Hydrologic and Water-Quality Data for the Lower Bradley River, Alaska, November Through April 1995-98

By Ronald L. Rickman

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Muitipiy	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
foot per second (ft/s)	0.3048	meter per second
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)

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, microsiemens 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 of 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, water depth, flow velocity, and specific conductance, as well as temperature and dissolved oxygen from both surface water and intragravel water. This report presents data collected between November 1995 and April 1998.

INTRODUCTION

The Alaska Energy Authority (AEA) began operation of the Bradley Lake Hydroelectric Project near Homer, Alaska, in 1991 (fig. 1). The dam, which is 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) stream-gaging station Bradley River near Tidewater (station No. 15239070; fig. 1). 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 this 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 and fill are usually gradual, and adjustments can be applied to the stage/discharge rating as needed. Channel geometry is also changed during peri-

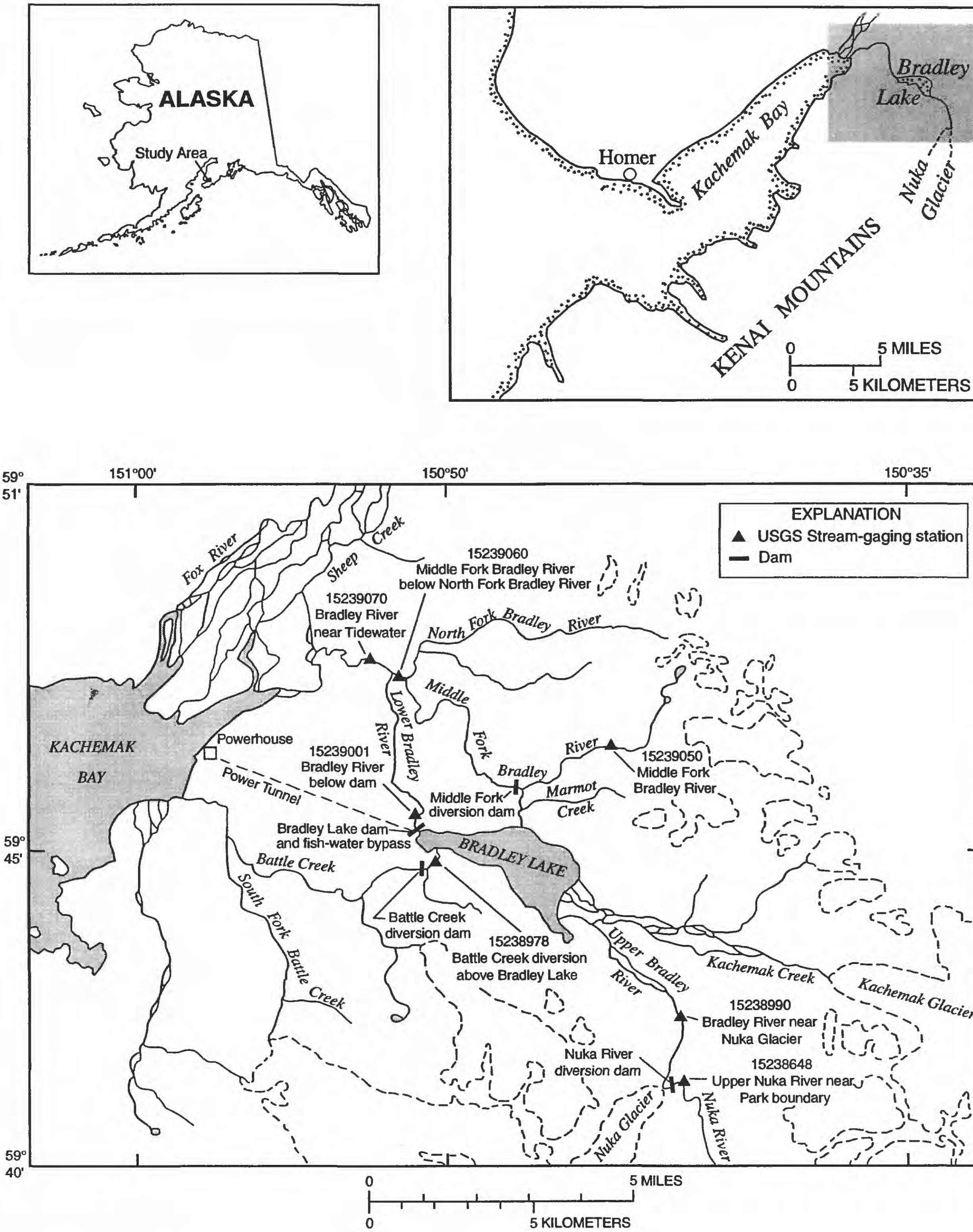

Figure 1. Location of the Bradley Lake Hydroelectric Project area.

ods of ice formation in the river. These changes are usually rapid and highly variable, rendering the stage/discharge relation useless.

During the winter, operators of the Bradley Lake Hydroelectric Project have released flows of 35 to 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 are usually well above the required minimum because the Middle and North Forks Bradley River contribute inflow that has not been adequately quantified.

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 of habitat for salmon incubation, and (3) gain insight into the minimum limits of flow to assure that the salmon incubation habitat is protected in the event of an unexpected decrease in flow.

Purpose and Scope

The purpose of this report is to present the hydrologic and water-quality data collected as part of the Lower Bradley River Salmon Incubation Habitat Study, an investigation of the effects of ice formation on salmon incubation habitat. Hydrologic and water-quality data for the periods March 1993 to April 1994 and November 1994 to April 1995 have been previously reported (Rickman, 1995, 1996).

In scope, this report includes hydrologic and water-quality data collected at six transects in the lower Bradley River between November 1995 and April 1998. Hydrologic properties include percent ice cover, ice conditions, instantaneous discharge, mean velocity, mean depth, mean hydrostatic head, and wetted perimeter for each of the six transects. Also presented are graphs showing hydrostatic head, water depth, and velocity distribution across the transects for a variety of discharges and ice conditions. Water-quality properties include temperature, dissolved oxygen and percent saturation, and specific conductance for surface water; and temperature, dissolved oxygen and percent saturation for intragravel water. Surface-water velocity and hydrostatic head at the intragravel-water sample points are also presented. In addition, sample collection and analysis methods are described.

Acknowledgments

The author gratefully acknowledge the assistance of John Morsell, of Northern Ecological Services (under contract with the Alaska Energy Authority), for providing salmon escapement information and aiding with study design.

Study Area and Data-Collection Sites

The Bradley River originates in the Kenai Mountains east of Homer, flows into Bradley Lake (fig. 1), and then flows northward from Bradley Lake for about 5 mi to Kachemak Bay. The Middle and the North Forks of the Bradley River flow into the main stem of the Bradley River 3.3 mi downstream from the Bradley Lake outlet. Flow from the upper basin of the Middle Fork is diverted into Bradley Lake.

Six transects were selected at known spawning areas of pink salmon—the predominant salmon species (Morsell and others, 1993; Morsell, 1996)—in the lower Bradley River between Bear Island and Lower Riffle Reach (fig. 2). Transect characteristics have been previously described (Rickman, 1996).

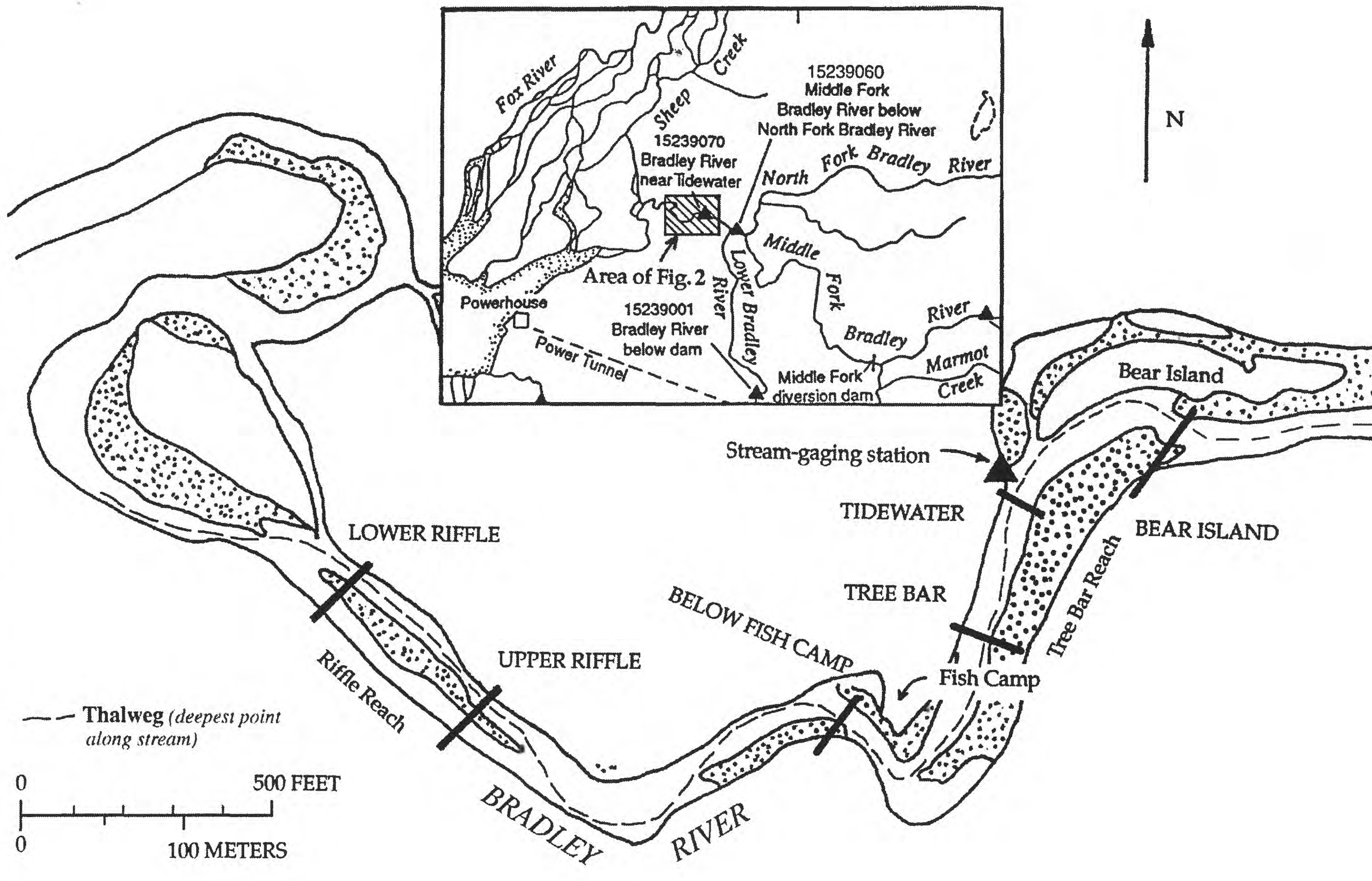

Figure 2. Lower Bradley River study cross section transects (modified from Morsell, 1994, fig.1).

METHODS AND MATERIALS

Discharge

The USGS has operated daily streamflow stations at Bradley River near Tidewater since 1983 and Middle Fork Bradley River below North Fork Bradley River since 1996 (fig. 1). Both stations are affected by ice much of the winter, during which time daily mean discharges are estimated using methods described by Rantz and others (1982, p. 360-376). Instantaneous discharge measurements were made at each of the six transects during field visits. A standard pygmy meter was used to measure velocity for all discharge measurements, except for periods when anchor ice was present, in which case a pygmy meter with polymer cups was used because it resists icing. Water depth and velocity were measured at 15 to 30 subsections at each transect with the following methods:

Subsection condition	Water depth (feet)	Depth method
Ice free	<1.5	0.6
	>1.5	0.2 and 0.8
Ice covered	<1.0	0.6
	1.0 - 1.5	0.2 and 0.8
	>1.5	0.2, 0.6, and 0.8

A description of methods is given by Rantz and others (1982, p. 134-136, p. 151-155). This approach for measuring ice-covered subsections gave the most consistent results for computing discharge.

Transect Survey and Datum

Transects of the lower Bradley River were established in March 1993 at six locations (fig. 2). At each location, steel markers were driven into the ground to delineate transect end points, and standard survey techniques were used to tie all the cross sections to the same datum (Rickman, 1995). Reference pins, used to determine water-surface elevation, were driven into the streambed at each transect. The pins were surveyed annually to ensure that water-surface elevation measurements were accurate. Reference pins were frequently damaged by ice, and were replaced as needed when possible. In the absence of reliable reference pins, water-surface elevation was estimated using cross-section comparison between field visits.

Hydraulics

Water depth, hydrostatic head, and flow velocity data were also collected at each of the six transects a minimum of four times each winter between November 1995 and April 1998. These properties were measured at several points across each transect using the procedures described by Buchanan and Sommers (1969) and Rantz and others (1982). In this report, water depth is defined as the distance from the streambed to the bottom of the ice shelf, and hydrostatic head is defined as the distance from the streambed to the water surface, measured in holes cut into the ice (fig. 3A). When ice is bridged above the water column, or if no ice present, then hydrostatic head equals water depth (fig. 3B). Hydrostatic head is always greater than or equal to the water depth under the ice. Hydrostatic head greater than water depth indicates pressurized flow. Wetted perimeter was computed for each section using the Slope-Area Computation Program (Fulford, 1994). For this study, wetted perimeter is defined as the part of streambed within a transect that is wetted by surface water, and does not include the ice/water boundary, nor does it include any parts of the streambed that are frozen.

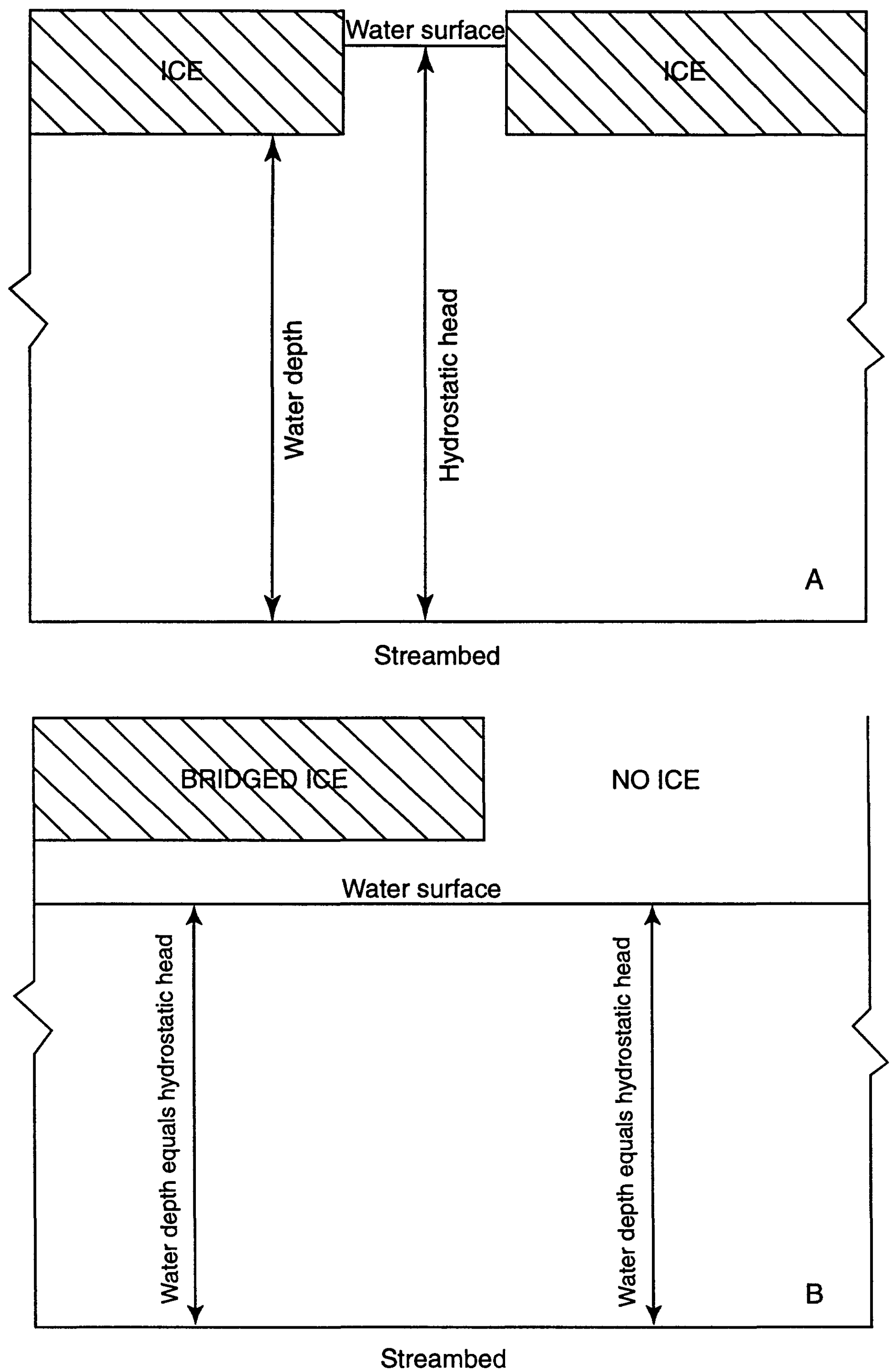

Figure 3. Water depth and hydrostatic head as used in this report: A) Ice supported by water column, and B) Bridged ice or no ice.

Water 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 transect (published as Bradley River near Tidewater, U.S. Geological Survey, 1987-98). 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. Surface-water-temperatures are recorded at 30-minute intervals and intragravel-water temperature at 60-minute intervals. Recorded data were verified using calibrated field thermometers (Stevens and others, 1975, p. 30), and are rounded to the nearest 0.5 °C.

Dissolved Oxygen

Dissolved-oxygen samples of surface water and intragravel water were collected at each transect 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.

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 using a peristaltic pump with Masterflex C-FLEX tubing (low oxygen permeability) at a rate of 10 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 measured in the BOD bottle during sample collection, except at Tree Bar Reach, where the recorded intragravel-water temperature data were available.

Specific Conductance

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

HYDROLOGIC DATA

Discharge

Daily mean discharge data for Bradley River near Tidewater from November 1 through April 30, water years 1996-98 are shown in figure 4. A water year begins October 1 and ends September 30. Streamflow that was estimated because of ice effect is shown using dashed lines. Distinct icing periods between November 1 and April 30 occurred twice in 1996, four times in 1997, and three times in 1998. Daily mean discharge for the study period ranged from 40 to 934 ft^3/s at the Bradley River near Tidewater stream-gaging station. Streamflow greater than 75 ft^3/s was caused by snowmelt and (or) rainfall in the lower Bradley River basin.

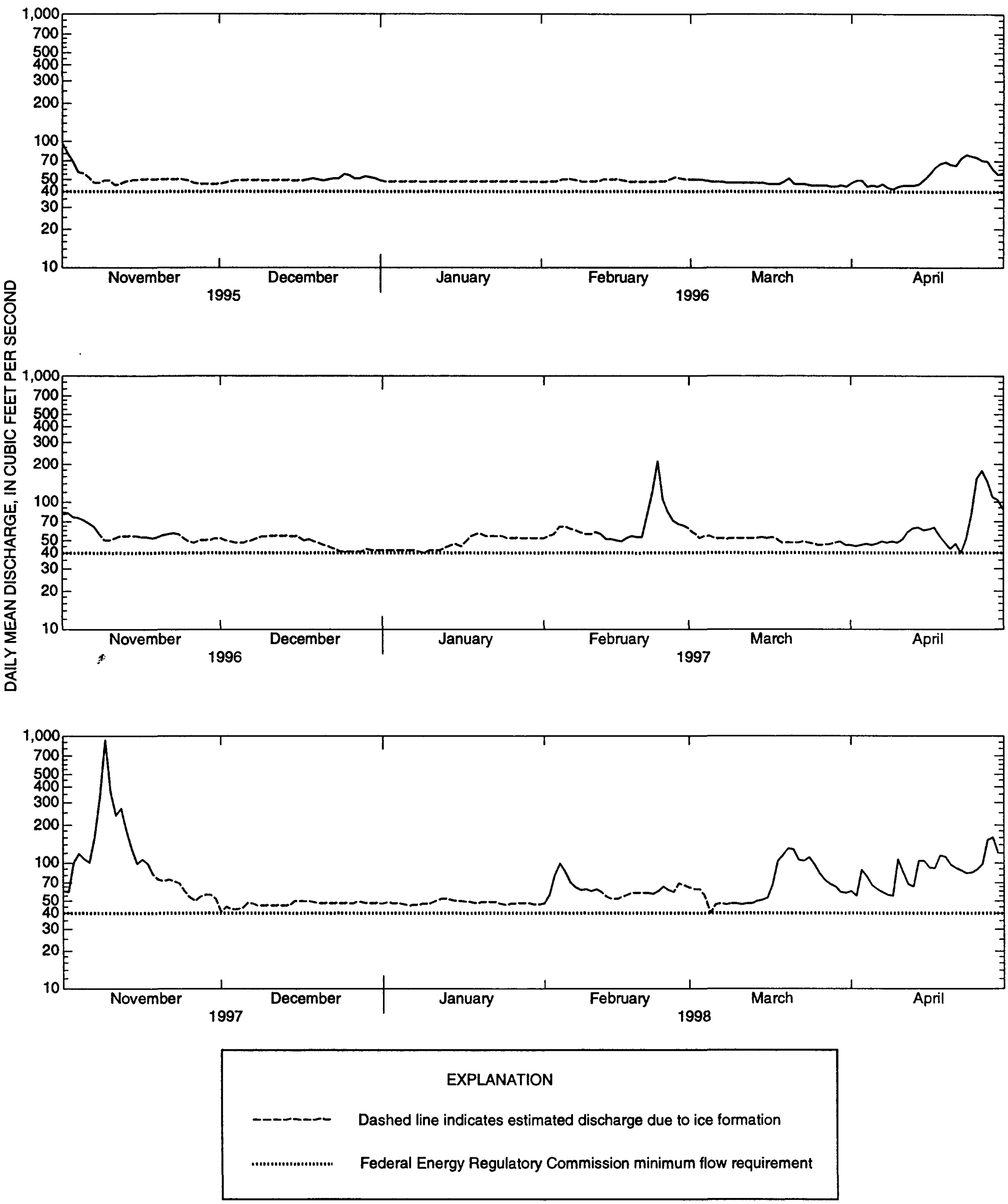

Figure 4. Daily mean discharges for Bradley River near Tidewater (station No. 15239070).

Discharge measurements were made at the six transects in the lower Bradley River (fig. 2) where most spawning activity occurs (Morsell and others, 1993, p. 12). Measured discharges ranged from 33.3 ft^3/s on March 5, 1998 at Lower Riffle Reach transect to 72.8 ft^3/s on March 4, 1998 at Tree Bar Reach transect. These measured discharges ranged between 83 and 182 percent of the 40 ft^3/s target flow. Comparison of discharge measurements made at the six study transects indicates no net exchange between ground water and streamflow from the Bear Island transect to the Lower Riffle Reach transect.

Intermittent instantaneous discharge measurements were made during the 1996 water year at the Middle Fork Bradley River below North Fork Bradley River. A USGS stream-gaging station was installed in July 1996 (station No. 15239060, figs. 1 and 2). Instantaneous discharge measurements for the 1996 water year and daily mean discharge data from November 1 through April 30, water years 1997 and 1998 are shown in figure 5. Streamflow that was estimated because of ice effect is shown using dashed lines. Four periods of ice formation occurred during water year 1997 and three occurred in 1998.

Daily mean discharge for the study period ranged from 2.5 to 626 ft^3/s. On many days, discharges were much less than the lowest instantaneous discharge measured between March 1993 and April 1995 (Rickman, 1995 and 1996). This phenomenon resulted because of unusually dry conditions. Precipitation in the Bradley River basin was 80 percent of normal during the 1996 and 1997 water years. Discharge contributions from the lower Middle Fork and North Fork Bradley River (fig. 1) to the lower Bradley River averaged 34 percent and ranged between 6 and 91 percent.

Hydraulic Data

Ice formation can significantly affect hydraulic conditions of the river. When ice constricts the open channel or changes the roughness of the channel, "ice backwater" effects change the stage/discharge relation. When ice backwater occurs, hydrostatic head and wetted perimeter usually increase, and mean velocity usually decreases when compared against ice-free conditions.

Three types of river icing phases were noted during this study. For this report, they are referred to as forming, stable, and eroding. Ice was observed to form in the lower Bradley River by coalescing of frazil ice, anchor ice formation, and shore-fast ice formation. Frazil ice formation is common in turbulent streams. Anchor ice forms when super-cooled liquid water attaches or nucleates to form ice on the streambed (Ashton, 1986, p. 282). Shore-fast ice was observed to grow and extend out into the river channel from both banks leaving a single narrow open lead. Eventually, this lead freezes over completely. Ice conditions eventually reach a point of equilibrium where ice is neither forming nor eroding at a noticeable rate. For this report, this is referred to as the *stable phase*. Frazil and anchor ice were never present in the study reach during the stable phase.

Eroding ice conditions occurred as air temperatures rose high enough to weaken and/or melt the ice. Frazil and anchor ice were never present in the study reach during the eroding phase. Eventually, the ice weakens to a point where backwater from high tides lifts and fractures the ice.

Forming ice conditions consistently resulted in ice backwater at the upper three transects (Bear Island, Tidewater, and Tree Bar Reach), when compared with ice-free periods

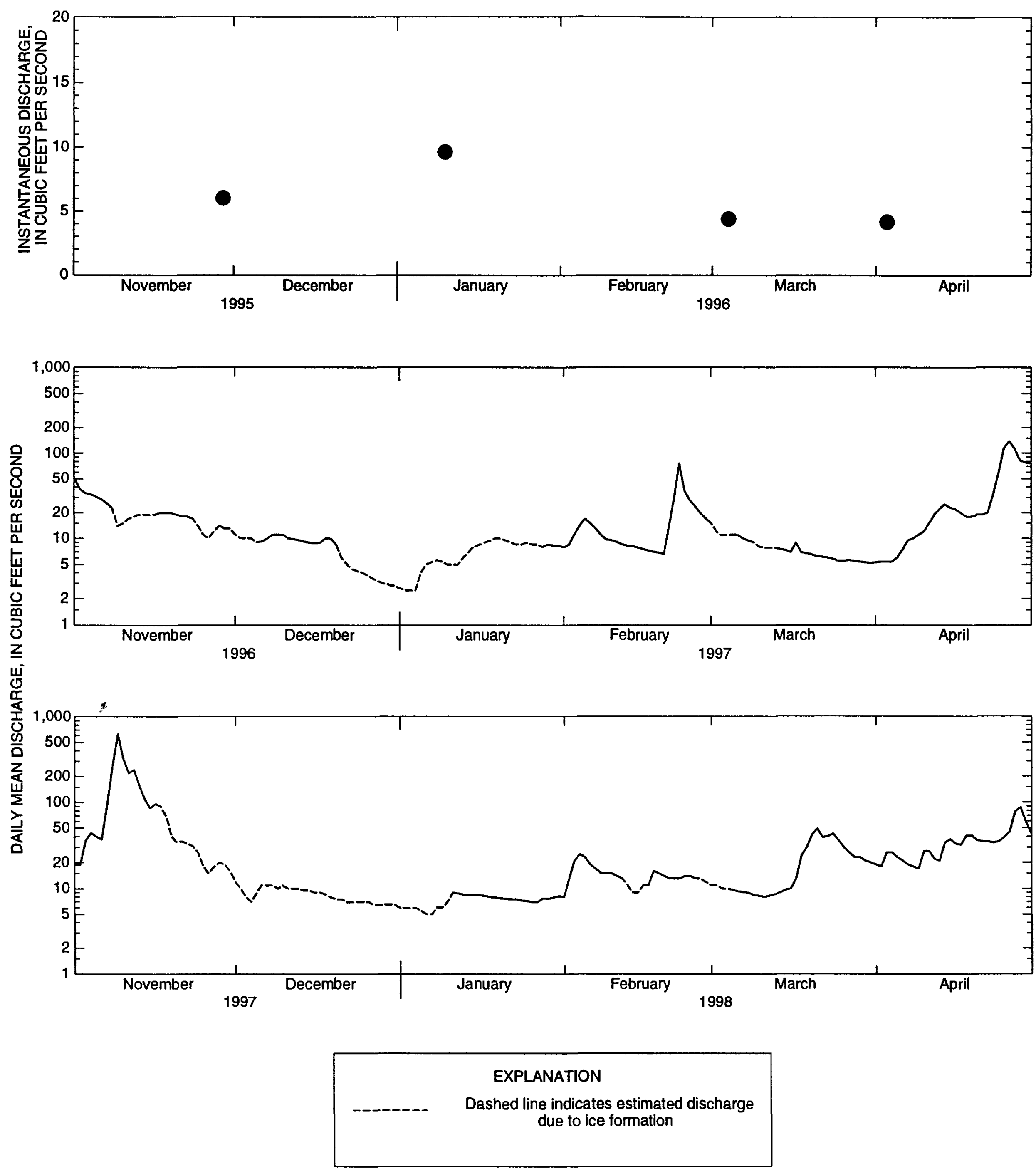

Figure 5. Instantaneous discharge measurements and daily man discharges for Middle Fork Bradley River below North Fork Bradley River (station No. 15239060).

at similar discharges. Increases in water depth and wetted perimeter, as well as decreases in mean velocity were also found in previous years (hydrostatic heads were not measured prior to November 1995) (Rickman, 1995 and 1996). The effects of forming ice on velocity, water depth, and wetted perimeter at the lower three transects (Fish Camp, Upper Riffle Reach, and Lower Riffle Reach) were not conclusive. These findings agree with measurements made in previous years (Rickman, 1995, 1996). However, hydrostatic head was greater at the Bradley River below Fish Camp and Upper Riffle Reach transects during periods of forming ice.

Stable and eroding ice conditions did not consistently create ice backwater when compared against ice-free conditions at similar discharges (table 1). Some exceptions to this are as follows: (1) wetted perimeter measured on December 17, 1996 (eroding ice conditions) at the Bradley River at Bear Island transect included a 26-foot-wide section of wetted gravels beneath the ice cover, with no layer of water in between (fig. 6E)[1]; (2) wetted perimeter measured on February 27, 1996 (eroding ice conditions) at the Bradley River near Tidewater transect was 8 percent less than that at a similar discharge with ice-free conditions; (3) wetted perimeter measured on March 18, 1997 (stable ice conditions) at the Bradley River below Fish Camp transect was 11 percent greater than that for ice-free conditions at a similar discharge, and was the largest measured for all ice conditions at similar discharge at the Upper Riffle Reach transect; and (4) wetted perimeter measured April 23, 1997 (no ice) at the Bradley River at Lower Riffle Reach was much lower than that for all other measurements because of extensive recent mud deposits along the banks.

Water velocity distribution within each transect varied significantly with ice formation at all six transects (figs. 6-11). The most striking examples are at Bradley River at Bear Island (fig. 6) and at Bradley River at Tree Bar Reach (fig. 8). Ice formation forces most of the flow into narrow parts of the channels. Each ice episode is unique, and no consistent patterns of velocity distribution were found when comparing episodes.

[1]Figures 6-12 are at the end of the report.

WATER-QUALITY DATA

Temperature

Surface-water temperature fluctuated more than intragravel-water temperature for 1995-96 (fig. 12), as had been observed in previous years (Rickman, 1996; U.S. Geological Survey, 1987-1998). Surface water is generally colder than intragravel water during cold weather periods, and warmer than intragravel water during warm weather periods. During 1996-97 and 1997-98, surface-water and intragravel-water temperatures were similar. Extended periods of 0 °C surface-water temperature are common. Intragravel-water temperature occasionally dropped to 0 °C, but for a shorter time, except during 1997-98 when surface- and intragravel-water temperatures were nearly identical. The reason for this change is unknown, but may be influenced by redd construction, which can change intragravel flow characteristics and circulate surface water past the intragravel-water temperature probe.

Surface-water temperature measurements, made concurrently with discharge measurements, show that temperatures were relatively constant among transects for each sample period (table 2). Intragravel-water temperature measurements were also made concurrently with discharge measurements at each transect. Intragravel-water temperatures varied more among transects for each sample period (table 2), probably because of a combination of difference in water source among transects, and measurement error.

Table 1. Selected hydrologic properties for the lower Bradley River, November 1995 to April 1998

[ft, foot; ft/s; foot per second; ft^3/s, cubic foot per second; <, less than; >, more than; e, estimated; --, no data]

Transect site (fig. 2)	Date	Ice cover (percent)	Ice condition	Discharge (ft^3/s)	Discharge error (percent)	Mean velocity (ft/s)	Mean depth (ft)	Mean hydrostatic head (ft)	Wetted perimeter (ft)
Bear Island	12-04-95	100	Forming	e46	>8	(a)	1.16	2.12	130.5
	01-11-96	100	Forming	45.1	>8	0.53	1.09	1.64	78.7
	02-27-96	60	Eroding	54.6	5	0.83	1.03	1.03	64.2
	04-02-96	10	Eroding	48.8	>8	1.13	0.54	0.54	60.0
	12-17-96	30	Eroding	52.6	5	1.12	0.48	0.48	98.7
	01-09-97	100	Stable	41.4	>8	1.90	0.41	1.02	63.3
	02-12-97	35	Eroding	58.6	5	1.28	0.65	0.65	70.1
	03-18-97	100	Stable	53.5	>8	1.46	0.57	0.76	68.7
	04-23-97	0	None	40.5	8	1.43	0.46	0.46	61.8
	03-03-98	50	Forming	e63	>8	--	--	--	96.1
	03-04-98	50	Forming	43.3	>8	0.98	0.54	0.80	80.2
	03-05-98	50	Forming	e34	>8	--	--	--	62.6
Tidewater	11-29-95	100	Forming	e46	>8	(a)	1.90	2.09	61.1
	01-11-96	100	Forming	43.4	>8	0.49	2.03	2.72	43.3
	02-27-96	35	Eroding	53.1	5	1.27	1.13	1.13	37.4
	04-02-96	0	None	48.6	5	1.17	1.04	1.04	40.3
	12-17-96	50	Eroding	52.6	5	1.14	1.11	1.11	42.5
	01-09-97	100	Forming	e40	>8	1.38	0.71	1.45	40.5
	02-12-97	0	None	52.9	5	1.15	1.14	1.14	40.5
	03-17-97	40	Forming	53.7	>8	1.37	1.06	1.30	37.6
	04-23-97	0	None	46.6	8	1.19	1.10	1.10	39.4
	12-03-97	45	Forming	43.4	8	0.59	1.62	1.62	46.0
	01-14-98	100	Forming	51.4	8	0.63	1.78	2.20	47.0
	03-03-98	30	Forming	62.2	8	0.95	1.56	1.90	42.9
	03-04-98	30	Forming	63.6	8	0.88	1.71	1.71	42.6
	03-04-98	30	Forming	59.4	8	0.89	1.60	1.60	42.3
	03-04-98	30	Forming	42.2	8	0.72	1.42	1.42	42.0
	03-05-98	30	Forming	37.2	>8	0.66	1.35	1.35	41.9
	03-05-98	30	Forming	33.5	8	0.59	1.37	1.37	42.1
	03-05-98	30	Forming	38.3	5	0.66	1.37	1.37	42.5
Tree Bar Reach	11-29-95	100	Forming	e46	>8	(a)	1.01	1.70	75.2
	01-11-96	95	Forming	e43	>8	(a)	1.40	2.17	73.9
	03-04-96	<20	Eroding	48.8	>8	1.20	0.62	0.62	65.6
	04-02-96	0	None	45.3	8	1.28	0.55	0.55	65.1
	12-17-96	60	Eroding	52.3	8	1.28	0.58	0.58	70.8
	01-09-97	100	Forming	39.0	>8	1.00	0.65	2.09	74.6
	02-12-97	0	None	54.5	5	1.22	0.64	0.64	70.4
	03-18-97	92	Stable	53.0	>8	0.80	0.93	1.31	71.6
	04-23-97	0	None	46.6	8	1.12	0.61	0.61	68.2
	12-03-97	33	Forming	46.1	>8	0.67	0.92	1.28	74.7

Table 1. Selected hydrologic properties for the lower Bradley River, November 1995 to April 1998 -- Continued

Transect site (fig. 2)	Date	Ice cover (percent)	Ice condition	Discharge (ft^3/s)	Discharge error (percent)	Mean velocity (ft/s)	Mean depth (ft)	Mean hydrostatic head (ft)	Wetted perimeter (ft)
Tree Bar Reach									
(continued)	03-03-98	56	Forming	65.8	8	0.81	1.12	1.59	73.4
	03-04-98	56	Forming	72.8	8	0.65	1.54	1.68	73.8
	03-05-98	56	Forming	34.0	8	0.53	0.89	1.23	72.3
Below Fish Camp	12-05-95	100	Forming	43.4	>8	0.82	0.79	2.24	67.5
	01-12-96	100	Forming	e43	>8	(a)	1.22	1.67	58.4
	03-04-96	67	Eroding	42.8	>8	0.61	1.23	1.64	57.7
	04-03-96	80	Forming	54.0	8	0.80	1.30	1.30	52.3
	12-18-96	100	Eroding	60.6	>8	1.01	1.08	1.58	57.2
	02-12-97	0	None	53.2	5	0.80	1.20	1.20	55.8
	03-18-97	100	Stable	50.9	>8	0.85	0.97	1.52	61.8
	04-23-97	0	None	48.0	8	0.75	1.18	1.18	55.6
	03-04-98	100	Forming	62.2	>8	0.95	1.08	1.71	61.3
	03-05-98	100	Forming	34.7	>8	0.62	1.00	1.46	56.5
	03-05-98	100	Forming	43.8	>8	0.73	1.07	1.60	56.8
Upper Riffle Reach	12-04-95	100	Forming	[b]40.1	>8	[b]0.67	0.72	1.60	84.3
	01-12-96	100	Forming	e43	>8	(a)	0.86	1.30	83.7
	03-05-96	100	Eroding	50.2	8	0.90	0.67	1.22	83.6
	04-03-96	60	Forming	54.5	8	0.75	0.94	0.94	77.8
	12-18-96	100	Eroding	60.6	>8	0.67	1.11	1.33	83.9
	02-12-97	0	None	60.6	5	0.79	0.92	0.92	84.0
	03-18-97	100	Stable	54.0	>8	0.86	0.73	0.96	87.0
	04-23-97	0	None	47.6	8	0.73	0.86	0.86	75.6
Lower Riffle Reach	12-04-95	100	Forming	42.1	>8	1.02	0.56	1.37	77.2
	01-12-96	100	Forming	e43	>8	(a)	0.51	1.10	69.0
	03-05-96	100	Eroding	41.0	>8	0.77	0.73	1.04	73.2
	04-03-96	<10	Forming	49.8	8	1.07	0.62	0.62	75.4
	12-18-96	100	Eroding	56.0	>8	1.12	0.68	1.34	74.0
	02-12-97	0	None	63.3	8	1.30	0.63	0.63	83.6
	03-18-97	100	Stable	50.8	>8	1.22	0.49	0.73	86.7
	04-23-97	0	None	49.9	8	1.32	0.62	0.62	[c]61.4
	03-04-98	60	Forming	64.1	>8	0.97	0.89	1.02	82.8
	03-05-98	60	Forming	33.3	8	0.81	0.53	0.71	79.3

[a]Unable to measure all properties because of anchor ice and multiple ice layers

[b]Measurements may be tide affected

[c] Channel banks have filled with mud brought in during high tides

Table 2. Selected water-quality data and site characteristics for the lower Bradley River, November 1995 to April 1998

[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; --, no data]

Transect site (fig. 2)	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)	Dissolved oxygen percent saturation	Hydrostatic head above streambed (ft)	Surface-water velocity (ft/s)
Bear Island	12-04-95	770	0.0	13.7	93	--	--	--	--	--	--
	01-11-96	764	0.0	14.4	98	--	--	14.0	--	1.42	0.11
	03-04-96	770	0.0	14.4	98	--	--	13.7	--	0.50	<0.20
	04-03-96	750	0.0	14.1	97	--	--	14.0	--	0.20	0.45
	12-17-96	748	0.0	14.4	100	65	0.0	13.6	95	0.70	0.19
	01-09-97	744	0.0	14.4	101	59	0.0	12.5	88	0.98	1.69
	02-12-97	744	1.0	--	--	71	1.0	13.8	99	0.50	0.30
	04-23-97	763	2.5	13.4	98	70	2.0	--	--	--	--
Tidewater	11-29-95	762	0.0	13.9	95	--	--	12.6	--	1.90	--
	01-11-96	764	0.0	14.6	99	--	--	12.5	--	3.04	0.49
	03-04-96	770	0.0	14.2	96	--	--	13.2	--	0.20	<0.20
	04-03-96	752	0.0	11.9	83	--	--	13.1	--	0.30	0.30
	12-17-96	748	0.0	13.7	95	65	1.5	9.2	67	1.05	1.09
	01-09-97	746	0.0	14.0	98	59	0.5	13.5	96	1.00	0.69
	02-12-97	744	1.0	13.8	99	71	1.5	13.3	97	0.41	0.60
	03-18-97	738	0.0	9.5	67	73	--	11.2	81	1.03	1.01
	04-23-97	763	2.5	13.8	101	70	2.5	13.1	95	0.58	0.98
	12-03-97	755	0.0	14.1	97	77	0.5	13.1	92	1.24	0.60
	03-04-98	772	0.0	14.4	97	72	0.5	14.0	96	0.60	0.18
	03-05-98	768	0.0	13.6	92	72	0.0	10.8	73	0.60	0.50
Tree Bar Reach	11-29-95	762	0.5	11.0	75	--	0.0	10.4	71	2.00	0.50
		762	0.5	12.6	88	--	0.0	9.3	63	2.00	0.50
	01-11-96	764	0.0	14.7	100	--	0.5	10.8	76	1.36	0.98
	03-04-96	770	0.0	14.3	97	--	0.5	8.2	57	0.60	0.76
	04-03-96	750	0.0	--	--	--	0.5	13.3	95	0.20	0.20
	12-17-96	748	0.0	14.2	99	65	0.0	13.2	92	0.83	0.95
	01-09-97	746	0.0	14.8	103	59	0.5	14.0	99	1.55	0.87
	02-12-97	754	1.0	14.2	101	71	1.5	12.2	88	0.32	0.74
	03-18-97	738	0.0	11.9	84	73	0.0	12.2	86	1.04	0.98
	04-23-97	763	2.5	13.1	96	70	2.0	11.7	84	0.36	0.83
	12-03-97	755	0.0	14.3	99	77	--	--	--	--	--
	03-04-98	773	0.0	14.4	97	72	0.0	9.6	65	1.30	1.35
	03-05-98	769	0.0	14.0	95	72	0.0	13.0	88	0.82	0.44

Table 2. Selected water-quality data and site characteristics for the lower Bradley River, November 1995 to April 1998 --Continued

Transect site (fig. 2)	Date	Baro-metric pressure (mm Hg)	Surface water				Intragravel water			Intragravel sample location	
			Temper-ature (°C)	Dis-solved oxygen (mg/L)	Dissolved oxygen percent saturation	Specific conduct-ance (µs/cm)	Temper-ature (°C)	Dis-solved oxygen (mg/L)	Dissolved oxygen percent saturation	Hydrostatic head above streambed (ft)	Surface-water velocity (ft/s)
Below Fish Camp	12-05-95	781	0.0	13.3	89	--	--	12.9	--	1.95	0.49
	01-12-96	768	0.0	14.6	99	--	0.5	10.0	68	1.80	0.31
	03-04-96	770	0.0	14.2	96	--	0.5	10.3	71	1.68	0.33
	04-03-96	752	0.0	12.3	84	--	--	14.0	--	0.20	0.69
	12-18-96	747	0.0	14.2	99	65	1.5	14.0	102	1.35	0.81
	02-12-97	754	0.5	14.0	98	71	2.0	12.6	92	0.98	0.62
	03-18-97	739	0.0	11.7	83	75	--	12.8	93	2.02	0.80
	04-23-97	768	2.0	13.5	97	70	1.5	15.3	108	1.22	0.64
	03-05-98	767	0.0	13.9	94	72	0.0	13.7	93	1.82	0.58
Upper Riffle Reach	12-04-95	770	0.0	13.8	93	--	--	8.7	--	1.20	--
	01-12-96	768	0.0	14.7	99	--	--	--	--	0.90	0.22
	03-05-96	769	0.0	14.2	96	--	--	11.4	--	1.00	0.35
	04-03-96	752	0.0	12.1	84	--	--	11.5	--	0.30	0.47
	12-18-96	748	0.0	13.5	94	65	0.0	10.0	70	1.30	0.16
	02-12-97	755	0.5	13.7	96	72	0.5	14.2	100	1.11	0.68
	03-18-97	741	0.0	12.8	90	75	--	10.5	74	1.80	0.51
	04-23-97	763	2.0	13.3	96	70	1.5	14.5	103	0.80	0.50
Lower Riffle Reach	12-04-95	770	0.0	14.3	97	--	--	11.0	--	1.50	1.01
	01-12-96	768	0.0	14.7	99	--	--	--	--	--	--
	03-05-96	769	0.0	14.3	97	--	--	13.5	--	0.80	0.83
	04-03-96	752	0.0	14.0	97	--	--	11.2	--	0.40	0.61
	12-18-96	742	0.0	13.6	96	65	0.5	13.0	93	1.52	1.69
	02-12-97	755	1.0	13.8	97	72	1.0	13.5	96	0.65	1.25
	03-18-97	742	0.0	11.7	82	73	--	9.5	67	0.80	1.49
	04-23-97	767	2.0	14.3	103	70	1.5	12.5	89	0.72	1.36
	03-04-98	773	0.0	13.8	93	72	--	--	--	--	--
	03-05-98	769	0.0	14.2	96	72	--	--	--	--	--

Dissolved Oxygen

Dissolved-oxygen concentrations of surface water ranged from 67 percent saturation at the Tidewater transect on March 18, 1997, to 103 percent saturation at both the Tree Bar Reach transect on January 9, 1997, and the Lower Riffle Reach transect on April 23, 1997 (table 2). The causes of the unusually low surface-water dissolved-oxygen concentration (9.5 mg/L) measured on March 18, 1997 at the Tidewater transect are not readily apparent. Surface-water dissolved-oxygen concentrations were lower than average at several other transects on March 18, 1997. Contributing factors—such as percent ice cover, velocity distribution, water depth, hydrostatic head, and water temperature—were within the ranges observed during other periods.

Intragravel-water dissolved-oxygen concentrations were usually 0.1 to 6.1 mg/L lower than those for surface water (table 2). This range in differences is larger than those previously reported (Rickman, 1995, 1996). Intragravel-water dissolved-oxygen concentrations were greater than dissolved-oxygen surface-water concentrations at several of the transects during the April 1996 and March 1997 sample collections. The reasons for this are not understood. All chemicals used in these analysis were checked and determined to be fresh and at their correct concentrations.

Specific Conductance

Specific conductance values ranged from 59 to 77 μS/cm and did not vary significantly among transects or between field visits (table 2). The ranges of specific conductances reported here are similar to those reported previously (Rickman, 1995, 1996). Specific conductance does not appear to be related to flow, nor is there evidence that salt-water intrusion occurred at any of the six transects during the field visits.

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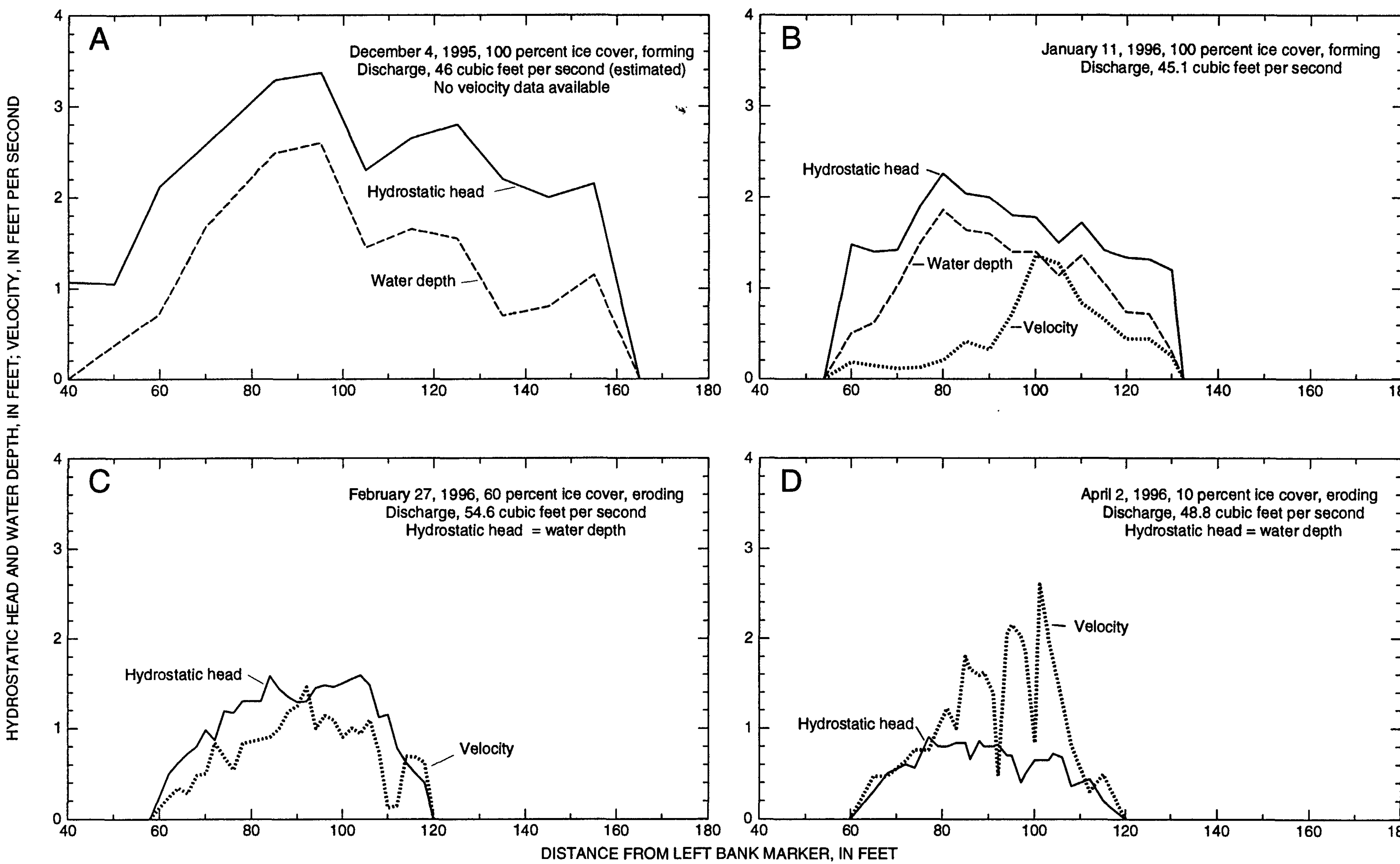

Figure 6. Hydrostatic head, water depth, and velocity distribution of the lower Bradley River at Bear Island. (See figure 2 for transect location).

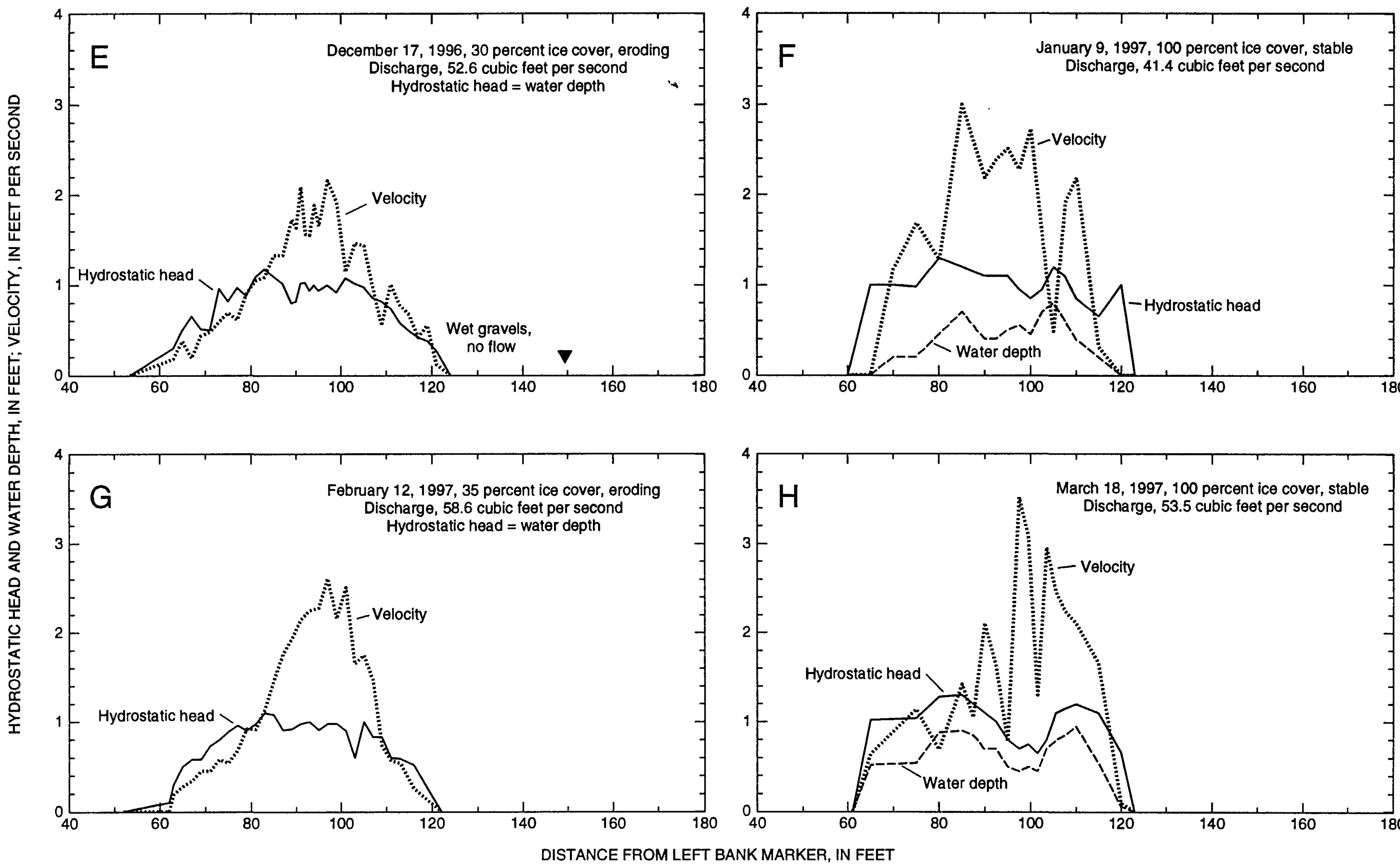

Figure 6. At Bear Island, Continued.

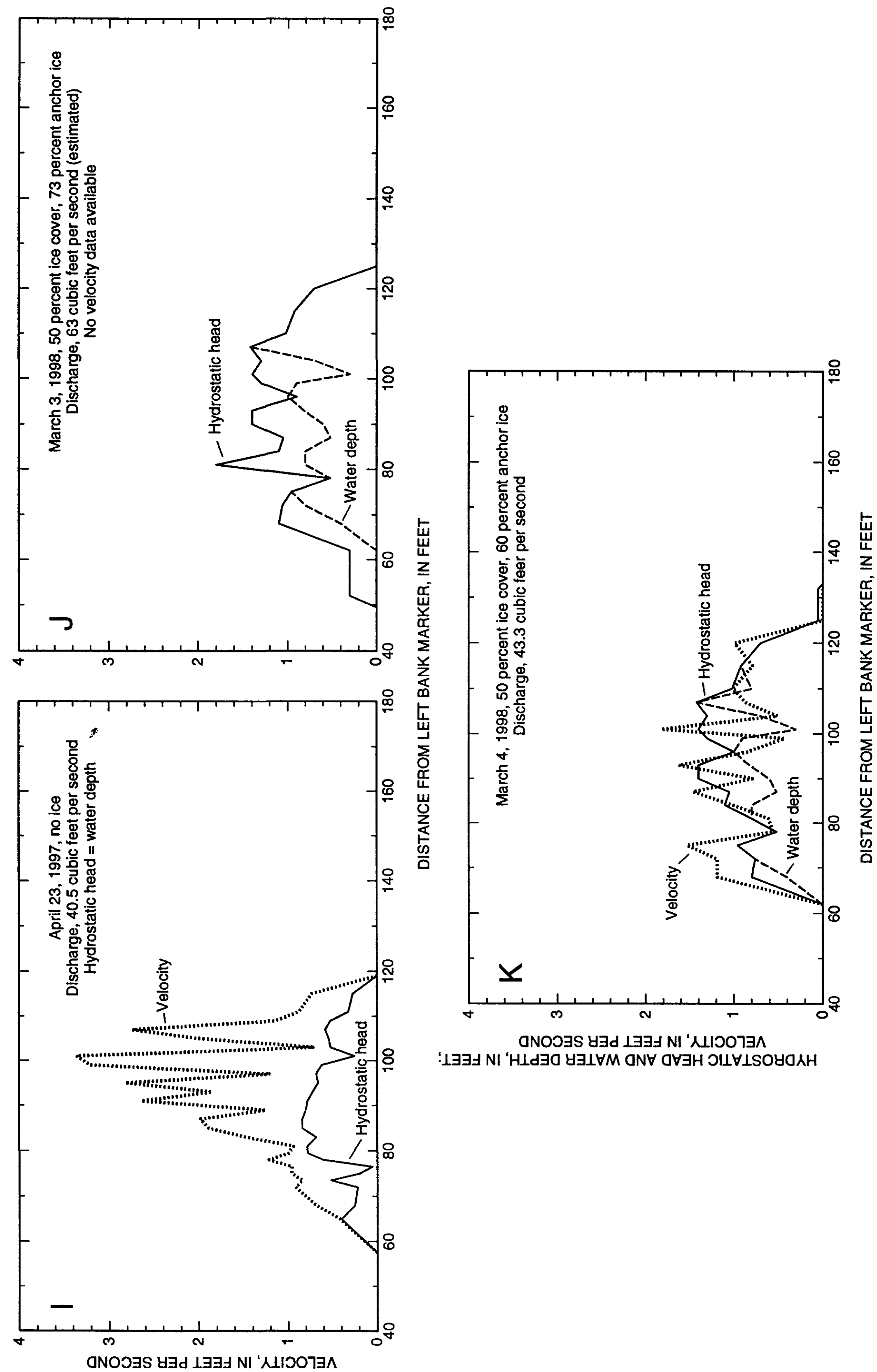

Figure 6. At Bear Island, Continued.

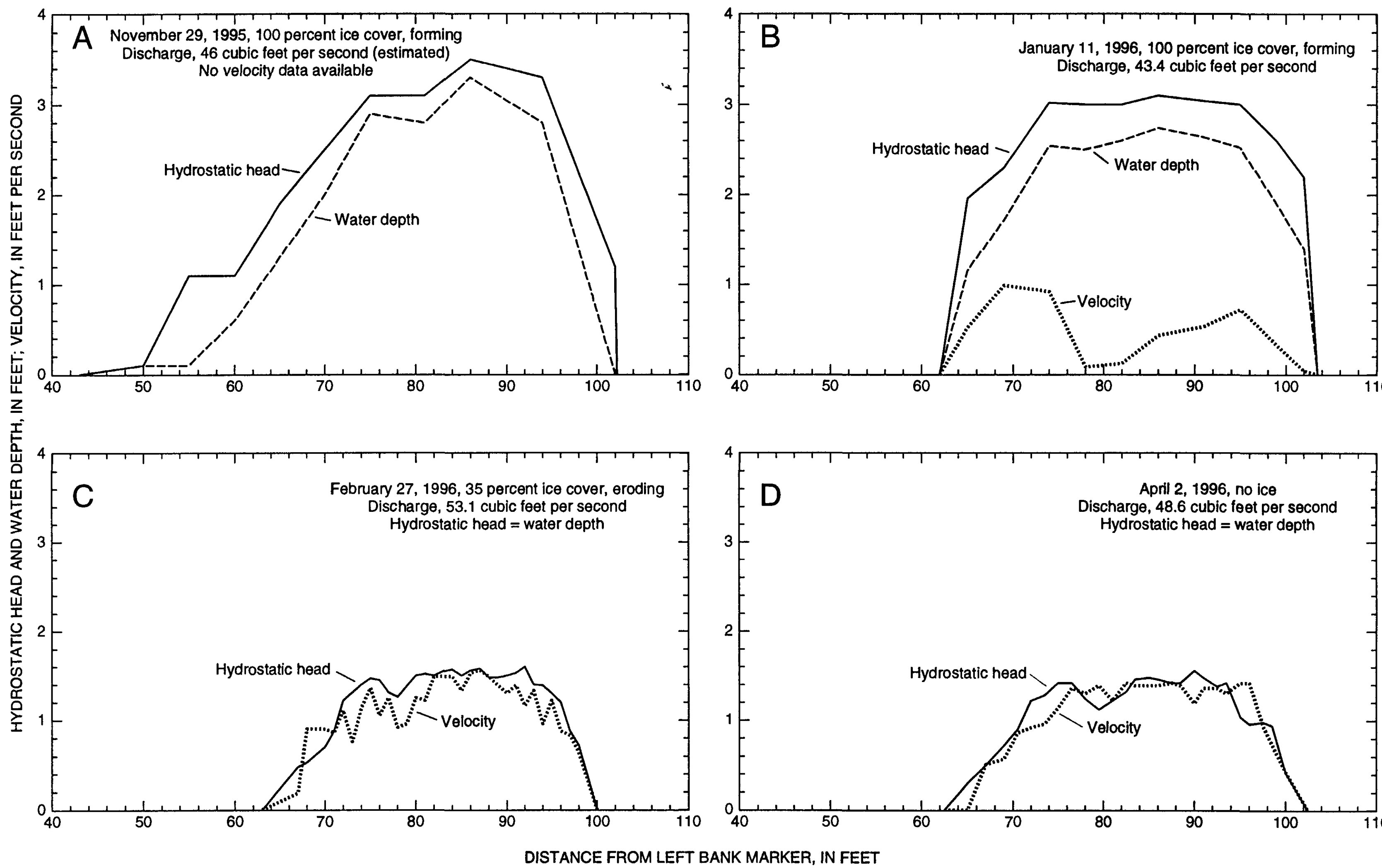

Figure 7. Hydrostatic head, water depth, and velocity distribution of the lower Bradley River near Tidewater. (See figure 2 for transect location).

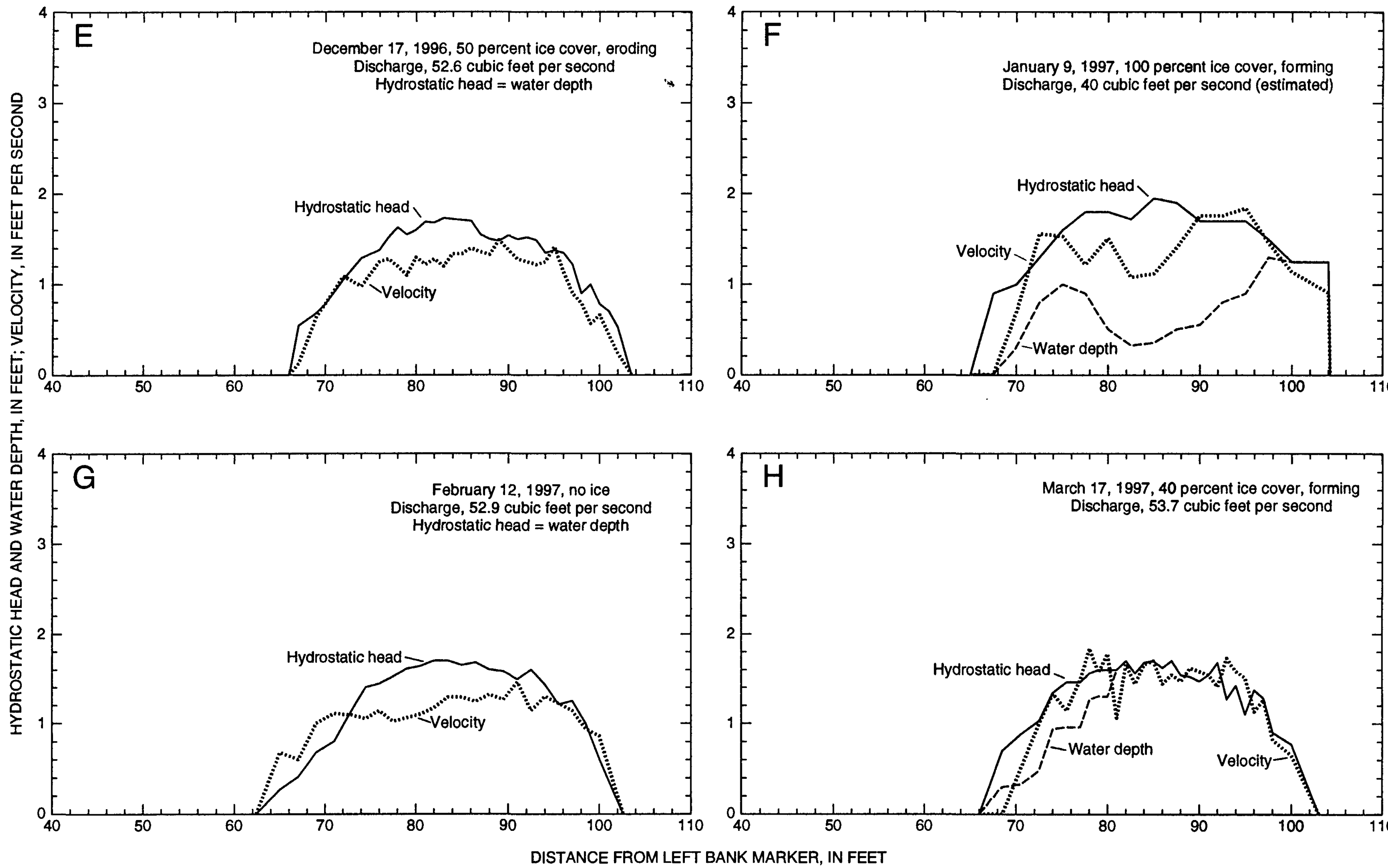

Figure 7. Near Tidewater, Continued.

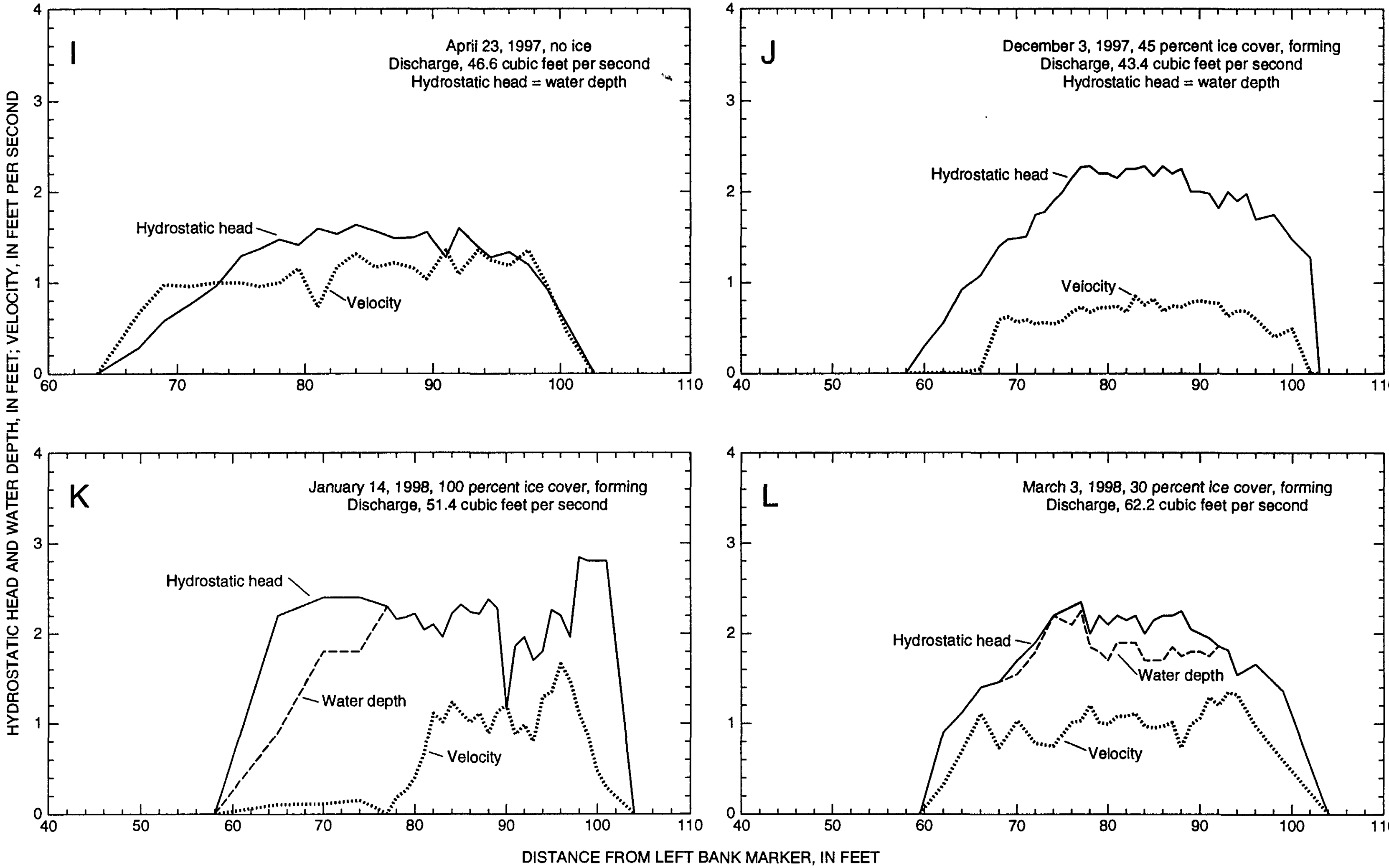

Figure 7. Near Tidewater, Continued.

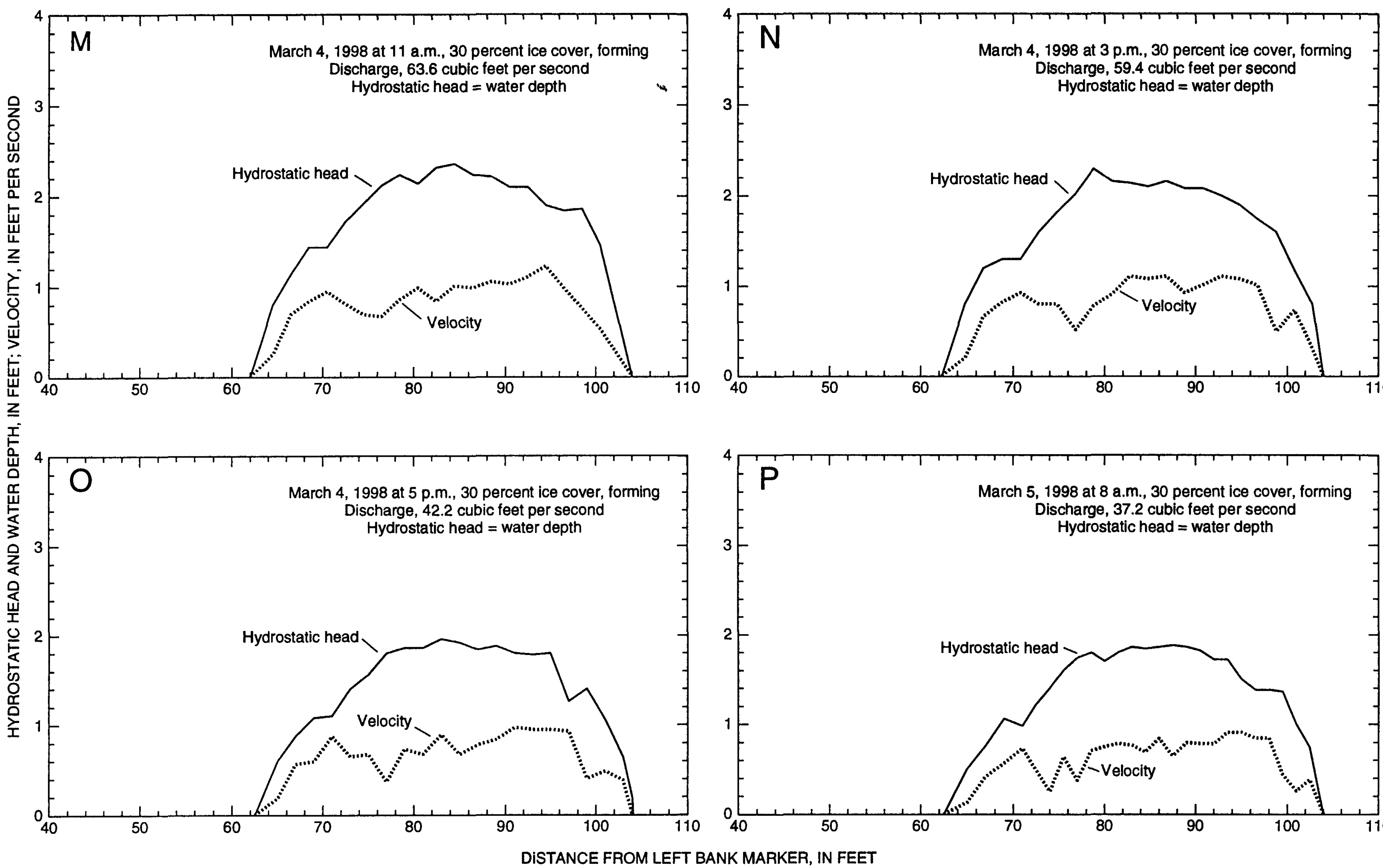

Figure 7. Near Tidewater, Continued.

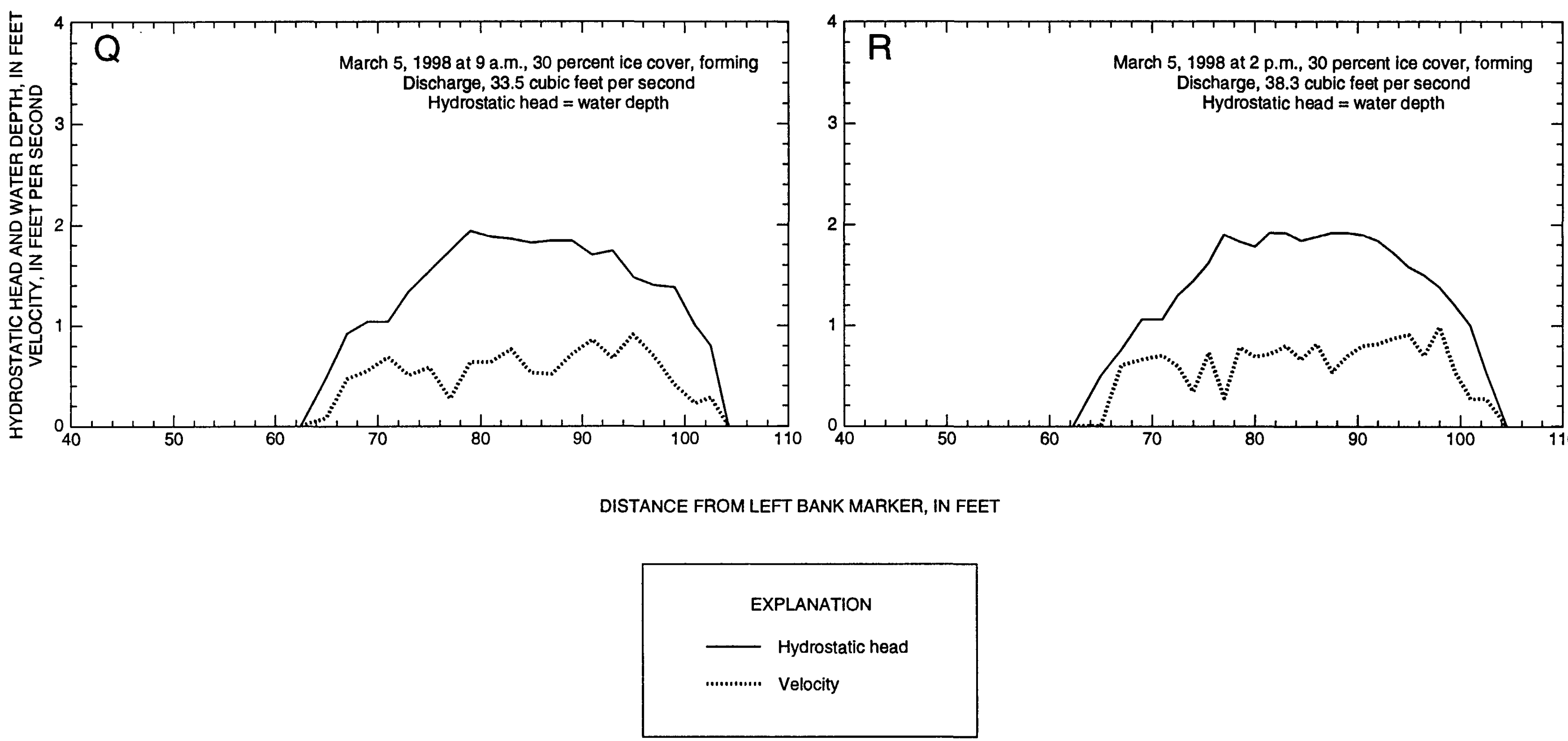

Figure 7. Near Tidewater, Continued.

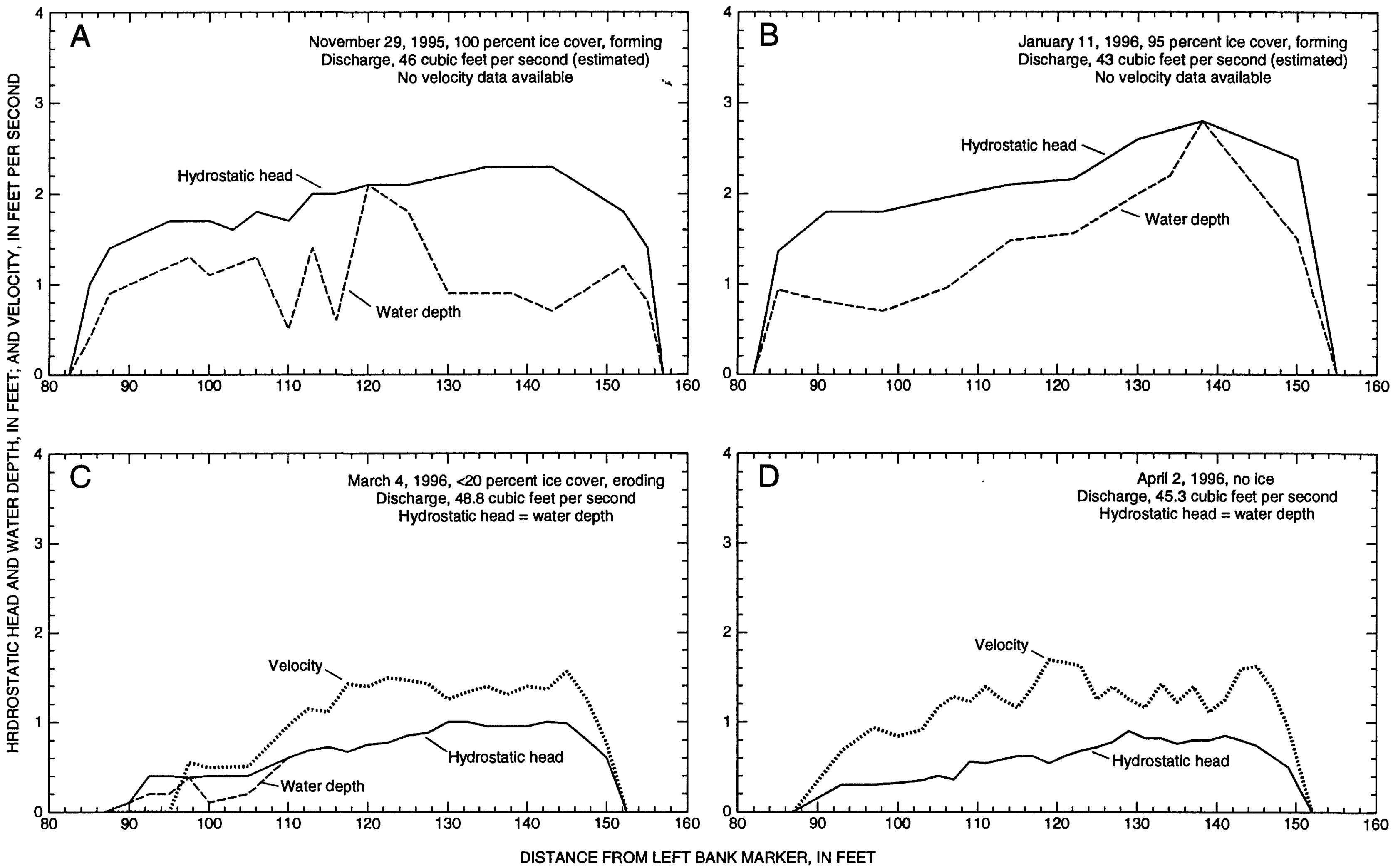

Figure 8. Hydrostatic head, water depth, and velocity distribution of the lower Bradley River at Tree Bar Reach. (See figure 2 for transect location).

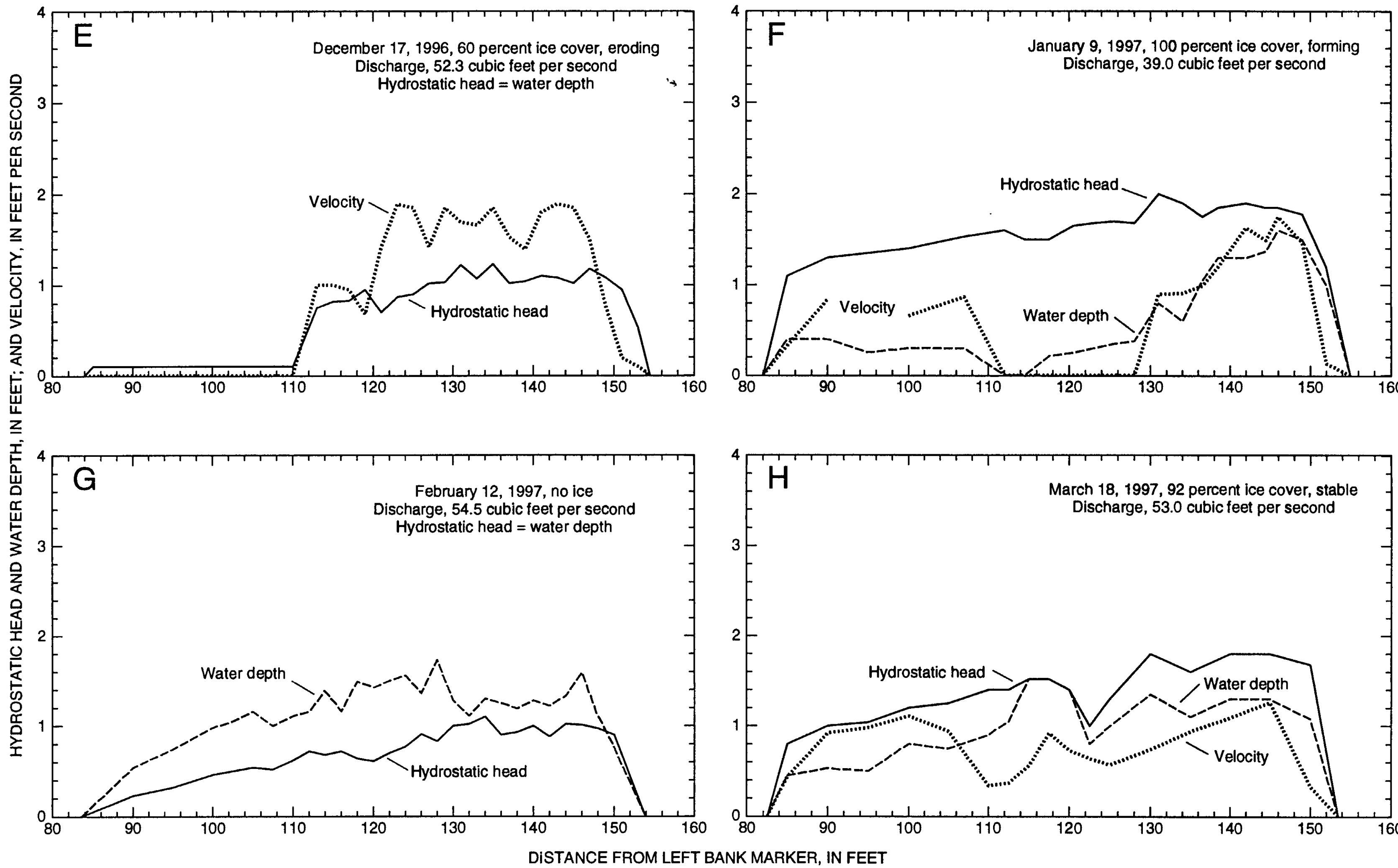

Figure 8. At Tree Bar Reach, Continued.

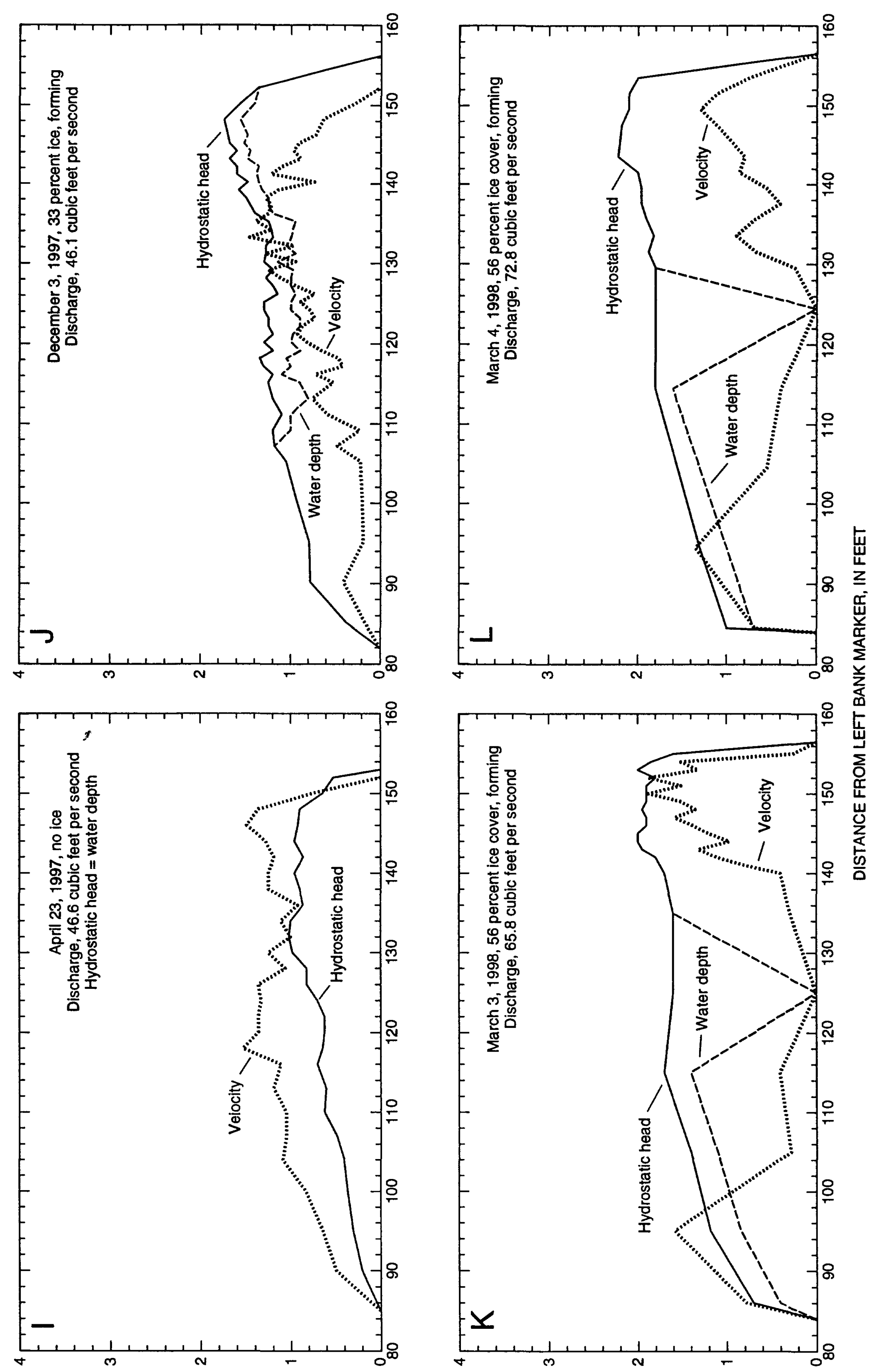

Figure 8. At Tree Bar Reach, Continued.

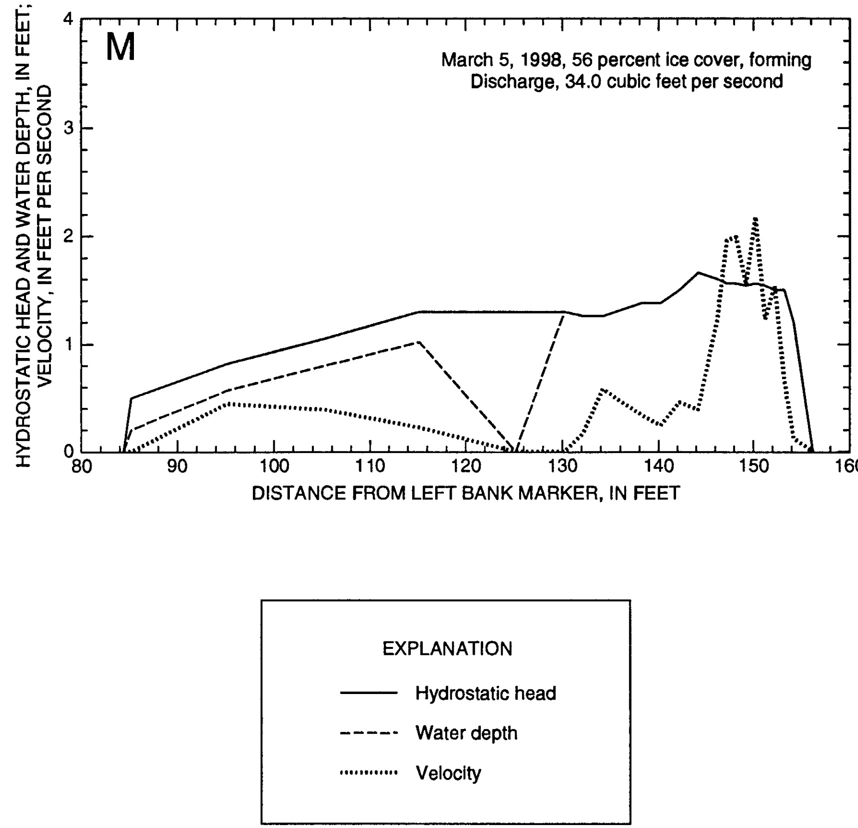

Figure 8. At Tree Bar Reach, Continued.

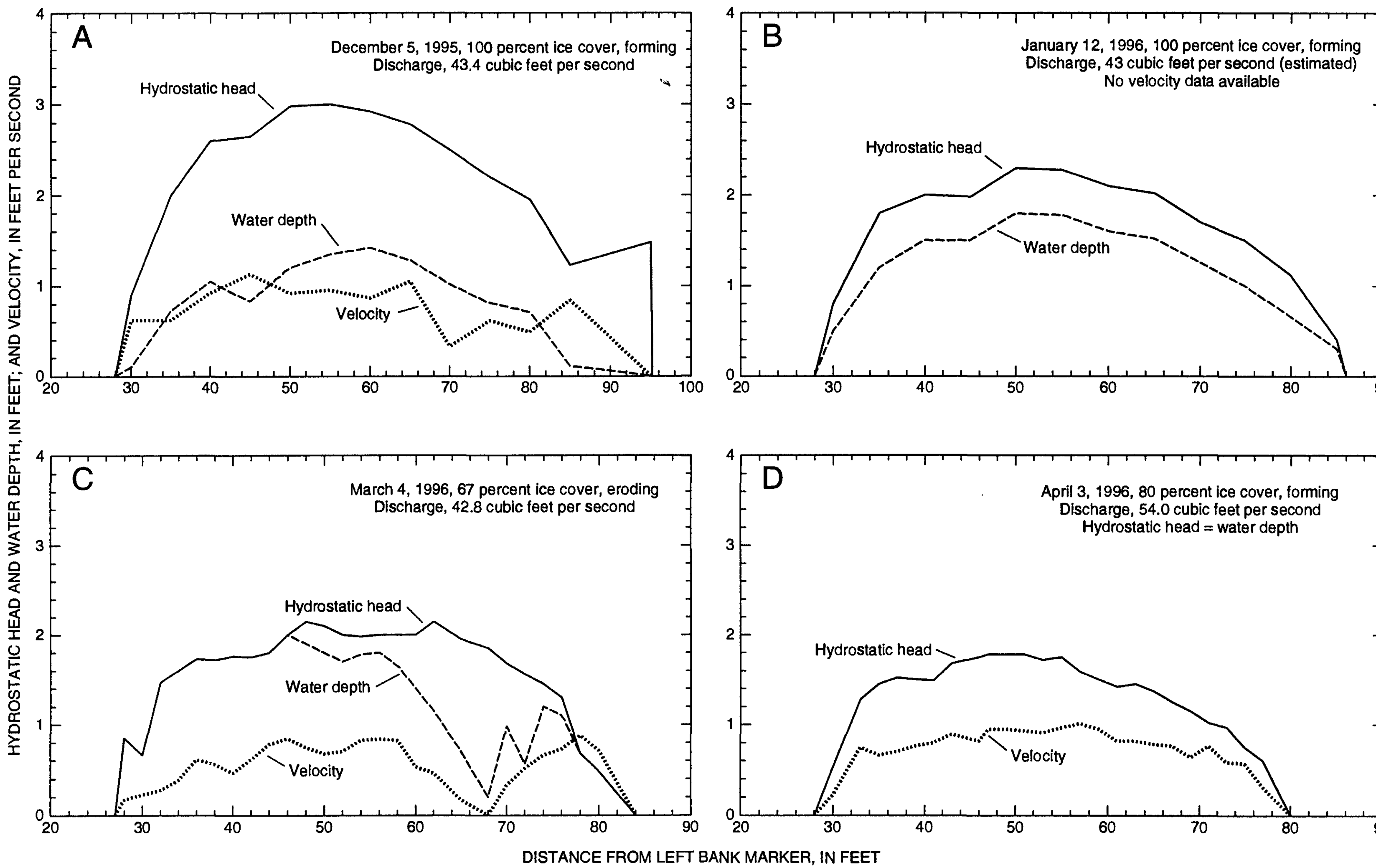

Figure 9. Hydrostatic head, water depth, and velocity distribution of the lower Bradley River below Fish Camp. (See figure 2 for transect location).

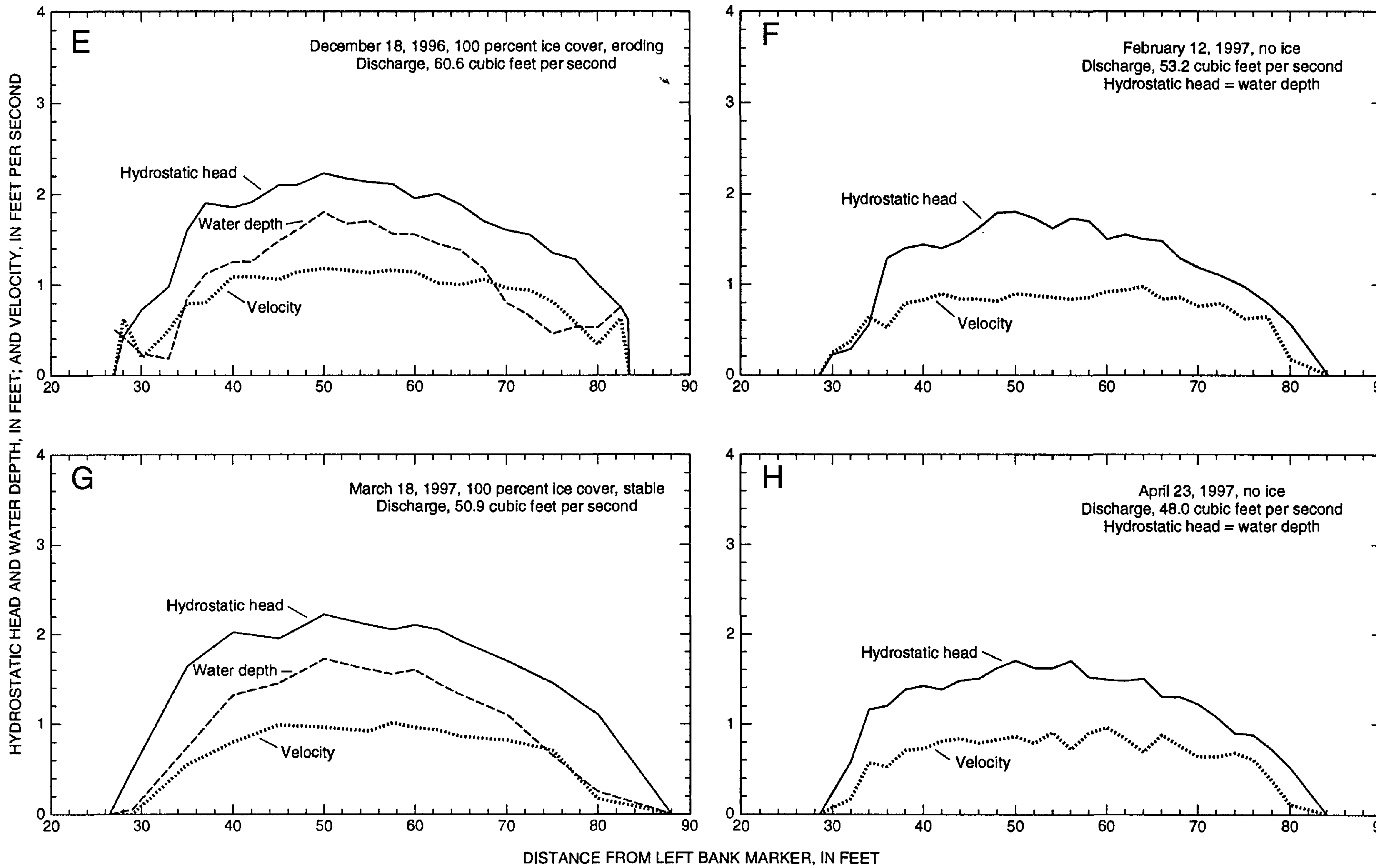

Figure 9. Below Fish Camp, Continued.

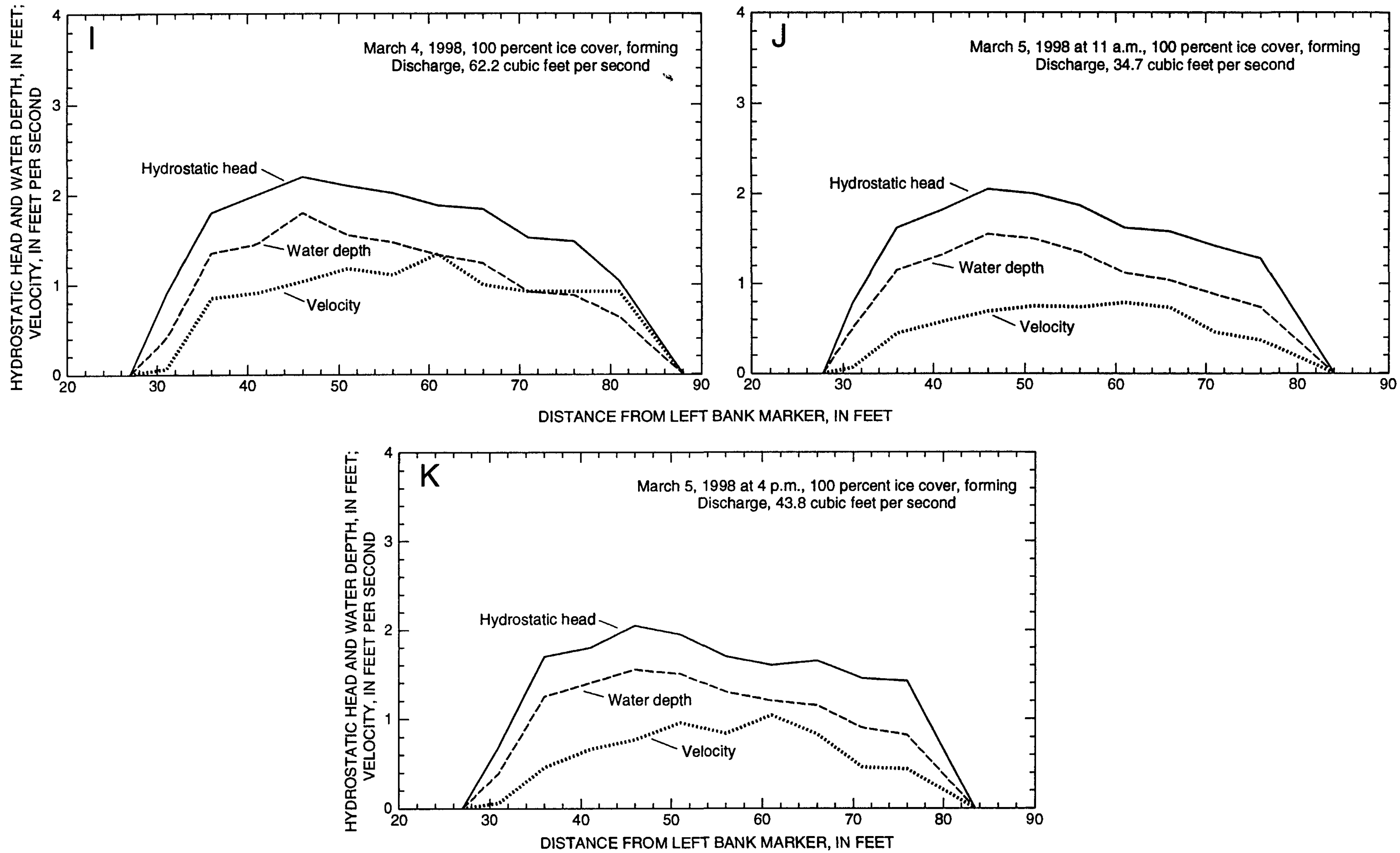

Figure 9. Below Fish Camp, Continued.

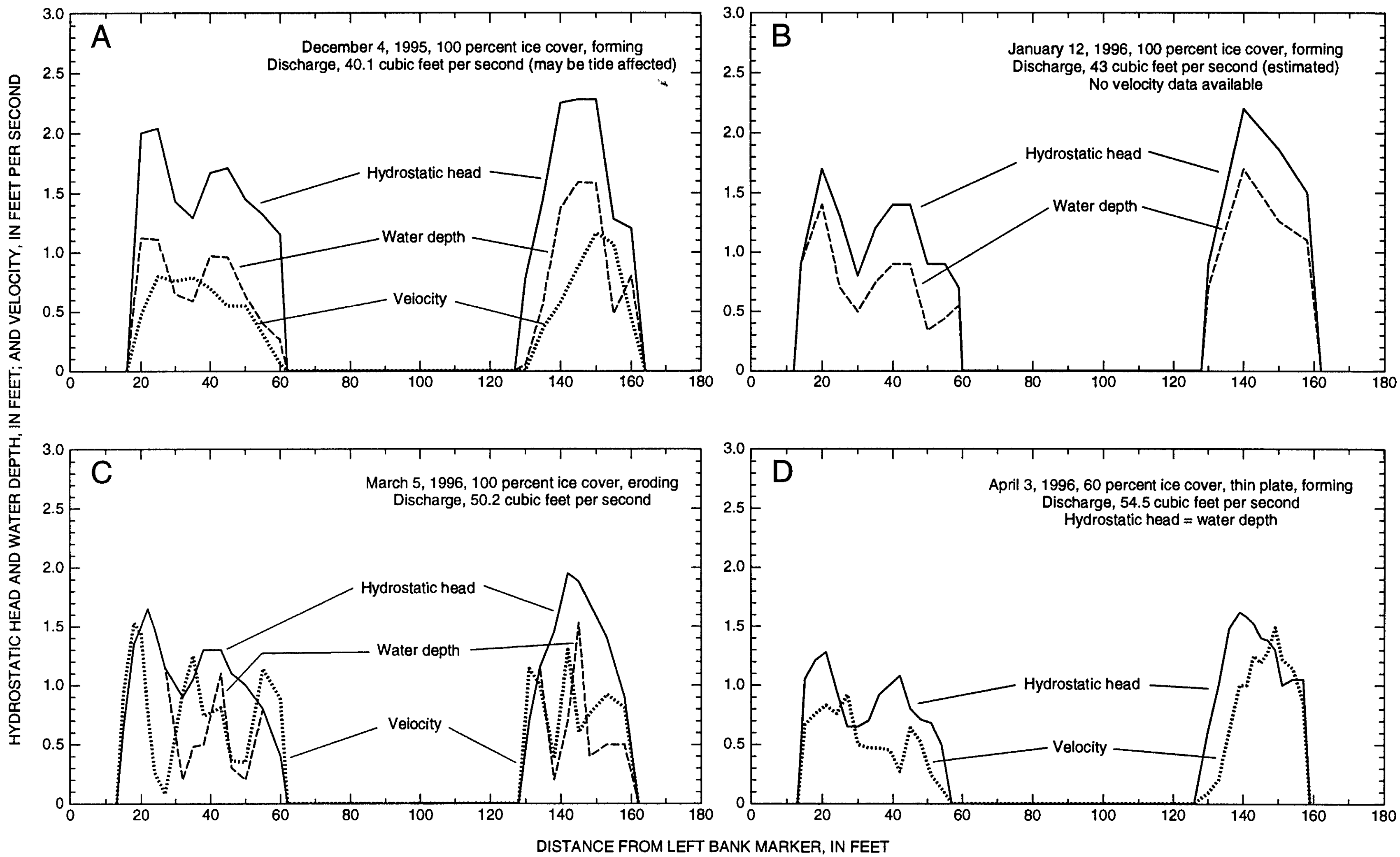

Figure 10. Hydrostatic head, water depth, and velocity distribution of the lower Bradley River at Upper Riffle Reach. (See figure 2 for transect location).

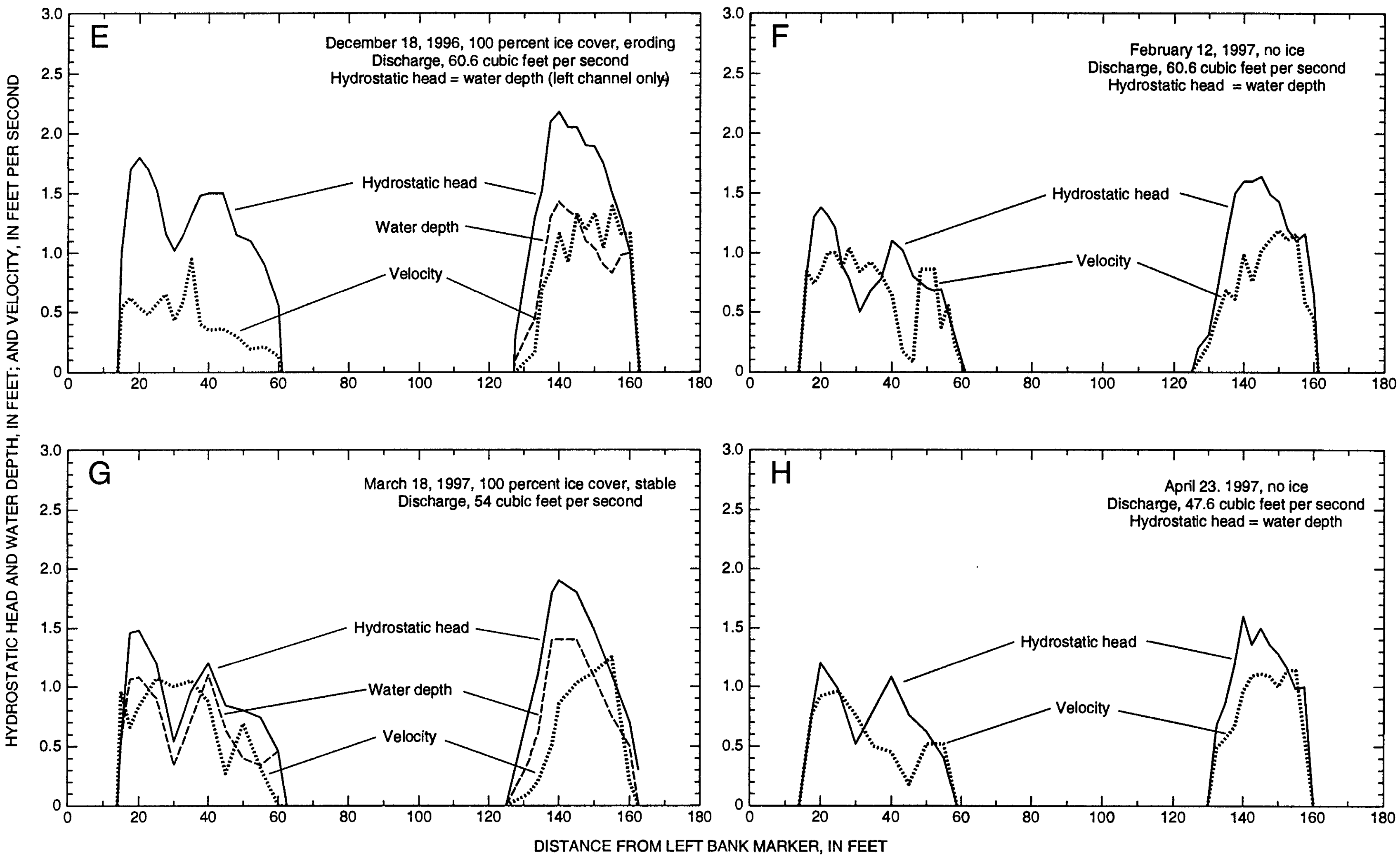

Figure 10. At Upper Riffle Reach, Continued.

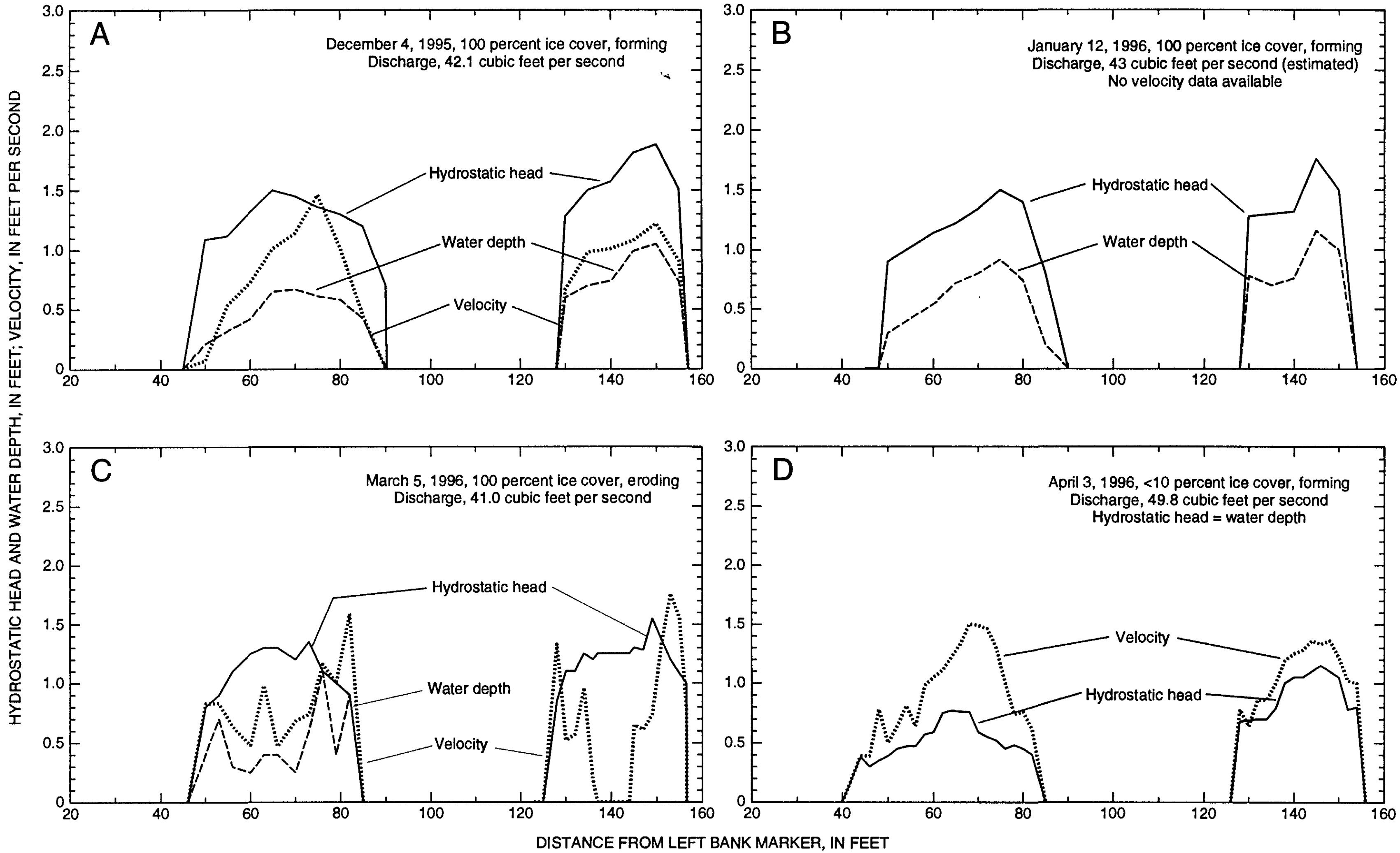

Figure 11. Hydrostatic head, water depth, and velocity distribution of the lower Bradley River at Lower Riffle Reach. (See figure 2 for transect location).

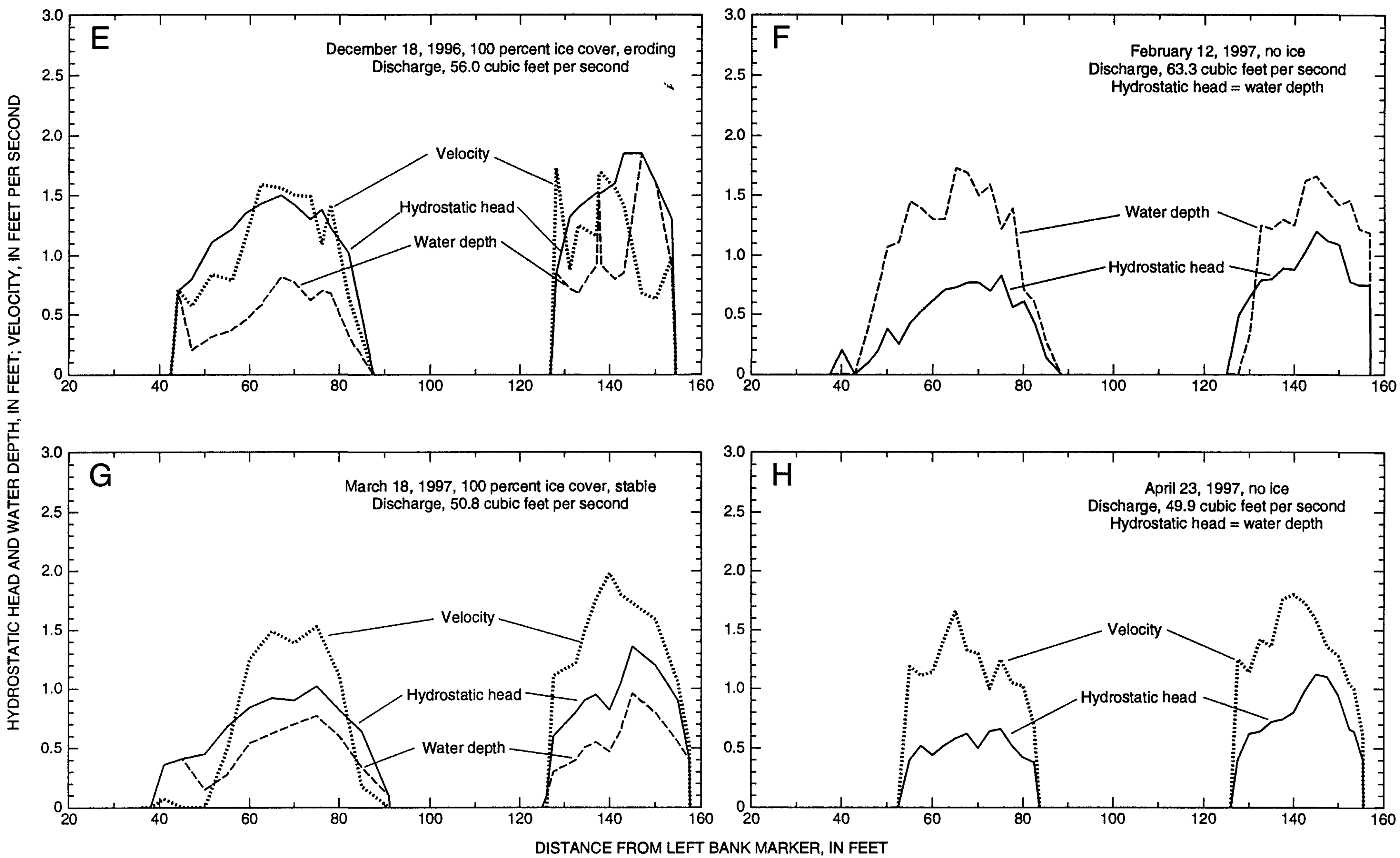

Figure 11. At Lower Riiffle Reach, Continued.

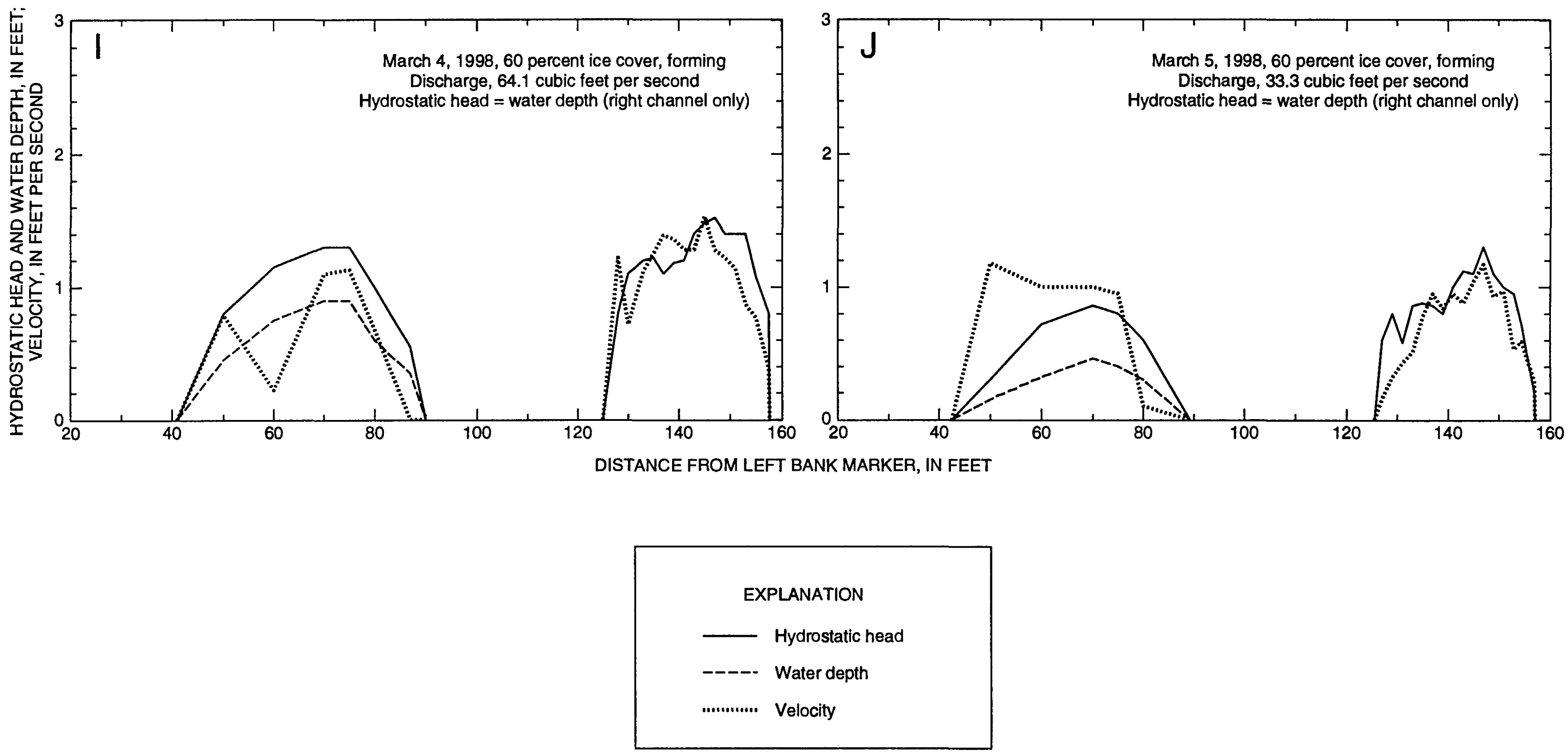

Figure 11. At Lower Riffle Reach, Continued.

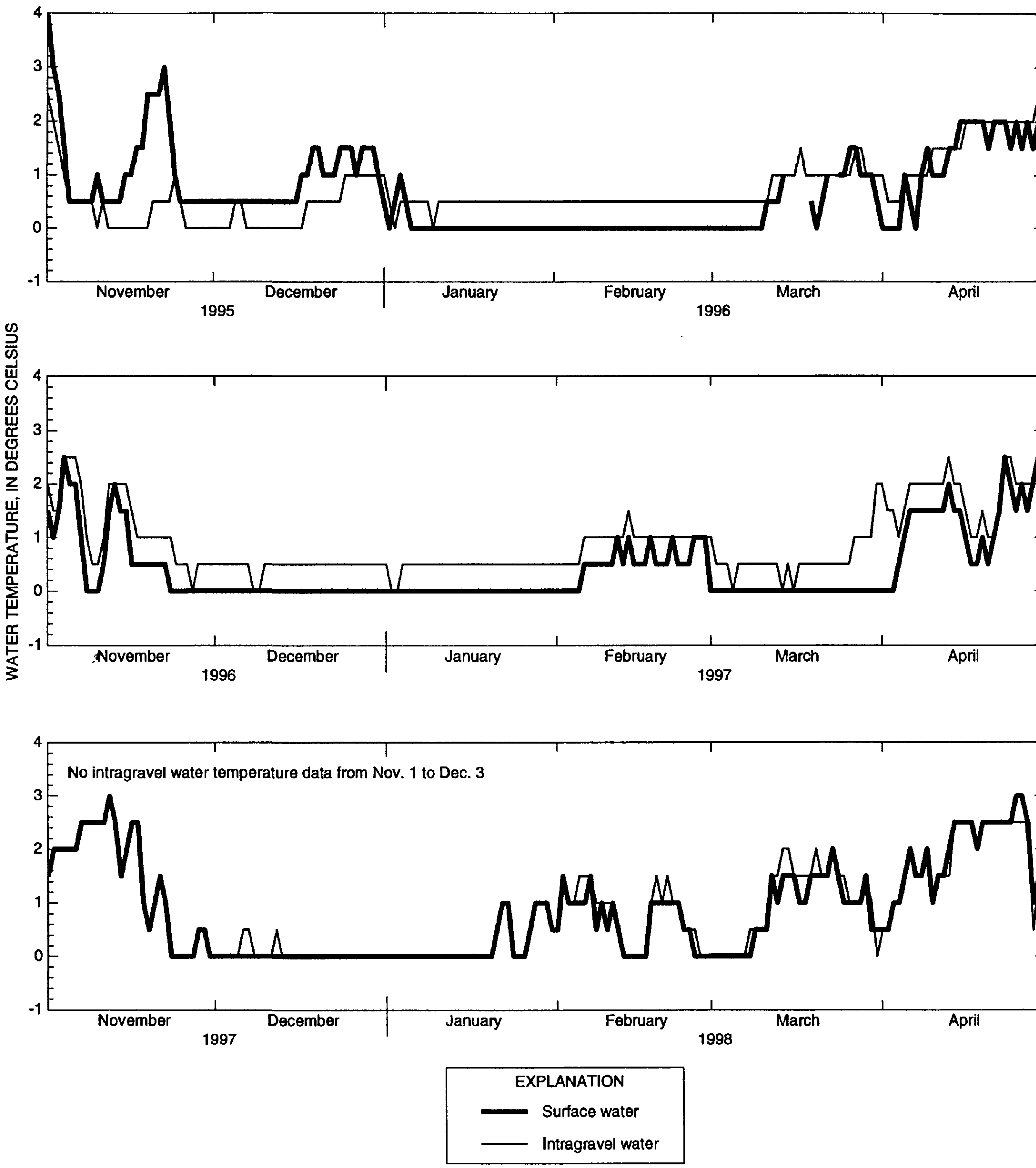

Figure 12. Daily mean surface- and intragravel-water temperature of Bradley River near Tidewater.