Prepared in cooperation with the U.S. Army Corps of Engineers, Idaho Department of Fish and Game, and Kootenai Tribe of Idaho

Surveying Cross Sections of the Kootenai River Between Libby Dam, Montana, and Kootenay Lake, British Columbia, Canada

Open-File Report 2004–1045

U.S. Department of the Interior
U.S. Geological Survey

Cover photos: *Left:* Edward Moran, hydrologist with the U.S. Geological Survey, Alaska Science Program, is setting up a survey-grade global positioning system on a Natural Resources Canada-Geodetic Survey Division benchmark. Survey-grade global positioning systems are used to update and expand survey control along Kootenay Lake, British Columbia. *Right:* U.S. Geological Survey scientists on the Kootenai River are mapping riverbank elevations by means of a mapping-grade laser rangefinder and angle encoder interfaced with a survey-grade global positioning system. The scientists also are mapping the river bathymetry by using an onboard, survey-grade echo sounder interfaced with a survey-grade global positioning system and bathymetric mapping software.

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Boise, Idaho
2004

U.S. DEPARTMENT OF THE INTERIOR
Gale A. Norton, Secretary

U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS, VERTICAL DATUM, AND OTHER ABBREVIATED UNITS

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)
mile (mi)	1.609	kilometer (km)
pound (lb)	0.4536	kilogram (kg)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by use of the following equation:

$$°C=(°F-32)/1.8$$

DATUM

Vertical coordinate information was referenced to the World Geodetic System of 1984 (WGS84, G873) and the North American Vertical Datum of 1988 (NAVD88).

Horizontal coordinate information was referenced to the World Geodetic System of 1984 (WGS84, G873) and the North American Datum of 1983 (NAD83), Idaho Transverse Mercator - North American Datum 1983/1998 Idaho West, in meters.

Other abbreviated units:
Hz, hertz
kHz, kilohertz

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ABSTRACT

The declining population of Kootenai River white sturgeon, which was listed as an Endangered Species in 1994, has prompted a recovery team to assess the feasibility of various habitat enhancement scenarios to reestablish white sturgeon populations. As the first phase in this assessment, the U.S. Geological Survey collected stream channel cross-section and longitudinal data during 2002–03 at about 400 locations along the Kootenai River from Libby Dam near Libby, Montana, to where the river empties into Kootenay Lake near Creston, British Columbia, Canada.

Survey control stations with a horizontal and vertical accuracy of less than 0.1 foot were established using a global positioning system (GPS) prior to collection of stream channel cross-section data along the Kootenai River. A total of 245 cross sections were surveyed. Six cross sections upstream from Kootenai Falls were surveyed using a total station where the river was too shallow or dangerous to navigate by vessel. The remaining 239 cross sections were surveyed by interfacing real-time GPS equipment with an echo sounder to obtain bathymetric data and with a laser range-finder to obtain streambank data. These data were merged, straightened, ordered, and reduced in size to be useful. Spacing between these cross sections ranged from about 600 feet in the valley flat near Deep Creek and Shorty Island and near bridges to as much as several miles in other areas.

These stream channel cross sections will provide information that can be used to develop hydraulic flow models of the Kootenai River from Libby Dam, Montana, to Queens Bay on Kootenay Lake in British Columbia, Canada.

INTRODUCTION

Many local, State, and Federal agencies are concerned about the declining population of white sturgeon (*Acipenser transmontanus*) in the Kootenai River in Idaho. In 1994, the Kootenai River white sturgeon was listed as an Endangered Species, and fishing for this species was prohibited. The white sturgeon population decline is reflected in fewer juvenile sturgeon and an overall decline in spawning success (U.S. Fish and Wildlife Service, 1999). The last successful recruitment of white sturgeon occurred in 1974. Recruitment occurs when a spawning event produces juvenile fish that survive to create a new year-class of fish in sufficient numbers to maintain the fish population.

Lack of Kootenai River white sturgeon recruitment has been attributed, at least in part, to changes in the natural streamflow regime of the Kootenai River after closure of Libby Dam near Libby, Montana, in 1972. These changes are hypothesized to have adversely affected channel substrate and sturgeon spawning habitat near Bonners Ferry, Idaho (fig. 1; Collier and others, 1996). Other changes in the Kootenai River that could have affected the spawning substrate are the construction of dikes on the natural levees, changes in backwater conditions near Bonners Ferry caused by changes in the level of Kootenay Lake, and loss of wetlands in the river valley.

The Kootenai River White Sturgeon Recovery Team, composed of scientists and engineers from the Kootenai Tribe of Idaho (KTOI) and several local, State, Federal, and Canadian agencies, is trying to reestablish the recruitment of white sturgeon. Recognizing this, the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, the Idaho Department of Fish and Game (IDFG), and the KTOI, is conducting several studies that will provide the recovery team with information to develop hydraulic flow models of the Kootenai River from Libby Dam, Montana, to Queens Bay on Kootenay Lake in British Columbia, Canada. These models can be used to assess the feasibility of various habitat enhancement scenarios to reestablish the recruitment of white sturgeon.

PURPOSE AND SCOPE

The purpose of this report is to (1) describe methods for surveying stream channel cross sections from Libby Dam (Montana) to where the Kootenai River empties into Kootenay Lake (British Columbia); (2) present latitude, longitude, and elevation data for survey control stations that were established to provide horizontal and vertical referencing for the cross-section data; and (3) provide an online link to the complete set of cross-section data collected during this study. Selected cross sections that were representative of each geomorphic reach in the study area are presented in graphical form in this report. Additional cross-section and longitudinal data were obtained in the white sturgeon spawning reach near Bonners Ferry, Idaho (fig. 1), for use in developing a multidimensional hydraulic model. Cross sections also were obtained at bridges throughout the study area. These bridge data are not published in this report but can be obtained by contacting the following USGS office: U.S. Geological Survey, 230 Collins Road, Boise, Idaho 83702-4520.

DESCRIPTION OF STUDY AREA

The Kootenai River begins in British Columbia, Canada, and flows through Montana, Idaho, and back into British Columbia (fig. 1). The study area is the reach of the Kootenai River from Libby Dam in Montana at river mile (rm) 221.9 to where the river empties into Kootenay Lake at rm 77.251 and includes the spawning habitat for the Kootenai River population of white sturgeon near Bonners Ferry, Idaho, from rm 139.8 to 153.3 (figs. 2 and 3a–g, back of report). The Kootenai River is referred to as the Kootenay River in British Columbia. For the purpose of this report and as a matter of convenience, the United States spelling (Kootenai) will be used when referring to the river, and the Canadian spelling (Kootenay) will be used when referring to the lake because it is located entirely within British Columbia, Canada.

The Kootenai River Basin is an international watershed that drains parts of British Columbia, Montana, and Idaho (fig. 1). The Kootenai River drainage basin is located within the Northern Rocky Mountains physiographic province, which is characterized by north- to northwest-trending mountain ranges. The Rocky Mountains form much of the eastern basin boundary, the Selkirk Mountains form the western basin boundary, and the Cabinet Mountains form the southern basin boundary. The Kootenai River is 448 mi long and drains an area of 17,600 mi^2. The river's elevation is 11,870 ft at its headwaters in British Columbia.

At Kootenai Falls, located 29 mi downstream from Libby Dam, the river loses 300 ft of elevation over a distance of a few hundred yards and creates a natural fish-migration barrier. At Bonners Ferry, located 69 mi downstream from Libby Dam and near the upstream end of the white sturgeon habitat, the Kootenai River flows westward into a nearly straight, northwest-trending, 298-mi-long trough known as the Purcell Trench. The Purcell Trench is flanked by the Selkirk Mountains on the west and by the Purcell Mountains on the east. Here, the river meanders northwestward through the broad, flat bottomlands referred to as the Kootenai Flats (fig. 1) for about 50 mi to Kootenay Lake near Creston, British Columbia. The Kootenai River then flows from the lower end of the West Arm of Kootenay Lake for about 20 mi and empties into the Columbia River at Castlegar, British Columbia.

Bonnington Falls, which now is the site of four dams, isolates white sturgeon from other populations of fish in the Columbia River Basin. The natural barrier has isolated the Kootenai River white sturgeon for approximately 10,000 years (Northcote, 1973).

The river's elevation is about 1,844 ft at the confluence of Kootenay Lake, located 146 rm downstream from Libby Dam. Kootenay Lake creates backwater conditions in the Kootenai River to a point downstream from the mouth of Deep Creek (rm 149.2) near Bonners Ferry. During May, June, and early July, when lake stage and river discharge are high, backwater conditions can extend a few miles upstream from the U.S. 95 Bridge (about rm 153) at Bonners Ferry (fig. 3e).

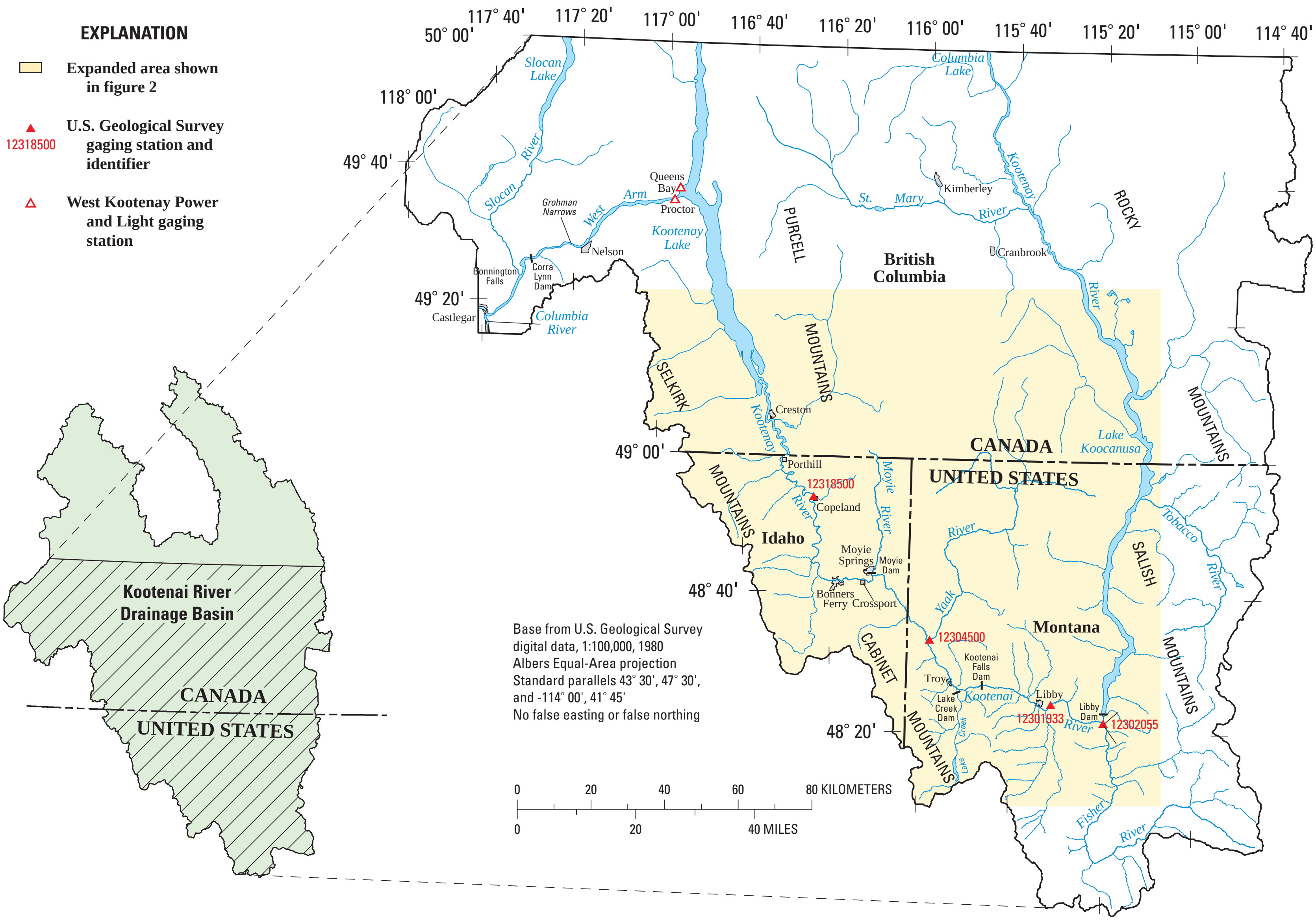

Figure 1. Location of the Kootenai River drainage basin, selected streamflow-gaging stations, and dams in Montana, Idaho, and British Columbia, Canada.

During periods of low flow, backwater conditions diminish and free-flowing water may extend a few miles downstream from the U.S. 95 Bridge.

Corra Lynn Dam, located at the outlet of Kootenay Lake (fig. 1), was completed in 1931. Corra Lynn Dam is operated for hydroelectric power and affects water levels in Kootenay Lake and, hence, in the backwater-affected reach of the Kootenai River. The river channel upstream from the dam at Grohman Narrows was deepened in 1939 to remove obstructions to free flow in the river and reduce hydraulic losses in the forebay of the dam (International Joint Commission, 1938, Order of Approval, Kootenay Lake; accessed January 21, 2004, at http://www.ijc.org/conseil_board/kootenay_lake/en/kootenay_mandate_mandat.htm). This allowed the lake to be kept at a lower level for dam operation, thus reducing the backwater effect in the Kootenai River. Construction of Libby Dam began in 1966, and Koocanusa Reservoir was officially impounded on March 21, 1972. Libby Dam is operated for flood protection, hydroelectric power, and recreational opportunities.

Synder and Minshall (1996) and Barton (in press) classified four geomorphic reaches in the Kootenai River between Libby Dam and Kootenay Lake: a canyon reach, a braided reach, a gravel-cobble reach, and a meander reach. The canyon reach extends from Libby Dam to 1.2 mi downstream from the mouth of the Moyie River. Here, the valley broadens and the river forms a low-gradient, braided reach as it courses over gravel and cobbles. This braided reach extends downstream into the study area to a bedrock constriction near the U.S. 95 Bridge over the Kootenai River at Bonners Ferry. The buried gravel-cobble reach extends downstream from this bedrock constriction to the mouth of Deep Creek near Bonners Ferry. The meander reach extends from rm 149.9, 0.7 mi upstream from the mouth of Deep Creek, to the confluence with Kootenay Lake (fig. 3e–g).

Paragamian and others (2001; 2002) identified five primary reaches in the Kootenai River between rm 141.6 and 149.0 where white sturgeon spawned during the period 1994–99 and observed that spawning occurred mostly in the outsides of river bends in the thalweg. The white sturgeon spawning habitat includes the buried gravel-cobble reach but principally lies within the meander reach.

ACKNOWLEDGMENTS

The authors thank the people of the Kootenai River Valley in Idaho, Montana, and British Columbia, who provided access to the Kootenai River for surveying. The authors also appreciate that Andre Mainville of the Geodetic Survey Division, Natural Resources Canada, in Ottawa, Canada, provided the USGS with Canadian survey control converted to the NAVD88 datum. Dennis G. Milbert of the National Geodetic Survey (NGS) in Silver Spring, Maryland, and Andre Mainville addressed the issue of modeling geoid height across the United States and Canadian international border. Curt Smith of the NGS contributed many hours to compute coordinates for survey control stations using static global positioning system (GPS) data collected by USGS field personnel. Rick Backsen of the USGS in Post Falls, Idaho, the lead vessel operator for this project, safely operated the vessel under very difficult flow conditions in the Kootenai River and helped with many logistic issues. Paul Kinzel, USGS hydrologist, provided technical support on configuring the bathymetric mapping system software. Jon Nelson, USGS research hydrologist in Denver, Colorado, provided a survey-grade depth sounder for the project. USGS hydrologic technicians Tim Morgan and Russ Christensen and USGS hydrologist John Gralow worked long hours establishing survey control stations. Kimberly Mueller, student with the USGS in Tacoma, Washington, entered survey control field measurements into the NGS database.

ESTABLISHING SURVEY CONTROL STATIONS

Survey control stations were established between Libby Dam, Montana, and Queens Bay, British Columbia. Survey control based on GPS data collected during March and April 2002 and October and November 2002 was used for the horizontal and vertical referencing of stream channel cross sections. Coordinates for 22 stations were calculated by the NGS, coordinates for 50 stations were calculated by a contractor, and coordinates for 8 stations were calculated by both the NGS and the contractor. Although the NGS and the contractor used different geoid models and data processing software, the data were comparable, on the basis of the results from the 8 stations processed by both approaches.

Static GPS data were collected at 30 survey control stations (fig. 3a–g, table 1) from Libby Dam, Mon-

Table 1. Site information for survey control stations on the Kootenai River between Libby Dam, Montana, and Kootenay Lake, British Columbia, Canada

[WGS84, World Geodetic System 1984; NAD83, North American Datum of 1983; NAVD88, North American Vertical Datum of 1988; NGS, National Geodetic Survey; NRCAN, Natural Resources Canada, Geodetic Survey Division; ID, Idaho; MT, Montana; CD, Canada; Geoid99, NGS 1999 geoid model of the United States; SD, System Dividends LLC; Kootenai, geoid model that is a subset of the Canadian HTv2.0 model and the American Geoid99 model with both models appended at the international border; --, no information presented]

Map identifier	Station identifier	Local station designation	NGS and NRCAN identifier	WGS84(G1150) coordinates		WGS84 (G1150) ellipsoid height, in feet[1]	NAD83(1999) coordinates		NAVD88 elevation, in feet[1]	NAVD88 ellipsoid height, in feet[1]	Geoid model used in computing coordinates and elevation	NGS or NRCAN benchmark	State	Agency computing survey solutions[1]	Comments
				Latitude[1]	Longitude[1]		Latitude[1]	Longitude[1]							
S1	PORT	Porthill gage	--	48 59 46.00685N	116 30 27.82384W	1,716.161	48 59 46.00689N	116 30 27.82410W	1,769.911	1,716.480	Geoid99	No	ID	NGS	(a, b)
S2	TBM1	TBM1	--	48 59 18.80705N	116 32 31.62269W	1,711.982	48 59 18.80714N	116 32 31.62284W	1,765.558	1,712.123	Geoid 99	No	ID	NGS	(a, b)
S3	V382	V 382	TO0627	48 57 45.70141N	116 25 10.87204W	2,158.579	48 57 45.70198N	116 25 10.87270W	2,211.519	2,158.635	Geoid99	Yes	ID	NGS	(b, c)
S4	COPE	Copeland RM 5 gage	--	48 54 42.81823N	116 25 02.21633W	1,717.930	48 54 42.81878N	116 25 02.21623W	1,771.575	1,718.238	Geoid99	No	ID	NGS	(a, b)
S5	TBM3	TBM3	--	48 54 12.62035N	116 24 01.02299W	1,722.215	48 54 12.62027N	116 24 01.02311W	1,775.633	1,722.300	Geoid99	No	ID	NGS	(a, b)
S6	F382	F 382	TO0612	48 48 19.17730N	116 19 43.81150W	2,197.713	48 48 19.17725N	116 19 43.81151W	2,251.493	2,197.881	Geoid99	Yes	ID	NGS	(b,c)
S7	KLOC	Klockman gage	--	48 47 37.72770N	116 22 53.89054W	1,739.642	48 47 37.72832N	116 22 53.89031W	1,793.573	1,739.826	Geoid99	No	ID	NGS	(a, b)
S8	TBM6	TBM6	--	48 44 20.03407N	116 24 51.85295W	1,718.898	48 44 20.03417N	116 24 51.85303W	1,772.667	1,719.062	Geoid99	No	ID	NGS	(a, b)
S9	S381	S 381 RESET	TO1176	48 43 52.82776N	116 15 29.79990W	2,276.342	48 43 52.82789N	116 15 29.80014W	2,330.154	2,276.430	Geoid99	Yes	ID	NGS	(b, c, d)
S10	F381	F 381 X	TO0518	48 43 50.77290N	116 17 35.02155W	2,279.472	48 43 50.77300N	116 17 35.02199W	2,333.514	2,279.564	Geoid99	Yes	ID	NGS	(b, c)
S11	PLS6	PLS 6050	--	48 43 29.21592 N	116 09 13.29477W	2,294.301	48 43 29.21574N	116 09 13.29516W	2,347.556	2,294.495	Geoid99	No	ID	NGS	(a, b)
S12	TBM7	TBM7	--	48 42 19.02312N	116 22 11.06155W	1,723.205	48 42 19.02326N	116 22 11.06146W	1,777.644	1,723.468	Geoid99	No	ID	NGS	(a, b)
S13	TRIB	Tribe gage	--	48 42 18.79595N	116 22 10.80187W	1,721.352	48 42 18.79462N	116 22 10.80246W	1,776.496	1,722.320	Geoid99	No	ID	NGS	(a, b)
S14	BONN	Bonners Ferry Gage	--	48 41 53.65111N	116 18 43.21616W	1,729.531	48 41 53.65106N	116 18 43.21643W	1,783.829	1,729.603	Geoid99	No	ID	NGS	(a, b)
S15	TBM8	TBM8	--	48 41 53.18653N	116 18 44.80826W	1,728.445	48 41 53.18628N	116 18 44.80846W	1,782.720	1,728.491	Geoid99	No	ID	NGS	(a, b)
S16	G381	G 381	TO0645	48 41 23.35287N	116 06 04.70846W	2,250.627	48 41 23.35291N	116 06 04.70843W	2,303.599	2,250.686	Geoid99	Yes	ID	NGS	(b, c, d)
S17	K383	K 383	TO0536	48 32 16.94254N	116 25 07.82454W	2,113.353	48 32 16.94284N	116 25 07.82514W	2,167.664	2,113.107	Geoid99	Yes	ID	NGS	(b, c, d)
S18	CENT	CENTRAL	TO0807	48 37 44.15800N	116 01 36.07663W	2,226.886	48 37 44.15778N	116 01 36.07735W	2,279.974	2,227.152	Geoid99	Yes	MT	NGS	(a, b, d)
S19	4A20	4A2002	--	48 35 07.00352N	115 59 01.71280W	2,226.565	48 35 07.00302N	115 59 01.71339W	2,279.760	2,226.903	Geoid99	No	MT	NGS	(a, b)
S20	P516	P 516	TN0726	48 32 46.80801N	115 57 42.85043W	1,808.576	48 32 46.80778N	115 57 42.85070W	1,861.811	1,808.901	Geoid99	Yes	MT	NGS	(b, c)
S21	FSO1	FSO1 SS	--	48 28 46.19106N	115 54 19.28431W	1,936.552	48 28 46.19128N	115 54 19.28453W	1,989.898	1,936.801	Geoid99	No	MT	NGS	(a, b)
S22	KOOT	KOOTFALL 1	--	48 27 06.28302N	115 46 21.60530W	2,008.688	48 27 06.28331N	115 46 21.60549W	2,061.568	2,008.980	Geoid99	No	MT	NGS	(a, b)
S23	TROY	TROY AZ MK	TN0713	48 26 14.01730N	115 51 10.57162W	2,073.468	48 26 14.01766N	115 51 10.57195W	2,127.142	2,073.868	Geoid99	Yes	MT	NGS	(b, c)
S24	T506	T 506	TN0702	48 26 09.48316N	115 38 19.06721W	2,019.114	48 26 09.48366N	115 38 19.06740W	2,072.178	2,019.518	Geoid99	Yes	MT	NGS	(b, c)
S25	Q506	Q 506	TN0696	48 24 27.48609N	115 35 35.62364W	2,004.409	48 24 27.48627N	115 35 35.62382W	2,057.822	2,004.895	Geoid99	Yes	MT	NGS	(b, c)
S26	LBBR	Libby Bridge	--	48 23 51.90255N	115 32 48.94692W	2,044.232	48 23 51.90258N	115 32 48.94711W	2,097.625	2,044.610	Geoid99	No	MT	NGS	(a, b)
S27	G506	G 506	TN0686	48 22 48.34279N	115 26 31.15685W	2,052.680	48 22 48.34310N	115 26 31.16007W	2,104.993	2,052.543	Geoid99	Yes	MT	NGS	(b, c)
S28	E506	E 506	TN0684	48 21 56.91003N	115 24 05.92364W	2,074.544	48 21 56.90974N	115 24 05.92410W	2,127.313	2,075.082	Geoid99	Yes	MT	NGS	(b, c)
S29	C506	C 506	TN0682	48 22 05.05482N	115 21 38.94634W	2,068.655	48 22 05.05500N	115 21 38.94707W	2,121.230	2,069.236	Geoid99	Yes	MT	NGS	(b, c, d)
S30	2766	27+6694	TN0674	48 24 33.16622N	115 18 41.26369W	2,424.193	48 24 33.16655N	115 18 41.26399W	2,476.299	2,424.754	Geoid99	Yes	MT	NGS	(b, c)
--	--	868J	31C868J	49 24 21.38066N	116 48 53.02263W	1,749.603	--	--	1,802.802	--	Kootenai	Yes	CD	SD	(c)
--	--	867J	31C873J	49 15 00.32528N	116 4140.79290W	1,722.356	--	--	1,775.335	--	Kootenai	Yes	CD	SD	(c)
--		DWP 1	46C002	49 39 14.42072N	116 55 48.34244W	1,719.518	--	--	1,773.612	--	Kootenai	Yes	CD	SD	(c)
--	--	DWP 20	46C009	49 37 01.51708N	117 00 00.60020W	1,698.993	--	--	1,752.654	--	Kootenai	Yes	CD	SD	(c)
--	--	Kuskonook gage	72C120	49 17 55.52630N	116 39 34.33286W	1,726.027	--	--	1,778.589	--	Kootenai	Yes	CD	SD	(c)
--	--	72C001, Duck Lake	72C001	49 10 43.88201N	116 33 13.35566W	1,802.769	--	--	1,855.561	--	Kootenai	Yes	CD	SD	(c)
--	--	72C004, Creston	72C004	49 07 01.75953N	116 34 44.72588W	1,732.077	--	--	1,785.682	--	Kootenai	Yes	CD	SD	(c)
--	--	85C062, Creston	85C062	49 03 41.01568N	116 31 06.52200W	1,765.151	--	--	1,818.491	--	Kootenai	Yes	CD	SD	(c)
--	--	85C068, Creston	85C068	49 07 22.41826N	116 36 34.37736W	1,695.646	--	--	1,749.026	--	Kootenai	Yes	CD	SD	(c)

Table 1. Site information for survey control stations on the Kootenai River between Libby Dam, Montana, and Kootenay Lake, British Columbia, Canada--Continued

Map identifier	Station identifier	Local station designation	NGS and NRCAN identifier	WGS84(G1150) coordinates		WGS84 (G1150) ellipsoid height, in feet[1]	NAD83(1999) coordinates		NAVD88 elevation, in feet[1]	NAVD88 ellipsoid height, in feet[1]	Geoid model used in computing coordinates and elevation	NGS or NRCAN benchmark	State	Agency computing survey solutions[1]	Comments
				Latitude[1]	Longitude[1]		Latitude[1]	Longitude[1]							
--	--	TBM-2	--	48 56 26.48376N	116 29 38.16786W	1,716.555	--	--	1,769.826	--	Kootenai	No	ID	SD	(a)
--	--	TBM-4	--	48 50 30.48260N	116 24 56.28810W	1,728.789	--	--	1,782.251	--	Kootenai	No	ID	SD	(a)
--	--	TBM-5	--	48 47 21.92669N	116 24 01.59611W	1,725.820	--	--	1,779.452	--	Kootenai	No	ID	SD	(a)
--	--	TBM-8	--	48 41 53.18618N	116 18 44.80778W	1,728.425	--	--	1,782.651	--	Kootenai	No	ID	SD	(a)
--	--	TBM-9	--	48 42 05.16137N	116 14 32.64767W	1,726.191	--	--	1,780.020	--	Kootenai	No	ID	SD	(a)
--	--	TBM-10	--	48 42 11.07663N	116 11 13.84533W	1,743.140	--	--	1,796.555	--	Kootenai	No	ID	SD	(a)
--	--	TBM-11	--	49 36 09.4216N	116 47 38.97743W	1,725.230	--	--	1,778.658	--	Kootenai	No	CD	SD	(a)
--	--	TBM-12	--	49 02 40.14138N	116 32 45.81290W	1,709.495	--	--	1,763.012	--	Kootenai	No	CD	SD	(a)
--	--	TBM-13	--	49 11 22.68539N	116 38 39.18233W	1,710.988	--	--	1,763.973	--	Kootenai	No	CD	SD	(a)
--	--	TBM-14	--	49 30 59.04876N	116 50 17.97173W	1,730.659	--	--	1,784.032	--	Kootenai	No	CD	SD	(a)
--	--	TBM-15	--	49 23 34.93101 N	116 44 10.99829W	1,707.818	--	--	1,760.781	--	Kootenai	No	CD	SD	(a)
--	--	TBM-151	--	49 23 34.37577N	116 44 10.97456W	1,707.457	--	--	1,760.420	--	Kootenai	No	CD	SD	(a)
--	--	TBM-16	--	49 32 01.43779N	116 46 59.62119W	1,796.929	--	--	1,850.030	--	Kootenai	No	CD	SD	(a)
--	--	T-1	--	48 47 16.20288N	116 23 45.76908W	1,714.403	--	--	1,768.084	--	Kootenai	No	ID	SD	(a)
--	--	T-2	--	48 47 13.04427N	116 24 28.64218W	1,721.972	--	--	1,775.535	--	Kootenai	No	ID	SD	(a)
--	--	T-3	--	48 46 55.37036N	116 24 14.56219W	1,723.593	--	--	1,777.205	--	Kootenai	No	ID	SD	(a)
--	--	T-4	--	48 46 20.76198N	116 23 10.57994W	1,715.807	--	--	1,769.600	--	Kootenai	No	ID	SD	(a)
--	--	T-5	--	48 45 39.45362N	116 23 15.19283W	1,728.425	--	--	1,782.244	--	Kootenai	No	ID	SD	(a)
--	--	T-6	--	48 45 13.99251N	116 23 58.68017W	1,730.010	--	--	1,783.737	--	Kootenai	No	ID	SD	(a)
--	--	T-7	--	48 44 46.98105N	116 24 45.13187W	1,724.160	--	--	1,777.749	--	Kootenai	No	ID	SD	(a)
--	--	T-8	--	48 44 27.71136N	116 23 47.43801W	1,729.672	--	--	1,783.478	--	Kootenai	No	ID	SD	(a)
--	--	T-9	--	48 44 10.56556N	116 22 56.58874W	1,718.881	--	--	1,772.828	--	Kootenai	No	ID	SD	(a)
--	--	T-10	--	48 43 40.57817N	116 23 11.04733W	1,716.736	--	--	1,770.689	--	Kootenai	No	ID	SD	(a)
--	--	T-11	--	48 43 04.64300N	116 23 29.85083W	1,726.686	--	--	1,780.630	--	Kootenai	No	ID	SD	(a)
--	--	T-13	--	48 42 13.44348N	116 21 15.53187W	1,730.971	--	--	1,785.197	--	Kootenai	No	ID	SD	(a)
--	--	T-14	--	48 41 44.88784N	116 19 55.20771W	1,710.381	--	--	1,764.659	--	Kootenai	No	ID	SD	(a)
--	--	TT 13 M=BONNERS	TO0023	48 40 32.65883N	116 20 01.54330W	1,792.270	--	--	1,846.624	--	Kootenai	Yes	ID	SD	(a, d)
--	--	D 383	TO0529	48 37 49.39258N	116 20 54.71604W	2,153.789	--	--	2,208.094	--	Kootenai	Yes	ID	SD	(c)
--	--	TO0632	TO0632	48 58 49.76901N	116 28 26.67621W	2,021.470	--	--	2,074.649	--	Kootenai	Yes	ID	SD	(c)
--	--	K 382	TO0616	48 50 52.13616N	116 20 03.22466W	2,155.502	--	--	2,208.865	--	Kootenai	Yes	ID	SD	(c)
--	--	T 382	TO0625	48 56 35.98050N	116 23 46.73511W	2,103.602	--	--	2,156.444	--	Kootenai	Yes	ID	SD	(c)
--	--	P 381	TO0652	48 43 42.61869N	116 11 53.40827W	2,240.764	--	--	2,294.114	--	Kootenai	Yes	ID	SD	(c)

[1] Static global positioning system data and survey control station information were supplied by representatives of the U.S. Geological Survey.

(a) Elevation determined by global positioning system in this project.
(b) WGS84 coordinates, elevation, and ellipsoid height were put in memory of global positioning system for use during real-time kinematic channel-geometry surveying.
(c) Vertical orthometric height existed in the National Geodetic Survey database or the Natural Resources Canada, Geodetic Survey Division database.
(d) Precise latitude and longitude existed.

tana, to Porthill, Idaho, during October and November 2002 using the Federal Geodetic Control Committee's (1989) geodetic accuracy standards and specifications for using GPS relative positioning techniques. These survey control stations fall into one of the following categories: (1) three existing NGS A- and B-order horizontal and first- and third-order vertical survey control stations, (2) one existing NGS first-order horizontal and first-order vertical survey control station, (3) one existing NGS B-order horizontal survey control station, (4) 10 existing NGS first-order vertical control stations, and (5) 15 newly established benchmarks. Time required for GPS data collection at survey control stations typically ranged from 2.5 hours to more than 5 hours. The static GPS data were collected using two 9-channel, dual-frequency, Trimble 4700 GPS receivers equipped with a microcentered L1/L2 antenna; a microcentered L1/L2 with ground plane antenna; and two 24-channel, dual-frequency, Trimble 5700 GPS receivers equipped with Zephyr and Zephyr Geodetic antennas. A technical report (Trimble, 2001) describes the Federal Geodetic Control Subcommittee evaluation of the Trimble 5700 GPS.

Horizontal control for the 30 survey stations where coordinates were calculated by NGS is based on NAD83 and vertical control is based on NAVD88. Vertical and horizontal coordinates for the survey control stations established during this study and horizontal coordinates for the existing NGS benchmarks are based on the NGS GPS data post-processing program PAGE-NT, version 2002.01.28. Coordinates (horizontal position) and ellipsoid heights are determined from a least-squares adjustment using the NGS program ADJUST, version 4.2. Orthometric heights are determined from least-squares adjustments using the NGS program ADJUST, version 4.2, and the geoid model Geoid99 by constraining all known, valid orthometric heights. The Geoid99 model was vertically constrained to the published orthometric and ellipsoid heights for the NGS A-, B-, and first-order vertical benchmarks and was horizontally constrained to five NGS continuously operating reference stations (NCORS) located southeast and southwest of the study area. Input to the model included the static GPS satellite data collected at each station during the field investigation and data from NCORS. The geoid model was used only to determine an "approximate" orthometric height (equation 1) from an ellipsoid height.

$$H = h - N \tag{1}$$

where

H = orthometric height,
h = ellipsoid height, and
N = geoid height (throughout much of the conterminous United States, the geoid is a negative number).

The difference between published orthometric height and ellipsoid plus geoid height is what is "adjusted" when constraining published orthometric heights. Field data were downloaded and converted to RINEX2 standard format using Trimble's DAT2RIN, version 1.14a. NCORS data and broadcast and International GPS Service (IGS) precise ephemeris data were downloaded from the NGS Website, http://www.ngs.noaa.gov. The accuracy of the entire network of survey control stations (table 1) was determined to be about 1.55 parts per million (ppm) vertical and 0.033 ft horizontal. Curt Smith, NGS State representative for Idaho and Montana, computed coordinates for survey control stations, and his report is provided in appendix A (back of report). Many of the survey control station data are also available from the NGS Website at http://www.ngs.noaa.gov/cgi-bin/datasheet.prl

Coordinates for 30 survey control stations from Moyie Springs, Idaho, to Queens Bay, British Columbia, were computed from static GPS data that the USGS collected during March and April 2002 (table 1). These data were collected using a somewhat less rigorous method compared with that employed later during the October and November 2002 static GPS surveying effort. Duration of GPS occupations at benchmarks was generally shorter, meteorological conditions were not recorded, and the antenna height was measured only at the beginning of each GPS occupation. Static GPS data were collected using the same four Trimble GPS receivers and antennas described earlier in this section; two of the receivers occupied the same survey control stations during consecutive measurements, so movement of receivers resembled a leapfrog pattern. Michael McInnis of System Dividends, Inc., Denver, Colorado, was contracted to compute coordinates for the survey control stations. McInnis employed Trimble's Geomatics computer model configured with a hybrid geoid model. Andre Mainville of the Geodetic Survey Division, Natural Resources Canada, generated and supplied the hybrid geoid model by appending the

Geoid99 model and the Canadian geoid model HT, version 2.0, modified to the study datum (NAVD88) at the international border. Dennis Milbert, developer of the American Geoid99 model, provided a cursory review of the hybrid geoid model and recommended using the modified model (Dennis Milbert, National Geodetic Survey, written commun., 2002). The computed coordinates for survey control stations are based on a minimally constrained adjustment which holds data from the NCORS, located in Spokane, Washington, and in Polson, Montana, fixed in the horizontal and holds data from NGS benchmark 85C068, located in the middle of the study area, fixed in the vertical. In comparison, the NGS processing constrained the data using 15 NGS A-, B-, and first-order vertical benchmarks and 5 NCORS. The latitude, longitude, and elevation of each survey control station are presented in table 1.

Both the NGS and System Dividends, Inc., computed coordinates and elevation at the same survey control stations at eight sites along the Kootenai River in Idaho. As previously mentioned, System Dividends, Inc., and the NGS computed coordinates and elevations on the basis of static GPS data collected at survey control stations during spring and fall 2002, respectively. The difference between elevations computed by System Dividends, Inc., and the NGS ranged from 0 to 0.128 ft; the median was 0.033 ft. The maximum discrepancy between the two sets of survey control solutions was less than the 0.155 ppm of vertical accuracy the NGS has rated for the network of survey control stations in Montana and Idaho.

COLLECTION OF STREAM CHANNEL CROSS-SECTION DATA

The U.S. Geological Survey collected stream channel cross-section and longitudinal data at about 400 locations along the Kootenai River between Libby Dam near Libby, Montana, to where the river empties into Kootenay Lake near Creston, British Columbia, Canada, during June and July 2002 and April, May, and June 2003. Of these, 245 cross sections were processed because they were suitable for use in one-dimensional hydraulic flow and sediment transport models. Cross sections were spaced at varying distances throughout the study reach (fig. 3a–g). Spacing was approximately 600 ft in the white sturgeon spawning reach between Deep Creek and Shorty Island, near the transition between backwater and the free-flowing river near Bonners Ferry, Idaho, and near bridges throughout the study reach. For other areas, spacing of cross sections averaged about 0.5 mi in Idaho and Montana but was as much as several miles in Canada. Each cross section was given a station number in river miles that corresponded to its location on the river.

River miles referenced in this report were derived from designations by the USGS National Mapping Division on 7.5-minute (1:24,000-scale) maps and by the Columbia Basin Inter-Agency Committee (1965). River miles generally are measured in 1-mi increments along the channel centerline in an upstream direction beginning with 0 at the river mouth, which, in this case, was the outlet to Kootenay Lake. Since the publication of these documents, the channel length in several places along the Kootenai River has changed somewhat because of bank erosion, deposition, or channel migration. As a result, the actual distances between the river mile designators shown on the maps are not always exactly 1.0 mi. However, it was decided to use these designators because many people are familiar with them and use them for a variety of purposes.

To utilize these river mile designators for identifying cross sections, the actual distance between river miles was measured in Idaho from the 1992 USGS 7.5-minute digital orthophoto quadrangles and in Montana from the 1995 USGS digital orthophoto quarter quadrangles. The digital orthophoto quadrangles are based on the rectification of aerial photos taken during the 1990s. The distance between the nearest downstream river mile designator to the cross section then was measured along the channel centerline. The ratio of cross-section distance to distance between river miles was calculated and used as the extension in the cross-section name. For example, a cross section located two-thirds of the way between rm 155 and 156 would be designated rm 155.667.

The surveying of stream channel cross sections during 2002 was referenced to System Dividends, Inc., computed coordinates for survey control stations. These cross sections are located between rm 105 and 162. The surveying of stream channel cross sections during 2003 was referenced to NGS computed coordinates for survey control stations. These cross sections are located between rm 77 and 105, rm 139 and 148, and rm 162 and 221.3. The surveying of all streambanks at cross sections was referenced to NGS computed coordinates for survey control stations. Because

System Dividends, Inc., and NGS computed coordinates for survey control stations were nearly identical, the stream channel cross-section data collected during summer 2002 were not adjusted to NGS computed coordinates.

SURVEYING STREAM CHANNELS AT CROSS SECTIONS

The PC-based Windows navigational and bathymetric mapping software, HYPACK MAX, by Coastal Oceanographics, Inc., was used to plan and manage the hydrographic surveys and edit and manage the bathymetric data collected at each stream channel cross section. This software was installed on a laptop computer interfaced with a GPS and survey-grade depth sounder (fig. 4). The GPS equipment is described in the section “Establishing Survey Control Stations.” To establish the precise position of the depth sounder, the GPS was operated in real-time kinematic mode using a base station with a geodetic antenna set up over a survey control station and a roving antenna mounted in the survey vessel above the depth-sounding transducer. The GPS base station and roving antenna were radio linked to facilitate real-time differential correction to the bathymetric data being obtained by the echo sounder. The coordinates output from the GPS were WGS84 and NAVD88. The navigational and bathymetric mapping software, HYPACK MAX, was configured to display and track the vessel positions against a background of USGS digital line graphs showing hydrography, topology, and survey control monuments (fig. 4).

Water depth was measured with a survey-grade Innerspace Technology, Inc., Model 448 thermal depth-sounder recorder. Manufacturer specifications for this depth sounder report that the depth of operation is from 0 to 335 ft, and speed of sound in water is selectable from 4,550 to 5,050 ft/s with a sounding rate of 20 Hz. The sounding signal is amplified with a time-varying gain that automatically compensates for spreading loss and attenuation over the depth range, and the depth measurement accuracy is ±0.1 ft. The depth-sounding transducer operated at 208 kHz with an 8-degree beam width at 3 decibels. During early summer 2002, water temperatures were recorded at the surface. During the spring 2003 surveying season, water temperatures were recorded both at the surface and near the riverbed with a Hydrolab Datasonde multiparameter water-quality probe. Water temperatures ranged from 41.0° to 44.6°F at these two depths throughout the entire survey. The difference in water temperatures did not warrant a change in the velocity of sound through water, which was set at 4,800 ft/s.

Six stream channel cross sections upstream from Kootenai Falls were surveyed using a Topcon GTS–302 total station instrument. This surveying method was used where the river was too shallow or dangerous to navigate by vessel. Cross-section geometry was defined by a series of land-surface elevation data measured at variably spaced distances along section lines perpendicular to the directions of flow.

SURVEYING STREAMBANKS AT CROSS SECTIONS

Streambank shots were taken on the streambank at cross sections at breaks in topographic slope using a mapping-grade laser rangefinder (Laser Technology Impulse 200LR) and angle encoder (Laser Technology Mapstar Angle Encoder System) interfaced with the Trimble 5700 GPS. Accuracy for the laser rangefinder is 0.1 ft at 164 ft, 0.2 ft at 492 ft, and 0.5 ft at its maximum range of 1,887 ft. Distance between the laser rangefinder and the streambank was typically less than 700 ft. Field testing by the USGS survey field crew showed that the vertical accuracy of the laser rangefinder and angle encoder was ±0.1 ft and the horizontal accuracy was 2 ft.

QUALITY CONTROL PROCEDURES

Good quality control procedures help maintain the accuracy and precision of measurements, ensure that field measurements reflect the conditions being monitored, and provide data that can be relied upon for their intended uses. Accuracy is the relation between the reported data and the “true” value. During the establishment of survey control in Montana and Idaho, quality control procedures were completed using standardized NGS methods (Federal Geodetic Control Committee, 1989). The real-time kinematic GPS and depth-sounder measurements were checked for accuracy at the start of each day during 2002 fieldwork and at the start, at random times during, and at the end of each field day during 2003 fieldwork.

Static Global Positioning System Measurements

Static GPS data collection for the purpose of establishing survey control stations during October and November 2002 included most of the quality control procedures that are outlined in the Federal Geodetic Control Committee’s (1989) guidelines for establishing

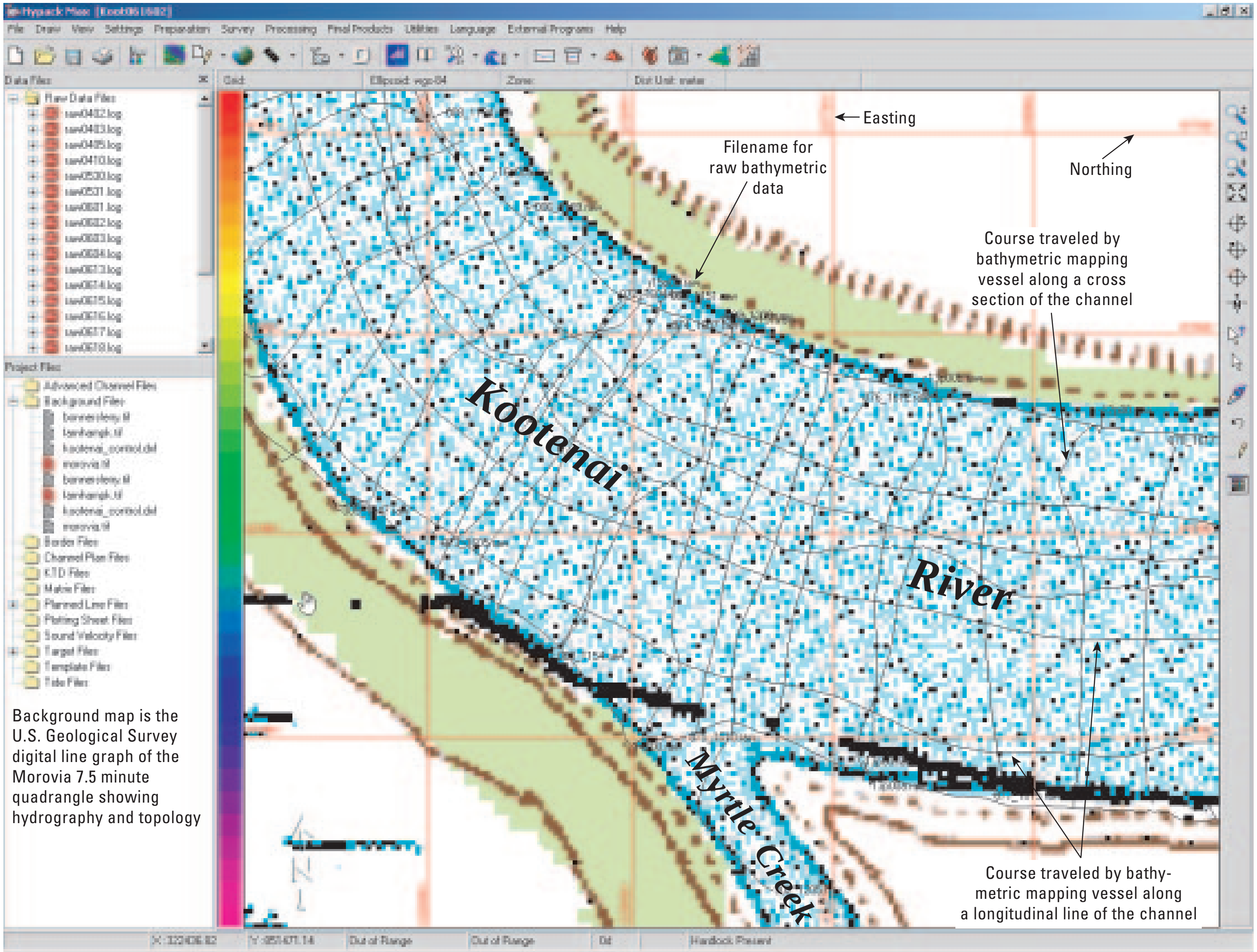

Figure 4. Computer screen image showing the navigational and bathymetric mapping software that displays and tracks the survey vessel positions.

GPS-derived ellipsoid heights. These quality control procedures included ensuring that the antenna height was measured at the start, middle, and end of a GPS occupation at each survey control station. The identifier number was recorded for each of the eight notches on the GPS antenna's microcentered L1/L2 with ground plane antenna and Zephyr Geodetic antenna that were measured to determine height above the benchmark. During the October and November 2002 fieldwork, weather conditions such as barometric pressure, temperature, and humidity were measured at the GPS antenna during GPS occupations at each survey control station. Quality control procedures for static GPS data collected during March and April 2002 for the purpose of establishing survey control stations included two sessions of static GPS data collection at each survey control station with a different antenna height for each session.

Computation of Coordinates and Elevations for Survey Control Stations

Quality control in the computation of coordinates and elevations included an analysis of the residuals in each step of the survey control adjustment process using the NGS program ADJUST, version 4.2 (appendix A). This analysis indicated that most of the existing NGS benchmarks conformed well to the GPS-determined orthometric heights; therefore, the newly determined benchmarks should reflect how well the processed vectors fit the network and constrained benchmarks.

Accuracy of Real-Time Kinematic Global Positioning System Measurements

The manufacturer reported that the accuracy of the Trimble 4700 and 5700 series GPS in the real-time kinematic mode is ±0.066 ft plus 1 ppm in the vertical and ±0.033 ft plus 1 ppm in the horizontal. Accuracy is subject to conditions such as multipath, obstructions, satellite geometry, and atmospheric parameters. Because the manufacturer reported that vertical accuracy is one-half the horizontal accuracy, the real-time kinematic GPS elevation (vertical) measurements were used to represent potential errors. Real-time kinematic GPS elevations were measured daily during fieldwork at survey control stations to provide quality control. The roving GPS antenna was removed from its mount on the survey vessel and set atop a survey control station. These measurements were almost always within 0.03 ft of the station's reported vertical solutions. This level of accuracy reflects a properly operated and functioning real-time kinematic GPS surveying system. In addition, the real-time kinematic GPS elevation measurements at survey control stations validate the integrity of the solutions that were computed for the network of survey control stations.

Accuracy of Depth-Sounder Measurements

Accuracy of the depth-sounder measurements was evaluated at the start of each field day at three depths; two depths from 3 to 20 ft below the transducer and the river bottom. The depth-sounding target was a 30-lb Columbus weight mounted on an E-reel. A measuring rod was used to measure the depth of water. Water temperatures were measured at the surface and near the riverbed to check for any indication of a change in the velocity of sound through water.

This test verified that accuracy was consistently within 0.1 ft. Upon completion of each depth-sounder accuracy check during the 2003 fieldwork, the HYPACK MAX computer-recorded streambed elevations were checked for consistency by comparing them with manually computed streambed elevations. Manual computations were based on the elevation of the GPS roving antenna read from the GPS receiver minus the vertical distance between the roving antenna and the depth-sounding transducer and the depth-sounder measurement.

Accuracy of Total Station Measurements

The manufacturer reported that the accuracy of the GTS–312 series total station is ±0.0066 ft + 2 ppm in the horizontal and ±0.0066 ft + 2 ppm in the vertical. The accuracy for surveying stream channels at cross sections using a total station exceeds that for surveying with GPS in the real-time kinematic mode and using a depth sounder. Although cross-section measurements with a total station may be more accurate, the speed of data acquisition is generally greater with a GPS in the real-time kinematic mode.

STREAM CHANNEL CROSS SECTIONS

Data (distance and elevation) for the 245 cross sections in figure 3a–g are available in tabular ASCII format from the U.S. Geological Survey, Idaho District Website at **http://id.water.usgs.gov/projects/kootxsections/index.html.** Selected stream channel cross sec-

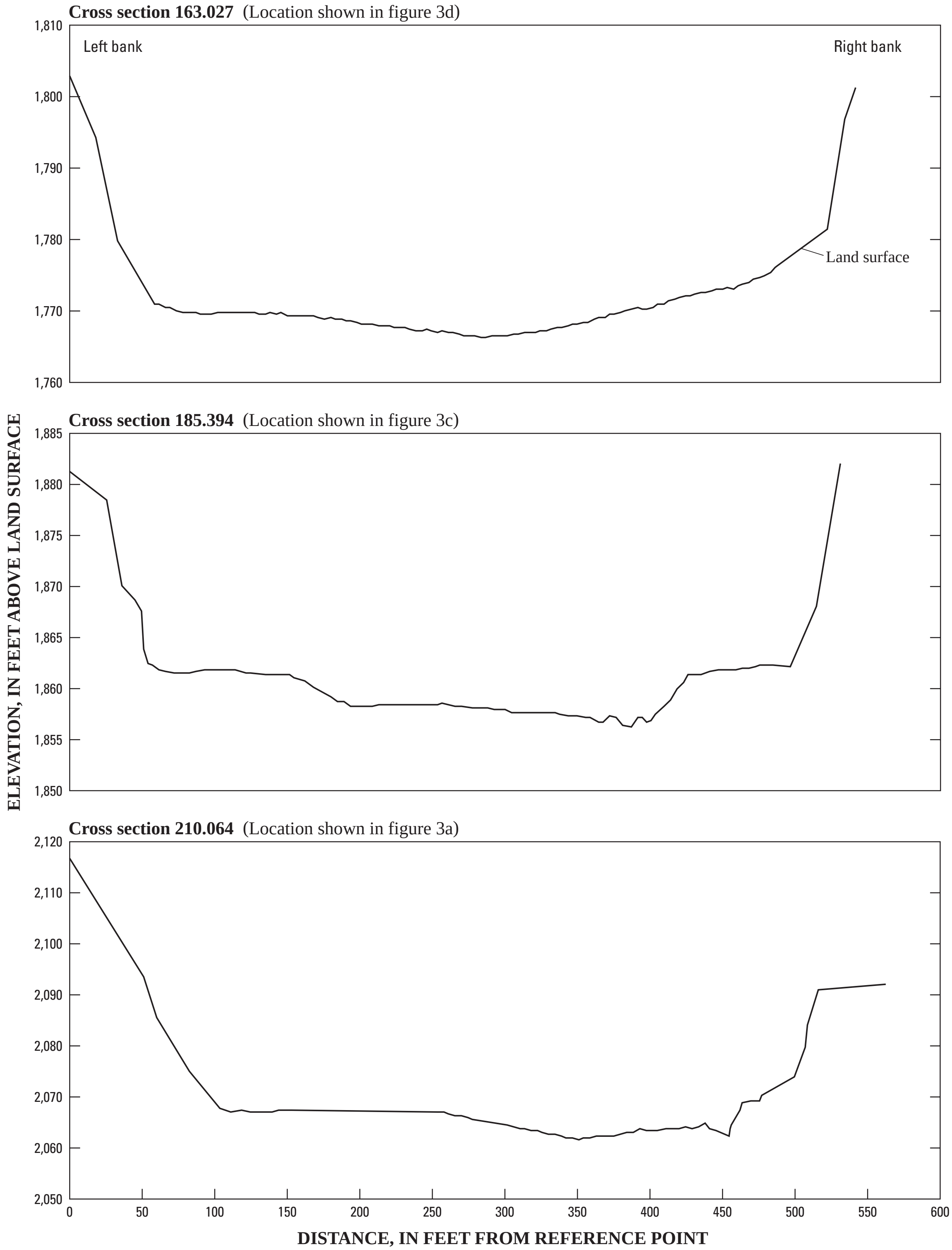

Figure 5a. Representative stream channel cross sections for the Kootenai River canyon reach from river mile 159.2 to 221.9 in Idaho and Montana.

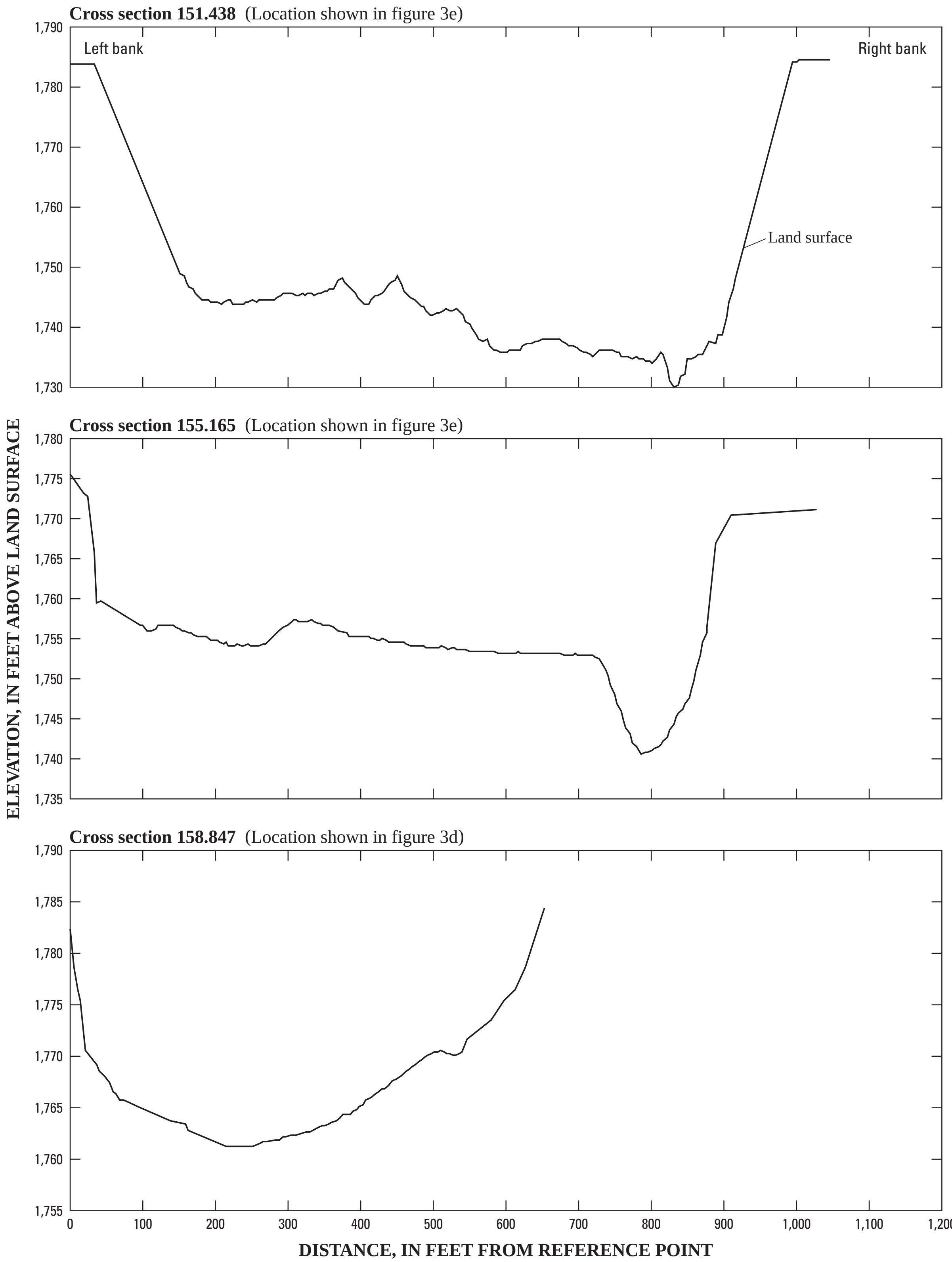

Figure 5b. Representative stream channel cross sections for the Kootenai River buried gravel-cobble reach and the braided reach from river mile 149.2 to 159.2 in Idaho.

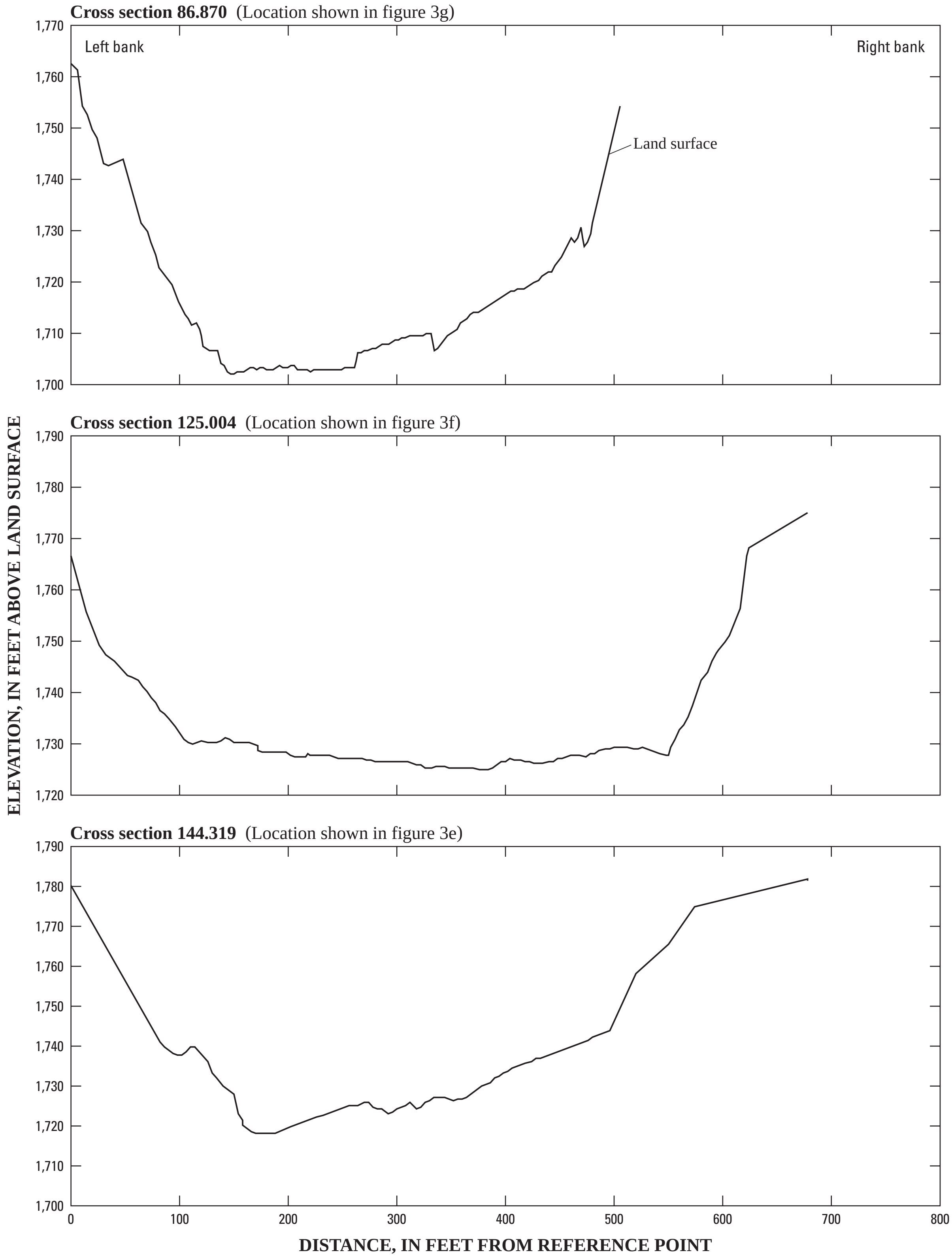

Figure 5c. Representative stream channel cross sections for the Kootenai River meander reach from river mile 77 to 149.2 in British Columbia, Canada, and Idaho.

tions that are representative of each geomorphic reach in the study area are presented in figures 5a–c. Distance across the channel, in feet, from the left-most surveyed point while facing downstream, and the land-surface elevation, in feet above NAVD88, are displayed. Information on the accuracy of stream channel survey data and on developing stream channel cross sections is provided in the following sections.

DEVELOPING STREAM CHANNEL CROSS SECTIONS

The following steps were used to develop 239 cross sections; slightly different procedures were used to develop 6 cross sections upstream from Kootenai Falls. First, bathymetric and streambank data for each cross section were merged. Second, each cross section was straightened along a line that was roughly perpendicular to the direction of streamflow because there were often slight variations resulting from vessel operation. At some cross sections, such as 218.383 and 155.855, the section line was bent to keep it roughly perpendicular to the direction of streamflow because of the changing direction of streamflow along the entire section. Then the data were ordered from left bank (viewed as looking downstream) to right bank, and the left-most data point was assigned a distance of 0 ft. Distances along a cross section for all other data points then were calculated from the left-most point. Last, the number of depth soundings per cross section was reduced because the number typically exceeded 1,000 points and was well beyond the number of points needed for hydraulic flow and sediment transport models. Therefore, cross-section data generally were reduced to fewer than 200 points per cross section by retaining only one point between each 4-ft interval. The reduced dataset then was viewed graphically to assess the difference between the computer-generated stream-bottom profile and the measured profile. Where necessary, data points were added back into the dataset until the profile of the reduced dataset generally represented the profile of the original dataset.

ACCURACY OF STREAM CHANNEL SURVEY DATA

Accuracy of the survey method used to map the stream channel bottom is less than ±0.1 ft in the vertical and ±0.05 ft in the horizontal and is based on a summation of the following sources of error. Mapping error associated with the accuracy of the GPS-derived survey control is about 0.016 ft in the vertical. The manufacturer reported that the accuracy of the real-time kinematic GPS used in this study was ±0.066 ft in the vertical and ±0.033 ft in the horizontal. Accuracy of depth-sounder measurements during daily field evaluations was consistently about ±0.0003 ft.

Surveys were conducted mainly during calm conditions on the river and the vessel was operated in a manner that minimized both pitch and roll. The effect of survey vessel pitch and roll on the accuracy of depth-sounder measurements could not be determined but is considered only a very small fraction of overall measurement error. The GPS antenna was mounted vertically above the transducer and, thus, the GPS measured any change in the depth of the echo sounder below the water surface. This configuration of GPS antenna and transducer minimized bathymetric surveying errors associated with pitch and roll of the survey vessel.

Accuracy of the survey method used to map the exposed riverbanks is ±0.3 ft in the vertical and ±2 ft in the horizontal and is based on a summation of the following sources of error rounded to one significant figure. The NGS determined that the accuracy of the entire GPS-derived survey control network, compared with first- and third-order NGS benchmarks, was ±0.16 ft. The manufacturer reported that the accuracy of the real-time kinematic GPS used in this study was ±0.066 ft in the vertical and ±0.033 ft in the horizontal. The vertical accuracy of the laser rangefinder and angle encoder was ±0.1 ft and the horizontal accuracy was 2 ft.

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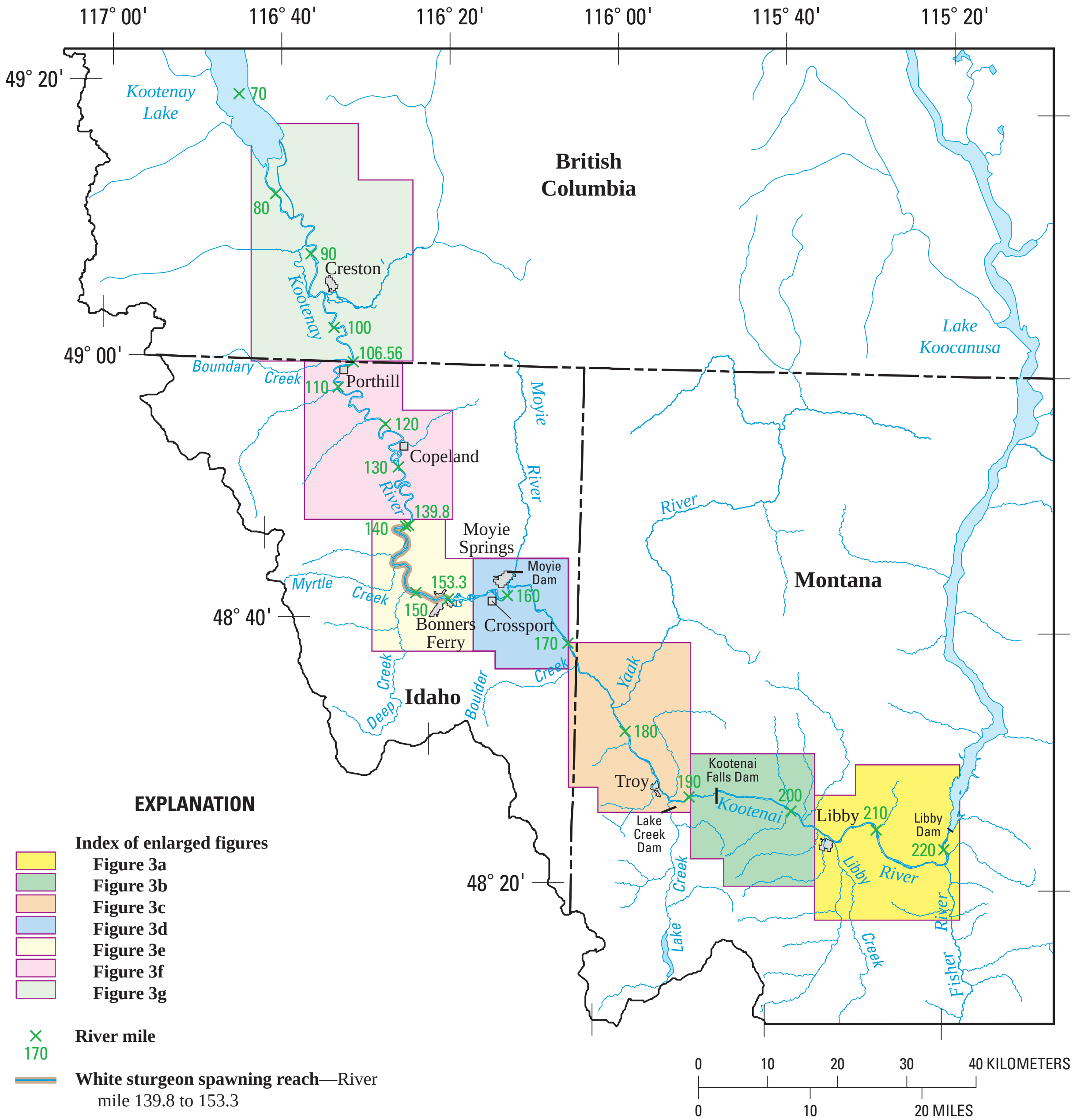

Figure 2. River mile locations and index of enlarged figures showing stream channel cross-section locations on the Kootenai River in Montana, Idaho, and British Columbia, Canada.

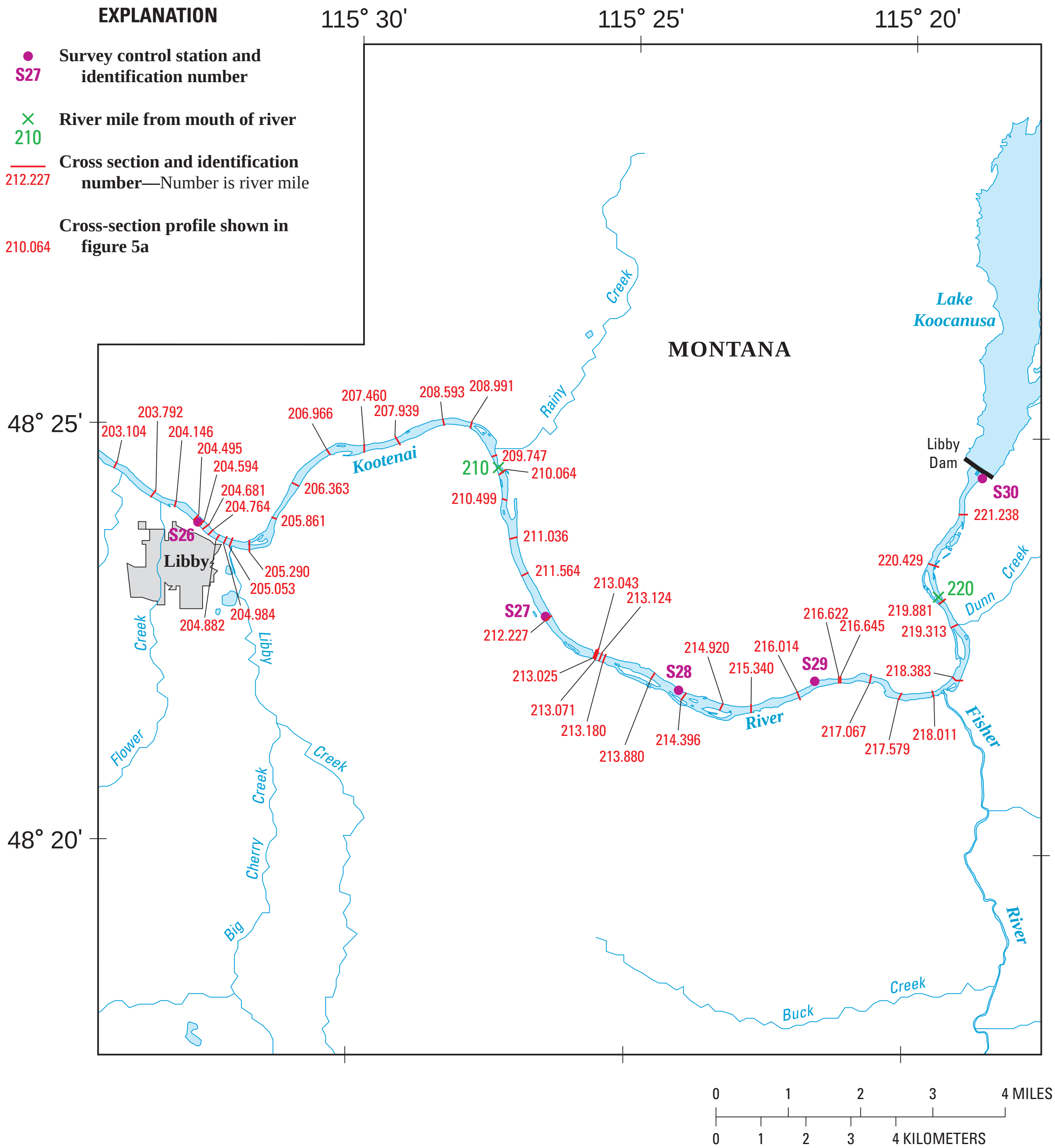

Figure 3a. Locations of stream channel cross sections and survey control stations on the Kootenai River, river mile 202.7 to 221.9 in Montana.

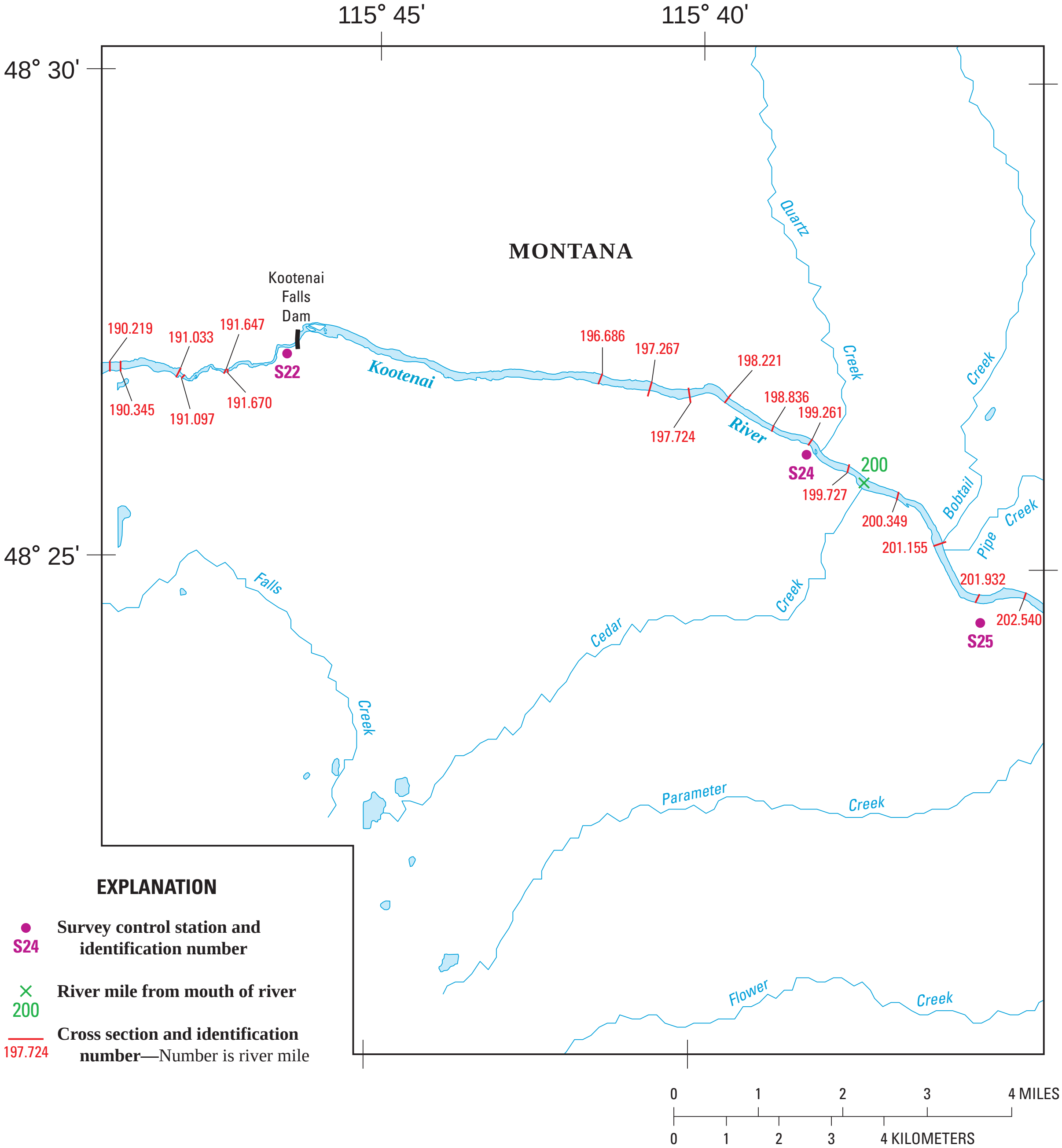

Figure 3b. Locations of stream channel cross sections and survey control stations on the Kootenai River, river mile 190.2 to 202.7 in Montana.

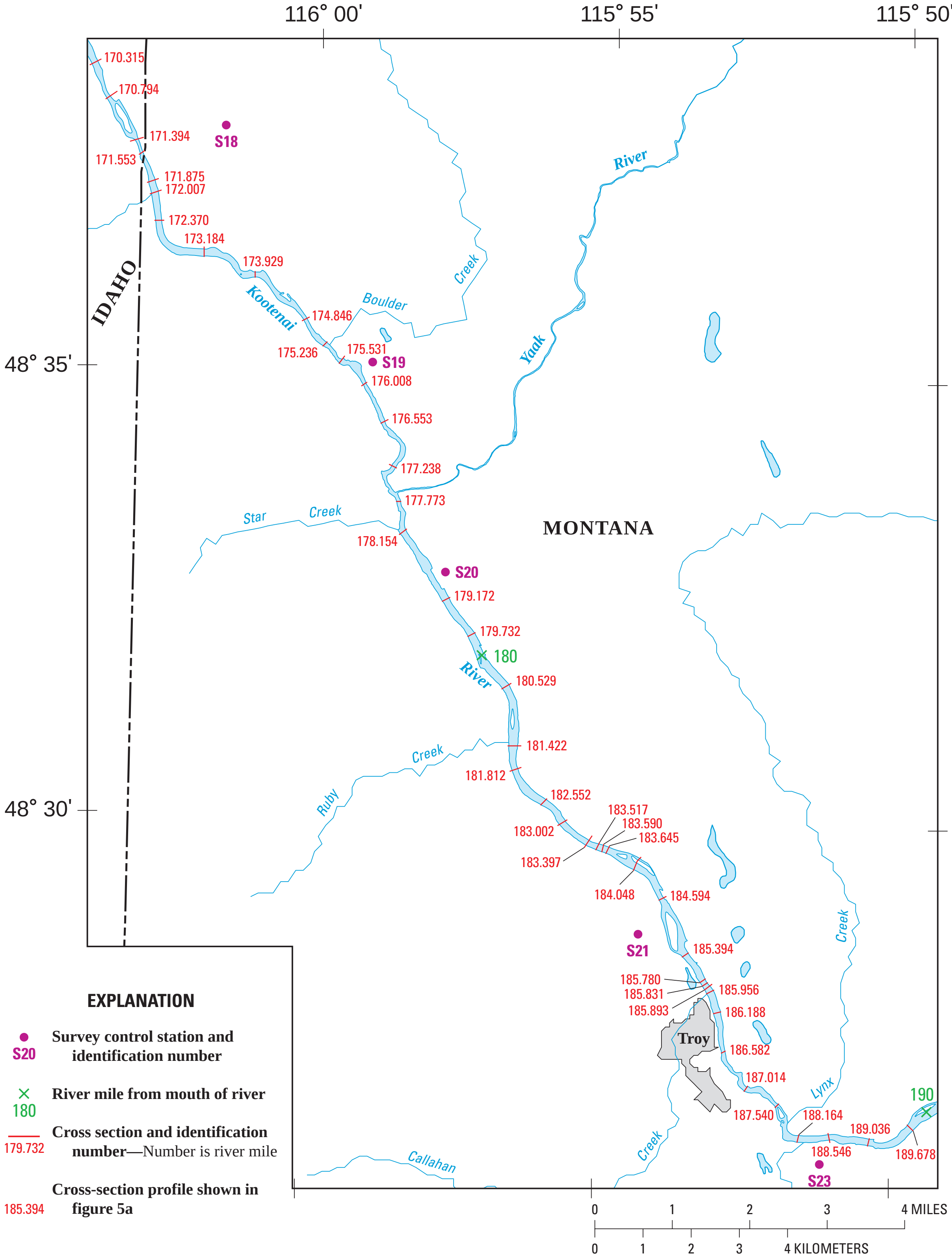

Figure 3c. Locations of stream channel cross sections and survey control stations on the Kootenai River, river mile 170.0 to 190.2 in Montana.

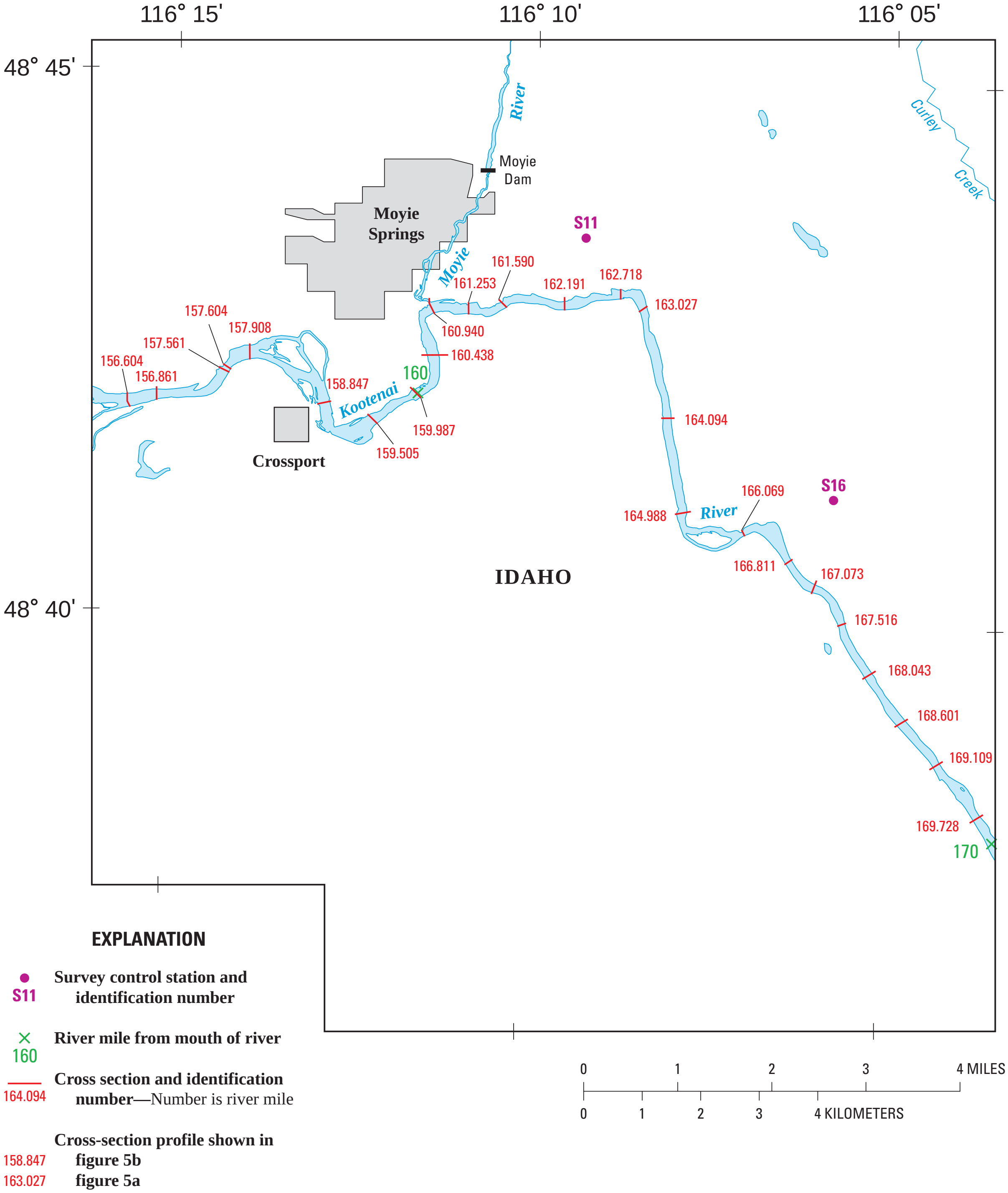

Figure 3d. Locations of stream channel cross sections and survey control stations on the Kootenai River, river mile 156.0 to 170.0 in Idaho.

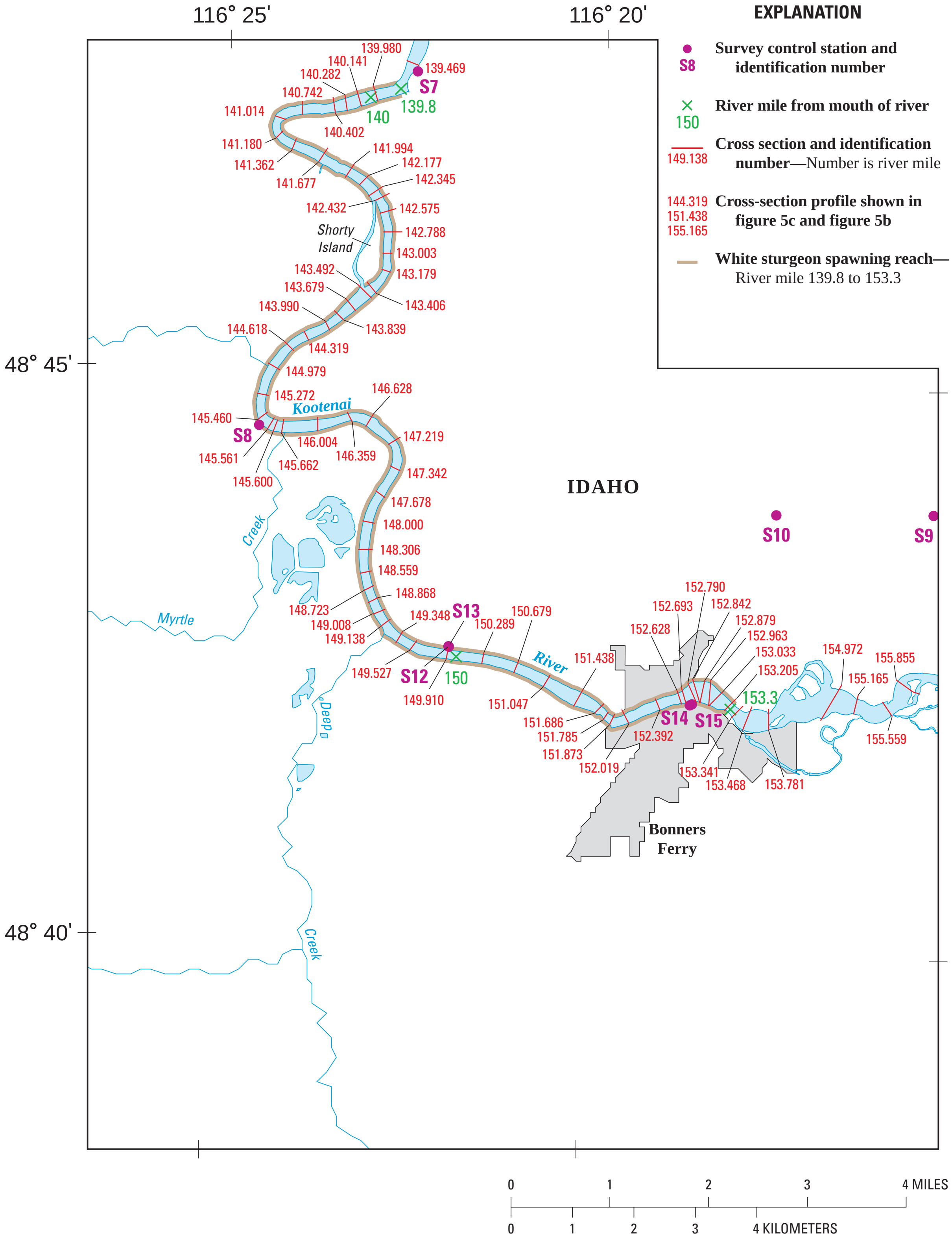

Figure 3e. Locations of stream channel cross sections and survey control stations on the Kootenai River, river mile 139.0 to 156.0 and the white sturgeon spawning reach near Bonners Ferry, Idaho.

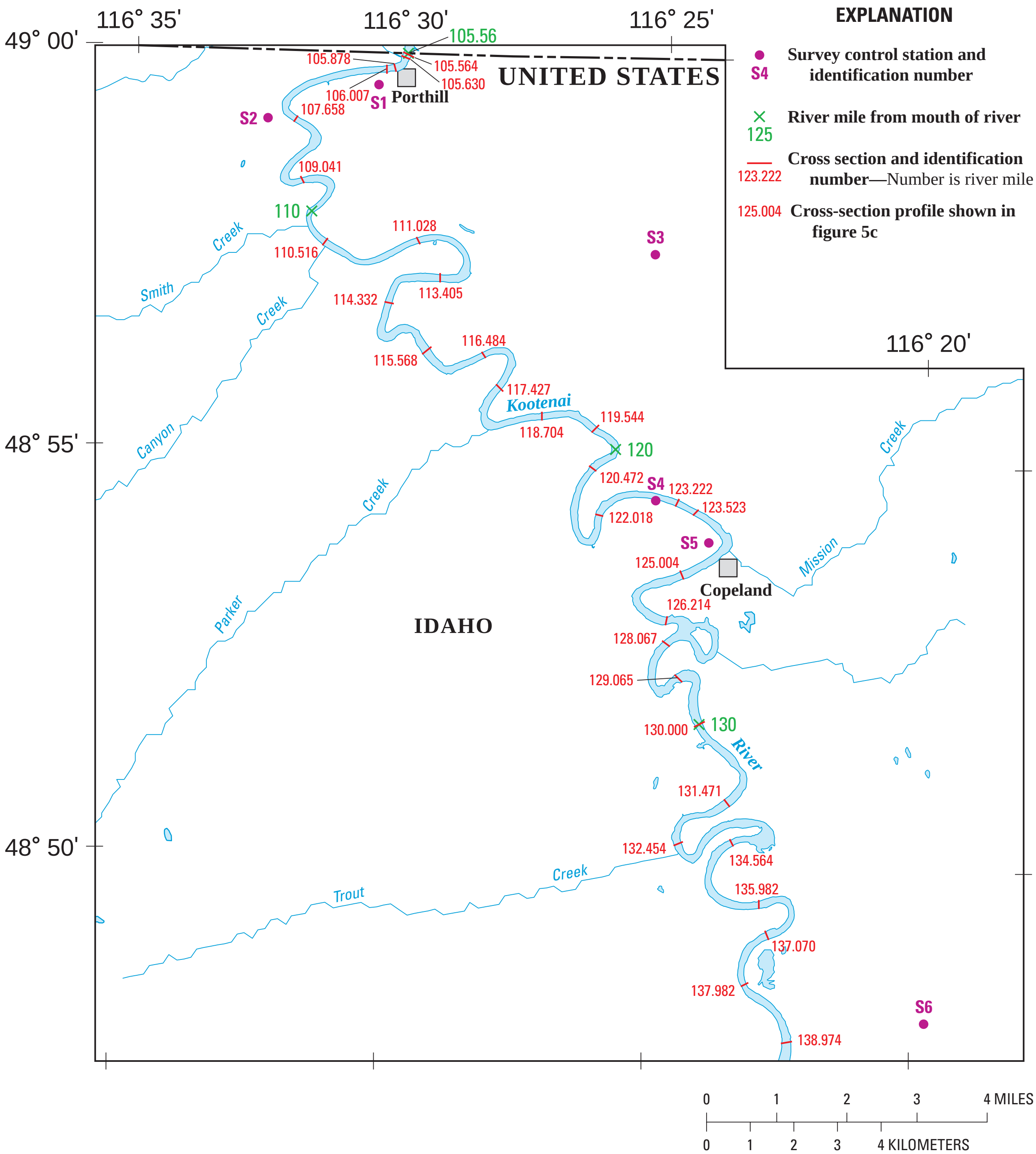

Figure 3f. Locations of stream channel cross sections and survey control stations on the Kootenai River, river mile 105.5 to 139.0 in Idaho.

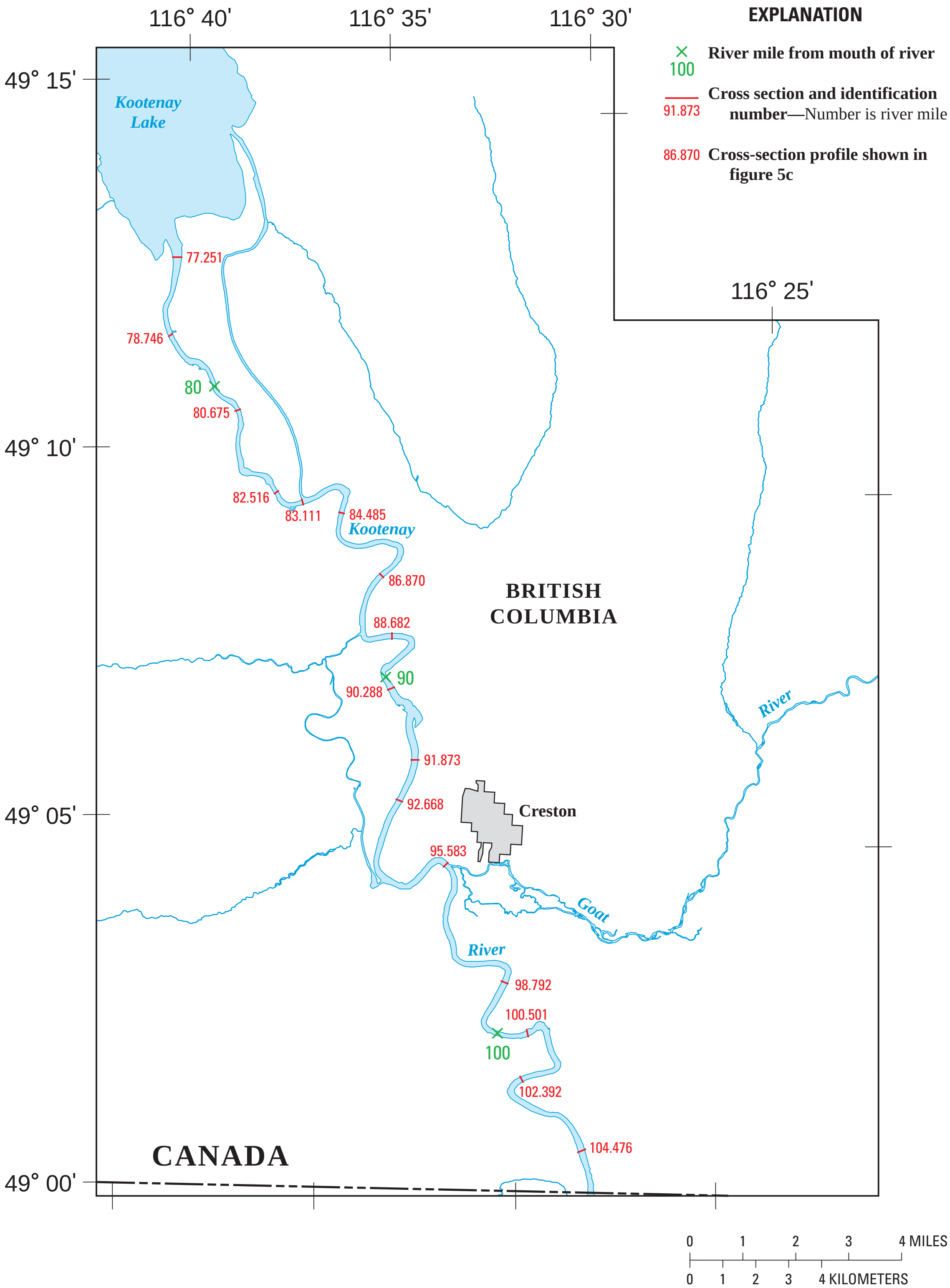

Figure 3g. Locations of stream channel cross sections and survey control stations on the Kootenay River, river mile 77.251 to 105.5 in British Columbia, Canada.

Appendix A. National Geodetic Survey report on coordinate computations for survey control stations in Idaho and Montana.

[GPS, Global Positioning System; Hz/V, Horizontal/Vertical; IGS, International GPS Service; NCORS, National Continuously Operating Reference Stations; NGS, National Geodetic Survey; PID, Permanent Identifier; RMS, Root Mean Square; SSN, Station Serial Number; TBM, Temporary Benchmark]

Kootenai River, Montana - Idaho, GPS Project, 2002

Horizontal Datum:	**NAD 83 (1998)**
Vertical Datum:	**NAVD 88**
State:	**Montana - Idaho**
Survey Type:	**Static GPS Survey**
Locality:	**Along Kootenai River, Montana &Idaho**
Year of Observations:	**2002**
Year of Computation:	**2002**
GPS Plan/Observers:	**U.S. Geological Survey**
Computed by:	**Curt Smith, National Geodetic Survey**

I. Data Processing and Analysis

A. Raw GPS Data: Data observed in the field was downloaded, converted to RINEX2 standard format using Trimble s DAT2RIN, version 1.14a, software by Ted Moran, U.S. Geological Survey, then submitted to Curt Smith for processing and analysis. NCORS data and broadcast and IGS precise ephemeris data were downloaded from the NGS web site at www.ngs.noaa.gov.

B. Vector Processing and Analysis: Vector processing was performed by Curt Smith using NGS program PAGE-NT version 2002.01.28, IGS precise ephemeris, and NCORS for coordinate seeding. PAGE-NT was used to create the project G-file named Koot_org.gfl. High RMS values and poor solutions for several of the new stations produced weak session processing results reflecting stations with questionable satellite visibility.

Questionable Processing Results by Vector and Session(s):

P516-C506	282A
T506-TROY	284A, 286B, 303A
T506-Q506	286B
T506-G506	284B, 287A
S381-PORT	288C, 289A
PORT-TRIB	288C
K383-PORT	289B
COPE-PORT	290A
TRIB-COPE	290B
TRIB-PORT	290B
BONN-COPE	290C
KLOC-COPE	290D
V382-PORT	290E
BONN-KLOC	306A

The NGS program Online Positioning User Service (OPUS) results for these stations showed high RMS values and difficulty solving ambiguities for many of the new stations, which were obviously partially or fully obstructed.

After final review of processed vectors the following network connections were found missing:

2766-E506 (essential)
Q506-LBBR (or other adjacent station; Q506 is a single occupation only, no check)
CENT-2766
K383-FSO1
S381-PLS6
S381-BONN
F382-KLOC (KLOC does not appear to be a very good GPS station)
TRIB-TBM8 (if TBM points are temporary, no future connections required)
TBM7-TRIB or K383 (if TBM points are temporary, no future connections required)
TBM6-TBM7 (if TBM points are temporary, no future connections required)
TBM1-PORT (PORT does not appear to be a very good GPS station)

C. Data Adjustment and Analysis: The NGS program ADJUST version 4.15 was used to perform all adjustments. There were 11 vectors rejected from the G-file after analysis of the original minimal constrained horizontal adjustment and the Koot_upd.gfl was used throughout the adjustment process. Digital copies of the constrained horizontal, Koot_Hc.adj, and vertical, Koot_Vc.adj, adjustments accompany this report.

Rejected Vectors by Session and Vector:

284B	T506-G506
287B	TROY-PLS1
288C	PLS1-S381
290A	COPE-BONN
290D	KLOC-PLS1
290D	KLOC-SPN1
290E	COPE-V382
290F	TBM3-COPE
291B	PLS1-TBM7
291B	SPN2-TBM7
303A	PLS1-T506

Vectors That Couldn t Be Rejected for Lack of Redundancy by Session and Vector:

282B	PORT-K383
283A	C506-G506
283A	T506-G506
290D	KLOC-COPE

D. Constrained Coordinates and Heights: Coordinates and heights were obtained from the NGS Intranet site for all constrained stations in the adjustments. Geoid heights were obtained using NGS program GEOID99 and added to the B-file. The various adjustment constraint A-files were created using MS WordPad.

E. Computed Coordinates and Heights: Computed coordinates and heights were derived from the final B-file, Koot_fin.bfl, which is created by combining the constrained horizontal and vertical B-files. Accuracies for the computed coordinates for new stations reflect the residuals listed by each vector associated with that station as found in the constrained adjustments.

II. Station Statistics

A total of 30 stations were directly occupied by representatives from the U.S. Geological Survey during this project. Data from 5 NCORS to the southwest and southeast of the project area were used in this project. See file Kootenai Prelimary Coordinates.doc. These stations fall into one of the following categories:

National CORS:	5
Existing NGSIDB A or B Order Horizontal/Vertical Control Stations:	3
Existing NGSIDB A or B Order Horizontal Control Stations:	1
Existing NGSIDB 1st, 2nd, or 3rd Order Horizontal/Vertical Control Stations:	1
Existing NGSIDB Vertical Control Stations:	10
New marks established:	15

III. Computation of Horizontal Control

A. First Free Adjustment with Rejected Vectors: An initial free adjustment was run. The NAD83 (1998) position and ellipsoid height of station CENTRAL (PID# TO0807) were held fixed.

Input Files:			
Koot_org.bfl	Degrees of Freedom	=	348
Koot_org.afl	Variance Sum	=	115294.0
Koot_org.gfl	Std. Dev. of Unit Weight	=	18.20
	Variance of Unit Weight	=	331.30

Output Files:
Kbbk.or ==> Koot_upd.bfl
Koot_org.adj

11 vectors showed unusually large residuals and adjustment was rerun, rejecting the 11 vectors, using updated B-file, Koot_upd.bfl, and G-file, Koot_upd.gfl.

Input Files:			
Koot_upd.bfl	Degrees of Freedom	=	315
Koot_upd.afl	Variance Sum	=	64836.1
Koot_upd.gfl	Std. Dev. of Unit Weight	=	14.35
	Variance of Unit Weight	=	205.83

Output Files:
Kbbk.up ==> Koot_fr.bfl
Koot_upd.adj

B. Minimal Constrained Horizontal Adjustment: A horizontal adjustment was run. The updated B-file from the first free adjustment was used as input along with the copied final G-file. Station CENTRAL (PID# TO0807) position and ellipsoid height were held constrained. The results were checked and indicated that the proper vectors had been rejected.

Input Files:			
Koot_fr.bfl	Degrees of Freedom	=	315
Koot_Hfr.afl	Variance Sum	=	64836.1
Koot_upd.gfl	Std. Dev. of Unit Weight	=	14.35
	Variance of Unit Weight	=	205.83

Output Files:
Kbbk.hf ==> Koot_Hfr.bfl
Koot_Hfr.adj

C. Constrained Horizontal Adjustment: A horizontal adjustment was run. The updated B-file from the first free adjustment was used as input along with the updated G-file. Positions and ellipsoid heights were constrained at the listed stations. The results revealed that all constrained control fit fairly well.

Horizontally Constrained NCORS:

SSN 4-Char PID Hz/V Latitude Longitude Station Name

```
0035|MSOL|DE8232|A- |46 55 45.8|114 06 31.8|MISSOULA CORS ARP
0019|PLS1|AJ1818|A- |47 39 49.5|114 06 50.0|POLSON 1 CORS ARP
0036|SC00|AJ7205|A- |46 57 03.3|120 43 28.5|SC00 CORS ARP
0024|SPN1|AJ1822|A- |47 31 06.0|117 25 25.2|SPOKANE 1 CORS ARP
0025|SPN2|AJ1824|A- |47 31 06.1|117 25 24.0|SPOKANE 2 CORS ARP
```

Horizontally Constrained A and B-Order Stations:

SSN 4-Char PID Hz/V Latitude Longitude Station Name

```
0005|C506|TN0682|B-1|48 22 05.0|115 21 38.9|C 506
0006|CENT|TO0807|B- |48 37 44.1|116 01 36.0|CENTRAL
0014|K383|TO0536|A-1|48 32 16.9|116 25 07.8|K 383
0023|S381|TO1176|A-3|48 43 52.8|116 15 29.8|S 381 RESET
```

Input Files:	Degrees of Freedom	=	339
Koot_Hfr.bfl	Variance Sum	=	98198.5
Koot_Hc.afl	Std. Dev. of Unit Weight	=	16.58
Koot_upd.gfl	Variance of Unit Weight	=	274.92

Output Files:
- Kbbk.hc ==> Koot_Hc.bfl
- Koot_Hc.adj

D. Minimally Constrained Vertical Adjustment: A vertical adjustment was run. The B-file from the first free adjustment after including Geoid heights was used as input along with the updated G-file. Station P 516 (PID# TN0726) position and orthometric height were constrained. This adjustment basically mirrored the first free adjustment because there is only one control station.

Input Files:	Degrees of Freedom	=	315
Koot_Vfg.bfl	Variance Sum	=	64836.1
Koot_Vfr.afl	Std. Dev. of Unit Weight	=	14.35
Koot_upd.gfl	Variance of Unit Weight	=	205.83

Output Files:
- Kbbk.vf ==> Koot_Vfr.bfl
- Koot_Vfr.adj

Comments: Comparisons between the minimal constraint vertical adjustment with published orthometric heights at all known orthometric stations indicated that all published NAVD88 orthometric heights fit well within the project area with the exception of G 506 (PID#TN0686). Both GPS solutions to G 506 were poor so there is no real GPS-derived check on the published NAVD88 height for this station.
Unconstrained –(Minus) Constrained NAVD88 Orthometric Heights Arranged East to West:

SSN	4-Char	Un-Constrained	Constrained	U - C
0001	2766	754.699	754.776	-0.077
0008	E506	648.323	648.405	-0.082
0005	C506	646.472	646.551	-0.079
0013	G506	641.623	641.602	0.021
0022	Q506	627.186	627.224	-0.038
0026	T506	631.573	631.600	-0.027
0033	TROY	648.312	648.353	-0.041
0018	P516	567.480	567.480	Constrained
0012	G381	702.183	702.137	0.046
0023	S381	710.286	710.231	0.055
0009	F381	711.315	711.255	0.060
0010	F382	686.279	686.255	0.024
0034	V382	674.104	674.071	0.033
0014	K383	660.846	660.704	0.142

E. Constrained Vertical Adjustment: A constrained vertical adjustment was run. The updated B-file from the minimally constrained vertical adjustment and the original G-file were used as input. Orthometric heights at the listed stations as well as the position at one station were constrained. The results revealed that all constrained control fit very well. Station G 506 (PID#TN0686) shows high height residuals but was constrained anyway as it only connects to two other constrained bench marks and does not affect the rest of the adjustment.

Vertically Constrained First and Third Order Stations from NGS Database:

SSN	4-Char	PID	Hz/V	Latitude	Longitude	Station Name
0001	2766	TN0674	-1	48 24 31.	115 18 35.	27+66.94
0005	C506	TN0682	B-1	48 22 05.0	115 21 38.9	C 506
0008	E506	TN0684	-1	48 21 57.	115 24 10.	E 506
0009	F381	TO0518	-1	48 43 50.	116 17 34.	F 381 X
0010	F382	TO0612	-1	48 48 18.	116 19 45.	F 382
0012	G381	TO0645	-1	48 41 23.	116 06 10.	G 381
0013	G506	TN0686	-1	48 22 50.	115 26 32.	G 506
0014	K383	TO0536	A-1	48 32 16.9	116 25 07.8	K 383
0018	P516	TN0726	1-1	48 32 46.8	115 57 42.8	P 516
0022	Q506	TN0696	-1	48 24 27.	115 35 36.	Q 506
0023	S381	TO1176	A-3	48 43 52.8	116 15 29.8	S 381 RESET
0026	T506	TN0702	-1	48 26 09.	115 38 20.	T 506
0033	TROY	TN0713	-1	48 26 12.	115 51 12.	TROY AZ MK
0034	V382	TO0627	-1	48 57 45.	116 25 10.	V 382

Horizontally Constrained B-Order Station:

SSN	4-Char	PID	Hz/V	Latitude	Longitude	Station Name
0006	CENT	TO0807	B-	48 37 44.1	116 01 36.0	CENTRAL

Input Files:			
Koot_Vfr.bfl	Degrees of Freedom	=	328
Koot_Vc.afl	Variance Sum	=	91948.0
Koot_upd.gfl	Std. Dev. of Unit Weight	=	16.74
	Variance of Unit Weight	=	280.33

Output Files:
Kbbk.vc ==> Koot_Vc.bfl
Koot_Vc.adj

F. Final Free Adjustment with Accuracies: A final free adjustment was run with B-file from constrained horizontal adjustment along with the copied free horizontal A-file with qq records and the original G-file producing final adjustment with accuracies.

Input Files:			
Koot_Hc.bfl	Degrees of Freedom	=	315
Koot_qq.afl	Variance Sum	=	64836.1
Koot_upd.gfl	Std. Dev. of Unit Weight	=	14.35
	Variance of Unit Weight	=	205.83

Output File:
Koot_qq.adj

G. Final B-file: The updated B-file from the vertical adjustment and the updated B-file from the horizontal adjustment were combined using NGS program ELEVUP.EXE to create the final B-file. See attached Final *80* Records from the final B-file in Attachment F at back of Appendix A.

Input Files:
Koot_Vc.bfl
Koot_Hc.bfl

Output File:
Koot_fin.bfl

H. Blue Book Accuracies: Program BBACCUR.EXE was run on the final adjustment to output project internal and external accuracies.
Input File:
Koot_qq.adj

Output File:
Koot_BAC.out

XI. Contacts

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Attachment F

```
000010*ID*HZTLOBS NGS   NATIONAL GEODETIC SURVEY              GPS   20020510
000020*10*KOOTENAI RIVER, MONTANA - IDAHO, GPS PROJECT, 2002 - 2003
000030*12*200202200203CLSCURTIS L SMITH                       4ORB0
000040*13*NORTH AMERICAN DATUM-83 GRS-80         63781370002982572221
020000*80*000127+6694                   48243316655N115184126399W 754784AIDB
020010*86*0001   754776A  Y88      -15711T   738912A  A
020020*80*00024A2002                    48350700302N115590171339W 694877GMT1
020030*86*0002   694871G  N88      -16111T   678692A  A
020040*80*0003BONNERS FERRY GAGE          48415365106N116184321643W 543711GIDB
020050*86*0003   543711G  N88      -16528T   527153A  A
020060*80*0005C 506                     48220505500N115213894707W 646556AMTB
020070*86*0005   646551A  Y88      -15848T   630563A  A
020080*80*0006CENTRAL                     48374415778N116013607735W 694945GMTB
020090*86*0006   694936G  N88      -16100T   678777A  A
020100*80*0007COPELAND RM 5 GAGE          48544281878N116250221623W 539985GID1
020110*86*0007   539976G  N88      -16257T   523655A  A
020120*80*0008E 506                     48215690974N115240592410W 648401AMTB
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020140*80*0009F 381 X                   48435077300N116173502199W 711253AIDB
020150*86*0009   711255A  Y88      -16444T   694804A  A
020160*80*0010F 382                     48481917725N116194381151W 686263AIDB
020170*86*0010   686255A  Y88      -16341T   669859A  A
020180*80*0011FSO1 SS                   48284619128N115541928453W 606521GMTB
020190*86*0011   606521G  N88      -16184T   590242A  A
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020220*86*0012   702137A  Y88      -16128T   685981A  A
020230*80*0013G 506                     48224834310N115263116007W 641607AMT1
020240*86*0013   641602A  Y88      -15987T   625558A  A
020250*80*0014K 383                     48321694284N116250782514W 660700AIDA
020260*86*0014   660704A  Y88      -16629T   644123A  A
020270*80*0015KLOCKMAN GAGE               48473772832N116225389031W 546683GID1
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020310*80*0017LIBBY BRIDGE                48235190258N115324894711W 639362GMTB
020320*86*0017   639356G  N88      -16159T   623083A  A
020330*80*0018P 516                     48324680778N115574285070W 567484AMTB
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020350*80*0019POLSON 1 CORS ARP           47394955341N114065007830W 989840GMTA
020360*86*0019   989841G  N88      -15327T   974425A  A
020370*80*0020PLS 6050                    48432921574N116091329516W 715543GIDB
020380*86*0020   715535G  N88      -16173T   699315A  A
020390*80*0021PORTHILL GAGE               48594600689N116302782410W 539476GID1
020400*86*0021   539469G  N88      -16286T   523108A  A
020410*80*0022Q 506                     48242748627N115353562382W 627224AMT1
020420*86*0022   627224A  Y88      -16132T   610971A  A
020430*80*0023S 381 RESET                 48435282789N116152980014W 710239CIDA
020440*86*0023   710231C  Y88      -16375T   693847A  A
020450*80*0024SPOKANE 1 CORS ARP          47310606265N117252525729W 738700GWAA
020460*86*0024   738704G  N88      -18260T   720365A  A
020470*80*0025SPOKANE 2 CORS ARP          47310610707N117252400200W 739180GWAA
020480*86*0025   739181G  N88      -18259T   720828A  A
020490*80*0026T 506                     48260948366N115381906740W 631606AMTB
020500*86*0026   631600A  Y88      -16051T   615440A  A
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020510*80*0027TBM1                    48591880714N116323162284W 538142GIDB
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020530*80*0028TBM3                    48541262027N116240102311W 541211GIDB
020540*86*0028   541213G  N88      -16256T   524892A  A
020550*80*0029TBM6                    48442003417N116245185303W 540310GIDB
020560*86*0029   540309G  N88      -16339T   523928A  A
020570*80*0030TBM7                    48421902326N116221106146W 541833GIDB
020580*86*0030   541826G  N88      -16513T   525276A  A
020590*80*0031TBM8                    48415318628N116184480846W 543370GIDB
020600*86*0031   543373G  N88      -16529T   526821A  A
020610*80*0032TRIBE GAGE                48421879462N116221080246W 541488GIDB
020620*86*0032   541476G  N88      -16513T   524876A  A
020630*80*0033TROY AZ MK                48261401766N115511057195W 648353AMT1
020640*86*0033   648353A  Y88      -16238T   631996A  A
020650*80*0034V 382                   48574570198N116251087270W 674075AIDB
020660*86*0034   674071A  Y88      -16119T   657906A  A
020670*80*0035MISSOULA CORS ARP          46554583733N114063184611W 975620GMTA
020680*86*0035   975617G  N88      -14822T   960639A  A
020699*80*0036SC00 CORS ARP              46570331152N120432853624W1198820GWAA
020700*86*0036  1198821G  N88      -19875T  1178801A  A
020710*90*0006
020720*ID*
```

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Barton and others—Surveying Cross Sections of the Kootenai River Between Libby Dam, Montana, and Kootenay Lake British Columbia, Canada—Open-File Report 2004–1045

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