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Simulation of Flow and Sediment Transport in the White Sturgeon Spawning Habitat of the Kootenai River near Bonners Ferry, Idaho

Scientific Investigations Report 2005–5173

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

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By Charles Berenbrock and James P. Bennett

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Kootenai Tribe of Idaho and Idaho Department of Fish and Game

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U.S. Geological Survey

U.S. Department of the Interior
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U.S. Geological Survey
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Suggested citation:
Berenbrock, Charles, and Bennett, J.P., 2005, Simulation of flow and sediment transport in the white sturgeon spawning habitat of the Kootenai River near Bonners Ferry, Idaho: U.S. Geological Survey Scientific Investigations Report 2005-5173, 72 p.

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Conversion Factors and Datums

Conversion Factors

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic yard (yd^3)	0.7646	cubic meter
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
kilogram per meter – squared second [$kg/(m–s^2)$]	1.0	Newton per squared meter (N/m^2)
mile (mi)	1.609	kilometer
Pascal (Pa)	1.0	Newton per squared meter (N/m^2)
pound per foot-squared second [$lb/(ft–s^2)$]	1.488	Newton per squared meter (N/m^2)
square mile (mi^2)	2.590	square kilometer
ton per day (ton/d)	0.01050	kilogram per second

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32.$$

Concentrations of suspended sediments in water are given in milligrams per liter (mg/L).

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Simulation of Flow and Sediment Transport in the White Sturgeon Habitat of the Kootenai River near Bonners Ferry, Idaho

By Charles Berenbrock and James P. Bennett

Abstract

Characterization of sediment transport of the Kootenai River in the white sturgeon spawning reach is needed by the Kootenai River White Sturgeon Recovery Team to predict sediment-transport conditions that improve spawning conditions for the white sturgeon (*Acipenser transmontanus*) in the Kootenai River near Bonners Ferry, Idaho. The decreasing population and spawning failure of the white sturgeon has led to much concern. Few wild juvenile sturgeon are found in the river today.

The Kootenai River begins in British Columbia, Canada, and flows through Montana, Idaho, and back into British Columbia. A 15-mile reach of the Kootenai River in Idaho was studied, including the white sturgeon spawning reach that has been designated as a critical habitat near Bonners Ferry, Idaho, and a 1-mile long side channel around the western side of Shorty Island.

A one-dimensional sediment-transport model of the study reach was developed, calibrated, and used to simulate the response of the hydraulic and sediment system to varying discharges and water-surface elevations. The model comprises 79 cross sections, most of which came from a previous river survey conducted in 2002-03. Bed-sediment samples collected in 2002 and additional samples collected for this study in 2004 were used in the model.

The model was calibrated to discharge and water-surface elevations at two U.S. Geological Survey gaging stations. The model also was calibrated to suspended-sediment discharge at several sites in the study reach.

The calibrated model was used to simulate six different management alternatives to assess erosion and deposition under varying hydraulic conditions at the end of 21 days of simulation. Alternative 1 was simulated with a discharge of 6,000 cubic feet per second (ft^3/s), alternative 2 with 20,000 ft^3/s, alternative 3 with 40,000 ft^3/s, and alternatives 4 through 6 with 60,000 ft^3/s and represents low to high discharges in the river since the construction of Libby Dam.

Sediment deposition was dominant in management alternatives 1 through 4. The streambed in the sandbed reach changed little or not at all. The gravel-cobble reach was more dynamic.

In alternatives 1 through 4, deposition was the dominant feature because increasing river discharge alone did not produce boundary shear stresses that can erode and transport streambed sediments. Water-surface slope probably was the limiting factor in these alternatives because backwater conditions flattens the stage throughout the reach. High flows in the river probably would be more effective in eroding the streambed and transporting sediments if water-surface slope was increased. One practical method for increasing the slope is to lower the water level in Kootenay Lake. Two additional alternatives (5 and 6) were simulated to demonstrate the effects of a steeper slope in the study reach.

Simulation results from management alternatives 5 and 6 (a discharge of 60,000 ft^3/s) were quite different than those from alternatives 1-4. Erosion was the dominant feature in these simulations because water-surface slopes were increased by lowering water levels in Kootenay Lake. Slopes in alternatives 5 and 6 were 2.4 and 3.5 times, respectively, greater than slope in alternative 4. For alternatives 5 and 6, sediment deposition dominated in the gravel-cobble reach while erosion dominated in the sandbed reach. Downstream of Ambush Rock (river mile 151.8) in the sandbed reach, maximum streambed decreased 2 and 3 feet in alternatives 5 and 6, respectively. Decreases also were prevalent in the side channel and averaged 1 foot or greater.

White sturgeon eggs have been collected in the study reach since 1994. The largest number of eggs have been collected in the reach adjacent to Shorty Island. Another large number of eggs was located between river miles 149 and 146. Although these reaches for alternatives 5 and 6 were erosional, these reaches are still considered unsuitable spawning habitat because of the sandy streambed. However, a more suitable spawning habitat could be developed if large boulders, nearly horizontal pilings, and such were placed in the river at these locations. Several weeks of high discharges with a corresponding low Kootenay Lake level also would be needed to prevent sand and silt buildup on these structures.

Introduction

The Kootenai River is an International watershed that encompasses parts of British Columbia, Montana, and Idaho (fig. 1). The Kootenai River has undergone many changes resulting from drainage of wetlands; construction of dikes along the river's corridor from Bonners Ferry, Idaho, to Kootenay Lake, British Columbia, construction of dikes along the river's corridor near Troy and Libby, Montana; and construction of Libby Dam near Libby, Montana. Streamflow and sediment-transport conditions within the basin have been substantially changed (Barton, 2004), and these changes may have negatively impacted the spawning success of selected resident fish species.

The population of one Kootenai River resident fish, the white sturgeon (*Acipenser transmontanus*), has decreased substantially since the construction of Libby Dam in 1972. The Kootenai River white sturgeon has been isolated from other sturgeon in the Columbia River Basin by natural barriers for more than 10,000 years (Northcote, 1973). The last successful recruitment of white sturgeon occurred in 1974. Recruitment occurs when a spawning event produces juvenile fish that survive to create a new year-class of fish in sufficient numbers to maintain the fish population. In 1994, the Kootenai River white sturgeon was listed as a Federal endangered species, and the existing catch and release fishery was closed. Today, few wild juvenile sturgeon are found in the river.

One suspected factor in the decrease of successful spawning events and, thus, the reduced population of wild sturgeon in the Kootenai River, is the flow and sediment transport change in the river that has resulted from the construction and operation of Libby Dam. Before dam construction, natural springtime flood flows peaked, on average, at about 80,000 ft^3/s; whereas, during the late 1970s through the early 1990s, post-dam flood flows peaked, on average, less than 10,000 ft^3/s. The elimination of peak flows probably prevents flushing of the fine sediments from the gravel-cobble substrate. As part of the recovery plan for the Kootenai River population of white sturgeon, spring flows were increased, beginning in 1994, through managed releases at Libby Dam to about 25,000 ft^3/s in an attempt to recreate historical peak flows and enhance the spawning substrate for the white sturgeon. These flows are still substantially less than the typical pre-dam spring flows.

Ensuring the long-term future of the Kootenai River white sturgeon is of concern and contention among biologists, ecologists, water managers, engineers, and other interested segments of the population. This concern has spurred a greater interest in finding ways to promote recruitment of the sturgeon. In 1997, the Kootenai River White Sturgeon Recovery Team (KRWSRT) was formed under the provision of the Endangered Species Act of 1974 to develop and implement a recovery plan (Duke and others, 1999). KRWSRT is comprised of International multi-government agencies, universities, and consultants. Projects initiated by KRWSRT will provide information to answer recovery and management questions and produce tools necessary to implement and manage the water resources in the Kootenai River.

Since 1997, the U.S. Geological Survey (USGS) has been working with the Kootenai Tribe of Idaho (KTOI), the Idaho Department of Fish and Game (IDFG), and KRWSRT members, to assess the hydraulic and sediment characteristics of the white sturgeon spawning habitat in the Kootenai River. The first study (Lipscomb and others, 1998), completed in 1997, characterized the spatial distribution of stream velocities upstream, within, and downstream of the white sturgeon spawning reach (fig. 2). In 1998, the USGS and IDGF conducted a seismic subbottom-profiling reconnaissance of the Kootenai River streambed (Barton, 1998), and results were presented in Barton (2004). During 2000-01, the USGS conducted a study to characterize the streambed and sediment transport in the white sturgeon spawning reach. The study supported the collection of streambed samples, vibra-core drilling through the streambed, and analyzing historical suspended-sediment samples.

The USGS, in cooperation with KTOI and IDFG, has developed computer models to improve understanding of the relation of flow and sediment-transport processes to the white sturgeon spawning habitat and gain insight into the effects of proposed recovery actions on the substrate. A one-dimensional sediment-transport model incorporating the white sturgeon spawning habitat was developed. This model encompasses the reach (15 mi) from Bonners Ferry to Klockmann Ranch, Idaho. A one-dimensional hydraulic model was developed by the USGS to determine the location of the transition between backwater and free-flowing water and other hydraulic conditions in the river (Berenbrock, 2005). This model encompasses a larger reach from Leonia to Porthill, Idaho, and this model simulates a fixed streambed (non-moveable). A two-dimensional hydraulic model is being developed by the USGS for a smaller reach of the spawning habitat from about Bonners Ferry to downstream of Shorty Island. The streambed in the two-dimensional model also is not moveable.

Purpose and Scope

The objective of this study is to assess the feasibility of enhancing white sturgeon spawning substrate habitat in the spawning reach of the Kootenai River, Idaho. The results from this study will provide scientific information to the KRWSRT's adaptive management decision process for determining whether or not to implement substrate enhancement measures in the spawning reach.

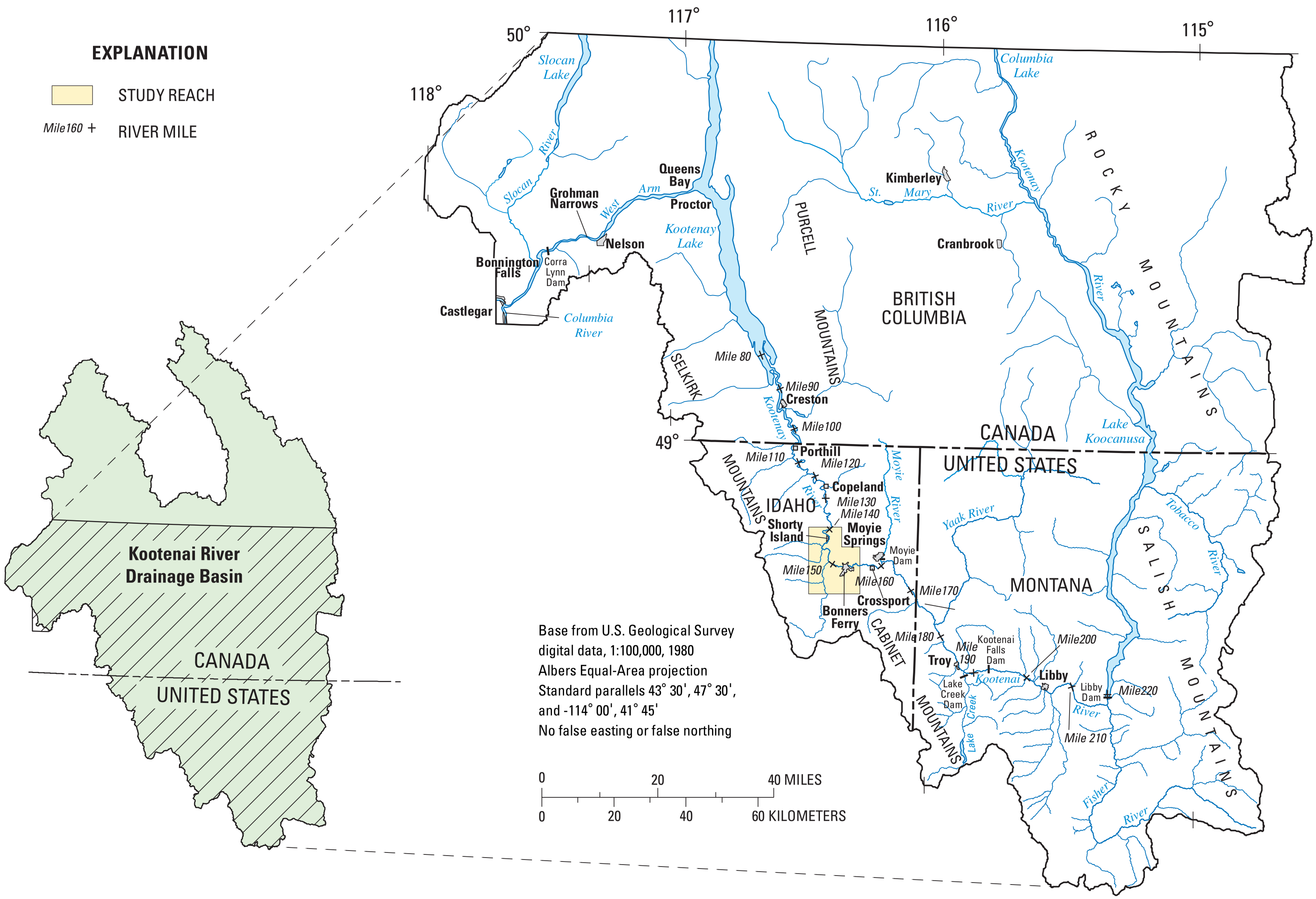

Figure 1. Location of the study reach, river miles, and Kootenai River drainage basin, Idaho, Montana, and British Columbia, Canada.

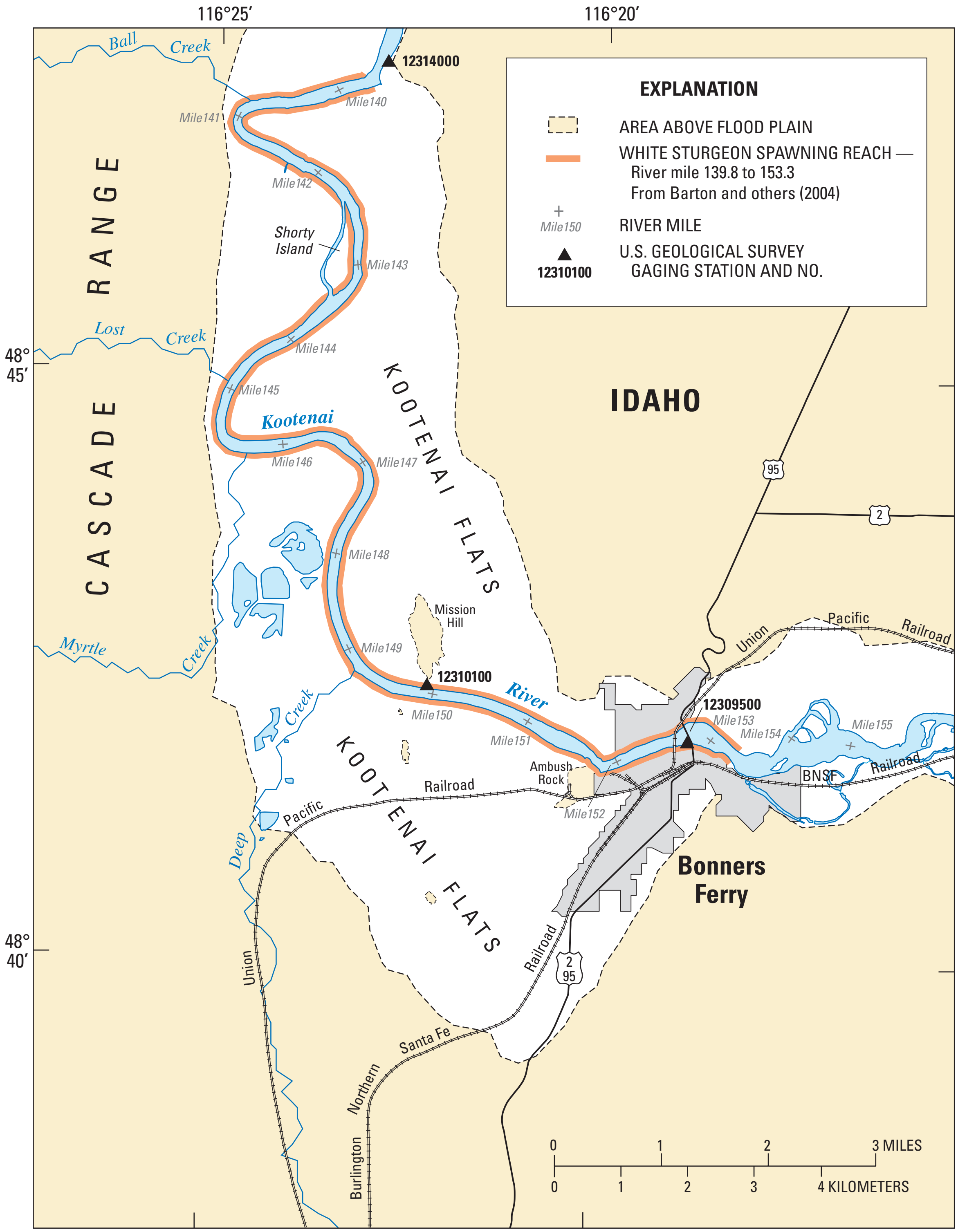

Figure 2. Location of study reach between river mile 139.8 and 153.8 on the Kootenai River and the white sturgeon spawning reach near Bonners Ferry, Idaho.

The purpose of this report is to document the development and calibration of a one-dimensional sediment-transport model in the white sturgeon spawning reach. The model was developed and calibrated using stream-channel cross sections presented in Barton and others (2004), bed-sediment data presented in Barton (2004), and additional data collected for this study. After model calibration, the response of the hydraulic and sediment system to four discharges (6,000, 20,000, 40,000, and 60,000 ft^3/s) was simulated and six water-surface elevations (four are based on historical data and two are hypothetical) for a total of six simulations to demonstrate the feasibility and potential effects of recovery actions (management alternatives) on substrate conditions.

The one-dimensional sediment-transport model used in this study simulates a moveable streambed in contrast to many two-dimensional hydraulic models in which the streambed does not change (fixed bed). Although the one-dimensional sediment-transport model averages across the cross section, the model calculates erosion, deposition, and sediment transport. The one-dimensional sediment model requires less set-up, run-time, and data requirements as compared to two-dimensional models.

Description of Study Reach

The Kootenai River flows through British Columbia, Canada, Montana, and Idaho. The Kootenai River originates in the Rocky Mountains in British Columbia, Canada, and flows southward into Lake Koocanusa in British Columbia and Montana (fig. 1). From there, the river flows basically in a westerly direction through Montana and part of Idaho until it is joined by Deep Creek near Bonners Ferry, Idaho. The river then flows in a northerly direction from Deep Creek to British Columbia where it empties into Kootenay Lake. The Kootenai River is 448 mi long and drains an area of 17,600 mi^2. The elevation of the river at its headwaters in British Columbia is about 11,900 ft, and at the confluence with Kootenay Lake, the elevation is about 1,745 ft. River length from Libby Dam (Lake Koocanusa southern most point) to Kootenay Lake is about 145 mi.

The study reach is the reach of the Kootenai River near Bonners Ferry, Idaho, from river mile (RM) 153.781 to RM 139.469, a length of about 15 mi (fig. 2). This reach includes the white sturgeon spawning reach (RM 139.8 to RM 153.3), and a 1-mi-long side channel around the western side of Shorty Island. The side channel around Shorty Island is much shallower and narrower than the main river channel. Much of the study reach is in backwater because water in Kootenay Lake backs upstream into the Kootenai River. Barton (2004) indicated that backwater conditions occur continuously at the confluence of Deep Creek and the Kootenai River (RM 149.2). In spring and early summer (periods of high flow), free-flowing water may extend several miles downstream of the U.S. Highway 95 Bridge (RM 152.790). The location of the transition between backwater and free-flowing water continually moves upstream and downstream near Bonners Ferry in response to changes in discharge in the river and changes in Kootenai Lake elevations. Backwater conditions usually extend farther upstream as Kootenay Lake levels rise. Levels in Kootenai Lake generally are at a minimum in autumn and winter and at a maximum in late spring and early summer because of snowmelt runoff.

Two geomorphic reaches were identified in the study reach (Snyder and Minshall, 1996). The braided reach extends from Crossport to about the U.S. Highway 95 Bridge (RM 152.790), and a meander reach extends downstream of U.S. Highway 95 Bridge (RM 152.790) to the confluence with Kootenay Lake (figs. 1 and 2).

The braided reach usually consists of multiple channels, and the streambed is composed primarily of gravels and cobbles. Water depths usually are less than 7 ft, and water-surface slope is about 4.6×10^{-4} ft/ft. White sturgeon spawning has not been detected in the braided reach (Paragamian and others, 2002).

The meander reach is a single channel with gentle bends. Upstream of Ambush Rock (RM 151.8) to the U.S. Highway 95 Bridge (RM 152.790), the channel is quite straight. Water depths are from about 10 to 20 ft, and water-surface slope is about 2×10^{-5} ft/ft, less than one-twentieth of the slope in the braided reach. White sturgeon spawning was detected in the meander reach only during 2001 near RM 152.7 (Vaughn Paragamian, Idaho Department of Fish and Game, oral commun., 2001). Downstream of Ambush Rock (RM 151.8), water depths usually exceed 40 ft, and the streambed consists primarily of sand. Sand dunes occurred throughout the meander reach including areas used by the white sturgeon for spawning (Barton, 2004). White sturgeon mostly spawn in the meander reach between RM 141.6 and RM 149.0 (Paragamian and others, 2001 and 2002).

Three USGS streamflow-gaging stations are located in the study reach (fig. 2). Two gaging stations, Kootenai River at Klockmann Ranch (12314000) and Kootenai River at Bonners Ferry (12309500), have been in operation since the late 1920s. These gaging stations only report stage because backwater conditions in the area make the development of a stage-discharge rating impracticable. A new gaging station using an acoustic Doppler velocity meter (ADVM) to determine discharge was installed at the Kootenai River near the Tribal Hatchery (12310100) in September 2002. Because the ADVM measures velocity directly, backwater conditions do not affect the determination of discharge. Stage and discharge are reported at this gaging station. The maximum mean daily discharge for water year 2003 at this gaging station was 31,500 ft^3/s on June 9, 2003; and the minimum was 4,230 ft^3/s on January 11, 2003. Water temperature also is collected at the gaging station.

From mid/late summer through early/mid spring, flow in the river is primarily regulated by flow farther upstream at Libby Dam, Montana (fig. 1). From mid/late spring through early/mid summer, the major contribution of flow to the river is from melting snow from tributary areas below Libby Dam.

Previous Investigations

There have been four surface-water models developed for various reaches of the Kootenai River in the study area. Each model had different objectives and, as with all models, known limitations.

The first model of the Kootenai River was a BRANCH model developed by the USGS in 1980 for explicitly determining the amount of streamflow entering British Columbia, Canada, from Idaho for the International Joint Commission (Schaffranek and others, 1981, p. 45-49). Stage-discharge relations do not work in the backwater reaches of the Kootenai River where it is affected by the Kootenay Lake in Canada because there may be many stages for one discharge or many discharges for one stage. The BRANCH model (one-dimensional unsteady flow) determined discharge from the water-surface slope between the Klockmann gaging station (12314000) and Porthill gaging station (12322000) (Schaffranek and others, 1981) using stage data from these gaging stations. The model uses seven cross sections and has the ability to include inflows from tributaries. The streambed in this model was non-moveable (fixed bed), and sediment transport was not simulated. The model was used until an acoustic Doppler velocity meter (ADVM) was installed in 2004 at the Porthill gaging station to directly determine discharge.

A flood insurance study completed in 1985 modeled the river adjacent to Bonners Ferry (Federal Emergency Management Agency, 1985). Five cross sections comprised the model for a total length of 5,800 ft. In this study, a fixed bed model was used, and sediment-transport characteristics were not estimated.

A one-dimensional unsteady flow model, UNET, was developed by the U.S. Army Corps of Engineers (COE) in 1995 (Patrick McGrane, written commun., 1995). This model extended from Bonners Ferry to Queens Bay, British Columbia, Canada, and contained 54 cross sections. Cross sections in Idaho were surveyed in 1982, and sections in Canada were surveyed in the 1990s. Again, a fixed bed model was used for this study, and sediment-transport characteristics were not estimated.

In 2003, a HEC-RAS model contained within the white sturgeon spawning reach was developed by Tetra Tech. Inc., and Perkins Geosciences (2004) for COE. The HEC-RAS model is a fixed-bed model. The model used unpublished and unverified cross sections surveyed only in 2002 by the USGS (Barton and others, 2004). About 50 cross sections were used and were adjusted to National Geodetic Vertical Datum of 1929 (NGVD 29) from North American Vertical Datum of 1988 (NAVD 88) by subtracting 3.64 ft (approximate conversion, Tetra Tech, Inc., and Perkins Geosciences, 2004, p. 48). The model was not calibrated to hydraulic or sediment-transport conditions. However, model results were used to calculate sediment transport and incipient motion characteristics.

Acknowledgments

The author gratefully acknowledges the support of personnel from the Kootenai Tribe of Idaho for collecting streambed samples at numerous locations along the river and collecting more than 100 suspended-sediment samples at the U.S. Highway 95 Bridge. Appreciation also is extended to the USGS Post Falls Field Office for collecting suspended-sediment samples at three sites along the river, and for preparing all suspended-sediment samples and sending them to the USGS Cascades Volcano Observatory's sediment laboratory for analysis. Appreciation also is extended to Gary Barton and Peter Van Metre, USGS scientists, who conducted additional river-sediment vibra cores in 2004. These cores were used to better define the substrate in selected reaches and especially in the Shorty Island side channel.

Channel and Streambed Characterization

Sediment-transport models require description of the stream channel and information on the particle-size distribution of the streambed as inputs. Barton (2004) presented planview maps and longitudinal cross-section graphs of the streambed sediments. His classification of sediments was generalized and no particle-size data were given. In 2002–03, data were collected on stream-channel cross sections and on streambed sediments in support of the sediment-transport modeling needs. Streambed data also were collected by vibra-coring techniques in 2004 throughout the reach and the channel around the western side of Shorty Island.

Channel Cross Sections

For this study, 71 cross sections from a river survey by Barton and others (2004) were used to define cross-section geometry for the sediment-transport model (fig. 3). These cross sections are located between RM 153.781 near Bonners Ferry, Idaho, and RM 139.469 near Klockmann Ranch gaging station. A complete description on the surveying, quality control, and processing of these cross sections are given in Barton and others (2004). These cross sections are readily available from the World Wide Web (http://id.water.usgs.gov/projects/kootxsections/cross.htm, accessed May 2, 2005). These cross sections also were geographically referenced and are available in a shapefile at the above Web address. These cross sections were based on a common datum. Horizontal control was based on North American Datum of 1983 (NAD 83), Idaho Transverse Mercator Coordinates, in meters; vertical control was based on the North American Vertical Datum of 1988 (NAVD 88), in feet.

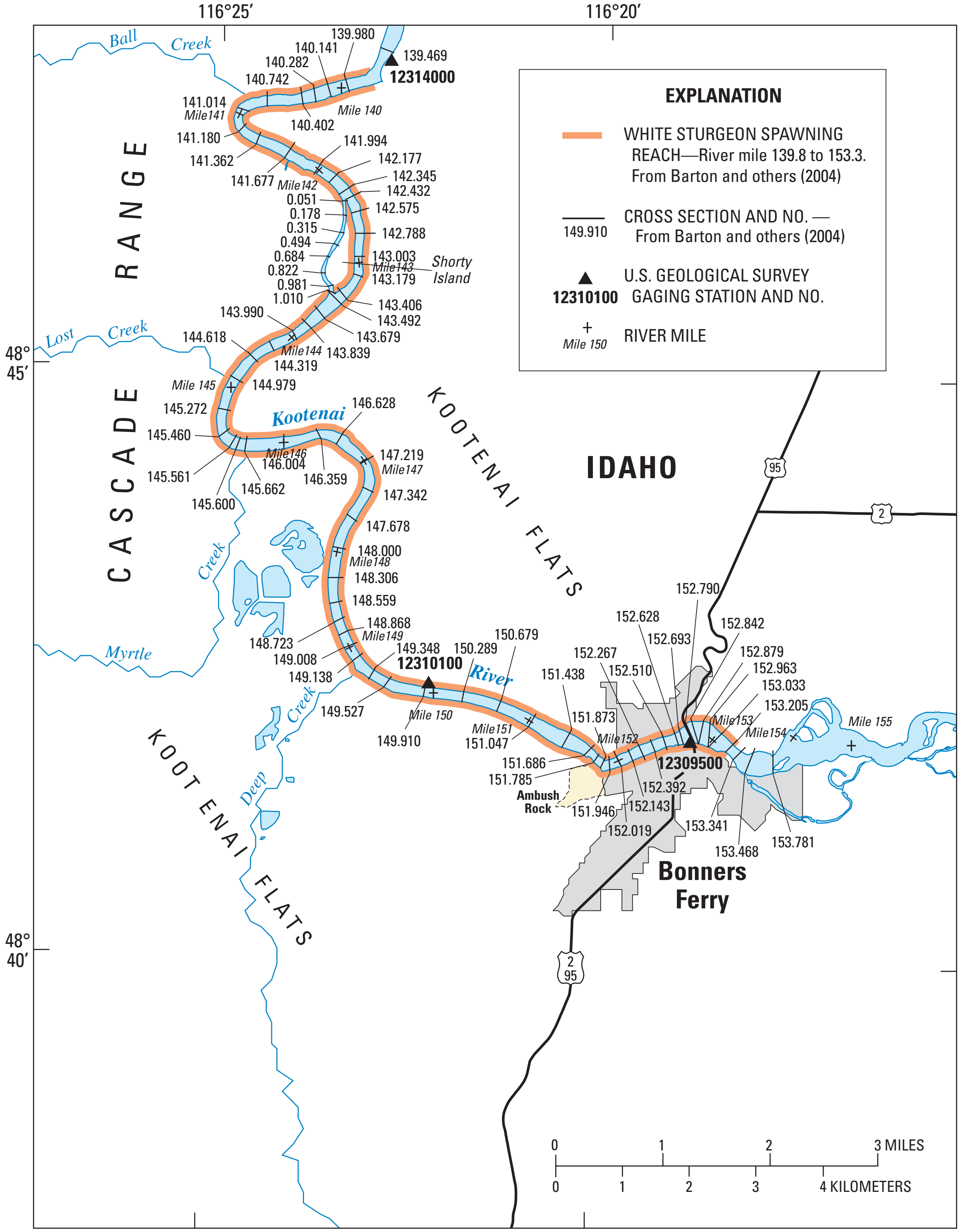

Figure 3. Location of stream channel cross sections used in the sediment-transport model on the Kootenai River and the white sturgeon spawning reach near Bonners Ferry, Idaho.

Eight cross sections on the side channel around Shorty Island were generated using Triangulated Irregular Network (TIN) data obtained from the longitudinal surveys and cross section surveys of the reach. The side channel was usually too narrow and shallow to obtain adequate transects for cross sections using a boat equipped with an echo sounder and global positioning system (GPS) (Moran and Berenbrock, 2003). As a substitute, many longitudinal surveys were made in the side channel (Rick Backsen, U.S. Geological Survey, oral commun., 2003) and bank data were collected by connecting a GPS to a laser rangefinder (Moran and Berenbrock, 2003).

Streambed Samples

Information on particle-size distribution came from streambed material samples that were collected by the Kootenai Tribe of Idaho at 11 sites between Bonners Ferry, Idaho, and the Klockmann Ranch gaging station (fig. 4) using a ponar dredge sampler. The streambed at the middle of the channel was sampled at all sites except at site B, which was sampled only near the left bank (Barton, 2004); at six sites, the streambed also was sampled near the right bank, and four sites near the left bank. These samples were analyzed at the USGS Cascades Volcano Observatory's sediment laboratory for particle size ranging from 0.0625 mm (0.0025 in.) to 64 mm (2.5 in.). Guy (1970) provides a detailed description of the techniques used for the analysis of sediment samples. Particle-size analysis and median diameters (d_{50}) of these samples are shown in table 1. The d_{50} for the streambed ranged from 0.094 mm (0.0037 in.) (very fine sand) to 0.32 mm (0.0126 in.) (medium sand). Classification of particle sizes is shown in table 2. These samples also show no significant variation in d_{50} from the middle of the channel to either bank.

Streambed sediments from three shovel-sampling sites (S7, S8, and S9) also were analyzed for their particle-size distribution (table 3). These shovel-sampling sites are located in the meander reach at Bonners Ferry (fig. 4). Samples were collected in 2002 using a shovel to a depth of about 15.2 cm (6 in.) and were analyzed at the USGS Cascades Volcano Observatory's sediment laboratory. The d_{50} from these cores ranged from 11 mm (0.43 in.) to 22 mm (0.87 in.) and are classified as medium to coarse gravels (table 3).

A streambed sample also was collected in 2003 at cross section 153.781, the upstream section of the study reach (fig. 3) using a specialized approach because an armored-surface layer exists at the site. Kellerhals and Bray (1971) and Church and others (1987) indicated that a representative sample of the streambed should be taken below the armor-surface layer at a depth of the largest particle on the surface layer. A particle count was performed to determine the largest particle of the armored-surface layer. A ½ ϕ gravelometer was used to sample the armored-surface layer, and a particle was sampled every 2.5 ft along the cross section starting from left bank. Particle-count analysis indicated that the largest particle on the surface layer was 64 mm (2½ in.)—the approximate thickness of the armored-surface layer (appendix A, at back of report). A particle of this size is considered very coarse gravel (table 2). Sampling of the streambed was resumed by removing the top 64 mm (2½ inches) of substrate, which is considered the armored-surface layer. Then all materials were collected to a depth of about 1 ft, a depth equal to about 3 times the largest particle diameter (Rankl and Smalley, 1992). Ten equally spaced areas across the channel were sampled using this procedure. The samples were composited and sent to the USGS Cascades Volcano Observatory's sediment laboratory for particle-size analysis (table 3). The d_{50} was 9.8 mm (0.36 in.) (table 3) and is classified as medium gravel (table 2)

The procedure of removing the armored-surface layer from a sample was not performed on samples from the shovel-sampling sites, therefore by including sediments from the armored-surface layer, the particle-size distribution and the d_{50} will be weighted toward larger sized particles than if the surface layers were removed. For this reason, the shovel samples are not completely representative of the streambed but are a combination of streambed and armor-surface layer, and may be a reason why d_{50} values from the shovel samples are greater than the d_{50} from cross section 153.781.

In 2004, additional vibra cores were collected to better define the streambed in selected reaches and in the Shorty Island side channel. The location of these cores is shown in figure 5, and the general description of the top 3 ft of these cores is shown in table 4. Results from cores located between U.S. Highway 95 Bridge and Deep Creek indicated that a gravel-buried reach does not exist as suggested by Barton (2004). The 2004 cores in this reach were composed of sand and (or) silt. The earlier cores from Barton (2004) in this reach probably intersected small lenses of coarse particles (gravels and cobbles) that were transported from upstream reaches, which gave the impression of a "buried gravel-cobble" reach. Upstream of Ambush Rock (RM 151.8), the 2004 vibra cores were characterized by gravels and cobbles. However, the percentage of sand usually increased in cores nearer the banks. Downstream of Ambush Rock (RM 151.8), no gravels and (or) cobbles were found in the 2004 cores, only sand, silt, and (or) clay.

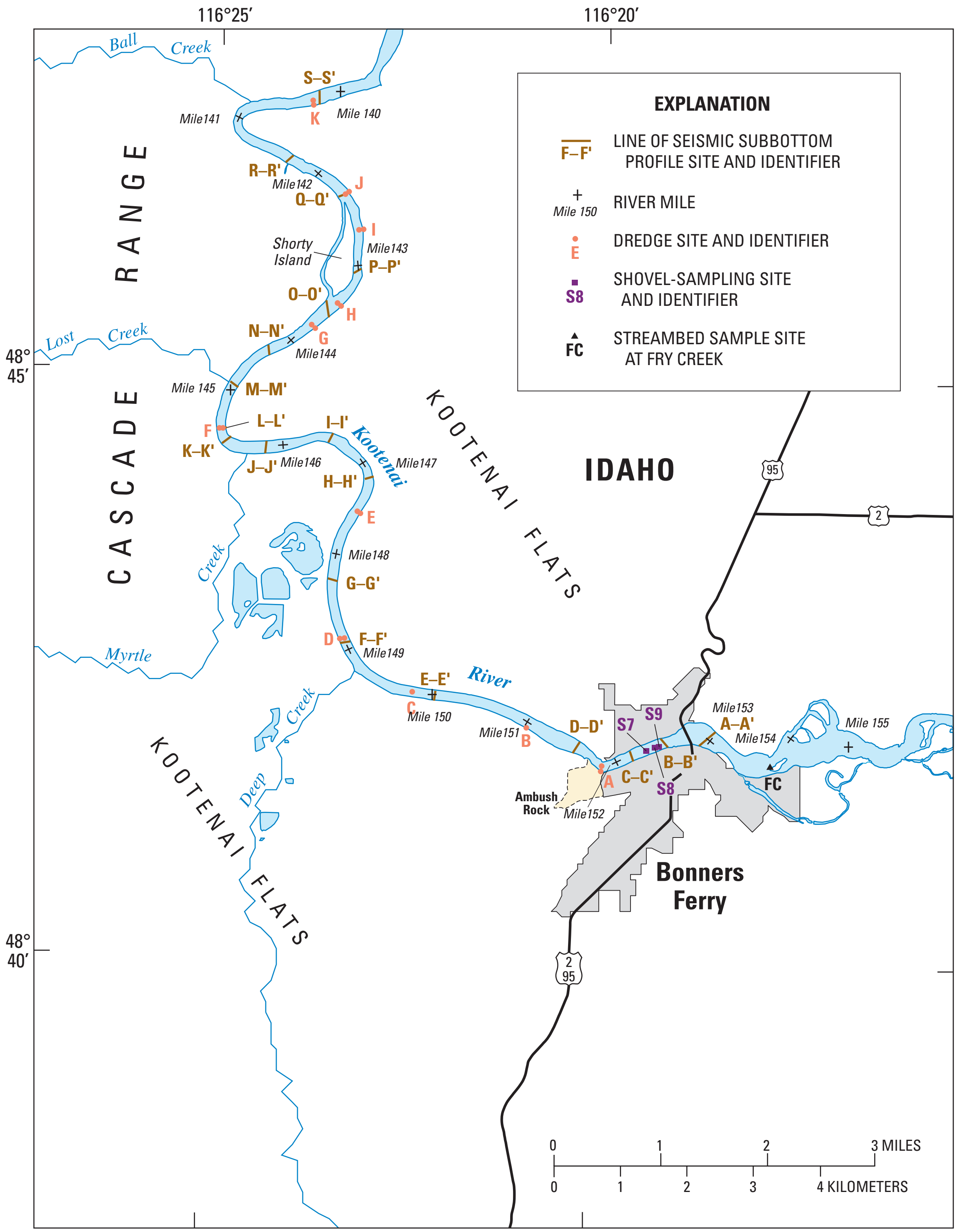

Figure 4. Location of streambed sediment sites and seismic subbottom profiles in the study reach near Bonners Ferry, Idaho.

Table 1. Particle-size analysis and median diameter of streambed samples collected using a ponar dredge sampler, Kootenai River near Bonners Ferry, Idaho, 2002.

[d_{50}, median diameter of streambed samples. Location of dredge sites are shown in figure 4. MID, sample collected near center of channel; LB, sample collected near left bank; RB, sample collected near right bank. mm, millimeter]

Particle size (mm)	Percent finer									
	Site A		Site B	Site C	Site D		Site E		Site F	
	MID	LB	LB	MID	MID	LB	MID	RB	MID	LB
4	100.0	100.0	100.0	100.0	100.0	99.5	100.0	100.0	100.0	100.0
2.8	100.0	100.0	100.0	100.0	100.0	97.4	100.0	100.0	100.0	100.0
2	100.0	99.9	100.0	100.0	99.9	95.4	100.0	99.9	100.0	100.0
1.4	99.9	99.7	99.9	100.0	99.9	94.6	100.0	99.6	100.0	100.0
1	99.8	99.5	99.9	99.8	99.9	94.4	100.0	99.1	99.9	100.0
0.71	99.6	99.2	99.7	99.1	99.9	94.0	99.9	98.1	99.9	99.9
0.5	99.5	98.9	98.5	95.5	99.8	93.3	99.8	94.9	99.8	99.9
0.355	94.6	97.6	87.8	66.3	90.7	85.5	98.4	69.8	96.1	99.3
0.25	33.5	86.6	26.4	6.0	26.4	25.8	64.0	7.5	55.6	97.3
0.18	7.8	57.0	2.1	.7	3.5	2.4	5.8	.9	6.0	57.0
0.125	3.3	41.3	1.2	.4	1.1	.7	2.1	.4	1.5	19.6
0.09	1.8	30.7	.3	.2	.4	.3	.5	.2	.4	4.4
0.063	1.2	22.3	.2	.1	.2	.1	.3	.1	.2	1.7
d_{50} (mm)	.27	.14	.28	.32	.27	.28	.23	.31	.17	.24

Particle size (mm)	Percent finer									
	Site G		Site H		Site I		Site J		Site K	
	MID	RB	MID	RB	MID	RB	MID	RB	MID	RB
4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2.8	100.0	99.4	100.0	100.0	99.9	100.0	100.0	100.0	100.0	99.9
2	99.9	97.4	100.0	100.0	99.6	100.0	100.0	100.0	100.0	99.7
1.4	99.8	95.0	99.8	99.9	98.8	100.0	99.9	100.0	100.0	99.1
1	99.5	93.0	99.4	99.9	97.8	100.0	99.8	99.9	100.0	97.8
0.71	99.0	90.9	99.0	99.8	96.1	99.9	99.7	99.9	99.9	94.9
0.5	97.3	89.2	97.8	99.6	93.5	99.9	99.5	99.6	99.8	90.3
0.355	86.0	85.7	90.4	96.2	83.3	99.6	98.8	94.5	98.8	78.4
0.25	29.2	75.8	50.5	64.1	20.6	97.8	98.4	28.0	86.1	29.1
0.18	2.5	26.8	5.8	33.6	2.0	34.5	94.9	1.6	42.4	2.2
0.125	1.0	5.9	1.3	12.8	0.8	7.0	74.2	1.0	14.1	1.0
0.09	.3	1.5	.4	2.8	.2	1.0	44.8	.3	3.2	.3
0.063	.1	.6	.2	.9	.1	.6	26.4	.2	1.2	.1
d_{50} (mm)	.28	.21	.25	.22	.29	.19	.094	.29	.18	.28

Streambed Description

For this study, the particle-size units mapped by Barton (2004) were used to characterize the streambed substrate in the study reach. Data from seismic subbottom profiles and vibra cores (Barton, 2004), dredge sites (table 1) (fig. 4), shovel-sampling and cross section 153.781 sites (table 3) (fig. 4) and the 2004 vibra core sites (table 4) (fig. 5) were used to develop a longitudinal, vertical section of the streambed (fig. 6).

Gravels and cobbles are the dominant particle sizes in the braided reach and in the meander reach upstream of Ambush Rock (RM 151.8). Whereas, sands, silts, and clays dominate in the meander reach in Ambush Rock and downstream. The abrupt gravel-sand transition just upstream of Ambush Rock probably is due to the markedly decrease in channel slope. In drill core samples in and around the U.S. Highway 95 Bridge, gravels and cobbles were the dominant substrate on the streambed and also at depth (about 130 ft) (Lotwick Reese, Idaho Transportation Department, written commun., 2004).

Vibra cores between the Railroad Bridge and Ambush Rock (RM 151.8) consist primarily of gravels and cobbles, but with increasing sands near the banks.

The lacustrine clay-silt deposits are region-wide throughout the valley and underlie the sandy bottom of the Kootenai River downstream of Ambush Rock (RM 151.8) (fig. 6). Thickness of the sand ranges from about 3 ft at seismic line *Q-Q*' to 36 ft at *O-O*' (fig. 4). Near Lost Creek, the left side of the channel is composed primarily of sands with some gravels and is about 10 ft thick near the right bank. In this area, Barton (2004) indicated that the channel was cutting into an alluvial fan near the edge of the valley. On the right side of the channel, the substrate is composed primarily of sand overlying the regional lacustrine clay-silt deposits. The average thickness of sand in this area is about 20 ft. Vibra core from sites K15.5 (Barton, 2004, fig. 2*B*) (RM 148.559) showed small gravels at the surface of the streambed to a depth of 1.3 ft. There was no evidence of gravels in the nearby seismic subbottom profiles (*F-F*' and *G-G*') (fig. 4).

Table 2. Particle-size classification.

[Particle-size classification was modified from Buffington and Montgomery (1999) and Folk (1980). ϕ, phi scale where $\phi = -\log_2$ (diameter in mm); mm, millimeter]

Diameter of particle: ϕ	Diameter of particle: mm	Classification name
-8	256	
		Coarse cobble
-7	128	
		Fine cobble
-6	64	
		Very coarse gravel
-5	32	
		Coarse gravel
-4	16	
		Medium gravel
-3	8	
		Fine gravel
-2	4	
		Very fine gravel
-1	2	
		Very coarse sand
0	1	
		Coarse sand
1	0.5	
		Medium sand
2	0.25	
		Fine sand
3	0.125	
		Very fine sand
4	0.0625	
		Silt

Table 3. Particle-size analysis, median diameter, geometric standard deviation, and particle-size classification of streambed samples collected from shovel-sampling sites and cross section 153.781, Kootenai River near Bonners Ferry, Idaho, 2002-03.

[d_{50}, median diameter of streambed samples. σ_g, geometric standard deviation of the size distribution. **Sampling sites**: Location of shovel-sampling sites and cross section 153.781 are shown in figure 4. mm, millimeter]

Particle size (mm)	Percent finer: Shovel-sampling sites: S7	S8	S9	Cross section 153.781
64	100.0	100.0	100.0	100.0
45	100.0	100.0	100.0	97.6
31.5	100.0	68.0	74.0	94.4
22.4	89.2	50.9	60.4	85.5
16	70.3	37.6	45.6	69.6
11.2	53.0	24.9	20.2	54.8
8	34.3	14.1	8.5	42.2
5.6	23.3	10.4	6.6	35.0
4	19.4	9.1	6.5	32.0
2.8	18.3	8.8	6.5	37.0
2	18.0	8.6	6.5	30.1
1.4	17.5	8.4	6.4	29.4
1	17.2	8.3	6.4	28.7
0.71	16.2	8.2	6.4	27.8
0.5	14.4	8.0	6.2	26.9
0.355	10.8	6.5	4.4	23.3
0.25	5.5	3.7	2.2	16.1
0.18	2.0	1.4	.9	7.8
0.125	1.0	.7	.4	2.8
0.09	.4	.3	.2	1.6
0.063	.2	.1	.1	.8
d_{50} (mm)	11	22	17	9.8
σ_g (mm)	5.35	2.02	1.85	9.38
Particle-size classification	medium gravel	medium gravel	coarse gravel	coarse gravel

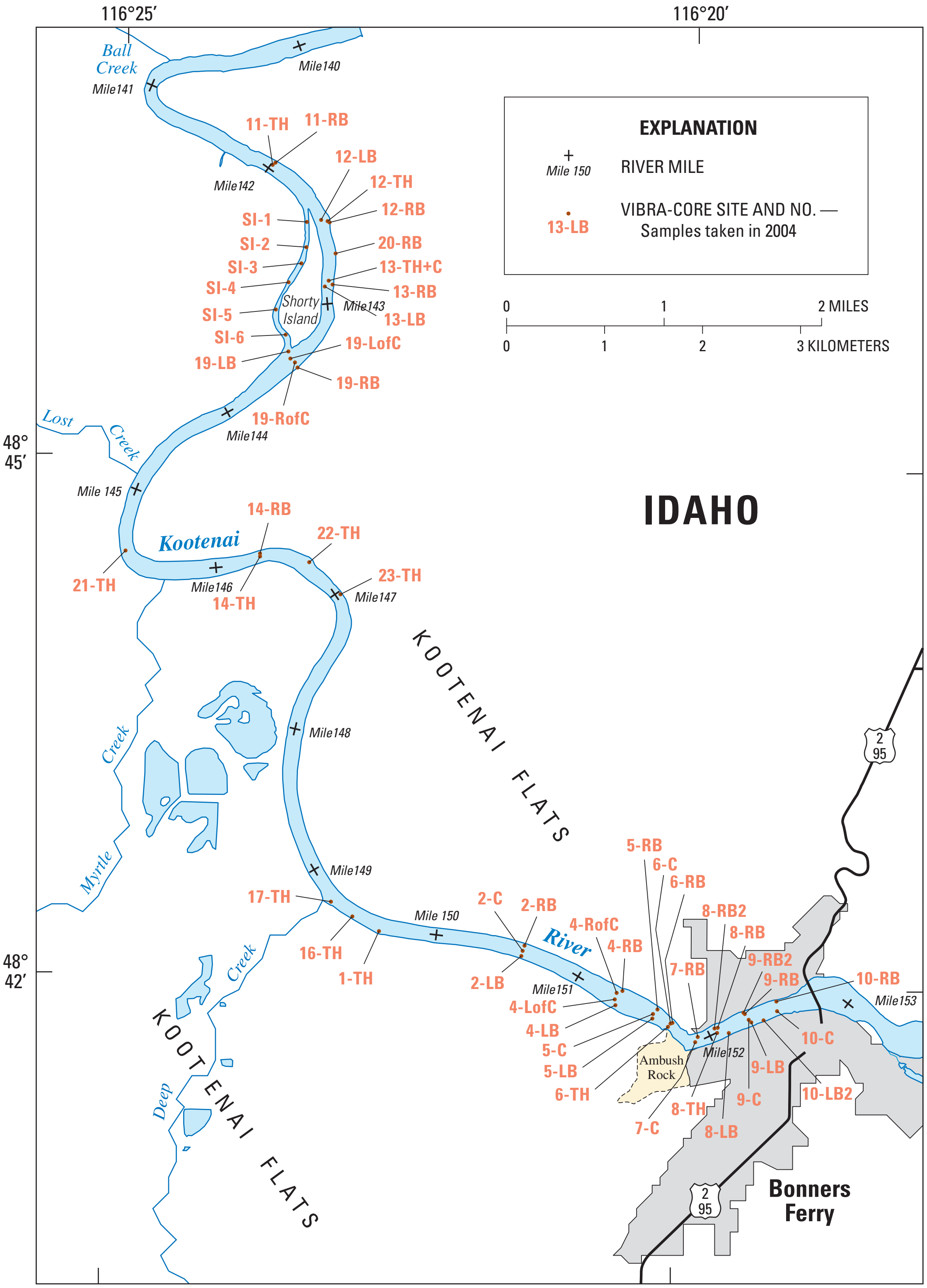

Figure 5. Location of the 2004 vibra-core sites, Kootenai River near Bonners Ferry, Idaho.

Table 4. Locations, depth, and general description of top 3 feet of the 2004 vibra cores, Kootenai River near Bonners Ferry, Idaho.

[Latitude and longitude are given in degrees (°), minutes (′), and seconds (″) and are based on North American Datum of 1983. –, unknown; min, minimum,; max, maximum; the min and max pertain to the length of the B-axes of the particle. cm, centimeter; mm, millimeter]

Site name	Latitude			Longitude			Vibra core depth (ft)	Core drilling date	General description of top 3 feet of core
	°	′	″	°	′	″			
10-RB	48	41	55.644	116	19	07.230	2.1	09/10/04	Medium to very fine sand, silt, woody debris
10-C	48	41	52.296	116	19	06.910	1.0	09/10/04	Gravel and cobbles (min=4 mm, max=7.5 cm)
10-LB2	48	41	48.918	116	19	13.751	1.4	10/14/04	Medium to very fine sand, silt, woody debris
9-RB2	48	41	51.428	116	19	24.390	0.8	09/14/04	Gravel (min= 7mm, B axis maximum=3.5 cm)
9-RB	48	41	51.061	116	19	23.674	1.0	–	Gravel (min=7mm, max=3.0 cm)
9-C	48	41	49.040	116	19	21.551	1.7	09/10/04	Gravel (min=7 mm, max=4 cm), medium to very find sand, woody debris
9-LB	48	41	48.136	116	19	20.264	0.7	09/10/04	Medium to very fine sand
8-RB	48	41	46.002	116	19	37.794	4.6	09/14/04	Very fine to medium sand, granite rock (3.5 cm), silt
8-TH	48	41	44.208	116	19	38.141	1.6	09/13/04	Gravel and cobbles (min=6 mm, max=6.0 cm)
8-LB	48	41	42.657	116	19	31.995	7.2	09/14/04	Very fine to fine sand
8-RB2	48	41	45.912	116	19	39.729	5.9	09/14/04	Very fine to fine sand, woody debris
7-C	48	41	40.938	116	19	49.573	1.5	09/11/04	Very fine to medium sand, woody debris
7-RB	48	41	42.588	116	19	48.072	1.3	09/11/04	Very fine to medium sand, gravel and cobble (min=4 mm, max=5.0 cm)
6-RB	48	41	47.304	116	20	01.586	8.8	09/11/04	Very fine to find sand, silt and clay
6-C	48	41	47.065	116	20	02.620	5.5	09/11/04	Very fine to medium sand, silt and clay
6-TH	48	41	45.931	116	20	03.984	0.3	09/11/04	Gravel and bedrock
5-LB	48	41	48.795	116	20	12.454	–	–	–
5-C	48	41	50.267	116	20	11.990	7.1	09/11/04	Very fine to medium sand, silt and clay
5-RB	48	41	52.002	116	20	09.877	7.2	09/11/04	Very fine to medium sand, silt and clay
4-LofC	48	41	55.045	116	20	32.393	3.2	–	Very fine to medium sand, woody debris
4-LB	48	41	53.063	116	20	31.767	3.8	09/11/04	Very fine to medium sand, gravel (3 cm), silt
4-RofC	48	41	57.353	116	20	31.331	6.9	09/11/04	Very fine to medium sand, woody debris
4-RB	48	41	58.194	116	20	28.511	6.7	09/11/04	Very fine to medium sand, woody debris
2-C	48	42	11.215	116	21	21.257	5.8	09/10/04	Very fine to medium sand, clay, woody debris
2-LB	48	42	09.390	116	21	21.844	8.4	09/10/04	Very fine to medium sand, woody debris
2-RB	48	42	12.914	116	21	20.440	2.1	09/10/04	Very fine to medium sand, silty clay
1-TH	48	42	16.876	116	22	37.173	1.3	09/14/04	Gravel (4 mm; 4.0 cm), sand, and silt
18-TH	48	42	19.723	116	42	47.581	3.4	09/14/04	Very fine to medium sand, gravel (min=1.5 cm, max=5.5 cm), silt
16-TH	48	42	21.628	116	22	51.240	3.0	09/14/04	Very fine to medium sand, gravel and cobble (min=2.5 cm, max=6.5 cm), silt
17-TH	48	42	26.747	116	23	02.754	2.1	09/14/04	Very fine to medium sand, silt, woody debris
23-TH	48	44	13.685	116	23	01.829	3.8	09/15/04	Very fine to medium sand, silt and clay, woody debris
22-TH	48	44	24.486	116	23	18.381	1.6	09/15/04	Very fine to medium sand, gravel and cobble (min=3.5 cm, max=6.5 cm)
14-RB	48	44	27.160	116	23	44.490	9.7	09/15/04	Silt and lacustrine clay
14-TH	48	44	26.365	116	23	44.435	2.8	09/12/04	Very fine to medium sand, silt, lacustrine clay
21-TH	48	44	27.069	116	24	55.393	–	09/15/04	–
19-RB	48	45	31.958	116	23	27.287	4.6	09/14/04	Very fine to find sand, silt and clay
19-RofC	48	45	33.774	116	23	28.663	6.4	09/14/04	Very fine to find sand, silt and clay
19-LofC	48	45	35.225	116	23	31.104	8.3	–	Very fine to medium sand, woody debris
19-LB	48	45	37.505	116	23	32.176	9.4	09/14/04	Very fine to medium sand, silt
13-RB	48	46	01.263	116	23	09.681	3.6	09/15/04	Silt and lacustrine clay
13-LB	48	46	00.359	116	23	14.029	7.8	–	Very fine to find sand, silt
13-TH+C	48	46	02.455	116	23	11.782	3.5	09/12/04	Very fine to medium sand, silt, lacustrine clay
20-RB	48	46	12.029	116	23	08.614	5.2	–	Silt and clay
12-RB	48	46	22.784	116	23	12.017	5.8	09/12/04	Silt with some clay, very fine sand to fine sand
12-TH+C	48	46	23.267	116	23	13.243	4.7	09/12/04	Very fine to very coarse sand, woody debris
12-LB	48	46	23.501	116	23	16.729	5.8	09/12/04	Very fine to very coarse sand, silt
11-TH	48	46	42.635	116	23	42.332	7.2	09/12/04	very fine to coarse sand, woody debris
11-RB	48	46	43.054	116	23	41.598	6.6	09/12/04	Silt, gravel (min=9 mm, max=2.8 cm), medium to very fine sand
SI-1	48	46	22.680	116	23	24.100	4.4	09/14/04	medium to very find sand, silt
SI-2	48	46	14.073	116	23	24.190	6.5	09/14/04	medium to very find sand, silt
SI-3	48	46	08.171	116	23	26.511	5.6	09/14/04	medium to very find sand, silt, organic debris
SI-4	48	46	01.556	116	23	33.073	1.0	09/14/04	Silt, medium and fine sand, organic debris
SI-5	48	45	51.947	116	23	39.442	3.8	09/14/04	Silt, medium and fine sand, organic debris
SI-6	48	45	43.411	116	23	33.718	4.4	09/14/04	Silt and clay, medium and fine sand, organic debris

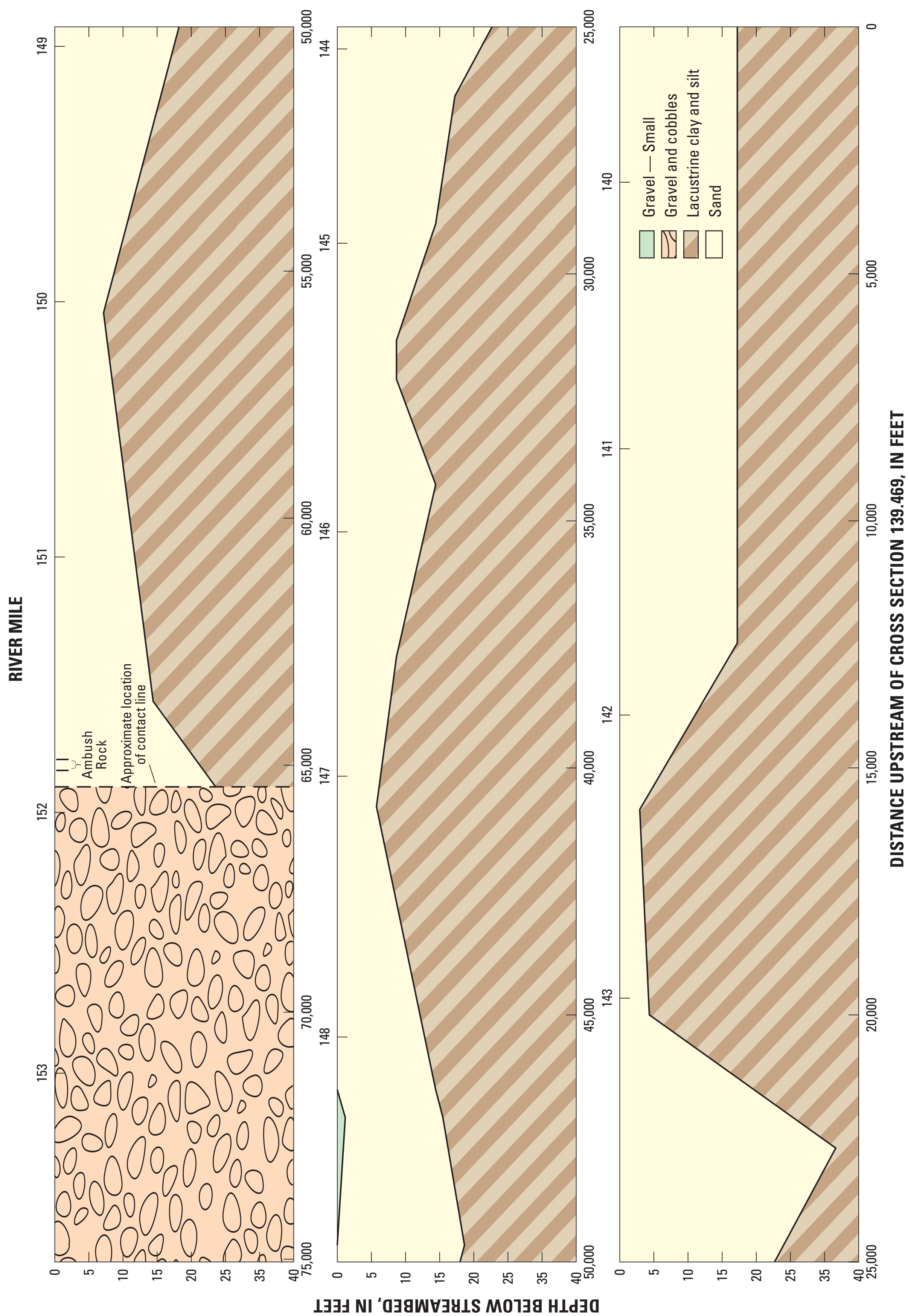

Figure 6. Longitudinal profile of streambed showing depth of sediments in the study reach, Kootenai River near Bonners Ferry, Idaho.

Sediment-Transport Characteristics

Sediment-transport models require input of the variation of total sediment discharge (suspended-sediment discharge plus bedload) with changes in stream discharge and particle-size distribution of the streambed at the upstream model boundary. Measurements of suspended-sediment discharge also are required to test model performance.

The suspended-sediment discharge of fine-grained particles in a stream typically is controlled by the available supply of fine-grained particles because the supply often is less than the stream can transport (Colby, 1956). These fine-grained sediments generally move downstream at about the same velocity as the water.

In contrast, the supply of coarser grained sediments in streams generally is greater than what the stream can transport and therefore the transport of coarser grained sediments as bedload typically is controlled by the ability of the stream to transport them (Guy, 1970). Bedload is sediment that moves on or near the streambed by sliding, rolling, or bouncing (Edwards and Glysson, 1999). Most bed sediment moves occasionally and remains at rest much of the time especially in gravel/cobble/boulder streams. As a result of these differences in transport mechanisms, large variations can be expected in the concentrations and grain-size characteristics of sediments at different locations in a stream and with changes in stream discharge. The concentration of fine and coarse-grained sediments in a stream generally increase with increasing stream discharge (Edwards and Glysson, 1999).

The Modified Einstein (ME) method (Einstein, 1950; and Colby and Hembree, 1955) was used to determine the incoming total sediment discharge at Kootenai River near Fry Creek because high velocities made bedload sampling from a boat impractical and unsafe at U.S. Highway 95 Bridge. The ME method was selected because it uses suspended sediment, streambed, and other hydraulic data that were collected at the site to determine total sediment discharge.

Suspended Sediment

Suspended-sediment samples were collected at three sites in the study reach: Kootenai River near Fry Creek (RM 153.781), Kootenai River at U.S. Highway 95 Bridge (RM 152.790), and Kootenai River near Ball Creek (near RM 140.402). Suspended-sediment data from these sites are given in table 12 (at back of report). Samples near Fry and Ball Creeks were collected using width- and depth-integrating techniques to obtain representative samples across the entire channel. Samples at Fry Creek were collected using a D-74 reel-mounted sampler in a boat; and samples at Ball Creek were collected using a P-72 or D-74 reel-mounted sampler in a boat. In contrast, samples from the U.S. Highway 95 Bridge were only collected at a single vertical stationary site. A DH-59 sampler attached to a handline was used to collect these samples. Edwards and Glysson (1999) provide detailed descriptions of collection methods and the different sampling devices used to sample suspended sediment. All suspended-sediment samples were analyzed at the USGS Cascades Volcano Observatory's sediment laboratory. These samples were analyzed for total concentration, and in addition, some samples were analyzed for particle size from 0.0625 mm (0.0025 in.) to 64 mm (2.5 in.). Guy (1970) provides a detailed description of the techniques used for the analysis of sediment samples for total mass and particle size.

Eleven width- and depth-integrated samples were collected from the Kootenai River near Fry Creek (cross section 153.781) (table 12). The best-fit regression line for this site indicates a poor log-log relation between stream discharge and total suspended-sediment discharge (fig. 7). The correlation coefficient is a measure of strength of the linear relation between two variables (Zar, 1998). An r value of 0 indicates that there is no linear association between the two variables, whereas an r value of 1 or –1 indicates a strong linear association. The correlation of discharge and total suspended-sediment discharge was poor (r=0.42).

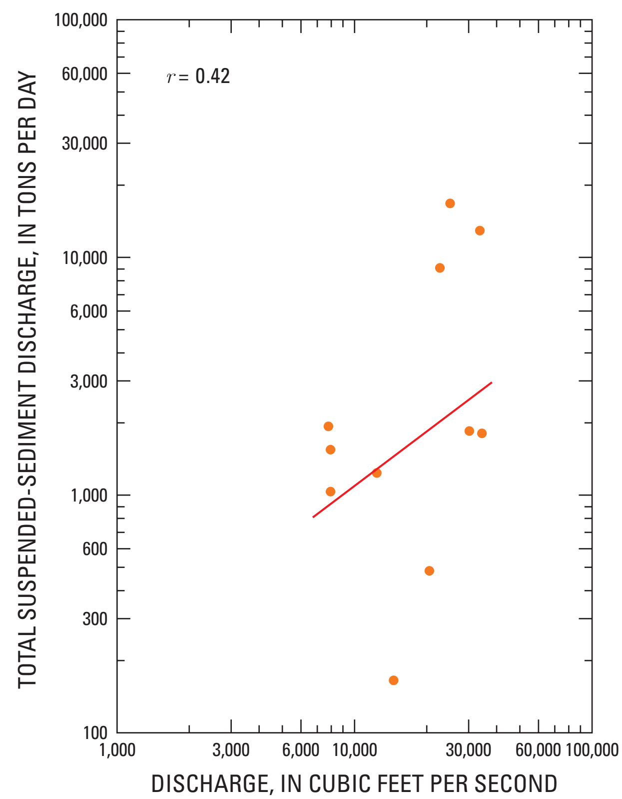

Figure 7. Relation between discharge and total suspended-sediment discharge at Kootenai River near Fry Creek (12309490), Idaho.

About 125 single vertical samples were collected at the U.S. Highway 95 Bridge (RM 152.790) from April through October 2002. An adjustment coefficient was used to adjust single vertical samples to width- and depth-integrated (cross section) samples. The adjustment coefficient is determined by computing the ratio between the concentration of single vertical samples and width- and depth-integrated (cross section) samples that were collected nearly at the same time. Because no cross-section samples were collected at U.S. Highway 95 Bridge, cross-section samples collected at Kootenai River near Fry Creek were used. Samples collected near Fry Creek can be used at U.S. Highway 95 Bridge because (1) flow conditions were similar, (2) no inflows occur between these sites, (3) the distance between these sites is relatively short (less than 1 mi), and (4) measurements from a boat at median and high flows cannot be made safely near the U.S. Highway 95 Bridge. Ratios were then determined using the five cross-section samples near Fry Creek and the average of single vertical samples at U.S. Highway 95 Bridge collected nearly at the same time (table 5). The average ratio for the five samples was 1.27. A coefficient of 1.0 is used if the adjustment coefficients are within 5 percent of unity (Edwards and Glysson, 1999). Although most coefficients were outside of this range, the one-to-one line (unity) probably is a satisfactory-fit line through the data (fig. 8). Therefore, an adjustment coefficient of 1.0 was applied to the single vertical samples at the U.S. Highway 95 Bridge to adjust them to the concentration of cross-section samples.

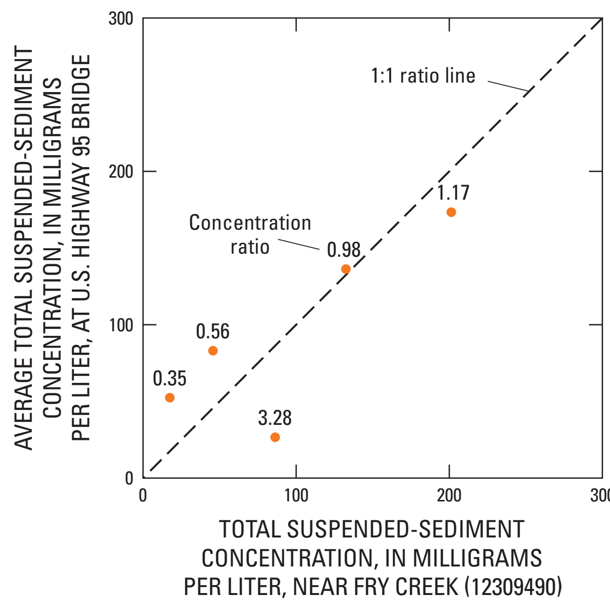

Figure 8. Total suspended-sediment concentrations in width- and depth-integrated samples collected at Kootenai River near Fry Creek (12309490) compared with average total suspended-sediment concentrations in single vertical samples collected at Kootenai River at U.S. Highway 95 Bridge, Idaho.

Table 5. Concentrations of total suspended sediment in width- and depth-integrated samples collected at Kootenai River near Fry Creek (12309490) compared with concentrations of average total suspended sediment in single vertical samples collected at Kootenai River at U.S. Highway 95 Bridge, Idaho.

[ft^3/s, cubic foot per second; mg/L, milligram per liter]

Date	Time	Discharge (ft^3/s)	Width- and depth-integrated samples at Kootenai River near Fry Creek (12309490)	Single vertical samples at Kootenai River at U.S. Highway 95 Bridge		Adjustment coefficient
			Total suspended-sediment concentration (mg/L)	Number of samples	Average total suspended-sediment concentration (mg/L)	
04 /16/02	1721	27,300	202	1	172	1.17
04/19/02	1440	8,290	46	3	82	.56
05/23/02	1225	36,000	133	4	136	.98
06/26/02	0915	36,900	18	2	51.5	.35
09/04/02	1518	8,090	87	2	26.5	3.28
					average ratio =	1.27

After applying the adjustment coefficient, the relation between stream discharge and total suspended-sediment discharge at Kootenai River at U.S. Highway 95 Bridge (fig. 9) is good, but with scatter that may reflect sample collection. The best-fit regression line for this site indicates a good log-log relation between stream discharge and total suspended-sediment discharge (correlation coefficient, $r = 0.91$). There is a fair amount of scatter about the regression line at this site. This scatter can be partly attributed to sample collection. Two samples usually were collected consecutively (5 to 10 minutes apart) to ensure systematic collection. Concentrations from consecutive samples should be quite similar unless stage or discharge is rapidly changing. The percentage of difference between consecutive samples ranged from about −70 to +240 percent. This large range indicates that sampling probably was not consistent between the consecutive samples.

Six width- and depth-integrated samples also were collected from the Kootenai River near Ball Creek (near RM 140.402) (table 12). The best-fit regression line for this site indicates a very good log-log relation between stream discharge and total suspended-sediment discharge ($r = 0.93$) (fig. 10). The amount of scatter about the regression line is quite minimal. One sample was not used in determining the regression line because field notes indicated that there were problems in collecting the sample.

Hysteresis also can affect the concentration of suspended sediment as stream discharge increases and decreases. When discharge in a stream increases, particles stored in the stream channel or in riparian zones become mobile as they are subjected to increased stream velocities. The magnitude of hysteresis can be affected by antecedent conditions, discharge magnitude, duration of the discharge, and the source of water. Samples collected during the rising part of the stream hydrograph usually have larger concentrations of suspended sediments as compared to samples collected at similar discharge during the falling part of the stream hydrograph. A hysteresis effect could not be determined from the data because of the large difference in concentrations in the consecutive samples and the low number of cross-section samples.

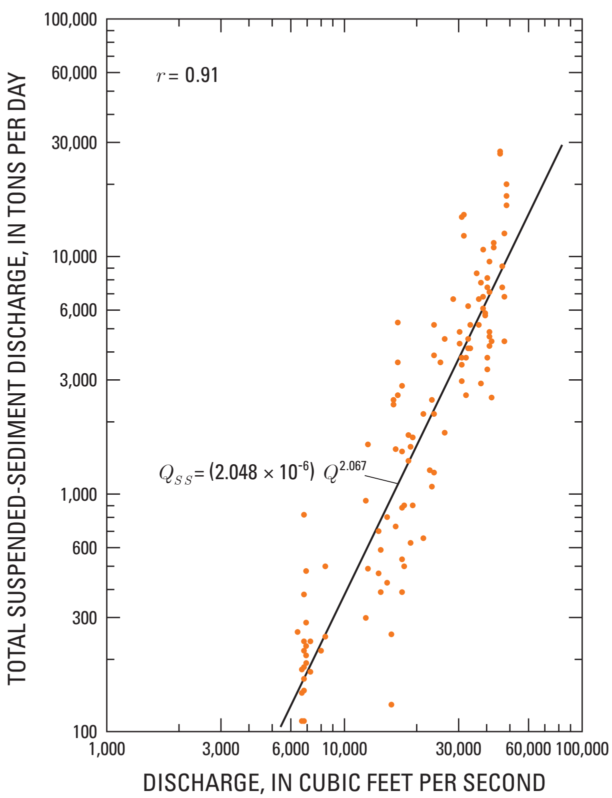

Figure 9. Sediment-transport curve for total suspended-sediment discharge at Kootenai River at U.S. Highway 95 Bridge, on the Kootenai River, Idaho.

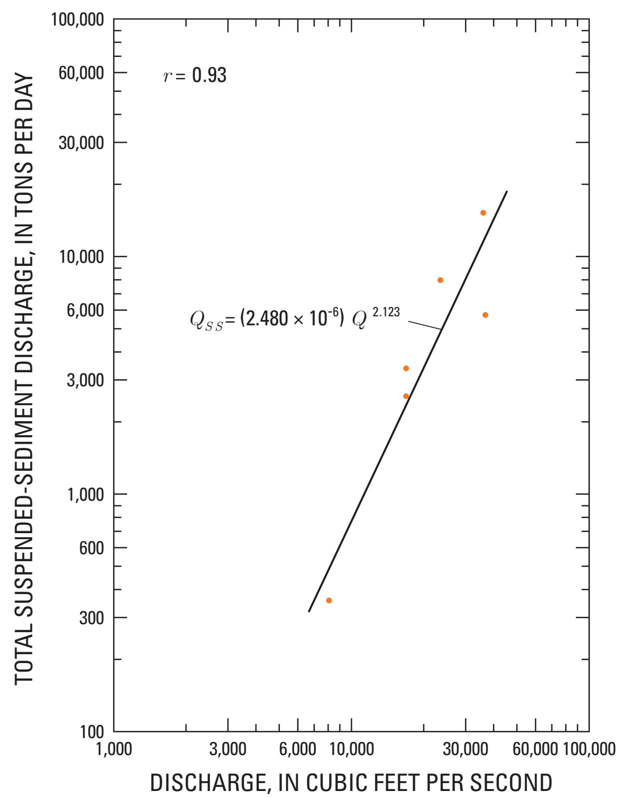

Figure 10. Sediment-transport curve for total suspended-sediment discharge at Kootenai River near Ball Creek (12313600), Idaho.

Seasonal changes in sources of water cause seasonal differences in sediment characteristics of the Kootenai River. During the early part of snowmelt runoff (mid/late spring through early summer), fine sediment (fine sand, silt, and clay) that has accumulated in the channel and tributary channels below Libby Dam during the low-flow season (late summer/early autumn through early/mid spring) will be flushed from the channels. In summer, stream discharge usually comes from Libby Dam. Water from the dam usually has low suspended-sediment concentrations for sands and larger size particles, but there might be silts and clays. The channel below the dam then becomes the major source of suspended sediment, and concentrations usually are much less than in first flushing flow.

Total Sediment Discharge

The Modified Einstein (ME) method was used to estimate total sediment discharge and particle-size distribution at the Kootenai River at the upstream end of the study reach. The ME method is applicable only if suspended-sediment, bed material, and other measured hydraulic data are available. This method is a widely accepted procedure for estimating total sediment discharge. For more information and familiarization on the method, the reader is referred to the following reports: Einstein (1950), Colby and Hembree (1955), and Yang (1996). The ME method extrapolates sediment discharge from the sampled region to the unsampled region to estimate total sediment discharge at a site.

The program "MODEIN" (Stevens, 1985), obtained from the World Wide Web at http://water.usgs.gov/software/modein.html (accessed May 2, 2005), was used to determine total sediment discharge and particle-size distribution. The program is quite efficient, and incorporates computations from Colby and Hembree (1955) based on the dominant particle size. The program requires the user to input measured suspended concentration, particle-size distribution of suspended sediment and streambed, and other data such as discharge, top width of channel, average depth of channel, and average depth at sampled (suspended sediment) verticals. These data were available at the Fry Creek site because they were either measured during suspended-sediment sampling or during discharge measurements. Sampling protocol also required a discharge measurement for cross-section (width- and depth-integrated) samples (Edwards and Glysson, 1999). Discharge was measured at cross section 153.781 using an acoustic Doppler current profiler (ADCP).

Data from 11 cross-section samples, associated discharge measurements, and sediment characteristics from the streambed from Kootenai River near Fry Creek (table 12) were input into MODEIN for estimating total sediment discharge at the upstream model boundary (cross section 153.781). The program, however, could not determine estimates for samples 1, 2, 3, and 6 and stopped because the slope between fall velocity and the suspended-load exponent was negative. Total sediment discharge was then determined by MODEIN for the remaining seven samples. Because a higher correlation existed in suspended-sediment discharge at U.S. Highway 95 Bridge (r=0.91, fig. 9) than near Fry Creek (r=0.42, fig. 7), the contribution from bedload as determined by MODEIN for the seven samples was added to the suspended-sediment equation (Q_{ss}) at U.S. Highway 95 Bridge to obtain total sediment (suspended plus bedload) discharge. This procedure was done on the seven samples, and then a best-fit regression line and equation was determined. The total sediment discharge curve (Q_T) and equation are shown in figure 11. The total sediment discharge equation (Q_T) was used to estimate the total sediment-transport discharge for any river discharge at the upstream boundary. The particle-size distribution also was estimated by MODEIN for each sample. The final particle-size distribution was estimated by averaging the seven distributions in each size class. However, Q_T does not differentiate between the different sources of water or from hysteresis.

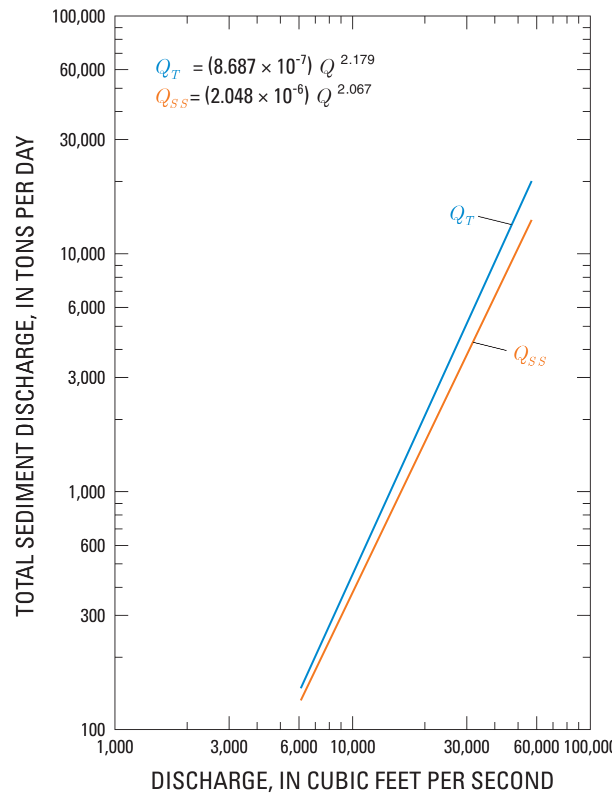

Figure 11. Total sediment discharge (Q_T) and suspended-sediment discharge (Q_{ss}) curves at Kootenai River at U.S. Highway 95 Bridge, Idaho.

Simulation of Flow and Sediment Transport

The primary objective for simulating discharge and sediment transport was to predict the effects of changing river discharges and water-surface and streambed elevations in the study reach on sediment transport. Successful models can be used to estimate water-surface elevations, velocities, shear stress, erosion, deposition, and sediment transport for flows of varying magnitudes and stages.

Model Implementation

The Mixed-Size Sediment Transport (SEDMOD) computer model (Bennett, 2001) was used to compute water-surface and streambed elevations, sediment transport, and size distribution of the streambed. SEDMOD is a computer program that analyzes one-dimensional, gradually varied, steady flow in open channels with movable boundaries. SEDMOD has no limits to the number of channels, cross sections, points defining the cross sections, or number of streambed layers. A hydrograph is simulated as a stepwise steady flow for each time increment. Steady flows exist when flow is constant for the entire time increment. SEDMOD uses the resulting hydraulic variables to compute transport, erosion, and deposition related characteristics. The steady-state flow equations are faster, much less cumbersome, and more stable than unsteady flow simulations, which can go through many more iterations to compute flow for each time step. The model also assumes that flow is unobstructed within the channel and free of debris.

SEDMOD simulates the transport of sediment from upstream sources, transport of bedload and suspended-sediment discharge for each size class, and the process of bed armoring. The model does not simulate bank erosion or lateral migration of the channel. Bedload and suspended transport occur in separate layers as described in Bennett (1995). Sediments are transported for each size class, and as many as 20 sediment size classes can be specified. The model emphasizes computations in the sand-size range (0.0625–2.0 mm or 0.00246–0.0787 in.), but any sizes can be simulated including silt (<0.0625 mm or <0.00246 in.) and gravel (>2.0 mm or 0.0.787 in.). Bennett (2001) reported that the model quite reasonably simulated coarse gravel to silt. The model does not adequately simulate erosion or deposition of cohesive materials. The model uses only the meter-kilogram-second (MKS) system of units except for sediment particle size in millimeters and time in days. The MKS system is based on the metric system and has meter of length, kilogram of mass, and second of time as its fundamental units. A right-to-left bank reference system for inputting cross-section data is required by SEDMOD.

The model first calculates the water surface at each cross section using the standard step method (Chow, 1959) in the Newton iteration form (Chaudhry, 1993). For subcritical flow, calculations start at the downstream most cross section and progress in an upstream manner to the upstream most cross section. Flow in streams and canals typically is subcritical, and in the study reach, flows in the Kootenai River are subcritical. The model also simulates supercritical flows, and mixed flow types can occur jointly in the model. For more information on calculations for supercritical or mixed flows in SEDMOD, the reader is referred to Bennett (2001).

Next, the potential sediment-transport rates are computed at each section and are combined with the flow to determine the volume of suspended-sediment transport within each reach. If input volume exceeds the reach's transport capacity, deposition occurs in the reach. If input volume is less than the reach's transport capacity, erosion occurs. After each time step (user specified), the model updates flow and channel geometry at each section to account for the effects of erosion and deposition. Flow and geometry also are updated if the change in bed elevation exceeds a user specified value. These steps ensure that flow, geometry, and transport are always synchronized in the model. Finally, the flow value from the next time step is read and a new water-surface elevation is calculated using the updated channel geometries. This procedure is repeated until all time steps specified by the user have been completed. The total number of time steps is based on hydrograph length divided by the time step. Sediment calculations are performed by particle-size class, which allows the model to simulate hydraulic sorting and to control the rate of erosion and deposition of sediment during the simulation period.

An example of model input for a discharge of 47,500 ft^3/s is shown in appendix B (at back of report). Model input consists of two files: network-description file (Xscdatm.txt) and boundary-condition file (bndhyd.txt). Complete explanations of these files are given in Bennett (2001). The model generates six output files, but only a partial listing of one file (SecTSSprSht.txt) is presented in appendix C (at back of report). Output files are explained by Bennett (2001).

Model Cross Sections

Initially, a total of 79 cross sections were used in SEDMOD: 67 field-surveyed, 8 TIN generated, and 4 interpolated. The field-surveyed and TIN-generated cross sections described in “Channel Cross Sections” were used. Before the cross sections could be used in the model, they were reversed to accommodate the right-to-left bank reference system and were converted from feet to meters. Only one data pair—distance and elevation—for each cross section was used to represent the alluvial portion of the cross section (moveable streambed). A representative value for elevation was determined from an average of data in the alluvial portion. SEDMOD automatically determines the average elevation if more than one data pair are entered.

To minimize excessive streambed and sediment-transport changes and maintain computational stability in the model, four in-fill cross sections were generated in the meander reach upstream of Ambush Rock [at RMs 152.510, 152.267, 152.143, and 151.946 (fig. 3)] by interpolating data from the two adjacent surveyed cross sections. In this reach, the d_{50} of the streambed decreased from 9.1 mm (0.36 in.) at cross section 152.392 to 0.26 mm (0.01 in.) at cross section 151.879, a 35-fold decrease in sediment particle size in a distance of less than 0.5 mi. For example, in-fill cross section 152.510 was interpolated from upstream cross section 152.628 and downstream cross section 152.392. Because the in-fill cross section was centered between the upstream and downstream cross sections, interpolation was computed by averaging data from the two cross sections.

The streambed was modified in the Ambush Rock reach to only include the active flow area by interpolating streambed elevation from the alluvial (streambed) data pair at cross sections upstream (152.019) and downstream (151.438) of a deep hole between cross sections 152.019 and 151.438 (fig. 3). The hole is about 50 ft deep at cross section 151.785 and about 40 ft deep at cross section 151.873 (fig. 3) and is about 0.6 mi long, which is less than 5 percent of the study reach length. SEDMOD assumes that area of water from the surface to the streambed will be conveyed downstream. This area usually is known as the active flow area and is used in calculations in SEDMOD. However, not all water in the hole will be actively conveyed downstream because it is ponded and velocities are nearly zero. The ponded water in the hole is not considered part of the active flow area.

The U.S. Highway 95 Bridge and railroad bridge were not incorporated into SEDMOD because model results probably are not affected by the configuration of these bridges. SEDMOD cannot simulate flows through bridges or culverts because the program does not include equations to simulate these features. For the U.S. Highway 95 Bridge (fig. 2), the ratio of bridge-pier area to flow area was less than 5 percent. This indicated that the piers probably do not affect flow through the bridge. The lowest part of the bridge deck also is higher than the 500-year flood (Federal Emergency Management Agency, 1985) indicating free-flowing water though the bridge. These factors also were similar for the railroad bridge (fig. 2) that is located about 0.5 mi downstream of the U.S. Highway 95 Bridge.

Because SEDMOD was written in single precision FORTRAN, elevation and cross-section coordinates (end points) were reduced to decrease round-off errors during computations in the program. In single precision, numbers are stored in 32 bits of 8 significant digits in computers with 32-bit operating system such as Windows 95/NT/2000 etc. Round-off errors occur because a computer stores only a finite value of the number and not the entire value. Round-off errors can become quite large when large and (or) small numbers are used in mathematical operations. For example, the geographic coordinates (cross section endpoints) for the left bank of cross section 13 is x = 329,222.3402 m and y = 846,539.8904 m (from shapefile). Written in single precision, $x = 0.32922234\times10^6$ m and $y = 0.84653989\times10^6$ m. Therefore, by discarding the least significant bits, errors (round-off) will take place in calculations. To reduce round-off errors, 320,000 and 845,000 m were subtracted from x and y cross-section endpoints, respectively. From the previous example, the single precision numbers become $x = 0.92223402\times10^6$ m and $y = 0.15398904\times10^6$ m, and the original significance of the numbers are retained for subsequent calculations. In addition, 400 m were subtracted from all elevation values for the same reason.

The model also requires a roughness coefficient (Manning’s n) at every bank point and one representative value for the streambed (alluvial data pair). Manning’s n represents the flow resistance in the channel. Factors that affect flow resistance include: (1) size, gradation, and angularity of particles comprising the streambed; (2) channel shape; (3) type of bed forms (for example dunes, antidunes, and ripples), and the presence of bars; (4) riparian vegetation; (5) man-made and natural structures (for example, dikes and bridges), (6) presence of suspended sediment and movement of the streambed; and (7) degree of meandering. Usually resistance decreases as flow increases because the streambed exerts less of an effect on flow as depth increases. Resistance also decreases as the size of the bed material decreases. For alluvial channels with coarse materials, streambed particle size and gradation probably are more important than the other factors for determining flow resistance.

Roughness coefficients established from the USGS one-dimensional hydraulic model of the river (Berenbrock, 2005) were used as the starting values for this study. Only values for the streambed portion were later adjusted during “model calibration.” Values for the banks were unchanged from the one-dimensional hydraulic model and were assigned a Manning’s n value of 0.060, which was based on the FEMA model that was developed for the Bonners Ferry Flood Insurance Study.

A longitudinal profile of streambed showing depth of sediments (fig. 6) shows that one model layer would be sufficient for all cross sections in SEDMOD. In the model, bedrock elevation—no erosion below this elevation—was set to a sufficient lower elevation for the gravel-cobble reaches because comparisons of cross sections used in this study and previous surveyed cross sections showed no large amounts of degradation of the streambed. For sandbed reaches, bedrock elevation was set to the elevation where the lacustrine clay-silt deposits were first encountered. This probably is reasonable because the lacustrine deposits are quite hard and resistant to erosion.

Particle-size distributions from the ponar dredge samples (table 1) were used to determine the sediment distribution for cross sections located at and downstream of Ambush Rock (RM 151.8). Data from the mid-channel, center, and (or) thalweg were used in the model because particle-size distribution of samples collected near the center of the channel are more representative of sediment conditions across the cross section than just from the left or right banks. However, at sample locations J and K, right bank samples were used because sediments from the mid-samples, which are along the thalweg, exhibited finer sediments probably resulting from tributary inflows from the side channel. These fine sediments from the side channel probably do not extend very deep into the streambed of the Kootenai River below Shorty Island. If a cross section was co-located at a sample site, the size distribution of sediments from the site was used in the model for that cross section. Otherwise, the particle-size distribution for a cross section was linearly interpolated from two adjacent streambed sites.

A feature in SEDMOD that allows for the use of median diameter (d_{50}) and geometric standard deviation of the size distribution (σ_g) instead of the particle-size distribution was used to input data from the drill cores. The d_{50} and average σ_g (3.0) from the three drill cores were used to represent the distribution for cross sections in the braided reach and the reach upstream of Ambush Rock (RM 151.8).

The size and sediment classifications from vibra cores taken in 2004 (table 4) also were used to enhance the representation of the streambed in the model because no size distributions were available for selected reaches. For cross sections between Ambush Rock (RM 151.8) and the drill-core sites, d_{50} was assigned to the minimum values given in table 4, and σ_g was assigned a value of 3.0. Data from six vibra-core sites located along the side channel (fig. 5) also were used. Sediments at these sites were composed of silt and sand (very fine to medium) (table 4). For these cross sections, d_{50} was assigned a value of 0.125 mm (0.038 in.) (fine sand), and σ_g was automatically assigned a value of 1.2, default value in SEDMOD.

Model Boundaries

At the upstream boundary (cross section 153.781), discharge, total sediment discharge, and the percentage of sediment in each size class were specified in the model. The total sediment discharge equation (Q_T) that was previously developed (see section "Total Sediment Discharge") for the upper model boundary (cross section 153.781) was used to estimate the total sediment discharge coming into the study reach. Results from the equation (Q_T) were converted from tons per day to cubic meters per second.

At the downstream boundary (cross section 139.469), water-surface elevation was specified. This elevation was based on data from the Klockmann Ranch gaging station adjusted to NAVD 88 datum.

Model Calibration

The model was calibrated using measured water-surface elevations and bedload and suspended-sediment transport. Calibration is the process of adjusting model parameters within reasonable limits to obtain the best fit of model results to measured data. The process involves repeatedly adjusting a parameter, running the model, and inspecting the difference between model results and measured data with the objective of minimizing the differences. In this study, calibration consisted of comparing the difference between simulated and measured water-surface elevations and between suspended-sediment transport rates at selected sites.

Calibration consisted of comparing simulated and measured water-surface elevations at the Tribal Hatchery gaging station (12310100) and Bonners Ferry gaging station (12309500) (fig. 3). Nine calibration points in 2002 and 2003 were identified where discharge and water-surface elevation remained steady through the study reach at least for several days. Discharge was based on a daily mean discharge from the Tribal Hatchery gaging station except for the discharge of 47,500 ft^3/s, which was estimated by subtracting discharge at the Boundary Creek gaging station (12321500) from the Porthill gaging station (12322000) for the previous day to account for time of travel. Water-surface elevation was calculated by adding the daily mean stage at the Tribal Hatchery and Bonners Ferry gaging stations to the NAVD 88 datum at the gaging station. Historical stage and discharge data prior to 2002 and especially prior to the construction of Libby Dam in 1974 were not used in the calibration of this model because the current cross-section geometry would not be representative of those conditions. In the model, *n* values were used as a calibration parameter. Model calibration was considered acceptable when the difference between simulated and measured water-surface elevations for each calibration point was within ±0.15 ft.

Results from the calibration of water-surface elevations are shown in table 6. Differences in water-surface elevations were ±0.10 ft or less except for one value. Only Manning's *n* values of the streambed (alluvial portion) were adjusted during this process. Adjustments were made equally to cross sections between each gaging station. The *n* values for the banks were not adjusted and remained at 0.060. The final calibrated *n* values throughout the study reach are given in table 7. The *n* values decreased as discharge increased. These values also are similar to *n* values used in a HEC-RAS model by Berenbrock (2005).

The model also was calibrated against measured bedload and suspended-sediment transport by simulating stage and discharge conditions from July 25, 2001, through January 27, 2004, 917 days or about a 2½-year period. This period encompasses the period when suspended-sediment sampling occurred at Kootenai River near Ball Creek and Kootenai River at U.S. Highway 95 Bridge. River discharge during the period was composed of daily mean discharge from several gaging stations. For the period July 25, 2001, through September 30, 2002, discharge in the model was calculated by subtracting discharge at the Boundary Creek gaging station (12321500) from the Porthill gaging station (12322000). For the period October 1, 2002, through January, 27, 2004, discharge was based on the Tribal Hatchery gaging station (12310100). Water-surface elevations in the model were based on stages from the Klockmann Ranch gaging station (12314000). In the model, the Meyer-Peter bedload coefficient (ϕ_o) sets the fractional amount of bedload transport from the total sediment transport and provides a way to adjust bedload transport. For this study, ϕ_o was used specifically to control the amount of streambed erosion in the gravel-cobble reach. The Meyer-Peter coefficient (ϕ_o) (Meyer-Peter and Mueller, 1948) is a dimensionless parameter and was initially set at the default value (8.0).

During the 2-½ year calibration period, model results showed streambed elevations in the gravel-cobble reach upstream of U.S. Highway 95 Bridge declining 3 ft or more for various values of the Meyer-Peter coefficient (ϕ_o), the only adjustment parameter used during the calibration of bedload. These declines probably were attributed to the model adjusting to equilibrium conditions for suspended-sediment and bedload concentrations, discharge, and water-surface and streambed elevations in a steep reach. However, comparison of cross sections in the gravel-cobble reach (Barton and others, 2004) to cross sections from previous studies (Schaffranek and others, 1981; Federal Emergency Management Agency, 1985; and Patrick McGrane, U.S. Corps of Engineers, written commun., 1995) showed little or no difference in streambed elevation at cross sections in the gravel-cobble reach near Bonners Ferry. By removing cross sections upstream of U.S. Highway 95 Bridge from the model, streambed decreases probably would lessen in the gravel-cobble reach throughout the simulated hydrograph. Thus, cross sections 153.781 through 152.842 were removed from the model, and cross section 152.790 (U.S. Highway 95 Bridge) became the upper model boundary where river discharge and total sediment discharge were specified. This model is referred to as the 'reduced model' in this report. Transferring the total sediment discharge to cross section 152.790 (U.S. Highway 95 Bridge) is quite acceptable because suspended-sediment samples were collected at the U.S. Highway 95 Bridge for the development of a total sediment discharge (Q_T) curve and equation (fig. 11) (see section "Sediment-Transport Characteristics").

Table 6. Differences in measured and simulated water-surface elevations at two gaging stations in the white sturgeon habitat reach of the Kootenai River, Idaho.

[ft^3/s, cubic foot per second; XS, cross section; –, no data]

(1) Model discharge (ft^3/s)	Water-surface elevation, in feet above North American Vertical Datum of 1988						
	Bonners Ferry gaging station (12309500) (XS 152.790)			Tribal Hatchery gaging station (12310100) (XS 149.910)			(8) Klockmann Ranch gaging station (12314000) (XS 139.469)
	(2) Measured	(3) Simulated	(4) = (2) – (3) Difference	(5) Measured	(6) Simulated	(7) = (5) – (6) Difference	
5,000	–	1,748.54	–	1,745.14	1,745.27	-0.13	1,744.44
5,200	1,749.22	1,749.18	0.04	1,748.22	1,748.18	.04	1,747.80
5,540	1,749.03	1,749.00	.03	1,747.45	1,747.45	.00	1,746.93
10,700	1,751.45	1,751.55	-.10	1,750.91	1,750.86	.05	1,750.03
18,900	1,754.80	1,754.85	-.05	1,754.08	1,754.07	.01	1,752.52
20,900	1,756.88	1,756.85	.03	1,756.31	1,756.30	.01	1,755.09
21,200	1,756.21	1,756.14	.07	1,755.54	1,755.48	.06	1,754.05
30,200	1,760.94	1,760.90	.04	1,760.35	1,760.37	-.02	1,758.92
47,500	1,765.66	1,765.66	.00	–	1,765.06	–	1,763.40

Table 7. Manning's *n* values (roughness coefficients) used in the model for three reaches, Kootenai River near Bonners Ferry, Idaho.

[ft^3/s, cubic foot per second]

Discharge (ft^3/s)	Roughness coefficients (*n* values) for reach between streamflow-gaging station		
	Klockmann Ranch to Tribal Hatchery	Tribal Hatchery to Bonners Ferry	Upstream of Bonners Ferry
5,000	0.038	0.038	0.038
5,200	.038	.038	.038
5,540	.038	.038	.038
10,700	.035	.030	.035
18,900	.0345	.030	.033
20,900	.033	.030	.033
21,200	.033	.030	.033
30,200	.032	.030	.032
47,500	.028	.028	.030

Calibration was then continued using the reduced model by changing the Meyer-Peter coefficient (ϕ_o) while holding all other input parameters constant. Results from these simulations indicated that a Meyer-Peter coefficient (ϕ_o) of 8.0 caused little or no erosion of the streambed in the gravel-cobble reach. Larger values of ϕ_o increased streambed erosion at cross sections in the gravel-cobble reach, and smaller values halted streambed interaction throughout the model.

The reduced model also was calibrated against the suspended-sediment transport using the 2-½ year calibration period. The McLean's coefficient (γ_o) (Bennett, 2001) was used as a calibration parameter for suspended-sediment transport rates. This coefficient sets the concentration at the base of the suspended transport layer and provides a way to calibrate or adjust suspended-sediment discharges to match measured. McLean's coefficient is a dimensionless parameter and was initially set at the default value (0.0040). All other input parameters were held constant, and the Meyer-Peter coefficient was held at its calibration value (8.0).

McLean's coefficient was adjusted manually for each model run within a range of 10 times to 1/10 times the default value (0.0040), and the root-mean-squared error (*RMSE*) was used as an objective function for measuring the goodness of fit between simulated and measured suspended-sediment transport rates. *RMSE* was calculated for each run using the simulated and measured suspended-sediment discharges from six samples collected in 2002 at Kootenai River near Ball Creek (near cross section 140.402). Results from the calibration of McLean's coefficient (γ_o) are shown in figure 12. McLean's coefficient was varied from 0.040 to 0.0004, and the minimum value of *RMSE* (57.9) was

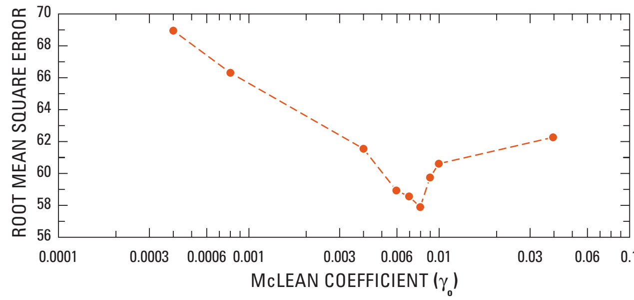

Figure 12. McLean coefficient (γ_o) and root-mean-square error (*RMSE*) between simulated and measured suspended-sediment discharges.

achieved by using a McLean coefficient of 0.0080. This value is higher than the default values (Bennett, 2001) for the following reasons: (1) large flow depths, (2) large discharges, (3) fine streambed sediments [d_{50}<0.30 mm (0.012 in.)], and (4) backwater conditions. Overall, model results show agreement between simulated and measured values of total suspended-sediment discharge (fig. 13) at Kootenai River near Ball Creek (near cross section 140.402) and at Kootenai River at U.S. Highway 95 Bridge (cross section 152.790) except for high spring-time (April and May) flows. The incoming total sediment discharge (Q_T) applied to the upper model boundary at U.S. Highway 95 Bridge represents average Q_T conditions that occur throughout the year. For example, high spring-time flows as in April and May 2002, Q_T at U.S. Highway 95 Bridge will be underestimated as shown in figure 13*B*. Therefore, the reduced model is considered to be calibrated, and hence, is referred as the "calibrated model" in this report. The calibrated values of ϕ_o and γ_o are 8.0 and 0.0080, respectively.

Sensitivity of the Model

The sensitivity of SEDMOD to variations in Manning's *n* and to variation in other parameters was evaluated. The procedure involves holding all input parameters constant except the one being analyzed, varying that value and observing the results. Changes in simulated water-surface elevations and sediment transport were used to determine the sensitivity of the model. Exact values of change from the sensitivity analysis should be viewed cautiously, but relative changes can provide insight as to how a particular input parameter may affect the results of the model. For all sensitivity simulations, cross-section geometry was not changed from the calibrated model. These sensitivity analyses were conducted for a discharge of 47,500 ft^3/s. The calibrated model was used for these analyses.

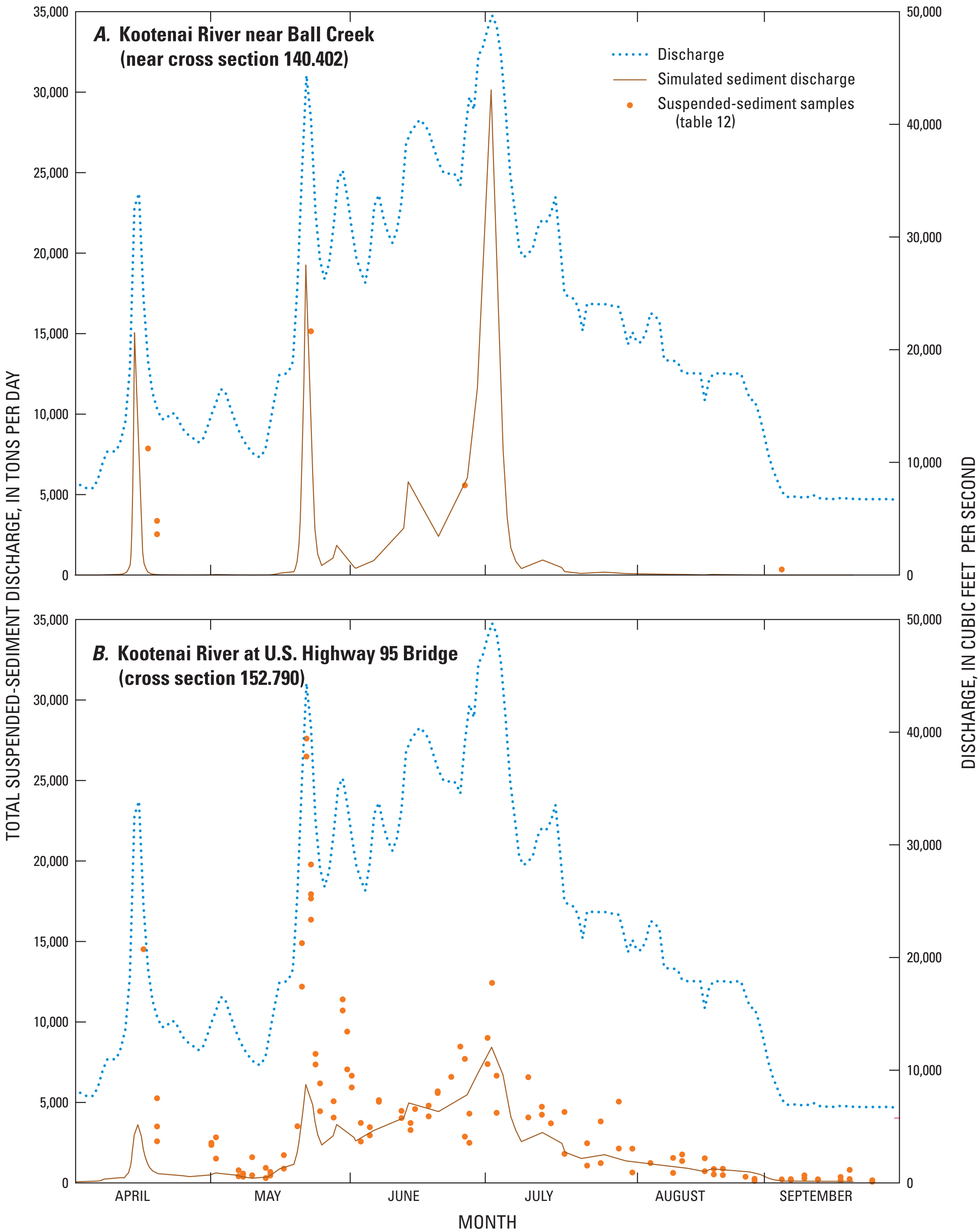

Figure 13. Discharge for the period April 1 through September 30, 2002 and simulated suspended-sediment discharge using a McLean coefficient of 0.0080 and Meyer-Peter coefficient of 8.0, Kootenai River, Idaho.

Manning's *n*

To determine the sensitivity of the model to variations in Manning's *n* of the main channel, a series of simulations at a discharge of 47,500 ft^3/s were made in which the *n* value varied by ±10 percent of the initial calibrated values. This discharge was selected because higher discharges probably would have greater effects on erosion and deposition. For the 10-percent reduction simulation, *n* values for the reach between the Klockmann Ranch and Tribal Hatchery gaging stations were reduced from 0.027 to about 0.024, and values in the reach between the Tribal Hatchery and Bonners Ferry gaging stations were reduced from 0.030 to 0.027. For the 10-percent increase simulation, *n* values were increased to about 0.030 for the reach between the Klockmann Ranch and Tribal Hatchery gaging stations and increased to 0.033 for the reach between the Tribal Hatchery and Bonners Ferry gaging stations. The boundary conditions at the upstream and downstream cross sections were not changed.

Results of the sensitivity simulations to changes in *n* values of the streambed (table 8) indicated that the water-surface elevation is sensitive to the *n* values. Varying *n* values by ±10 percent of the calibrated values resulted in water-surface elevation changes from near 0 to about 0.4 ft. The average difference for the entire modeled area (about 0.2 ft) and average differences for selected reaches are shown in table 8. The greatest differences occurred at cross sections near Bonners Ferry. The upstream most cross section (152.790) had the greatest difference of 0.42 ft for the 10-percent reduction simulation and 0.44 ft for the 10-percent increase simulation. Differences in the meander reach were much smaller, and the differences were smallest (<0.04 ft) in the reach below Shorty Island (table 8). The differences in the gravel-cobble reaches are large and indicate that the model is sensitive to changes in *n* values. Changes in Manning's *n* of the streambed had no effect on suspended-sediment and total sediment discharge, or sediment transport.

Evaluation of the sensitivity of the model to variations in Manning's *n* of the bank indicated that the water-surface elevation is not sensitive to bank *n* values. In these simulations, a discharge of 47,500 ft^3/s was used because greater discharges would inundate and therefore affect more of the bank. Manning's *n* of the bank was varied by ±10 percent of the calibrated values. Results of the sensitivity simulations to changes in *n* values of the bank were less than 0.01 ft . Because bank *n* values may have greater uncertainty than ±10 percent, Manning's *n* of the bank was varied by 0.5 times (-50 percent) and 1.5 times (+150 percent) the calibrated values. Results of these sensitivity simulations (table 9) showed changes less than 0.07 ft. The greatest differences occurred at cross sections near Bonners Ferry. Average difference for cross sections within the modeled area were –0.03 and 0.01 ft for the 0.1 times and 10 times simulations, respectively. The differences are quite small and indicated that the model is not sensitive to changes in *n* values of the banks. Changes in Manning's *n* of the bank had no affect on suspended-sediment and total sediment discharge, or sediment transport.

Table 8. Sensitivity of simulated water-surface elevation to changes in Manning's *n* (roughness coefficient) of the streambed for a discharge of 47,700 cubic feet per second, Kootenai River near Bonners Ferry, Idaho.

[ft^3/s, cubic foot per second. Positive value is an increase in the simulated water-surface elevation as compared with the calibrated model; negative value is a decrease, as compared with the calibrated model]

Reaches	Average difference in water-surface elevation, in feet, when Manning's *n* is changed by:	
	-10 Percent	+10 Percent
Upstream of Shorty Island	-0.26	0.28
Main channel at Shorty Island	-.09	.09
Side channel	-.09	.10
Downstream of Shorty Island	-.04	.04
U.S. Highway 95 Bridge to Tribal Hatchery	-.33	.35
Tribal Hatchery to Klockmann Ranch	-.13	.14
Entire modeled reach (*n*=71)	-.19	.21

Table 9. Sensitivity of simulated water-surface elevation to changes in Manning's *n* (roughness coefficient) of the banks for a discharge of 47,700 cubic feet per second, Kootenai River near Bonners Ferry, Idaho.

[ft^3/s, cubic foot per second. Positive value is an increase in the simulated water-surface elevation, as compared with the calibrated model; negative value is a decrease, as compared with the calibrated model]

Reaches	Average difference in water-surface elevation, in feet, when Manning's *n* is changed by:	
	-50 percent	+150 percent
Upstream of Shorty Island	-0.04	0.01
Main channel at Shorty Island	-.01	.00
Side channel	-.02	.00
Downstream of Shorty Island	.00	.00
U.S. Highway 95 bridge to Tribal Hatchery	-.05	.02
Tribal Hatchery to Klockmann Ranch	-.02	.01
Entire modeled reach (*n*=71)	-.03	.01

McLean's Coefficient

To determine the sensitivity of the model to variations in suspended-sediment discharge, a series of simulations at a river discharge of 47,500 ft^3/s were made in which McLean's coefficient (γ_o) was varied by 0.1 ($\gamma_{0.1}$) and 10 (γ_{10}) times the calibrated value (γ_c) of 0.080. This river discharge was selected because greater discharges probably would have greater effects on suspended sediment. Cross-section geometry and bed composition at the end of the hydrograph period (July 25, 2001–January 27, 2004) were used in these simulations because the model had sufficient amount of time to achieve equilibrium between the bed composition and suspended transport (Bennett, 2001, p. 7). Boundary conditions at the upstream cross section (152.790) and downstream cross section (139.469) were not changed. The Meyer-Peter coefficient (ϕ_o) was held constant at its calibrated value of 8.0.

Results of the sensitivity simulations (fig. 14) to changes in γ_o values after 14 days indicated that the suspended-sediment discharge is sensitive to the γ_o values. Varying γ_o values by 0.1 and 10 times the calibrated value resulted in suspended-sediment discharge changes from about 10 to more than 800 percent of the calibrated simulation. The γ_{10} simulation had the greatest differences from the γ_c simulation in suspended-sediment discharge. Differences of about 5 times greater than the γ_c simulation occurred in the reach downstream of Shorty Island, which probably is caused by large amounts of fine streambed sediments being transported from the side channel. Large differences also occurred in the sandbed reach between Ambush Rock and Tribal Hatchery gaging station. The gravel-cobble reach (U.S. Highway 95 Bridge to about Ambush Rock) showed relatively small changes probably because of the large particle sizes (gravels and cobbles) on the streambed. Suspended-sediment discharge in the $\gamma_{0.1}$ simulation resulted in a gently sloping curve in the modeled reach (fig. 14), whereas, the γ_{10} simulation had in several large and local responses in the suspended-sediment discharge (fig. 14). These results suggest that suspended-sediment discharge is sensitive to changes in McLean's coefficient. Changes in γ_o had no effects on water-surface elevations.

Results of sensitivity simulations to changes in γ_o values on streambed elevations after 14 days ranged from moderately to little sensitivity (fig. 15). The largest differences (about 0.8 ft) in streambed elevations occurred in the reach from Ambush Rock to the Tribal Hatchery gaging station for the γ_{10} simulation, whereas, differences were less than 0.45 ft for the $\gamma_{0.1}$ simulation. Large changes also occurred in the γ_{10} simulation upstream and downstream of Shorty Island (fig. 15). However, average streambed differences throughout the modeled reach were 0.04 and 0.15 ft for the $\gamma_{0.1}$ and γ_{10} simulations, respectively. These simulations indicate that the elevation of the streambed generally is insensitive to changes in γ_o.

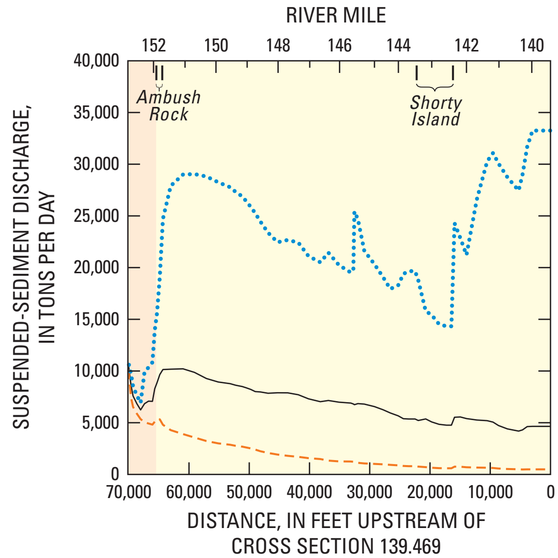

Figure 14. Sensitivity of simulated suspended-sediment discharge to changes in McLean's coefficient (γ_o) for a river discharge of 47,500 cubic feet per second, Kootenai River near Bonners Ferry, Idaho.

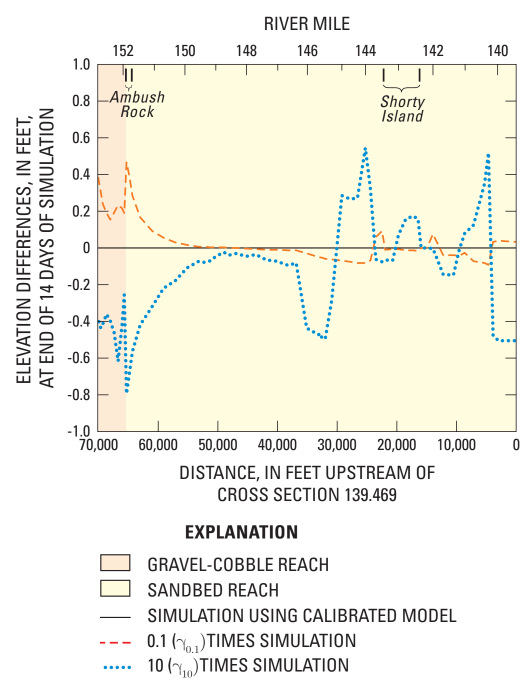

Figure 15. Sensitivity of streambed elevation at the end of 14 days of simulation to changes in McLean's coefficient (γ_o) for a discharge of 47,500 cubic feet per second, Kootenai River near Bonners Ferry, Idaho.

Total Sediment Discharge Input

To determine the sensitivity of the model to variations in the input of total sediment discharge at the upstream boundary, a series of simulations at a discharge of 47,500 ft^3/s were made in which the total sediment discharge was varied by 0.1 ($Q_{T\text{-}0.1}$) and 10 ($Q_{T\text{-}10}$) times the calibrated value (Q_{T-C}). Total sediment discharge (Q_T) is the amount of sediment from both suspended and bedload coming into the model at the upstream boundary (cross section 152.790, U.S. Highway 95 Bridge). The calibrated value was determined by the total sediment discharge curve (Q_T) in figure 11 (see section "Total Sediment Discharge"). A discharge of 47,500 ft^3/s was used because higher river discharges probably would have greater effects on the total sediment discharge than at lower river discharges. Other boundary conditions at the upstream and downstream cross sections were not changed. Cross-section geometry and bed composition at the end of the hydrograph period also were used.

Results of the sensitivity simulations indicated that total suspended sediment discharge generally was sensitive to variations in the incoming total sediment discharge at upstream reaches and generally insensitive in downstream reaches (fig. 16). The gravel-cobble reach (U.S. Highway 95 Bridge to about Ambush Rock) had the largest differences in $Q_{T\text{-}0.1}$ and $Q_{T\text{-}10}$ simulations. For the simulation using $Q_{T\text{-}10}$, total sediment discharge was at least two times greater than the calibrated simulation (Q_{T-C}) in the modeled reach and average five times greater than Q_{T-C} in the gravel-cobble reach. For the $Q_{T\text{-}0.1}$ simulation, sediment discharges were about equivalent to sediment discharges in Q_{T-C} except in the gravel-cobble reach. Changes in total sediment discharge also had no effects on water-surface elevations.

Results of the sensitivity simulation on streambed elevation at the end of 14 days to the incoming total sediment discharge generally were insensitive except at upstream reaches (fig. 17). Differences were largest for the gravel-cobble reach especially for the $Q_{T\text{-}10}$ simulation where the upstream most cross sections (152.790) increased to about 8 ft. For the $Q_{T\text{-}10}$ simulation, the average increase in the streambed elevation in the gravel-cobble and sandbed reaches was 3 and 0.3 ft, respectively. For the $Q_{T\text{-}0.1}$ simulation, the average decline in the streambed elevation in the gravel-cobble and sandbed reaches was 0.3 and 0.04 ft, respectively. These results indicate that total sediment discharge in the sandbed reach does not effect streambed elevation.

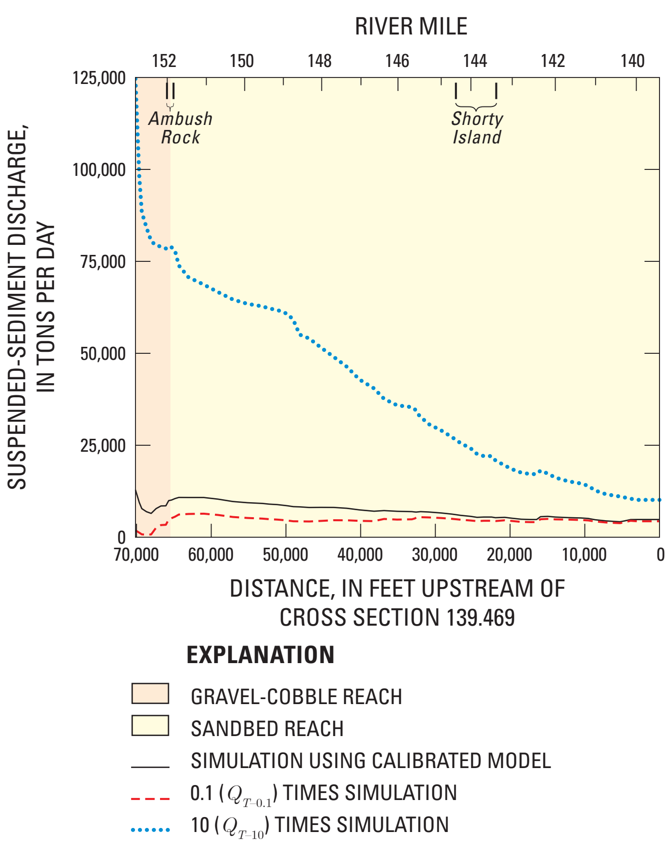

Figure 16. Sensitivity of simulated total suspended-sediment discharge to changes in total sediment discharge input at the upstream boundary for a river discharge of 47,500 cubic feet per second, Kootenai River near Bonners Ferry, Idaho.

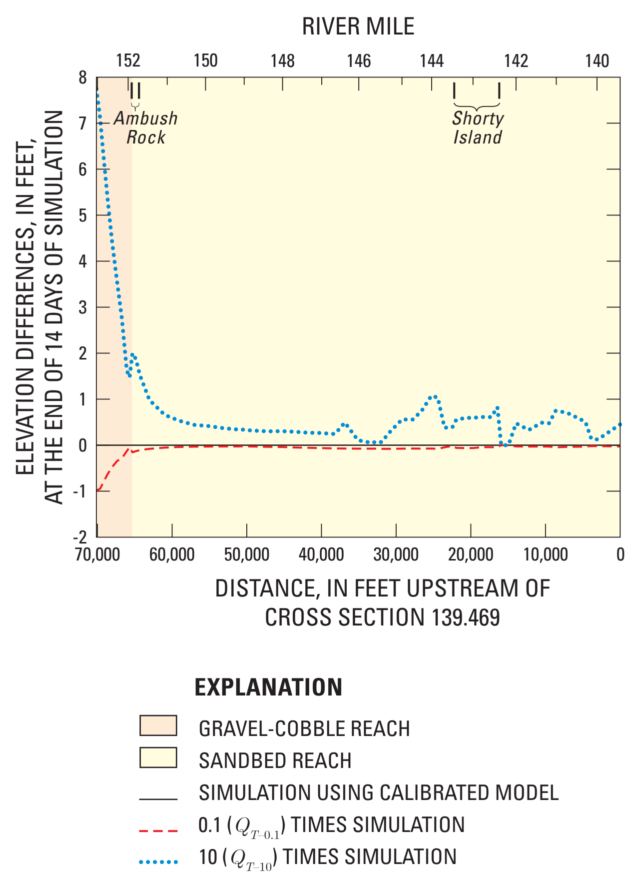

Figure 17. Sensitivity of streambed elevation at the end of 14 days of simulation to changes in total sediment discharge input at the upstream boundary for a river discharge of 47,500 cubic feet per second, Kootenai River near Bonners Ferry, Idaho.

Simulation of Erosion and Deposition Under Varying Hydraulic Conditions

Having been verified as capable of simulating water-surface elevations and suspended-sediment concentrations, the calibrated model can be used to simulate changes in water-surface elevations, sediment transport, streambed elevation (erosion and deposition) resulting from management alternatives such as changing river discharge and stage. Determining the amount of sediment transport, aggradation, and (or) degradation in the model reach is important for substrate quality for white sturgeon spawning. Reaches where the white sturgeons have spawned in the sanded reach such as the reach adjacent to Shortly Island are of particular importance. The gravel-cobble reach also is important because keeping the gravel-cobble reach free from sands and silts would improve the substrate quality for white sturgeon spawning.

For this study, a total of six management alternatives were simulated using four discharges and six representative water-surface elevations. The four discharges are 6,000, 20,000, 40,000, and 60,000 ft^3/s and were used to represent low to high discharges in the river since the construction of Libby Dam. The maximum flow from Libby Dam is about 25,000 ft^3/s. The last flow exceeding 60,000 ft^3/s occurred on June 26, 1971 prior to the completion of the dam. All simulations were run for 21 days (3 weeks). In the model, discharges were increased over 3 days and held constant for 18 days except for alternative 1. Cross-section geometry and bed composition at the end of the hydrograph period (see section "Model Calibration") were used because the model had sufficient time to achieve equilibrium between the bed composition and suspended-sediment transport (Bennett, 2001, p. 7). The McLean and Meyer-Peter coefficients were not changed from the calibrated values.

The management alternatives were based on current and historic stage data for the downstream boundary (cross section 139.469) at Klockmann Ranch gaging station (12314000). Because no stage-discharge relation exists in the Kootenai River below Bonners Ferry (backwater conditions), water-surface elevations at Klockmann Ranch were determined by regressing measured elevations near the objective discharges to find the average elevation at Klockmann Ranch for the indicated discharge. From 10 to 33 measured water-surface elevations around each objective discharge were selected and were regressed to find the average elevation for the indicated discharge. Measured water-surface elevations for the objective discharges equal to and less than 20,000 ft^3/s were from 2002 to 2003. Water-surface elevation data for the objective discharge of 40,000 and 60,000 ft^3/s were from pre-Libby Dam period when discharges were much higher. The average water-surface elevation for discharges of 6,000, 20,000, 40,000, and 60,000 ft^3/s were 1,748.41, 1,753.81, 1,761.34, and 1,766.72 ft, respectively.

The model had low sediment-volume errors for each of the management alternatives; low errors do not indicate the adequacy of a solution, but it does indicate the relative accuracy of a solution. SEDMOD computes the volume error for the pertinent time step (reported time stated in the output file "Sumry.txt") by taking the difference between the net input of sediment for the entire simulation period up to the reporting time and the net sediment volume accumulated in all channels in the model up to that time step. The net input of sediment for the reported period is the sum of the incoming sediment volumes since the beginning of the simulation and up until that time for all channels that enter the model, minus the sum of all sediment volumes leaving the model during the period. Ideally, net input equals all sediment volume accumulated in all channels up to the reported period. The volume error, then, is the difference between the net input volume and the computed sediment accumulation for the model (table 10). The volume error is a measure of the accuracy of the model's mass conservation.

Management Alternative 1: Discharge of 6,000 ft^3/s

For management alternative 1, a river discharge of 6,000 ft^3/s and a water-surface elevation of 1,748.41 ft were used in the simulation. The incoming total sediment discharge was determined from the total sediment discharge curve (fig. 11) for a discharge of 6,000 ft^3/s. Model results for alternative 1 showed very little erosion or deposition of the streambed at the end of 21 days of simulation (fig. 18 and table 10).

Table 10. Net deposition or erosion and mass-balance errors for six management alternatives at the end of 21 days of simulation, Kootenai River near Bonners Ferry, Idaho.

[yd^3, cubic yard]

Management alternatives	Net deposition (+) or erosion (-) (yd^3)	Total volume of mass-balance errors (yd^3)	Total percentage of mass-balance error
1	+1,400	1.5	0.10
2	+16,700	-.5	.00
3	+66,000	-7.5	-.01
4	+101,000	-11.2	-.01
5	-230,000	7.9	.04
6	-594,000	52.5	.03

Erosion was the dominant feature in the upper gravel-cobble reach where as much as 0.25 ft of erosion occurred at U.S. Highway 95 Bridge. Average streambed decreases in the gravel-cobble reach was 0.12 ft. The d_{50} of streambed sediments at cross section 152.392 (near Bonners Ferry) increased by 1 mm (0.04 in.) at the end of 21 days of simulation because finer sediments were eroded. However, deposition occurred in the lower part of the gravel-cobble reach where the streambed increases as much as 0.60 ft.

Deposition was the dominant feature in the sandbed reach downstream of Ambush Rock, but the streambed increase was less than 0.01 ft. The d_{50} of streambed sediments in this reach showed no changes throughout the 21 days of simulation.

Changes in the streambed and d_{50} of streambed sediments in the Shorty Island side channel also were negligible for this alternative. Simulated discharge in the side channel was about 110 ft^3/s.

Overall, the modeled reach was depositional for alternative 1. The total volume of sediment deposition at the end of 21 days of simulation was +1,400 yd^3 (table 10), which resulted in an overall streambed increase of 0.013 in. throughout the modeled reach.

Management Alternative 2: Discharge of 20,000 ft^3/s

For management alternative 2, a river discharge of 20,000 ft^3/s and a water-surface elevation of 1,753.81 ft were used in the simulation. The incoming total sediment discharge was determined from the total sediment discharge curve (fig. 11) for a discharge of 20,000 ft^3/s. Model results for alternative 2 were similar to results from alternative 1 except in the gravel-cobble reach (fig. 18) where the streambed increased upstream of cross section 152.392 and decreased near Ambush Rock. The streambed showed minor amounts of erosion or deposition at the end of 21 days of simulation in the modeled reach.

Deposition was the dominant feature in the gravel-cobble reach. The streambed increased about 0.35 ft and decreased about 0.25 ft. The d_{50} of streambed sediments at cross section 152.392 decreased by 0.5 mm (0.02 in.) at the end of 21 days of simulation because finer sediments are being deposited.

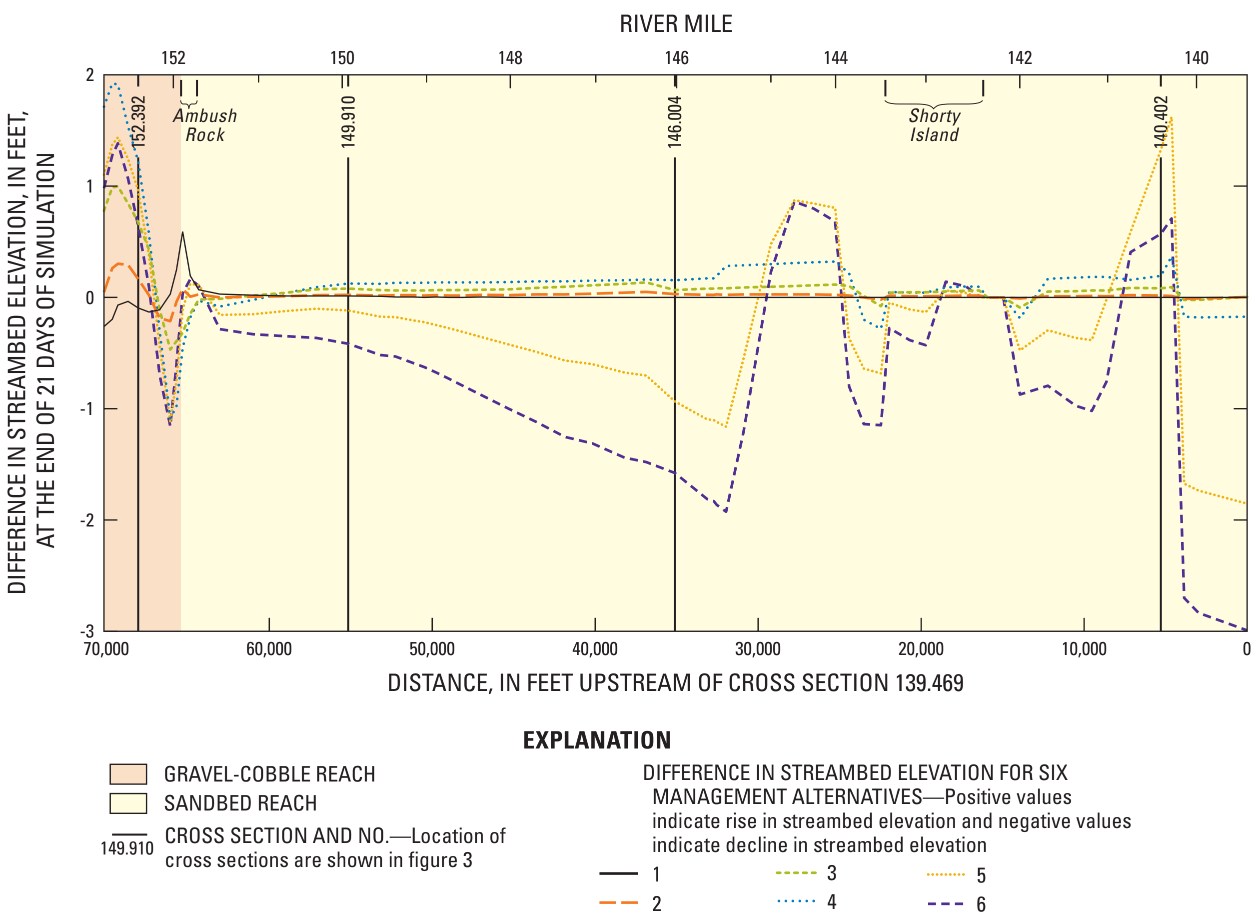

Figure 18. Difference in streambed elevation for six management alternatives at the end of 21 days of simulation, Kootenai River near Bonners Ferry, Idaho.

Deposition was the dominant feature in the sandbed reach downstream of Ambush Rock, but the streambed showed little or no changes (less than 0.016 ft). The streambed generally increased about 0.02 ft higher than the streambed in alternative 1. The d_{50} of streambed sediments in this reach showed no changes throughout the 21 days of simulation.

Changes in the streambed and d_{50} of streambed sediments in the Shorty Island side channel also were negligible for alternative 2. Simulated discharge in the side channel was about 1,530 ft^3/s.

Overall, the modeled reach was depositional for alternative 2. The total volume of sediment deposition at the end of 21 days of simulation was +16,700 yd^3 (table 10), which resulted in an overall streambed increase of about 0.15 in. throughout the modeled reach.

Management Alternative 3: Discharge of 40,000 ft^3/s

For alternative 3, a river discharge of 40,000 ft^3/s and a water-surface elevation of 1,761.34 ft were used in the simulation. The incoming total sediment discharge was determined from the total sediment discharge curve (fig. 11) for a discharge of 40,000 ft^3/s. Model results for alternative 3 were similar to alternative 2 where streambed increased and decreased at nearly the same locations (fig. 18). However, streambed increases and decreases were greater in alternative 3 than in alternative 2.

Deposition was the dominant feature in the gravel-cobble reach where the streambed increased about 1 ft at cross section 152.628 (about 0.2 mi downstream of U.S. Highway 95 Bridge) and decreased about 0.5 ft at cross section 152.019 (about 0.8 mi downstream of U.S. Highway 95 Bridge). Average streambed decrease was 0.42 ft throughout the gravel-cobble reach. The d_{50} of streambed sediments at cross section 152.392 decreased by 2.2 mm (0.086 in.) at the end of 21 days of simulation because finer sediments are being deposited.

Deposition is the dominant feature in the sandbed reach, but downstream of Ambush Rock, changes in streambed were less than 0.1 ft. The d_{50} of streambed sediments in this reach showed no changes throughout the 21 days of simulation.

The streambed at several cross sections in the Shorty Island side channel decreased about 0.2 ft, but average decrease in the side channel was less than 0.1 ft. Simulated discharge in the side channel was about 5,210 ft^3/s.

Overall, the modeled reach was depositional for alternative 3. The total volume of sediment deposition at the end of 21 days was about +66,000 yd^3 (table 10), which resulted in an overall streambed increase of 0.60 in. throughout the modeled reach.

Management Alternative 4: Discharge of 60,000 ft^3/s

For alternative 4, a river discharge of 60,000 ft^3/s and water-surface elevation of 1,766.72 ft were used in the simulation. The incoming total sediment discharge was determined from the total sediment discharge curve (fig. 11) for a discharge of 60,000 ft^3/s. Model results for this alternative also were similar to the alternatives 2 and 3 where streambed increased and decreased at nearly the same locations (fig. 18). However, increases and decreases were greater in alternative 4 than in alternatives 2 and 3.

Deposition was the dominant feature in the gravel-cobble reach where the streambed increased about 2 ft near U.S. Highway 95 Bridge and decreased 1.1 ft near Ambush Rock, and average decrease was 0.60 ft. The d_{50} of streambed sediments at cross sections 152.392 decreased by 1.3 mm (0.05 in.) at the end of 21 days of simulation because of finer sediments being deposited.

Deposition was the dominant feature in the sandbed reach, but downstream of Ambush Rock, changes in the streambed were less than 0.33 ft (fig. 18). The d_{50} of streambed sediments in this reached showed no changes throughout the 21 days of simulation.

The streambed in the Shorty Island side channel decreased as much as 0.4 ft and averaged 0.25 ft. Simulated discharge in the side channel was about 9,850 ft^3/s.

Overall, the modeled reach was depositional for alternative 4. The total volume of sediment eroded at the end of 21 days of simulation was +101,000 yd^3 (table 10), which resulted in an overall streambed increase of 0.93 in. throughout the modeled reach.

Management Alternative 5: Discharge of 60,000 ft^3/s and Water-Level Slope of 2.5 Times Management Alternative 4 Slope

The shear stress (τ_0) exerted on a channel boundary or streambed by flowing water is the driving force for sediment transport. The average boundary shear stress may be expressed as the product of fluid density of water (ρ_w), gravitational acceleration (g), hydraulic radius (R), and water-surface slope (S): $\tau_0 = \rho_w\, g\, R\, S$. For wide channels such as the Kootenai River in the study reach, flow depth (D) nearly equals R, and thus, replaces R in the equation. The resulting boundary shear stress is $\tau_0 = \rho_w\, g\, D\, S$. Boundary shear stress is dependent on the flow depth and slope which in turn is influenced by river discharge.

In alluvial rivers, deposition and erosion generally follows shear stress. Erosion generally occurs where shear stress is increasing and deposition generally occurs where shear stress is decreasing. However, whether the streambed will erode or deposit also depends on the amount or concentration of particles in suspension in the reach.

Simulated flow depths and slopes from management alternatives 1 through 4 generally produced depositional conditions throughout the study reach (fig. 18 and table 10). The primary reason for this is lower boundary shear stresses caused by backwater conditions. Between alternatives 1 and 4, river discharge increased 10 times while average flow depth increased 2.3 times and water-surface slope increased 1.5 times (table 11). The increase in flow depth accounts for most of the increase in the boundary shear stress. Slope probably was the limiting factor in these alternatives because backwater conditions in the reach caused water-surface elevations to be nearly horizontal or flat throughout the reach. Boundary shear stress for each management alternative was calculated and also is shown in table 11. The boundary shear stress increased about 4 times between alternatives 1 and 4 (table 11). In alternative 4 (a river discharge of 60,000 ft^3/s), a boundary shear stress of 4 N/m^2 (table 11) was still not large enough to cause erosion throughout most of the model reach especially in the sandbed reach.

Because increasing river discharge alone did not produce shear stresses that can erode and transport streambed sediments (table 11), the water-surface slope was increased. One practical method for increasing the slope is to lower the water level in Kootenay Lake. Therefore, two additional management alternatives (5 and 6) were simulated to demonstrate the effects of a steeper slope in the study reach.

For alternative 5, a river discharge of 60,000 ft^3/s and a hypothetical water-surface elevation at Klockmann Ranch gaging station of 1,756.72 ft were used in the simulation. This water-surface elevation was set to 10 ft below that of alternative 4 and is about 8 ft below the lowest measured water-surface elevation at the Klockmann Ranch gaging station for a discharge of 60,000 ft^3/s. The combination of simulated hydraulic conditions for this alternative has not been observed during 1965-2003, but this does not indicate that these conditions are impossible. This water-surface elevation represents a water level in Kootenay Lake at Queens Bay of 1,751.90 ft, which was determined from a regression equation between Klockmann Ranch and Queens Bay gaging stations (Berenbrock, 2005, fig. 7*B*). The incoming total sediment discharge was the same as in alternative 4. Model results for alternative 5 were quite different from alternatives 1 through 4 except in the gravel-cobble reach (fig. 18). The water-surface slope for alternative 5 was about 2.5 times greater than the slope in alternative 4 (table 11). Boundary shear stress for alternative 5 also was about 2 times greater than the stress in alternative 4 (table 11).

Deposition was the dominant feature in the gravel-cobble reach where the streambed increased about 1.4 ft near U.S. Highway 95 Bridge and decreased about 0.8 ft near Ambush Rock, and averaged about 0.5 ft. The d_{50} of streambed sediments at cross section 152.392 decreased by 1.1 mm (0.043 in.) at the end of 21 days of simulation because finer sediments were deposited.

Table 11. Simulated river discharges, slopes and calculated boundary shear stress for six management alternatives at the end of 21 days, Kootenai River near Bonners Ferry, Idaho.

[**Abbreviations:** ft^3/s, cubic feet per second; ft, feet; ft/ft, foot per foot; N/m^2, Newton per squared meter; ρ, density of water = 1,000 kilograms per cubic meter; g, gravitational acceleration = 9.81 meters per squared second]

(1) Management alternative	(2) River discharge (ft^3/s)	(3) Average flow depth (ft)	(4) Water-surface slope (ft/ft)	(5) = ρg(3)(4) Boundary shear stress (N/m^2)
1	6,000	14.6	2.587×10^{-5}	1.1
2	20,000	20.6	3.181×10^{-5}	2.0
3	40,000	28.1	3.223×10^{-5}	2.7
4	60,000	33.7	3.948×10^{-5}	4.0
5	60,000	25.9	9.407×10^{-5}	7.3
6	60,000	23.0	13.99×10^{-5}	9.6

Erosion was the dominant feature in the sandbed reach where a maximum streambed change of about 2 ft occurred downstream of Ambush Rock (fig. 18). The streambed decreased from 0 to 1 ft from RM 151.7 to RM 145.7. Streambed decreases were 0.12 and 0.94 ft at cross sections 149.910 (Tribal Hatchery) and 146.004, respectively. The d_{50} of streambed sediments at these cross sections changed very little because the distribution of sediments in the reach were similar. Reaches from RM 145.5 to RM 144.0 and from RM 141.2 to RM 140.3 became depositional and the streambed increased 0.9 and 1.9 ft, respectively, at the end of 21 days of simulation. At cross section 140.402, the streambed increased 1.3 ft, and the d_{50} of streambed sediments decreased slightly from 0.20 to 0.18 mm (0.0079 to 0.0071 in.). The reach from RM 144.0 to RM 141.2 was characteristic of both erosion and deposition. The reach from RM 140.3 to RM 139.5 (Klockmann Ranch), about 2 ft of erosion occurred, and the d_{50} of streambed sediments at cross sections in this reach slightly increased. At cross section 139.469, for example, the d_{50} increased from 0.20 to 0.24 mm (0.0079 to 0.0094 in.). The streambed in the Shorty Island side channel decreased as much as 2.3 ft and averaged 1.5 ft.

Overall, the modeled reach was erosional for alternative 5. The total volume of sediment eroded at the end of 21 days of simulation was –230,000 yd^3 (table 10), which resulted in an overall streambed decrease of 2.1 in. throughout the modeled reach.

Management Alternative 6: Discharge of 60,000 ft^3/s and Water-Level Slope of 3.5 Times Management Alternative 4 Slope

For alternative 6, a river discharge of 60,000 ft^3/s and a water-surface elevation of 1,751.72 ft were used in the simulation. This water-surface elevation was set to 15 ft below that of alternative 4 (5 ft below alternative 5) and is about 13 ft below the lowest measured water-surface elevation at the Klockmann Ranch gaging station for a discharge of 60,000 ft^3/s (fig. 19). The combination of simulated hydraulic conditions for this alternative has not been observed during 1965-2003 (fig. 18), but this does not indicate that these conditions are impossible. This water-surface elevation represents a water level in Kootenay Lake at Queens Bay of 1,748.10 ft. The incoming total sediment discharge was the same as in alternatives 4 and 5. Model results for alternative 6 were similar to alternative 5 where streambed increased and decreased at nearly the same locations (fig. 18). However, increases and decreases usually were greater than those in alternative 6. The water-surface slope for alternative 6 was more than 3.5 times greater than the slope in alternative 4 and 1.5 times greater than the slope in alternative 5 (table 11). Boundary shear stress for alternative 6 also was about 2.5 times greater than the stress in alternate 4 (table 11).

Deposition was the dominant feature in the gravel cobble reach where the streambed increased about 1.4 ft near U.S. Highway 95 Bridge and decreased about 0.7 ft near Ambush Rock, and averaged about 0.3 ft.

Erosion was the dominant feature in the sandbed reach downstream of Ambush Rock where streambed changes of 3 ft occurred (fig. 18). In the reach from RM 151.7 to RM 145.7, the streambed decreased from 0 to about 2 ft. At cross sections 149.910 (Tribal Hatchery) and 146.004, streambed decreases were 0.42 and 1.6 ft, respectively. The d_{50} of streambed sediments at these cross sections changed very little because the distribution of sediments in the reach were similar. In the reach from RM 140.3 to RM 139.5 (Klockmann Ranch), 3 ft of erosion occurred. The streambed in the Shorty Island side channel decreased as much as 1.8 ft and averaged 1.0 ft.

Overall, the modeled reach was erosional for alternative 6. The total volume of sediment eroded at the end of 21 days of simulation was –594,000 yd^3 (table 10), which resulted in an overall streambed decrease of 5.5 in. throughout the modeled reach.

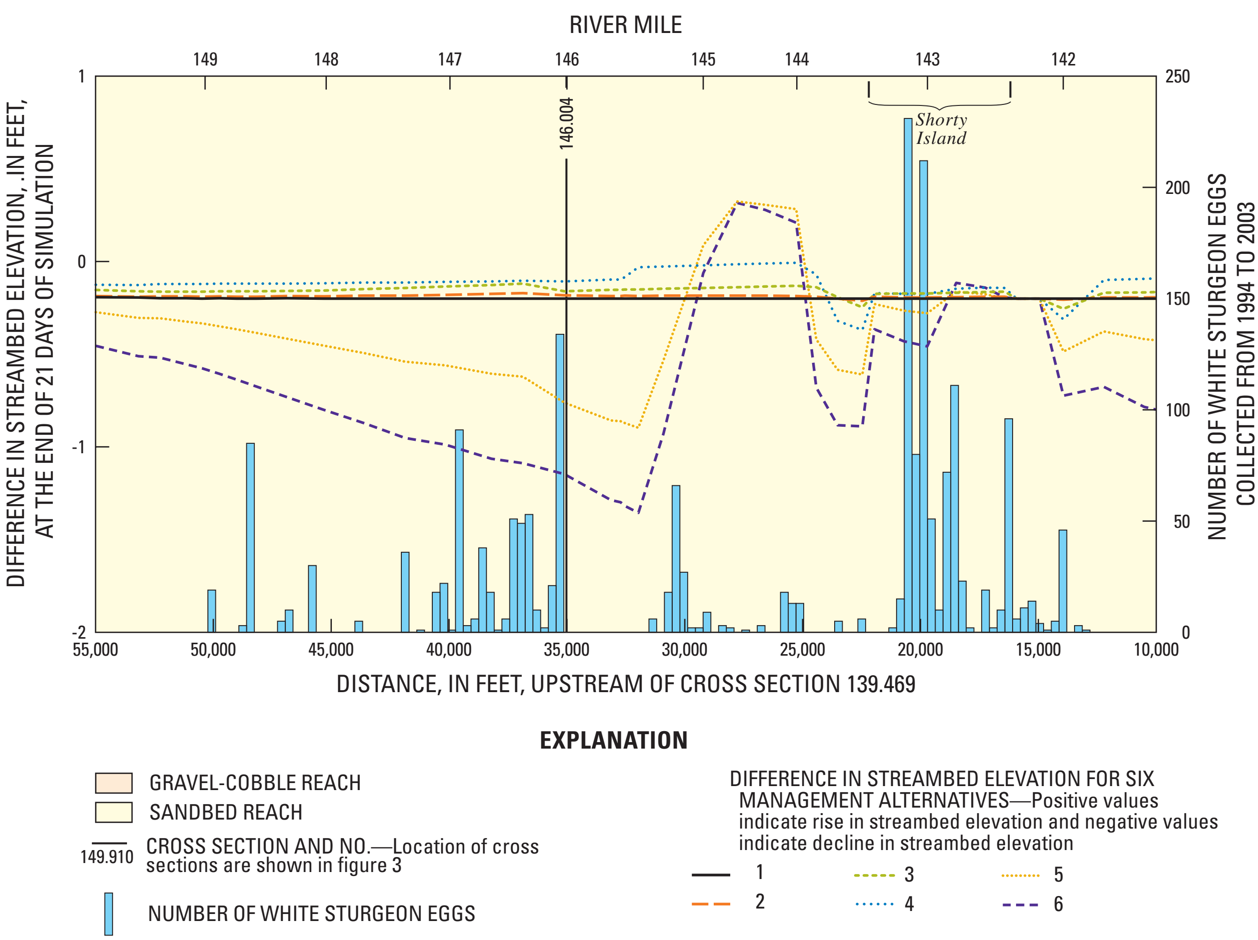

Figure 19. Difference in streambed elevations for six management alternatives at the end of 21 days of simulation and number of white sturgeon eggs collected from 1994 to 2003, Kootenai River near Bonners Ferry, Idaho.

Implications of Management Alternatives to White Sturgeon Spawning

Since 1994, the IDGF has been collecting Kootenai River white sturgeon eggs in the white sturgeon spawning reach (figs. 2 and 3). The largest number of eggs were collected in the reaches adjacent to Shorty Island near RM 143.2 and from RM 149 to RM 146 (fig. 19) (Paragamian and others, 2002). Figure 19 shows the number of eggs collected between 1994 and 2003 in the Kootenai River (Paragamian and others, 2002).

The streambed for management alternatives 1 through 4 showed a slight increase (depositional) in the reach adjacent to Shorty Island, but for management alternatives 5 and 6, about 0.5 ft or more of the streambed was eroded.

In the reach between RM 149 to RM 146, the streambed for management alternatives 1 through 4 was depositional and for alternatives 5 and 6 this reach was being eroded. Several reaches such as RM 144.0 to RM 141.2 also were eroded for alternatives 5 and 6. Although the model shows erosion occurring in these reaches, these reaches are still considered unsuitable spawning habitat because of the sandy streambed.

A more suitable spawning habitat may be developed if large boulders, nearly horizontal pilings, and such were placed in the river at these locations. High discharges, low Kootenay Lake water levels, and the duration of flows and stages lasting 2 to 3 weeks may prevent sand and (or) silt buildup on the boulders and (or) structures.

Many other discharge and stage conditions can be simulated using the calibrated model. Finding combinations of water-surface elevation and discharge for when the study reach turns from deposition to erosion is important for removing sands and silts from the white sturgeon spawning habitat. However, this work is left for future investigations.

Limitations of the Model

A digital model can be a useful tool for predicting water-surface and streambed elevations and sediment transport response to changes in the riverine system. However, the accuracy with which a model can project water-surface and streambed elevations, and sediment transport is directly related to the accuracy and adequacy of the input data used to calibrate the model. When using the model to make projections, it is important to realize the limitations of the model.

The computer model, SEDMOD, incorporates many simplifying assumptions about the riverine system. Most important are the assumptions of one-dimensional flow, gradually varied flow, steady flow, moveable streambed, and sediment transport. These simplifications might cause the model to calculate water-surface and streambed elevations and sediment transport with discharges greater than or less than would be experienced under actual conditions in the study reach. SEDMOD is quite successful in calculating water-surface and streambed elevations and sediment transport in the Kootenai River, even though it fails to account for (1) uneven velocities in a cross section especially in curved sections at bends, (2) uneven water-surface elevation in a cross section, (3) uneven erosion and deposition and sediment transport in a cross section, (4) infiltration losses and (or) grains in the channel, and (5) other aspects of the actual river discharge and sediment-transport processes in the Kootenai River.

Considerable uncertainty is associated with how velocity and sediment transport are distributed throughout the study reach. These uncertainties cannot be addressed by a one-dimensional model like SEDMOD. The application of multiple-dimensional models that would simulate the discharge and sediment transport more precisely are needed to refine velocity, shear stress, and sediment transport of the Kootenai River in the study reach. SEDMOD was considered sufficient to provide reasonable results in meeting the objectives of this study.

SEDMOD is capable of simulating the transport of sediment sizes of 0.0625 mm (0.0025 in.) (very fine sand) and greater. However, it cannot take into account silt and clay particles (less than 0.0625 mm [0.0025 in.]).

Because SEDMOD uses single-precision variables, sediment volume errors can be magnified by round-off errors. If cross-section coordinate (end points) values are large, for example, then round-off errors will increase because the end points are used by the model in computations. However, sediment volume errors for each of the management alternatives were quite low (table 11). These low errors can partially be attributed to decreasing endpoint and elevation values for each cross section (see section on “Model Cross Sections”).

Another limitation of the model is that the total sediment-transport rate coming into the study reach at the upstream boundary (cross section 152.790, U.S. Highway 95 Bridge) does not differentiate between the different sources of water (snowmelt runoff or Libby Dam) or from hysteresis. The total sediment-transport rate used in the model may, in reality, be underestimated or overestimated depending on the type of event. Many more total sediment discharge data would need to be collected at the upstream boundary before equations defining each event can be developed. Particle-size distribution of total sediment discharge also was held constant for all flows. The amount of larger particles coming into the study reach will be underestimated for higher flows and overestimated for lower flows, and the opposite for smaller particles.

Summary

The Kootenai River originates in British Columbia, Canada, and flows southward into Lake Koocanusa in British Columbia and Montana. From there, the river flows westward through Montana and Idaho until it meets Deep Creek near Bonners Ferry, Idaho. Then the river flows in a northerly direction from Deep Creek to where it empties into Kootenay Lake. From Kootenay Lake, it flows in a westerly direction to its confluence with the Columbia River. The study reach is about 15 miles in length starting at river mile (RM) 153.8 and ending at the Klockmann gaging station (RM 139.5). The study reach also includes an approximately 1-mile long side channel around the western side of Shorty Island. Streamflow in the river has been dramatically altered by dams and levees. which may negatively impact the spawning of the Kootenai River white sturgeon. The population of white sturgeon has been declining and was listed as an Endangered Species in 1994.

In the study reach, the Kootenai River is characterized by a braided reach and a meander reach. The braided reach extends from Crossport (upstream of the study area) to U.S. Highway 95 Bridge, and the meander reach extends downstream of U.S. Highway 95 Bridge to the confluence with Kootenay Lake. The braided reach has many exposed islands and (or) bars that divides the river into multiple channels especially at low flows, and the streambed is composed primarily of gravels and cobbles. The meander reach is a single channel with gentle bends. Upstream of Ambush Rock, the streambed is composed primarily of gravels and cobbles, and downstream of Ambush Rock, the streambed is composed primarily of sand. White sturgeon spawn in the meandering reach primarily between RM 141.6 and RM 149.0, which is considered an inferior spawning habitat because of the sands. Spawning in this area possibly is linked to the white sturgeons reacting to hydraulic conditions caused by changes in Kootenay Lake levels and flows in the river primarily controlled by Libby Dam.

A mathematical computer sediment-transport model, SEDMOD, was used to simulate water-surface and streambed elevations, erosion and deposition of the streambed, and sediment transport. The steady state, one-dimensional model simulates the resultant erosion and deposition averaged across the streambed at any cross section in the river reach due to variations in discharge and stage. The one-dimensional model used in this study required less model set-up, run-time, and data requirements as compared to two-dimensional models. The model was calibrated to water-surface elevations and discharges. Model calibration was considered acceptable when the difference between measured and simulated water-surface elevations was ±0.15 foot or less. Actual differences were ±0.10 foot or less except for one value. The model also was calibrated to suspended-sediment discharge by simulating a 2½-year period that started on July 25, 2001, and ended on January 27, 2004. This period was used to calibrate the Meyer-Peter bedload coefficient (ϕ_o) and the McLean coefficient (γ_o) in the model. The Meyer-Peter coefficient (ϕ_o) was used specifically to control streambed elevation in the gravel-cobble reach, and the McLean coefficient (γ_o) was used to control suspended-sediment transport rates in the model.

The Meyer-Peter and McLean coefficients (ϕ_o and γ_o) were adjusted separately. These simulations were conducted by simulating a period from July 25, 2001, through January 27, 2004, a period when suspended-sediment discharges were measured at two sites in the study reach. Simulations at first showed unrealistic decreases in the streambed at cross sections upstream of U.S. Highway 95 Bridge for any value of ϕ_o, which is attributed to the model adjusting to equilibrium conditions for suspended-sediment and bedload concentrations, discharge, and water-surface elevations in a steep reach. The model was shortened by removing cross sections upstream of the U.S. Highway 95 Bridge, and then cross section 152.790 (U.S. Highway 95 Bridge) became the upper model boundary. Results from these simulations indicated that a Meyer-Peter bedload coefficient (ϕ_o) of 8.0 caused little or no streambed erosion in the gravel-cobble reach while allowing streambed interaction in the sandbed reach. A McLean coefficient (γ_o) of 0.0080 also produced the lowest *RMSE* between measured and simulated suspended-sediment discharges.

The calibrated model was used to simulate six different management alternatives to assess erosion and deposition under varying hydraulic conditions at the end of 21 days of simulation. Alternative 1 was simulated with a discharge of 6,000 cubic feet per second (ft^3/s), alternative 2 with 20,000 ft^3/s, alternative 3 with 40,000 ft^3/s, and alternatives 4 through 6 with 60,000 ft^3/s. These alternatives represent low to high discharges in the river since the construction of Libby Dam. Results of the simulations show that deposition was dominant when water-surface slopes are low, and erosion was dominant when slopes are high. For management alternatives 1 through 4, the streambed showed little or no changes especially in the sandbed reach. In these simulations, discharge increased 10 times from 6,000 to 60,000 ft^3/s while water-surface slopes increased 1.5 times. For alternative 1, average streambed increase throughout the study reach was 0.013 in., and total volume of sediment deposition was +1,400 cubic yards.

Alternative 2 (a discharge of 20,000 ft^3/s) was similar to alternative 1 in that the streambed overall showed little or no changes especially in the sandbed reach. The streambed increased 0.35 foot and decreased about 0.25 foot in the gravel-cobble reach. The streambed generally increased about 0.14 foot higher for alternative 2 than for alternative 1. For alternative 2, average streambed increase throughout the study reach was about 0.15 inch, and total volume of sediment deposition was +16,700 cubic yards.

For alternative 3 (a discharge of 40,000 ft^3/s), streambed increased and decreased in the same locations as in alternative 2, but the increases and decreases were of greater magnitude in alternative 3 than in alternative 2. The streambed increased about 1 foot and decreased about 0.5 foot in the gravel-cobble reach. At cross section 152.392 in the gravel-cobble reach, the d_{50} of streambed sediments decreased by 2.2 millimeters (0.086 inch) because finer sediments were deposited. The average streambed increase in the sandbed reach was less than 0.1 foot. The average streambed increase throughout the study reach was about 0.60 inch, and total volume of sediment deposition was +66,000 cubic yards.

For alternative 4 (a discharge of 60,000 ft^3/s), model results were similar to alternatives 2 and 3. However, increases and decreases were greater in alternative 4 than in alternatives 2 and 3. The streambed increased about 2 feet and decreased about 1.1 feet in the gravel-cobble reach. The d_{50} of streambed sediments at cross section 152.392 decreased by 1.3 millimeter (0.05 inch). The average streambed increase in the sandbed reach was less than 0.33 foot. The average streambed increase throughout the study reach was 0.93 inch, and total volume of sediment deposition was +101,000 cubic yards.

Deposition was the dominant feature in alternatives 1 through 4 because increasing river discharge alone did not produce boundary shear stresses that can erode and transport streambed sediments. Between these alternatives, river discharge increased 10 times and the shear stress increased 4 times with flow depth accounting for most of the increase. Water-surface slope was the limiting factor in these simulations because backwater conditions in the reach flattens the stage throughout the reach. Even if discharge was increased to 100,000 ft^3/s, the modeled reach may still be depositional because the corresponding observed slope is still small. To increase the boundary shear stress to cause erosion throughout the modeled reach, slope needs to increase. One practical method for increasing the slope is to lower the water level in Kootenay Lake. Two additional alternatives (5 and 6) were simulated to demonstrate the effects of a steeper slope in the study reach.

Alternative 5 (a discharge of 60,000 ft^3/s) overall showed much different results than alternatives 1 through 4 at the end of 21 days of simulation except in the gravel-cobble reach. Erosion was the dominant feature in this simulation because water-surface slope was steeper. The water-surface slope in alternative 5 was 2.4 times greater than the slope in alternative 4 and boundary shear stress in alternative 5 was about 2 times greater than the stress in alternative 4. The maximum streambed decrease of 2 feet occurred in the sandbed reach. The streambed decreased from about 0 to about 1 foot in the reach between RM 151.7 to RM 145.7. At cross sections 149.910 (Tribal Hatchery) and 146.004, streambed decreases were 0.4 and 1.5 feet. However, deposition of about 1 foot occurred in the reach between RM 145.5 and RM 144.0 and 1.9 ft between RM 141.2 and RM 140.3. About 2 feet was eroded in the reach from RM 140.3 to Klockmann Ranch (RM 139.5). Streambed decreases also were prevalent in the Shorty Island side channel and averaged 1.5 feet. Total volume of sediments eroded at the end of 21 days of simulation was –230,000 cubic yards and average streambed decrease throughout the study reach was 2.1 inch.

Model results for alternative 6 were similar to alternative 5 where streambed increased and decreased at nearly the same locations, but increases and decreases usually were greater for alternative 6 than alternative 5. Erosion was the dominant feature in this simulation The water-surface slope in alternative 6 was 3.5 times greater than slope in alternative 4 and 1.5 times greater than slope in alternative 5. The boundary shear stress in alternative 6 was about 2.5 times greater than the stress in alternative 4. The maximum streambed decrease in the sandbed reach was 3 feet. Streambed decreased from about 0 to about 2 feet in the reach between RM 151.7 to RM 145.7 and about 3 feet between RM 140.3 to RM 139.5 (Klockmann Ranch). Streambed decreases also were prevalent in the Shorty Island side channel and average decrease was 1.0 feet. Total volume of sediments eroded at the end of 21 days of simulation was –594,000 cubic yards, and average streambed decreases throughout the study reach was 5.5 inches.

Number and locations of white sturgeon eggs have been collected by the Idaho Department of Fish and Game in the study reach since 1994. The river adjacent to Shorty Island (RM 143.2) had the largest number of collected eggs. Another reach where many eggs were collected was RM 149 through RM 146. These reaches were eroding in alternatives 5 and 6 where the water-surface slopes were increased, and were slightly depositional in alternatives 1 through 4. These reaches are still unsuitable for spawning habitat because of the sandy streambed. However, they probably can be made suitable if large boulders, nearly horizontal pilings, and such were placed in the river at these locations. High discharges and low Kootenay Lake levels lasting several weeks also are needed to prevent sand and silt build up on these structures.

The model developed and calibrated for this study closely duplicates measured water-surface elevations and suspended-sediment discharges. However, in spring and early summer high flows (April through early June) where there are few suspended-sediment measurements, there is uncertainty about the accuracy of the simulated suspended-sediment discharges. The total sediment discharge curve that was used in the model does not differentiate between the different sources of water (snowmelt runoff or Libby Dam) or from hysteresis. Additional suspended-sediment data are needed in the study reach before these sources can be simulated adequately.

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Table 12. Suspended-sediment samples, Kootenai River near Bonners Ferry, Idaho, 2002–03.

[**Sampler:** USGS, U.S. Geological Survey; KTOI, Kootenai Tribe of Idaho. Location of cross sections are shown in figure 3. Cross section number is river mile. USGS, U.S. Geological Survey. RM, river mile. ft, foot; ft^3/s, cubic foot per second; ^oC, degrees Celsius; mi, mile; mg/L, milligram per liter; ton/d, ton per day. –, no data]

Width- and depth-integrated (cross-section) samples from Kootenai River near Fry Creek (12309490) (RM 153.781) by USGS personnel

Sample	Date	Time	Discharge (ft^3/s)	Water temperature (^oC)	Sediment concentration (mg/L)	Sediment discharge (ton/d)	Remarks
1	04/16/02	1721	27,300	–	202	14,873	–
2	04/19/02	1440	8,290	6.6	46	1,028	–
3	04/19/02	1450	8,290	6.6	69	1,543	–
4	05/23/02	1225	36,000	7.5	133	12,913	Poor sample—overfilled bottles
5	07/23/02	0900	24,200	14.5	136	8,876	–
6	06/26/02	0915	36,900	12.0	18	1,791	Poor sample—overfilled bottles
7	09/04/02	1518	8,091	14.2	87	1,905	Sampled 800 ft downstream of Railroad Bridge
8	04/02/03	0945	13,000	5.5	35	1,227	Sampled 0.35 mi downstream of Highway 95 Bridge
9	06/09/03	0930	32,500	12.0	21	1,841	–
10	06/24/03	1015	22,000	10.0	8	475	–
11	07/10/03	1045	15,300	14.0	4	165	–

Single vertical samples from Kootenai River at U.S. Highway 95 Bridge (RM 152.790)

Sample	Date	Time	Sampler	Discharge (ft^3/s)	Sediment concentration (mg/L)	Sediment discharge (ton/d)
1	04/16/02	1721	USGS	31,300	172	14,519
2	04/19/02	0845	USGS	17,100	56	2,583
3	04/19/02	0850	USGS	17,100	76	3,505
4	04/19/02	0855	USGS	17,100	114	5,257
5	05/01/02	1616	USGS	16,200	54	2,359
6	05/01/02	1620	USGS	16,200	57	2,490
7	05/02/02	0746	KTOI	17,500	60	2,832
8	05/02/02	0756	KTOI	17,500	32	1,510
9	05/07/02	1255	KTOI	15,400	19	789
10	05/07/02	1303	KTOI	15,400	10	415
11	05/08/02	0825	KTOI	14,300	15	578
12	05/08/02	0830	KTOI	14,300	10	386
13	05/10/02	0750	KTOI	12,600	47	1,597
14	05/10/02	0756	KTOI	12,600	14	476
15	05/13/02	1414	KTOI	12,400	28	936
16	05/13/02	1418	KTOI	12,400	9	301
17	05/14/02	0755	KTOI	14,200	12	460
18	05/14/02	0759	KTOI	14,200	18	689
19	05/17/02	1955	KTOI	19,400	33	1,727
20	05/17/02	1959	KTOI	19,400	17	889
21	05/20/02	1244	KTOI	25,600	51	3,521
22	05/20/02	1248	KTOI	25,600	51	3,521
23	05/21/02	1618	USGS	32,300	140	12,196
24	05/21/02	1623	USGS	32,300	171	14,896
25	05/22/02	0940	KTOI	45,900	214	26,491
26	05/22/02	0948	KTOI	45,900	223	27,605
27	05/23/02	0902	KTOI	48,900	134	17,672
28	05/23/02	0909	KTOI	48,900	150	19,782
29	05/23/02	1310	USGS	48,900	124	16,353
30	05/23/02	1315	USGS	48,900	136	17,936
31	05/24/02	1400	USGS	40,700	73	8,013
32	05/24/02	1405	USGS	40,700	67	7,354

Table 12. Suspended-sediment samples, Kootenai River near Bonners Ferry, Idaho, 2002–03.—Continued

[**Sampler:** USGS, U.S. Geological Survey; KTOI, Kootenai Tribe of Idaho. Location of cross sections are shown in figure 3. Cross section number is river mile. USGS, U.S. Geological Survey. RM, river mile. ft, foot; ft^3/s, cubic foot per second; °C, degrees Celsius; mi, mile; mg/L, milligram per liter; ton/d, ton per day. –, no data]

Single vertical samples from Kootenai River at U.S. Highway 95 Bridge (RM 152.790)—Continued

Sample	Date	Time	Sampler	Discharge (ft^3/s)	Sediment concentration (mg/L)	Sediment discharge (ton/d)
33	05/25/02	0650	KTOI	33,700	68	6,180
34	05/25/02	0655	KTOI	33,700	49	4,453
35	05/28/02	1500	USGS	34,200	55	5,073
36	05/28/02	1503	USGS	34,200	44	4,058
37	05/30/02	1939	KTOI	42,700	99	11,401
38	05/30/02	1942	KTOI	42,700	93	10,710
39	05/31/02	1700	KTOI	41,500	84	9,402
40	05/31/02	1702	KTOI	41,500	63	7,051
41	06/01/02	0904	KTOI	38,600	64	6,663
42	06/01/02	0908	KTOI	38,600	57	5,934
43	06/03/02	1836	KTOI	32,900	42	3,727
44	06/03/02	1840	KTOI	32,900	29	2,573
45	06/05/02	1941	KTOI	31,300	41	3,461
46	06/05/02	1945	KTOI	31,300	35	2,955
47	06/07/02	1130	KTOI	37,400	50	5,043
48	06/07/02	1133	KTOI	37,400	51	5,144
49	06/12/02	2040	KTOI	33,200	45	4,029
50	06/12/02	2042	KTOI	33,200	50	4,477
51	06/14/02	1702	KTOI	40,600	30	3,285
52	06/14/02	1704	KTOI	40,600	34	3,723
53	06/15/02	1016	KTOI	41,500	41	4,589
54	06/18/02	1825	KTOI	41,400	37	4,131
55	06/18/02	1827	KTOI	41,400	43	4,801
56	06/20/02	1912	KTOI	39,800	52	5,582
57	06/20/02	1920	KTOI	39,800	53	5,689
58	06/23/02	2006	KTOI	37,000	66	6,586
59	06/23/02	2045	KTOI	36,100	87	8,470
60	06/26/02	1535	USGS	38,100	28	2,877
61	06/26/02	1539	USGS	38,100	75	7,707
62	06/27/02	2055	KTOI	42,000	38	4,304
63	06/27/02	2058	KTOI	42,000	22	2,492
64	07/01/02	2015	KTOI	46,400	59	7,383
65	07/01/02	2018	KTOI	46,400	72	9,010
66	07/02/02	1836	KTOI	47,500	97	12,426
67	07/03/02	1650	KTOI	47,500	52	6,661
68	07/03/02	1653	KTOI	47,500	34	4,356
69	07/10/02	1700	KTOI	29,000	52	4,067
70	07/10/02	1703	KTOI	29,000	84	6,570
71	07/13/02	1412	KTOI	30,800	51	4,236
72	07/13/02	1414	KTOI	30,800	57	4,735
73	07/15/02	1600	KTOI	31,200	44	3,702
74	07/18/02	1700	KTOI	26,800	25	1,807
75	07/18/02	1703	KTOI	26,800	61	4,409
76	07/23/02	1400	USGS	23,400	17	1,073
77	07/23/02	1433	KTOI	23,400	39	2,461
78	07/26/02	1115	KTOI	24,000	59	3,819

Table 12. Suspended-sediment samples, Kootenai River near Bonners Ferry, Idaho, 2002–03.—Continued

[**Sampler:** USGS, U.S. Geological Survey; KTOI, Kootenai Tribe of Idaho. Location of cross sections are shown in figure 3. Cross section number is river mile. USGS, U.S. Geological Survey. RM, river mile. ft, foot; ft^3/s, cubic foot per second; ^oC, degrees Celsius; mi, mile; mg/L, milligram per liter; ton/d, ton per day. –, no data]

Single vertical samples from Kootenai River at Highway 95 Bridge (RM 152.790)—Continued						
Sample	**Date**	**Time**	**Sampler**	**Discharge (ft^3/s)**	**Sediment concentration (mg/L)**	**Sediment discharge (ton/d)**
79	07/26/02	1117	KTOI	24,000	19	1,230
80	07/30/02	1130	KTOI	24,000	33	2,136
81	07/30/02	1132	KTOI	24,000	78	5,049
82	08/02/02	1005	KTOI	21,900	36	2,126
83	08/02/02	1010	KTOI	21,900	11	650
84	08/06/02	1111	KTOI	22,900	20	1,235
85	08/11/02	1630	KTOI	19,200	30	1,553
86	08/11/02	1632	KTOI	19,200	12	621
87	08/13/02	0946	KTOI	18,700	27	1,362
88	08/13/02	0950	KTOI	18,700	35	1,765
89	08/18/02	1820	KTOI	16,700	16	721
90	08/18/02	1824	KTOI	16,700	34	1,531
91	08/20/02	1143	KTOI	17,800	18	864
92	08/20/02	1145	KTOI	17,800	11	528
93	08/22/02	0917	KTOI	18,100	18	879
94	08/22/02	0920	KTOI	18,100	10	488
95	08/27/02	0909	KTOI	17,800	8	384
96	08/29/02	1120	KTOI	15,800	6	256
97	08/29/02	1123	KTOI	15,800	3	128
98	09/04/02	1518	USGS	8,070	43	936
99	09/04/02	1521	USGS	8,070	10	218
100	09/06/02	0937	KTOI	7,250	12	235
101	09/06/02	0939	KTOI	7,250	9	176
102	09/09/02	0910	KTOI	6,970	25	470
103	09/09/02	0912	KTOI	6,970	15	282
104	09/12/02	0827	KTOI	6,990	12	226
105	09/12/02	0829	KTOI	6,990	11	207
106	09/17/02	1000	KTOI	6,860	20	370
107	09/17/02	1002	KTOI	6,860	9	167
108	09/19/02	0939	KTOI	6,830	13	239
109	09/19/02	0949	KTOI	6,830	44	810
110	09/24/02	0847	KTOI	6,840	4	74
111	09/24/02	0850	KTOI	6,840	9	166
112	10/01/02	0837	KTOI	6,760	12	219
113	10/01/02	0840	KTOI	6,760	6	109
114	10/03/02	0837	KTOI	6,710	8	145
115	10/03/02	0840	KTOI	6,710	6	109
116	10/08/02	1058	KTOI	6,730	10	182
117	10/08/02	1101	KTOI	6,730	5	91
118	10/10/02	0922	KTOI	6,470	15	262
119	10/10/02	0925	KTOI	6,470	5	87
120	10/16/02	1619	KTOI	8,360	22	496
121	10/16/02	1622	KTOI	8,360	11	248
122	10/18/02	0909	KTOI	6,890	10	186
123	10/18/02	0912	KTOI	6,890	8	149

Table 12. Suspended-sediment samples, Kootenai River near Bonners Ferry, Idaho, 2002–03.—Continued

[**Sampler:** USGS, U.S. Geological Survey; KTOI, Kootenai Tribe of Idaho. Location of cross sections are shown in figure 3. Cross section number is river mile. USGS, U.S. Geological Survey. RM, river mile. ft, foot; ft^3/s, cubic foot per second; ^oC, degrees Celsius; mi, mile; mg/L, milligram per liter; ton/d, ton per day. –, no data]

Width- and depth-integrated (cross-section) samples from Kootenai River near Ball Creek (RM 140.282)					
Sample	**Date**	**Time**	**Discharge (ft^3/s)**	**Sediment concentration (mg/L)**	**Sediment discharge (ton/d)**
1	4/17/02	1028	23,900	122	7,864
2	4/19/02	1220	17,100	55	2,536
3	4/19/02	1235	17,100	73	3,367
4	5/23/02	1100	36,000	156	15,146
5	6/26/02	1415	36,900	56	5,573
6	9/04/02	1400	8,091	16	349

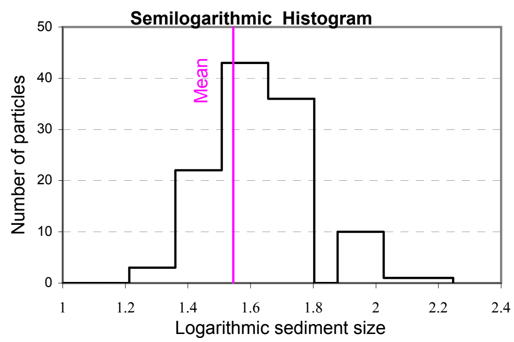
Appendix A. Particle-Count Analysis at Cross Section 153.781 on the Kootenai River, Near Bonners Ferry, Idaho.

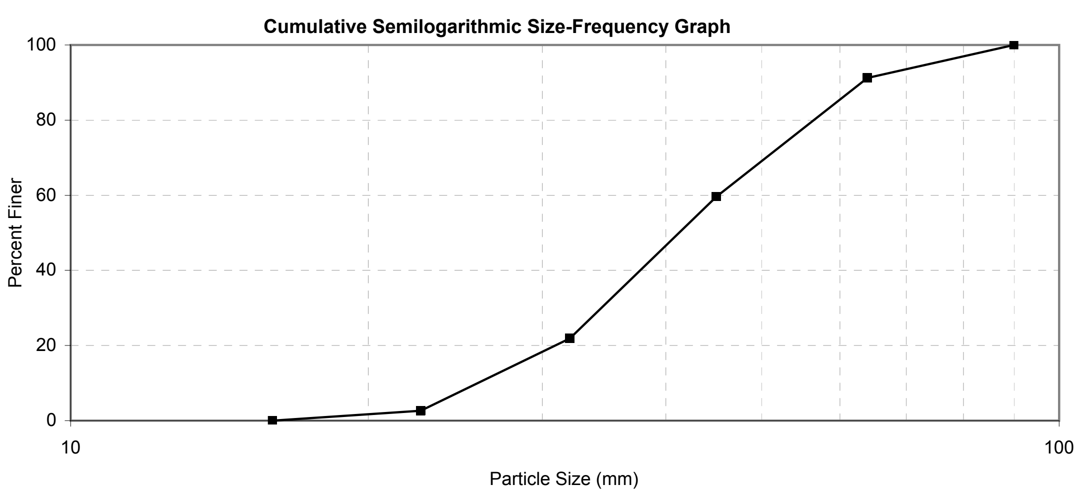
Site: River Mile 153.781 (PC25LB)
Date: October 28, 2003
Measurement by: Steve Lipscomb, and Gary Barton
Remarks: Sampled using a 1/2ϕ Gravelometer starting on left bank at edge of vegetation at about every 2.5 feet along the cross section.

NOTE: See original notes for more info on sampling this site.

DATA: Particle size (mm)				
45	32	22.6	32	22.6
32	64	32	32	22.6
32	22.6	45	45	32
32	16	45	45	
22.6	32	45	45	
16	32	22.6	32	
64	32	45	32	
22.6	32	32	32	
32	22.6	22.6	64	
64	32	22.6	45	
32	32	45	90	
22.6	64	22.6	45	
22.6	45	32	45	
16	45	45	45	
45	32	45	32	
32	45	45	32	
32	45	64	32	
32	32	32	22.6	
32	64	45	22.6	
45	45	45	64	
45	45	32	32	
22.6	64	32	45	
32	32	22.6	45	
32	32	32	45	
32	22.6	32	22.6	
64	45	45	32	
45	22.6	32	22.6	
45	22.6	45	45	

Particle Characteristics			
d_{90}	=	63.1	mm
$d_{84.1}$	=	59.1	mm
d_{65}	=	47.8	mm
d_{50}	=	41.2	mm
d_{35}	=	36	mm
$d_{15.9}$	=	28.7	mm
d_g	=	41.2	mm
σ_g	=	1.44	mm
G	=	0.85	





Appendix B. Listing of Model Network-Description File, Xscdatm.txt.

Listing of model network description file (Xscdatm.txt)

The following is the input network description file in the white sturgeon reach of the Kootenai River near Bonners Ferry, Idaho, for the 47,500 ft^3/s discharge simulation. Model input data are in black print; descriptive is in blue print.

```
4
1 4 52                                                 (Reach 1)
11089.9062 1521.4375  11108.2525 1169.9295            (Cross section 153.781)
0.
123.26 0.025
0.030
3 1 2 1
0.00 139.40 0.060  4.69 137.36 0.060  5.06 134.10 0.060
6.25 133.26
312.30 134.95 0.060  351.98 138.25 0.060
-1
17. 3

10787.7500 1562.0625  10627.9232 1175.2538            (Cross section 153.468)
0.
123.28 0.025
0.030
3 1 5 1
0.00 139.74 0.060  14.94 136.36 0.060  16.28 135.50 0.060
27.25 133.28
371.86 135.41 0.060  374.51 138.25 0.060  379.78 137.24 0.060
380.73 139.31 0.060  418.52 142.85 0.060
-1
17. 3

10679.0707 1605.8816  10491.5173 1404.2166            (Cross section 153.341)
0.
122.34 0.025
0.030
5 1 4 1
0.00 143.12 0.060  53.74 141.45 0.060  75.38 134.41 0.060
76.29 134.25 0.045  77.51 133.77 0.060
79.71 132.34
260.24 136.36 0.060  261.73 136.57 0.060  273.38 143.98 0.060
275.39 143.98 0.060
-1
17. 3

10542.2188 1732.0000  10354.0418 1548.2372            (Cross section 153.205)
0.
122.31 0.025
0.030
6 1 3 1
0.00 143.12 0.060  52.03 141.45 0.060  64.71 140.35 0.060
72.97 137.12 0.060  77.88 133.61 0.060  79.03 133.49 0.060
80.25 132.31
252.59 136.57 0.060  254.20 136.57 0.060  263.01 142.73 0.060
-1
17. 3
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
10311.5000 1857.0625  10082.9920 1610.8873            (Cross section 153.033)
0.
122.76 0.025
0.030
9 1 2 1
0.00 143.03 0.060  8.44 140.38 0.060  9.33 135.87 0.060
9.63 134.98 0.060  9.81 134.28 0.060  10.42 134.34 0.060
10.85 134.13 0.060  11.00 133.86 0.060  11.67 133.95 0.060
11.95 132.76
325.80 136.48 0.060  335.89 139.65 0.060
-1
17. 3

10112.5000 2047.9375  10055.1129 1619.6619            (Cross section 152.963)
0.
122.46 0.025
0.030
3 1 7 1
0.00 142.57 0.060  3.96 142.18 0.060  22.62 132.82 0.060
23.07 132.46
406.09 133.70 0.060  407.52 134.89 0.060  408.86 135.87 0.060
426.96 136.20 0.060  429.28 136.27 0.060  431.35 138.83 0.060
432.08 139.77 0.060
-1
17. 3

9999.5000 2075.5000  9928.8502 1706.2879              (Cross section 152.879)
0.
122.34 0.025
0.030
6 1 4 1
0.00 143.18 0.060  0.24 143.00 0.060  3.11 142.91 0.060
20.70 136.02 0.060  21.18 134.89 0.060  23.56 133.67 0.060
24.81 132.34
361.07 133.74 0.060  362.38 135.23 0.060  365.76 139.01 0.060
375.91 141.54 0.060
-1
17. 3

9798.8125 2092.1875 9910.4775 1714.0464               (Cross section 152.842)
0.
122.39 0.025
0.030
6 1 8 1
0.00 145.47 0.060  5.58 145.13 0.060  11.52 144.77 0.060
52.82 136.36 0.060  53.55 135.81 0.060  56.54 133.25 0.060
57.91 132.39
361.92 133.95 0.060  363.53 134.59 0.060  365.97 136.48 0.060
370.45 135.84 0.060  379.05 135.72 0.060  381.46 136.36 0.060
392.46 143.95 0.060  394.26 144.01 0.060
-1
17. 3
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
9715.9375 1987.8125  9849.0758 1705.0776             (Cross section 152.790)
0
122.03 0.025
0.028
2 1 8 1
0.00 145.20 0.060  20.06 132.03 0.060
20.51 132.03
291.72 133.40 0.060  292.97 134.01 0.060  294.86 134.95 0.060
296.42 135.11 0.060  297.67 135.38 0.060  298.92 135.90 0.060
309.49 143.95 0.060  312.51 144.01 0.060
-1
17. 3

9603.0000 1951.6875  9681.0578 1664.3699             (Cross section 152.693)
0.
121.75 0.025
0.028
3 1 2 1
0.00 145.20 0.060  75.44 134.53 0.060  76.11 133.95 0.060
77.33 131.75
271.18 131.78 0.060  297.73 143.82 0.060
-1
17. 3

9503.8020 1881.5523  9589.2853 1635.9804             (Cross section 152.628)
0.
121.76 0.025
0.028
2 1 11 1
0.00 144.22 0.060  60.02 132.24 0.060
60.35 131.76
216.19 133.80 0.060  217.51 134.22 0.060  218.85 135.32 0.060
220.10 136.05 0.060  221.41 136.45 0.060  222.75 136.27 0.060
224.06 136.33 0.060  225.28 136.33 0.060  226.53 136.33 0.060
227.78 136.42 0.060  260.02 144.95 0.060
-1
17. 3

9326.6600 1811.4400  9405.0900 1587.5700             (Cross section 152.510)
0.
121.64 0.025
0.028
2 1 2 1
0.00 144.01 0.060  38.47 132.55 0.060
38.71 131.64
211.53 134.77 0.060  237.10 144.34 0.060
-1
17. 3
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
9146.6458 1740.2193  9222.3402 1539.8904              (Cross section 152.392)
0.
121.33 0.025
0.028
2 1 2 1
0.00 143.76 0.060  17.04 132.82 0.060
17.65 131.33
195.29 133.13 0.060  214.18 143.76 0.060
-1
11. 3

8954.5000 1664.4600 9048.9900 1451.9100               (Cross section 152.267)
0.
120.38 0.025
0.028
4 1 5 1
0.00 143.70 0.060  0.64 143.58 0.060  1.77 143.34 0.060
13.69 140.44 0.060
32.25 130.378
201.14 133.86 0.060  208.06 136.51 0.060  209.73 137.21 0.060
215.55 139.22 0.060  231.47 143.85 0.060
-1
9. 3

8769.2500 1591.5700 8869.6400 1360.0000               (Cross section 152.143)
0.
119.47 0.025
0.012
4 1 4 1
0.00 143.67 0.060  0.98 143.64 0.060  2.65 143.49 0.060
20.15 141.78 0.060
47.46 130.299
216.53 137.45 0.060  218.85 138.31 0.060  226.89 140.23 0.060
248.78 143.95 0.060
-1
7. 3

8582.4304 1517.8714  8689.9208 1274.4921              (Cross section 152.019)
0.
120.12 0.025
0.012
4 1 2 1
0.00 143.61 0.060  1.28 143.67 0.060  3.47 143.67 0.060  26.61 143.12 0.060
62.67 130.219
238.17 141.26 0.060  266.06 144.04 0.060
-1
6. 3
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
8517.9100 1489.3900 8524.2200 1289.5900            (Cross section 151.946)
0.
116.61 0.025
0.012
5 1 7 1
0.00 141.63 0.060  0.98 141.63 0.060  2.62 141.60 0.060
3.75 141.57 0.060  19.96 139.95 0.060
43.89 130.173
185.47 133.28 0.060  194.22 136.23 0.060  196.35 137.06 0.060
203.12 139.01 0.060  203.73 139.25 0.060  217.93 143.89 0.060
223.88 144.77 0.060
-1
5. 3

8457.7800 1462.0000  8372.3443 1305.5570           (Cross section 151.8)
0.
115.34 0.025
0.012
3 1 4 1
0.00 139.65 0.060  2.50 139.50 0.060  29.23 132.82 0.060
30.02 130.127
158.07 131.27 0.060  168.92 136.91 0.060  178.03 144.53 0.060
181.69 145.47 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.012 0.018 0.033 0.077 0.334 0.945 0.995 0.996 0.998 0.999 1. 1. 1. 1. 1.

8386.5784 1552.1296  8270.8496 1423.2080           (Cross section 151.785)
0.
111.94 0.025
0.012
8 1 2 1
0.00 142.39 0.060  57.15 136.08 0.060  58.22 134.95 0.060
59.07 134.25 0.060  59.83 133.86 0.060  61.02 133.64 0.060
61.94 133.55 0.060  62.88 133.40 0.060
63.79 130.070
157.28 131.42 0.060  173.28 146.05 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.011 0.016 0.030 0.071 0.327 0.938 0.994 0.996 0.998 0.999 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
8273.1912 1670.3783  8130.2155 1490.8183             (Cross section 151.686)
0.
115.76 0.025
0.012
7 1 5 1
0.00 142.39 0.060  33.71 142.27 0.060  41.97 138.86 0.060
48.07 135.17 0.060  49.04 134.59 0.060  50.51 133.80 0.060
50.96 133.28 0.060
51.91 130.007
193.15 133.49 0.060  194.37 134.04 0.060  215.80 137.00 0.060
218.42 135.56 0.060  229.51 142.24 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.010 0.014 0.028 0.064 0.318 0.930 0.993 0.996 0.998 0.999 1. 1. 1. 1. 1.

7921.1264 1903.2120  7777.2236 1618.3237             (Cross section 151.438)
0.
120.68 0.025
0.028
7 1 5 1
0.00 143.98 0.060  4.24 143.95 0.060  10.39 143.92 0.060
12.07 143.92 0.060  13.75 143.85 0.060  15.73 143.79 0.060
39.01 132.91 0.060
40.42 129.848
272.83 133.13 0.035  308.95 143.70 0.060  310.47 143.70 0.060
312.02 143.70 0.060 319.16 143.73 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.007 0.010 0.022 0.048 0.297 0.910 0.990 0.997 0.999 0.999 1. 1. 1. 1. 1.

7368.6210 2162.6722  7242.1089 1955.7289             (Cross section 151.047)
0.
119.60 0.025
0.028
6 1 1 1
0.00 143.64 0.060  36.18 133.64 0.060  37.40 133.61 0.060
39.01 133.58 0.060  41.51 133.58 0.060  42.98 133.40 0.060
44.47 129.599
242.56 143.64 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.002 0.003 0.012 0.021 0.264 0.878 0.985 0.997 0.999 0.999 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
6823.5334 2408.8809  6742.9563 2204.2749            (Cross section 150.679)
0.
119.11 0.025
0.028
1 1 2 1
0.00 143.82 0.060
26.76 129.11
191.05 132.94 0.060  219.91 143.49 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.002 0.003 0.010 0.017 0.203 0.813 0.976 0.995 0.999 0.999 1. 1. 1. 1. 1.

6217.4752 2562.4477  6171.7393 2354.5480            (Cross section 150.289)
0.
119.24 0.025
0.028
3 1 4 1
0.00 143.76 0.060  4.30 144.13 0.060  27.65 132.52 0.060
28.16 129.24
180.65 133.40 0.060  181.87 134.59 0.060  212.17 143.40 0.060
212.87 143.40 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.001 0.002 0.007 0.012 0.138 0.745 0.966 0.993 0.998 1. 1. 1. 1. 1. 1.

5622.0313 2639.1250  5584.1987 2438.0528            (Cross section 149.910)
0.
117.98 0.025
0.028
3 1 3 1
0.00 143.67 0.060  6.92 141.32 0.060  26.24 132.18 0.060
27.13 127.98
174.38 133.16 0.060  175.69 133.43 0.060  204.58 143.31 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.001 0.002 0.005 0.008 0.074 0.678 0.957 0.991 0.998 1. 1. 1. 1. 1. 1.

5065.7188 2768.3750  4969.7282 2581.1986            (Cross section 149.527)
0.
123.85 0.025
0.028
3 1 5 1
0.00 144.01 0.060  0.73 144.01 0.060  24.81 133.03 0.060
26.15 128.05
182.97 133.40 0.060  186.08 135.72 0.060  187.48 136.14 0.060
194.61 142.97 0.060  210.37 143.28 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.001 0.003 0.006 0.016 0.123 0.738 0.968 0.993 0.998 1. 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4835.7813 2907.7500  4715.2510 2724.0640             (Cross section 149.348)
0.
122.78 0.025
0.028
6 1 7 1
0.00 143.82 0.060  0.24 143.98 0.060  17.25 135.14 0.060
30.11 134.74 0.060  31.33 134.01 0.060  32.83 133.19 0.060
34.11 127.58
171.63 133.06 0.060  172.97 134.47 0.060  174.92 134.65 0.060
176.27 134.53 0.060  178.06 134.80 0.060  197.30 143.21 0.060
219.70 143.21 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.001 0.003 0.007 0.021 0.161 0.783 0.976 0.995 0.998 1. 1. 1. 1. 1. 1.

4639.9062 3125.8125  4464.7128 3000.6092             (Cross section 149.138)
0.
123.05 0.025
0.028
9 1 6 1
0.00 143.89 0.060  0.12 143.82 0.060  30.36 142.03 0.060
32.67 135.69 0.060  33.86 135.41 0.060  35.14 135.11 0.060
36.42 134.59 0.060  37.67 134.04 0.060  39.01 133.31 0.060
40.29 128.60
187.85 133.22 0.060  189.16 133.98 0.060  190.44 134.50 0.060
191.66 134.92 0.060  213.36 143.40 0.060  215.31 143.55 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.002 0.003 0.009 0.026 0.198 0.828 0.984 0.996 0.999 0.999 0.999 1. 1. 1. 1.

4540.7813 3291.6250  4354.1578 3186.0323             (Cross section 149.008)
0.
123.08 0.025
0.028
4 1 5 1
0.00 144.01 0.060  1.83 143.89 0.060  35.27 134.10 0.060
35.63 133.40 0.060
36.85 129.03
190.80 133.61 0.060  192.02 133.86 0.060  193.43 134.80 0.060
194.71 136.20 0.060  214.43 143.55 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.002 0.004 0.010 0.031 0.233 0.870 0.992 0.998 0.999 0.999 0.999 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4450.3750 3474.5625  4259.4351 3397.8418            (Cross section 148.868)
0.
122.08 0.025
0.028
8 1 3 1
0.00 143.67 0.060  1.10 143.49 0.060  32.34 135.38 0.060
32.58 134.95 0.060  33.80 134.65 0.060  35.17 134.86 0.060
35.30 134.92 0.060  35.84 133.22 0.060
36.42 128.58
183.55 132.88 0.060  186.08 133.77 0.060  205.77 143.12 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.011 0.035 0.263 0.906 0.998 0.999 0.999 0.999 0.999 1. 1. 1. 1.

4369.2500 3676.6250  4179.1519 3616.4742            (Cross section 148.723)
0.
122.31 0.025
0.028
6 1 2 1
0.00 143.58 0.060  29.20 135.35 0.060  30.02 135.02 0.060
30.57 134.98 0.060  31.36 134.38 0.060  32.58 133.31 0.060
33.86 128.51
179.01 133.34 0.060  199.37 143.34 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.012 0.037 0.302 0.915 0.998 0.999 0.999 0.999 0.999 1. 1. 1. 1.

4310.9062 3918.3750  4118.5707 3870.1529            (Cross section 148.559)
0.
122.37 0.025
0.028
3 1 2 1
0.00 143.98 0.060  1.19 143.89 0.060  30.30 133.16 0.060
31.46 128.17
177.39  133.28 0.060  198.30  143.15 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.013 0.040 0.348 0.924 0.998 0.999 0.999 0.999 0.999 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4291.3125 4280.1875  4074.0542 4292.6314            (Cross section 148.306)
0.
123.11 0.025
0.028
5 1 4 1
0.00 143.98 0.060  0.12 144.01 0.060  33.01 134.77 0.060
33.89 134.19 0.060  35.11 133.19 0.060
36.36 128.31
189.68 133.37 0.060  190.93 133.95 0.060  192.18 134.80 0.060
217.60 143.15 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.015 0.044 0.419 0.939 0.998 0.999 0.999 0.999 0.999 1. 1. 1. 1.

4358.7793 4732.7449  4147.3201 4779.8938            (Cross section 148.000)
0.
123.68 0.025
0.028
2 1 2 1
0.00 144.07 0.060  43.92 132.06 0.060
44.50 128.00
190.74 132.00 0.060  216.65 143.55 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.005 0.017 0.050 0.505 0.956 0.998 0.999 1. 1. 1. 1. 1. 1. 1.

4529.0617 5173.5530  4337.7959 5293.8255            (Cross section 147.678)
0.
124.88 0.025
0.028
6 1 12 1
0.00 143.70 0.060  0.37 143.61 0.060  27.61 135.78 0.060
27.98 135.75 0.060  29.20 135.08 0.060  30.48 133.28 0.060
31.76 128.33
181.66 135.93 0.060  184.13 135.84 0.060  186.60 135.53 0.060
188.79 135.84 0.060  190.47 135.69 0.060  192.60 135.63 0.060
194.92 135.96 0.060  197.63 135.66 0.060  208.33 140.84 0.060
217.93 141.02 0.060  222.63 143.85 0.060  225.95 144.01 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.003 0.005 0.020 0.055 0.597 0.975 0.998 0.999 1. 1. 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4808.4688 5642.1250  4639.3380 5729.3562            (Cross section 147.342)
0.
124.88 0.025
0.028
5 1 9 1
0.00 143.58 0.060  0.06 143.55 0.060  21.37 134.10 0.060
21.79 133.83 0.060  23.04 133.13 0.060
24.26 127.41
165.57 133.34 0.060  166.06 134.44 0.060  166.60 134.68 0.060
166.79 135.75 0.060  168.52 135.66 0.060  175.41 139.53 0.060
179.95 140.32 0.060  184.22 141.72 0.060  190.32 143.64 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.003 0.005 0.020 0.058 0.633 0.982 0.998 0.999 1. 1. 1. 1. 1. 1. 1.

4826.2500 6230.3125  4617.5419 6104.1267            (Cross section 147.219)
0.
123.80 0.025
0.028
2 1 4 1
0.00 143.64 0.060  62.12 132.73 0.060
62.48 125.95
175.29 133.13 0.060  176.51 133.74 0.060  239.42 143.58 0.060
243.90 143.61 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.003 0.005 0.020 0.058 0.620 0.979 0.998 0.999 1. 1. 1. 1. 1. 1. 1.

4335.0625 6659.1875  4218.8469 6446.1288            (Cross section 146.628)
0.
126.00 0.025
0.028
2 1 2 1
0.00 143.46 0.060  21.21 133.16 0.060
22.43 128.85
211.01 135.59 0.060  242.68 143.58 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.003 0.005 0.019 0.059 0.606 0.975 0.998 0.999 1. 1. 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
3871.9375 6684.2500  3933.4793 6527.9436              (Cross section 146.359)
0.
121.26 0.025
0.028
4 1 6 1
0.00 143.34 0.060  18.93 134.10 0.060  19.54 133.74 0.060
20.76 133.49 0.060
22.01 124.66
124.72 133.61 0.060  125.94 133.89 0.060  127.19 134.01 0.060
128.41 134.41 0.060  167.49 143.55 0.060  167.98 143.58 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.018 0.059 0.596 0.972 0.998 0.999 0.999 1. 1. 1. 1. 1. 1.

3363.5625 6615.7500  3393.6957 6373.0857              (Cross section 146.004)
0.
124.73 0.025
0.028
6 1 2 1
0.00 143.58 0.060  9.27 140.84 0.060  11.73 140.78 0.060
12.98 141.17 0.060  14.87 141.14 0.060  31.58 131.88 0.060
32.00 129.28
206.78 132.09 0.060  244.54 143.64 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.017 0.059 0.583 0.968 0.998 0.999 0.999 1. 1. 1. 1. 1. 1.

2795.1704 6598.9010  2766.5538 6360.9019              (Cross section 145.662)
0.
125.26 0.025
0.028
8 1 4 1
0.00 143.64 0.060  0.00 143.64 0.060  7.28 140.72 0.060
11.06 139.92 0.060  17.40 139.92 0.060  17.98 139.62 0.060
19.48 139.47 0.060  44.53 131.88 0.060
44.81 129.16
228.23 131.91 0.060  231.01 135.14 0.060  236.16 133.95 0.060
239.73 136.45 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.016 0.060 0.568 0.964 0.998 0.999 0.999 1. 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
2710.0619 6623.0344  2643.1275 6397.5711           (Cross section 145.600)
0.
125.43 0.025
0.028
4 1 3 1
0.00 143.76 0.060  39.38 135.32 0.060  40.69 135.05 0.060
41.91 133.52 0.060
43.22 128.98
233.14 133.19 0.060  233.60 134.77 0.060  235.21 137.33 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.016 0.060 0.566 0.964 0.998 0.999 0.999 1. 1. 1. 1. 1. 1.

2672.3502 6637.1913  2555.5851 6427.6584           (Cross section 145.561)
0.
125.31 0.025
0.028
5 1 6 1
0.00 143.79 0.060  38.92 136.14 0.060  39.35 135.32 0.060
40.57 134.31 0.060  40.87 133.40 0.060
41.79 128.66
218.66 133.55 0.060  219.88 134.10 0.060  220.74 135.53 0.060
221.25 135.72 0.060  222.47 136.05 0.060  239.88 139.98 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.016 0.060 0.564 0.963 0.998 0.999 0.999 1. 1. 1. 1. 1. 1.

2580.5000 6702.3750 2387.4686 6580.1643            (Cross section 145.460)
0.
124.16 0.025
0.028
5 1 16 1
0.00 143.67 0.060  51.97 135.41 0.060  52.21 135.23 0.060
53.46 133.80 0.060  54.68 133.06 0.060
55.93 127.16
206.04 132.97 0.060  207.26 133.61 0.060  208.54 133.95 0.060
209.03 134.53 0.060  209.40 135.23 0.060  209.76 135.17 0.060
210.98 135.47 0.060  212.20 135.99 0.060  213.42 135.99 0.060
214.64 136.05 0.060  215.92 135.96 0.060  217.17 135.96 0.060
218.48 135.96 0.060  222.05 136.08 0.060  224.97 140.29 0.060
228.45 140.50 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.015 0.060 0.560 0.962 0.998 0.999 0.999 1. 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
2553.2188 6926.0625  2369.1103 6964.7095              (Cross section 145.277)
0.
122.09 0.025
0.028
3 1 4 1
0.00 143.79 0.060  0.43 143.73 0.060  58.46 131.94 0.060
59.8 125.54
173.03 131.69 0.060  184.59 136.02 0.060  184.65 139.22 0.060  188.09 139.68 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.015 0.058 0.538 0.954 0.996 0.998 0.999 1. 1. 1. 1. 1. 1.

2717.3750 7370.8750  2521.1961 7489.9376              (Cross section 144.979)
0.
123.18 0.025
0.028
3 1 5 1
0.00 143.52 0.060  0.03 143.52 0.060  34.81 135.84 0.060
53.68 128.08
202.05 135.72 0.060  206.59 138.83 0.060  225.67 142.27 0.060
228.17 143.31 0.060  229.48 143.28 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.014 0.050 0.479 0.931 0.991 0.996 0.998 0.999 1. 1. 1. 1. 1.

2957.0777 7697.0014  2803.3190 7862.9502              (Cross section 144.618)
0.
122.07 0.025
0.028
19 1 4 1
0.00 143.61 0.060  1.22 143.34 0.060  4.91 141.42 0.060
7.28 140.44 0.060  8.75 139.77 0.060  10.00 139.68 0.060
16.00 140.20 0.060  18.50 140.47 0.060  20.94 139.65 0.060
21.95 138.70 0.060  23.26 137.91 0.060  24.96 136.63 0.060
27.34 136.23 0.060  28.22 136.02 0.060  28.53 136.11 0.060
29.05 135.32 0.060  29.54 135.08 0.060  30.97 134.28 0.060
32.22 133.40 0.060
33.47 127.57
184.10 132.79 0.060  184.19 133.43 0.060  184.62 133.80 0.060
226.22 143.21 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.013 0.043 0.428 0.912 0.986 0.995 0.997 0.999 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
3229.7500 7892.1250  3126.7813 8071.5000            (Cross section 144.319)
0.
121.46 0.025
0.028
5 1 1 1
0.00 143.34 0.060  0.15 143.40 0.060  31.76 141.29 0.060
39.08 138.43 0.060  48.28 136.17 0.060
55.72 127.36
206.84 142.94 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.001 0.003 0.012 0.037 0.386 0.896 0.982 0.993 0.996 0.999 0.999 1. 1. 1. 1.

3588.3750 8072.4375  3489.0219 8233.1590            (Cross section 143.990)
0.
119.29 0.025
0.028
4 1 2 1
0.00 143.31 0.060  0.18 143.37 0.060  19.57 137.36 0.060
29.20 137.12 0.060
44.04 126.74
188.58 142.94 0.060  188.98 143.00 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.001 0.003 0.011 0.031 0.340 0.879 0.978 0.992 0.996 0.998 0.999 1. 1. 1. 1.

3816.3665 8223.6745  3677.5773 8389.4355            (Cross section 143.839)
0.
119.42 0.025
0.028
6 1 5 1
0.00 143.49 0.060  15.85 136.30 0.060  16.70 136.14 0.060
17.98 136.23 0.060  18.50 135.38 0.060  19.20 134.25 0.060
20.42 128.17
174.80 133.34 0.060  176.08 133.64 0.060  177.33 134.22 0.060
178.55 134.28 0.060  216.19 142.82 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.001 0.003 0.010 0.027 0.311 0.867 0.975 0.991 0.995 0.998 0.999 1. 1. 1. 1.

4039.6250 8398.3125  3859.7145 8583.1683            (Cross section 143.679)
0.
119.02 0.025
0.028
2 1 2 1
0.00 143.46 0.060  17.31 132.88 0.060
17.71 128.97
205.71 133.52 0.060  257.95 143.46 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.001 0.003 0.011 0.031 0.332 0.868 0.974 0.990 0.995 0.998 0.999 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4299.8744 8588.7394  4058.2805 8832.9755              (Cross section 143.492)
0.
120.24 0.025
0.028
4 1 10 1
0.00 143.28 0.060  21.37 135.11 0.060  22.16 134.50 0.060
23.38 134.25 0.060
25.79 130.19
261.21 133.74 0.060  262.43 133.95 0.060  263.68 134.10 0.060
264.90 134.71 0.060  266.21 134.77 0.060  267.43 134.95 0.060
269.90 135.84 0.060  288.71 136.36 0.060  294.86 140.84 0.060
343.54 143.12 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.012 0.050 0.452 0.893 0.977 0.990 0.994 0.998 1. 1. 1. 1. 1.


2 4 6                                                 (Reach 2)
4407.0625 8695.1875  4247.1579 8877.0396              (Cross section 143.406)
0.
121.40 0.025
0.028
1 1 2 1
0.00 143.28 0.060
24.38 129.60
238.96 136.11 0.060  242.16 141.32 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.012 0.053 0.464 0.894 0.972 0.986 0.992 0.997 0.999 1. 1. 1. 1.

4651.1250 9032.3125  4514.1187 9096.9923              (Cross section 143.179)
0.
123.30 0.025
0.028
5 1 4 1
0.00 143.31 0.060  17.56 134.83 0.060  17.68 134.41 0.060
18.44 133.83 0.060  19.35 133.58 0.060
20.39 127.15
143.80 133.22 0.060  144.78 133.67 0.060  145.91 134.38 0.060
151.52 140.35 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.004 0.012 0.049 0.438 0.888 0.968 0.983 0.990 0.996 0.999 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4694.7500 9357.8750  4531.5842 9361.9094            (Cross section 143.003)
0.
125.24 0.025
0.028
6 1 8 1
0.00 143.06 0.060  14.81 135.47 0.060  15.21 135.63 0.060
15.51 135.38 0.060  16.73 134.59 0.060  17.98 133.46 0.060
19.23 126.69
134.39 133.46 0.060  135.64 134.71 0.060  142.25 136.33 0.060
144.69 136.20 0.060  146.46 136.42 0.060  151.64 136.39 0.060
159.75 141.45 0.060  163.22 142.48 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.003 0.011 0.045 0.401 0.879 0.963 0.980 0.988 0.995 0.999 1. 1. 1. 1.

4890.4375 9727.2500 4542.5500 9736.7756             (Cross section 142.788)
0.
126.91 0.025
0.028
7 1 4 1
0.00 142.85 0.060  31.00 137.85 0.060  54.99 133.40 0.060
110.40 137.85 0.060  166.27 138.28 0.060  174.10 133.52 0.060
174.44 133.40 0.060
175.66 128.21
315.68 133.74 0.060  339.67 138.70 0.060  341.71 138.61 0.060
348.02 139.77 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32 64
0.002 0.003 0.011 0.042 0.382 0.875 0.960 0.978 0.987 0.994 0.998 1. 1. 1. 1.

4743.7500 10143.0625  4480.0847 10074.8950          (Cross section 142.575)
0.
126.44 0.025
0.028
23 1 2 1
0.00 142.94 0.060  16.34 142.91 0.060  19.20 142.30 0.060
22.52 141.78 0.060  25.42 140.87 0.060  29.93 139.68 0.060
32.00 139.56 0.060  35.27 139.34 0.060  37.46 139.34 0.060
40.48 138.83 0.060  42.92  138.83 0.060  46.63 138.95 0.060
49.65 139.25 0.060  52.12 139.22 0.060  54.38 139.25 0.060
56.75 139.47 0.060  59.04 139.34 0.060  74.86 139.07 0.060
83.73 135.69 0.060  85.07 135.35 0.060  86.35 134.83 0.060
87.75 134.04 0.060  89.12 133.40 0.060
90.37 127.59
258.01 136.78 0.040  272.34 140.17 0.040
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.002 0.009 0.019 0.230 0.869 0.954 0.973 0.985 0.992 0.997 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4668.7188 10442.0625  4435.4437 10282.4924          (Cross section 142.432)
0.
126.60 0.025
0.028
40 1 7 1
0.00 142.88 0.060  2.59 142.79 0.060  5.43 141.63 0.060
8.02 140.96 0.060  10.33 140.50 0.060  12.56 140.29 0.060
14.57 140.14 0.060  16.86 140.04 0.060  22.43 139.80 0.060
24.66 139.68 0.060  27.04 139.56 0.060  29.38 139.53 0.060
31.52 139.56 0.060  33.50 139.37 0.060  38.44 139.28 0.060
40.39 139.25 0.060  42.67 139.47 0.060  44.14 139.50 0.060
45.35 139.50 0.060  49.77 139.50 0.060  52.79 139.65 0.060
55.50 139.65 0.060  57.64 139.47 0.060  59.89 139.56 0.060
64.71 139.34 0.060  66.81 139.40 0.060  69.74 139.44 0.060
72.66 139.40 0.060  74.71 139.50 0.060  76.90 139.50 0.060
80.44 139.53 0.060  82.54 139.50 0.060  84.64 139.59 0.060
87.36 139.53 0.060  89.52 139.37 0.060  91.47 139.31 0.060
95.31 139.10 0.060  97.57 139.01 0.060  100.34 139.07 0.060
102.90 138.98 0.060
122.74 127.65
263.80 133.58 0.060 265.08 133.80 0.060  266.33 134.65 0.060
267.55 135.17 0.060  268.77 135.72 0.060  270.05 135.87 0.060
277.64 136.42 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.009 0.017 0.259 0.914 0.979 0.988 0.993 0.997 0.999 1. 1. 1. 1. 1.

2 4 8                                               (Reach 3)—side channel
4230.2800 8853.3100  4061.9400 8861.1900            (Cross section 0.051)
0.
125.05 0.025
0.028
11 1 29 1
0.00 136.72 0.060  2.04 136.42 0.060  4.05 136.14 0.060
6.55 135.87 0.060  8.05 135.75 0.060  11.03 135.75 0.060
11.55 135.59 0.060  12.53 135.29 0.060  13.05 135.20 0.060
14.54 134.95 0.060  15.54 134.71 0.060
17.04 132.85
90.56 134.59 0.060  92.05 134.86 0.060  94.03 135.20 0.060
96.53 135.53 0.060  100.04 135.84 0.060  103.54 136.11 0.060
105.03 136.42 0.060  107.05 136.75 0.060  109.03 137.03 0.060
114.03 137.36 0.060  119.05 137.67 0.060  120.03 137.88 0.060
121.55 138.28 0.060  123.54 138.86 0.060  124.54 139.10 0.060
126.03 139.47 0.060  128.05 139.80 0.060  130.55 140.11 0.060
133.53 140.41 0.060  137.04 140.75 0.060  140.54 141.02 0.060
145.05 141.32 0.060  150.05 141.63 0.060  156.03 141.93 0.060
162.55 142.24 0.060  170.54 142.54 0.060  180.05 142.85 0.060
189.04 143.06 0.060  197.54 143.09 0.060
1
0.125
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4248.4359 8901.1894 4061.5481 8903.9377            (Cross section 0.178)
0.
124.51 0.025
0.028
14 1 15 1
0.00 139.13 0.060  2.41 138.64 0.060  3.90 138.28 0.060
5.39 137.94 0.060  6.89 137.51 0.060  8.41 137.03 0.060
9.91 136.60 0.060  11.40 136.14 0.060  12.89 135.72 0.060
14.42 135.56 0.060  17.40 135.69 0.060  18.90 135.47 0.060
20.39 135.32 0.060  21.92 135.14 0.060
23.41 133.26
77.39 134.98 0.060  78.91 135.17 0.060  80.41 135.23 0.060
81.90 135.35 0.060  83.39 135.50 0.060  87.90 135.53 0.060
89.40 135.59 0.060  93.91 136.11 0.060  95.40 136.23 0.060
101.41 136.66 0.060  110.40 137.45 0.060  123.90 138.64 0.060
140.39 139.95 0.060  161.39 141.45 0.060  186.90 143.06 0.060
1
0.125

4138.9541 9136.5745 3987.9827 9103.0253            (Cross section 0.315)
0.
129.11 0.025
0.028
34 1 24 1
0.00 140.75 0.060  9.69 140.68 0.060  13.69 140.62 0.060
14.69 140.56 0.060  15.70 140.47 0.060  16.67 140.44 0.060
17.68 140.38 0.060  18.68 140.29 0.060  19.69 140.17 0.060
20.70 139.98 0.060  21.67 139.68 0.060  22.68 139.44 0.060
23.68 139.28 0.060  24.69 139.10 0.060  25.69 138.98 0.060
26.70 138.86 0.060  27.68 138.73 0.060  28.68 138.58 0.060
29.69 138.46 0.060  30.69 138.37 0.060  31.70 138.28 0.060
32.67 138.15 0.060  33.68 138.00 0.060  34.69 137.70 0.060
35.69 137.36 0.060  36.70 137.09 0.060  37.67 136.81 0.060
38.68 136.45 0.060  39.68 136.05 0.060  40.69 135.78 0.060
41.70 135.63 0.060  42.67 135.44 0.060  43.68 135.23 0.060
44.68 135.02 0.060
45.69 133.11
98.69 134.98 0.060  99.70 135.63 0.060  100.68 136.05 0.060
101.68 136.27 0.060  102.69 136.51 0.060  103.69 136.87 0.060
104.70 137.27 0.060  105.67 137.64 0.060  106.68 138.00 0.060
107.69 138.25 0.060  108.69 138.49 0.060  109.70 138.70 0.060
110.67 138.89 0.060  111.68 139.16 0.060  112.68 139.53 0.060
113.69 139.92 0.060  114.70 140.56 0.060  115.67 141.20 0.060
116.68 141.69 0.060  117.68 142.15 0.060  118.69 142.42 0.060
122.68 142.91 0.060  137.68 143.15 0.060  154.69 143.31 0.060
1
0.125
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4155.7287 9317.7402 4006.4348 9374.7738            (Cross section 0.494)
0.
131.5 0.025
0.028
23 1 20 1
0.00 140.78 0.060  6.80 140.59 0.060  11.31 140.50 0.060
14.30 140.32 0.060  15.82 140.14 0.060  17.31 139.77 0.060
18.81 139.37 0.060  20.30 139.04 0.060  21.79 138.64 0.060
23.32 138.28 0.060  24.81 138.06 0.060  26.30 137.91 0.060
27.80 137.79 0.060  29.32 137.64 0.060  30.82 137.39 0.060
32.31 137.06 0.060  33.80 136.51 0.060  35.30 136.14 0.060
36.82 135.87 0.060  38.31 135.69 0.060  39.81 135.53 0.060
41.30 135.32 0.060  42.79 134.98 0.060
44.32 133.00
95.31 135.56 0.060  96.80 136.20 0.060  98.30 136.60 0.060
99.79 137.09 0.060  101.32 137.64 0.060  102.81 138.12 0.060
104.30 138.58 0.060  105.80 139.04 0.060  107.32 140.08 0.060
108.81 140.90 0.060  110.31 141.57 0.060  111.80 142.12 0.060
113.29 142.54 0.060  119.30 143.21 0.060  120.79 143.09 0.060
122.32 143.15 0.060  123.81 143.25 0.060  129.81 143.21 0.060
146.30 143.28 0.060  159.81 143.25 0.060
1
0.125

4299.9902 9577.7464 4165.7935 9649.8771            (Cross section 0.684)
0.
131.41 0.025
0.028
23 1 24 1
0.00 140.96 0.060  9.36 140.90 0.060  16.37 140.84 0.060
19.35 140.78 0.060  20.36 140.72 0.060  21.37 140.62 0.060
22.37 140.53 0.060  23.38 140.38 0.060  24.38 140.20 0.060
25.36 139.89 0.060  26.37 139.59 0.060  27.37 139.16 0.060
28.38 138.73 0.060  29.38 138.12 0.060  30.36 137.39 0.060
31.36 136.84 0.060  32.37 136.39 0.060  33.38 135.99 0.060
34.38 135.81 0.060  35.36 135.63 0.060  36.36 135.50 0.060
37.37 135.35 0.060  38.37 134.95 0.060
39.38 132.81
85.37 136.17 0.060  86.38 137.88 0.060  87.36 138.79 0.060
88.36 139.25 0.060  89.37 139.62 0.060  90.37 139.77 0.060
91.38 139.98 0.060  92.35 140.32 0.060  93.36 140.65 0.060
94.37 141.08 0.060  95.37 141.51 0.060  96.38 141.87 0.060
97.38 142.21 0.060  98.36 142.51 0.060  99.36 142.73 0.060
100.37 142.94 0.060  104.36 143.28 0.060  106.38 143.34 0.060
110.37 143.06 0.060  113.36 142.88 0.060  119.36 142.91 0.060
145.36 143.31 0.060  150.36 143.31 0.060  152.37 143.28 0.060
1
0.125
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4436.7032 9841.9463 4299.8225 9880.8633             (Cross section 0.822)
0.
131.63 0.025
0.028
14 1 20 1
0.00 140.93 0.060  3.35 140.72 0.060  7.35 140.47 0.060
8.35 140.41 0.060  14.36 140.23 0.060  24.35 139.37 0.060
30.33 138.79 0.060  31.33 138.70 0.060  32.34 138.55 0.060
33.35 138.40 0.060  34.35 138.09 0.060  35.36 137.79 0.060
36.33 136.87 0.060  37.34 135.90 0.060
38.34 132.88
83.33 134.98 0.060  84.34 135.26 0.060  85.34 135.81 0.060
86.35 136.36 0.060  87.36 136.94 0.060  88.33 137.48 0.060
89.34 137.94 0.060  90.34 138.34 0.060  91.35 138.67 0.060
98.33 139.98 0.060  103.33 140.81 0.060  108.36 141.26 0.060
113.36 141.81 0.060  118.35 142.27 0.060  123.35 142.64 0.060
128.35 143.09 0.060  133.35 143.40 0.060  136.34 143.40 0.060
139.35 143.09 0.060  142.34 143.09 0.060
1
0.125

4449.2841 10072.5969 4278.1832 10084.3392           (Cross section 0.981)
0.
132.31 0.025
0.028
14 1 30 1
0.00 139.83 0.060  0.49 139.83 0.060  1.98 139.80 0.060
3.47 139.74 0.060  4.97 139.71 0.060  6.49 139.53 0.060
7.99 139.19 0.060  9.48 138.46 0.060  10.97 138.19 0.060
12.47 138.12 0.060  13.99 138.06 0.060  15.48 137.00 0.060
16.98 135.75 0.060  18.47 134.98 0.060
19.99 133.31
67.97 135.14 0.060  69.49 135.32 0.060  70.99 135.44 0.060
72.48 135.53 0.060  73.97 135.81 0.060  75.47 136.11 0.060
76.99 136.36 0.060  78.49 136.45 0.060  79.98 136.51 0.060
81.47 136.51 0.060  82.97 136.54 0.060  84.49 136.48 0.060
85.98 136.39 0.060  87.48 136.42 0.060  88.97 136.45 0.060
90.50 136.48 0.060  91.99 136.45 0.060  93.48 136.81 0.060
94.98 137.18 0.060  96.47 137.39 0.060  97.99 137.55 0.060
99.49 137.70 0.060  100.98 137.91 0.060  103.97 138.00 0.060
109.97 138.52 0.060  120.49 139.47 0.060  129.48 140.32 0.060
139.99 140.99 0.060  165.48 142.94 0.060  171.48 143.03 0.060
1
0.125
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4434.1870 10282.2794  4264.7636 10268.8597           (Cross section 1.010)
0.
132.20 0.025
0.028
5 1 14 1
0.00 136.02 0.060  0.46 135.99 0.060  1.95 135.87 0.060
3.44 135.72 0.060  4.97 135.26 0.060
6.46 133.25
69.46 135.99 0.060  70.96 137.03 0.060  72.45 137.70 0.060
73.94 137.91 0.060  75.47 138.03 0.060  79.95 138.06 0.060
81.44 138.15 0.060  82.97 138.15 0.060  84.46 138.19 0.060
87.45 138.43 0.060  93.45 138.98 0.060  102.44 139.47 0.060
133.96 140.90 0.060  169.96 142.36 0.060
1
0.125

2 1 13                                                (Reach 4)
4533.4375 10552.3125   4327.5094 10381.0390          (Cross section 142.345)
0.
126.97 0.025
0.028
18 1 21 1
0.00 143.21 0.060  33.92 138.52 0.060  35.48 138.52 0.060
37.34 138.46 0.060  39.08 138.58 0.060  41.00 138.55 0.060
43.46 138.61 0.060  44.78 138.64 0.060  47.49 138.79 0.060
50.81 138.83 0.060  55.69 139.01 0.060  57.82 138.89 0.060
63.76 138.43 0.060  66.42 138.22 0.060  69.56 135.50 0.060
76.35 135.14 0.060  76.90 134.31 0.060  77.51 133.98 0.060
78.73 127.97
227.93 133.31 0.060  229.18 133.52 0.060  230.43 133.77 0.060
231.68 133.95 0.060  232.93 133.92 0.060  234.15 133.95 0.060
235.37 134.07 0.060  236.59 134.19 0.060  237.80 134.62 0.060
239.15 134.77 0.060  240.52 135.23 0.060  241.86 135.14 0.060
243.17 135.05 0.060  244.45 135.17 0.060  245.88 135.63 0.060
247.35 135.78 0.060  248.56 136.11 0.060  249.81 136.14 0.060
251.09 136.23 0.060  260.06 138.83 0.060  267.83 140.29 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.016 0.278 0.942 0.995 0.998 0.998 1. 1. 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
4298.8125 10761.4375  4146.6156 10577.8320           (Cross section 142.177)
0.
125.35 0.025
0.028
12 1 25 1
0.00 143.15 0.060  2.62 141.90 0.060  4.91 141.08 0.060
8.32 139.95 0.060  11.06 139.31 0.060  13.41 138.89 0.060
19.11 138.55 0.060  21.15 138.43 0.060  24.54 138.28 0.060
26.58 138.31 0.060  29.11 138.43 0.060  33.65 138.43 0.060
44.20 127.75
184.95 133.52 0.060  186.23 133.61 0.060  187.54 133.89 0.060
188.85 134.04 0.060  190.07 134.47 0.060  191.29 134.83 0.060
192.57 135.17 0.060  193.94 135.32 0.060  195.29 135.38 0.060
196.66 135.41 0.060  197.88 135.53 0.060  199.16 135.38 0.060
200.47 135.47 0.060  201.69 135.63 0.060  203.06 135.50 0.060
204.58 135.53 0.060  205.95 135.38 0.060  207.29 135.50 0.060
208.85 135.93 0.060  210.07 136.05 0.060  216.13 136.02 0.060
225.22 135.75 0.060  226.68 135.87 0.060  229.36 136.60 0.060
238.51 138.25 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.016 0.281 0.932 0.989 0.995 0.997 0.999 1. 1. 1. 1. 1. 1.

4007.3437 10925.3125  3871.1617 10662.5271           (Cross section 141.994)
0.
123.42 0.025
0.028
2 1 26 1
0.00 142.82 0.060  5.88 142.73 0.060
30.24 127.30
156.12 133.43 0.060  157.37 133.77 0.060  158.80 133.86 0.060
160.05 134.01 0.060  161.39 134.10 0.060  162.73 134.34 0.060
164.01 134.41 0.060  165.69 134.65 0.060  167.73 134.62 0.060
169.47 134.71 0.060  170.69 134.95 0.060  172.15 134.98 0.060
173.71 134.77 0.060  175.26 134.83 0.060  176.54 134.74 0.060
178.06 135.05 0.060  179.28 134.98 0.060  180.56 135.05 0.060
182.18 135.20 0.060  184.56 135.44 0.060  186.11 135.66 0.060
187.45 135.75 0.060  188.79 135.99 0.060  190.13 136.05 0.060
231.10 136.60 0.060  295.96 142.88 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.017 0.282 0.918 0.980 0.991 0.995 0.998 0.999 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
3578.6250 11204.7500  3429.0618 10967.3935           (Cross section 141.677)
0.
122.42 0.025
0.028
20 1 5 1
0.00 142.91 0.060  7.99 142.76 0.060  10.73 142.00 0.060
12.92 141.42 0.060  15.76 140.90 0.060  18.56 140.38 0.060
20.85 140.11 0.060  25.36 139.74 0.060  27.77 139.22 0.060
30.14 139.07 0.060  32.58 138.79 0.060  34.81 138.61 0.060
38.71 138.76 0.060  40.87 138.86 0.060  42.49 138.73 0.060
44.87 138.58 0.060  47.15 138.89 0.060  49.44 139.56 0.060
51.60 140.53 0.060  54.47 141.02 0.060
74.77 128.42
241.74 133.10 0.060  243.08 133.43 0.060  244.39 134.10 0.060
245.64 136.17 0.060  280.57 142.60 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.018 0.284 0.894 0.966 0.983 0.992 0.997 0.999 1. 1. 1. 1. 1.

3066.0364 11387.1636  2977.1822 11185.6842           (Cross section 141.362)
0.
122.06 0.025
0.028
4 1 5 1
0.00 141.72 0.060  28.10 134.10 0.060  29.20 133.61 0.060
30.51 133.46 0.060
31.18 128.06
182.54 133.46 0.060  183.86 134.22 0.060  185.07 134.59 0.060
186.35 135.41 0.060  220.19 143.06 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.019 0.285 0.869 0.952 0.975 0.989 0.996 0.999 1. 1. 1. 1. 1.

2838.6562 11499.8750  2708.2392 11403.0216           (Cross section 141.180)
0.
120.53 0.025
0.028
7 1 6 1
0.00 141.32 0.060  3.26 140.50 0.060  4.54 135.20 0.060
5.27 134.95 0.060  5.97 134.53 0.060  6.19 133.37 0.060
6.52 133.37 0.060
7.74 126.53
148.74 134.83 0.060  148.96 135.50 0.060  150.17 135.96 0.060
154.35 135.14 0.060  161.36 140.65 0.060  162.46 140.99 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.019 0.286 0.855 0.944 0.971 0.987 0.995 0.998 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
2818.7188 11669.2500  2679.4811 11741.7789           (Cross section 141.014)
0.
116.91 0.025
0.028
6 1 3 1
0.00 142.88 0.060  1.74 143.00 0.060  9.08 142.30 0.060
9.69 136.78 0.060  18.65 135.44 0.060  20.57 131.75 0.060
20.97  122.91
153.16 135.99 0.060  155.75 141.57 0.060  157.00 140.96 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.020 0.287 0.843 0.937 0.967 0.986 0.994 0.998 1. 1. 1. 1. 1.

3143.4757 11764.5557  3113.5114 11988.1517           (Cross section 140.742)
0.
121.44 0.025
0.028
9 1 4 1
0.00 141.42 0.060  17.95 136.66 0.060  48.40 134.62 0.060
49.47 134.56 0.060  50.72 134.47 0.060  51.94 134.04 0.060
53.19 133.98 0.060  54.44 133.74 0.060  55.72 133.37 0.060
56.97 127.44
201.38 134.13 0.060  202.63 134.59 0.060  203.91 134.98 0.060
225.55 143.28 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.021 0.288 0.822 0.925 0.961 0.983 0.993 0.998 1. 1. 1. 1. 1.

3720.2775 11780.3029  3668.3454 12044.7195           (Cross section 140.402)
0.
121.06 0.025
0.028
23 1 1 1
0.00 143.37 0.060  0.70 143.31 0.060  3.78 143.12 0.060
6.10 141.23 0.060  8.75 140.65 0.060  10.85 140.65 0.060
13.47 140.23 0.060  16.58 139.86 0.060  17.86 138.98 0.060
19.81 138.73 0.060  22.13 138.52 0.060  27.71 138.49 0.060
29.38 138.58 0.060  32.86 138.98 0.060  35.54 139.53 0.060
37.67 139.74 0.060  40.29 139.07 0.060  42.40 138.79 0.060
74.34 133.92 0.060  74.92 133.89 0.060  76.20 133.70 0.060
77.54 133.52 0.060  78.79 133.34 0.060
80.07 127.06
269.47 142.97 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.022 0.290 0.795 0.909 0.952 0.979 0.992 0.997 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
3924.2209 11815.4811  3851.2763 12097.5397            (Cross section 140.282)
0.
118.41 0.025
0.028
5 1 6 1
0.00 141.90 0.060  8.63 137.85 0.060  10.55 136.30 0.060
12.37 135.35 0.060  14.81 133.28 0.060
16.03 124.41
200.47 133.19 0.060  204.25 135.50 0.060  206.47 137.06 0.060
209.89 137.67 0.060  214.30 140.17 0.060  219.73 141.90 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.022 0.291 0.786 0.904 0.950 0.978 0.991 0.997 1. 1. 1. 1. 1.

4166.4012 11882.0004  4063.1610 12160.5087            (Cross section 140.141)
0.
122.85 0.025
0.028
3 1 1 1
0.00 143.28 0.060  10.52 140.44 0.060  11.58 140.20 0.060
36.64 128.85
297.03 142.91 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.022 0.291 0.784 0.903 0.949 0.978 0.991 0.997 1. 1. 1. 1. 1.

4412.8437 11950.4375  4331.0096 12239.0577            (Cross section 139.980)
0.
123.07 0.025
0.028
8 1 3 1
0.00 143.21 0.060  0.85 143.25 0.060  12.62 140.53 0.060
12.74 140.81 0.060  13.87 140.32 0.060  40.29 139.01 0.060
40.78 139.28 0.060  42.03 139.44 0.060
55.75 129.07
261.55 133.16 0.060  297.36 142.94 0.060  300.01 142.94 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.022 0.291 0.784 0.903 0.949 0.978 0.991 0.997 1. 1. 1. 1. 1.
```

Appendix B. Listing of Model Network-Description File, Xscdatm.txt.—Continued

```
5150.5000 12562.5000  4960.1958 12641.9966           (Cross section 139.469)
0.
121.39 0.025
0.028
6 1 7 1
0.00 148.64 0.060  10.36 143.61 0.060  17.04 139.74 0.060
19.05 137.67 0.060  19.99 137.00 0.060  24.63 134.04 0.060
25.21 127.39
186.42 133.46 0.060  187.67 133.64 0.060  188.95 133.95 0.060
190.26 134.07 0.060  191.48 134.31 0.060  205.25 136.51 0.060
206.26 139.86 0.060
15
.0625 .0884 .125 .177 .25 .354 .5 .707 1 1.41 2 4 8 16 32
0.003 0.010 0.022 0.291 0.784 0.903 0.949 0.978 0.991 0.997 1. 1. 1. 1. 1.
2
3 -1  2  3
3 -2 -3  4
```

Listing of model boundary condition file (bndhyd.txt)

The following is the input boundary condition file in the white sturgeon reach of the Kootenai River near Bonners Ferry, Idaho, for the 47,500 ft^3/s discharge simulation.

```
CS
0  1
1
0 1345.050       10.
1    0.000195
0.   0.053887453  8
0.0884 0.1768 0.3536 0.7071 1.4142 2.8284 5.6569 11.3137
0.330 0.468 0.579 0.688 0.855 0.981 0.997 1.
1
0  137.484
```

Appendix C. Partial listing of model output file, SecTSSprSht.txt.

The following is a partial listing of the SecTSSprSht.txt output file generated by SEDMOD for the white sturgeon reach of the Kootenai River near Bonners Ferry, Idaho, for the 47,700 ft^3/s discharge simulation.

```
Multi-Channel Transport, by James P. Bennett, U.S. Geological Survey, 2000

Run Date and Time    2004 12  29   1048

Basic maximum time step, days     0.100
Maximum bed elevation change before new sub-timestep,  m,     0.010
Maximum bedform height, as fraction of flow depth     0.350
Coefficient in McLean, s Ca. relationship     0.00800
Coefficient in MPM bedload equation     8.0000
Default active layer thickness as a fraction of depth     0.100

Node elevation balancing Disabled
Alluvial channel resistance computed from User supplied coefficients

                                 File  SecTSSprSht.txt
```

Channel Segment	Cross Section	Time (days)	Ch Dist (m)	WS Elev (m)	Hyd Rad (m)	X-Sec Area (m*m)	Velocity (m/m)	Discharge (m*m*m/s)
1	1	7.65042E-04	0.00000E+00	1.38292E+02	4.57921E+00	1.61497E+03	8.32865E-01	1.34505E+03
1	1	2.06948E-02	0.00000E+00	1.38291E+02	4.57808E+00	1.61456E+03	8.33074E-01	1.34505E+03
1	1	4.07096E-02	0.00000E+00	1.38292E+02	4.57814E+00	1.61459E+03	8.33059E-01	1.34505E+03
1	1	6.00389E-02	0.00000E+00	1.38293E+02	4.57881E+00	1.61485E+03	8.32928E-01	1.34505E+03
1	1	8.02377E-02	0.00000E+00	1.38294E+02	4.57869E+00	1.61481E+03	8.32946E-01	1.34505E+03
1	1	1.00544E-01	0.00000E+00	1.38295E+02	4.57920E+00	1.61500E+03	8.32846E-01	1.34505E+03
1	1	1.20174E-01	0.00000E+00	1.38296E+02	4.57949E+00	1.61511E+03	8.32789E-01	1.34505E+03
1	1	1.40623E-01	0.00000E+00	1.38298E+02	4.58072E+00	1.61557E+03	8.32553E-01	1.34505E+03
1	1	1.60279E-01	0.00000E+00	1.38300E+02	4.58260E+00	1.61626E+03	8.32198E-01	1.34505E+03
1	1	1.80203E-01	0.00000E+00	1.38303E+02	4.58522E+00	1.61722E+03	8.31703E-01	1.34505E+03
1	1	2.00590E-01	0.00000E+00	1.38306E+02	4.58750E+00	1.61806E+03	8.31274E-01	1.34505E+03
1	1	2.20355E-01	0.00000E+00	1.38310E+02	4.59027E+00	1.61907E+03	8.30753E-01	1.34505E+03
1	1	2.40703E-01	0.00000E+00	1.38312E+02	4.59208E+00	1.61974E+03	8.30411E-01	1.34505E+03
1	1	2.60254E-01	0.00000E+00	1.38315E+02	4.59430E+00	1.62056E+03	8.29992E-01	1.34505E+03
1	1	2.80209E-01	0.00000E+00	1.38319E+02	4.59772E+00	1.62182E+03	8.29348E-01	1.34505E+03
1	1	3.00786E-01	0.00000E+00	1.38323E+02	4.60016E+00	1.62271E+03	8.28890E-01	1.34505E+03
1	1	3.20481E-01	0.00000E+00	1.38327E+02	4.60369E+00	1.62401E+03	8.28230E-01	1.34505E+03
1	1	3.40028E-01	0.00000E+00	1.38331E+02	4.60726E+00	1.62532E+03	8.27562E-01	1.34505E+03
1	1	3.60259E-01	0.00000E+00	1.38337E+02	4.61178E+00	1.62697E+03	8.26718E-01	1.34505E+03
1	1	3.80390E-01	0.00000E+00	1.38342E+02	4.61603E+00	1.62853E+03	8.25927E-01	1.34505E+03
1	1	4.00766E-01	0.00000E+00	1.38347E+02	4.62017E+00	1.63005E+03	8.25158E-01	1.34505E+03
1	1	4.20124E-01	0.00000E+00	1.38352E+02	4.62476E+00	1.63173E+03	8.24308E-01	1.34505E+03
1	1	4.40178E-01	0.00000E+00	1.38357E+02	4.62907E+00	1.63331E+03	8.23510E-01	1.34505E+03
1	1	4.60743E-01	0.00000E+00	1.38363E+02	4.63347E+00	1.63493E+03	8.22698E-01	1.34505E+03
1	1	4.80793E-01	0.00000E+00	1.38368E+02	4.63781E+00	1.63652E+03	8.21898E-01	1.34505E+03
1	1	5.01017E-01	0.00000E+00	1.38373E+02	4.64267E+00	1.63830E+03	8.21005E-01	1.34505E+03
1	1	5.21068E-01	0.00000E+00	1.38379E+02	4.64754E+00	1.64008E+03	8.20112E-01	1.34505E+03

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Channel Segment	Cross Section	Time (days)	Ch Dist (m)	WS Elev (m)	Hyd Rad (m)	X-Sec Area (m*m)	Velocity (m/m)	Discharge (m*m*m/s)
4	79	3.00786E-01	4.75199E+03	1.37484E+02	7.35904E+00	1.38518E+03	9.71030E-01	1.34505E+03
4	79	3.20481E-01	4.75199E+03	1.37484E+02	7.18676E+00	1.35275E+03	9.94306E-01	1.34505E+03
4	79	3.40028E-01	4.75198E+03	1.37484E+02	7.02035E+00	1.32143E+03	1.01787E+00	1.34505E+03
4	79	3.60259E-01	4.75197E+03	1.37484E+02	6.85544E+00	1.29039E+03	1.04236E+00	1.34505E+03
4	79	3.80390E-01	4.75195E+03	1.37484E+02	6.70147E+00	1.26141E+03	1.06631E+00	1.34505E+03
4	79	4.00766E-01	4.75194E+03	1.37484E+02	6.55505E+00	1.23385E+03	1.09013E+00	1.34505E+03
4	79	4.20124E-01	4.75193E+03	1.37484E+02	6.42209E+00	1.20882E+03	1.11270E+00	1.34505E+03
4	79	4.40178E-01	4.75192E+03	1.37484E+02	6.28923E+00	1.18381E+03	1.13620E+00	1.34505E+03
4	79	4.60743E-01	4.75190E+03	1.37484E+02	6.15643E+00	1.15881E+03	1.16071E+00	1.34505E+03
4	79	4.80793E-01	4.75189E+03	1.37484E+02	6.03000E+00	1.13502E+03	1.18505E+00	1.34505E+03
4	79	5.01017E-01	4.75188E+03	1.37484E+02	5.90679E+00	1.11182E+03	1.20977E+00	1.34505E+03
4	79	5.21068E-01	4.75187E+03	1.37484E+02	5.78708E+00	1.08929E+03	1.23479E+00	1.34505E+03
4	79	5.41033E-01	4.75186E+03	1.37484E+02	5.66999E+00	1.06725E+03	1.26029E+00	1.34505E+03
4	79	5.60638E-01	4.75185E+03	1.37484E+02	5.55570E+00	1.04574E+03	1.28622E+00	1.34505E+03
4	79	5.81221E-01	4.75184E+03	1.37484E+02	5.43872E+00	1.02372E+03	1.31388E+00	1.34505E+03
4	79	6.00223E-01	4.75183E+03	1.37484E+02	5.33141E+00	1.00352E+03	1.34033E+00	1.34505E+03
4	79	6.20037E-01	4.75182E+03	1.37484E+02	5.22294E+00	9.83106E+02	1.36816E+00	1.34505E+03
4	79	6.41065E-01	4.75181E+03	1.37484E+02	5.11313E+00	9.62435E+02	1.39755E+00	1.34505E+03
4	79	6.60048E-01	4.75185E+03	1.37484E+02	5.01768E+00	9.44471E+02	1.42413E+00	1.34505E+03
4	79	6.80163E-01	4.75183E+03	1.37484E+02	4.92193E+00	9.26446E+02	1.45184E+00	1.34505E+03
4	79	7.00764E-01	4.75181E+03	1.37484E+02	4.82836E+00	9.08834E+02	1.47997E+00	1.34505E+03
4	79	7.20186E-01	4.75178E+03	1.37484E+02	4.74365E+00	8.92889E+02	1.50640E+00	1.34505E+03
4	79	7.40268E-01	4.75175E+03	1.37484E+02	4.66038E+00	8.77215E+02	1.53332E+00	1.34505E+03
4	79	7.60887E-01	4.75171E+03	1.37484E+02	4.57830E+00	8.61766E+02	1.56081E+00	1.34505E+03
4	79	7.80841E-01	4.75168E+03	1.37484E+02	4.50286E+00	8.47566E+02	1.58696E+00	1.34505E+03
4	79	8.00091E-01	4.75165E+03	1.37484E+02	4.43348E+00	8.34506E+02	1.61179E+00	1.34505E+03
4	79	8.20212E-01	4.75161E+03	1.37484E+02	4.36470E+00	8.21560E+02	1.63719E+00	1.34505E+03
4	79	8.40509E-01	4.75157E+03	1.37484E+02	4.30221E+00	8.09797E+02	1.66097E+00	1.34505E+03
4	79	8.60585E-01	4.75154E+03	1.37484E+02	4.24624E+00	7.99263E+02	1.68286E+00	1.34505E+03
4	79	8.80423E-01	4.75151E+03	1.37484E+02	4.19661E+00	7.89921E+02	1.70276E+00	1.34505E+03
4	79	9.00555E-01	4.75148E+03	1.37484E+02	4.15111E+00	7.81357E+02	1.72143E+00	1.34505E+03
4	79	9.20483E-01	4.75145E+03	1.37484E+02	4.10939E+00	7.73504E+02	1.73890E+00	1.34505E+03
4	79	9.42127E-01	4.75141E+03	1.37484E+02	4.06811E+00	7.65733E+02	1.75655E+00	1.34505E+03
4	79	9.61949E-01	4.75138E+03	1.37484E+02	4.03394E+00	7.59302E+02	1.77143E+00	1.34505E+03
4	79	9.81931E-01	4.75136E+03	1.37484E+02	4.00363E+00	7.53596E+02	1.78484E+00	1.34505E+03
4	79	1.00109E+00	4.75133E+03	1.37484E+02	3.97757E+00	7.48691E+02	1.79654E+00	1.34505E+03

					Sand Transport			Susp Sand Transport		
Elevation (m)	Bed d50 (mm)	sig g	Non Tran Size	Total Tran Rate (m*m*m/s)	Rate (m*m*m/s)	d50 (m)	sig g (m/m)	Rate (m*m*m/s)	d50 (m)	sig g (m/m)
1.33260E+02	7.463	1.836	123	4.14524E-02	3.92869E-02	0.114	2.628	3.80386E-02	0.109	2.519
1.33261E+02	7.455	1.840	123	3.97410E-02	3.82019E-02	0.110	2.523	3.80383E-02	0.109	2.519
1.33262E+02	7.446	1.844	123	3.97080E-02	3.81689E-02	0.109	2.521	3.80383E-02	0.109	2.519
1.33262E+02	7.438	1.847	123	3.96914E-02	3.81521E-02	0.109	2.519	3.80426E-02	0.109	2.519
1.33263E+02	7.430	1.851	123	3.96819E-02	3.81428E-02	0.109	2.519	3.80384E-02	0.109	2.519
1.33264E+02	7.421	1.855	123	3.96825E-02	3.81433E-02	0.109	2.519	3.80426E-02	0.109	2.519
1.33265E+02	7.413	1.859	123	3.95776E-02	3.80385E-02	0.109	2.519	3.80385E-02	0.109	2.519
1.33265E+02	7.405	1.863	123	3.95900E-02	3.80507E-02	0.109	2.519	3.80430E-02	0.109	2.519
1.33266E+02	7.397	1.866	123	3.95940E-02	3.80549E-02	0.109	2.518	3.80392E-02	0.109	2.519
1.33266E+02	7.388	1.870	123	3.96035E-02	3.80642E-02	0.109	2.518	3.80439E-02	0.109	2.519
1.33267E+02	7.380	1.873	123	3.96067E-02	3.80676E-02	0.109	2.518	3.80403E-02	0.109	2.519
1.33267E+02	7.371	1.877	123	3.96209E-02	3.80816E-02	0.109	2.518	3.80451E-02	0.109	2.519
1.33268E+02	7.363	1.880	123	3.96289E-02	3.80896E-02	0.109	2.518	3.80455E-02	0.109	2.519
1.33268E+02	7.355	1.884	123	3.96357E-02	3.80965E-02	0.109	2.518	3.80418E-02	0.109	2.519
1.33269E+02	7.347	1.888	123	3.96485E-02	3.81092E-02	0.109	2.518	3.80467E-02	0.109	2.519
1.33270E+02	7.338	1.891	123	3.96524E-02	3.81132E-02	0.109	2.518	3.80431E-02	0.109	2.519
1.33271E+02	7.330	1.895	123	3.96615E-02	3.81223E-02	0.109	2.518	3.80439E-02	0.109	2.519
1.33271E+02	7.322	1.899	123	3.96672E-02	3.81280E-02	0.109	2.518	3.80447E-02	0.109	2.519
1.33272E+02	7.314	1.902	123	3.96747E-02	3.81355E-02	0.109	2.518	3.80457E-02	0.109	2.519
1.33273E+02	7.306	1.906	123	3.96837E-02	3.81443E-02	0.109	2.519	3.80507E-02	0.109	2.519
1.33274E+02	7.298	1.910	123	3.96857E-02	3.81465E-02	0.109	2.519	3.80475E-02	0.109	2.519
1.33274E+02	7.290	1.914	123	3.96930E-02	3.81537E-02	0.109	2.519	3.80485E-02	0.109	2.519
1.33275E+02	7.282	1.918	123	3.96989E-02	3.81596E-02	0.109	2.519	3.80495E-02	0.109	2.519
1.33276E+02	7.274	1.921	123	3.97102E-02	3.81707E-02	0.109	2.519	3.80545E-02	0.109	2.519
1.33276E+02	7.266	1.925	123	3.97116E-02	3.81722E-02	0.109	2.519	3.80514E-02	0.109	2.519
1.33277E+02	7.258	1.929	123	3.97171E-02	3.81777E-02	0.109	2.519	3.80524E-02	0.109	2.519
1.33277E+02	7.250	1.933	123	3.97235E-02	3.81841E-02	0.109	2.519	3.80535E-02	0.109	2.519

1.29270E+02	0.191	1.161	121	1.59225E+01	1.57969E+01	0.173	1.154	1.57962E+01	0.173	1.154
1.29470E+02	0.189	1.159	121	1.52852E+01	1.51664E+01	0.173	1.157	1.51657E+01	0.173	1.157
1.29664E+02	0.188	1.159	121	1.44208E+01	1.43123E+01	0.173	1.159	1.43115E+01	0.173	1.159
1.29856E+02	0.187	1.159	121	1.35652E+01	1.34624E+01	0.173	1.161	1.34615E+01	0.173	1.161
1.30035E+02	0.186	1.159	121	1.26431E+01	1.25452E+01	0.173	1.164	1.25443E+01	0.173	1.164
1.30205E+02	0.186	1.160	121	1.17813E+01	1.16888E+01	0.174	1.165	1.16878E+01	0.174	1.165
1.30360E+02	0.186	1.161	121	1.13501E+01	1.12643E+01	0.175	1.166	1.12632E+01	0.175	1.166
1.30514E+02	0.186	1.163	121	1.09531E+01	1.08706E+01	0.175	1.168	1.08694E+01	0.175	1.168
1.30669E+02	0.186	1.164	121	1.06714E+01	1.05912E+01	0.176	1.170	1.05899E+01	0.176	1.170
1.30816E+02	0.186	1.165	121	1.03038E+01	1.02261E+01	0.176	1.172	1.02248E+01	0.176	1.172
1.30959E+02	0.187	1.166	121	9.85064E+00	9.77788E+00	0.177	1.175	9.77647E+00	0.177	1.175
1.31098E+02	0.187	1.167	121	9.74162E+00	9.67294E+00	0.177	1.172	9.67144E+00	0.177	1.172
1.31235E+02	0.187	1.168	121	9.51633E+00	9.45379E+00	0.178	1.171	9.45219E+00	0.178	1.171
1.31368E+02	0.188	1.168	121	9.40290E+00	9.34336E+00	0.178	1.170	9.34166E+00	0.178	1.170
1.31504E+02	0.188	1.167	121	9.32860E+00	9.27118E+00	0.178	1.167	9.26936E+00	0.178	1.167
1.31629E+02	0.189	1.167	121	9.03512E+00	8.97958E+00	0.179	1.172	8.97765E+00	0.179	1.172
1.31755E+02	0.189	1.168	121	8.57342E+00	8.52048E+00	0.180	1.177	8.51842E+00	0.180	1.177
1.31883E+02	0.190	1.169	121	8.12631E+00	8.07568E+00	0.181	1.182	8.07348E+00	0.181	1.182
1.31994E+02	0.191	1.171	121	7.75092E+00	7.70256E+00	0.182	1.186	7.70022E+00	0.182	1.186
1.32105E+02	0.192	1.172	121	7.34456E+00	7.29789E+00	0.182	1.188	7.29539E+00	0.182	1.188
1.32214E+02	0.193	1.173	121	7.03808E+00	6.99291E+00	0.182	1.190	6.99025E+00	0.182	1.190
1.32312E+02	0.194	1.174	121	6.74613E+00	6.70272E+00	0.182	1.191	6.69989E+00	0.182	1.191
1.32409E+02	0.194	1.174	121	6.50091E+00	6.45902E+00	0.182	1.192	6.45602E+00	0.182	1.192
1.32505E+02	0.195	1.175	121	6.24401E+00	6.20363E+00	0.182	1.192	6.20043E+00	0.182	1.192
1.32593E+02	0.195	1.175	121	6.01024E+00	5.97115E+00	0.181	1.191	5.96776E+00	0.181	1.191
1.32673E+02	0.195	1.175	121	5.81979E+00	5.78180E+00	0.181	1.191	5.77822E+00	0.181	1.191
1.32753E+02	0.196	1.176	121	5.37799E+00	5.34329E+00	0.182	1.195	5.33951E+00	0.182	1.195
1.32826E+02	0.196	1.176	121	4.80050E+00	4.77006E+00	0.184	1.201	4.76609E+00	0.184	1.201
1.32891E+02	0.197	1.176	121	4.32761E+00	4.30053E+00	0.185	1.207	4.29636E+00	0.185	1.207
1.32949E+02	0.198	1.176	121	3.91535E+00	3.89107E+00	0.187	1.211	3.88665E+00	0.187	1.211
1.33002E+02	0.200	1.176	121	3.55518E+00	3.53316E+00	0.188	1.214	3.52851E+00	0.188	1.214
1.33050E+02	0.201	1.177	121	3.20911E+00	3.18896E+00	0.190	1.210	3.18410E+00	0.190	1.210
1.33098E+02	0.202	1.180	121	2.94374E+00	2.92540E+00	0.191	1.214	2.92035E+00	0.191	1.214
1.33138E+02	0.203	1.180	121	2.72528E+00	2.70829E+00	0.191	1.218	2.70307E+00	0.191	1.218
1.33173E+02	0.204	1.180	121	2.51901E+00	2.50318E+00	0.191	1.221	2.49781E+00	0.191	1.221
1.33204E+02	0.205	1.180	121	2.34872E+00	2.33393E+00	0.191	1.224	2.32842E+00	0.191	1.224

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Manuscript approved for publication, August 2005

Prepared by the USGS, Tacoma Publishing Service Center

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Berenbrock and Bennett

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SIR 2005–5173

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