# ALTERED DYNAMICS OF KOOTENAI RIVER WHITE STURGEON SPAWNING HABITAT AND FLOW MODELING

**By Gary Barton, USGS, Boise, ID, gbarton@usgs.gov, Richard McDonald, USGS, Golden, CO, r*mcd@usgs.gov*, Jonathan Nelson, USGS, Golden, CO, *jmn@usgs.gov*, Charles Berenbrock, USGS, Boise, ID, *ceberenb@usgs.gov*, Mary Donato, USGS, Boise, ID, mdonato@usgs.gov, Pete VanMetre, USGS, Austin, TX,*pcvanmet@usgs.gov*, and Barbara Mahler, USGS, Austin, TX, *bjmahler@usgs.gov***

**ABSTRACT**
In 1994, the Kootenai River white sturgeon (*Acipenser transmontanus*) was listed as an Endangered Species. In response to the listing, the Kootenai River White Sturgeon Recovery Team was established to find and implement ways to improve spawning and rearing habitat used by white sturgeon. The team identified the need to develop and apply a multidimensional flow model to certain reaches of the river to quantify physical habitat in a spatially-distributed manner. The U.S. Geological Survey has addressed these needs by using the agency's MultiDimensional Surface-Water Modeling System (MD_SWMS) to construct a flow model for the critical-habitat reach of the Kootenai River white sturgeon near Bonners Ferry, Idaho. This paper describes the altered white sturgeon habitat and the model, presents the results of a few simple simulations, and demonstrates how the model can be used to link physical characteristics of streamflow to biological or other habitat data. This study was conducted in cooperation with the Kootenai Tribe of Idaho, the Idaho Department of Fish and Game, and the Bonneville Power Authority.

## INTRODUCTION

Many local, State, and Federal agencies are concerned about the declining population of the endangered white sturgeon (*Acipenser transmontanus*) in the Kootenai River in Idaho (fig. 1). Biologists have observed an overall decline in recruitment of juvenile sturgeon beginning in the 1950s with an almost total absence of recruitment after 1974. Consistent annual recruitment of large year-classes has not been observed since before 1960 (Paragamian and others, 2005). Lack of Kootenai River white sturgeon recruitment has been attributed, at least in part, to changes in the natural streamflow regime, sediment transport, and water clarity of the Kootenai River after emplacement of Libby Dam, near Libby, Montana, in 1972 (U.S. Fish and Wildlife Service, 1999). Other changes could have affected sturgeon recruitment include the construction of dikes on natural levees, changes in the level of Kootenay Lake and in backwater conditions near Bonners Ferry, loss of wetlands in the river valley, and reduction of the river's nutrient load (Duke and others, 1999), and over fishing. The Kootenai River White Sturgeon Recovery Team was established to find and implement ways to improve spawning and rearing habitat used by white sturgeon. The team identified the need to develop and apply a multidimensional flow model to certain reaches of the river to quantify physical habitat in a spatially distributed manner. The U.S. Geological Survey (USGS) has addressed these needs by using a multidimensional flow model to simulate streamflow and sediment mobility in the critical habitat.

Kootenai River is 721 kilometers (km) long. Beginning in British Columbia, Canada, the river flows through Montana and Idaho, and then turns northwest back into British Columbia (fig. 1). The model reach lies within the designated critical habitat for white sturgeon nears Bonners Ferry, Idaho (fig 1; U.S. Fish and Wildlife Service, 1999). Since 1994, spawning has occurred in the model reach between river kilometers (RKM) 228.7 and 245.7 (Paragamian and others, 2002). River width in the model reach ranges from about 65 to 255 m and near the downstream boundary, Shorty Island divides the flow into main and secondary channels.

The model reach is subdivided into two reaches based on the primary sediment forming the river substrate: (1) a straight reach (Tetra Tech, Inc., 2003) between the upstream model boundary at RKM 245.9 and the upstream end of Ambush Rock at RKM 244.6 with a sand, gravel, and cobble substrate, and (2) a meandering reach between the upstream end of Ambush Rock and the downstream model boundary at RKM 228.4 consisting primarily of a sand substrate and dunes with minor amounts of lacustrine clay and silt. Seismic subbottom profiles and vibracores (fig. 2) of the river substrate show that isolated areas in the meander reach could be suitable for egg incubation where gravel, cobble, and riprap is present, but is partly buried by thin layers of sand, such as in the meander bend below the mouth of Myrtle Creek between RKM 234.20 and 234.60 (Barton, 2004; McDonald, and others, in press). Habitat suitability curves for white sturgeon in the Lower Columbia River (Parsley and Beckman, 1994), suggest that the particle size of substrate in the braided reach and the straight reach has poor to moderate suitability for egg incubation and in the meander reach has poor suitability (fig. 3) with moderate suitability in a few small areas such as RKM 233.9 to 234.6 near Myrtle Creek.

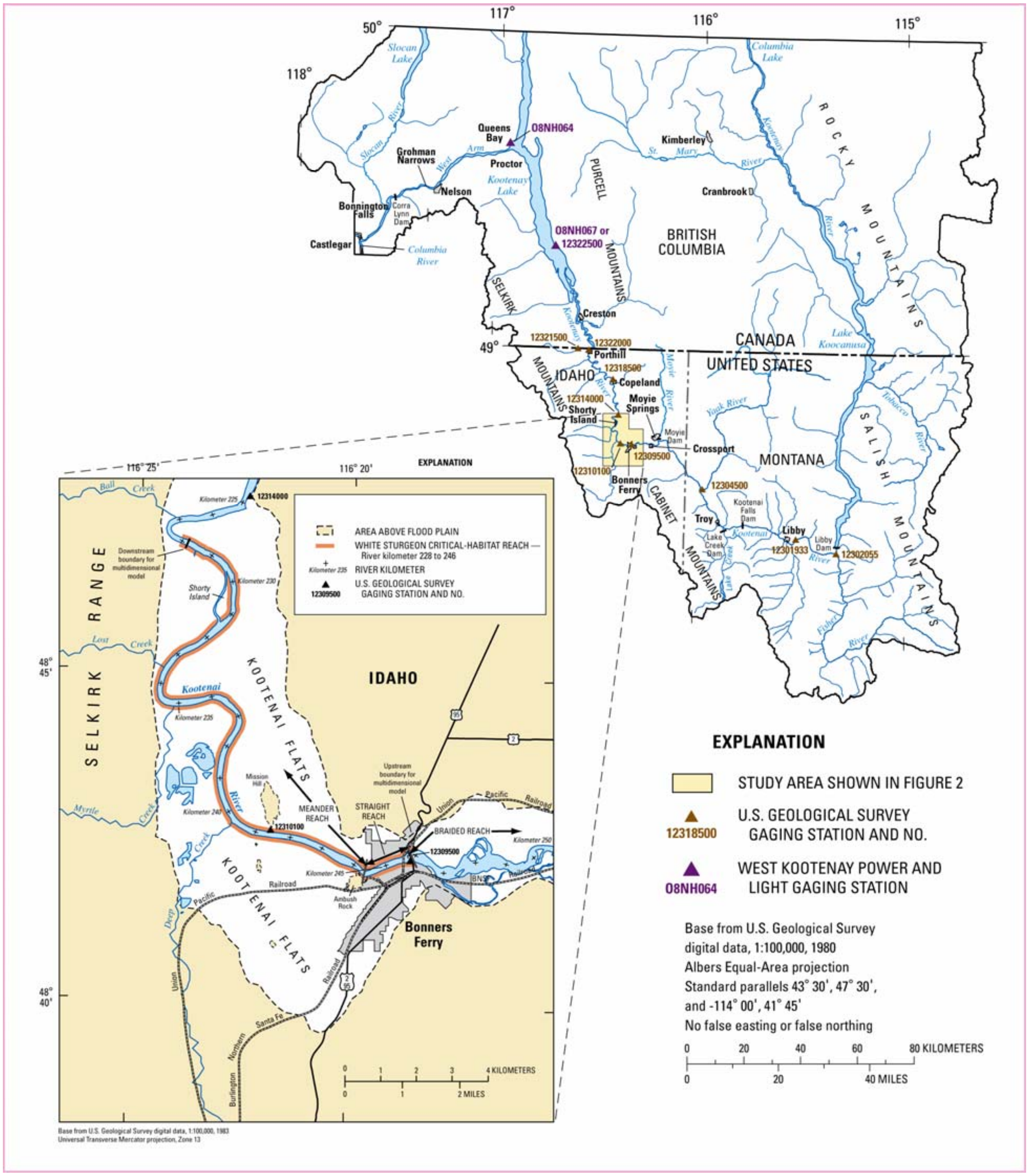


**Figure 1.** Map showing the location of the study area, near Bonners Ferry, Idaho, and selected streamflow-gaging stations and dams in the Kootenai River drainage basin, Idaho, Montana, and British Columbia, Canada. (modified from Barton and others, 2005)

**Figure 2.** U.S. Geological Survey personnel collecting a 3.7-meter-long vibracore sample of riverbed sediments in the Kootenai River, Idaho. (from Barton, 2004)

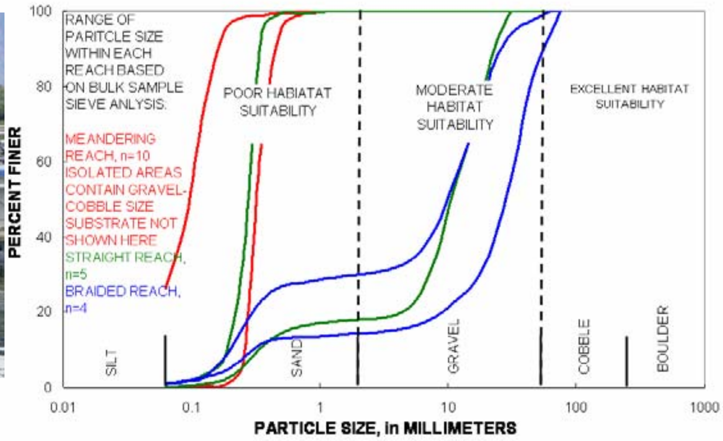


**Figure 3**. Range of riverbed particle size in the meandering, straight, and braided reaches near Bonners Ferry, Idaho. (modified from Berenbrock and Bennett, 2005, and from Barton and others, 2005)

## ALTERED DYNAMICS IN THE WHITE STURGEON CRITICAL HABITAT REACH

The altered dynamics of streamflow are described for 1966-83 when suspended-sediment concentrations were measured daily at the Copeland gaging station (12318500, located 31 km downstream of spawning reach) and described for 1994 -2005. Copeland is the most complete and consistent data available for describing sediment transport before the dam and during the dam era. Prior to the emplacement of Libby Dam, the flow regime of the Kootenai River during the period of suspended sediment record at the Copeland gaging station (12318500), 1966-71, was characterized by peak streamflows resulting from spring snowmelt from late April through mid-July. Median annual peak streamflow was about 2,240 $m^3/s$. A slow recession of streamflow generally started in mid-June and stabilized in September. The annual median base streamflow during October through February was 88.0 $m^3/s$. The average cross-sectional velocity for 62 measurements from the cableway at the Copeland gaging station ranged from 0.06 to 1.21 m/s.

After the dam was constructed in 1972, the flow regime of the Kootenai River during the period of suspended-sediment record at the Copeland gaging station, 1973-83, was characterized by median annual peak streamflows of about 600 $m^3/s$, less than one-third of the pre-Libby Dam value. Long periods of sustained higher flows occurred during the autumn and winter, reflecting the greater demand for hydroelectric power generation and water storage in Lake Koocanusa. Average cross-sectional velocity during 83 measurements from the cableway at the Copeland gaging station ranged from 0.11 to 0.80 m/s. Since the mid-1990s, the U.S. Fish and Wildlife Service has requested that Kootenai River flows be increased during white sturgeon spawning in May and June to help re-establish recruitment. Kootenai River flows are augmented with additional releases of water from Libby Dam. However, instantaneous flow during spawning season is less than one-half that of the pre-Libby Dam era (Barton, 2004).

Kootenay Lake levels and Kootenai River backwater conditions have changed over time due to the operation of Corra Linn Dam and Libby Dam, and these conditions possibly influence white sturgeon spawning patterns (Duke and others, 1999). During the spawning season prior to the emplacement of Libby Dam, higher peak plows resulted in backwater extending further upstream into the braided reach where the substrate is more suitable for sturgeon egg incubation. Kootenay Lake creates backwater conditions in Kootenai River to a variable point upstream of the mouth of Deep Creek (RKM 240.2) near Bonners Ferry. During May, June, and early July, when lake water-surface elevation and river discharge are high, backwater conditions can extend several kilometers upstream of Bonners Ferry. During periods of low streamflow, backwater conditions diminish and free-flowing water may extend a few kilometers downstream of the bridge (Berenbrock, 2005). Corra Linn Dam was completed in 1931, and it affects water levels in Kootenay Lake and, consequently, in the backwater-affected reach of the Kootenai River (Duke and others, 1999). After the river channel at Grohman Narrows upstream of Corra Linn Dam was deepened in 1939, the lake level remained stable at an intermediate elevation for longer periods of the calendar year, probably in response to the operation of Corra Lynn Dam. Seasonal fluctuations still occurred, but over a shorter period of time. From 1940 to 1972 (prior to the construction of Libby Dam), monthly median lake elevations ranged from 529.6 to 536.4 m, from 1973 to 1998 (after the dam was in place), elevations ranged from 529.9 to 534.2 m (Barton, 2004). The lower lake levels during the Libby Dam era indicate that backwater did not extend as far upstream as during the pre-Libby Dam era.

During snowmelt runoff in the pre-Libby Dam era, sediment data collected at the USGS gaging station at Copeland (12318500) indicate that large amounts of suspended sediment were transported through the white sturgeon critical-habitat reach. The annual suspended-sediment load leaving the Kootenai River critical-habitat reach decreased dramatically after the closure of Libby Dam in 1972. During the pre-Libby Dam era, annual average load at the Copeland gaging station from 1966 to 1971 was 1,740,000 metric tons (mt), and annual median daily load ranged from 14 to 48,700 metric tons per day (mt/d). Most of the sediment load was transported during May and June when streamflow and suspended-sediment concentrations were highest. In contrast, after dam closure the annual average load from 1973 to 1983 was 190,000 mt and the annual median daily load ranged from 53 to 1,560 mt/d.

Suspended-sediment transport during the Libby Dam era has been about 11 percent of the pre-Libby Dam era amount. This reduction was caused by the influence of Libby Dam on the flow regime and on the reduction of sediment in the river below the dam due to its sediment trapping characteristics. In addition to the effects of changes in streamflow, less sediment was available for transport because 70 percent of the basin is upstream of Libby Dam (Barton, 2004).

Prior to the closure of Libby Dam, when sediment transport was greater, minor amounts of gravel and cobble may have been exposed on the riverbed in the spawning reach just below the mouth of Myrtle Creek in the critical-habitat reach (Barton, 2004). The large reduction in suspended–sediment concentration after the closure of Libby Dam (Barton, 2004, fig. 14) has caused an increase in water clarity during May and June. Residents in Idaho and Montana have reported the river becoming much less turbid in the months of May-July (present day white sturgeon spawning season) after the closure of Libby Dam (Bob Hallock, U.S. Fish and Wildlife Service, oral commun. 2005). Additional information about the hydraulics and sediment transport can be found in Berenbrock (2005) and Berenbrock and Bennett (2005). Gadomski and Parsley (2005) reported that significantly more embryos may be preyed upon at lower turbidity.

## METHODS

The USGS MultiDimensional Surface-Water Modeling System, MD_SWMS, was used to construct a flow model for the critical-habitat reach of the Kootenai River. The computational grid was 17,525 m in length with 3,505 nodes in the downstream direction and 800 m in width with 161 nodes in the cross-stream direction, forming an approximately 5.0-by-5.0-m grid. MD_SWMS was used to simulate water-surface elevation, velocity (stream-wise and cross-stream velocity components), boundary (bed) shear stress, and in conjunction with subsidiary methods, the incipient motion of sediment on the riverbed. MD_SWMS is a graphical user interface (GUI) developed by the USGS (McDonald and others, 2001) for hydrodynamic models. FaSTMECH is one computational model within MD_SWMS; it was developed at the USGS (Nelson and McDonald, 1997; Thompson and others, 1998; Nelson and others, 2003). FaSTMECH includes a 2-dimensional, vertically-averaged model and a sub-model that calculates vertical distribution of the primary velocity and the secondary flow about the vertically-averaged flow. Calibration, sensitivity analysis, and validation of the model are discussed in detail in Barton and others (2005).

The model's ability to simulate the velocity flow field, bed shear stress, and sediment mobility is constrained largely by (1) the accuracy and level of channel geometry detail, especially regarding errors that could arise because topography was measured during varying streamflows and different streamflows were used in the model, and because the accuracy of the current topography available for Shorty Island is not known (Barton and others, 2004), (2) the way the relation between streamflow and bedforms was characterized, and (3) the potential errors incurred by applying a steady-state model to unsteady flow situations. Although strong evidence indicates that pre-dam era and dam era channel geometry generally are similar, the accuracy of streamflow simulations for pre-dam peak flows is expected to be less than streamflow simulations for dam era peak flows (Barton and others, 2005).

## RESULTS

The model was used to simulate water-surface elevation, depth, velocity, bed shear stress, and sediment mobility in the Kootenai River for streamflows of 170, 566, 1,130, 1,700, and 2,270 $m^3/s$. The range of simulated streamflows was selected to span river conditions typical of those before and since the construction of Libby Dam. The three lowest streamflows represent a range of conditions that have occurred throughout the historical record. The highest streamflow represents a discharge that is approximately equal to the annual median peak streamflow (2,237 $m^3/s$) prior to emplacement of Libby Dam in 1972. A few simple simulations are presented here to demonstrate how the model can be used to link physical characteristics of streamflow to biological or other habitat data. Some measures of depth, velocity, and substrate composition generally are considered when assessing sturgeon spawning habitat (Parsley and others, 1993). Discussions of the model simulation include relating the model results to observed patterns of spawning and egg locations, specifically the number of spawning events per unit of effort (SEPUE) during 1994-2001.

### Depth

Spawning depth habitat suitability in the model is evaluated with the model using the research of Parsley and Beckman (1994): the straight reach ranges from poor to excellent, and the meandering reach is generally excellent (fig. 4). Parsley and Beckman (1994) showed that depths for spawning white sturgeon in the Lower Columbia River ranged from 3.5 to 25 m; and they rated habitat suitability as poor for depths less than 2 m, moderate for depths of 2 to 4 m. Model simulated median and maximum river depth for all wet nodes for the lowest and highest streamflow simulations, 170 and 2,270 $m^3/s$, ranged from 4.5 to 10.4 m and from 20.0 to 27.8 m, respectively. The model also simulated average and maximum water depth for the five streamflows at cross sections every 100 m along the modeled reach (fig. 4). Included in this figure is spawning depth habitat suitability from Parsley and Beckman (1994). The river depth is shallowest in the upper kilometer of the straight reach and here spawning habitat suitability is poor at the lowest streamflow. In this area, the average depth for the lowest and highest streamflow simulations is 2.5 and 8.7 m, and the maximum depth is 4.3 and 12.0 m. Below Ambush Rock, in the meandering reach, the average depth is 6.8 and 14.6 m, and the maximum river depth is 15.6 and 23.1 m (Barton and others, 2005).

### Velocity

Higher velocities are associated with more suitable substrate for white sturgeon egg incubation, greater egg dispersal, and reduction of egg predation. A general description of the river velocity structure can be developed by examining variation of the median and maximum values of simulated velocity for all model nodes. Median and maximum velocity ranged from 0.25 and 1.07 m/s for the lowest streamflow to 1.0 and 1.8 m/s for the highest streamflow. The model reach can be divided into three velocity zones on the basis of simulated maximum velocity for cross-sections located every 100 m along the length of the model reach (fig. 5). Zone A, between the upstream model boundary and Ambush Rock, is a region of high velocity. Maximum velocities in zone A generally are higher than those in the rest of the model reach, but the differences decrease with increasing streamflow. Zone B, between Ambush Rock and the first sharp meander below the mouth of Deep Creek at RKM 237.5, has uniform maximum streamflow velocities compared to the rest of the model reach. One notable exception is near the deep hole and lateral recirculation eddy above Deep Creek. Zone C, downstream of zone B and extending to the downstream model boundary at RKM 228.4, shows variations in the maximum velocity that increase with increasing streamflow. The spatial variation in velocity across the river channel has been quantified using the standard deviation of velocity at cross sections positioned every 100 m along the length of the model reach. The greatest variability in velocity shown by the standard deviation is a reflection of both the complex channel geometry through the S-shaped meander and the flow divergence around Shorty Island. The greatest occurrence of white sturgeon spawning is in zone C.

Spawning habitat suitability for streamflow velocity in the model is evaluated here using the research of Parsley and Beckman (1994): in the meander reach the average velocity at streamflow of 1,700 $m^3/s$ and less is classified as poor and in the straight reach only a streamflow of 170 $m^s/s$ is classified as poor (fig. 5). Figure 5 shows the relation between simulated velocity results and sturgeon spawning habitat. McDonald and others (2004) showed a correlation between the model's maximum cross-sectional velocity and white sturgeon spawning location. In other studies, lake sturgeon were found to spawn in tributary rapids (Auer, 1996; LaHaye and others, 1992). Streamflow velocities equal to or greater than 1.0 m/s are believed to greatly reduce or eliminate predation of white sturgeon

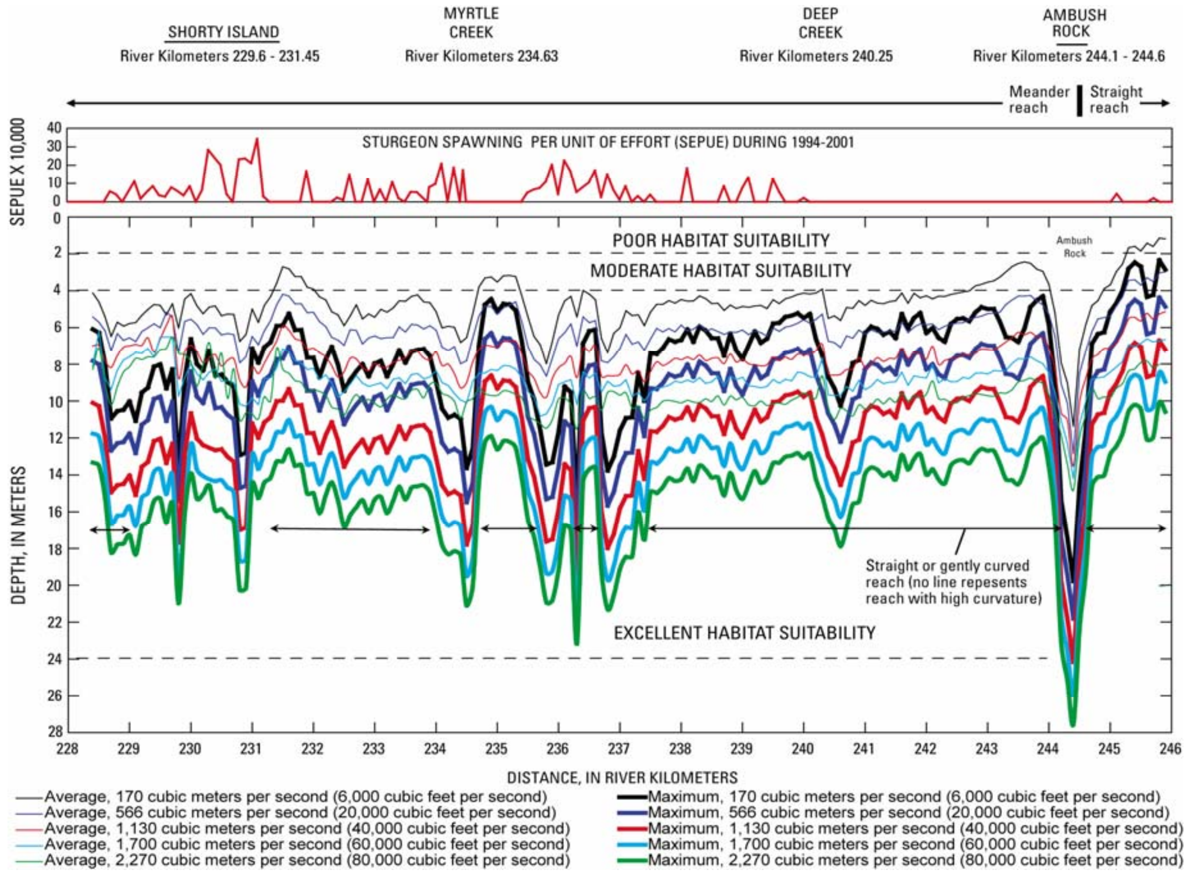


**Figure 4.** Simulated average and maximum depth for five streamflows at cross sections positioned every 100 meters along the white sturgeon critical-habitat reach of the Kootenai River near Bonners Ferry, Idaho, and spawning event locations. (modified from Barton and others, 2005; spawning habitat suitability from Parley and Beckman, 1994)

eggs (Bob Hallock, U.S. Fish and Wildlife Service, oral commun., 2005). The simulated average velocity in the main channel at Shorty Island, where white sturgeon most frequently spawn (Paragamian and others, 2002), does not approach 1.0 m/s until streamflow is 2,270 $m^3$/s, and this only occurs for portions of the reach between RKM 230.3 and 231.1 (fig. 5). However, the maximum simulated velocity in this reach (fig. 5) is greater than 1.0 m/s for flows equal to and greater than a streamflow of 1,130 $m^3$/s (Barton and others, 2005).

## DISCUSSION

Many biologists believe that some or many of the altered dynamics in the Kootenai River have contributed to the lack of sustainable white sturgeon recruitment. Habitat suitability curves developed for white sturgeon in the Lower Columbia River (Parsley and Beckman, 1994) were used to characterize conditions in the Kootenai River spawning habitat. Requirements for Kootenai River white sturgeon spawning habitat may vary from that in the Lower Columbia; however, both rivers are highly regulated systems. Substrate suitability for egg incubation is poor to moderate in both the braided and straight reach and generally poor in the meander reach with moderate suitability in a few small areas such as RKM 233.9 to 234.6 near Myrtle Creek. Model simulations showed that depth suitability ranges from poor to excellent in the straight reach and is generally excellent in the meandering reach, and that average-velocity suitability is generally moderate in the straight reach and poor in the meander reach. Overall habitat suitability is better in the straight reach rather than the meander reach due to coarser substrate and higher velocities.

White sturgeon seldom spawn in the straight reach and avoid the adjacent braided reach; avoidance may be related to light attenuation--function of depth and clarity. Both reaches are significantly shallower and have more suitable substrate for egg incubation than the meandering reach. Perhaps during the pre-Libby Dam era when the river was

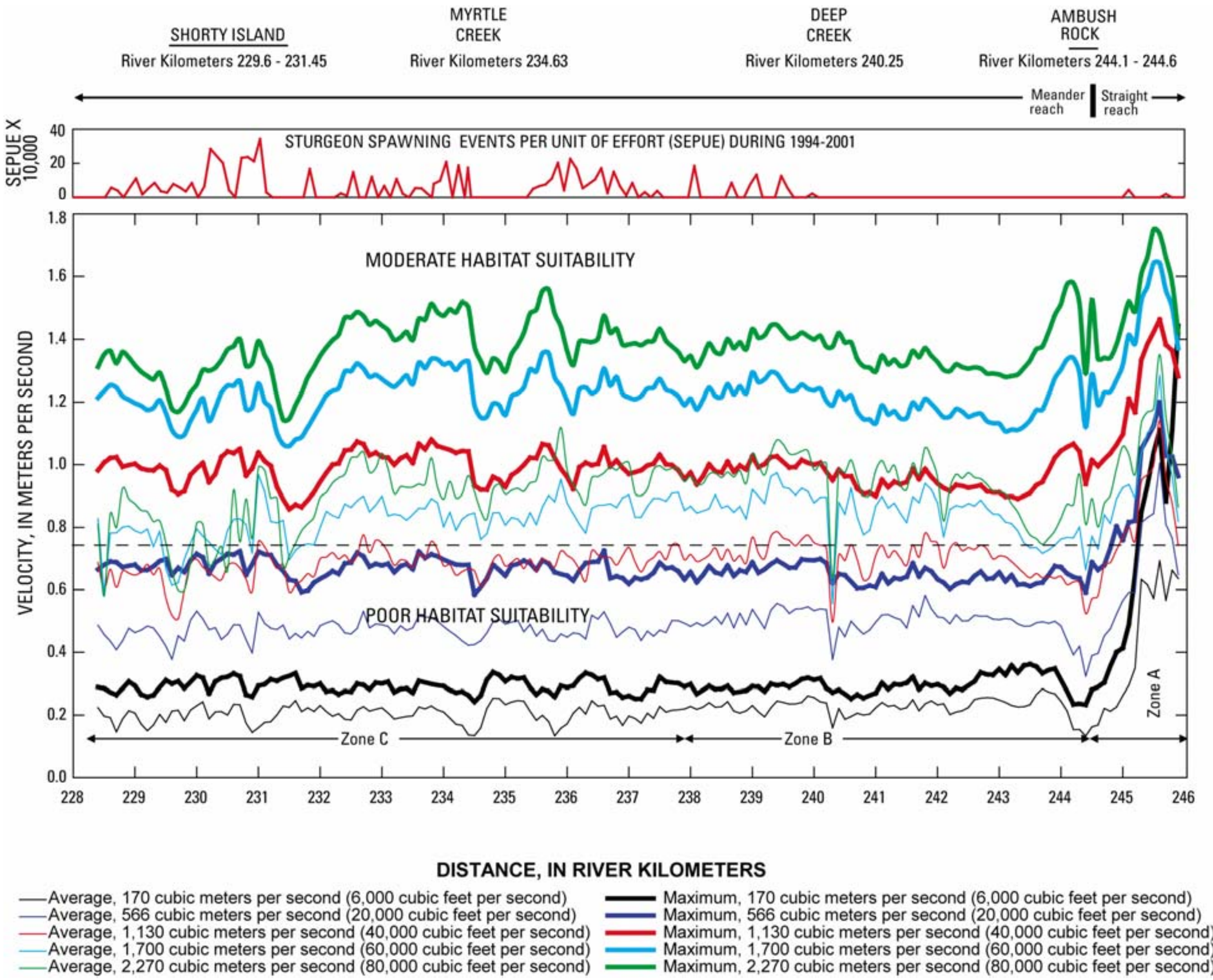


**Figure 5**. Simulated average and maximum velocity for five streamflows at cross sections positioned every 100 meters along the white sturgeon critical-habitat reach of the Kootenai River near Bonners Ferry, Idaho, and spawning event locations. (modified from Barton, 2005; spawning habitat suitability from Parley and Beckman, 1994)

more turbid and deeper the sturgeon spawned frequently in the shallow straight and braided reaches. Large reduction in suspended–sediment concentration after the closure of Libby Dam caused an increase in water clarity during the spawning season. (Perrin and others (2003) pointed out that water clarity as a factor affecting white sturgeon spawning patterns has not been examined on the Kootenai River. If white sturgeon are generally photophobic because of evolutionary history, light attenuation may be an important factor affecting spawning location and depth. Suspended-sediment concentration is one of the controlling factors on the amount of ultraviolet radiation penetrating the water column and Zagarese and Williamson (2001) have shown that the range of potential effects include DNA damage resulting in egg and larval mortality. The photophobic and ultraviolet radiation issues might explain why the white sturgeon avoid spawning in the shallow braided reach and seldom spawn in the straight reach.

## ACKNOWLEDGEMENTS

The authors thank Sue Ireland of the Kootenai Tribe of Idaho for providing storage facilities for USGS equipment. Vaughn Paragamian, Diane Wakkinnen, and Peter Rust of the Idaho Department of Fish and Game provided white sturgeon spawning location and egg location data. Rick Backsen, John Gralow, and Russ Christensen of the USGS in Post Falls, Idaho, and Edward Moran of the USGS in Anchorage, Alaska, worked long hours collecting data for this project. Sandra Ball of the USGS in Post Falls, Idaho, helped with many logistical issues.

## REFERENCES


Auer, N.A, 1996, Response of spawning lake sturgeon to changes in hydroelectric facility operations: Trans. Am., Fish. Soc. 125, p. 66 – 77.

Barton, G.J., 2004, Characterization of channel substrate, and changes in suspended sediment transport and channel geometry in white sturgeon spawning habitat in the Kootenai River near Bonners Ferry, Idaho, following the closure of Libby Dam: U.S. Geological Survey Water-Resources Investigations Report 03-4324, 102 p.

Barton, G.J., McDonald, R.R., Nelson, J.M., and Dinehart, R.L., 2005, Simulation of flow and sediment mobility using a multidimensional flow model for the white sturgeon critical-habitat reach, Kootenai River near Bonners Ferry, Idaho: U.S. Geological Survey Scientific Investigations Report 2005-5230, 75 p.

Barton, G.J., Moran, E.H, and Berenbrock, C., 2004, Surveying cross sections of the Kootenai River between Libby Dam, Montana, and Kootenay Lake, British Columbia, Canada: U.S. Geological Survey Open-File Report 2004–1045, 34 p.

Berenbrock, Charles, 2005, 1D Simulations of hydraulic characteristics in the white sturgeon spawning habitat of the Kootenai River near Bonners Ferry, Idaho: U.S. Geological Survey Scientific Investigations Report 2005-5110, 30p.

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, 43 p.

Duke, S., Anders, P., Ennis, G., Hallock, R., Hammond, J., Ireland, S., Laufle, J., Lauzier, R., Lockhard, L., Marotz, G., Paragamian, V., and Westerfhol, R., 1999, Recovery plan for Kootenai River white sturgeon (*Acipenser transmontanus*): J. of Applied Ichthyology, v. 15, p. 157-163.

LaHaye and others, 1992, Reproduction , early life history, and characteristics of the spawning grounds of lake sturgeon (*Acipenser transmontanus*) in Des Prairies and L'Assomption rivers, near Montreal, Quebec, Can. J. Zool. 70, p. 1681–1689.

McDonald, R.R., Barton, G.J., Nelson, J.M., and Paragamian, V., in press, Modeling hydraulic and sediment transport processes in white sturgeon spawning habitat on the Kootenai River: proceeding in the Joint 8$^{th}$ Federal Interagency Sedimentation and 3$^{rd}$ Federal Interagency hydrologic modeling conference, 8 p.

McDonald, R.R., Bennett, J.P., and Nelson, J.M., 2001, The USGS multi-dimensional surface water modeling system, in Proceedings, 7th U. S. Interagency Sedimentation Conference, Reno, Nev., p. I-161-I-167.

McDonald, R.R., Nelson, J.M., Barton, G., and Paragamian, V., 2004, Flow and sediment-transport modeling of Kootenai River White Sturgeon spawning habitat: Eos Trans., American Geophysical Union, v. 85, no. 47, Abstract H53B-1239.

Nelson, J.M., Bennett, J.P., and Wiele, S.M., 2003, Flow and sediment-transport modeling, *in* Kondolf, G.M., and Piegay, H., eds., Tools in fluvial geomorphology: England, Wiley, p.539-576.

Nelson, J.M., and McDonald, R.R., 1997, Mechanics and modeling of flow and bed evolution in lateral separation eddies: Bureau of Reclamation, Glen Canyon Environmental Studies Report, 69 p.

Parsley, M.J., and Beckman, L.G., 1994, White sturgeon spawning and rearing habitat in the lower Columbia River: North American J. of Fish Management, v. 14, p. 812-827.

Parsley, M.J., Beckman, L.G., and McCabe Jr., G.T., 1993, Spawning and rearing habitat used by white sturgeon in the Columbia River downstream of McNary Dam: Trans. of the American Fisheries Soc., v. 122, 10 p.

Paragamian, V.L., Wakkinnen, V.D., and Crews, G., 2002, Spawning locations and movement of Kootenai River white sturgeon: J. of Applied Ichthyology, v. 18, 9 p.

Paragamian, V.L., Beamesderfer, R.C., and Ireland, S.C., 2005, Status, population dynamics, and future prospects of the endangered Kootenai River white sturgeon population with and without hatchery intervention: spawning locations and movement of Kootenai River white sturgeon: Trans. of the American Fisheries Soc., v. 134, 14 p.

Perrin, C.J., Rempel, L.L., and Rosenau, M.L., 2003, White sturgeon spawning habitat in an unregulated river: Fraser River, Canada: Trans. of the American Fisheries Soc., v. 132, p. 154-165.

Tetra Tech, Inc., 2003, Kootenai River geomorphic assessment: Seattle, Washington, 114 p.

Thompson, D.M., Nelson, J.M., and Wohl, E.E., 1998, Interactions between pool geometry and hydraulics, Water Resources Research, v. 34(12), p. 3673-3681.

U.S. Fish and Wildlife Service, 1999, Recovery plan for the Kootenai River population of the white sturgeon (*Acipenser transmontanus*): Portland, Oregon, variously paginated.

Zagarese H.E., and Williamson, C.E., 2001, The implications of solar UV radiation exposure for fish and fisheries: Fish and Fisheries v. 2, no. 3, p. 250-260.