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Simulations of Hydraulic Characteristics for an Upstream Extension of the White Sturgeon Habitat of the Kootenai River near Bonners Ferry, Idaho—A Supplement to Scientific Investigations Report 2005-5110

Scientific Investigations Report 2006–5019

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

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

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

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Suggested citation:
Berenbrock, Charles, 2006, Simulations of hydraulic characteristics for an upstream extension of the white sturgeon habitat of the Kootenai River near Bonners Ferry, Idaho—A supplement to Scientific Investigations Report 2005-5110: US Geological Survey Scientific Investigations Report 2006-5019, 17 p.

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Conversion Factors

Inch Pound to SI

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

SI to Inch Pound

Multiply	By	To obtain
kilometer (km)	0.6214	mile
meter (m)	3.281	foot

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).

Simulations of Hydraulic Characteristics for an Upstream Extension of the White Sturgeon Spawning Habitat of the Kootenai River, Idaho— A Supplement to Scientific Investigations Report 2005–5110

By Charles Berenbrock

Abstract

The U.S. Geological Survey (USGS) developed a one-dimensional (1-D) hydraulic-flow model of the Kootenai River in Idaho to aid in evaluating hydraulic characteristics in the reach. The modeled reach extends from Leonia to Porthill, Idaho, a distance of 105.6 kilometers. Concerned with enhancing spawning conditions of the white sturgeon in the Kootenai River, biologists need the ability to evaluate hydraulic effects of changes in river discharge and water-surface elevations in Kootenay Lake especially in the braided and canyon reaches. The extension of the white sturgeon spawning habitat reach into the upstream braided and (or) canyon reaches is under consideration because streambed material (gravels and cobbles) of the braided and canyon reaches are suitable for white sturgeon spawning. Whereas, streambed materials (medium to fine sand) of the meander reach are unsuitable for spawning.

A previous developed model of the study area was used to simulate steady conditions associated with various river discharges and water-surface elevations in Kootenay Lake. Modeled river discharges ranged from 6,000 to 75,000 cubic feet per second, and modeled water-surface elevations in Kootenay Lake ranged from 531.32 to 537.09 meters.

Introduction

A one-dimensional (1-D) hydraulic-flow model of a 105.6 km reach of the Kootenai River in Idaho was developed by the U.S. Geological Survey (USGS) to aid in evaluating hydraulic characteristics in the reach (Berenbrock, 2005). The primary focus of the model was to determine the location of the transition between backwater and free-flowing water in the Kootenai River because many biologists believe that hydraulic changes at the transition affect the location where sturgeon choose to spawn. The modeled reach starts at Leonia (river kilometer [RKM] 276.5) near the Montana/Idaho border and ends at Porthill (RKM 169.9) near the International Border (fig. 1). The modeled reach also encompasses the white sturgeon spawning habitat reach (RKM 246.7 to RKM 224.9) that has been designated as a critical habitat. The model has proven to be a useful tool to simulate hydraulic changes especially in determining the location of backwater extent.

Concerned with enhancing spawning conditions of the white sturgeon in the Kootenai River, the U.S. Fish and Wildlife (USFWS) is deciding how far to extend the critical habitat reach upstream into the braided and (or) canyon reaches. The braided reach extends from U.S. Highway 95 Bridge (RKM 245.8) at Bonners Ferry to RKM 256.6 (near Crossport). The canyon reach extends from RKM 256.6 to Libby Dam (RKM 354) (fig. 2). The streambed in the braided and canyon reaches is composed primarily of gravel and cobbles and is suitable for white sturgeon spawning. Whereas, the meander reach (downstream of Bonners Ferry) of the Kootenai River is composed primarily of medium to fine sand, which is unsuitable for spawning. In September 2005, the USGS, in cooperation with the USFWS, used the 1-D hydraulic model to aid the USFWS in deciding how best to extend the length of channel designated as the critical habitat reach. These additional simulations are needed to determine if hydraulic characteristics of the braided and canyon reaches are reasonable for white sturgeon spawning.

The purpose of this report is to document simulations that were not included in Berenbrock (2005) and that are needed to determine if hydraulic characteristics of the braided and canyon reaches are reasonable for white sturgeon spawning.

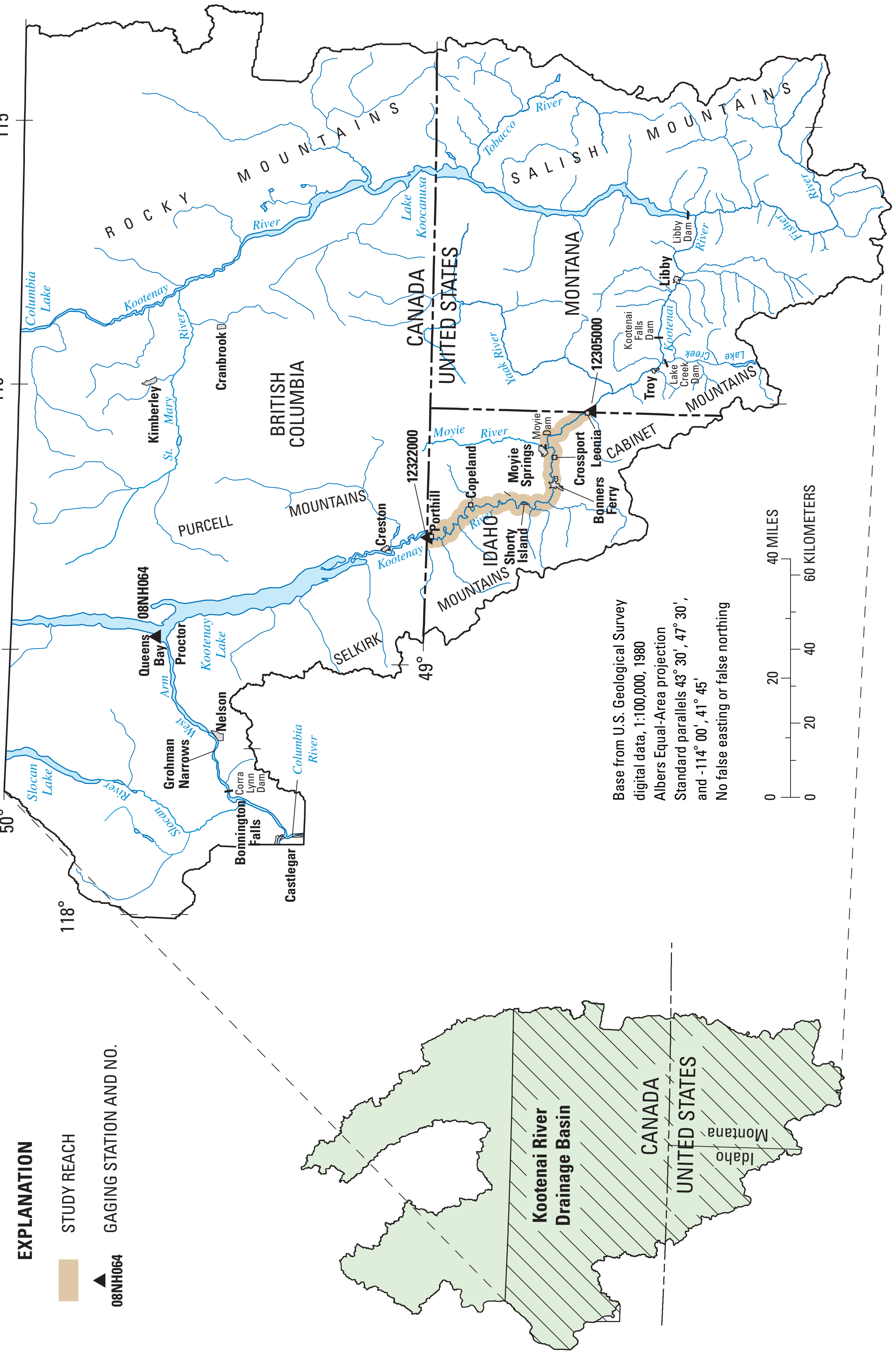


Figure 1. Location of the study reach and Kootenai River drainage basin, Idaho, Montana, and British Columbia, Canada.

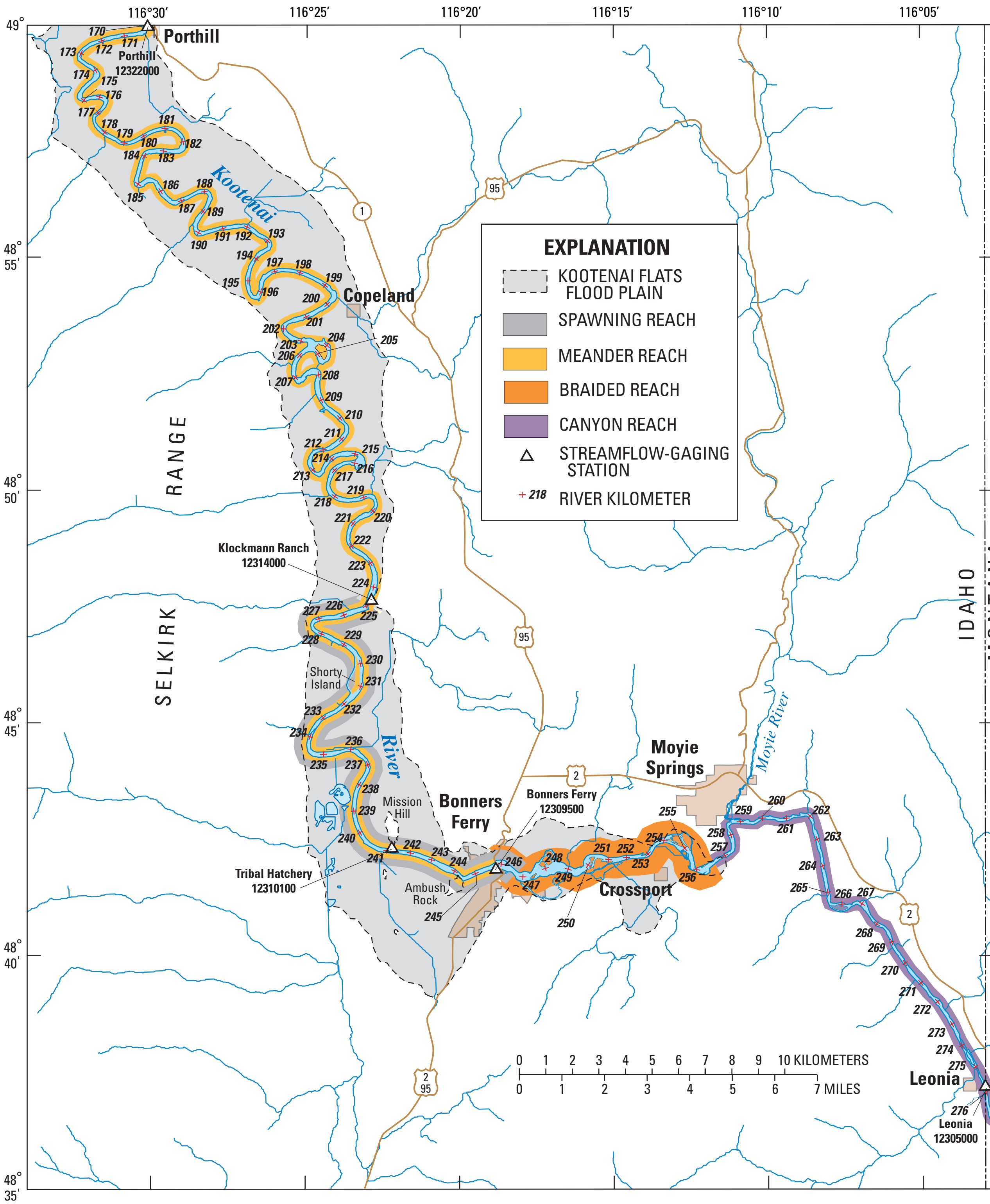


Figure 2. Location of meander, braided, and canyon reaches and river kilometers in the Kootenai River drainage basin in Idaho.

Hydraulic characteristics in the braided and canyon reaches are of primary focus in these simulations. Two tasks comprise these simulations. Task 1 consists of simulating combinations of five river discharges (6, 000; 20,000; 40,000; 60,000; and 75,000 ft^3/s) and three water-surface elevations (low, median, and high) in Kootenay Lake. Task 2 consists of simulating nine river discharges (6,000; 10,000; 20,000; 30,000; 40,000; 50,000; 60,000; 70,000; and 75,000 ft^3/s) and only the median water-surface elevations in Kootenay Lake. For river discharges of 40,000 ft^3/s and less, water-surface elevations in Kootenay Lake were based on data from the Libby Dam era (1973 to 2003). For river discharges greater than 40,000 ft^3/s, lake elevations were based on data from the pre-Libby Dam era (1940 to 1972). A complete description of the study reach and the 1-D model that was calibrated is contained in a report by Berenbrock (2005).

River kilometers identified in this report were based on interpolating between the river miles designators that were established by the Columbia Basin Inter-Agency Committee (1965). The river mile designators are usually shown on USGS 7.5-minute (1:24,000 scaled) maps, and they were also shown on maps in previous USGS investigations of the Kootenai River (Barton and others, 2004; Berenbrock, 2005, Berenbrock and Bennett, 2005). Please note that other river kilometers designators that have been established by other agencies and (or) identities such as the Idaho Department of Fish and Game may not agree with the locations of river kilometers used in this report.

Model Development and Calibration

The HEC-RAS computer model (Brunner, 2002a and 2002b; and Warner and others, 2002) was used to construct a surface-water, hydraulic-flow model of the Kootenai River. HEC-RAS is a computer program that simulates 1-D, gradually varied, steady flow in open channels with fixed boundaries. The HEC-RAS model uses the standard step method (Chow, 1959, p. 265) to determine changes in water-surface elevations from one cross section to the next by balancing total energy head at the sections. This 1-D model assumes that energy is uniform in a cross section. This assumption is not valid at locations where flow is not parallel to the main channel or where vertical velocities are significant. The model also assumes that flow is unobstructed within the channel and free of debris. The modeled reach extends from Leonia to Porthill (fig. 1), a distance of 105.6 km.

A total of 164 cross sections were used in HEC-RAS: 131-field-surveyed, 8 Triangulated Irregular Network (TIN) generated, 2 bridges, and 23 interpolated. The field-surveyed cross sections by Barton and others (2004) were used to define channel geometry characteristics. The eight TIN-generated cross sections were developed for the Shorty Island side channel, and the two bridge cross sections were generated from bridge design plans. Distances between cross sections ranged from about 180 m in the valley flat near Deep Creek and Shorty Island to as much as 2.4 km in other areas. Cross sections in the white sturgeon spawning habitat reach are about 300 m apart.

The model was calibrated to surface-water elevation at specific discharges at five gaging stations in the study reach. Nine calibration points were identified where discharge and water-surface elevation remained steady throughout the study reach for at least several days. Calibrated water-surface elevations ranged from about 531.3 to about 536.2 m, and discharge used in calibration ranged from 5,000 to 47,500 ft^3/s. Model calibration was considered acceptable because differences between measured and simulated water-surface elevations was ±0.031 m or less. Measured and simulated average velocities also were compared at selected cross sections. These comparisons were acceptable because differences between measured and simulated average velocities were 0.076 m/s or less.

Simulations of Hydraulic Characteristics for an Upstream Extension of the White Sturgeon Spawning Habitat of the Kootenai River

The hydraulic-flow model of the Kootenai River developed by Berenbrock (2005) primarily was used to determine the location of the transition between backwater and free-flowing water. The white sturgeon spawning habitat reach also was the main reach of focus in that study as cross sections were spaced closer than in the braided and canyon reaches and in other areas.

Paired data comprised of discharge in the study reach and water level or elevation in Kootenay Lake at Queens Bay gaging station (08NH064), available since the early 1930s, were used for boundary (upstream and downstream) conditions in the model. Discharge in the study reach is specified at the upstream boundary (Leonia gaging station [12305000]), and water-surface elevation is specified at the downstream boundary (Porthill gaging station [12322000]). Discharges of 40,000 ft^3/s and less were used to represent discharges in the river since the construction of Libby Dam (1973 to 2003), and discharges greater than 40,000 ft^3/s were used to represent discharges prior to the construction of Libby Dam (1940 to 1972). Water-surface elevations were based on current and historic elevations in Kootenay Lake at Queens Bay.

Water-surface elevations, flow depths, and flow velocities in the modeled reach are needed to determine if hydraulic characteristics of the braided and canyon reaches are reasonable for white sturgeon spawning. At cross sections, a single value for each hydraulic characteristic (water-surface elevation, flow depth, and flow velocity, and such) was computed by the model. For example, model-simulated velocity represents average velocity at a cross section. Because the model is one dimensional, the maximum velocity or other velocities in a cross section cannot be determined.

In task 1, a total of 15 simulations were run using combinations of five discharges and three water-surface elevations. The five objective discharges were 6,000, 20,000, 40,000, 60,000, and 75,000 ft^3/s and were used to represent low to high discharges in the river. Three water-surface elevations in Kootenay Lake were used to represent low, median, and high elevations at Queens Bay. The low, median, and high lake elevations were determined by calculating the spread in lake elevations near the objective discharge. The spread is the difference between the highest measured elevation minus the lowest measured elevation. All paired values (measured discharge in the study reach and measured water-surface elevation at Queens Bay) within ±1,000 ft^3/s of each objective discharge were used to determine the spread in lake elevation at the objective discharges. Low lake elevation was set to the 15th percentile and high elevation to the 85th percentile. The 50th percentile is known as the median. The 15th percentile, for example, is a value which exceeds 15 percent of the spread in lake elevations and is exceeded by 85 percent of the spread. The 85th percentile is a value which exceeds 85 percent of the spread in lake elevations and is exceeded by 15 percent of the spread. Water-surface elevations at Queens Bay for each objective discharge and percentile are shown in table 1.

The water-surface elevation at Porthill was determined using a regression equation that relates water-surface elevations at Queens Bay and Porthill (Berenbrock, 2005, fig. 7*A*). These objective discharges in the study reach and water-surface elevations at Porthill (table 1) were then used as boundary conditions in the model for the task 1 simulations.

In task 2, nine simulations were run using nine objective discharges and corresponding median water-surface elevations at Queens Bay gaging station. The nine objective discharges are 6,000, 10,000, 20,000, 30,000, 40,000, 50,000, 60,000, 70,000, and 75,000 ft^3/s. The median or 50th percentile water-surface elevations were determined by taking the median of the spread in lake elevations near each objective discharge. All paired values (discharge in the study reach and water-surface elevation at Queens Bay) within ±1,000 ft^3/s of each objective discharge were used to determine the spread in elevation at the objective discharges. Median water-surface elevations at Queens Bay for each objective discharge are shown in table 2.

Water-surface elevations at Porthill were then determined from the regression equation in Berenbrock (2005, fig. 7*A*). These objective discharges in the study reach and water-surface elevations at Porthill (table 2) were then used as boundary conditions in the model for task 2 simulations.

Table 1. Objective discharges, percentiles, and water-surface elevations used as boundary conditions in the model for task 1 simulations in an upstream extension of the White Sturgeon habitat of the Kootenai River near Bonners Ferry, Idaho.

[**Porthill water-surface elevations** are based on regression equation that relates water-surface elevations between Queens Bay and Porthill (Berenbrock, 2005, fig. 7*A*)]

Objective discharge (cubic feet per second)	Percentile	Lake level category	Water-surface elevations (meters)	
			Queens Bay	Porthill
6,000	15th	Low	531.32	531.60
6,000	50th	Median	532.09	532.47
6,000	85th	High	532.85	533.34
20,000	15th	Low	531.75	532.09
20,000	50th	Median	532.81	533.30
20,000	85th	High	533.88	534.51
40,000	15th	Low	533.47	532.22
40,000	50th	Median	533.74	534.35
40,000	85th	High	535.40	536.24
60,000	15th	Low	536.25	537.20
60,000	50th	Median	534.86	535.62
60,000	85th	High	533.47	534.04
75,000	15th	Low	534.59	535.32
75,000	50th	Median	535.84	536.74
75,000	85th	High	537.09	538.16

Table 2. Objective discharges and median water-surface elevations used as boundary conditions in the model for task 2 simulations in an upstream extension of the White Sturgeon habitat of the Kootenai River near Bonners Ferry, Idaho.

[**Porthill water-surface elevations** are based on regression equation that relates water-surface elevations between Queens Bay and Porthill (Berenbrock, 2005, fig. 7*A*)]

Objective discharge (cubic foot per second)	Median water-surface elevations (meter)	
	Queens Bay	Porthill
6,000	532.09	532.47
10,000	532.51	532.95
20,000	532.81	533.30
30,000	533.18	533.71
40,000	533.74	534.35
50,000	534.35	535.04
60,000	534.86	535.62
70,000	535.49	536.34
75,000	535.84	536.74

Task 1 Simulations

The objective discharges and water-surface elevations in table 1 were used in task 1 simulations. Simulated water-surface elevations, flow depths, and flow velocities are shown in figures 3, 4, and 5. The 15th, 50th, and 85th percentile curves of water-surface elevation, flow depth, and flow velocity converge in the braided or canyon reach downstream of the confluence with the Moyie River. At the point where these curves converge, the effects of backwater cease. Upstream of the convergence point, velocities and depths are not affected by Kootenay Lake elevations. The 15th, 50th, and 85th percentile curves of water-surface elevation (fig. 3) show that the influence of backwater on the reach moves upstream with higher Kootenay Lake elevations. As river discharge increases, the influence of backwater moves downstream.

Flow depths in the meander reach usually are greater than flow depths in the braided and canyon reaches for all discharges. The large flow depths near RKM 244, as shown in figure 4, are caused by the deep hole in and around Ambush Rock.

Flow velocities in the canyon and braided reaches usually are greater than flow velocities in the meander reach. At a discharge of 6,000 ft^3/s, flow velocities in the canyon and braided reaches on average were four times greater than flow velocities in the meander reach (fig. 5*A*); at 75,000 ft^3/s, flow velocities were 2.5 times greater in the canyon and braided reaches than in the meander reach (fig. 5*E*). The low-flow velocities in cross sections near RKM 244, as shown in figure 5, are caused by a deep hole in the river in and around Ambush Rock. The streambed portion of cross sections that traverse this area should be artificially modified to only include the active flow area. The hole is about 15 m deep at RKM 244.2 and about 12 m deep at RKM 244.4 and is about 1 km long, which is less than 1 percent of the modeled reach length. The model assumes that the 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 the model. 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.

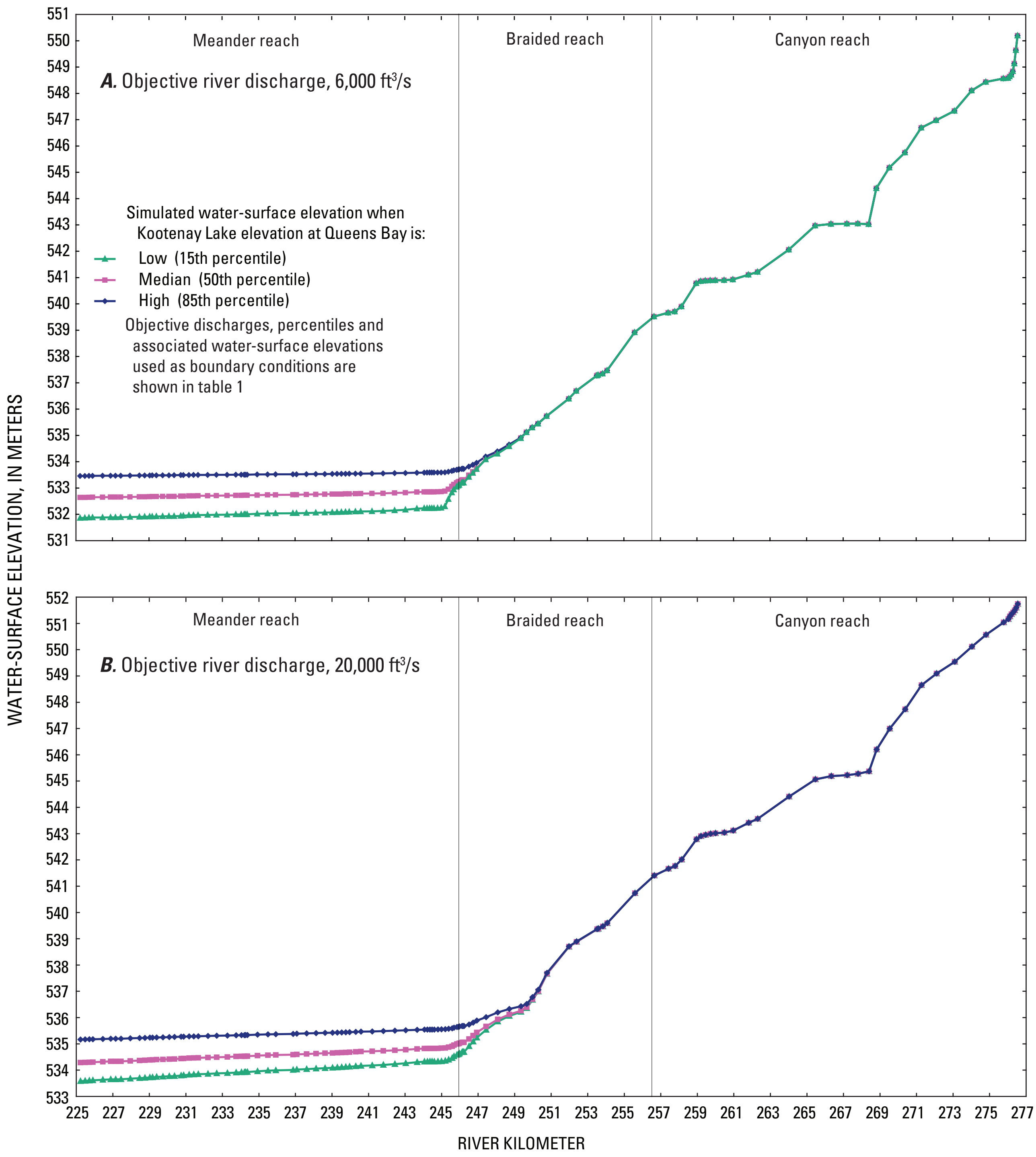
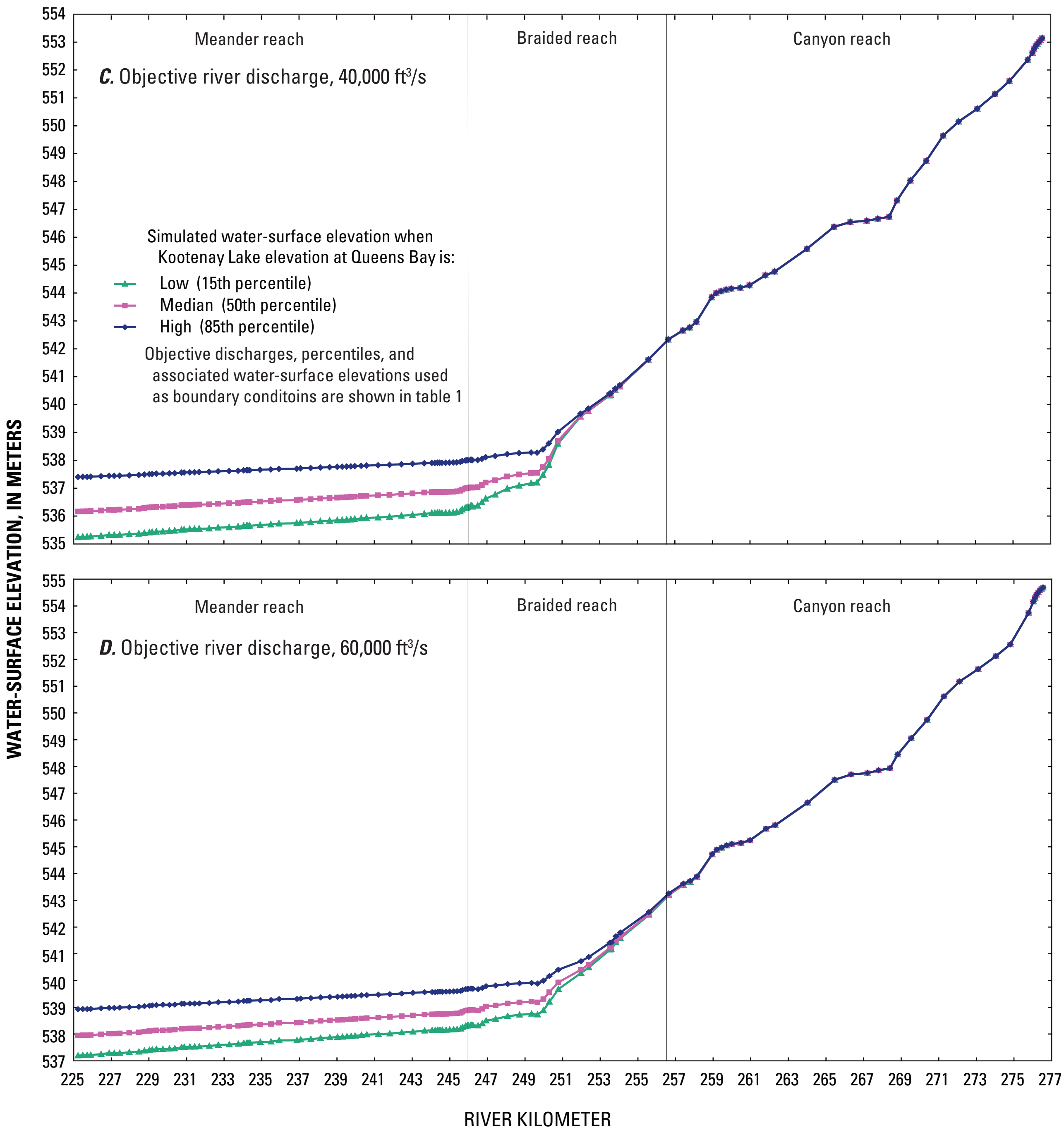


Figure 3. Simulated water-surface elevations for five objective river discharges in the upstream extension of the white sturgeon habitat of the Kootenai River, Idaho.



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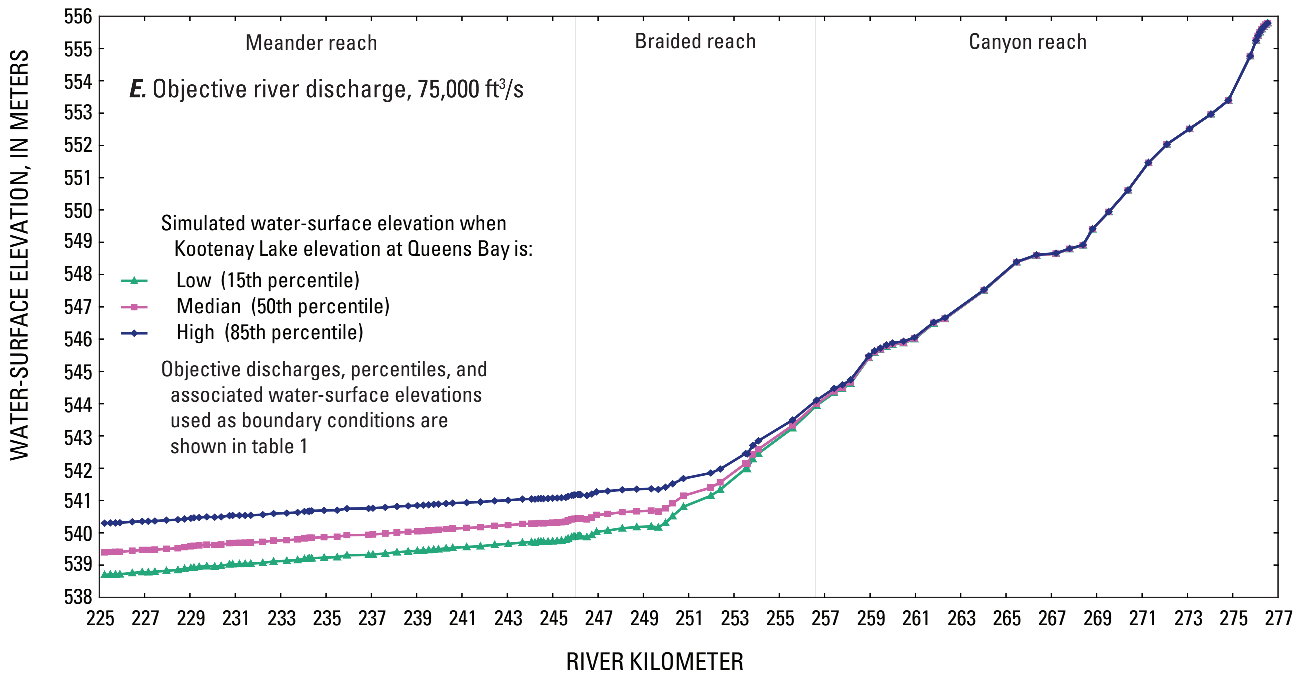

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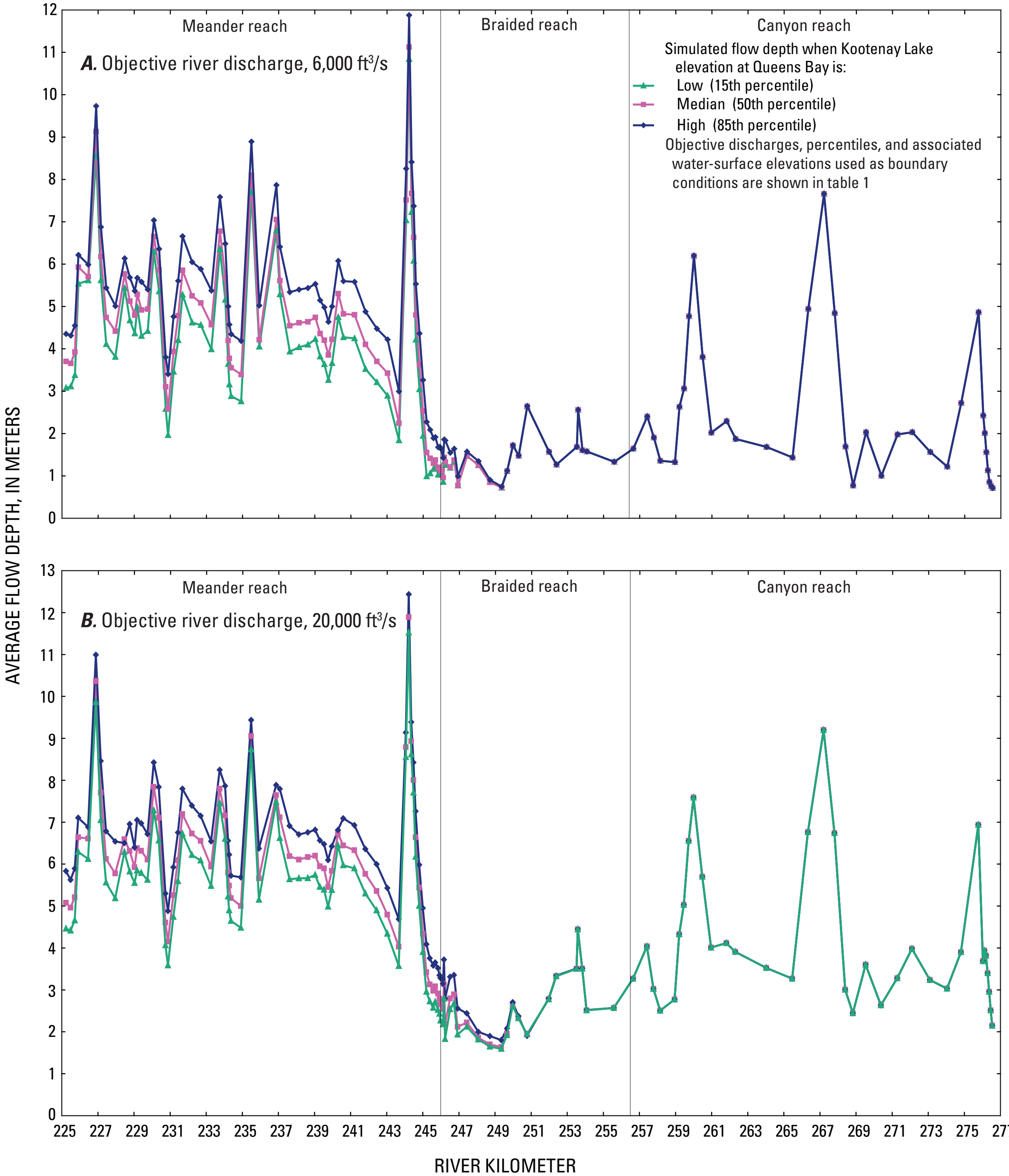

Figure 4. Simulated flow depths for five objective river discharges in the upstream extension of the white sturgeon habitat of the Kootenai River, Idaho.

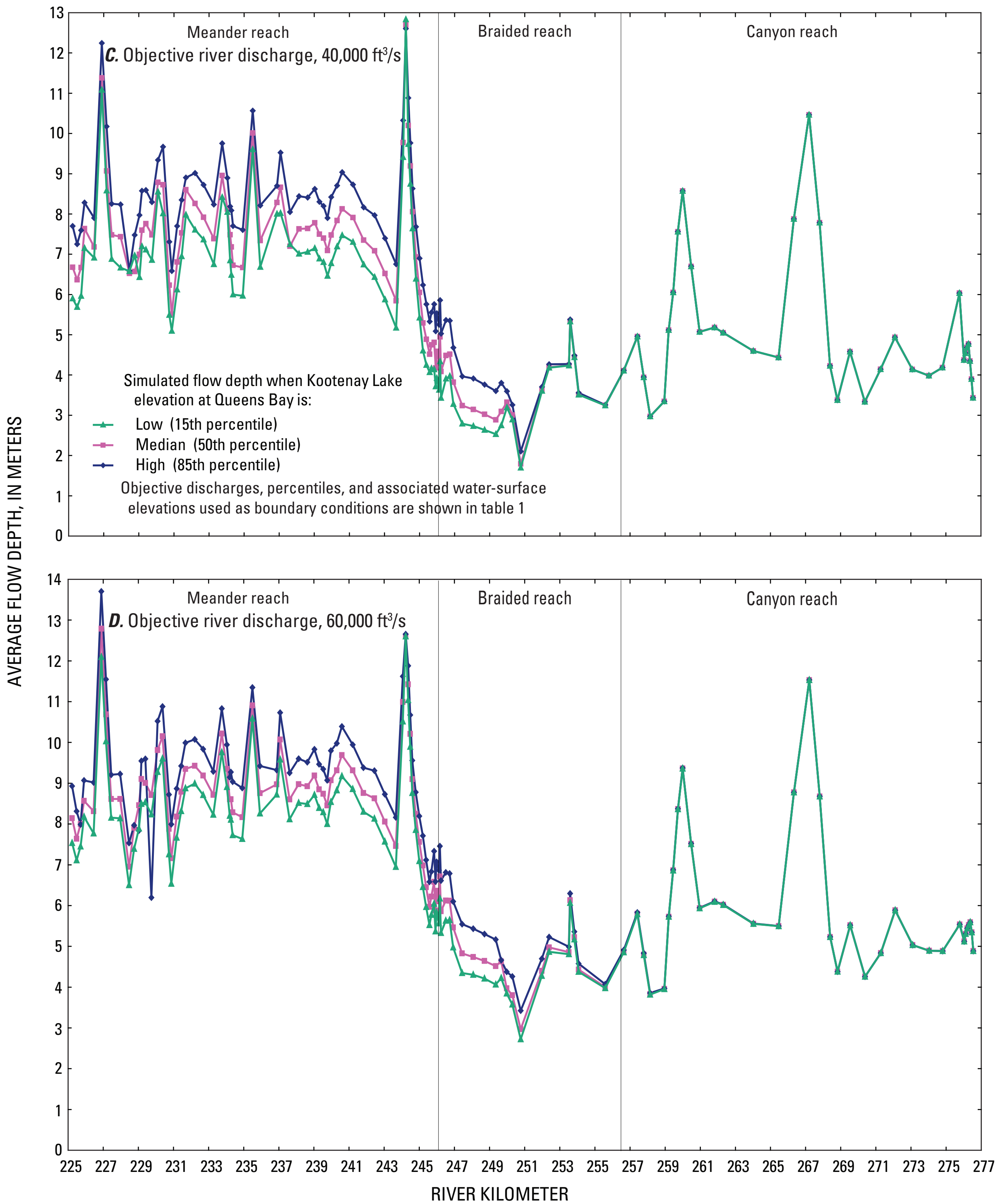

Figure 4.—Continued.

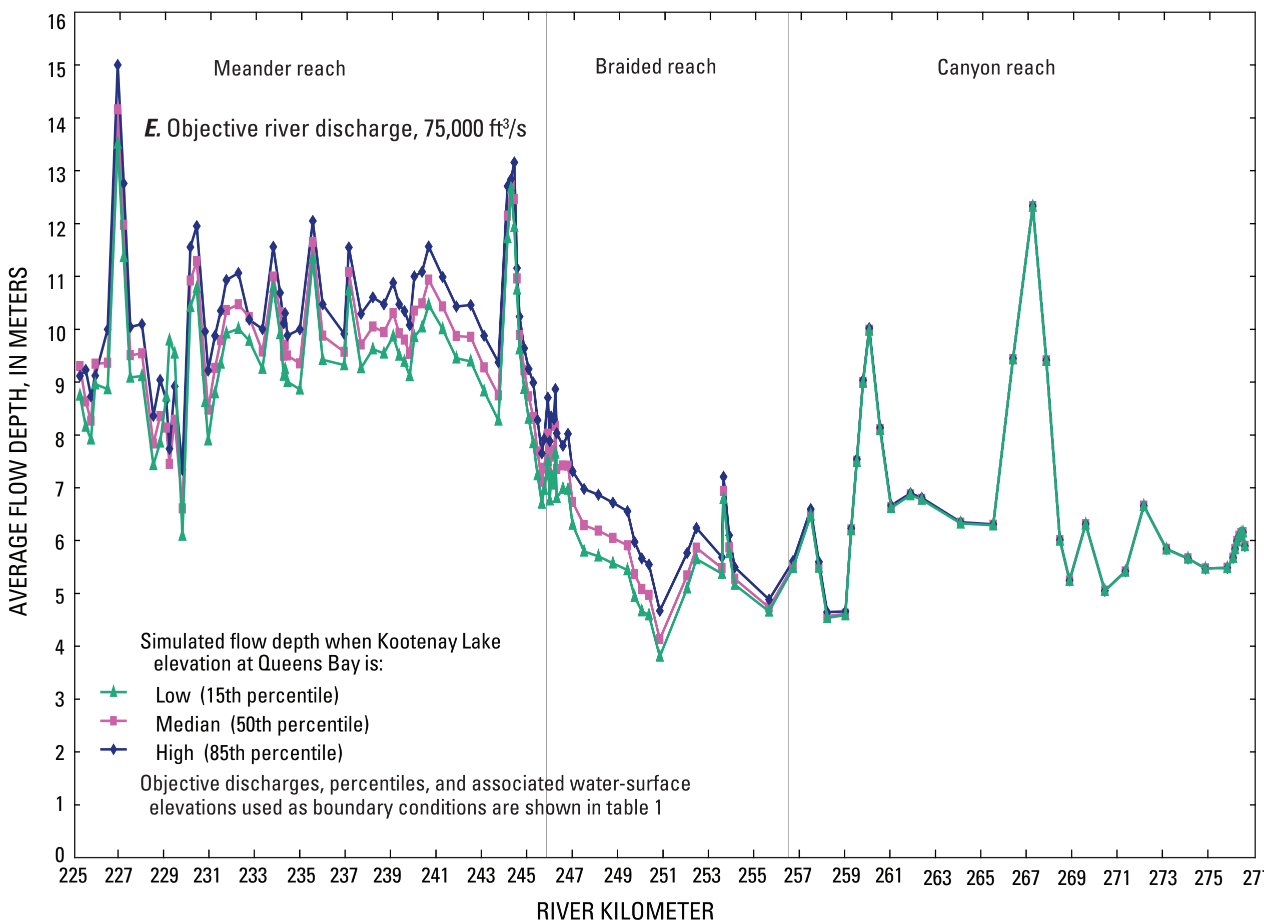

Figure 4.—Continued.

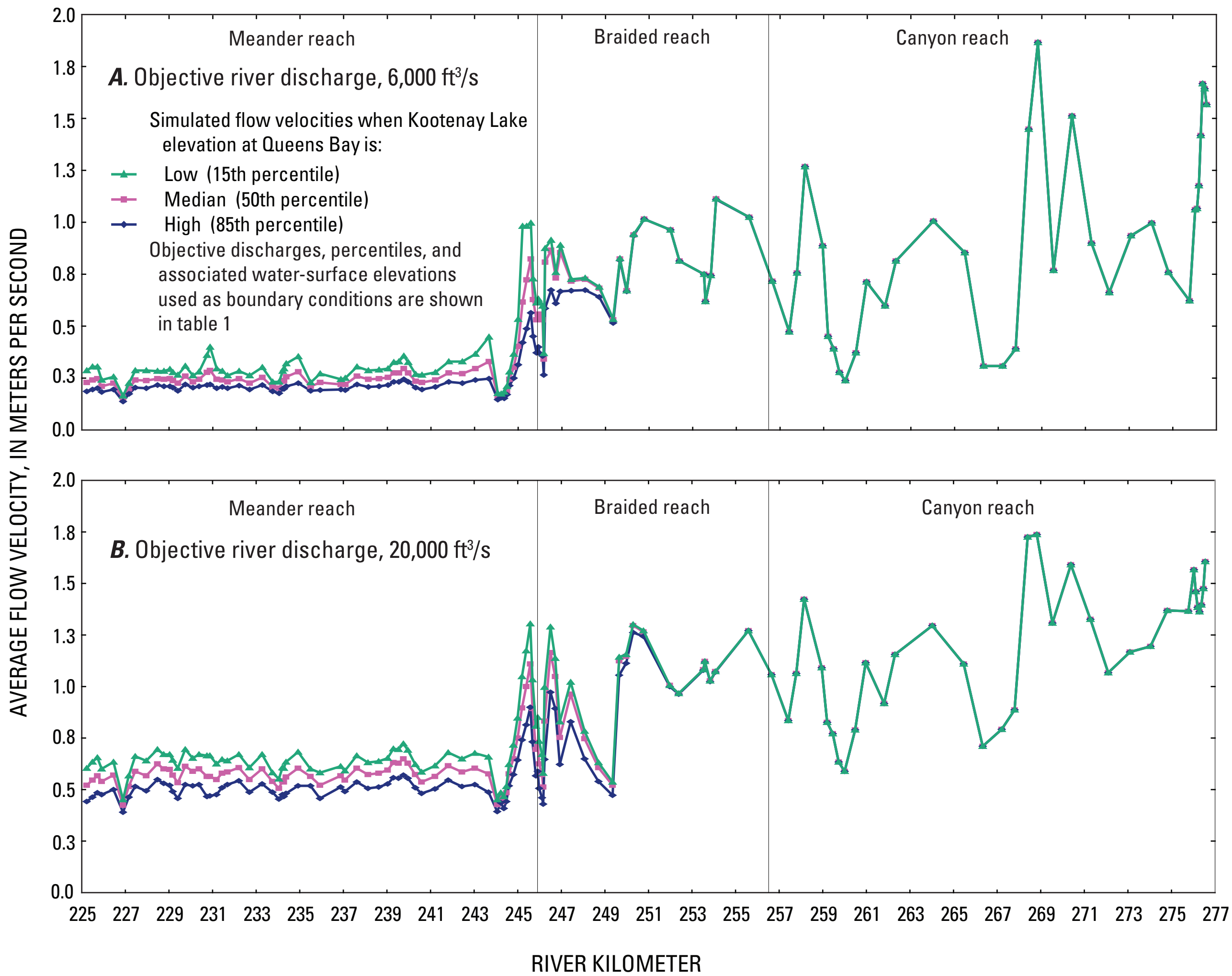

Figure 5. Simulated flow velocities for five objective river discharges in the upstream extension of the white sturgeon habitat of the Kootenai River, Idaho.

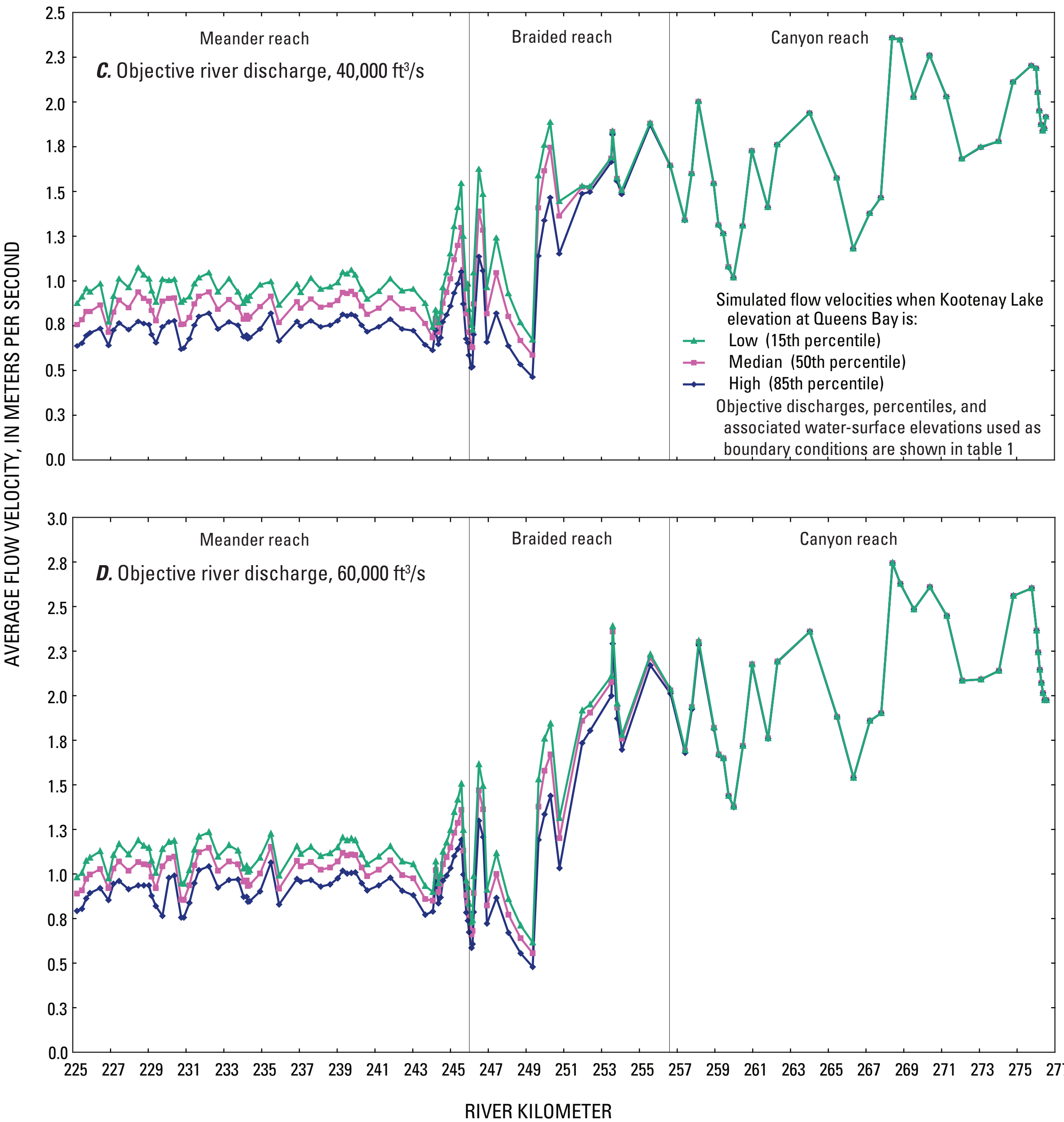

Figure 5.—Continued.

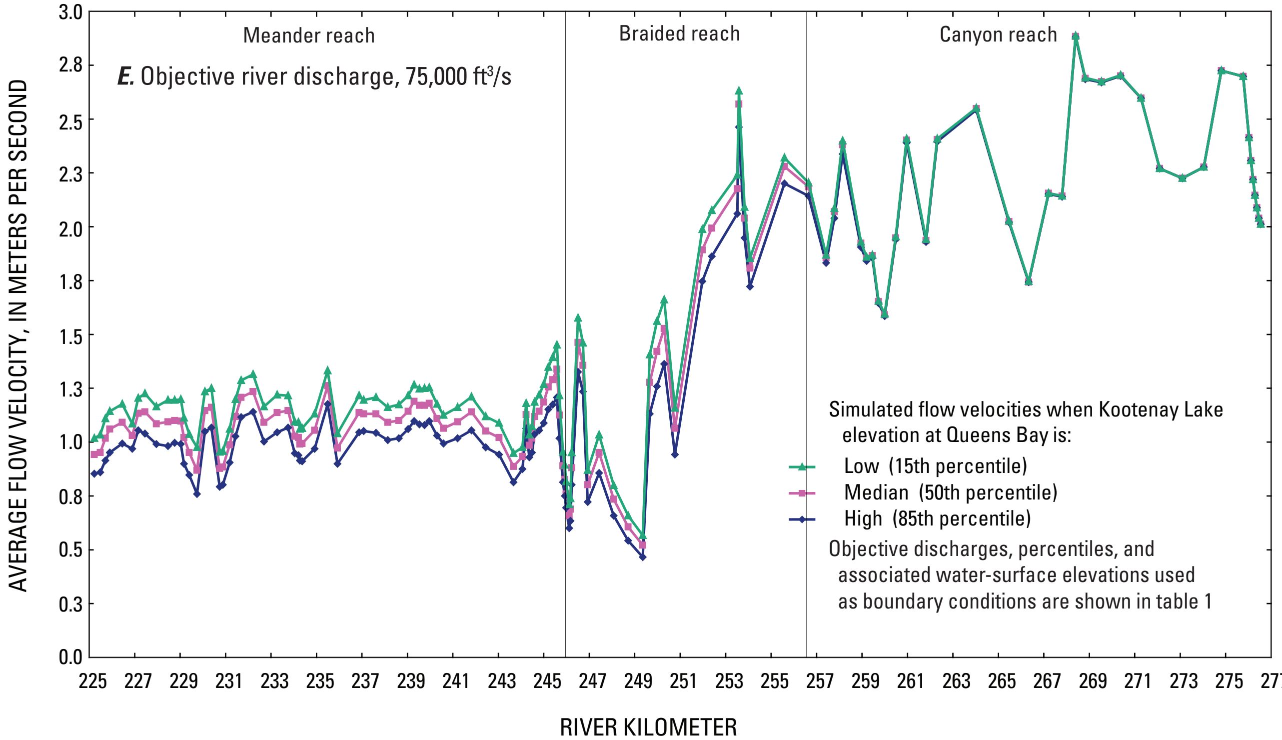

Figure 5.—Continued.

Task 2 Simulations

For task 2, nine objective discharges and associated median water-surface elevations at Queens Bay gaging station (table 2) were used for these simulations. Simulated water-surface elevations, flow depths, and flow velocities are shown in figures 6, 7, and 8. Only a portion of the results were shown, from RKM 260 near the confluence with the Moyie River to RKM 244 near Ambush Rock. The curves in these figures show that as river discharge increases, water-surface elevation, flow depth, and flow velocities increases. The large flow depths near RKM 244 (fig. 7) are caused by a deep hole in and around Ambush Rock. As previously mentioned, cross sections in this reach could be artificially modified to only include the active flow area. The low-flow depths at cross section 155.855 (near RKM 251) (fig. 7) are caused from a sudden widening of the channel at the section. The width of the river can be greater than 300 m at high discharges. At discharges less than 10,000 ft^3/s, river width narrows at this cross section to less than 60 m exposing a gravel bar on the left side of the channel. Average flow depths in the braided reach can be greater at low discharges than at median to high discharges (fig. 7). The channel near RKM 260 (canyon reach) deepens and causes flow depths to increase.

Flow velocities in the braided reach are greater than velocities in the canyon and meandering reaches (fig. 8). Flow velocities usually are lowest in the meandering reach except for the braided reach between RKM 249.5 and RKM 248 (fig. 8). In this reach, flow velocities were much lower than in surrounding reaches. The reason for this is that cross section 154.972 (near RKM 249.4) is not perpendicular to flow but is skewed to flow. A skewed cross section is wider than an actual cross section, and produces a flow area that is greater than actual, which results in a lower modeled flow velocity at the cross section. The modeled flow areas of two cross sections immediately downstream from cross section 154.972 (near RKM 249.4) probably also were greater than actual resulting in lower flow velocities because these cross sections were interpolated from the skewed cross section 154.972 (near RKM 249.4). Improvements to the model in this reach could be made by replacing these cross sections with cross sections that are generated from the recently collected bathymetry data (Barton and others, 2005) and LIDAR data (Richard Duncan, GeoEngineers, written commun., 2005).

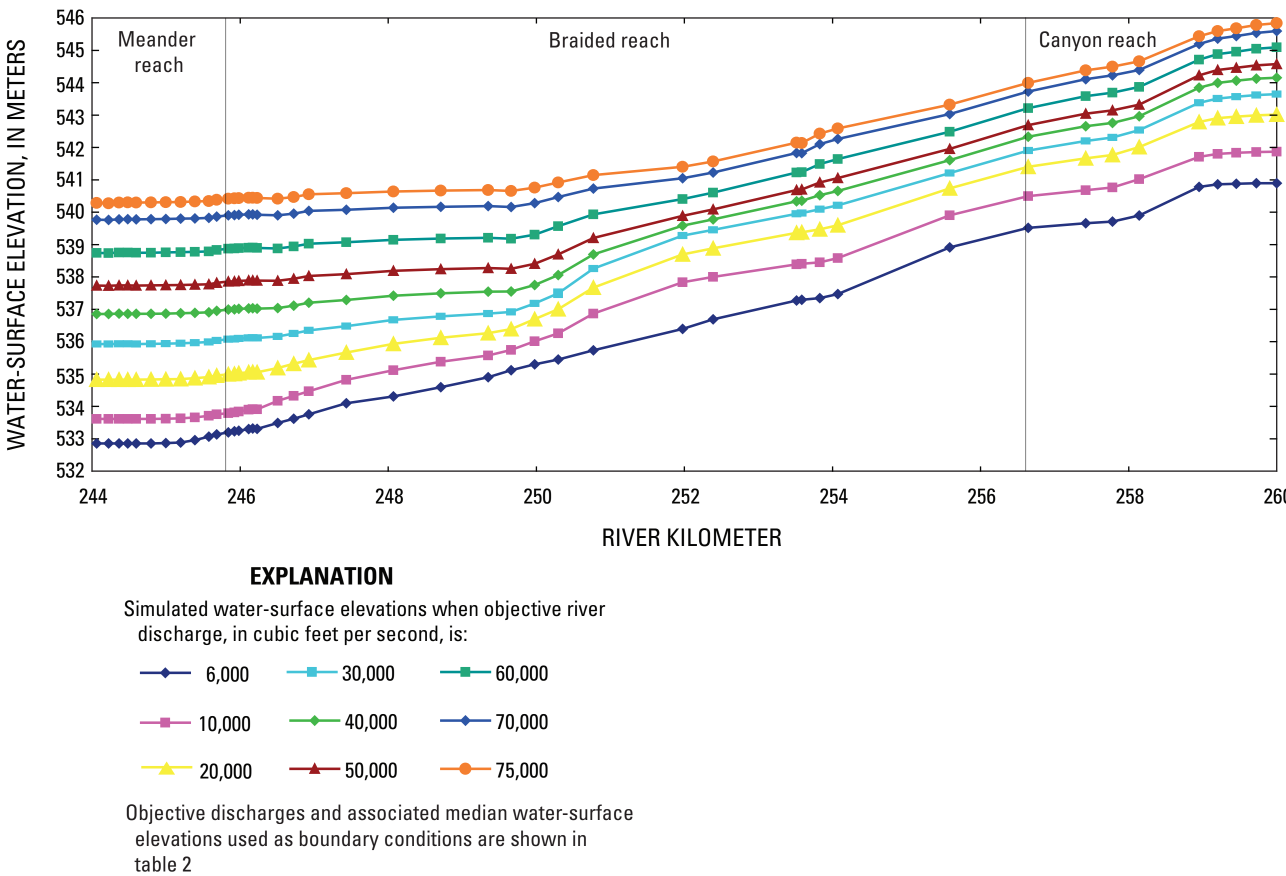

Figure 6. Simulated water-surface elevations for objective river discharges in the braided reach of the upstream extension of the white sturgeon habitat of the Kootenai River, Idaho.

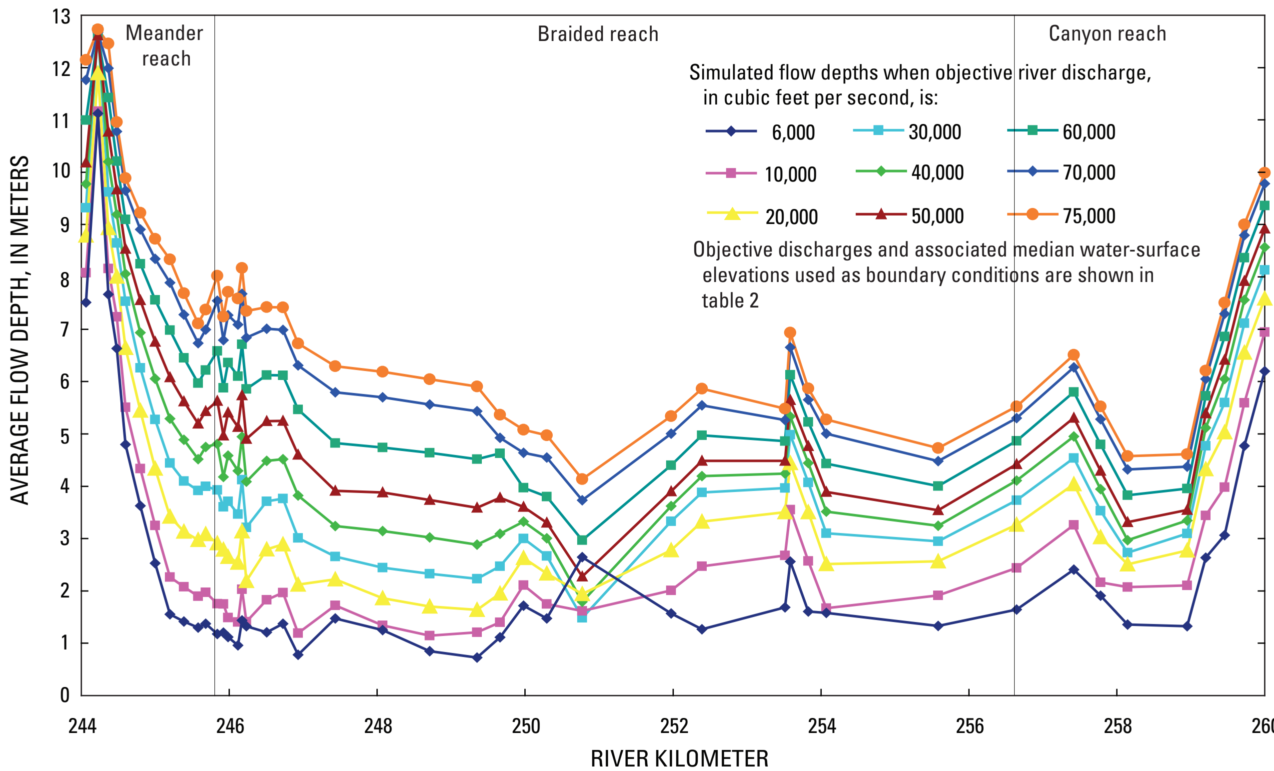

Figure 7. Simulated flow depths for objective river discharges in the braided reach of the upstream extension of the white sturgeon habitat of the Kootenai River, Idaho.

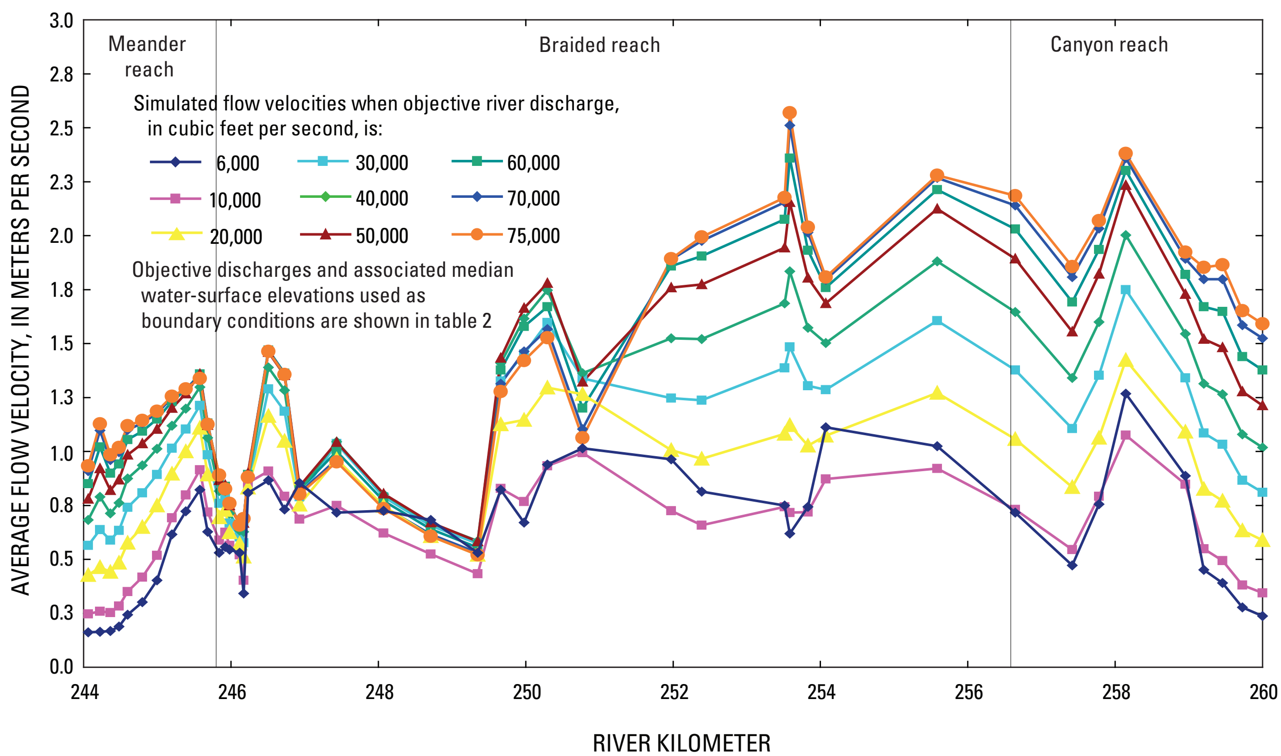

Figure 8. Simulated flow velocities for objective river discharges in the braided reach of the upstream extension of the white sturgeon habitat of the Kootenai River, Idaho.

Summary

A one-dimensional hydraulic-flow model of a 105.6 kilometer reach of the Kootenai River in Idaho was developed to aid in evaluating hydraulic characteristics in the reach. Concerned with enhancing spawning conditions of the white sturgeon in the Kootenai River, biologists need the ability to evaluate hydraulic effects of changes in river discharge and water-surface elevations in Kootenay Lake, especially in the braided and canyon reaches. The extension of the white sturgeon spawning habitat reach into the braided and (or) canyon reaches is under consideration because streambed materials (gravels and cobbles) of these reaches are suitable for white sturgeon spawning. Whereas, the meander reach is composed primarily of sand, which is unsuitable for spawning.

A previously developed one-dimensional hydraulic model of the study area was used to simulate water-surface elevations, flow depths, and flow velocities that are needed for possible extension of the white sturgeon spawning habitat reach into the braided and (or) canyon reaches. The model was used to simulate steady conditions associated with various river discharges and water-surface elevations in Kootenay Lake. River discharges ranged from 6,000 to 75,000 cubic feet per second, and water-surface elevations in Kootenay Lake ranged from 531.32 to 537.09 meters.

Simulations showed that as river discharge increases, water-surface elevations, flow depths, and flow velocities increases. Generally, flow depths in the meander reach are greater than flow depths in the braided and canyon reaches, and flow velocities in the braided reach are greater than flow velocities in the canyon and meander reaches. Flow velocities usually are lowest in the meander reach.

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Manuscript approved for publication, January 13, 2006

Prepared by the U.S. Geological Survey,
Publishing Service Center, Tacoma, Washington

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SIR 2006–5019