Kootenai River Habitat Restoration Project Master Plan

Appendix B – Sediment-Transport

Kootenai Tribe of Idaho
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Appendix B – Sediment-Transport

Introduction and Purpose

Sediment transport in the project area is a critical element in evaluating channel morphology, the Kootenai River's response to altered hydraulics and the effects of altered sediment-transport conditions on aquatic habitat for Kootenai sturgeon and other focal species. Sediment transport in the project area is characterized by the balance between the available supply of various size classes and the hydraulic capacity to either fully or partially transport the sediment load. Hydraulic capacity in the project area is governed by the river's energy regime, which is primarily affected by the decreasing gradient through the project area, changes in river morphology through the project reaches and the backwater influence of Kootenay Lake.

The purpose of this preliminary sediment-transport investigation was to support development of limiting factors for this Master Plan. The investigation made use of the best available data and is intended to be used for planning purposes only. Results presented in this appendix were used to develop the preliminary interpretation of sediment-transport conditions presented in Chapter 2, and therefore are not intended to inform detailed design decisions. The information presented herein describes the data, methods and results of the investigation that were used to support the discussion of altered sediment-transport in Chapter 2.

Because the available data were limited, additional data collection and technical analyses are planned for future project phases in order to refine the understanding of sediment-transport in the project area. As such, the objectives of this preliminary sediment-transport analysis were:

1. Estimate the quantities of sediment-transported into, through, and out of the Critical Habitat Reach (RM 141.4 to 159.7) using measured data.
2. Describe the gradation and transport characteristics of the sediment-transported through the project area and make comparisons with the existing bed gradation.
3. Identify data gaps and next steps for refining the understanding of sediment-transport in the project area.

Methods

Approximately 500 sediment load measurements in the project area were assembled from historical and recent datasets for the post-dam era. Of these measurements, over 80% were suspended load, with the remainder of the measurements being bedload samples. In general, the most reliable samples were those collected by the U.S. Geological Survey (USGS) over 16 days during water year

2008 (WY2008). These samples were collected from a boat at three stations for discharges up to 47kcfs. Figure B-1 depicts sediment-sampling stations in the study reach. The spatial distribution of sediment measurements by river mile is presented in Figure B-2.

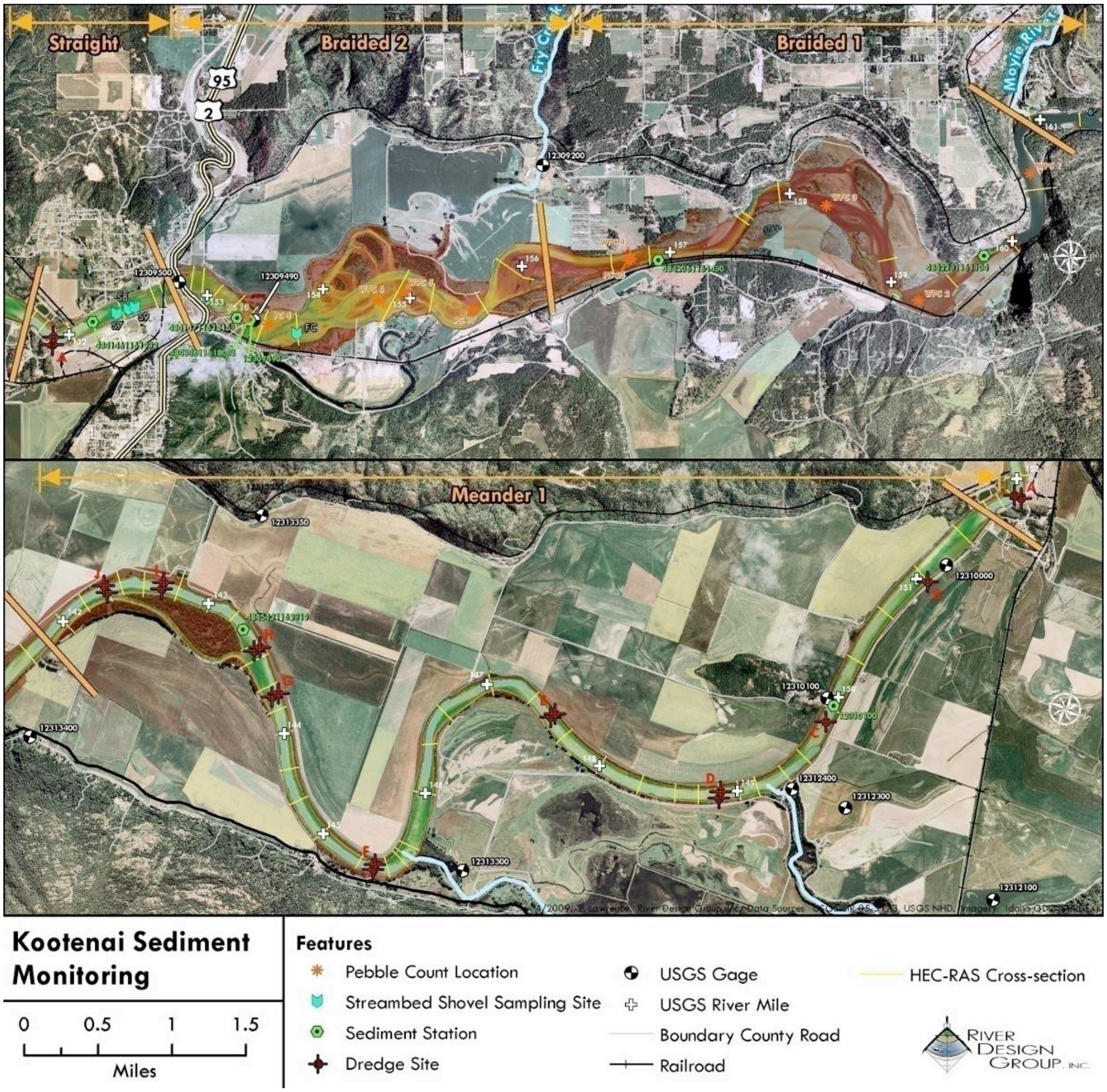

Figure B-1. Sediment sampling stations in the study reach.

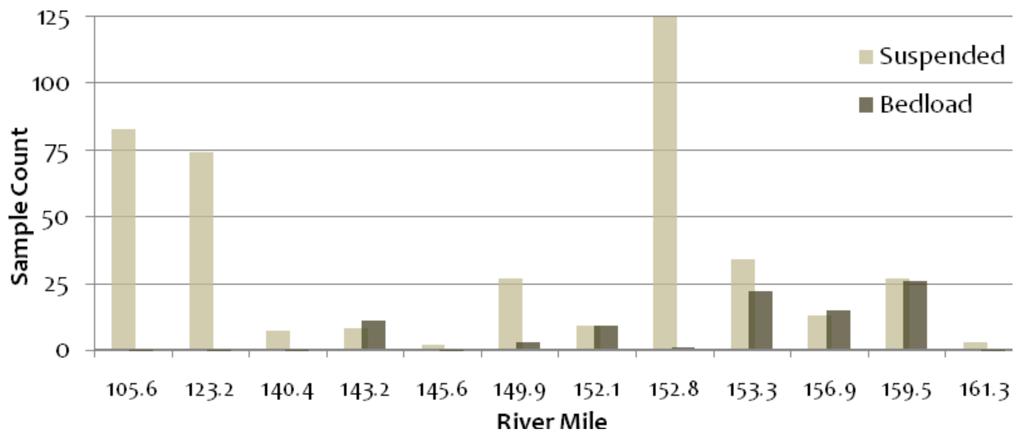

Figure B-2. Sample count of sediment measurements through the study reach. WY 2008 sampling was conducted at RM 159.5, RM 156.9 and RM 143.2.

Sediment sampling during WY2008 was conducted by the USGS from a jet-boat using cable mounted depth-integrating suspended and Federal Information Processing Standard (FISP) compliant bedload samplers with standard width integrating methods (Edwards and Glysson, 1999). Three nearly equidistant stations were selected within the U.S. Fish and Wildlife Service (USFWS) designated Kootenai Sturgeon Critical Habitat Reach to represent the upper project reach (RM 159), the Braided Reach transition zone (RM 153) and the upper Meander Reach (RM 143). The most upstream sampling site at RM 159.5 is located above the Kootenay Lake backwater influence at the upper end of the Braided Reach 1, approximately one-half mile below the Moyie River and seven river miles upstream of Bonner's Ferry. The central sampling station near RM153 is located in the backwater transition zone (see § 2.3.5) at the lower end of the Braided Reach 2 between the Highway 95 bridge crossing in Bonner's Ferry and Fry Creek. The downstream sampling station is located near the upper end of Shorty's Island in the Meander Reach 1, where river hydraulics are influenced year round by the Kootenay Lake backwater.

Sediment sampling events for WY2008 were timed to coincide with three hydrograph targets in the project reach, including winter power loading at Libby Dam, the spring freshet correlated with the seasonal snowmelt peak, and the regulated Sturgeon pulse used to simulate historical spring discharges.

The mass flux rate of measured bedload sediment was computed using the total cross section method while the mass flux rate of suspended sediment was computed from the product of the section discharge and volumetric concentration. The gradation of composited bedload samples was determined via mechanistic sieving on a 1/2 phi interval with the bed-material fraction of the suspended load determined based on the weight fraction retained on a #230 sieve (0.063 mm) which is commonly referred to as the sand/silt break.

A common application of sediment-transport measurements is the development of sediment-transport curves that correlate sediment discharge with stream discharge. Predictive transport functions can be used to construct synthetic sediment-discharge hydrographs which can then be used to estimate annual sediment yields and evaluate related sedimentation impacts. Transport functions can be cast in a number of different forms and generally rely upon two classes of independent variables. The first class includes variables related to the overall supply of sediment within the reach and corresponding sediment characteristics; variables within the second class are those that influence the capacity of the alluvial system to transport the available sediment. Due to the temporal variability and overall uncertainty associated with sediment supply in the project reach at this time, provisional predictive transport equations (in support of identifying limiting factors for this master plan) were developed based on hydraulic transport capacity under equilibrium conditions. It is important to note that the actual transport may be less than the capacity or more than the capacity as a result of a decrease or increase in the local supply of one or more size classes respectively.

As discussed in Appendix A, Kootenai River hydraulics within the project reach are influenced by the backwater effect from Kootenay Lake, and thus correlations between bed material transport and stream discharge were found to be poor. To accurately account for the variable backwater effect in the study reach, synthetic hydraulics were derived using the one-dimensional USGS backwater model (Berenbrock 2005) described in Appendix A and calibrated to field velocity measurements.

To evaluate the mean sediment-transport trends between sampling sites, section averaged shear stress was converted to a dimensionless effective Shields stress and correlated with dimensionless transport rate on a 1/2 phi scale using standard regression techniques with log transformed values. These provisional transport equations assume equilibrium transport over the entire water year and similarity in mobility by size class. Additional factors expected to influence transport capacity and yield such as bed form effects on roughness, two dimensional hydraulic effects and turbulence, and temporal variation in sediment supply were not considered for this analysis.

In general, the coefficients of determination for the regression correlations were better for suspended load versus bedload, averaging 0.85 and 0.53 respectively. Similarly, discrepancy ratios between measured and predicted dimensionless transport rate were found to be less than 200% for suspended sediment estimates and generally within an order of magnitude for bedload. The provisional transport equations were then applied to synthetic hydraulics for WY2008 to estimate annual bed material loads for the three sites as discussed below.

Results and Discussion

Estimated Annual Bed Material Load

In order to quantify sediment loads in the Critical Habitat Reach, preliminary estimates of annual bed material load were prepared using data collected in 2008. Bedload and suspended sediment measurements were taken at three locations in the project area. Measurements from the upstream sampling site (RM 159) are assumed to represent the sediment supply entering the project area from the watershed. Measurements from the middle sampling site (RM 153) are assumed to represent the sediment supply near the downstream end of the Braided Reaches and within the backwater influence of Kootenay Lake. Measurements from the downstream sampling site (RM 143) are assumed to represent the sediment supply at the downstream end of Meander Reach 1. Figure B-3 shows the 2008 sampling events overlain on the WY 2008 hydrograph.

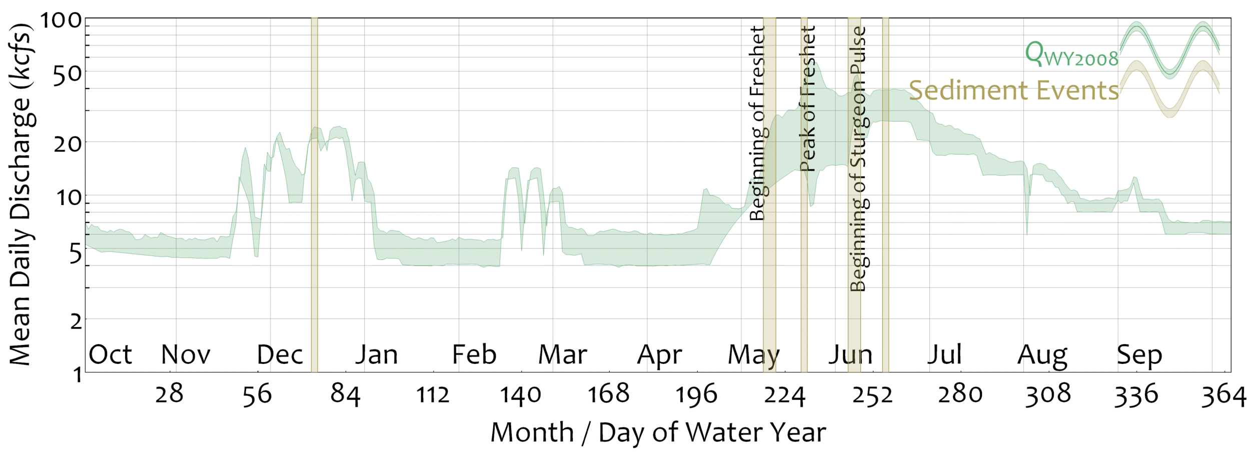

Figure B-3. Hydrograph at Porthill (USGS #12322000) and Libby Dam (USGS #12301933) with sediment sampling events for water year 2008.

Annual bed material load was estimated for the three sampling sites and is presented in Figure B-4. Bed material load includes both measured bedload and the sand fraction measured in the suspended load (particles greater than 0.0625mm). Washload (particles less than 0.063mm) is not included in the bed material load estimates. Results are presented for the sand (0.063mm to 2mm) and coarse (greater than 2mm) fractions.

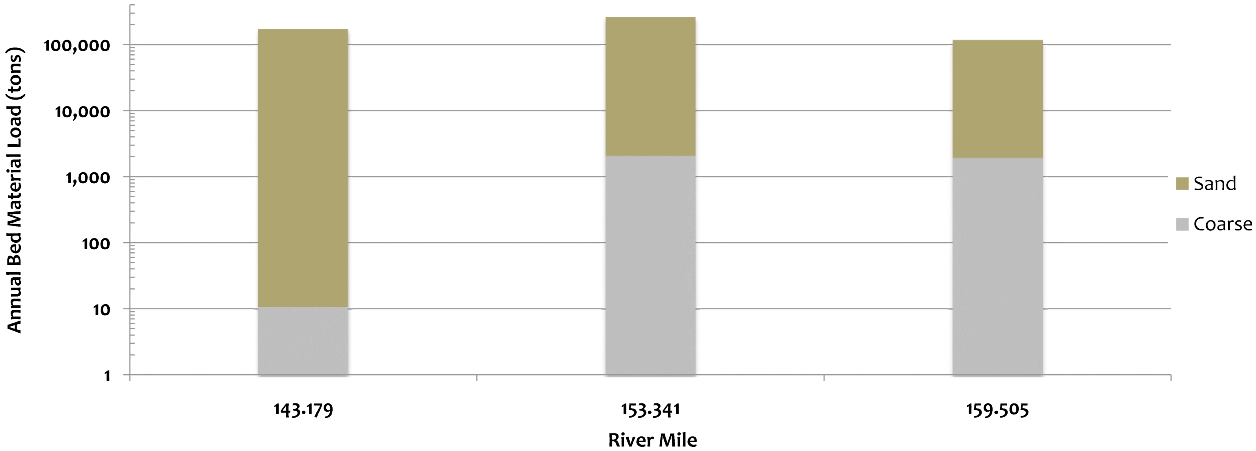

Figure B-4. Estimated annual flux of bed material in the Critical Habitat Reach during WY2008. Bed material increases threefold through the Braided Reaches (RM159.5 to 153.3) and decreases threefold through the Straight and Meander 1 Reaches (RM 153.3 to 143.2).

From a sediment loading perspective, a significant portion of the medium to fine sand fraction (0.125 to 0.50mm) is transported through the study reach in suspension, rather than bedload. The sand fraction of suspended load measurements through the study reach was found to vary by season and discharge, with median values ranging between 20% and 50%. Median suspended sand flux in the study reach averaged about 30% of the total suspended load, with median values up to 2,000 tons/day and seasonal peaks between 5,000 and 20,000 tons/day (Figure B-5).

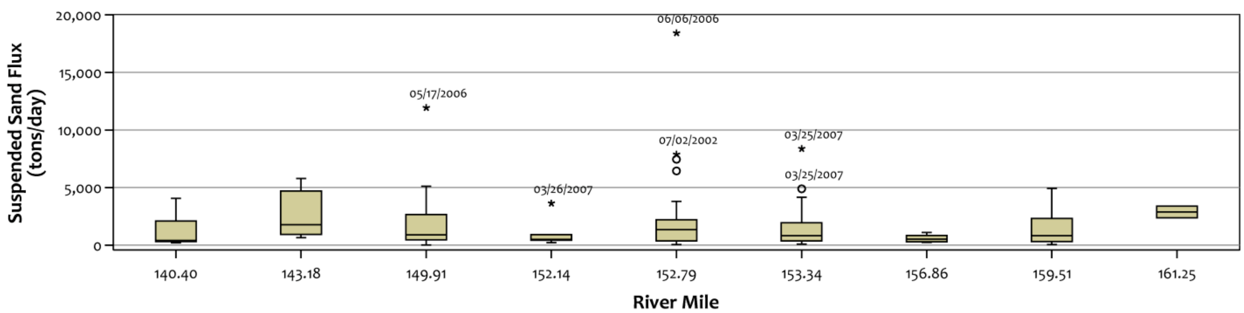

Figure B-5. Variation in measured suspended sand concentration and corresponding suspended sand flux within the study reach by river mile.

Conversely, median measured bedload flux in the study reach was found to range between 10 and 30 tons/day, with the outer quartile range generally between 0 and 50 tons/day. This represents a nearly forty fold decrease for bedload transport capacity when compared to the suspended flux of bed material load. Seasonal spikes in bedload transport coincident with larger discharge were measured at up to 300 tons/day as shown in Figure B-6 below.

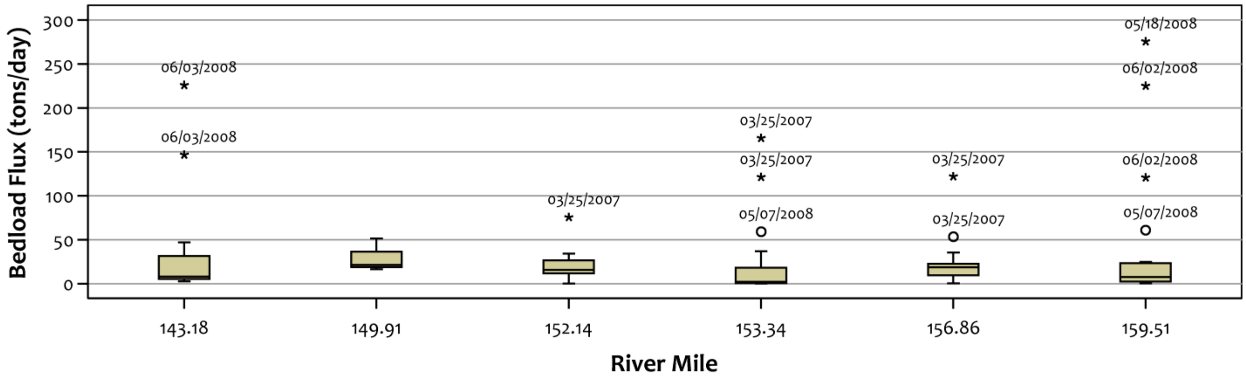

Figure B-6. Variation in measured bedload flux within the study reach by river mile.

Dimensional correlations between suspended sediment load and various hydraulic parameters such as stream power were found to be positive, but exhibited a typical variability of up to two orders of magnitude, indicating the presence of seasonal variation in sediment supply on measured transport (Figure B-7). Dimensional correlations of bedload with various hydraulic parameters were generally lower, as the variability resulting from secondary processes such as particle sorting and particle hiding is not sufficiently represented in the sample sets due to the effect of the decreased supply of coarse particle fractions >2mm.

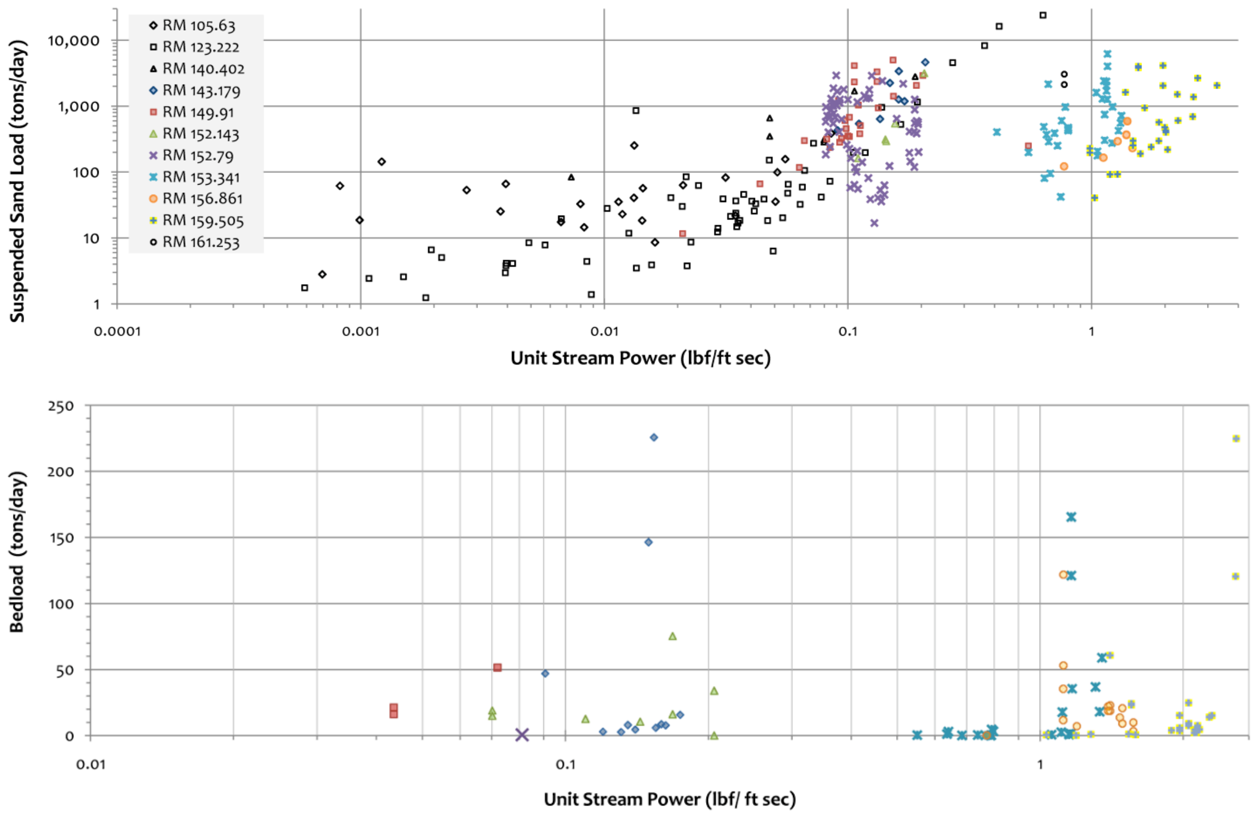

Figure B-7. Dimensional suspended load and bedload versus unit stream power. The coefficients of determination for the regression correlations were better for suspended load versus bedload, averaging 0.85 and 0.53 respectively.

Comparison of Channel Bed Gradation and Bed Material Load Gradation

In order to develop an understanding of the supply of sediment available for transport within the Critical Habitat Reach, comparisons were made between the channel bed gradation and bed material load. These comparisons provide useful information regarding the mobility of the channel bed.

The trend towards finer particle size classes in the downstream direction is reflected by the decrease in effective diameter of the channel bed sediments by river mile (Figure B-8). Between RM 159 and RM 152, small cobble and coarse gravels present in the Braided 1 Reach gradually trend towards medium to fine gravels through the Braided 2 Reach. The channel bed sediment abruptly transitions to coarse sands and finer sands in the Straight and Meander reaches (Figure B-9).

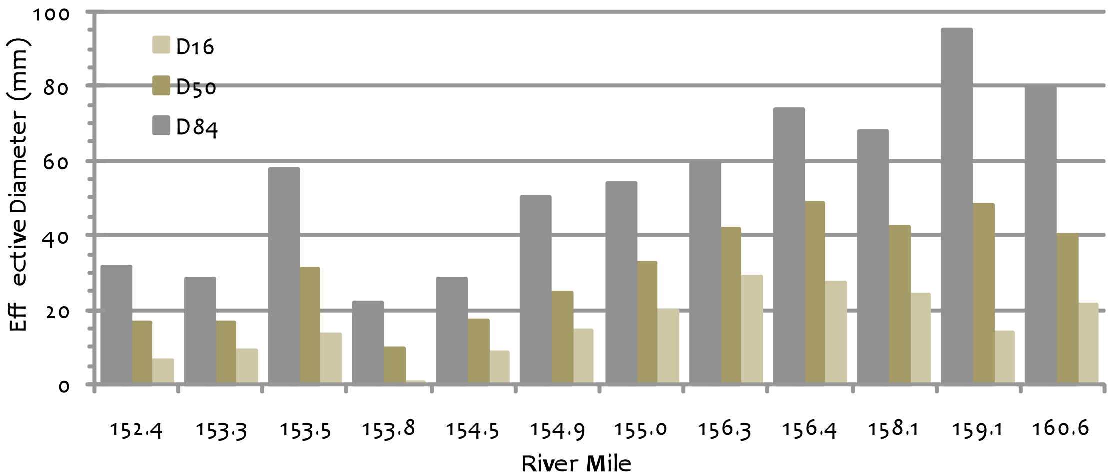

Figure B-8. Effective diameters for local channel bed sediment in Braided 1 and 2 Reaches. Cobble dominates the bed composition at the upstream end of the Braided Reaches, whereas gravel is the dominant substrate at the downstream end.

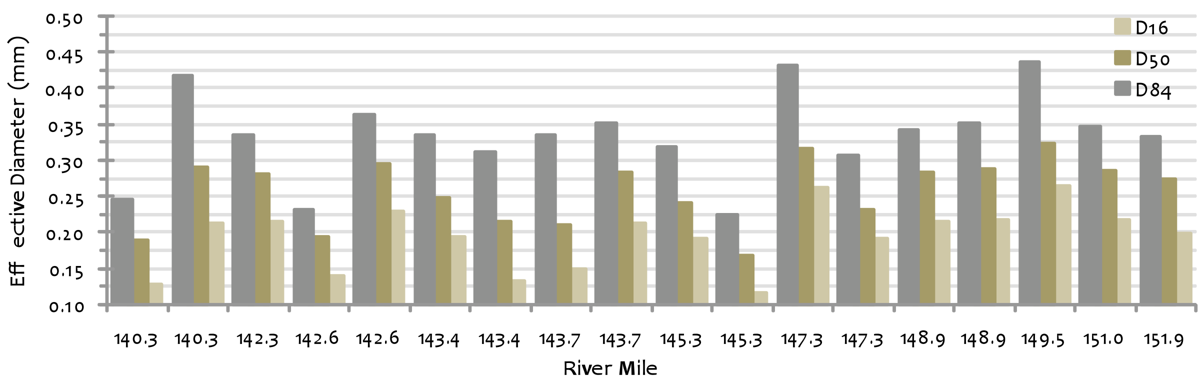

Figure B-9. Effective diameters for local channel bed sediment in Straight and Meander 1 reaches. The bed is composed predominantly of sand and finer materials.

Coincident with the gradation shift in the channel bed sediment and available energy, the gradation of the bed material load in transport also reflects the general trend of downstream fining. Between RM 159 and RM 152 the range of effective diameters for measured bed material decreased from medium gravels to medium sands (Figure B-10).

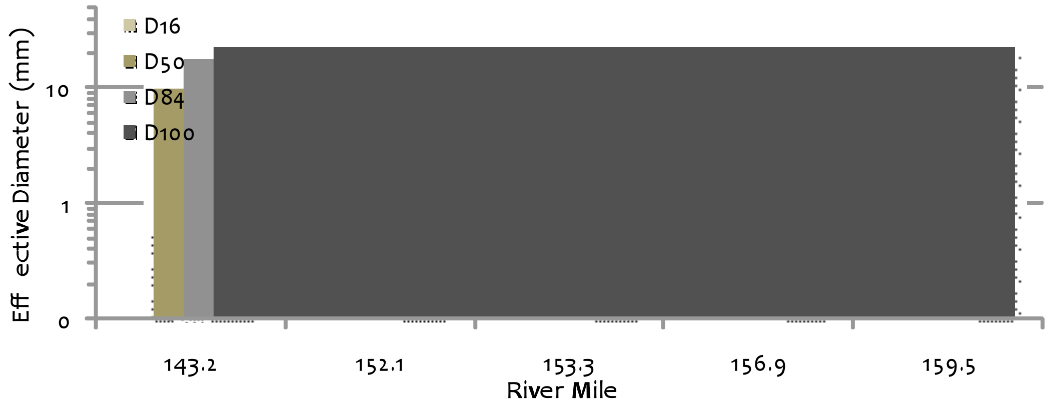

Figure B-10. Average effective diameters for sampled bed material load through the study reach. The bed material load includes the sand load travelling in suspension, and therefore, is skewed toward a less coarse gradation.

Figure B-11 displays a direct comparison between the effective diameter of select size classes of the channel bed and the effective diameter of the largest particles measured in the bedload samples in the Braided Reaches. Results indicate that the largest particles measured in the bedload samples correspond with the D84 size class of the channel bed material.

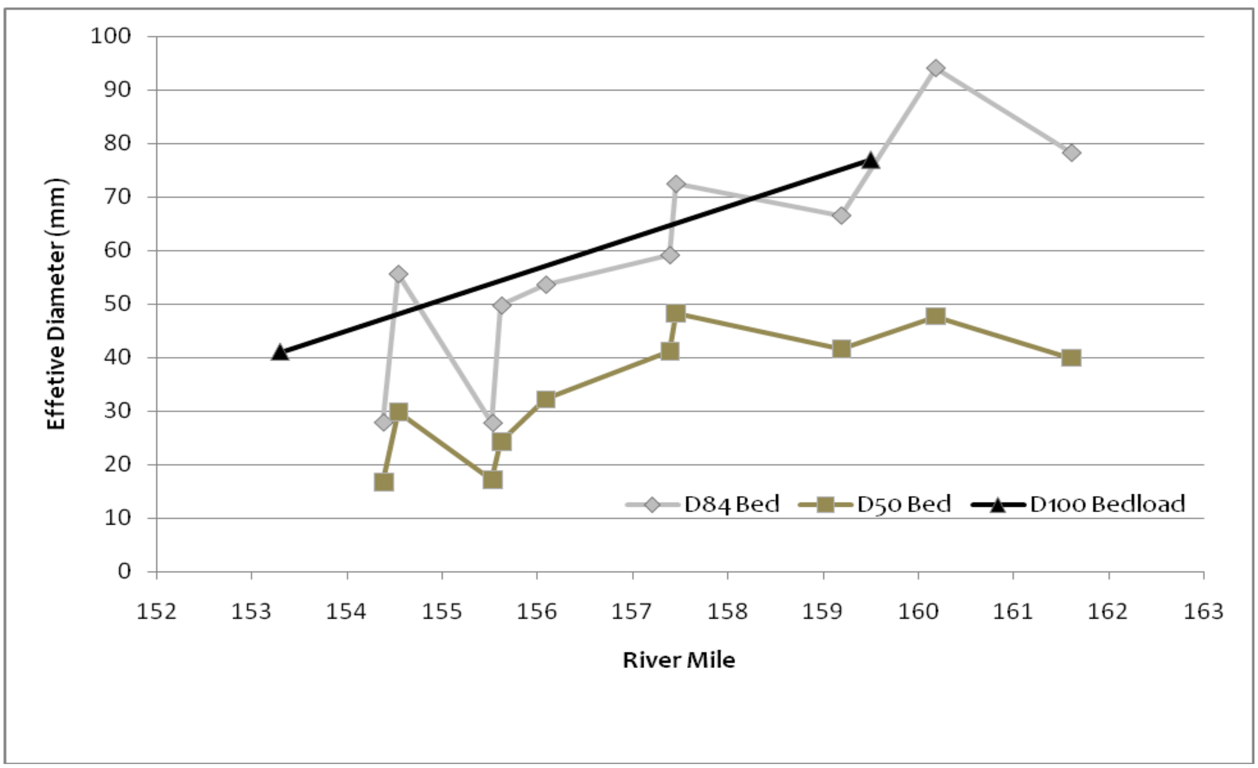

Figure B-11. Comparison of average effective diameter for select size classes of the channel bed material with the effective diameter of the largest particles capture in the bedload samples. The largest particles captured in the bedload samples correspond with the D84 size class of the channel bed.

Transport Characteristics

Sediment transport characteristics were evaluated to determine the dominant modes of transport (suspended versus bedload) by reach. The shift in transport mode through the study reach is illustrated in a sedimentation diagram that plots dimensionless Shields stress versus particle Reynolds number, a surrogate for grain size (Figure B-11). In this diagram, the solid black line (labeled Motion/No Motion) represents the empirical Shields criteria for initiation of particle motion. Values below the empirical Shields line, particles remain at rest; values above the line suggest particles are moving in contact with the channel bed. The critical condition for particle suspension occurs where the particle fall velocity equals the shear velocity as indicated by the solid red line (labeled Suspension/No Suspension). Values above this line suggest a particle is transported in suspension; values below this line suggest the particles are transported along the channel bed and are not in suspension. The upper dashed red line signifies where the ratio between shear velocity and particle fall velocity exceeds 6.5 indicating the conditions under which suspended transport dominates. Also shown are transition zones indicated by the diagonal brown lines that represent conditions for sand related bedforms (e.g., ripples and dunes) that can occur downstream of the Straight Reach in the Meander Reaches.

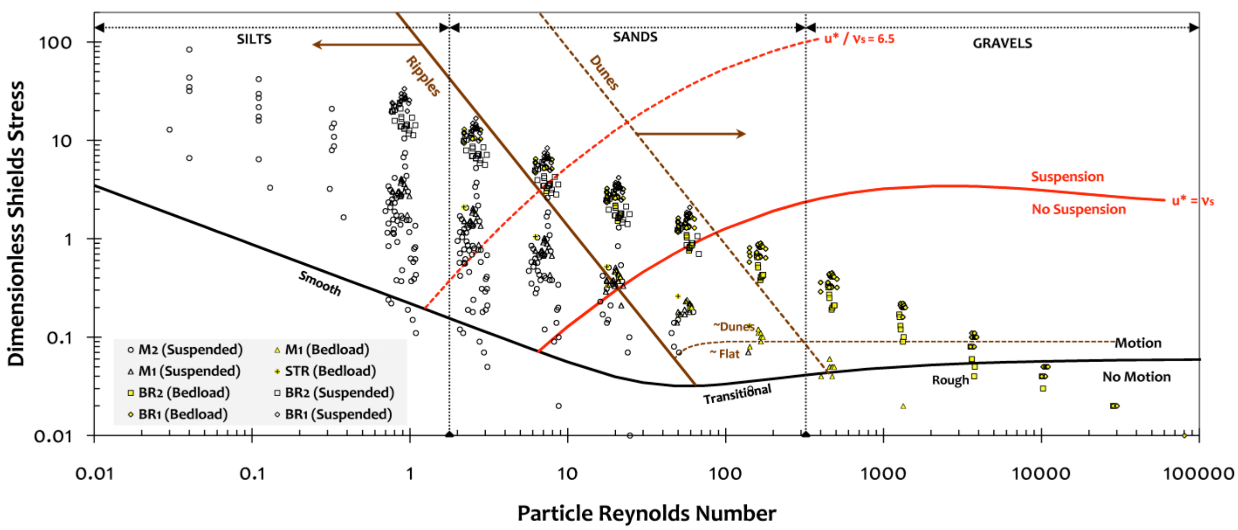

Figure B-11. Sedimentation diagram of dimensionless Shields stress versus particle Reynolds number, a surrogate for grain size. A significant portion of the sediment load is sand travelling in suspension.

Plotting the measured size fractions present in suspended load and bedload samples on the sedimentation diagram provides an indication of dominant mode of transport by size class and project area reach. In general, bedload measurements through the study reach are comprised of fine gravels and coarse sands, plotting above the Shields incipient motion curve (solid black line) and below the suspension curve (solid red line) for the Braided and Straight reaches. In these reaches, the sand fraction is transported as both bedload (coarser sands) and suspended load (finer sands) with transitional bedforms, trending towards finer size classes in suspension in the downstream direction.

Summary

The quantity of sediment-transported into, through, and out of the Critical Habitat Reach was estimated using measured bedload and suspended sediment data collected in 2008. Initial estimates of annual sediment loading indicate that under median hydrologic conditions the annual flux of bed material load increases threefold through the Braided Reaches and decreases threefold through the Straight Reach and Meander 1 Reach (Figure B-4). This trend suggests that significant sediment inputs are derived from the Braided Reaches and subsequently deposited in the Straight Reach and Meander Reaches. Because of the altered morphology in the Straight Reach and the Meander Reaches and loss of floodplain connection, the only place for sediment to deposit is within the channel bed. Deposition of fine sediment on the channel bed in the Critical Habitat Reach is reported to negatively affect spawning success for Kootenai sturgeon.

Preliminary comparisons between the bed gradation and the bed material load indicate that the channel bed is coarser than the measured bed material load. However, the bed material load gradation may be skewed lower by the large proportion of sand that is travelling in suspension. Comparison of the bedload without the suspended sand component indicates that the gradation of the bedload is similar, but still less coarse than the channel bed gradation. This similarity suggests that a large proportion of the channel bed (80% or greater) is potentially mobile and available for transport.

Sediment transport characteristics were evaluated to determine the dominant modes of transport. While the estimated annual tonnages are nearly equal for the upstream (RM 159.5) and downstream (RM 143.2) sampling locations, the gradation is notably finer downstream, with a significant portion of the bed material load comprised of fine to medium sands (0.125 to 0.50 mm) being transported in suspension. Suspended load and bedload sampling suggest the Kootenai River's sediment load is dominated by sand that is mobilized in suspension. Measured suspended load is nearly 40 times greater than bedload in the project area.

The implications of sediment-transport on channel morphology, vegetation and aquatic habitat are discussed in greater detail in Chapter 2.

Data Gaps and Next Steps

Prediction of bedload transport was limited by few bedload measurements and large variability within the data, resulting in predictions that vary by more than one order of magnitude. Continued collection of bedload data over a range of higher flows should improve the predictions. Provisional transport relationships developed for the purpose of this Master Plan will be updated following additional collection of sediment, hydraulic, and bathymetric data by the USGS in WY2009.

Because bed material transport was observed to increase through the Braided Reaches, an additional sampling site was added for WY2009 sampling near Crossport (RM 157) in order to identify the respective increases in sediment loading between Braided Reach 1 and Braided Reach 2. Data collected at this additional sampling site will be useful for evaluating restoration treatments in the Braided Reaches.

In support of the ongoing effort to characterize sediment-transport within the project area, data is being stored within a database management system supporting strongly typed hierarchical data structures between related data. Relevant datasets include field notes and measurements, lab results and transport measurements, sample gradations, analysis results as well as both field measured and synthetic hydraulics. Because datasets are being collected by multiple parties, the database provides a standard workflow for the collection, QA/QC, analysis and exchange of sediment data between project teams. The sediment database will be updated with new data collected during WY2009 and is available upon request.