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# Characterization of Channel Substrate and Changes in Suspended-Sediment Transport and Channel Geometry in White Sturgeon Spawning Habitat in the Kootenai River near Bonners Ferry, Idaho, Following the Closure of Libby Dam

Water-Resources Investigations Report 03–4324
Version 1.0

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

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

**U.S. Department of the Interior**
Gale A. Norton, Secretary

**U.S. Geological Survey**
Charles G. Groat, Director

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# CONVERSION FACTORS

| Multiply | By | To obtain |
|---|---|---|
| | **Length** | |
| centimeter (cm) | 0.3937 | inch (in.) |
| kilometer (km) | 0.6214 | mile (mi) |
| meter (m) | 3.281 | foot (ft) |
| millimeter (mm) | 0.03937 | inch (in.) |
| | **Area** | |
| square kilometer ($km^2$) | 247.1 | acre |
| square kilometer ($km^2$) | 0.3861 | square mile ($mi^2$) |
| | **Volume** | |
| cubic meter per day ($m^3$/d) | 35.31 | cubic foot per day ($ft^3$/d) |
| cubic meter per day ($m^3$/d) | 264.2 | gallon per day (gal/d) |
| cubic meter per second ($m^3$/s) | 70.07 | acre-foot per day (acre-ft/d) |
| cubic meter per second ($m^3$/s) | 35.31 | cubic foot per second ($ft^3$/s) |
| meter per second (m/s) | 3.281 | foot per second (ft/s) |
| | **Mass** | |
| metric ton per day (mt/d) | 1.102 | ton per day (t/d) |

Temperature in degrees Celsius ($^{o}$C) may be converted to degrees Fahrenheit ($^{o}$F) as follows:

$$^{o}F=1.8\ ^{o}C+32.$$

**Concentrations of chemical constituents** in water are given either in milligrams per liter (mg/L) or micrograms per liter (mg/L).

**Sea level:** In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD 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.

# Characterization of Channel Substrate, and Changes in Suspended-Sediment Transport and Channel Geometry in White Sturgeon Spawning Habitat in the Kootenai River near Bonners Ferry, Idaho, Following the Closure of Libby Dam

By Gary J. Barton

## Abstract

Many local, State, and Federal agencies have concerns over the declining population of white sturgeon (*Acipenser transmontanus*) in the Kootenai River and the possible effects of the closure and subsequent operation of Libby Dam in 1972. In 1994, the Kootenai River white sturgeon was listed as an Endangered Species. A year-long field study was conducted in cooperation with the Kootenai Tribe of Idaho along a 21.7-kilometer reach of the Kootenai River including the white sturgeon spawning reach near Bonners Ferry, Idaho, approximately 111 to 129 kilometers below Libby Dam. During the field study, data were collected in order to map the channel substrate in the white sturgeon spawning reach. These data include seismic subbottom profiles at 18 cross sections of the river and sediment cores taken at or near the seismic cross sections. The effect that Libby Dam has on the Kootenai River white sturgeon spawning substrate was analyzed in terms of changes in suspended-sediment transport, aggradation and degradation of channel bed, and changes in the particle size of bed material with depth below the riverbed.

The annual suspended-sediment load leaving the Kootenai River white sturgeon spawning reach decreased dramatically after the closure of Libby Dam in 1972: mean annual pre-Libby Dam load during 1966–71 was 1,743,900 metric tons, and the dam-era load during 1973–83 was 287,500 metric tons. The amount of sand-size particles in three suspended-sediment samples collected at Copeland, Idaho, 159 kilometers below Libby Dam, during spring and early summer high flows after the closure of Libby Dam is less than in four samples collected during the pre-Libby Dam era. The supply of sand to the spawning reach is currently less due to the reduction of high flows and a loss of 70 percent of the basin after the closure of Libby Dam. The river's reduced capacity to transport sand out of the spawning reach is compensated to an unknown extent by a reduced load of sand entering the spawning reach.

Since the closure of Libby Dam, the most notable change in channel geometry at the Copeland streamflow-gaging station was the initiation of cyclical aggradation and degradation of the riverbed in the center of the channel. The aggradation and degradation of the riverbed are reflected in a twofold increase, from 1.3 to 2.5 meters, in the fluctuation of the minimum riverbed elevation, which suggests that during the Libby Dam era, parts of the riverbed in the spawning reach may have aggraded or degraded by as much as 2.5 meters.

Before the closure of Libby Dam, there was a greater propensity for aggradation and degradation of sand over the discontinuous gravel and cobble layers in the buried gravel-cobble reach at Bonners Ferry. The gravel and cobble in this reach, 111.3 to 115.9 kilometers below Libby Dam, are buried by sand. Unregulated spring snowmelt-runoff flows flushed part of the sand layer and exposed some of the buried gravel-cobble layer because streamflow velocities were higher at that time. Unregulated autumn-winter base flows gradually deposited silt and sand and reestablished a sand layer, burying the gravel-cobble layer. This cyclical process of aggradation and degradation of the riverbed sediment is reflected in the alternating gravel-cobble layers and sand layers found in sediment core K18-TH taken as part of this project.

White sturgeon spawning substrate in the Kootenai River meander reach is currently composed of alluvial sand that forms sand dunes and of minor amounts of lacustrine clay and silt that generally are found in the river's thalweg. The present substrate composition in the meander reach is considered similar to that which existed prior to closure of Libby Dam, with one possible exception. Prior to closure of Libby Dam, minor amounts of gravel and cobble may have been exposed on the riverbed in the spawning reach just below the mouth of Myrtle Creek 230 kilometers below Libby Dam. The substrate composition near Shorty Island, 234 kilometers below Libby Dam, a notable white sturgeon

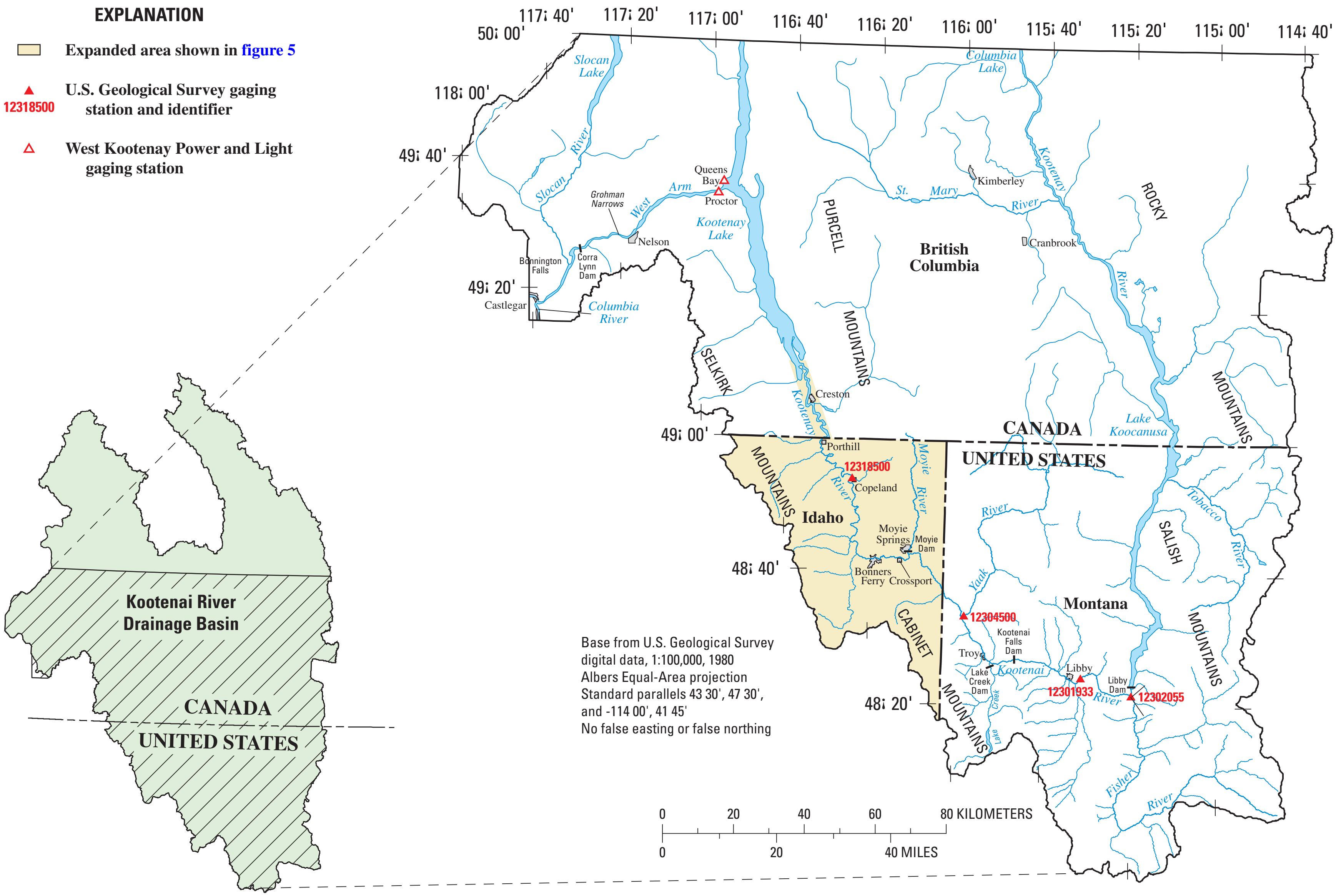


**Figure 1.** Location of the study area, near Bonners Ferry, Idaho, and selected streamflow-gaging stations and dams in the Kootenai River drainage basin, Idaho, Montana, and British Columbia, Canada.

spawning reach, is predominantly sand and is similar to that which existed prior to closure of Libby Dam.

# INTRODUCTION

Many local, State, and Federal agencies have concerns 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 was prohibited. The white sturgeon population decline is reflected in fewer juvenile sturgeon and an overall decline in spawning success. The last successful recruitment of white sturgeon occurred in 1974 (U.S. Fish and Wildlife Service, 1999). 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 recruitment has been attributed, at least in part, to changes in the natural streamflow regime of the Kootenai River after closure (completion) of Libby Dam, near Libby, Montana, in 1973 because these changes could have altered the 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.

White sturgeon are broadcast spawners that release adhesive, negatively buoyant eggs that sink to the riverbed (Stockley, 1981; Brannon and others, 1984). Paragamian and others (2001; 2002) identified five primary reaches in the Kootenai River downstream from Bonners Ferry where white sturgeon spawned during 1994–99. These investigators collected most sturgeon eggs in the outsides of riverbends in the thalweg (the deepest part of any cross section of a river). Parsley and others (1993, p. 224) reported that in the Lower Columbia River, most sturgeon eggs were collected over substrates of cobble or boulder, where the eggs are sheltered by attaching to and incubating on the rocky substrate. Rocky substrate also provides cover for yolk sac larvae before they become free swimming.

Egg suffocation and predation have been hypothesized as potential factors for white sturgeon egg mortality in the Kootenai River (Anders and Richards, 1996; Paragamian and Kruse, 1996; and U.S. Fish and Wildlife Service, 1999). More than 96 percent (428 of 444) of the naturally produced white sturgeon eggs collected between 1991 and 1995 in this reach were from sand substrate that appeared to be suboptimal for incubation (Anders and Richards, 1996; Paragamian and Kruse, 1996). The hypothesis of egg suffocation is supported by the observation that mats placed on the riverbed to catch sturgeon eggs typically are buried by sand within 48 hours of deployment (Vaughn Paragamian, Idaho Department of Fish and Game, and Sue Ireland, Kootenai Tribe of Idaho, oral commun., 1999). Gravel and cobble are optimal substrate for sturgeon spawning habitat, whereas sand is considered detrimental.

In 2000–2001, the U.S. Geological Survey (USGS), in cooperation with the Kootenai Tribe of Idaho (KTOI), conducted a study to assess changes in suspended-sediment transport and channel substrate in the Kootenai River near Bonners Ferry, between RKM (river kilometers) 225 and 246.7, after closure of Libby Dam in 1972, and the effects of any changes on the substrate in the white sturgeon spawning reaches there. Historical data on streamflow and suspended sediment in the Kootenai River and tributaries were used to determine suspended-sediment transport during the pre-Libby Dam and Libby Dam eras, and sediment cores and seismic subbottom profiles of the Kootenai River bed in the study area were analyzed to describe channel substrate during each era.

The Kootenai River White Sturgeon Recovery Team, composed of scientists and engineers from several local, State, Federal, and Canadian agencies, is trying to reestablish the recruitment of white sturgeon. Recognizing this, the USGS is conducting several studies that will provide the recovery team with information and tools that may help to reestablish recruitment. These tools will, among other objectives, allow investigators to assess the potential for enhancing the quality of the white sturgeon spawning substrate.

## Purpose and Scope

This study is part of an overall effort by local, State, and Federal agencies and the Kootenai Tribe of Idaho to improve the Kootenai River white sturgeon spawning habitat. The purposes of this report are to (1) describe the physical characteristics of the channel substrate in the Kootenai River between RKM 225 and 246.7—132 to 110.3 RKM below Libby Dam—before and after closure of Libby Dam, (2) assess the changes in suspended-sediment transport resulting from changes in streamflow after closure of the dam, and (3) assess the possible effects of these changes on the substrate in the white sturgeon spawning reaches of the study area. The report documents changes in (1) suspended-sediment transport, (2) channel geometry, and (3) sediment texture of channel substrate before and after dam closure. The scope of the study included (1) analyzing historical data on streamflow and suspended-sediment loads in the Kootenai River and tributaries, water levels in Kootenay Lake, particle-size distribution of suspended sediment, and channel geometry of the Kootenai River at Copeland, Idaho; and (2) collecting sediment cores and seismic subbottom profiles of the Kootenai River bed in the study area. The study included data from streamflow-gaging stations (hereafter referred to as gaging stations or gages) in Idaho, Montana, and British Columbia. Because there were no gaging stations located in the study reach, the gaging station at Copeland, the closest to the study reach, was used as a surrogate to assess changes in channel geometry.

## Acknowledgments

I would like to thank the people of the Kootenai River valley for their support of this project. I also appreciate Sue Ireland of the Kootenai Tribe of Idaho for providing the U.S. Geological Survey with boats for seismic surveys and for river-sediment coring operations. Vaughn Paragamian of the Idaho Department of Fish and Game provided information about the location of white sturgeon spawning reaches. Peter Van Metre, Michael Dorsey, Barbara Mahler, Keith Ludwig, and Marcus Gary, U.S. Geological Survey scientists from offices in Texas and Florida, conducted the river-sediment coring operations. Eric White of the U.S. Geological Survey in Connecticut assisted with the river seismic survey. Sabrina Conti, U.S. Geological Survey scientist in Idaho, transcribed archived stream-geometry data into spreadsheets and assisted with graphical analysis of the data. Kim Trask, student with the U.S. Geological Survey in Washington, assisted with graphical analysis and prepared geologic striplogs.

## DESCRIPTION OF STUDY AREA

The Kootenai River begins in British Columbia, Canada, and flows through Montana and Idaho (fig. 1). Libby Dam is located on the Kootenai River 16 RKM upstream from Libby, Montana. The study area is the reach of the Kootenai River near Bonners Ferry, Idaho, from RKM 246.7 to 225 (approximately 111 to 129 RKM below Libby Dam), which includes the spawning habitat for the Kootenai River population of white sturgeon (fig. 2). Five reaches in the study reach were used by sturgeon for spawning between 1994 and 1999 (in descending order of number of eggs collected from the riverbed): Middle Shorty Island, RKM 230.0 to 231.0; upstream from Myrtle Creek, RKM 236.1 to 236.9; downstream from Deep Creek, RKM 238.9 to 239.9; downstream from Myrtle Creek, RKM 233.5 to 234.7; and below Shorty Island, RKM 228.0 to 229.0 (Paragamian and others, 2001; 2002). Sturgeon were detected spawning as far upstream as Bonners Ferry only during the 2001 season, near RKM 245.6 (Vaughn Paragamian, Idaho Department of Fish and Game, oral commun., 2001).

### Kootenai River Watershed

The Kootenai River Basin is an international watershed that drains parts of British Columbia, Montana, and Idaho (fig. 1). ("Kootenai" is spelled "Kootenay" in Canada.) 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 Continental Divide forms 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 721 km long and drains an area of 45,584 $km^2$. The river's elevation is 3,618 m at its headwaters in British Columbia. Kootenai Falls, a 61-m-high waterfall and natural fish-migration barrier, is located 46 RKM downstream from Libby Dam. At Bonners Ferry, located 111 RKM below Libby Dam, near the upstream end of the white sturgeon habitat, the Kootenai River flows westward into a nearly straight, northwest-trending, 480-km-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 flows toward the northwest in a meandering course through the broad, flat bottomlands referred to as Kootenai Flats (fig. 2) for about 80 km to the head of Kootenay Lake in British Columbia located 235 RKM below Libby Dam. The Kootenai River flows from the West Arm of Kootenay Lake for about 32 km and empties into the Columbia River at Castlegar, British Columbia.

A natural barrier at Bonnington Falls, now a series of four dams including the Corra Lynn Dam, isolates fish from other populations in the Columbia River Basin. The natural barrier has isolated sturgeon for approximately 10,000 years (Northcote, 1973).

The river's elevation is about 532 m at the confluence with Kootenay Lake. The main body of Kootenay Lake occupies 104 km of the length of the Purcell Trench. Water in Kootenay Lake backs up into the Kootenai River. Backwater conditions in the Kootenai River constantly prevail below the mouth of Deep Creek (116.7 RKM below Libby Dam) near Bonners Ferry, and during May, June, and July, can extend a few kilometers upstream from the U.S. 95 Bridge (111 RKM below Libby Dam) at Bonners Ferry (fig. 3). During periods of low flow, free-flowing water may extend a few kilometers downstream from the U.S. 95 Bridge.

The Kootenai watershed has undergone many changes due to loss of wetlands, construction of dikes on the natural levees, changes in backwater conditions because of changes in the level of Kootenay Lake, and the construction of dams. The construction of dikes eliminated flood-plain connectivity and related processes such as the deposition of

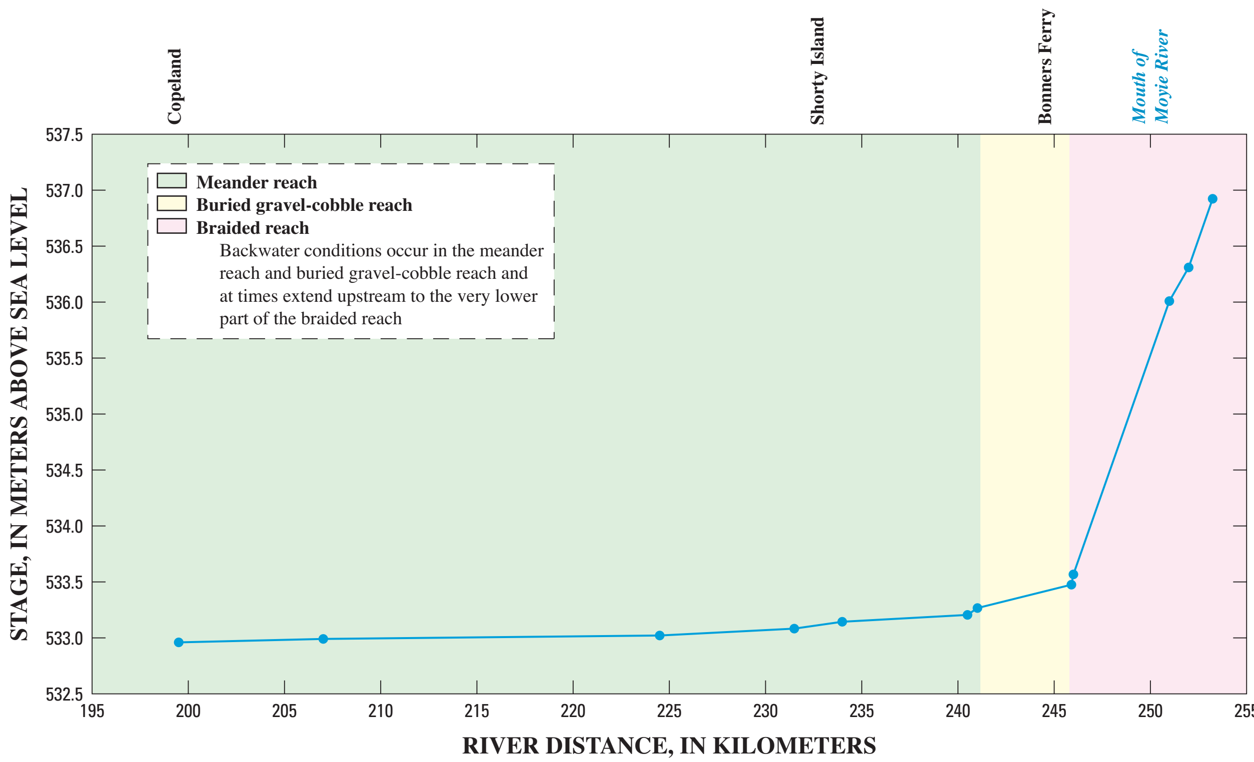


**Figure 3.** Generalized stage of the Kootenai River along three types of geomorphologic reaches from below the mouth of the Moyie River to Copeland, Idaho. (Stage obtained from U.S. Geological Survey 1:24,000 quadrangle maps)

sediments onto the flood plain. The dikes increased confinement of streamflow to the river channel during floods, which resulted in increased stream energy and sediment transport during high flow, primarily prior to the closure of Libby Dam, because the dam greatly reduced high flows. 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. The river channel above the dam at Grohman Narrows was deepened in 1939 in order 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, **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.

The boundary between backwater and free-flowing water continually moves up and down the Kootenai River near Bonners Ferry in response to changes in Kootenay Lake elevations, inflow from tributaries between Bonners Ferry and Libby Dam, and releases from Libby Dam (fig. 3). Backwater conditions generally extend farther up the river as Kootenay Lake levels rise. Kootenay Lake levels generally are at a minimum during the autumn and winter months and at a maximum during the spring snowmelt runoff and the late spring and early summer releases from Libby Dam.

Kootenay Lake levels and Kootenai River backwater conditions have changed over time. After the river channel at Grohman Narrows was deepened in 1939, lake level remained stable at an intermediate elevation for longer periods of the calendar year, probably in response to operation of Corra Lynn Dam (fig. 4). Seasonal fluctuations still occurred, but over a shorter period of time. Prior to Libby Dam, from 1940 to 1972, monthly median lake elevation ranged from 529.6 to 536.4 m, and the median elevation was 531.8 m. In 1948, West Kootenay Power and Light was granted, for a period of 5 years from autumn 1949

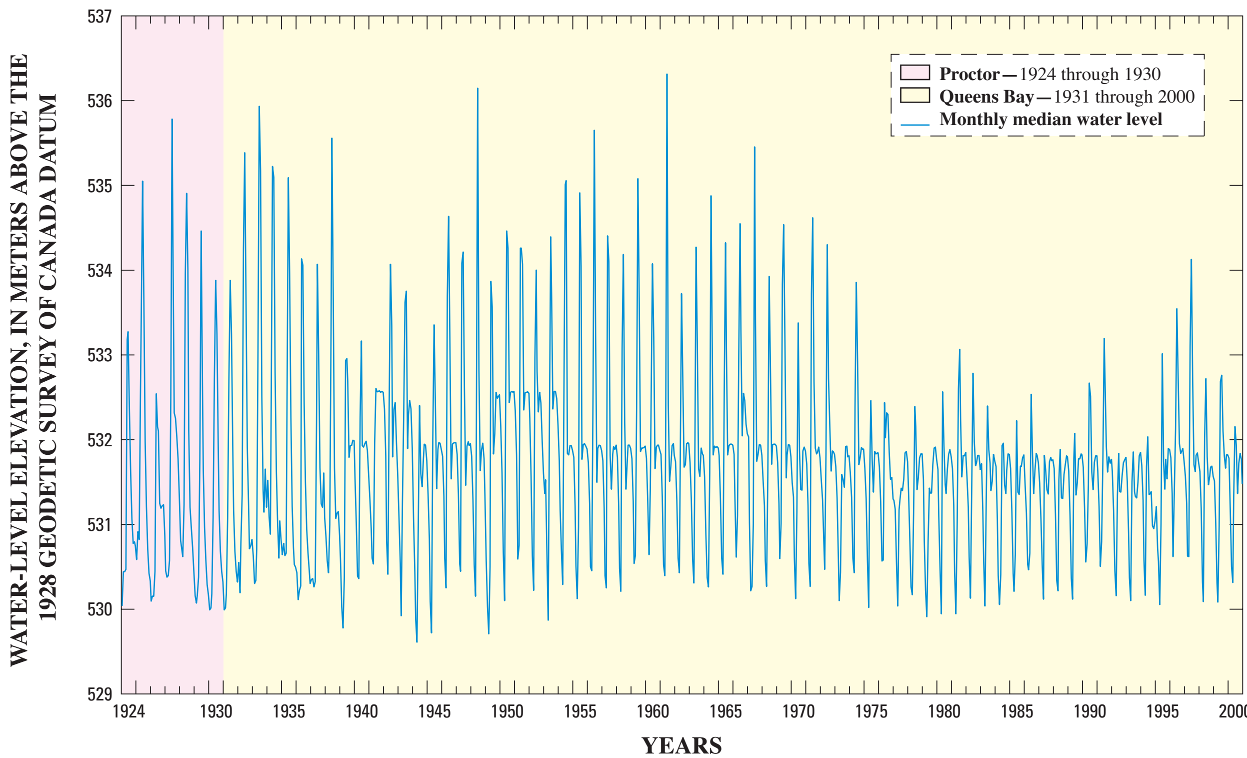


**Figure 4.** Monthly median water levels on Kootenay Lake at Proctor (1924–30) and Queens Bay (1931–2000), British Columbia, Canada. (Source of data is Environment Canada)

to spring 1954, an additional 0.6 m of storage above that approved in 1938 (Lynne Campo, West Kootenay Power and Light, written commun., 2000). From 1949 to 1954, the monthly median lake levels stabilized at a higher elevation of about 532.4 m. During the Libby Dam era from 1973 to 1998, the monthly median lake elevation ranged from 529.9 to 534.2 m and the median lake elevation was 531.6 m.

## Geology of the Kootenai River Basin

The present geological and topographical characteristics of the Kootenai River Basin reflect the effects of massive glaciations during the Pleistocene Epoch, although in the white sturgeon spawning reach, bedrock is exposed near the bank of the river as far west as Mission Hill near Bonners Ferry (fig. 2A). The sills located just east of Bonners Ferry are the hardest geologic materials in the region (Kirkham and Ellis, 1926) and, therefore, the least eroded by glacial advances and retreats.

During the Pleistocene Epoch, a lobe of the Canadian Cordilleran ice sheet repeatedly advanced down the Purcell Trench, filling the Kootenai River valley and mostly submerging the Purcell and Selkirk Mountains in northern Idaho. Ice finally left the valley about 10,000 years ago. During times when ice blocked the outlet of Kootenay Lake, a glacial lake formed in the Kootenai River valley and deposited a thick sequence of generally fine-grained lacustrine sediment consisting of clay and silt. Since the final glacial retreat and draining of glacial Kootenay Lake, the Kootenai River has incised and eroded some of the lacustrine clay-silt layer and deposited alluvial sediment onto the regional lacustrine clay-silt layer (Alden, 1953; Atwater, 1986; Buchanan, 1989). The contact between the alluvial sand and the lacustrine clay-silt layer is a geologic unconformity. Distribution and thickness of glacial lacustrine clay-silt layers are, in part, functions of location in the Kootenai River, according to J-U-B Engineers (1998). Near Porthill, Idaho, drillers' logs show thick clay-silt layers, some in excess of 610 m thick. In the upstream direction toward Bonners Ferry, these clay-silt layer units tend to become silty and thin, and near Bonners Ferry, the layers become discontinuous. The regional lacustrine clay-silt layer is most often underlain by sand and gravel associated with Purcell Trench lobe retreats.

Lost Creek, Cascade Creek, and Myrtle Creek incise into alluvial fan deposits (fig. 2*B* and fig. 2*C*), according to erosion shift maps prepared by the U.S. Army Corps of Engineers (1983). Sediment resembling coarse-grained alluvial fan deposits has been identified in several wells near tributaries to the Kootenai River that drain either the Selkirk Mountains or the Purcell Mountains (J-U-B Engineers, 1998).

## Geomorphology of the Kootenai River Below Libby Dam

Snyder and Minshall (1996) classified three geomorphologic reaches in the Kootenai River between Libby Dam and Kootenay Lake: a canyon reach, a braided reach, and a meander reach. The canyon reach is outside of the study area and extends from Libby Dam to 2 km below the mouth of the Moyie River. Here, the valley broadens and the river forms a braided reach as it courses over gravel and cobbles. This braided reach extends downstream into the study area (fig. 5) to a bedrock constriction near the U.S. 95 Bridge over the Kootenai River at Bonners Ferry. The meander reach extends from the bedrock constriction at Bonners Ferry, through the study area, and on to the confluence with Kootenay Lake.

An additional geomorphological reach identified in the study area is a buried gravel-cobble reach. In this reach the gravel and cobble are buried with sand. The white sturgeon spawning habitat includes the braided reach and the buried gravel-cobble reach and principally lies within the meander reach.

The water-surface slope of the Kootenai River decreases at Bonners Ferry (fig. 3) and greatly influences the geomorphology of the white sturgeon spawning habitat. The braided reach of the Kootenai River extends from RKM 256.2, which is 2.5 RKM downstream from the Moyie River, to RKM 245.75, which is about 0.25 RKM downstream from the U.S. 95 Bridge in Bonners Ferry (fig. 2*A*). The average water-surface slope in this reach is roughly 0.00046. The braided reach has a relatively shallow water depth, typically less than 2 m during low flow. This reach consists mostly of gravel and cobble. White sturgeon have not been detected spawning in the braided river reach (Paragamian and others, 2002).

The buried gravel-cobble reach, RKM 245.75 to 241.1, represents a transition zone between the higher gradient braided reach and the lower gradient meander reach (fig. 2*A* and fig. 3). This reach is relatively straight and stable, with no evidence of the rapid channel shifting observed in the braided reach. The straightness and stability of the channel may be controlled by an outcrop of bedrock near the river channel between the U.S. 95 Bridge and Mission Hill (fig. 2*A*). The water-surface slope in this reach is about 0.00017, less than one-half the gradient in the braided reach. Water depths in the buried gravel-cobble reach are deeper than in the braided reach and typically range from 3 to 6 m. Sand overlies most of the discontinuous cobble and gravel deposits along this reach.

The meander reach (fig. 5) is between RKM 241.1, downstream from Bonners Ferry near the confluence of Deep Creek, and Kootenay Lake. The Kootenai River gently bends north and begins meandering at about RKM 241.1. The average water-surface slope is roughly 0.00002 in the meander reach between RKM 199.5 to 241.1, about one-tenth the gradient in the buried gravel-cobble reach. Water depths in the meander reach exceed 12 m in the thalweg. Fluvial sand occurs throughout most of the meander reach. A reconnaissance seismic survey (Barton, 1998) found that the fluvial sand forms dunes throughout the buried gravel-cobble reach and the meander reach, including areas used by sturgeon for spawning (fig. 6). The Pleistocene lacustrine clay-silt layer forms the river substrate in parts of the thalweg. Prior to European settlement, the valley bottom consisted of wide flood plains, wetlands, and riparian forest. Subsequently, natural levees and sloughs were replaced with constructed dikes to contain overbank flow, and wetlands were drained and developed into annual and pasture croplands (Pacific Watershed Institute and Resources, 1999).

# STUDY METHODS

The approach to meeting the objectives of the study was threefold: analysis of sediment transport, analysis of channel geometry, and mapping of channel substrate. Analysis of sediment transport and channel geometry was based on data previously collected by the USGS.

## Measuring Streamflow and the Concentration of Suspended Sediment

Suspended sediment is the sediment that at any given time is maintained in suspension as a colloid or by the upward components of turbulent currents. Suspended-sediment concentration is the velocity-weighted mean concentration of suspended sediment in a sampling zone from the water surface to a point approximately 0.1 m above the bed, expressed as milligrams of dry sediment per liter of water-sediment mixture (mg/L). Suspended-sediment load, reported as metric tons per day (mt/d), is the rate at which the dry weight of sediment passes a section of a stream in a given time. Depth-integrated techniques are used to define the sediment concentration at vertical transit points in a river cross section. The suspended-sediment concentration over the cross section is determined from depth-integrated measurements at vertical transit points. Daily monitoring of suspended sediment is provided by samples collected at a fixed point which are related to sediment concentration over the cross section with empirical coefficients. Additional information about USGS suspended-sediment sampling techniques can be found in Edwards and Glysson (1999).

The inactive USGS streamflow-gaging station 12318500 at Copeland, Idaho (**fig. 5**), is the only suspended-sediment station near the present white sturgeon spawning reach. This gage is located 15 RKM downstream from the white sturgeon spawning reach. Suspended-sediment samples were collected daily from 1966 to 1983, and the data reside in the USGS National Water Inventory System (NWIS) database. Three samples from 1968 to 1970 and four samples from 1974 to 1976 were analyzed for particle-size distribution by $^1/_2$ Phi classes using the visual-accumulation tube methods. Particle-size distribution is reported as diameter, in millimeters, by $^1/_2$ Phi class sizes: 0–0.002, 0.002–0.004, 0.004–0.008, 0.008–0.016, 0.016–0.031, 0.031–0.062, 0.062–0.125, 0.125–0.25, and 0.25–0.5 millimeters. For the 1974–76 samples, class sizes 0.062–0.5 were determined using the wet sieve method.

Suspended-sediment load was measured periodically at three USGS streamflow-gaging stations. Station 12301933 was measured from May 1968 to June 1971 and from May 1999 to July 2000. This gaging station is located on the Kootenai River about 28 km below Libby Dam in Libby, Montana (**fig. 1**). The Fisher River and Libby, Rainy, and Alexander Creeks flow into the Kootenai River between this gaging station and Libby Dam. Station 12304500 was measured from May through August 1999. This gage is located on the Yaak River about 0.5 km upstream from its mouth at the Kootenai River (**fig. 1**). The Yaak River enters the Kootenai River just east of the Idaho-Montana border below Kootenai Falls: this unregulated tributary drains a 1,226-$km^2$ basin and has an annual mean daily flow of 20 $m^3/s$ for 1956–99. Station 12302055 was measured from April 1969 to December 1975 and from May 1999 to July 2000. This gaging station is located on the Fisher River about 1.3 km upstream from its mouth at the Kootenai River (**fig. 1**). The Fisher River enters the Kootenai River just below Libby Dam; this unregulated tributary drains a 1,341-$km^2$ basin and has an annual mean daily flow of 20 $m^3/s$.

## River Channel Geometry Computation

The streamflow-gaging station nearest the present white sturgeon spawning reach is the Copeland gage on the Kootenai River (**fig. 1**). Stream-discharge measurements, which included information about river geometry, were made from 1929 to 1993 from a permanent cableway that crosses the river at Copeland, Idaho. The river stage, depth, and other data recorded along this cross section were measured in relation to permanent benchmarks. Measurement interval was typically about 6 weeks. Data of this type are extremely reliable in analyzing changes in river geometry over time since they are repeatedly obtained from the same location.

Data from the Copeland gage such as discharge, average velocity, river stage, cross-sectional area of the river, and river width reside in the USGS NWIS database. Channel cross-section elevation data and thalweg data at the Copeland gaging station are not stored in the NWIS database but were compiled for analysis from archived notes made by USGS personnel while measuring discharge at the gaging station. USGS level notes for the Copeland gaging station, retrieved from Federal archives, indicate that the datum for this gaging station typically was resurveyed once a year to verify the accuracy of river-stage measurements. These level notes were reviewed to insure that any changes to the gage datum were (1) correctly entered into the NWIS database and (2) correctly applied to the channel cross-section elevation data and thalweg data compiled from archived field records.

Mean riverbed elevation was computed by subtracting the mean river depth from river stage at the time of the discharge measurement. The mean river depth was computed by dividing the cross-sectional area of the river by the water-surface width. The river stage is calculated as gage height plus stream-gage datum elevation. Thalweg elevation was computed by subtracting the thalweg depth from the river stage at the time of the discharge measurement. Thalweg depth is not stored in the NWIS database but was computed by subtracting the maximum depth along the river cross section that was recorded on the discharge measurement note from the river stage at the time of the discharge measurement. The riverbed elevation was computed by subtracting river depth from river stage at the time of the discharge measurement. Depth values are relative to water-surface elevation.

## Mapping of Channel Substrate

The description of the channel substrate—lacustrine clay-silt layer and alluvial deposits—in the white sturgeon spawning reach of the Kootenai River is based on seismic subbottom profiles, sediment cores, and ponar dredge samples of the riverbed. Locations of seismic subbottom profiles and sediment-coring sites are shown on **figure 2**.

### SEISMIC SUBBOTTOM PROFILING

Seismic subbottom profiles were made at various cross-section locations in the study area from RKM 244.3 to

**Table 1.** Sediment cores of the Kootenai River bed near Bonners Ferry, Idaho, October 19–22, 2000

[Geologist logs presented in figure 24; C, near center of river; TH, thalweg; LB, near left bank; RB, near right bank, RTH, right of thalweg; VC, vibracore; PC, piston core; core recovery, does not include a thickness correction for compaction of sand due to vibratory movement; AL, Alluvial; LU, Lacustrine clay and silt; flow at Bonners Ferry was 227 cubic meters per second]

| USGS identifier | Date | Latitude (degrees, minutes, seconds) | Longitude (degrees, minutes, seconds) | River kilometer | Sediment core type | Depth core penetrated, in meters | Core recovery, in meters | Water depth, in meters | Type of sediment | Core contains sediment coarser than sand |
|---|---|---|---|---|---|---|---|---|---|---|
| K3-TH | 9/21/00 | 48 47.301 | 116 23.703 | 228.5 | VC | 3.5 | 2.1 | 7.9 | AL | No |
| K3-C | 9/21/00 | 48 47.346 | 116 23.707 | 228.5 | VC | 3.5 | 2.0 | 4.9 | AL | No |
| K5-C | 9/21/00 | 48 46.546 | 116 23.423 | 229.5 | VC | 3.2 | 2.5 | 7.3 | AL, LU | No |
| K5-TH | 9/21/00 | 48 46.568 | 116 23.392 | 229.5 | VC | 3.5 | 2.0 | 8.5 | LU | No |
| K6-RB | 9/21/00 | 48 45.873 | 116 23.179 | 230.9 | VC | 3.5 | 3.4 | 6.1 | AL | No |
| K6-TH | 9/21/00 | 48 45.880 | 116 23.202 | 230.9 | VC | 3.5 | 2.7 | 14.9 | AL, LU | No |
| K6-LB | 9/21/00 | 48 45.865 | 116 23.221 | 230.9 | VC | 3.5 | 1.9 | 9.8 | AL | No |
| K6.5-C | 9/21/00 | 48 45.416 | 116 23.750 | 232.0 | VC | 3.3 | 0.8 | 3.7 | AL | No |
| K9-LB | 9/19/00 | 48 44.831 | 116 24.852 | 233.8 | PC | 0.3 | 0.3 | 5.1 | AL | No |
| K9-C | 9/19/00 | 48 44.84 | 116 24.851 | 233.8 | PC | 0.6 | 0.4 | 5.2 | AL | No |
| K9-RB | 9/20/00 | 48 44.837 | 116 24.771 | 233.8 | VC | 1.3 | 1.3 | 4.2 | AL | No |
| K9.5-TH | 9/20/00 | 48 44.611 | 116 24.935 | 234.3 | VC | 0.2 | 0.0 | 12.5 | AL | Yes |
| K9.5-C | 9/20/00 | 48 44.595 | 116 24.915 | 234.3 | VC | 0.3 | 0.3 | 10.2 | AL | Yes |
| K9.5-RB | 9/20/00 | 48 44.597 | 116 24.901 | 234.3 | VC | 3.5 | 1.9 | 6.9 | AL | No |
| K10-RC | 9/20/00 | 48 44.406 | 116 24.833 | 234.5 | VC | 3.5 | 0.8 | 7.3 | AL | No |
| K10-TH1 | 9/19/00 | 48 44.375 | 116 24.885 | 234.5 | PC | 0.1 | 0.0 | 8.4 | AL | Yes |
| K10-TH2 | 9/19/00 | 48 44.379 | 116 24.881 | 234.5 | PC | 0.8 | 0.3 | 12.8 | AL | Yes |
| K10-RTH | 9/20/00 | 48 44.382 | 116 24.879 | 234.5 | VC | 3.5 | 2.0 | 8.4 | AL | No |
| K11-C | 9/20/00 | 48 44.358 | 116.24.300 | 235.1 | VC | 3.5 | 1.9 | 4.7 | AL | No |
| K11-LB | 9/20/00 | 48 44.333 | 116 24.319 | 235.1 | VC | 3.5 | 2.1 | 3.7 | AL | No |
| K12-TH1 | 9/20/00 | 48 44.559 | 116 23.607 | 236.1 | VC | 3.5 | 1.9 | 13.7 | AL | Yes |
| K12-TH2 | 9/22/00 | 48 44.469 | 116 23.580 | 236.1 | VC | 2.9 | 1.4 | 13.1 | AL | Yes |
| K12-LB | 9/22/00 | 48 44.450 | 116 23.590 | 236.1 | VC | 3.5 | 2.0 | 8.5 | AL, LU | No |
| K13-LB1 | 9/20/00 | 48 44.105 | 116 22.993 | 237.1 | VC | 3.5 | 1.8 | 6.1 | AL | No |
| K13-LB2 | 9/20/00 | 48 44.102 | 116 23.005 | 237.1 | VC | 3.5 | 1.3 | 2.9 | AL | No |
| K13-RB | 9/19/00 | 48 44.121 | 116 22.941 | 237.1 | PC | 0.0 | 0.4 | 5.9 | AL, LU | No |
| K13-TH | 9/20/00 | 48 44.113 | 116 22.965 | 237.1 | VC | 3.5 | 3.4 | 11.9 | LU | No |
| K14-TH | 9/22/00 | 48 43.719 | 116 23.282 | 237.9 | VC | 2.0 | 0.6 | 6.6 | AL, LU | No |
| K15.5-TH | 9/22/00 | 48 43.125 | 116 23.471 | 239.0 | VC | 3.5 | 2.1 | 8.8 | AL, LU | Yes |
| K16-C1 | 7/22/00 | 48 42.815 | 116 23.335 | 239.7 | VC | 0.6 | 0.6 | 5.6 | AL | No |
| K16-C2 | 9/22/00 | 48 42.814 | 116 23.340 | 239.7 | VC | 3.1 | 2.1 | 5.6 | AL | No |
| K16-LB | 9/22/00 | 48 42.798 | 116 23.360 | 239.7 | VC | 3.5 | 3.4 | 4.6 | LU | No |
| K18-LB | 9/22/00 | 48 42.240 | 116 21.881 | 241.6 | VC | 3.5 | 2.2 | 5.5 | AL, LU | No |
| K18-TH | 9/22/00 | 48 42.261 | 116 21.871 | 241.6 | VC | 2.3 | 1.6 | 5.5 | AL, LU | Yes |
| K20-TH | 9/22/00 | 48 41.807 | 116 20.221 | 243.9 | VC | 1.5 | 0.6 | 4.6 | AL | Yes |

226 using a seismic system from the USGS Branch of Geophysical Operations and Support, Stoors Mansfield, Connecticut (fig. 7). Seismic subbottom profiling methodology is described in detail in Haeni (1986). This system transmits swept FM waveforms that operate between 0.5 and 2.0 kHz (kilohertz). A 0.2-mt tow vehicle that transmits and receives the FM signal was pulled behind the survey boat in the water. During surveying operations, the boat was propelled at 2–3 km per hour, the sound source was fired every 0.5 second, and a continuous record of the subsurface was obtained. The unprocessed data were digitally recorded to allow for post-data acquisition processing. Spatial referencing of seismic subbottom profiles was accomplished using a Global Positioning System (GPS).

The seismic-acoustic signals displayed on subbottom profiles show the interface between different layers of sediment below the riverbed. The interface of the profiles is referred to as a subsurface reflector. Depths of subsurface reflectors were calculated assuming an acoustic velocity of 1,524 m per second. Depth of geophysical exploration corresponds to the deepest seismic reflector and ranged from less than 1 m to greater than 10 m below the riverbed. Some natural, coarse-grained subsurface materials that limit depth of exploration caused the variation in depth of exploration. Seismic resolution, the ability to identify the contact between different layers, is on the order of 0.2 m or greater. Ghost reflectors representing seismic ringing in the water column between the free-water surface and riverbed are present on many subbottom profiles.

### CORING OF RIVERBED SEDIMENT

Thirty-five cores of riverbed sediment were collected from RKM 243.9 to 225.8 in the study area (table 1; see fig. 2 for locations). A 7.3-m pontoon coring boat was employed for taking vibracores and piston cores of sediment beneath the riverbed (fig. 8). Sites for instream sediment cores were not evenly distributed throughout the study area but were concentrated in the spawning reaches. The core sites were referenced spatially using GPS. The 35 sediment cores were taken at or near cross sections of the river where seismic subbottom profiles were obtained. Generally, one core was taken from the deepest part of the thalweg where erosion may occur and another in shallower water where deposition may occur. At eight cross sections, two or three cores were taken in shallower water. Thirty cores were collected using the vibracoring system and five cores were collected using a piston coring system. The vibracoring system is equipped with a 0.08-m-diameter core barrel that is 3.66 m in length and capable of recovering the clay-silt layer, silt, sand, gravel, and some cobble. The maximum length of core recovered during data collection was 3.5 m, with an average recovery of 3.0 m. Twenty-two vibracores sampled 3 to 3.5 m of the channel substrate. The piston coring system is equipped with a 0.08-m-diameter core barrel that is 1.52 m in length. The maximum recovery for the piston core was 0.8 m and the average recovery was 0.6 m.

The vibrating action of the vibracore greatly enhanced penetration of the core barrel into the substrate. However, the vibrating action caused compaction of sand and organic debris (no effect on clay-silt layers) in the core barrel. Compaction of sand in vibracores has been observed in other settings (Keith Ludwig, U.S. Geological Survey, oral commun., 2000). Thickness of sand and organic layers in vibracores was adjusted for compaction by multiplying measured thickness by a correction factor. The thickness correction factor was determined from layer thickness penetrated by the vibracore divided by the thickness of sand or organic material recovered in the core barrel. Calculations were adjusted to account for any silt or clay layer(s) recovered in the core. The average correction factor was about 1.6.

The Kootenai Tribe of Idaho collected bed material samples from the Kootenai River on June 20, 2000, between RKM 226 and 244.3. These samples were taken with a ponar dredge sampler at 22 sites located near mid-channel and near the riverbanks (table 2).

### LIMITATIONS ON MAPPING CHANNEL SUBSTRATE

Because of the limited resolution of seismic subbottom profiles and a limited number and distribution of sediment cores, the contact lines defining the composition of the river substrate are general delineations and are inferred in most cases. Seismic reflectors on subbottom profiles do not always indicate a specific type of sediment layer, but may indicate only the boundary between two adjacent layers of sediment. Thus, cores of riverbed sediment or other “ground truth” are required to correctly interpret the sediment texture of seismic reflectors displayed on subbottom profiles. Only three riverbed sediment cores were collected in the buried gravel-cobble reach near Bonners Ferry, RKM 245.75 to 241. Current understanding of the lateral extent, thickness, and particle-size distribution of the buried gravel-cobble layers is generalized. Additional cores of the riverbed are needed in this reach in order to construct a more detailed map that shows the lateral extent, thickness, and particle-size distribution of the buried gravel-cobble layers.

## CHANGES IN STREAMFLOW AND SUSPENDED-SEDIMENT REGIMES

Analysis of streamflow and suspended-sediment regimes for the Kootenai River is based largely on the period of record at the Copeland gage that includes both stream-flow and suspended-sediment load from 1966 to 1983 (fig. 9). Streamflow for the gage at Porthill (12322000) also is used in the analysis (fig. 10) because this gage, unlike the Copeland gage, was operational throughout the 1980s and 1990s and, hence, provides an account of streamflow con-ditions during that period of time. Streamflow at Porthill is slightly greater than at Copeland owing to a larger drainage area.

## Streamflow

On the basis of records for the Copeland gage from 1966 to 1971, the streamflow regime for the Kootenai River during the pre-Libby Dam era was characterized by peak flows resulting from spring snowmelt occurring from late April through mid-July (**fig. 9*A***). Annual median peak spring-summer runoff flow was about 2,237 $m^3/s$, with a slow recession of flow generally starting in mid-June and reaching base-flow conditions in September. The remaining months had stable base-flow conditions with occasional smaller peaks caused by infrequent storms including rain-on-snow events. The annual median base flow during the months of October through February was 88 $m^3/s$.

From 1966 to 1971, the average cross-sectional streamflow velocity during 62 measurements at the Copeland gage ranged from 0.06 to 1.21 m/s (**fig. 11**). During 1929–1971, the period of record at the Copeland gage for the pre-Libby Dam era, the maximum average cross-sectional streamflow velocity and flow among the 600 measurements were 1.34 m/s and 3,115 $m^3/s$ on May 28, 1961. Although one of the principal effects of Libby Dam is a decrease in the range of daily mean flows, the annual daily mean flow was nearly identical after the closure of Libby Dam, based on the period of record at the Porthill gage (**fig. 10**). The annual daily mean flow from 1929 to 1971 was 469 $m^3/s$, compared with 454 $m^3/s$ from 1973 to 2000.

On the basis of the records for the Copeland gage from 1973 to 1983, the streamflow regime for the Kootenai River for the Libby Dam era was characterized by daily median flows that peaked at about 600 $m^3/s$ (**fig. 9*B***). Peak flows generally occurred twice a year, during the winter and during the spring and early summer (**fig. 9*B***). Median daily spring-summer runoff streamflow during the Libby Dam era was several times less than during the pre-Libby Dam era (**fig. 9*A*** and **fig. 9*B***). During the fall and winter months, the annual median daily flows fluctuated much more than during the pre-Libby Dam era (**fig. 9*A*** and **fig. 9*B***). Long periods of sustained higher flows occurred during the fall and winter of the Libby Dam era, reflecting hydroelectric power generation when electrical demand is greatest in this area. The average cross-sectional streamflow velocity from 83 measurements at the Copeland gage ranged from 0.11 to 0.8 m/s (**fig. 11**). The maximum average cross-sectional streamflow velocity during the Libby Dam era was about three-fifths that during the pre-Libby Dam era.

Beginning in 1991, Kootenai River flows were augmented with additional release of water from Libby Dam during white sturgeon spawning in May and June in an attempt to help resume recruitment; however, the augmented flow is much less than pre-Dam peak flows. Since 1995, flows in the Kootenai River during white sturgeon spawning have been higher with the additional release of water from Libby Dam. The augmented streamflow is

**Table 2.** Sediment samples of Kootenai River bed taken with ponar dredge sampler on June 20, 2000. (Samples collected by the Kootenai Tribe of Idaho.)

[Streamflow at Bonners Ferry was about 708 cubic meters per second.]

| River kilometer | Water depth at dredging location in meters | | | General lithologic description |
|---|---|---|---|---|
| | Mid-channel | Near right bank | Near left bank | |
| 244.3 | 15.2 | | 8.2 | Fine- to coarse-grained alluvial sand |
| 243 | 6.7 | | 7.9 | Fine- to coarse-grained alluvial sand |
| 241 | 8.2 | | 7.3 | Fine- to coarse-grained alluvial sand |
| 239.8 | 7.9 | | 7.0 | Fine- to coarse-grained alluvial sand |
| 237.5 | 7.9 | 9.4 | | Fine- to coarse-grained alluvial sand |
| 234.5 | 7.6 | | 9.8 | Fine- to coarse-grained alluvial sand |
| 323 | 6.7 | 9.8 | | Fine- to coarse-grained alluvial sand |
| 231.5 | 5.5 | 7.0 | | Fine- to coarse-grained alluvial sand |
| 230.3 | 9.1 | 6.7 | | Fine- to coarse-grained alluvial sand |
| 229.5 | 8.8 | 4.0 | | Fine- to coarse-grained alluvial sand |
| 226 | 6.7 | 3.7 | | Fine- to coarse-grained alluvial sand |

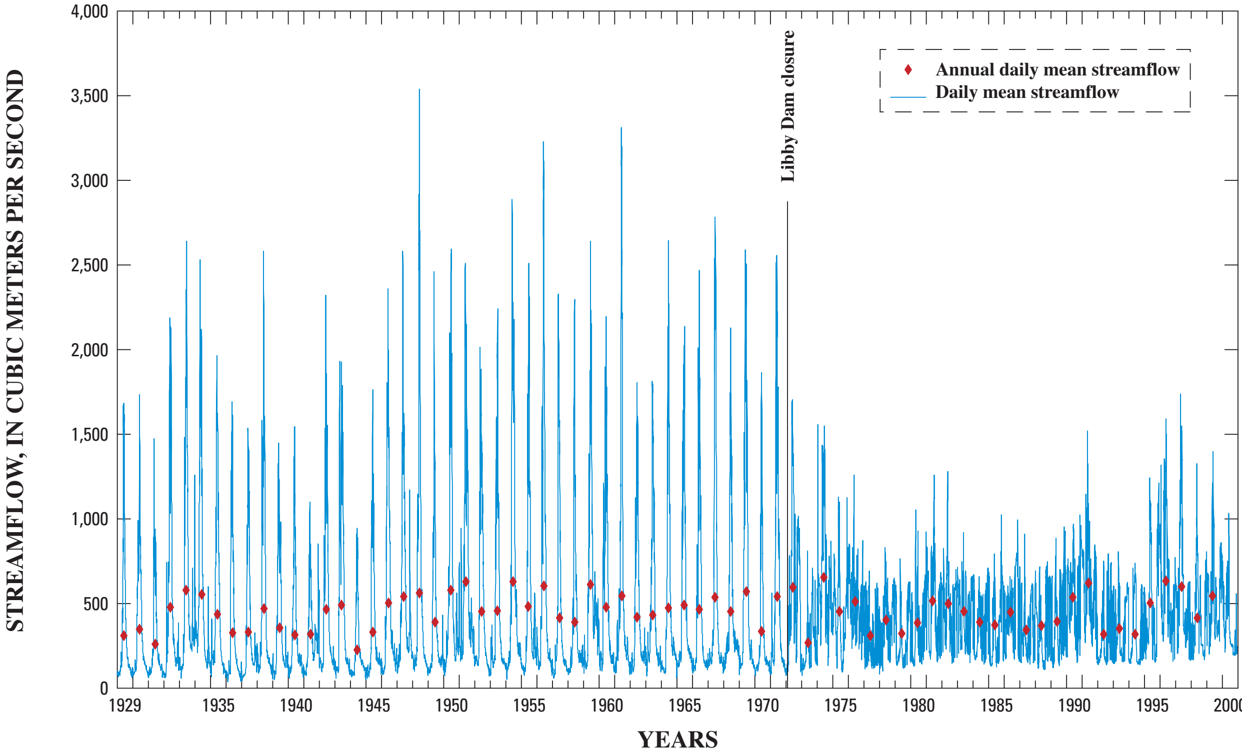


**Figure 10.** Streamflow at U.S. Geological Survey streamflow-gaging station 12322000 on the Kootenai River at Porthill, Idaho, 1929–2000.

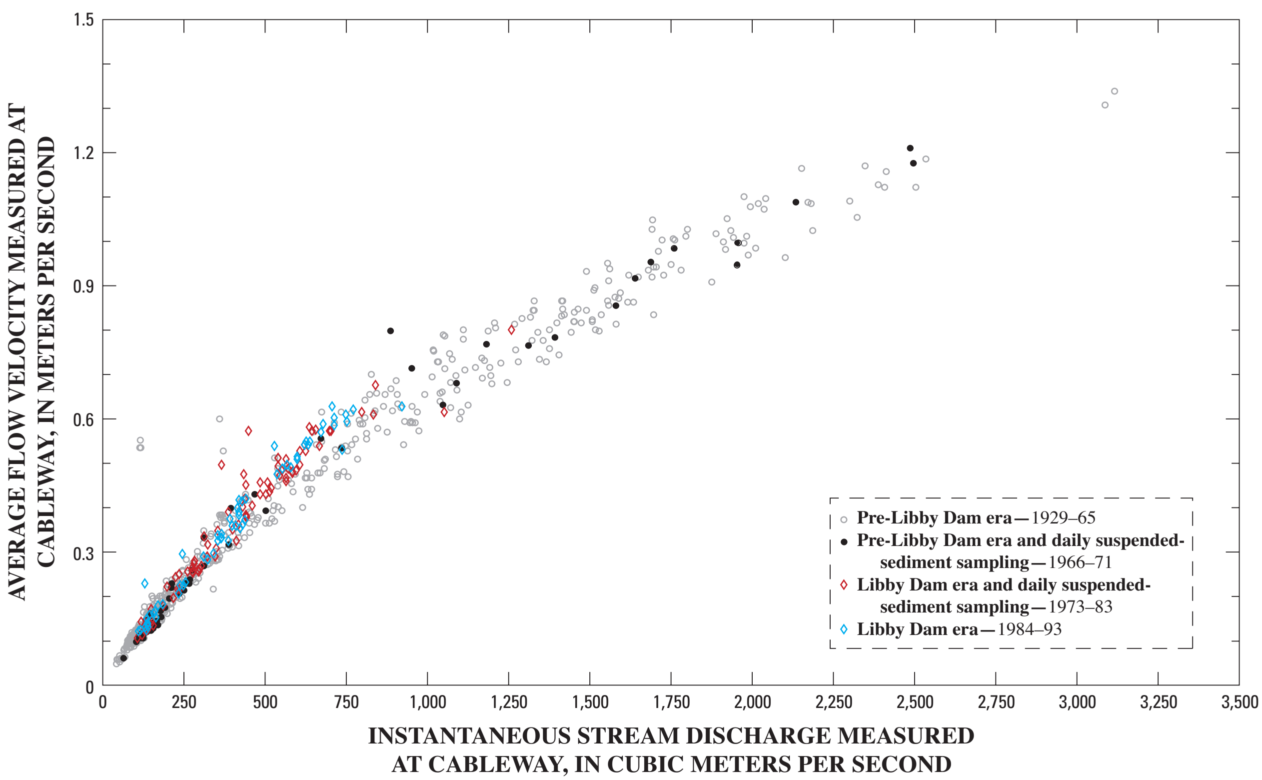


**Figure 11.** Relation between stream discharge and streamflow velocity at U.S. Geological Survey streamflow-gaging station 12318500 on the Kootenai River at Copeland, Idaho, 1929–93.

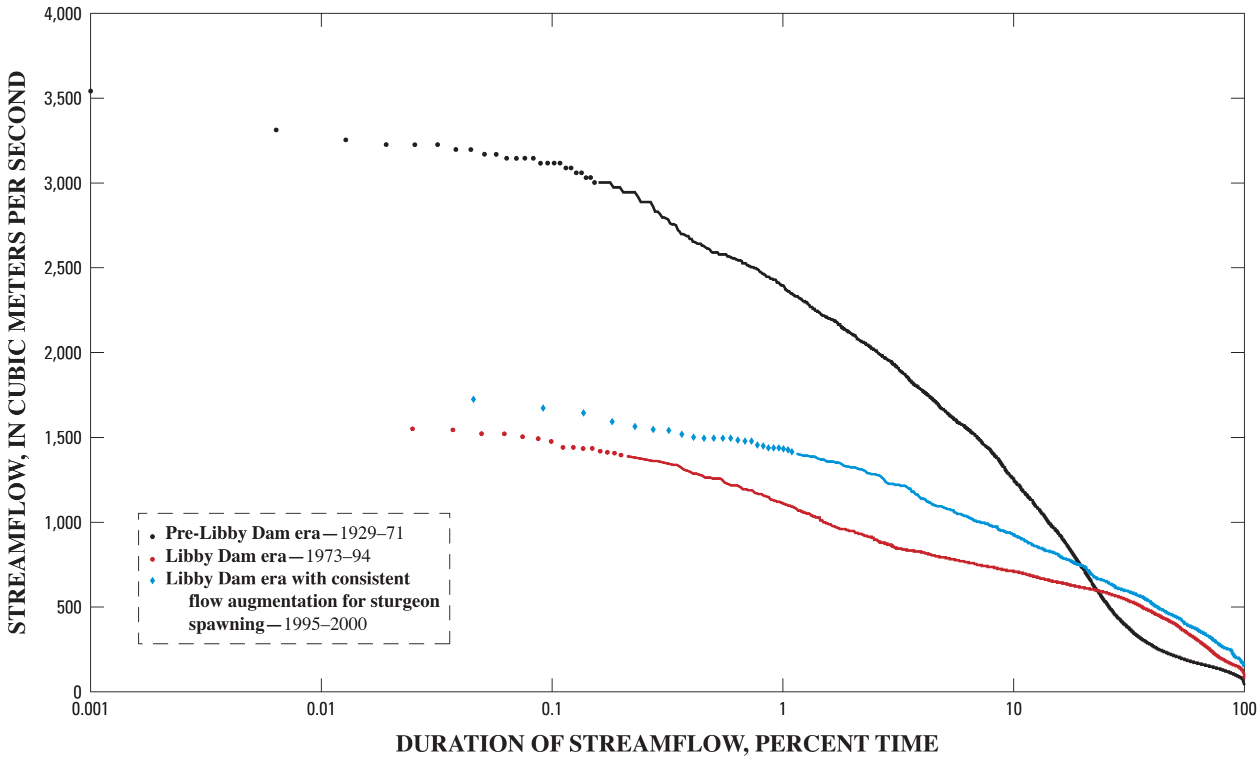


**Figure 13.** Comparison of the duration for daily mean flows during the pre-Libby Dam era and Libby Dam era at U.S. Geological Survey streamflow-gaging station 12322000 on the Kootenai River at Porthill, Idaho, 1929–2000.

roughly one-half the peak streamflow during the pre-Libby Dam era.

Lipscomb and others (1997) conducted an Acoustic Doppler Current Profiler survey on June 11 and 12, 1997, under augmented streamflows of 1,240 and 1,260 $m^3/s$. This survey measured streamflow velocities in the white sturgeon spawning reach at three 500-m reaches. The average streamflow velocity calculated for each reach at a depth of 6.8 m ranged from 0.53 to 0.89 m/s (Lipscomb and others, 1997, table 1). These velocities are lower than the velocities observed at the Copeland gage during snowmelt runoff, when peak discharge exceeded 1,500 $m^3/s$ most years, during the pre-Libby Dam era.

## Suspended-Sediment Regime

In the white sturgeon spawning reach, transport of the abundant sand is controlled by streamflow. The sources of sand since the closure of Libby Dam in the white sturgeon spawning reach are Deep Creek, Myrtle Creek, and erosion of the riverbanks, but mainly upstream sources, including tributaries and the bed of the Kootenai River below Libby Dam.

During snowmelt runoff in the pre-Libby Dam era, the data collected at the USGS gage at Copeland (fig. 9*A* and fig. 12) indicate that large amounts of suspended sediment were transported through the white sturgeon spawning reach. The annual suspended-sediment load transported through the Kootenai River white sturgeon spawning reach (fig. 9*C*) decreased by a factor of 6 after the closure of Libby Dam in 1972: mean annual pre-Libby Dam load (1966–71) was 1,743,900 mt, whereas the dam-era load (1973–83) was 287,500 mt. Annual median daily load during the pre-Libby Dam era ranged from 13 mt/d at 114 $m^3/s$ to 48,700 mt/d at 2,135 $m^3/s$, and during the Libby Dam era from 53 mt/d at 199 $m^3/s$ to 1,560 mt/d at 581 $m^3/s$. Suspended-sediment transport during the Libby Dam era was minimal, about 16 percent of the pre-Libby Dam era amount.

The magnitude of Kootenai River flows that occur less than 10 percent of the time has been significantly decreased since closure of Libby Dam; therefore, the capacity of the river to transport suspended sediment has been greatly reduced. In general, streamflow equaled or exceeded less than 10 percent of the time usually transports a majority of the annual sediment load (Wolman and Miller, 1960); moreover, the increment of discharge that transports the largest quantity of sediment over a period of years is equaled or exceeded less than 3 percent of the time (Andrews, 1986). During the pre-Libby Dam era, daily mean flow exceeded 1,242 $m^3$/s fewer than 37 days per year. Daily mean flow exceeded 1,242 $m^3$/s fewer than 3 days per year during the Libby Dam era from 1973 to 1994, and 10 days per year during the Libby Dam era from 1995 to 2000 with consistent flow augmentation from Libby Dam for white sturgeon spawning. In addition, during the pre-Libby Dam era, flows exceeded 3,230 $m^3$/s almost 11 days per year; flows have not exceeded 1,739 $m^3$/s during the Libby Dam era (fig. 13).

Suspended sediment is being trapped behind Libby Dam that otherwise was transported downstream from the upper part of the river basin during the pre-Libby Dam era. On the basis of periodic suspended-sediment samples collected at the USGS gaging station 12301933 below Libby Dam at Libby, Montana, the median suspended-sediment concentration during the pre-Libby Dam era was 337 mg/L (measured during eight sampling events between May 27, 1968, and June 1, 1971) and, during the Libby Dam era, the concentration was 2 mg/L (measured during seven sampling events between May 19, 1999, and June 27, 2000) (fig. 12*A*). On the basis of these samples and on streamflow, the median daily suspended-sediment load at Libby, Montana, during the pre-Libby Dam era was 39,400 mt/d and, during the Libby Dam era, the load was 39 mt/d (fig. 12*B*).

During periods of high flow in tributaries between Bonners Ferry and Libby Dam, the water flowing out of Libby Dam is likely a much smaller source of suspended sediment to the Kootenai River than are its tributaries. During periods of low flow in tributaries, the water flowing out of Libby Dam is a larger source of suspended sediment to the Kootenai River than are its tributaries. Tributary additions of suspended sediment to the Kootenai River between the white sturgeon spawning reach near Bonners Ferry and Libby Dam have been measured only during the Libby Dam era and only for two tributaries, Yaak River and Fisher Creek. Suspended-sediment load was measured during four sampling events on the Yaak River from May to August 1999 at USGS gage 12304500. The load ranged from 0.7 mt/d with a flow of 8 $m^3$/s on August 17 to 1,370 mt/d with a flow of 202 $m^3$/s on May 25. For comparison, during roughly the same period, measurements taken at USGS gage 12301933 below Libby Dam show the median daily load was 39 mt/d during spring snowmelt runoff, on the basis of six sampling events between May 19, 1999, and June 27, 2000 (fig. 12*B*).

## Hysteresis Effect on Transport of Suspended Sediment

In the pre-Libby Dam era, suspended-sediment concentrations at the Copeland gage during first flush (the sudden and dramatic increase in streamflow near the start of the snowmelt runoff period after months of low flow) were about two to three times higher than concentrations measured at similar streamflow later in the runoff season. This hysteresis effect on sediment transport is characteristic of streams with large variation in flows. For example, suspended-sediment concentrations ranged from about 400 mg/L to 600 mg/L on 3 days during first-flush events in 1967 (fig. 14*A*). More important is that the sediment concentrations subsequent to the first flush are lower (150–350 mg/L) even though the flows are still elevated. Prior to these first-flush events, the suspended-sediment concentrations were less than 20 mg/L. This hysteresis effect can be further explored by studying the median daily suspended-sediment load during the pre-Libby Dam era from about April 30 to June 6 on the rising limb of the hydrograph and during June 7 to July 25 on the falling limb of the hydrograph (fig. 9*A*). During the April 30 to June 6 period, the volume of suspended sediment transported through the white sturgeon spawning habitat and past the Copeland gage was roughly 24 percent greater on the rising limb of the hydrograph than on the falling limb. Furthermore, the volume of streamflow through the white sturgeon spawning habitat was roughly 10 percent less on the rising limb of the hydrograph than on the falling limb.

In the Libby Dam era, some data also show a hysteresis effect for sediment transport. During the period of record for the Libby Dam era, the only significant first-flush event occurred in 1974. Suspended-sediment concentrations at the beginning of the first-flush event in April ranged from 200 to 300 mg/L for 3 days (fig. 14*B*) and concentrations quickly decreased, although streamflow remained high. During 1978 and 1983, the maximum suspended-sediment concentrations (fig. 14*B*) were less than 55 mg/L.

## Suspended-Sediment Transport During the 1974 White Sturgeon Recruitment

The 1974-year class of wild sturgeon is the progeny of the most recent successful white sturgeon recruitment. Although the Kootenai River white sturgeon have apparently spawned on a yearly basis since 1974, these spawning events have failed to produce new generations of white sturgeon (Vaughn Paragamian, Idaho Department of Fish and Game, written commun., 2000). During the period of suspended-sediment record for the Libby Dam era (1973–83), the only notable transport of suspended sediment

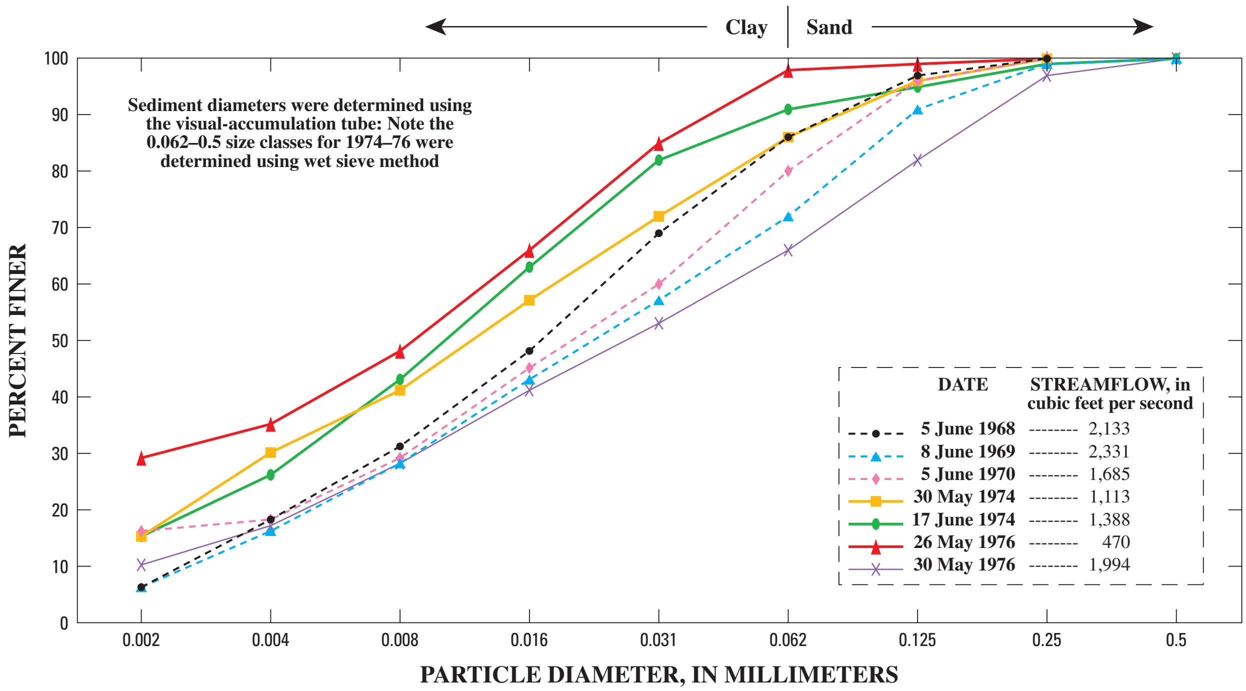


**Figure 15.** Distribution of particle size in suspended-sediment samples collected at U.S. Geological Survey streamflow-gaging station 12318500 on the Kootenai River at Copeland, Idaho, 1968–76.

occurred prior to and during the 1974 spawning recruitment event.

Prior to the spring-summer 1974 white sturgeon recruitment event, a large, warm-rain-on-snow event took place during January 15–17, 1974 (fig. 14B). On January 17, the Fisher River, 5.6 RKM downstream from Libby Dam, produced 56,900 mt/d of suspended sediment at flows of 186 $m^3$/s. The load that moved past the Copeland gage was 5,940 mt/d at 1,090 $m^3$/s on January 18. The sediment load data for the Fisher River gage on January 17 and for the Copeland gage on January 18 are compared because a particle of water requires roughly 0.7 day of traveling between the two sites on the Kootenai River; the amount of time needed is a function of streamflow and backwater conditions. During the period January 15–20, about 175,900 mt of suspended sediment moved past the Fisher River gage at a 6-day mean flow of 120 $m^3$/s, whereas about 105,600 mt of suspended sediment moved past the Copeland gage at a 6-day mean flow of 1,040 $m^3$/s. A minimum of 70,300 mt of sediment was deposited onto the bottom of the Kootenai River between the two sites. Because this computation does not include the sediment loads from other tributaries, the amount of sediment deposited is greater than 70,300 mt. The loads from other tributaries were not measured.

During the period of suspended-sediment record for the Libby Dam era, the only notable multiweek suspended-sediment transport event with streamflow that approached pre-Libby Dam conditions took place from April 24 to July 5, 1974 (fig. 14*B*), during the white sturgeon spawning season. Daily mean streamflow ranged from approximately 736 to 1,416 $m^3$/s. During May 5–24, flows ranged from 736 to 850 $m^3$/s. Daily mean flows exceeded 850 $m^3$/s for 53 days during the 73-day period. The peak flushing flow occurred on April 27. The sediment load peaked at 24,500 mt/d with a mean daily flow of 1,266 $m^3$/s, and sediment concentration peaked at 265 mg/L. During this period, there were 20 days when loads were greater than 9,070 mt/d. This event represents roughly an order-of-magnitude increase in sediment transport over the median daily load during the period of suspended-sediment record for the Libby Dam era. Immediately after dam construction, the sudden change in river hydraulics meant that sediment transport, including the aggradation and degradation of the river bottom, was in the process of shifting to a new equilibrium. Thus, sediment transport conditions in the river might be unique and not representative of conditions during either the pre-Libby Dam or Libby Dam era.

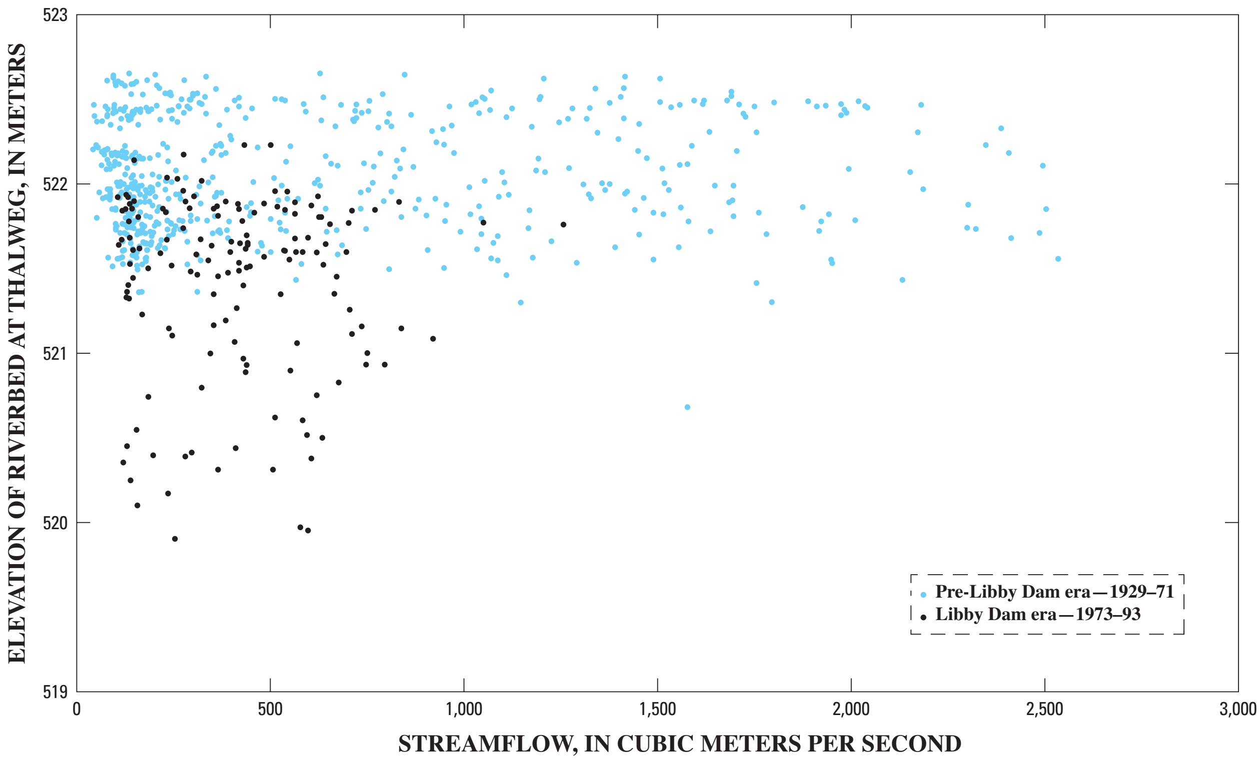


**Figure 17.** Fluctuation of minimum riverbed elevation with streamflow for the pre-Libby Dam and Libby Dam eras on the Kootenai River beneath the stationary cableway at U.S. Geological Survey streamflow-gaging station 12318500 at Copeland, Idaho, 1929–93.

## Suspended-Sediment Particle Size

On the basis of limited particle-size analyses performed on samples collected at the Copeland gage, the percentage of sand in three of the four suspended-sediment samples collected during spring and early summer high flows during the Libby Dam era appears to be less than the percentage in three samples collected during the pre-Libby Dam era (fig. 15). The $^1/_2$ Phi particle-size data are limited to three suspended-sediment samples collected during 1968–70 at flows ranging from 1,685 to 2,331 $m^3$/s and to four samples collected during 1974–76 at flows ranging from 470 to 1,388 $m^3$/s. The wash load, silt and clay that are suspended in the water column and found in relatively small quantities in the alluvial substrate, is a greater percentage of the overall suspended-sediment load during the Libby Dam era. Stream velocity does not affect wash load but does affect the transport of sand.

# CHANGES IN CHANNEL GEOMETRY AND SUBSTRATE

Changes in the geometry and composition of the channel substrate in the white sturgeon spawning reach of the Kootenai River after closure of Libby Dam were determined by assessing historical gaging-station data and seismic subbottom profiles and sediment core samples of the riverbed. There are no streamflow gages located in the white sturgeon spawning reach, but data from the Copeland gage were used as a surrogate to describe changes in channel geometry in the spawning reach because conditions at the Copeland gage are similar to those in the spawning reach: both are located in the meander reach and in backwater. The degree to which the fluctuation of channel substrate at Copeland could be compared with that in the spawning reach could not be determined.

## Channel Geometry

The channel geometry was evaluated for the period of record at the Copeland gage, 1929 to 1993. The effect of changing flow regulation at Libby Dam on channel geometry during the mid- and late 1990s could not be evaluated because the gage was deactivated in 1994. The Copeland gage is located 15 RKM downstream from the white sturgeon spawning reach (see fig. 5 for location). The Kootenai River at the Copeland gage flows toward the northwest. Beneath the cableway near the toe of the right bank, the riverbed is roughly 3 to 5 m deeper than the riverbed near the toe of the left bank. The thalweg generally is formed near the toe of the right bank; however, there have been periods where a thalweg forms in the center of the channel.

### CHANNEL WIDTH AND MIGRATION

A somewhat subtle change during the Libby Dam era was an increase in channel migration. On the basis of the entire record of stream-gaging discharge measurements, the median river width was 147 m for both the pre-Libby Dam era (1929–71) and the Libby Dam era (1973–93). The average river width was 149 m for the pre-Libby Dam era (n = 599) and 147 m (n = 145) for the Libby Dam era. The following analysis is based on the channel-geometry profiles for 20 stream-gaging measurements made from 1931 to 1970 and for 20 stream-gaging measurements made from 1978 to 1993 (**fig. 16**). Each channel-geometry profile is based on about 40 depth measurements that were made during the measurement of streamflow discharge. During the period of record, the river channel migrated toward the northeast and toward the southwest on somewhat of a cyclical basis. During the pre-Libby Dam era and the Libby Dam era, the right bank migrated over a distance of about 7 m and 15 m and the left bank migrated about 11 m and 20 m, respectively. The distance the channel migrates laterally varies with time and represents less than 14 percent of the overall width of the channel.

### AGGRADATION AND DEGRADATION OF RIVERBED

The most notable change during the Libby Dam era was the initiation of cyclical aggradation and degradation of the riverbed in the center of the channel at the Copeland cableway. After the closure of Libby Dam, the riverbed beneath the Copeland cableway aggraded by about 0.5 to 1.0 m between the left bank and center and remained unchanged near the right bank (**fig. 16**). The aggradation and degradation are reflected in a twofold increase in the fluctuation of the minimum riverbed elevation measured beneath the Copeland cableway during regular flow measurements (**fig. 17**). The minimum riverbed elevation between 1931 and closure of Libby Dam ranged from 522.6 to 521.3 m (n = 599), a fluctuation of 1.3 m, and during the Libby Dam era, ranged from 522.4 to 519.9 m (n = 145), a fluctuation of 2.5 m. Dune movement is a likely explanation for some of the fluctuation in riverbed elevation. Closure of Libby Dam did not influence the long-term mean elevation of the riverbed beneath the Copeland cableway (**fig. 18**): 524.7 m (n = 599) is the median value during the pre-Libby Dam era from 1929 through 1971 and 524.7 m (n = 145) is the median value during the Libby Dam era from 1972 to 1993.

## Composition of Channel Substrate

Seismic subbottom profiling and sediment coring provided the basic data for characterizing the composition of substrate in the Kootenai River white sturgeon spawning reach. Cross sections of the Kootenai River at 19 locations show channel geometry, seismic subbottom profile, sediment core(s), and the substrate sediment texture (**fig. 23**). The depth of subsurface exploration is generally sufficient for describing the alluvial sediment deposited prior to and since the closure of Libby Dam in the Kootenai River where white sturgeon currently spawn. The basis for this assessment is provided in the following paragraphs.

Although the bottom of this river is covered mainly with alluvial sediment, a regional lacustrine clay-silt layer underlies and, to a limited extent, forms the bottom of the Kootenai River throughout most of the spawning habitat, as can be seen in sediment cores along a longitudinal section of the river between RKM 239.7 and 225.8 (**fig. 19*C***) and in some seismic subbottom profiles (**fig. 23*H***). The contact between the alluvial sand and the underlying dense clay-silt layer indicates the minimum possible riverbed elevation since the closure of Libby Dam. Clay-silt layers are deposited only at low velocities. For example, Hjulstrom (1935, p. 298) found that the silts and clays he studied settled at flow velocities of less than 0.01 m/s. Such stagnant streamflow conditions have not existed during the period of record at the Copeland gage (1929–93). Alluvial sediment lying above the lacustrine layer includes any sediment deposited since the retreat of glacial Kootenay Lake.

Geologist striplogs for sediment cores along a longitudinal section of the river from RKM 241.6 to 229.5 show the contact between alluvial sediments and lacustrine clay in the spawning reach (**fig. 19*B***). In these cores, the depth below the river channel to the first dense clay-silt layer ranged from 0.2 m in core K14-TH to 1.6 m in core K5-C.

The contact between alluvial deposits for the pre-Libby Dam and the Libby Dam eras could not be identified. However, inferences about alluvial sediment deposition and scouring since the closure of Libby Dam were made on the basis of (1) changes in the particle size of sediment with depth below the riverbed, and (2) the maximum probable aggradation of the channel substrate during the Libby Dam era. A 2.5-m fluctuation of the minimum riverbed elevation was measured in the thalweg beneath the Copeland cableway during the Libby Dam era (**fig. 18**). This fluctuation indicates that during the Libby Dam era, the channel substrate aggraded by 2.5 m and also degraded by nearly the same amount.

A 2.5-m depth criterion was selected to establish a maximum depth for the contact between sediments deposited on the riverbed during the Libby Dam era and the underlying sediments deposited prior to the closure of Libby

Dam. A caveat applies to this depth criterion: channel-geometry data at the Copeland gaging station indicate that the channel substrate in parts of the meander reach may not have undergone aggradation, may have remained relatively stable, or may have undergone degradation.

Inferences about alluvial sediment deposition and scouring since the closure of Libby Dam are: (1) where a sediment core penetrated a sand layer less than 2.5 m thick that overlies a lacustrine clay-silt layer, it is assumed that gravel and cobble were not present above the lacustrine layer at the time of the closure of Libby Dam; (2) where a sediment core penetrated only alluvial sand and organic matter to a depth greater than 2.5 m, it is assumed that a gravel and cobble layer was not present on the riverbed at the time of the closure of Libby Dam; and (3) where a sediment core penetrated a layer of sand less than 2.5 m thick, then a gravel layer and a lacustrine clay-silt layer, it is assumed that the gravel layer existed prior to the closure of Libby Dam and subsequently was buried.

## GENERAL DESCRIPTION OF SUBSTRATE

Alluvial sand forms active sand dunes in the Kootenai River throughout all but the uppermost reach of the white sturgeon spawning habitat. The vertical relief of these dunes varies from less than 0.3 m to more than 2 m, and most are less than 1.3 m. On the basis of the geologist logs for the sediment cores (**fig. 24**), the mineralogical composition of the alluvial sand varies widely, ranging from granitic to metamorphic mineral assemblages with an overall abundance of quartz, feldspar, biotite, and mica. Sand color ranges predominantly from light to medium olive gray, with isolated occurrences of dark yellowish brown. Alluvial sand-grain diameters range from very fine (0.125 mm) to very coarse (2.0 mm) with a predominance of medium-grained sand (0.5–1.0 mm). Ponar dredge samples of the riverbed (**table 2**) show fine- to coarse-grained alluvial sand at the 22 locations sampled between RKM 226 and 244.3. Sand-grain diameters tend to decrease along the inside bend of meanders. The sand tends to be moderately sorted to well sorted and individual grains are subrounded to subangular. The sand layer contains traces of shell fragments such as those identified at 1.9 m below the riverbed in sediment core K3-C (**fig. 24*A***), taken near the center of cross-section S-S' (**fig. 2*C***).

The alluvial sand generally included layers of organic-rich debris composed mainly of wood fragments. The thickness of some organic-rich layers was slightly greater than 0.2 m, such as the case in sediment core K11-LB (**fig. 20** and **fig. 24*S***). These layers typically appeared as thin black lamina less than 3 cm thick. Some of the wood fragments are charred, evidence that the material originated in a forest fire. The sediment cores essentially show that thin, discontinuous layers of organic debris are ubiquitous in the sandy layer. Organic debris sometimes covers the river floor in the deepest part of the thalweg.

Gravel and cobble are exposed along the bottom of the Kootenai River in the braided reach and are exposed intermittently in the upstream part of the buried gravel-cobble reach. Sediment cores of alluvial sand overlying gravel and cobble layer(s) have been divided into two populations on the basis of depth. Cores K9.5-C, K9.5-TH, K15.5-TH, K18-TH, and K20-TH (**fig. 24*L***, **fig. 24*M***, **fig. 24*CC***, **fig. 24*HH***, and **fig. 24*II***) have less than 1 m of sand overlying a gravel and cobble layer. Cores K10-TH2, K12-TH1, and K12-TH2 (**fig. 24*Q***, **fig. 24*V***, and **fig. 24*W***) have 1 to 2.9 m of sand overlying a cobble and gravel layer.

The lacustrine clay-silt layer is generally dense, dry, and stiff, ranges from light to dark olive gray, and is mottled in some samples. This layer contains layers of silt and very fine sand and a few thin lenses of shell fragments. The riverbanks below the natural levee and the dike typically are incised into the regional lacustrine clay-silt layer. Some of the riprap and sediment added to the levee and dike have slumped onto the submerged riverbank and have covered the lacustrine clay-silt layer.

## BRAIDED REACH

Cobble and gravel-bar substrate occurs throughout the braided reach (**fig. 21*A***) and forms multiple channels at low flow. The gravel bars extend some distance downstream from U.S. 95 Bridge, roughly 0.5 RKM. The Idaho Department of Transportation (IDOT) made several test borings in the river at the bridge. The IDOT geologist log for test boring DH-7 in the center of the channel at the bridge (**fig. 19*A***) shows that gravel deposits extend at least 30 m below the river. This test boring did not penetrate the regional lacustrine layer. On the basis of this log and of seismic subbottom profiles at cross sections A-A' and B-B' (**fig. 2*A***, **fig. 23*A***, and **fig. 23*B***), the regional lacustrine clay-silt layer is completely or severely eroded beneath the river in the vicinity of the U.S. 95 Bridge.

The boundary between the braided reach and the buried gravel-cobble reach shifts upstream and downstream in response to changes in sediment transport. A high-flow event in 1996 during the Libby Dam era apparently caused a small but noticeable degradation of the sand layer, burying gravel and cobble near the downstream end of the braided reach. Patrick McGrain (Bureau of Reclamation, oral commun., 2000) observed muddy-silty-sandy sediment beneath part of the U.S. 95 Bridge during 1993 and 1994. After the large 1996 spring runoff event (USGS measured 1,263 $m^3$/s of streamflow from the U.S. 95 Bridge in Bonners Ferry on June 7, 1996), Pat McGrain observed that the river substrate beneath the bridge and for an undetermined distance downstream toward the railroad bridge at RKM 245.6 was covered with clean cobble.

## BURIED GRAVEL-COBBLE REACH

The streambed surface in the buried gravel-cobble reach, RKM 241.1 to 245.75, is predominantly alluvial sand deposited on a discontinuous gravel, cobble, and sand layer or deposited unconformably on the regional lacustrine clay-silt layer (fig. 21*A* and fig. 21*B*). At the upstream end of this reach, the streambed consists of gravel, cobble, and sand. On the basis of limited data, the composition of the streambed alluvium in this reach is such that the percentage of cobble and gravel decreases and the percentage of sand increases in the downstream direction. Upstream from the sharp riverbend at RKM 244.5, where Ambush Rock is exposed along the southern bank of the river, the substrate is noticeably less sandy and contains greater amounts of gravel and cobble.

Seismic subbottom profiles and sediment cores collected in this reach show that a thin layer of sand overlies a discontinuous layer of cobbles, gravel, and sand. Sediment core K-18TH (fig. 22 and fig. 24*HH*), collected near the river's right bank at cross-section E-E' (fig. 23*E*), penetrated a 0.7-m-thick layer of sand and organic debris; a 0.2-m-thick layer of gravel, cobble, sand, and organic debris; a 0.69-m-thick layer of sand and organic debris; and the upper 0.7 m of the regional lacustrine clay-silt layer. Where the cobble, gravel, and sand layer is not present, alluvial sand overlies the lacustrine clay-silt layer. Sediment core K-18LB (fig. 24*GG*), on the opposite side of the river near the left bank, penetrated a 2.6-m-thick layer of sand and organic debris and the upper 0.9 m of the regional lacustrine clay-silt layer, but no gravel-cobble-sand layer. Farther upstream in this reach, sediment core K20-TH, at cross-section D-D' (fig. 23*D* and fig. 24*II*), penetrated a 0.9-m-thick layer of sand and organic debris; a 0.2-m-thick layer of gravel, cobble, and sand; and 0.3 m of sand, whereupon the core barrel could not be advanced into the substrate (refusal depth). The refusal depth for coring represents a change in sediment texture, the base of a silty sand layer and top of another layer of gravel and cobble. Here, a seismic subbottom profile recorded a seismic reflector at about 5 m below the streambed that likely indicates the top of the regional lacustrine layer (fig. 23*D*).

## MEANDER REACH

The channel substrate in the meander reach is a reflection of channel morphology. Straight reaches, such as near cross-sections J-J' and R-R' (fig. 2*B*, fig. 23*J*, and fig. 23*R*), typically have flat bottoms composed of alluvial sand to a depth of at least 3.5 m below the streambed, the maximum depth that was cored. Seismic data indicate that the thickness of the alluvial sand generally ranges from 5 to 10 m below the riverbed (fig. 23*H*). Meanders have pronounced thalwegs more than 9 m deep near the outside banks (fig. 23*H*, fig. 23*I*, fig. 23*K*, fig. 23*L*, and fig. 23*P*). Seismic and sediment core data indicate that meander thalwegs generally incised into the lacustrine clay-silt layer; however, the lacustrine layer can be overlain with sand or organic debris. Other parts of the channel bed consist of alluvial sand deposited on the lacustrine clay-silt layer. Along inside banks, the alluvial sand deposited over the lacustrine clay-silt layer is locally thicker than the 3.5-m vibracore depth penetration. These sands have been shaped into dunes as high as 2 m. Sediment with a diameter greater than sand (granules, gravel, cobbles, and riprap) is present in the channel substrate in very small amounts downstream from Deep Creek near cross-sections G-G' and I-I' and downstream from Myrtle Creek in the general vicinity of cross-sections L-L' and K-K'. Gravel and cobble are not present in the most prolific white sturgeon spawning reach near Shorty Island.

### Upstream from Myrtle Creek

The substrate of the Kootenai River meander reach upstream from Myrtle Creek is predominantly sand and some lacustrine clay (fig. 19*B*). For example, on the steep face of the thalweg near the right bank at cross-section H-H' (fig. 2*B* and fig. 23*H*), sediment core K13-RB penetrated the regional lacustrine clay-silt layer. Here, sand covers the riverbed between the thalweg and the left bank, with thickness increasing toward the left bank. Cores K13-LB1 and K13-LB2 penetrated more than 2.5 m of alluvial sand (fig. 24*X* and fig. 24*Y*). Farther downstream near Myrtle Creek at cross-section J-J' (fig. 23*J*), sediment cores K11-LB and K11-C penetrated more than 2.5 m of sand (fig. 24*S* and fig. 24*T*). Where sediment cores penetrated only alluvial sand and organic matter to a depth of 2.5 m or greater, it is assumed that a layer of gravel or cobble was not present on the riverbed at the time of closure of Libby Dam. The river substrate prior to the closure of Libby Dam is similar to the present condition, lacking gravel and cobble spawning substrate needed for white sturgeon recruitment.

Two sediment cores of the Kootenai River substrate between the mouth of Deep Creek and the mouth of Myrtle Creek penetrated sediment with a particle size greater than sand. Near the left bank at RKM 238.9, upstream from cross- section G-G' (fig. 23*G*), sediment core K15.5-TH penetrated 0.02 m of wood debris, 0.4 m of granules (diameter 2–4 mm, between sand and gravel size), 1.6 m of sand, 0.05 m of lacustrine clay, and 1.5 m of sand (fig. 24*CC*). The granule layer is limited to the outside of this gentle riverbend where flow velocities are greatest. The source of the granules is likely a large runoff event in Deep Creek. Because these granules are on the riverbed surface, the runoff event most likely occurred during the Libby Dam era. The clay-silt layer indicates the minimum possible riverbed elevation since the closure of Libby Dam; therefore, gravel or cobble substrate was not present at the coring site at the time of closure of Libby Dam (**fig. 23*G*** and **fig. 24*CC***). Sediment core K12-TH1, near the thalweg at cross-section I-I', penetrated 3 m of sand and organic debris and 0.4 m of fine gravel (**fig. 23*I*** and **fig. 24*V***). This layer of fine gravel was probably buried by sand prior to the closure of Libby Dam.

### Downstream from Myrtle Creek

There is evidence of gravel, cobble, and larger sediment buried by a thin layer of sand and lying exposed on the riverbed in the spawning reach below Myrtle Creek, between RKM 233.5 and 234.7 (**fig. 21*B***). The source, as well as the extent, of the large-diameter sediment is unclear. Along part of this spawning reach, riprap on the dike left bank may have rolled into the channel. Here, sediment cores did not penetrate the regional lacustrine clay-silt layer.

Downstream from Myrtle Creek at cross-section K-K', between the thalweg and left bank (outside bend of the meander), gravel and larger sediment lie on the riverbed and are locally buried by thin layers of sand (**fig. 23*K***). Here, a seismic subbottom profile shows several parabolic reflectors at or just below the riverbed in the thalweg and between the thalweg and left bank. These reflectors indicate the presence of cobble or riprap. Sediment core K10-TH1 (**fig. 24*P***), taken in the thalweg at cross-section K-K', penetrated a few centimeters of the riverbed and did not recover sediment; this core was assumed to have met with gravel, cobble, or riprap. Sediment core K10-TH2 (**fig. 24*Q***), also taken in the thalweg, penetrated about 0.7 m of sand and then 0.1 m farther into a layer of gravel, and could not be advanced farther into the riverbed. Sediment cores K10-RC and K10-RTH (**fig. 24*O*** and **fig. 24*R***), located between the thalweg and right bank in the depositional side of the meander, penetrated 3.5 m and 2.1 m of sand and organic debris, respectively.

Downstream from Myrtle Creek, in the thalweg at cross-section L-L', sediment core K9.5-TH penetrated 0.2 m of sand and then struck gravel, cobbles, or riprap that prevented the core from advancing farther into the riverbed; there was no recovery of sediment (**fig. 23*L*** and **fig. 24*M***). Sediment core K9.5-C (**fig. 24*L***), taken in the center of the river, penetrated about 2.1 m of sand and could not be advanced farther into the riverbed. The bottom of the core barrel had numerous pea-gravel-size indentations, indicating the presence of gravel; however, gravel was not recovered in the core barrel. Sediment core K9.5-RB (**fig. 24*N***), taken between the right bank and center of the river, penetrated 3.5 m of sand and organic fragments.

The Kootenai River meander below Myrtle Creek and near the base of Cascade Ridge appears to have incised into an alluvial fan composed of gravel, cobble, and sand (**fig. 21*B***). The meander bend is within 183 m of the base of Cascade Ridge. The 1983 Kootenai Flats erosion shift maps (U.S. Army Corps of Engineers, 1983) show that Lost Creek, Cascade Creek, and Myrtle Creek incise into alluvial-fan deposits. The alluvial-fan deposits are composed of sand, gravel, and cobble. The channel geometry at cross-section K-K' appears to support the presence of an alluvial fan at this section (**fig. 23*K***). Here, the channel geometry is significantly different from that of other cross sections. The submerged left bank that forms the face of the thalweg along the outside riverbend is much more gently inclined than elsewhere in the meander reach of the white sturgeon spawning habitat. The relatively gentle sloping face of the thalweg includes a collapse feature along the riverbed below depths of about 4 m. This collapse feature suggests that the face of the thalweg along the left bank is not composed of a stiff, cohesive, lacustrine clay-silt layer and silt that can support a steep thalweg but is instead composed of noncohesive silt, sand, gravel, and cobble that tend to lack the intrinsic properties needed to support a steep thalweg face.

The Kootenai River at cross-section M-M' (**fig. 23*M***), located at the downstream end of the white sturgeon spawning reach below Myrtle Creek, is dominated by sand across the river: sediment cores K9-LB, K9-C, and K9-RB penetrated only sand (**fig. 24*I***, **fig. 24*J***, and **fig. 24*K***). The seismic subbottom profile of cross-section M-M' shows sand filling in the thalweg near the left bank. The seismic subbottom profile near the left bank shows a seismic reflector at 11 m below the riverbed. The capacity of the seismic sound wave to propagate and reflect off a layer at a depth of 11 m indicates that a layer of gravel and cobble is not present in the substrate to a depth of 11 m.

### Shorty Island

Sediment cores and seismic subbottom profiles obtained in the Kootenai River white sturgeon spawning reaches near Shorty Island—RKM 230.0–231.0 and 228.7–229.5—show that the substrate composition is similar to that which existed before closure of Libby Dam. There is no indication of gravel or cobble in the substrate near Shorty Island (**fig. 21*C***).

In this reach, seismic subbottom profiles and sediment cores were obtained at cross-sections P-P' and Q-Q'. Cross-section P-P' shows that the riverbed forms a sloping terrace between the center and the right bank (**fig. 23*P***). Near the left bank, sediment core K6-LB penetrated 3.5 m of sand (**fig. 24*E***). It is assumed that at this location a layer of gravel or cobble was not present on the riverbed at the time of closure of Libby Dam. The thalweg, between the right bank and center of the channel, is incised into the regional lacustrine clay-silt layer. The lower part of the thalweg is covered with a veneer of sand. At cross-section Q-Q', the thalweg is located along the right bank and incised into the lacustrine clay-silt layer, which is exposed at the bottom of the thalweg (fig. 23*Q*). Sediment core K5-C (fig. 24*D*) and the seismic subbottom profile at cross-section P-P' show that sand is present on the riverbed and the thickness of the sand increases from the thalweg toward the left bank. Sediment core K5-C penetrated 1.6 m of sand and 1.6 m of lacustrine clay and silt. It is assumed that at this location a layer of gravel or cobble was not present on the riverbed at the time of closure of Libby Dam.

## EFFECTS OF CHANGES IN SUSPENDED-SEDIMENT TRANSPORT AND CHANNEL SUBSTRATE ON WHITE STURGEON SPAWNING SUBSTRATE

The white sturgeon spawning substrate in the Kootenai River has been affected in some areas by changes in suspended-sediment transport and channel substrate. Assessment of the effects is based, in part, on suspended-sediment samples and stream-gaging measurements from the Copeland gage, located 15 RKM below the spawning habitat, for the period of record 1929–93. As previously discussed, data collected from the Copeland gage appear to be a reasonable surrogate for describing changes in the white sturgeon spawning reach because both the gage and nearly all of the spawning reach are located in backwater. The degree to which the fluctuation of channel substrate at Copeland could be compared with that in the spawning reach could not be determined.

After the closure of Libby Dam in 1972, the Kootenai River transported smaller volumes of suspended sand through the white sturgeon spawning reach that lies within the buried gravel-cobble reach and meander reach. During the Libby Dam era, the annual suspended-sediment load leaving the Kootenai River white sturgeon spawning reach decreased about sixfold (fig. 9*C*). On the basis of a small set of suspended-sediment samples, the river appears to be transporting finer grained sediment in suspension since the closure of Libby Dam. The percentage of sand-size particles in suspended-sediment samples collected during spring and early summer high flows at the Copeland gage is less than in samples collected during the pre-Libby Dam era (fig. 15). The reduction in peak flows during the Libby Dam era has reduced the Kootenai River's capacity to transport suspended sediment through the spawning reach. The reduction in peak flow has also resulted in a larger proportion of finer grained sediment in suspension. Contributing to the decrease in suspended-sediment load in the spawning reach is the loss of 70 percent of the basin after the closure of Libby Dam. Monitoring the sediment load transported into and out of the spawning reach over a period of several years could address whether or not sand is accumulating in the spawning reach, but this is a resource-intensive investigation (Andrews, 1984).

Since the closure of Libby Dam, the most notable change in channel geometry beneath the Copeland streamgaging cableway was the initiation of cyclical degradation and aggradation of the riverbed in the center of the channel, which is reflected in a twofold increase, from 1.3 to 2.5 m, in the fluctuation of the minimum riverbed elevation beneath the cableway (fig. 17). The fluctuation of minimum riverbed elevation suggests that during the Libby Dam era, parts of the riverbed in the spawning reach may have aggraded or degraded by as much as 2.5 m. The change in the minimum riverbed elevation at Copeland during the Libby Dam era is considered a reasonable estimate of the maximum thickness of alluvial sediment possibly deposited on the Kootenai River white sturgeon spawning reach since the closure of Libby Dam. This information helped determine that the depth of seismic exploration and sediment coring, which on average exceeded 2.5 m, was sufficient to sample and describe any alluvial sediment that formed the riverbed just prior to the closure of Libby Dam and that was subsequently buried by alluvial sediment after the closure of Libby Dam.

The sediment texture of channel substrate in the buried gravel-cobble reach, RKM 241.1 to 245.75, within the white sturgeon spawning reach indicates sand accumulation during the Libby Dam era. This cyclical process of degradation and aggradation of the riverbed sediment is the most likely cause of alternating gravel-cobble layers and sand layers in sediment core K18-TH in the reach (fig. 24*HH*). Gravel and cobble layers in this core are present at 0.7 to 0.9 m and 1.4 to 1.5 m below the riverbed. In the buried gravel-cobble reach, there was a greater propensity for aggradation and degradation of sand over the discontinuous gravel and cobble layers before the closure of Libby Dam than after. Unregulated spring snowmelt-runoff flows flushed part of the sand layer and exposed some of the buried gravel-cobble layer because streamflow velocities were higher. The transport of gravel and cobble into this reach was much greater before the closure of Libby Dam than after. One source of this gravel and cobble is located a short distance upstream at the U.S. 95 Bridge near Bonners Ferry. Here, the center of the channel contains a large volume of gravel and cobble at least 30 m thick, as shown in sediment core DH-7 (fig. 19*A*). In this reach where the river is under backwater conditions, unregulated fall-winter base flows gradually deposited silt and sand and reestablished a sand layer, burying the gravel-cobble layer.

White sturgeon spawning substrate in the meander reach is currently composed of alluvial sand that forms sand dunes and of minor amounts of lacustrine clay and silt generally found in the rivers thalweg. The data presented in this report show that the present substrate composition in the meander reach is considered similar to that which existed prior to closure of Libby Dam, with one possible exception. Prior to the closure of Libby Dam, minor amounts of gravel and cobble may have been exposed on the riverbed in the spawning reaches just below the mouth of Myrtle Creek near cross-sections L-L' and K-K'.

Seismic subbottom profiles and coring in the white sturgeon spawning reach below Myrtle Creek, between RKM 233.5 and 234.7 (**fig. 2*B***) in the vicinity of K-K' and L-L' (**fig. 23*K*** and **fig. 23*L***), provided evidence of gravel, cobble, and larger sediment buried by a thin layer of sand or lying exposed on the riverbed. The source, as well as the extent, of the large-diameter sediment is subject to speculation. Along part of this spawning reach, riprap on the dike left bank may have rolled into the channel. The thalweg along the outside bend of the meander could be incised into an alluvial fan (composed of a mixture of gravel, cobble, and sand) that extends from Cascade Ridge. During the pre-Libby Dam era, the higher spring-summer flows may have scoured the sand, exposing this gravel and cobble.

Sediment cores and seismic subbottom profiles obtained in the most active Kootenai River white sturgeon spawning reach, near Shorty Island, show that the current substrate composition is similar to that which existed prior to closure of Libby Dam. There is no indication of gravel or cobble in the substrate near Shorty Island (**fig. 21*C***).

## SUMMARY AND CONCLUSIONS

A year-long field study was conducted in cooperation with the Kootenai Tribe of Idaho along a 21.7-kilometer reach of the Kootenai River including the white sturgeon spawning reach near Bonners Ferry, Idaho, which is located 111 kilometers downstream from Libby Dam. Temporal changes in the daily and annual suspended-sediment loads leaving the white sturgeon spawning reach were characterized during 1966–83 using historical data collected at the U.S. Geological Survey streamflow-gaging station at Copeland, Idaho. In addition, temporal changes in suspended-sediment loads were characterized at a U.S. Geological Survey stream-gaging station in Libby, Montana, for a brief period prior to and after the closure of Libby Dam. Changes in channel geometry were evaluated at the Copeland gage, located 159 kilometers downstream from Libby Dam for the period of record, 1929–93. The gage was deactivated in 1994. During the time of this study, there were no streamflow gages in the white sturgeon spawning reach located 111 to 129 kilometers below Libby Dam. The Copeland stream-gaging data are used as a surrogate to describe changes in suspended-sediment transport and channel geometry in the spawning reach because of similar conditions at the Copeland gage and the spawning reach: both are located in the meander reach and in backwater.

During the field study, data were collected in order to map the channel substrate in the white sturgeon spawning reach. These data include seismic subbottom profiles at 18 cross sections of the river and sediment cores taken at or near the seismic cross sections. Generally, one core was taken from the deepest part of the thalweg where erosion may occur and another in shallower water where deposition may occur. Thirty cores were collected using a vibracoring system and five cores were collected using a piston coring system. The vibracoring system is equipped with a 0.08-meter-diameter core barrel that is 3.66 meters in length and capable of recovering the clay-silt layer, silt, sand, gravel, and some cobble. Twenty-two vibracores sampled 3 to 3.5 meters of the channel substrate. The piston coring system is equipped with a 0.08-meter-diameter core barrel that is 1.52 meters in length. The maximum recovery for the piston core was 0.8 meter and the average recovery was 0.6 meter. Because of the limited resolution of seismic subbottom profiles and a limited number and distribution of sediment cores, the contact lines defining the composition of the river substrate are general delineations and inferred in most cases.

The annual suspended-sediment load leaving the Kootenai River white sturgeon spawning reach decreased dramatically after the closure of Libby Dam in 1972: mean annual pre-Libby Dam load during 1966–71 was 1,743,900 metric tons, and the dam-era load during 1973–83 was 287,500 metric tons. The lower peak flows during the Libby Dam era have reduced the Kootenai River’s capacity to transport suspended sand through the white sturgeon spawning reach. The amount of sand-size particles in suspended-sediment samples collected at Copeland during spring and early summer high flows after the closure of Libby Dam is roughly 50 to 75 percent less than in samples collected during the pre-Libby Dam era. Under these conditions, sand and silt may accumulate at a faster rate in the white sturgeon spawning reach than during the Libby Dam era. However, the supply of sand to the spawning reach is currently less as a result of the reduction of high flows and a loss of 70 percent of the basin after the closure of Libby Dam. The river’s reduced capacity to transport sand out of the spawning reach is compensated to an unknown extent by a reduced load of sand entering the spawning reach. There is insufficient suspended-sediment data to determine whether sand is accumulating in the spawning reach within the meander reach; however, sediment cores indicate sand accumulation in the buried gravel-cobble reach.

Since the closure of Libby Dam, the most notable change in channel geometry beneath the Copeland streamgaging cableway was the initiation of cyclical aggradation and degradation of the sand riverbed in the center of the channel. Aggradation and degradation of the riverbed are reflected in a twofold increase, from 1.3 to 2.5 meters, in the fluctuation of the minimum riverbed elevation beneath the Copeland cableway for the period of record 1929–71 and 1973–93. This maximum fluctuation of the minimum riverbed elevation suggests that during the Libby Dam era, parts of the riverbed in the spawning reach may have aggraded or degraded by as much as 2.5 meters. The maximum fluctuation of the minimum riverbed elevation at Copeland during the Libby Dam era is considered a reasonable estimate of the maximum thickness of alluvial sediment possibly deposited on the Kootenai River white sturgeon spawning reach since the closure of Libby Dam. This information helped determine that the depth of seismic exploration and sediment coring, which on average exceeded 2.5 meters, was sufficient to sample and describe any alluvial sediment that formed the riverbed just prior to the closure of Libby Dam and that was subsequently buried by alluvial sand and silt after the closure of Libby Dam.

The white sturgeon spawning substrate in the Kootenai River has been affected in some areas by changes in suspended-sediment transport and channel substrate after the closure of Libby Dam. Before the closure of Libby Dam, there was probably a greater propensity for aggradation and degradation of sand over the discontinuous gravel and cobble layers in the buried gravel-cobble reach at Bonners Ferry. Unregulated high-velocity spring snowmelt-runoff streamflows flushed part of the sand layer and exposed some of the buried gravel-cobble layer. Unregulated fall-winter base flows gradually deposited silt and sand and reestablished a sand layer, burying the gravel-cobble layer. This cyclical process of aggradation and degradation of the riverbed sediment is reflected in the alternating gravel-cobble layers and sand layers found in sediment core K18-TH. White sturgeon spawning substrate in the Kootenai River meander reach is currently composed of alluvial sand that forms sand dunes and of minor amounts of lacustrine clay and silt that are generally found in the river's thalweg. The present substrate composition in the meander reach is considered similar to that which existed prior to closure of Libby Dam, with one possible exception. Prior to the closure of Libby Dam, minor amounts of gravel and cobble may have been exposed on the riverbed in the spawning reach just below the mouth of Myrtle Creek. The substrate composition near Shorty Island, a notable white sturgeon spawning reach, is predominantly sand and is similar to that which existed prior to closure of Libby Dam.

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