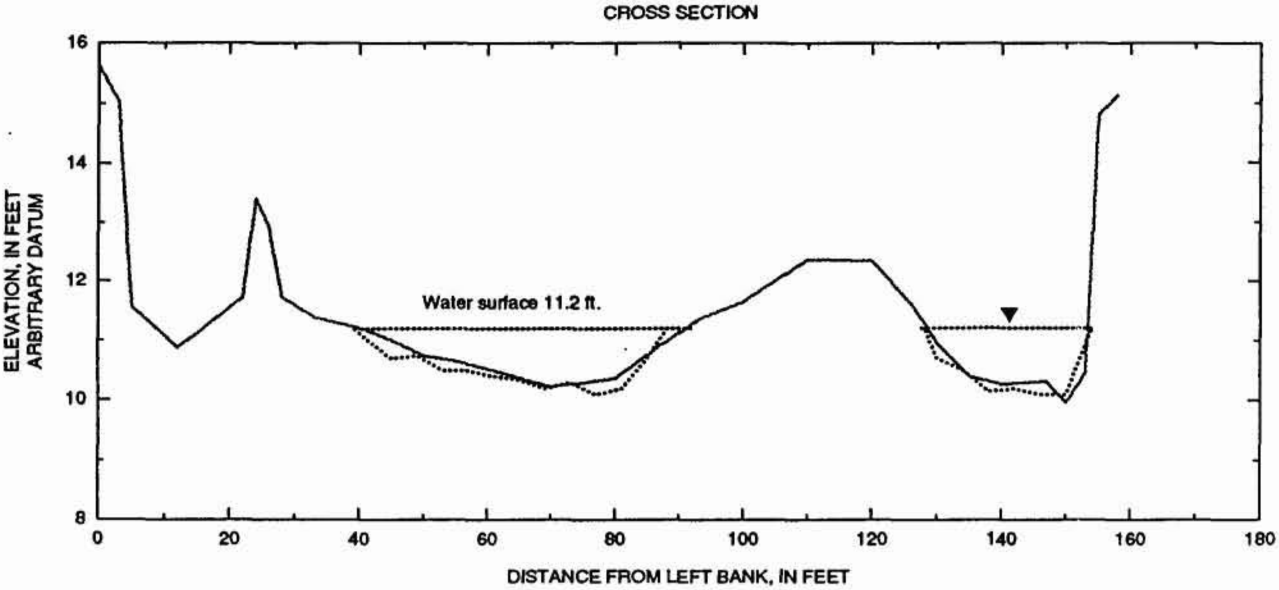


Date of survey, ice conditions, and discharge

—— December 3, 1993, minor shore ice
Discharge, 54.8 cubic feet per second

Figure 9. Continued.

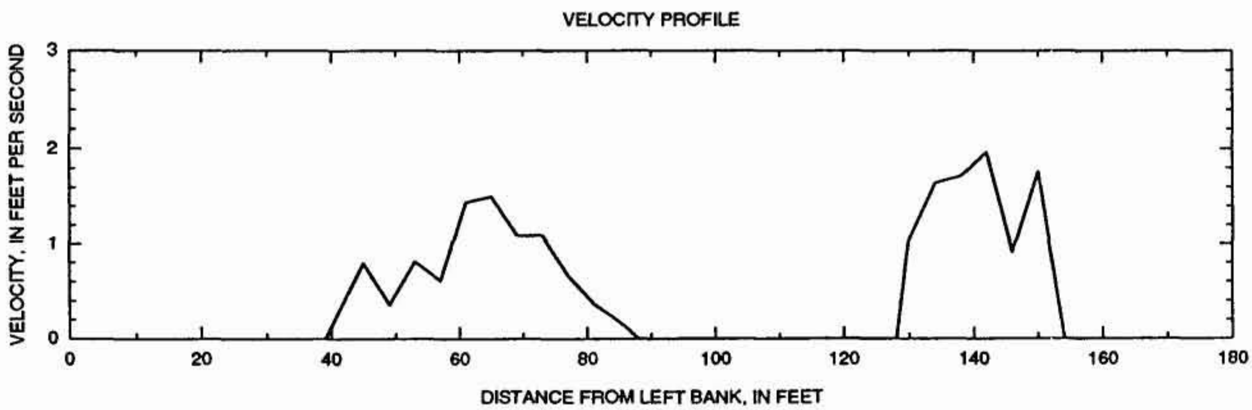
BRADLEY RIVER AT LOWER RIFFLE REACH



Date of survey, ice conditions and discharge

—— June 30, 1993, open-wa'er baseline

········ February 24, 1994, 100 percent ice cover
Discharge, 62.2 cubic feet per second



Date of survey, ice conditions and discharge

Figure 9. Continued.

—— February 24, 1994, 100 percent ice cover
Discharge, 62.2 cubic feet per second

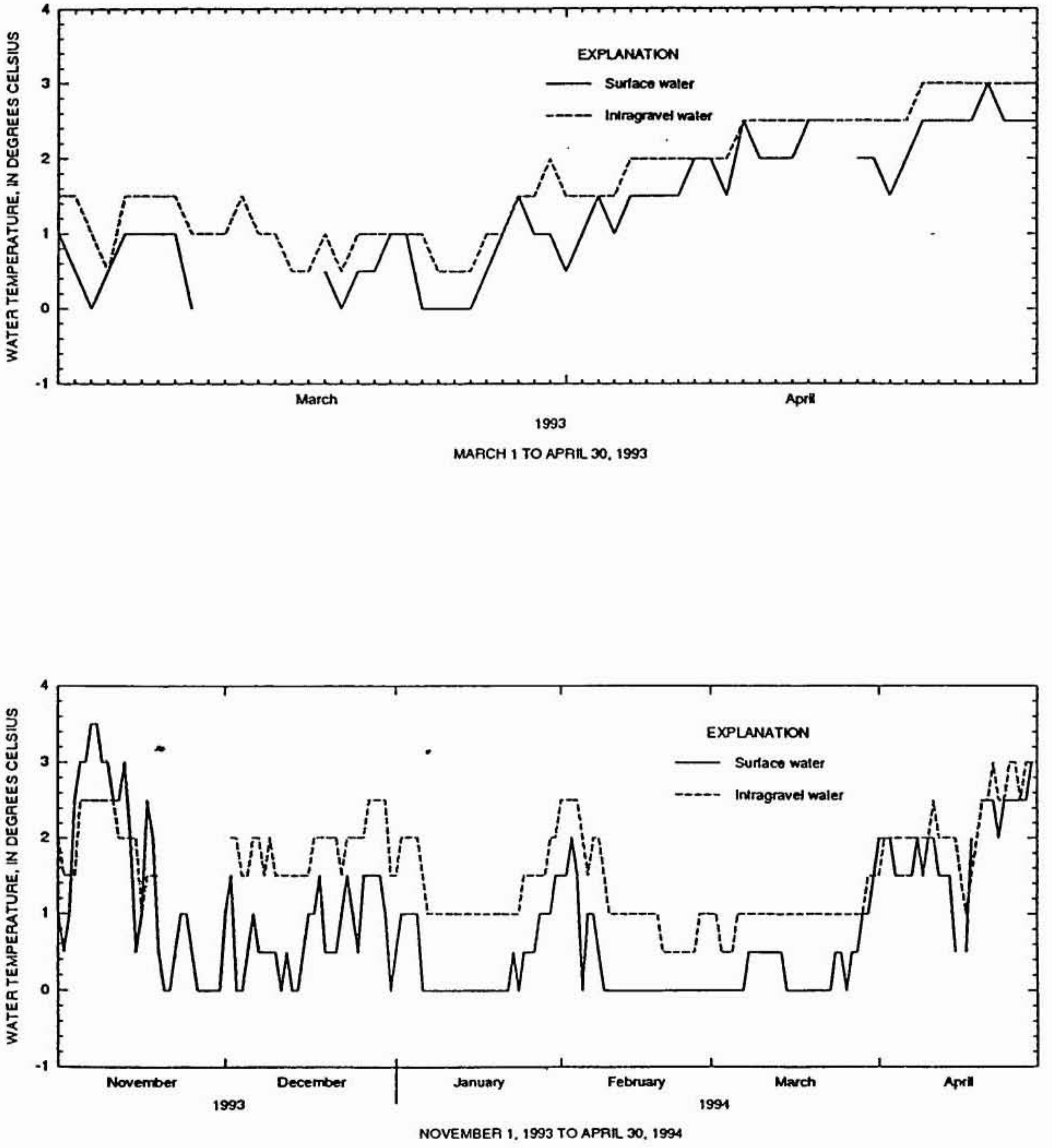


Figure 10. Daily mean surface and intragravel water temperature of Bradley River near tidewater.