

## **SEDIMENT CHARACTERISTICS AND TRANSPORT IN THE KOOTENAI RIVER WHITE STURGEON CRITICAL HABITAT NEAR BONNERS FERRY, IDAHO**

**Ryan Fosness, Hydraulic Engineer, USGS, Boise, ID, rfosness@usgs.gov;  
Marshall Williams, Biologist, USGS, Boise, ID, mlwilliams@usgs.gov**

**Abstract:** The U.S. Geological Survey, Idaho Water Science Center, conducted suspended- and bedload-sediment sampling to assess sediment characteristics and transport at three sites along the Kootenai River within the federally designated critical habitat of the endangered white sturgeon population. Sediment samples and acoustic Doppler current profiles of streamflow were collected to assess the variability in sediment-transport over the spring runoff. Suspended- and bedload-sediment characteristics indicate the differences in the total sediment load at each sampling location. The sediment trapping characteristics of Libby Dam 108 kilometers upstream of the study reach, in combination with the backwater affect of Kootenay Lake 102 kilometers downstream, required a unique approach to estimating total sediment load. Results from this study are being used to provide guidance in developing habitat improvement projects that will assist in the recovery of the Kootenai River white sturgeon (*Acipenser transmontanus*) in the Kootenai River.

### **INTRODUCTION**

Anthropogenic effects are evident along the reach of the Kootenai River (or Kootenay for the Canadian areas) that includes the federally designated critical habitat of the Kootenai River inhabited by the white sturgeon (*Acipenser transmontanus*). The Kootenai River white sturgeon critical habitat is a 29.5 km reach extending from river kilometer mile (RKM) 257.0, downstream of the Moyie River, to RKM 228.0 in the meandering reach downstream of Shorty's Island. The critical habitat was recently extended 11.4 km upstream to include the braided reach from RKM 246.0 to 257.0 (Federal Register, 2008).

Dikes were built on natural levees early in the 20th century to protect agriculture from flooding on the Kootenai River floodplain (Turney-High, 1969; Boundary County Historical Society, 1987; Redwing Naturalists, 1996), contributing to detrimental changes in the natural river environment in the critical habitat. Furthermore, the 1972 completion and subsequent operation of Libby Dam, put into service in 1972, significantly altered the Kootenai River streamflow and water quality, and created a habitat unsuitable to sustain natural recruitment of the Kootenai River white sturgeon (U.S. Fish and Wildlife Service, 2006). Research by the Idaho Department of Fish and Game on sturgeon populations determined that there was a lack of juvenile sturgeon in all but the four- year old age class during a 16-year study period (Partridge, 1983).

In 1994, the U.S. Fish and Wildlife Service (USFWS) listed the Kootenai River population of white sturgeon as an endangered species under the provisions of the Endangered Species Act of 1973, as amended. The population was listed as endangered because of declining numbers and a lack of juvenile recruitment that was first noted in the mid-1960s (Federal Register, 1994; U.S. Fish and Wildlife Service, 1999). Many researchers attributed these declining numbers and lack of recruitment to the degradation of white sturgeon habitat, particularly in the spawning habitat (Paragamian and others, 2001, 2002; Kock and others, 2006).



the Selkirk Mountain range (fig. 1). In 1972, construction of Libby Dam was completed on the upper Kootenai River near Libby, Montana, creating Lake Koocanusa, a 145-km long reservoir with a full-pool storage capacity of 7,262.37 hm<sup>3</sup> (U.S. Fish and Wildlife Service, 2006).

The major tributary systems feeding the Kootenai River downstream of Libby Dam are the Fisher and Yaak Rivers in Montana, and the Moyie River in Idaho. The Fisher River has a drainage area of about 2,160 km<sup>2</sup> at its confluence with the Kootenai River at RKM 351.2. Based on 40 years of USGS streamflow data for the Fisher River near Libby, Montana (USGS 12302055), an estimated bankfull streamflow (66.7 percent exceedance probability) is about 62 m<sup>3</sup>/s. The Yaak River has a drainage area of about 1,984 km<sup>2</sup> at its confluence with the Kootenai River at RKM 285.9. Based on 54 years of USGS streamflow data for the Yaak River near Troy, Montana (USGS 12304500), a streamflow estimate for bankfull conditions (66.7 percent exceedance probability) is about 153 m<sup>3</sup>/s. The Moyie River is controlled by Moyie Dam 2.59 km upstream of the confluence with the Kootenai River. A flood-frequency analysis was not applied to this drainage, because the system is regulated.

The study reach of the Kootenai River includes three major geomorphic reaches: a canyon reach, a braided reach, and a meander reach (fig. 2). The canyon reach begins near Kootenai Falls (RKM 312.0) (fig. 1) and continues downstream to near the confluence of the Moyie River (RKM 257.0). The braided reach extends from the end of the canyon reach downstream to Bonners Ferry (RKM 246.0). The meander reach extends from the braided reach downstream to the confluence with Kootenay Lake in British Columbia (RKM 120.0) (fig. 1). The most upstream part of the meander reach includes a 1.4 km reach referred to as the “transition zone” the braided reach transitions to the meander reach between RKMs 245.9 and 244.5 (Federal Register, 2008). Although the transition zone typically refers to the location of the transition between the backwater of Kootenay Lake and the free-flowing river upstream, Berenbrock (2005) found this transition often occurs between RKMs 252.7 and 244.6.

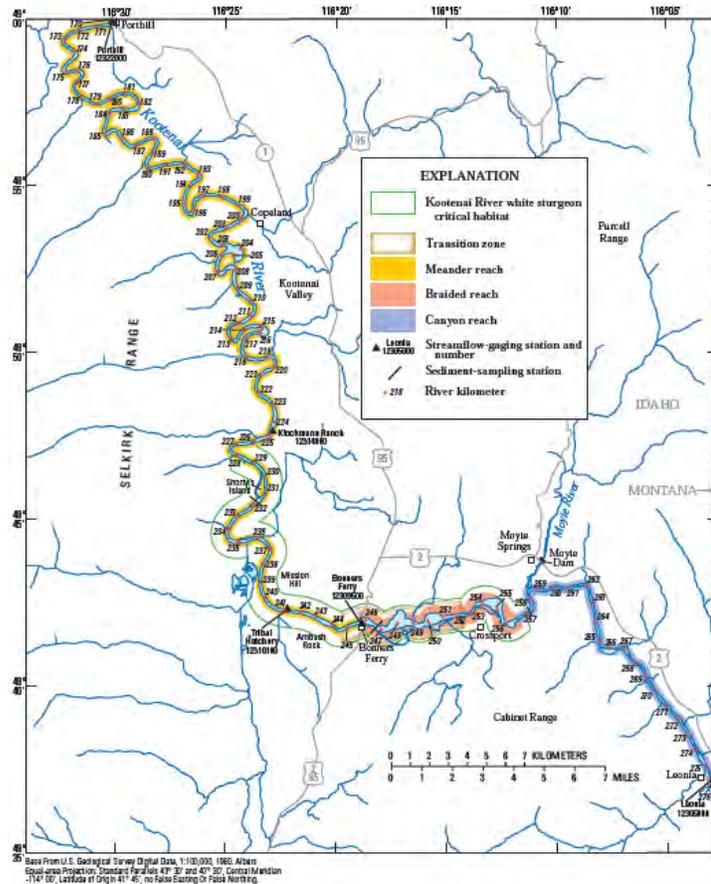


Figure 2 Location of the Kootenai River white sturgeon critical habitat in the study reach, near Bonners Ferry, Idaho.

## METHODS

**Selection of Sediment Sampling Sites:** Three sampling sites, two in the braided reach and one in the meander reach, were selected to sample within the white sturgeon critical habitat (fig. 2). Suspended- and bedload-sediment samples were collected during each sampling period. The two sampling sites farthest upstream in the braided reach were sampled in 2007 and 2008, and the sampling site farthest downstream in the meander reach was established in 2008 (fig. 2). Each site is representative of the three distinct geomorphic and hydrologic features that characterize the critical habitat. The sediment-sampling sites were not operated in conjunction with real-time USGS gaging stations. Instead, an acoustic Doppler current profiler (ADCP) was used according to methods described by Mueller and Wagner (2009) to obtain streamflow and velocity data at the sampling sites (fig. 3).

**Sampling Frequency:** Streamflow in the Kootenai River is regulated primarily by operations at Libby Dam. Sediment samples were collected during three runoff peaks during water year 2008 (fig. 3). Two of the three sampling periods coincided with substantial regulated streamflow from Libby Dam reflecting the winter ramping and the sturgeon pulse that conform to levels prescribed in the 2006 biological opinion (U.S. Fish and Wildlife Service, 2006). The third sampling period was during the spring runoff, a combination of snowmelt runoff from local tributaries downstream of Libby Dam and controlled streamflow from the dam.

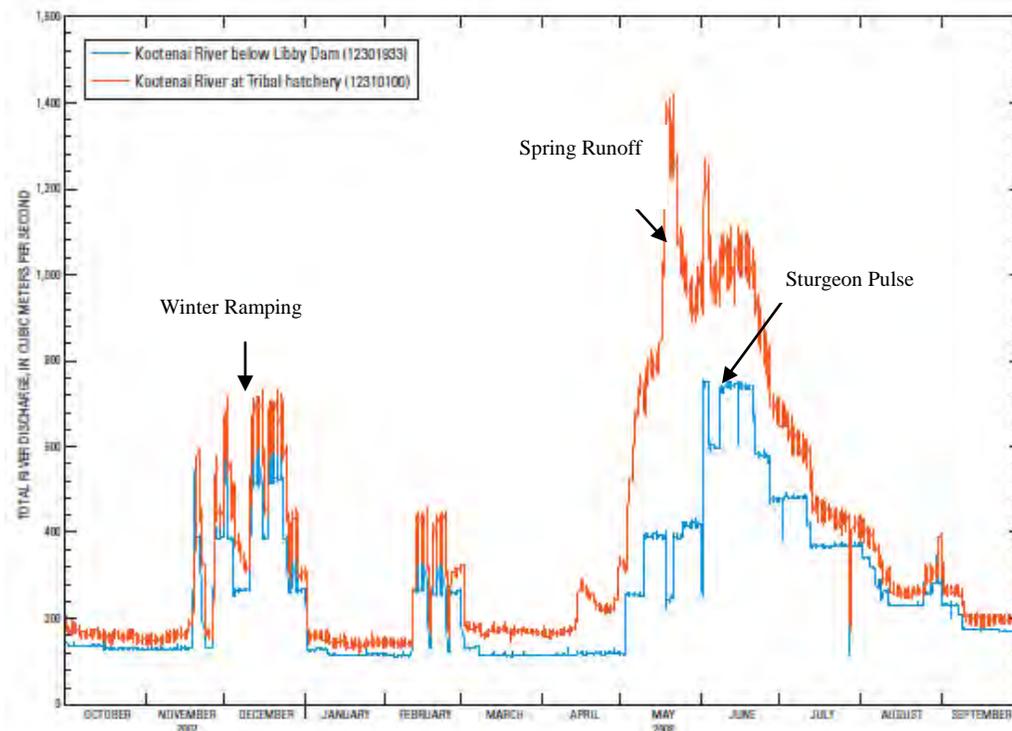


Figure 3 Streamflow at Kootenai River at Libby Dam and Kootenai River at Tribal hatchery near Bonners Ferry, Idaho, for water year 2008.

**Sampling Methods:** A jet boat equipped with a hydraulic boom was used for all sediment sampling. Both suspended- and bedload-sediment sampling followed the equal-width-increment

method (EWI) for suspended sediment and single equal-width-increment method (SEWI) for bedload-sediment described by Edwards and Glysson (1999). The SEWI sampling method was modified as the widths of the first and last sampled zones were not equal to the width of the other sampled zones. This modification was necessary to establish 20 equally spaced sampling stations. Sampling stations were created using digital imaging software that included the left and right bankfull locations and each vertical sampling station. Using this technique, each vertical was sampled in the same spatial location during the sampling sequence. The location of each sampling station was accurately determined using Fugawi™ navigation software with positioning from a mapping grade TrimbleAg232™ global positioning system (GPS) to enable repeated sampling on different site visits.

Suspended sediment was sampled using a D-96 suspended sediment sampler. It was sampled from the water surface to within 102.0 mm of the channel bed. Bedload sediment was sampled using either an Elwha (102.0 x 203.0 mm) or Helley-Smith (77.0 x 77mm) bedload samplers. Bedload sediment was sampled from the bottom of the channel to 102.0 mm above the bed for the Elwha sampler and 77.0 mm above the bed for the Helley-Smith. Sediment not sampled included, (1) the 25.0 mm vertical distance defining the unsampled zone by either the Helley-Smith bedload sampler or the suspended-sediment sampler, and (2) the sediment that passed through the 0.025 and 0.050 mm mesh bedload sediment sample bags.

**Data Analysis:** Suspended- and bedload-sediment samples were processed for analysis to define the quantity and particle-size characteristics of the sediment collected. All suspended-sediment samples were composited and analyzed at the USGS Cascade Volcano Observatory (CVO) Sediment Laboratory. Sediment concentration and particle-size distribution were determined from the analysis. The CVO laboratory analyzed a total of 29 suspended-sediment samples, 25 of which were analyzed for concentration, total weigh mass, percentage of sand-versus-silt and finer, and half-phi scale particle-size distribution (PSD), and the remaining four samples analyzed for concentration only. Suspended-sediment transport was estimated for sand (diameter greater than or equal to 0.063 mm) and silt/clay (diameter less than 0.063 mm) using the concentration and sand-silt percentages and PSD along with the sediment transport equation developed by Guy (1978).

Bedload-sediment samples were analyzed at the USGS Idaho Water Science Center laboratory in Boise. Each bagged sample was weighed individually, and then composited for the entire cross-section. Sieve analysis was completed on composited samples to determine the PSD of bedload at each cross section. The bedload sediment was sieved down to the 0.5 mm sieve, corresponding to the mesh size of the bag used to capture the sediment. Eighteen sieves were used to create the PSD. Bedload-sediment transport rates were estimated using the midsection method (eq. 2; Edwards and Glysson, 1999) to account for varying width for the first and last sampling vertical in the cross section.

## **SEDIMENT CHARACTERISTICS, SUPPLY, AND TRANSPORT**

**Suspended-Sediment Transport:** Since the completion of Libby Dam in 1972, the supply of suspended sediment downstream of Libby Dam has been reduced, largely by the trapping capacity of Lake Koochanusa. Historical data from eight suspended-sediment samples collected

prior to the construction of Libby Dam and 25 samples collected after construction of the dam are shown in figure 4. A power function fitted through each of the two data sets shows the relation between streamflow and suspended sediment transport before and after the construction of Libby Dam. Construction of the dam has reduced sediment supply downstream of the dam and peak-flow magnitude, where current maximum streamflow through Libby Dam without spilling is about  $736 \text{ m}^3/\text{s}$ . When combined with a maximum suspended-sediment concentration of  $3 \text{ mg/L}$ , this streamflow results in a maximum estimated suspended-sediment transport of about 196 metric tons per day.

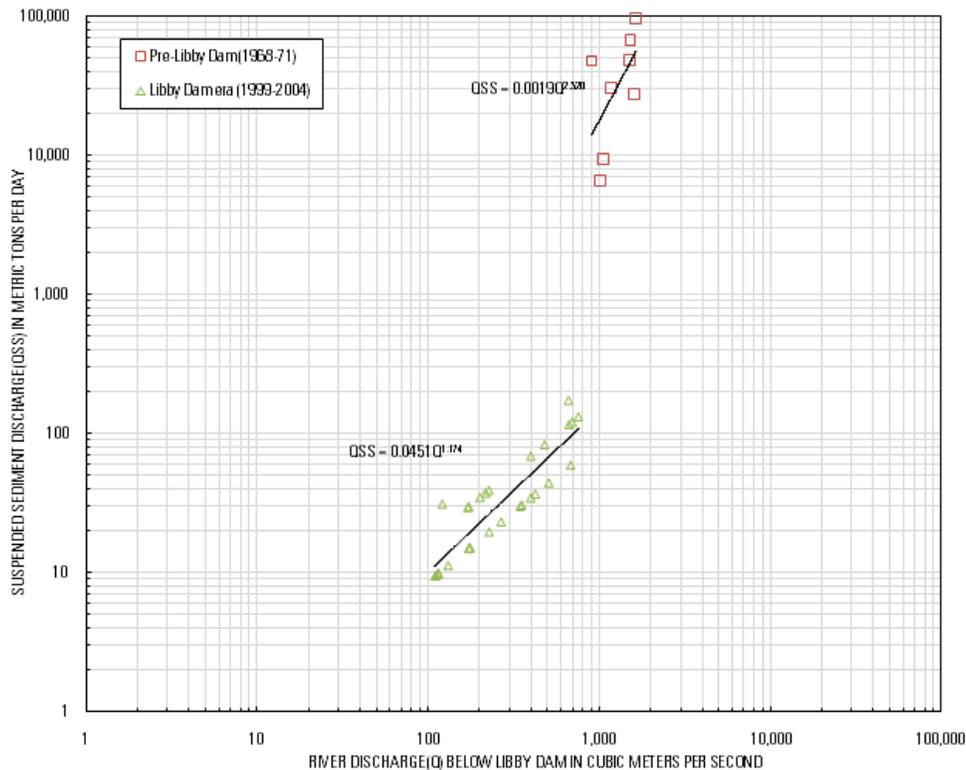


Figure 4 Historical suspended-sediment and streamflow, Kootenai River below Libby Dam, Montana, 1968–71 and 1999–2004.

Suspended-sediment transport remains low (less than 200 metric tons per day) within the white sturgeon critical habitat until the spring runoff, when tributary flooding contributes suspended sediment to the Kootenai River. The contribution of streamflow from Kootenai River below Libby Dam (USGS 12301933) to Kootenai River at Tribal hatchery (USGS 12310100) is shown in figure 3. The tributary streamflow is estimated as the difference in streamflow between these two stations, and the lag time between Libby Dam and the tribal hatchery downstream was taken into account by aligning the peak flows of the two hydrographs. A lag time of 12 hours was used to estimate the offset of streamflow between the two locations. Estimated tributary streamflow and suspended-sediment transport for the three sampling sites are shown in figure 5. To account for contribution of suspended sediment from these tributaries, the suspended-sediment transport curves were developed as a function of tributary streamflow.

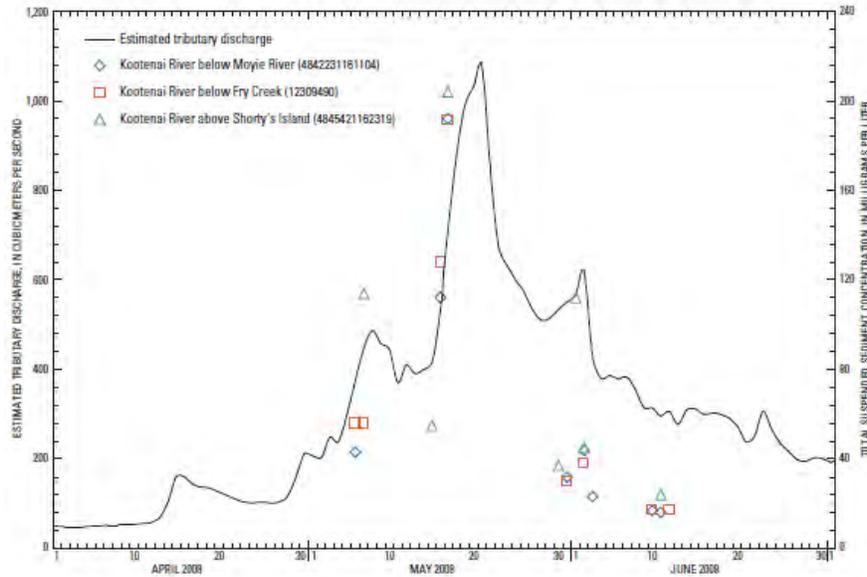


Figure 5 Estimated tributary streamflow and suspended-sediment transport at three locations in the study reach, Kootenai River near Bonners Ferry, Idaho, April–June 2008.

**Bedload-Sediment Transport:** Sieve analysis of the bedload material was conducted to determine the size distribution of the material and to determine the magnitude of bedload for each sampling location. The results were characterized in terms of the relation between total streamflow (independent variable) and sediment transport (dependent variable) according to certain particle-size classes. Three particle-size classes were used to describe the bedload-sediment transport:

- Class 1 – Diameter less than 0.5 mm (silt to medium sand)
- Class 2 – Diameter greater than or equal to 0.5 mm and less than 2 mm (coarse sand to very coarse sand)
- Class 3 – Diameter greater than or equal to 2 mm (very fine gravel to coarse cobble).

Class 1 bedload-sediment represents that amount of collected sediment that is typically transported at velocities greater than 0.61 m/s. Bedload in this size class is smaller than the mesh-size of the bag used to capture the bedload sample. The PSD occasionally indicated that most of the bedload sediment sampled was from size class 1. This apparent discrepancy might occur when the mesh openings become plugged with fine suspended sediment and debris, which prevents the fine-grained bedload material from passing through the mesh. This problem was especially evident for data collected using the Helley-Smith sampler because the mesh size for that bag was only 0.25 mm.

Class 2 sediment consists of sand in the bedload sediment that is larger than the mesh diameter of the sediment bag. The largest transport of Class 2 sediment downstream of the Moyie River occurred during the two periods of greatest streamflow, with the peak of 71.7 metric tons per day occurring during the spring runoff in May. Another peak in the Class 2 transport occurred during the sturgeon pulse in June. The streamflow was only 8 percent less than the spring runoff while the bedload sediment transport was 34 percent less than the spring runoff peak while.

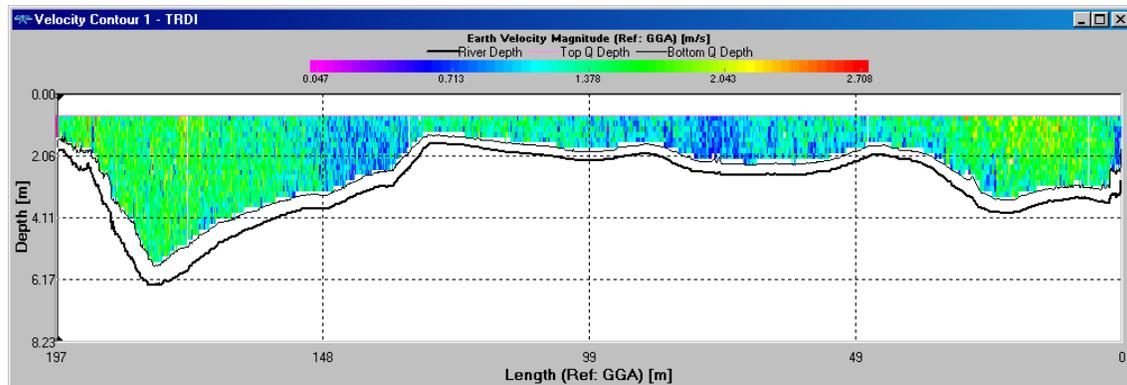
Transport of Class 2 sediment within the transition zone is dependent on the backwater extent of Kootenay Lake. The greatest quantity of Class 2 sediment was transported when the sampled streamflow was lowest, but during the highest mean water velocity. This peak class 2 sediment transport was 36.3 metric tons per day on May 7, 2008. The combination of increased backwater effects and the limited supply of sand to the system likely was the reason for the decrease in Class 2 sediment transport during the spring runoff.

The sampling site upstream of Shorty's Island reflects a sand-dominated system that is in a backwater-affected area throughout the year. The particle-size distribution of the material at this site was nearly identical for each of the sampling periods. The highest measured bedload-sediment transport was 6.08 metric tons per day. Class 2 bedload-sediment transport appears to have increased slightly with increasing water velocity; however, this cannot be confirmed given the limited number of samples. Samples collected with the Helley-Smith sampler were not included in the results because the sampler bags tended to plug with fine-sediment material in suspension.

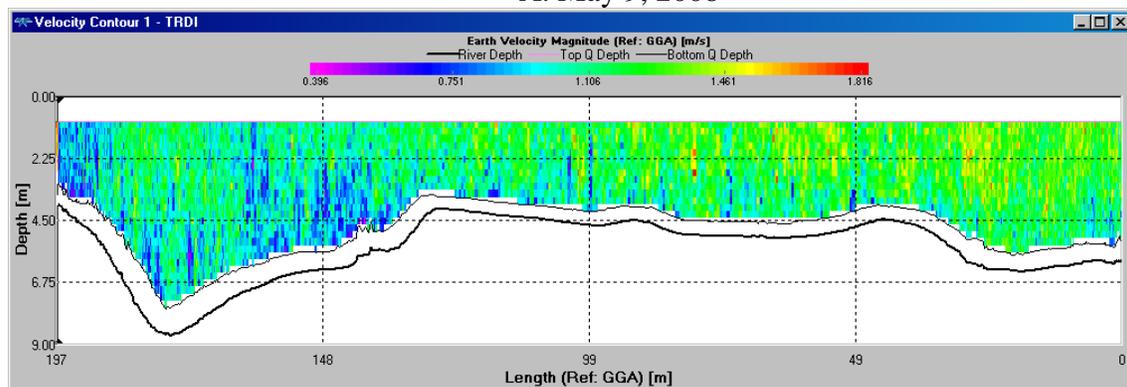
Class 3 sediment consists of bedload material greater than or equal to 2.0 mm in diameter. The greatest transport of class 3 sediment downstream of the Moyie River occurred during the two highest peaks in streamflow. A streamflow of about 1,130 m<sup>3</sup>/s appears to be the threshold required to begin transport of class 3 material at this site. Pebble count data indicate that coarse gravels ( $D_{50} = 39.9$  mm and  $D_{16} = 20.8$  mm) are the dominant streambed material; however, the average particle-size of the sampled bedload was only 6.5 mm during peak transport. This indicates that the predominant material on the channel bottom was not mobilized at the sampled streamflows. The smaller gravels that were collected during sampling indicate that bedload originates from some distance upstream and is not characteristic of the streambed material in the sampling reach. The Helley-Smith sampler was used to sample bedload during two peak streamflow events, and was considered appropriate for this site because the nozzle opening is twice as large as the average particle-size in the channel. On June 1, 2008, an Elwha sampler was used to collect samples at a streamflow of 1,020 m<sup>3</sup>/s with a computed Class 3 bedload transport of 5.0 metric tons per day. During June 2 and 4, 2008, the Helley-Smith sampler was used to collect samples at streamflows of 1,210 and 988 m<sup>3</sup>/s, respectively, with Class 3 sediment transport computed to equal 107.0 and 1.7 metric tons per day, respectively. The large difference in Class 3 bedload transport between June 1 and 4 was likely caused by a decrease in the stream velocity and not because a different type and size of the bedload sampler was used.

Class 3 sediment transport within the transition zone was dependent on the backwater effect of Kootenay Lake. The greatest mass of Class 3 bedload was transported with the highest mean water velocity measured, which also was the lowest measured streamflow. The  $D_{50}$  of the bedload sediment during the highest mean water velocity was about 18.0 mm. Pebble count data indicate that smaller gravels ( $D_{50} = 29.8$  mm and  $D_{16} = 12.8$  mm) are available for transport in this reach, but only while the backwater effect is minimal early in the spring. Although the streamflow tends to increase during spring runoff, the resulting backwater of Kootenay Lake limits sediment transport to Class 1 and Class 2 sediment. Two ADCP measurements (fig. 6) were made on (1) May 9 when the extent of the backwater was near the sampling site (RKM = 246.7) at a streamflow of 700 m<sup>3</sup>/s and (2) June 3 when the extent of the backwater was highest (near RKM = 250.7) at a streamflow of 1,100 m<sup>3</sup>/s. Although the total streamflow increased by

64 percent, the velocity decreased by nearly 1 m/s and the stage increased by 3 m illustrating how the area becomes inundated by backwater and loses the ability to transport bedload greater than Class 2.



A. May 9, 2008



B. June 3, 2008

Figure 6 Acoustic Doppler current profiler measurements from (A) May 9 and (B) June 3, 2008 showing change in velocity characteristics due to backwater from Kootenay Lake at Kootenai River below Fry Creek, near Bonners Ferry, Idaho.

Bedload sediment at the sampling site upstream of Shorty's Island primarily consists of particles less than 2 mm. Transport of Class 3 sediments in this area was assumed to be zero because 99 percent of the streambed material was coarse sand.

**Total Sediment Transport:** Total sediment transport is the sum of all sediment moving past a cross section during a given time period. Thus, the sum of suspended-sediment and bedload-sediment transport was used to estimate the total sediment transport at each of the sampling locations in the Kootenai River.

During the sediment-sampling period, 52–90 percent of the total sediment transport consisted of sediment less than 0.063 mm. The silt- and clay-sized sediment was thought to have remained in suspension and transported through the white sturgeon critical habitat. Most of the sand-sized material (>0.063mm) was noted during peak tributary streamflow. The sand appears to remain in suspension until water velocities decrease due to backwater and then settles. Results of this analysis show no decrease in transport from upstream to downstream, but do show an increase in the suspended sand portion of the load. Mass wasting of the banks likely contributed to the

increase in suspended sands through the white sturgeon critical habitat. This wasting effect is evident as the streambed material changes from coarse gravel, to fine gravel, to medium sand from upstream to downstream in the white sturgeon critical habitat.

Bedload transport was less than 3 percent of the total sediment transport. Particles less than 0.5 mm in diameter were excluded from the analysis because they were only partially recovered. The sand portion of the total sediment transport varied at each sampling site, but seemed to be a function of sediment supply and the extent of backwater.

## SUMMARY

Three sampling sites were selected at the Kootenai River near Bonners Ferry, Idaho, to represent the varied hydrologic conditions in the white sturgeon critical habitat. Twenty-nine suspended-sediment samples and 25 bedload-sediment samples were collected.

Sediment data were analyzed to understand the relations between sediment transport and streamflow within the three different reaches of the white sturgeon critical habitat. The suspended sediment primarily consisted of silt and clay sized sediment that remains in suspension through the white sturgeon critical habitat. The concentration of sand in the suspended sediment was greatest during peak tributary runoff, indicating that most of the sand in the system originates from tributaries.

Sediment-transport curves for bedload transport were not developed because the number of samples obtained at each site was limited. The limited samples indicate, however, that substantial differences exist in sediment size and gradation characteristics for each site. Bedload transport in the upper reach of the white sturgeon critical habitat is characteristic of a sediment-limited system. Coarse gravel on the surface of the streambed armors the channel, and prevents mobilization of smaller gravel underneath. Large quantities of fine-to-coarse gravel were available for transport in the lower braided reach, but the backwater of Kootenay Lake limits transport to fine and coarse-grained sand.

Total sediment transport in the study reach is dominated by fine-grained sediment less than 0.063 millimeters in particle size. These fine-grained particles likely remain in suspension through the entire reach of the white sturgeon critical habitat. Peak streamflow and sediment transport typically occur during the spring runoff or during the spring sturgeon pulse. Peak sediment transport occurred during the spring runoff, when silt and clay sized particles composed more than 75 percent of the total load. The sturgeon pulse transports fewer fines, but transports about the same mass of sand as spring runoff. Transport of coarse sand and gravel represented less than about 3 percent of the total sediment transport through the white sturgeon critical habitat. A lack of sediment supply in the upper part of the critical habitat accounts for the lack of bedload in the study reach. In the middle part of the critical habitat near the end of the braided reach, a large quantity of bedload sediment is available for transport, but backwater from Kootenay Lake results in a decrease in the hydraulic gradient and a decrease in total sediment transport.

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