BIGHORN RIVER, MONTANA
FLUSHING FLOWS ANALYSIS

INTRODUCTION

A special high-flow release from Yellowtail Dam on the Bighorn River is being considered to flush sand-size sediment from the gravel bed. Releases from Yellowtail Dam are typically in the 3,000 to 4,000 cfs range and, in the past, these flows have been sufficient to prevent sand from depositing on the gravels. However, flow releases in the past 3 to 4 years have been reduced to 1,200 to 1,500 cfs because of drought conditions and sand is thought to have accumulated in the channel. Fishery biologists and others have requested that Reclamation make a greater release to flush sand-size sediment from the gravel. The Sedimentation and River Hydraulics Group was asked to do an initial study to help determine the magnitude and duration of a special high-flow release that would be sufficient to flush sand from the gravel over a 13-mile reach of the Bighorn River downstream from Yellowtail Dam.

The study approach was to review the master's thesis by Wiley (1995) on flushing flows, perform the hydraulic modeling, determine sediment transport capacity and make future recommendations for flows and monitoring.

REVIEW OF THE MASTER'S THESIS

Donald Wiley of the University of Wyoming completed a Masters Thesis in 1995. He studied extensively the sediment, bed-material sizes, hydraulics, and spawning gravel during and prior to two test flushing flows in the early 1990's on the Bighorn River and Wind River in Wyoming; between Wedding of the Waters and Kirby Creek. The extensive information and data provided in this report gave insight into the effects of flushing flows below a dam, and the type of data that could be collected to monitor the effects of the flow and understand the condition of the river channel.

Water diversion and storage can alter flow regimes and can affect stream channel morphology such that mean-width, width-depth ratio, mean cross-sectional area and conveyance are reduced by structures in the rivers. For example, the average channel width, length, sinuosity, number of islands, and length of secondary channels on the North Platte River decreased downstream of Gray Reef Reservoir from 1947 to 1989 (Wiley, 1995). Channel length and width is generally reduced below dams. Downcutting and dewatering of side channels is probable. Below dams, it is likely that bed-material load is diminished and mobilization of sediment is reduced because of the lack of high enough flows to mobilize the fines from the beds (Wiley, 1995).

Wiley (1995) conducted extensive field measurements to determine flushing flows for the Wind and Bighorn Rivers. He measured bedload with a bedload sampler, and the suspended load was also measured. He selected sites for all measurements that had extensive spawning areas for rainbow and brown trout. Wiley also collected bed-material samples at key locations with a MacNeil core sampler. Wiley measured river cross-sections before and after the flushing flows. Key tributaries that delivered sediment during flood events were studied in terms of sediment load, cross-sections, hydrographs and bed-material size. Special samples were also taken at known spawning areas and compared to bed-material size data at other locations.

Hydraulic modeling was also done with the Physical Habitat Simulation Model (PHABSIM) (Wiley, 1995). The PHABSIM Model is software that was initially developed by Reclamation and Fish and Wildlife Service to predict the micro-habitat (depth, velocities, and channel indices) conditions in rivers as a function of streamflow, and the relative suitability of those conditions to aquatic life (http://www.mesc.usgs.gov/products/software/phabsim/phabsim.asp). Suspended sediment concentrations were also measured continuously during the flushing flows. It was observed that the highest concentrations occurred for the upstream stations during the test flows. Further demonstration of the effect of the test flow was found in the changes in the bed-material size data, which showed an increase in the d-50 of the bed-material size data. This indicates that fine sediment was eroded from the bed as a result of the flushing flows (Wiley, 1995). The results and recommendations of Wiley's study are listed below:

1. The test release downstream of Boysen Reservoir on the Bighorn was successful in gaining insight into the size of the flushing flows and flow regimes necessary to scour pools, clean spawning gravel, maintain secondary channels and remove fine sediment. This was achieved through extensive collection of field data. This included measurement of flows, suspended sediment concentration, bedload, bed-material size data, and changes in key cross-sections before and after the flushing flow, and determination of sediment loads from key tributaries. Biological data were also collected at trout spawning locations, including the quality of the gravels. This study served as a good example of how a flushing flow, on a regulated stream, of sufficient duration can flush fine sediment from a gravel-bed river.

2. The flushing flow for the Bighorn below Boysen was 5,000 cfs, which has a recurrence interval of 3.5 years and approaches a bank full discharge since construction of the reservoir. Data obtained during the flushing flow study suggest that the magnitude of the flushing flow on the Bighorn below Boysen Reservoir should be in the range of 5,000 cfs. Sediment transport becomes sufficiently strong in the spawning areas as the flow approaches 5,000 cfs. A possible approach to determine the actual flushing flow is to determine the bankfull discharge or channel-forming flow.

The bankfull discharge flow for the Bighorn River below Yellowtail Afterbay Dam has not been determined, but should be in the range between the 2- and 5-year return period flood based on regulated flows since dam construction. A plot of the flows for the Bighorn River at St. Xavier is shown in Figure 1. The dam closed in 1966, and flow peaks have dropped since the closure of the dam. The reduced flows since 2000 are noted in the figure. Measured cross-sections downstream of the afterbay would help determine the bankfull discharge.

FORMULATION OF THE HEC-RAS MODEL

U.S. Geological Survey (USGS) digital raster graphics maps were downloaded from the GIS data depot internet website for the Bighorn River below Yellowtail Afterbay Dam. Recent orthographic quadrangle maps (mid 1990's) were also downloaded from the State of Montana website to supplement the data. Between the USGS quadrangle maps and orthoquad map, a very general Hydrologic Engineering Center River Analysis System (HEC-RAS), Army Corps of Engineers (2003) model was constructed using widths estimated from the aerial photographs. Slopes were determined from the quadrangle maps. Water surface elevations produced from the model were not calibrated or verified, but can be used to show approximate hydraulics until a more detailed survey data can be obtained. The HEC-RAS model was created for a distance of 13 river miles below the afterbay dam. Slopes in this reach ranged from 0.002 to approximately .0006. Channel widths, measured from aerial photographs, were estimated to range from 200 ft. to 500 ft.

FLOOD HYDROGRAPHS

A series of hydrographs below the Yellowtail Afterbay Dam was evaluated with the HEC-RAS model to predict the flow peak attenuation as the flood wave travels downstream. The peak discharge for the hydrographs varied from 2,500 to 5,000 cfs. The rate of the hydrographs rise was assumed to be 100 cfs per hour. The stage change in the model was approximately 0.1 ft per hour. This would suggest that the release hydrographs could be increased at a faster rate to reach the maximum discharge. Peak flow rates and duration of the release hydrographs are shown in Figure 2 and also Table 1. The duration of the peak flows were just long enough to prevent significant attenuation of the peak. Upstream and downstream flow hydrographs are shown in figures 3-6. As the figures show, the peak discharge does not attenuate because the channel is steep. However, the model does not account for bank storage, which would result in some attenuation of peak flow rates. Tributary inflows or groundwater gain could offset the attenuation. The sediment transport and mobilization of the bed will be explained in the next section.

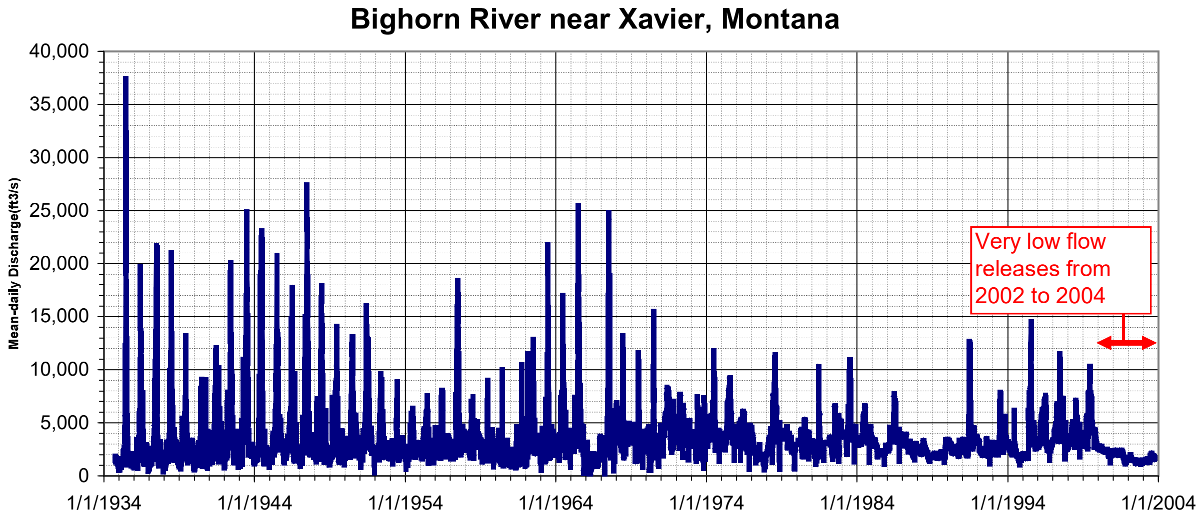


Table 1. Duration of Peak Flows Before and After Flow Release

Discharge (cfs)	Number of Hours to Reach Peak Assuming Increase in Discharge of 100 cfs per hour and Based Flow of 1500 cfs	Duration of Peak (hours)	Duration After Routing Through Reach
2500	10	9	6
3000	15	6	4
4000	25	6	4
5000	35	6	4

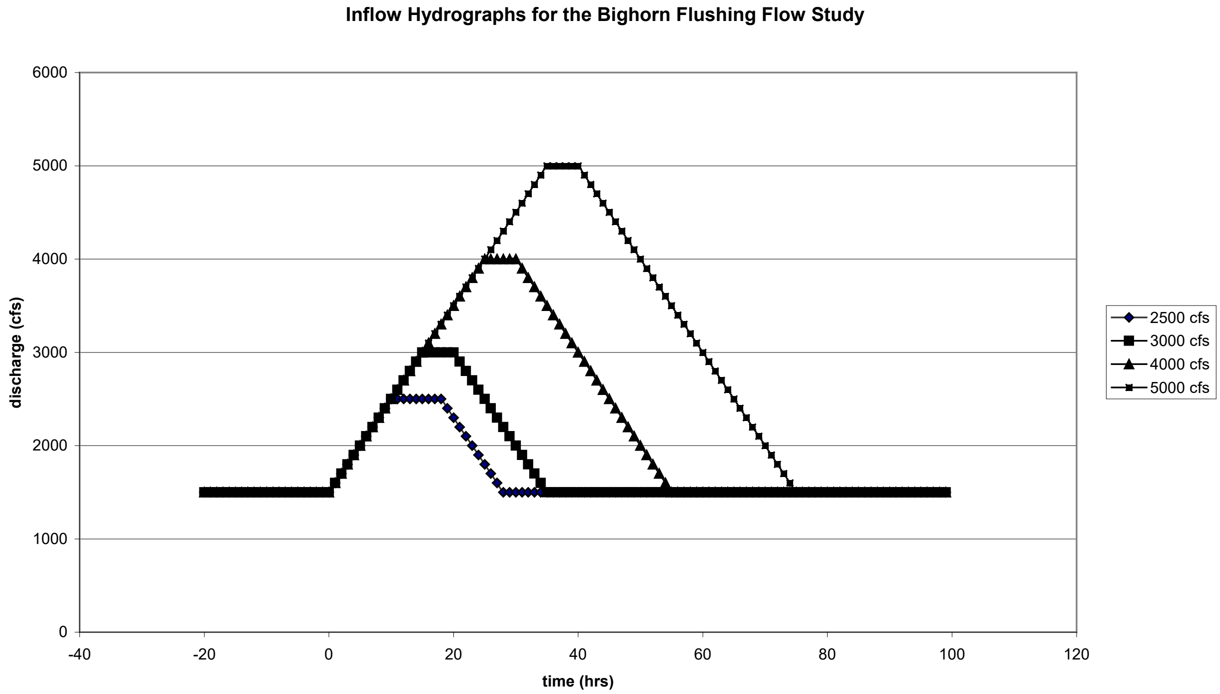
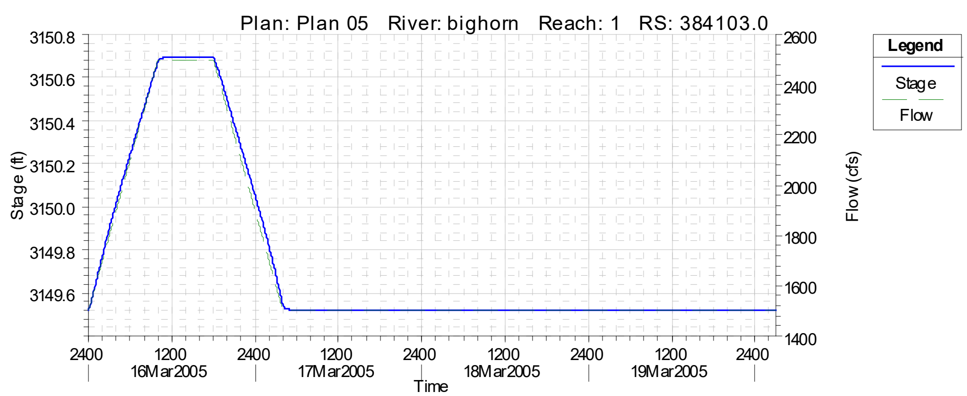


Figure 2 - Release Hydrographs



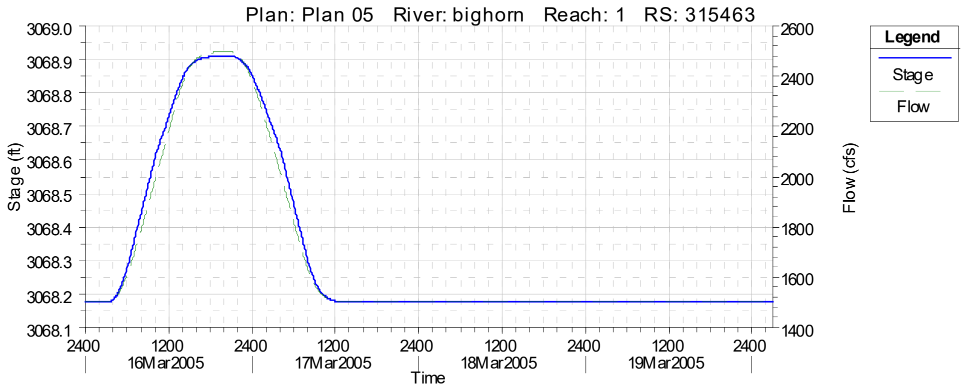


Figure 3 - Upstream and downstream hydrographs for 2500 cfs

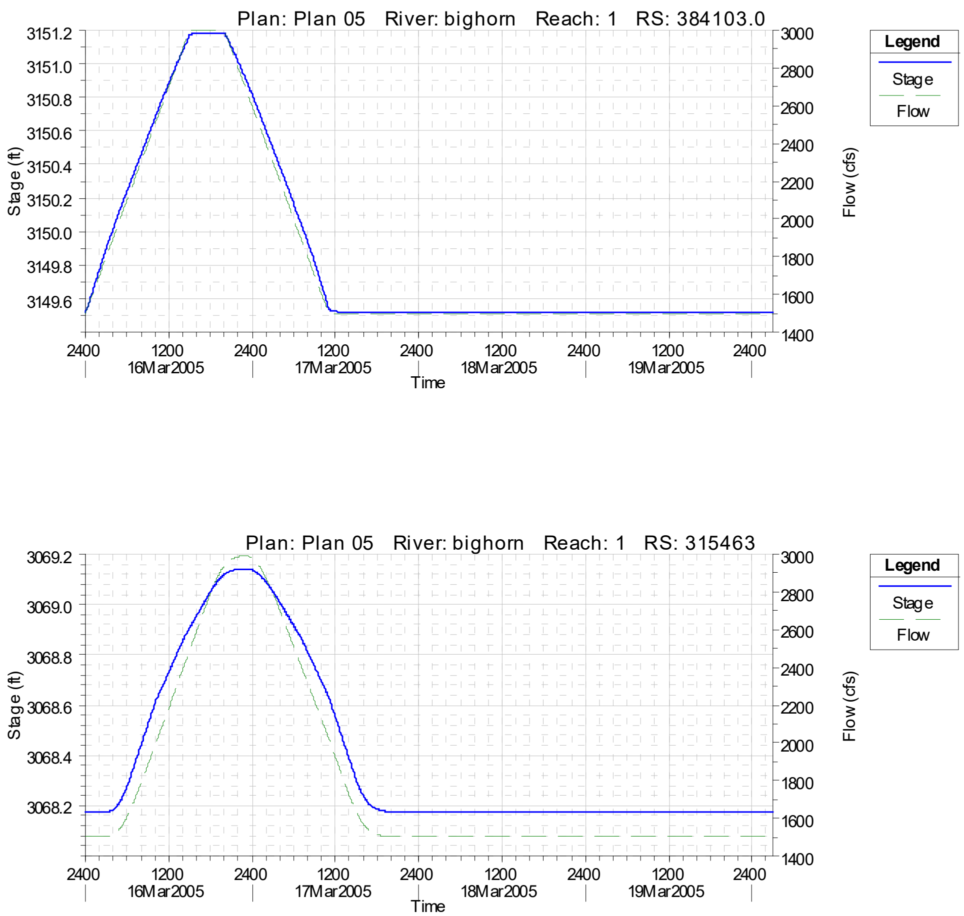
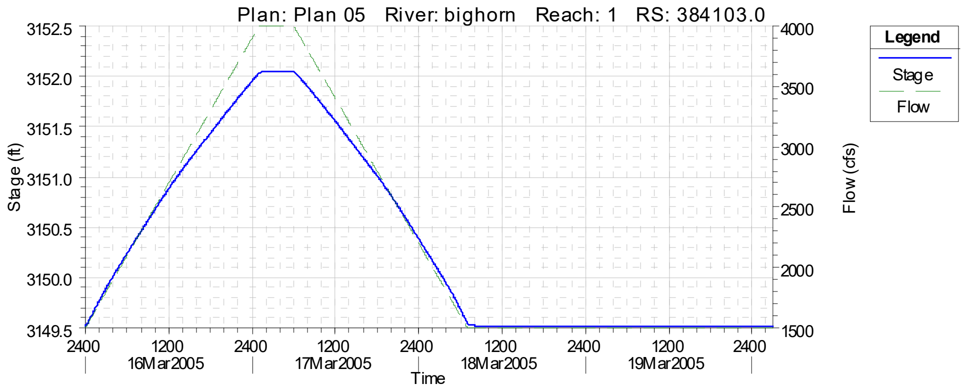


Figure 4 - Upstream and downstream hydrographs for 3000 cfs



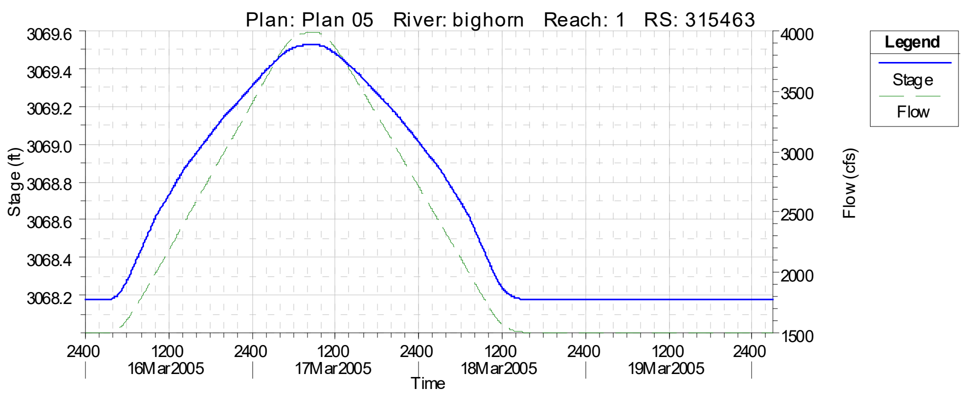
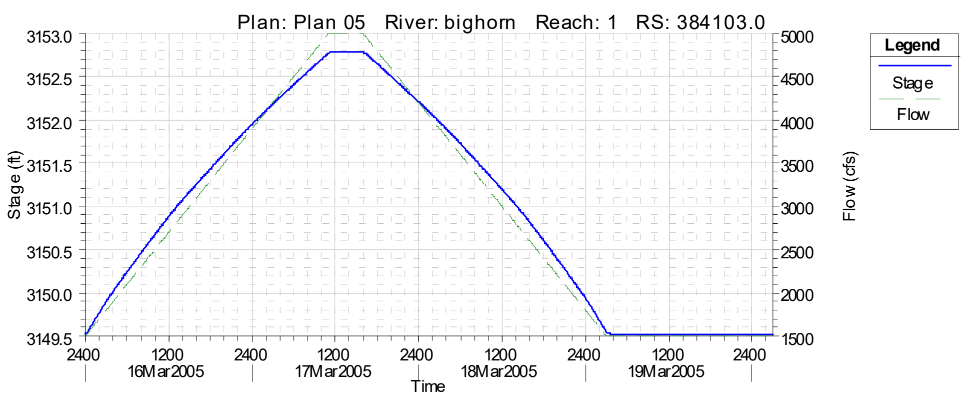


Figure 5 - Upstream and downstream hydrographs for 4000 cfs



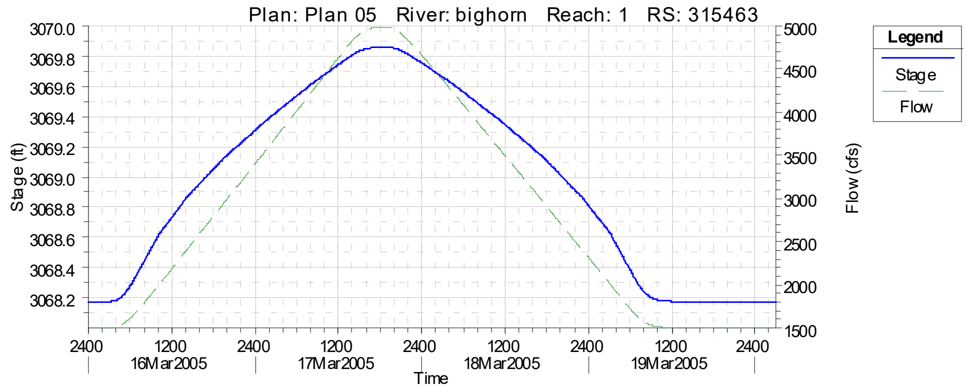


Figure 6 - Upstream and downstream hydrographs for 5000 cfs

SEDIMENT TRANSPORT DURING FLUSHING FLOWS

Both unsteady flow and steady flow hydrographs for the peak discharges were modeled. A longitudinal channel profile of the model is shown in Figure 7. The results of the steady flow hydrographs for discharges of 2,500, 3,000, 4,000, and 5,000 cfs were utilized in the sediment transport capacity analysis routine of HEC-RAS. Average bed-material size data (Figure 8), based on the data collected in the early 1990's, and were utilized for the calculations. This grain size distribution has a median size of 6 mm. The results of the sediment transport capacity analysis are shown in Figures 9-11. Three different sediment transport equations were utilized to provide a range of predictions because of the lack of measured bedload and suspended sediment concentrations. The results are shown for very fine gravel (2 to 4 mm) and fine gravel transport (4 to 8 mm). Variations in results for individual cross-sections occur because of the change in channel slope and velocity. Influences from tributary sediment delivery cannot be determined without measurements, but at least two tributaries may deliver sediment when the streams are flowing at higher discharges. The current research on flushing flows indicates that if gravel is mobilized, then the fine sediment will also be mobilized from the gravel and flushed out downstream (Webb et. al., 2000). The results indicate that both discharges (2,500 and 5,000 cfs) would mobilize the gravels, which is expected to flush fine sediment. The caution should be that this study is based on very limited data (without measured cross-sections), a lack of bed-load and suspended-load data, and a lack of bed-material size data.

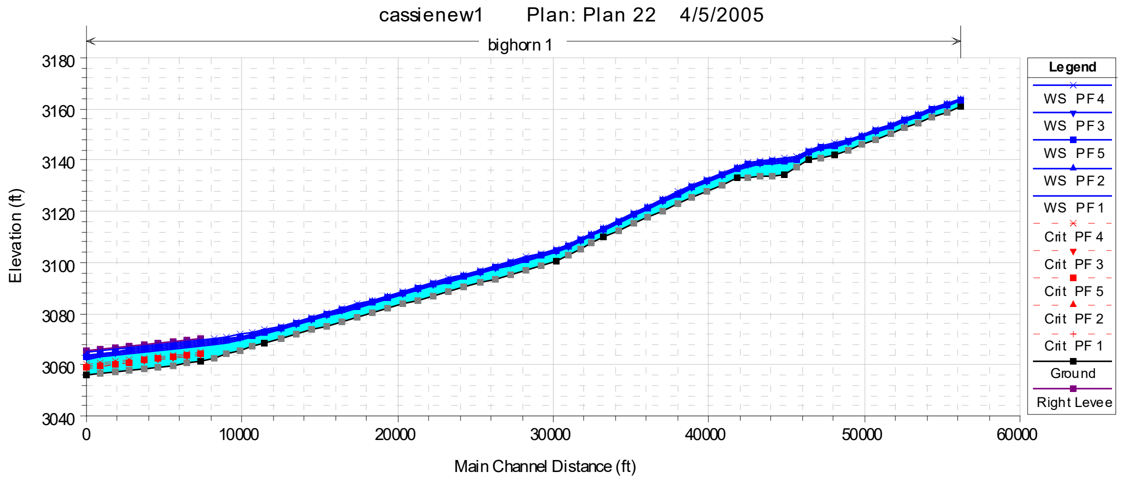


Figure 7 -Water surface profile from mouth to afterbay

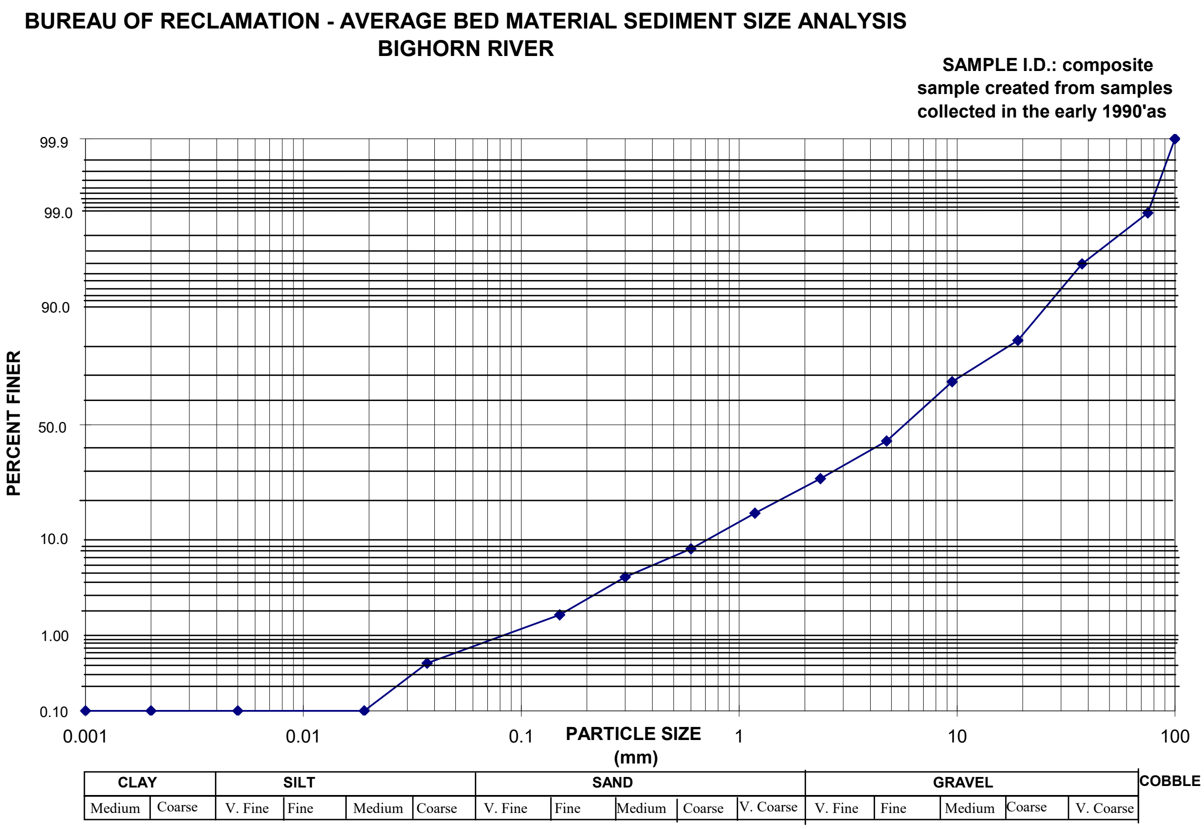


Figure 8 - Average bed-material size data used in the flushing flow analysis

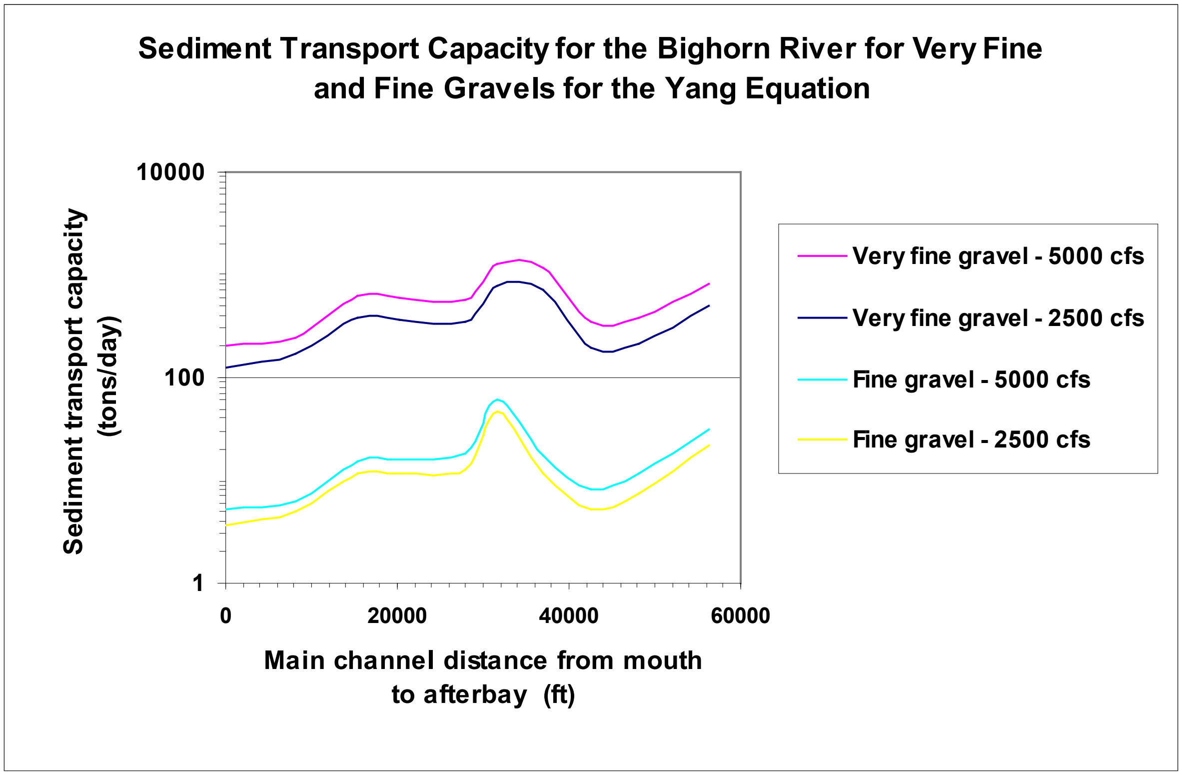


Figure 9 - Estimated transport rate for gravel based on the Yang Equation

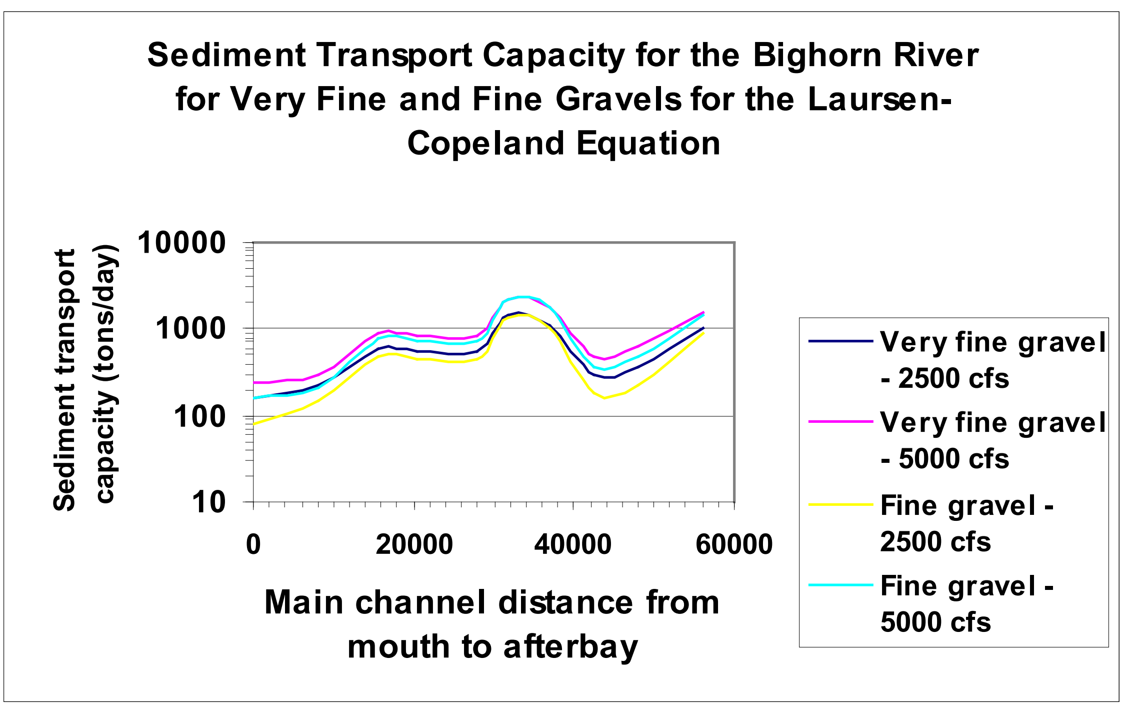


Figure 10 - Estimated transport rate for gravel based on the Laursen Copeland Equation

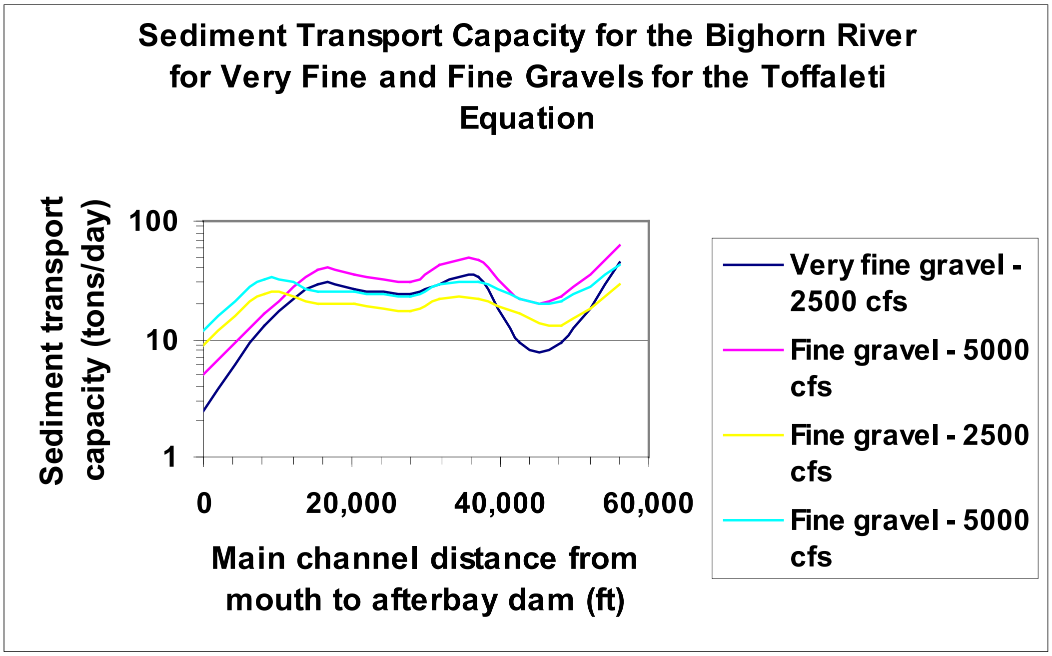


Figure 11 - Estimated transport rate for gravel based on the Toffaleti Equation

FUTURE MONITORING AND RECOMMENDATIONS

The Master's Thesis (Wiley, 1995) provides and excellent reference to use as a guide for potential monitoring data, depending on budget and time. Measurement of selected cross-sections before and after the flushing flow would be very beneficial. Specific locations could be based on areas that have historically been good for spawning. Concurrent with measurement of the cross-sections would be the collection of bed-material size data at specific locations along the 13-mile reach in pools, riffles, and side channels. Cross-section and bed-material data would be the most important data to collect. If additional money is available, collection of suspended sediment concentrations, both during and following the flushing flow, would also be helpful to document sediment transport rates. Bedload measurements would also be important to understand the current and future changes of the gravels. Analysis of any tributaries that are significant sources of sediment supply would also be important. Fishery biologists would need to identify fish spawning areas.

In conclusion, a flushing flow with a peak flow rate of 5,000 cfs is expected to be able to flush the fine sediment from the gravel-bed. It is possible that less flushing would occur in the downstream portion of the reach because of a decrease in slope. The release hydrographs could be increased and decreased at a faster rate than presented in this analysis.

REFERENCES

U. S. Army Corps of Engineers, 2003, HEC-RAS – Hydrologic Engineering Center River Analysis System User Manual and Computer Program, Davis, Ca.

Webb, R.H.; Wegner, D.L.; Andrews, E.D.; Valdez, R.A.; and Patten, D.T., 2000. "Downstream Effects of Glen Canyon Dam on the Colorado River in Grand Canyon: A Review," in *The Controlled Flood in Grand Canyon*, Geophysical Monograph 110, American Geophysical Union, Washington, D.C, pages 1-22.

Wiley, Donald E., 1995, Development and Evaluation of Flushing Flow Recommendations for the Bighorn River.

BIGHORN RIVER FLUSHING FLOWS ANALYSIS
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