SEDIMENT MODELING ON THE LOWER YELLOWSTONE RIVER AT INTAKE DAM, MONTANA

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Abstract: The Lower Yellowstone Project at Intake is a Bureau of Reclamation (BoR) irrigation project located on the Yellowstone River. The low head dam, constructed in 1906, presents a barrier to fish passage. A bypass channel in eastern Montana is proposed to improve upstream and downstream fish passage for the endangered pallid sturgeon and other native fish. The proposed bypass channel has a bottom width of 40 feet (ft) with side slopes varying from 1V:8H (one vertical to eight horizontal) to 1V:4H. With a length of approximately 11,150 ft and cut depths ranging from 4 to 20 ft, the total excavation quantity is approximately 950,000 cubic yards.

Hydraulic and sediment modeling using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) and Adaptive Hydraulics (ADH) has been conducted by the U.S. Army Corps of Engineers (USACE). Additionally, the BoR's Technical Service Center used Sedimentation and River Hydraulics – Two-Dimensional (SRH-2D) to analyze hydraulics and sediment. The intent of the hydraulics analysis was to evaluate depths and velocities throughout the bypass channel with respect to fish passage. The primary goal of the sediment modeling was to evaluate sediment continuity throughout both the main and bypass channels. Coordination between USACE and BoR began with use of the same topographic and hydrographic surface data. Comparison of similarities and differences in model results allowed for better definition of natural and modeling uncertainties.

The focus of this paper is on HEC-RAS sediment modeling of the proposed bypass channel along with associated sensitivity analyses.

INTRODUCTION

Numerous sediment transport runs were completed with HEC-RAS, version 4.2.0 Beta, July 2013. Geometries representing both the main channel of the Yellowstone River and the proposed bypass channel were evaluated. Results presented herein focus on the proposed bypass channel. Figure 1 shows the project location; Figure 2 shows a general overview of the proposed project.

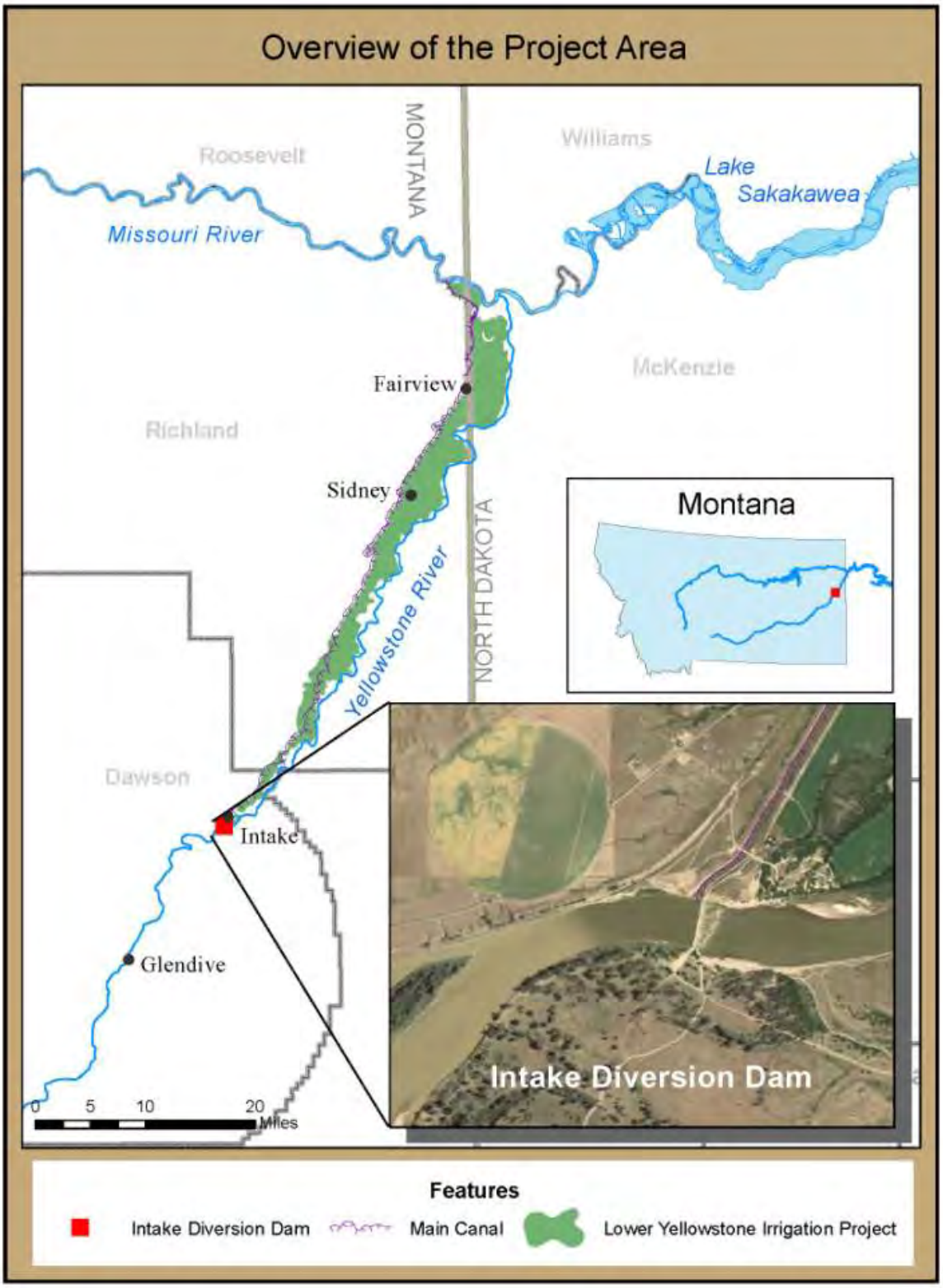

Figure 1 Project location map

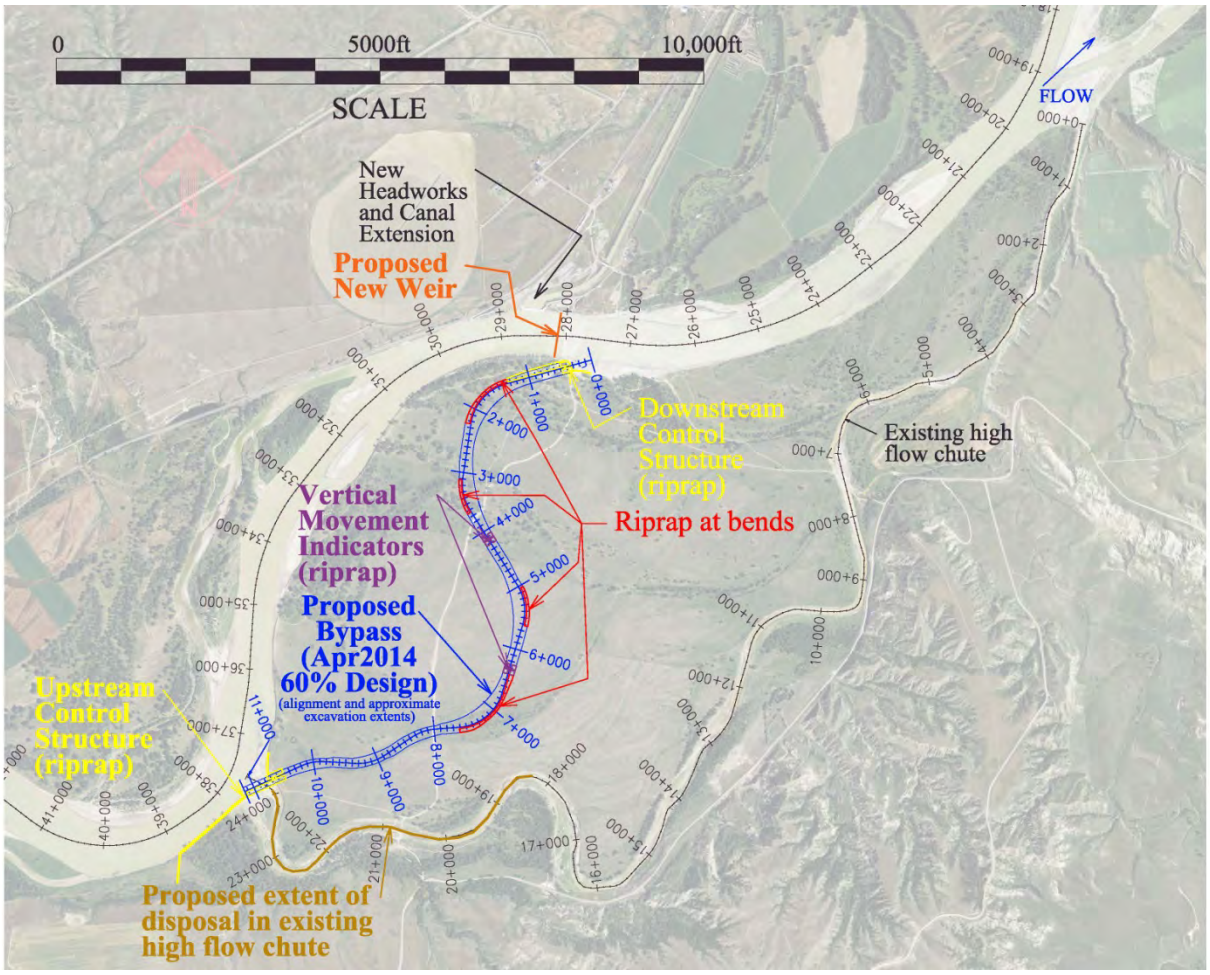

Figure 2 General overview

Because no calibration data are available for the proposed bypass channel, sensitivity runs on multiple sediment loading values, incoming gradation, bed gradation, transport functions, sorting methods, discharges and channel slopes were completed.

Historic flows from USGS gage at Sidney, Montana (approximately 42 miles downstream) were used to evaluate long-term trends. Additionally, constant flows representing the approximate channel-forming discharge were evaluated. Split flow modeling of the 50% annual chance of exceedance (50% ACE, commonly referred to as the two-year discharge) results in approximately 6,500 cfs in the bypass channel; this flow was selected as the channel-forming discharge used to evaluate channel stability. Once a relatively stable channel configuration was selected, model analysis was performed with the post-Yellowtail Dam period of record flows (1967-2014) from the Sidney gage. The maximum flow through the bypass during this analysis was limited to the approximate bankfull discharge, 9,000 cfs (equivalent to 60,000 cfs total Yellowstone flow) due to model instabilities when larger discharges were used. Similar instabilities occur in the main channel when modeling large flows, indicating that model limitations (rather than actual geometry or sediment loading) are the cause. Future evaluation will further investigate modeling of extreme Yellowstone River flows, mainly with 2-D

modeling where overland flows can be modeled with sediment (at the current time, HEC-RAS cannot model more than one reach with sediment).

BASE CONDITIONS

The proposed bypass channel characteristics are summarized below:

- Length ≈ 11,150 ft
- Base cross section shape: 40 ft bottom width, side slopes go from 1V:8H to 1V:6H to 1V:4H
- Channel slope = 0.0007 ft/ft
- Excavation quantity ≈ 950,000 yd^3

Base data used in the sediment transport analysis include the following:

- Median incoming load from the Sidney gage data (USGS Gage #06329500) was used to develop a suspended sediment loading curve for the bypass channel based on the estimated flow split. Figure 3 shows the load in tons/day and compares measured data from the Intake site to the gage data. The load was converted to a concentration which was then used to determine the load in the bypass channel.
- Gradation of incoming suspended load based on estimated median of Sidney gage data. Figure 4 shows the Sidney data as well as the selected load curves for use in HEC-RAS.
- Estimated bedload of approximately 5% of suspended load (varies from 0.5-7% depending on flow) with gradation based on 2008 bar samples (grab samples taken with shovel) collected by USACE and analyzed by USGS. Maximum incoming material size was limited to medium gravel (8-16 mm). Figure 5 shows combined suspended load/bedload as entered into HEC-RAS.
- Transport function used for base is Laursen-Copeland (Copeland 1989 and Laursen 1958), a total load function that was generalized by Copeland for gravel transport so the equation could be used for graded beds.
- Bed gradation was based on Wolman (Wolman 1954) counts collected in 2008. The design includes a processed armor layer in the bypass invert to minimize post-construction degradation. The processed armor layer includes materials greater than one inch diameter screened from the excavation. Figure 6 shows several bed gradations. The Wolman count gradation is coarser than the bar samples or test pits, but is expected to be representative of the processed armor layer after construction.

Figure 7 shows the results of the "base" run using both a constant discharge of 6,500 cfs (between 45,000 and 50,000 cfs in the main channel) and using the gaging record discharges from the post-Yellowtail Dam period (1967-2014). Bypass geometry for the base run does not include natural channel elements that are included in final design. Natural channel elements in the final design include variable cross section shapes and invert elevations representing a pool/riffle sequence (as opposed to the uniform cross section shape and channel slope used in the base run). Design of the natural channel elements generally followed guidance presented in ERDC/CHL CR-01-1 (Soar 2001).

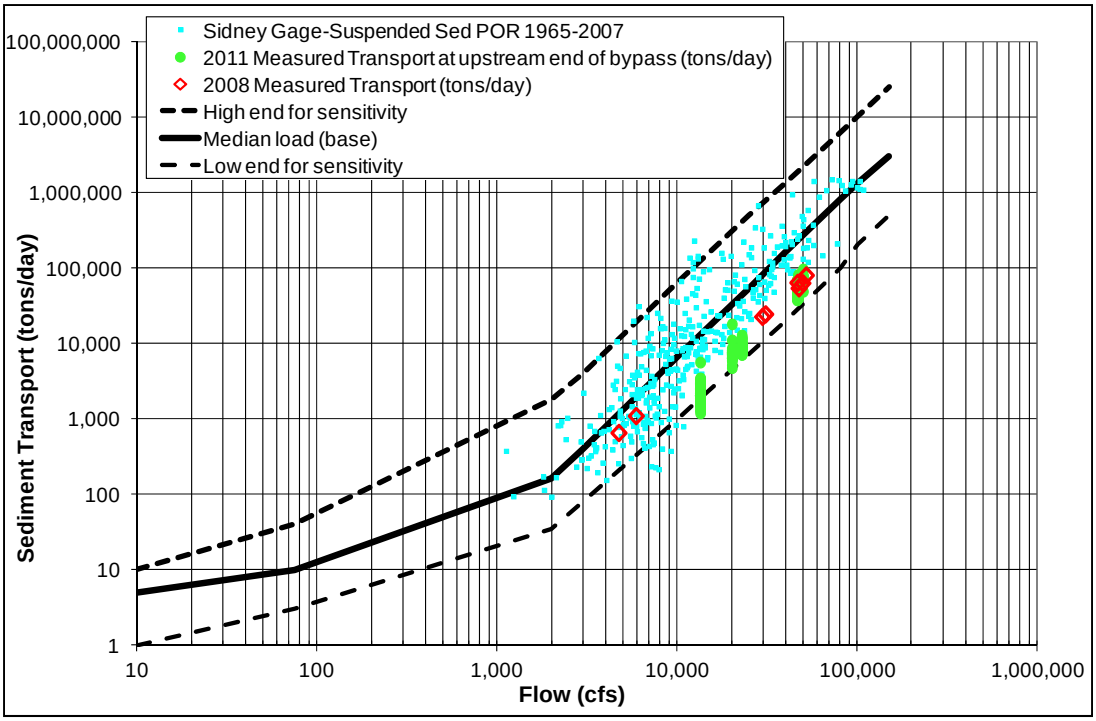

Figure 3 Incoming load data

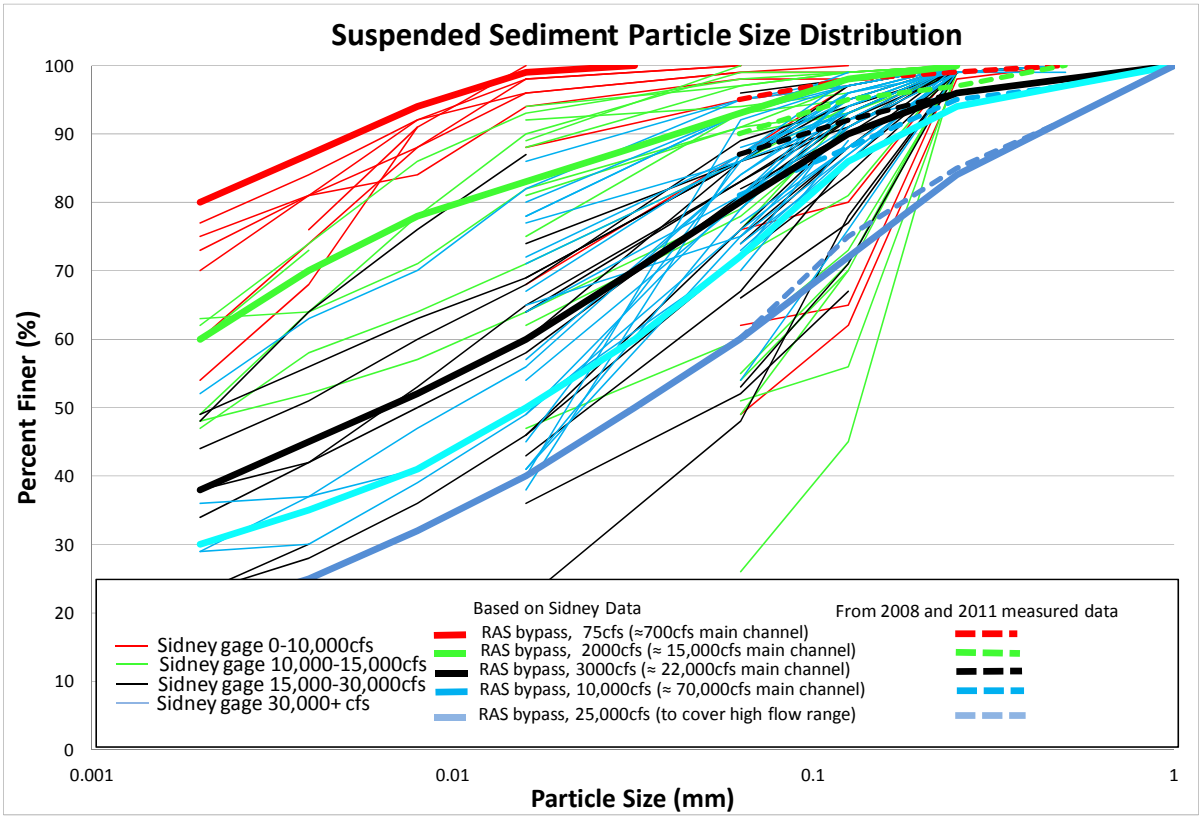

Figure 4 Suspended load gradations

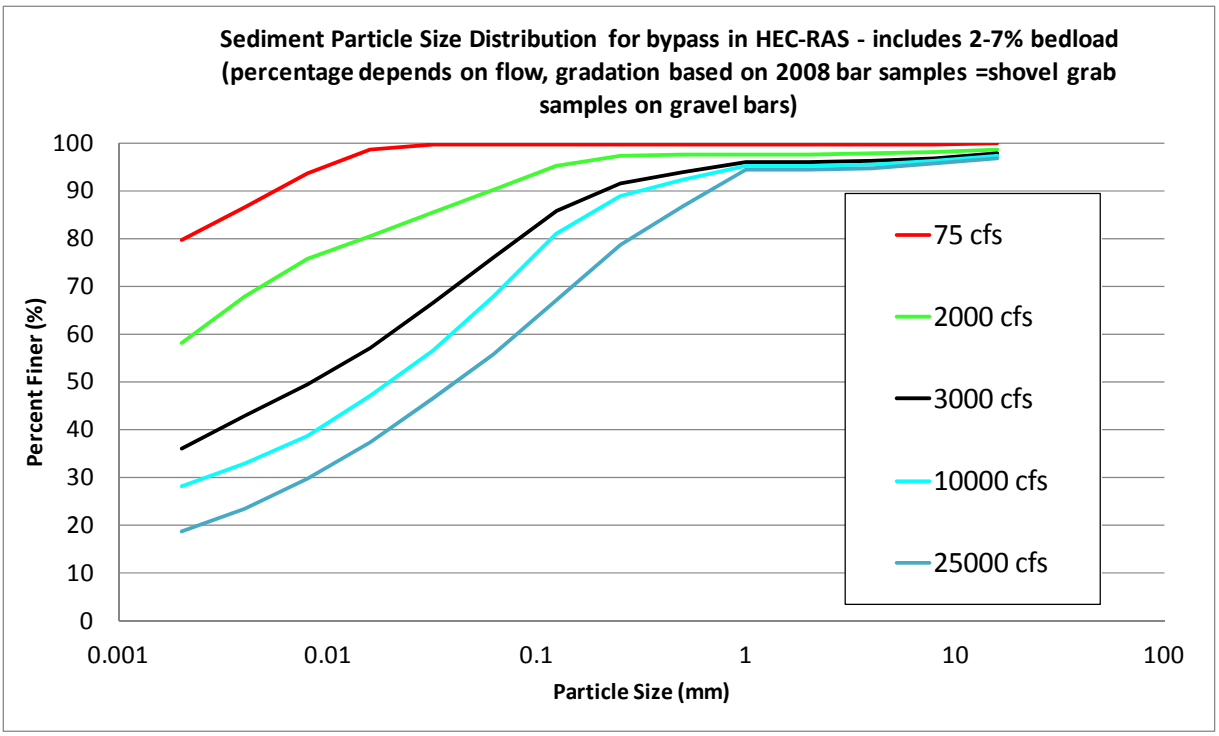

Figure 5 Combined suspended/bedload used in HEC-RAS for bypass channel

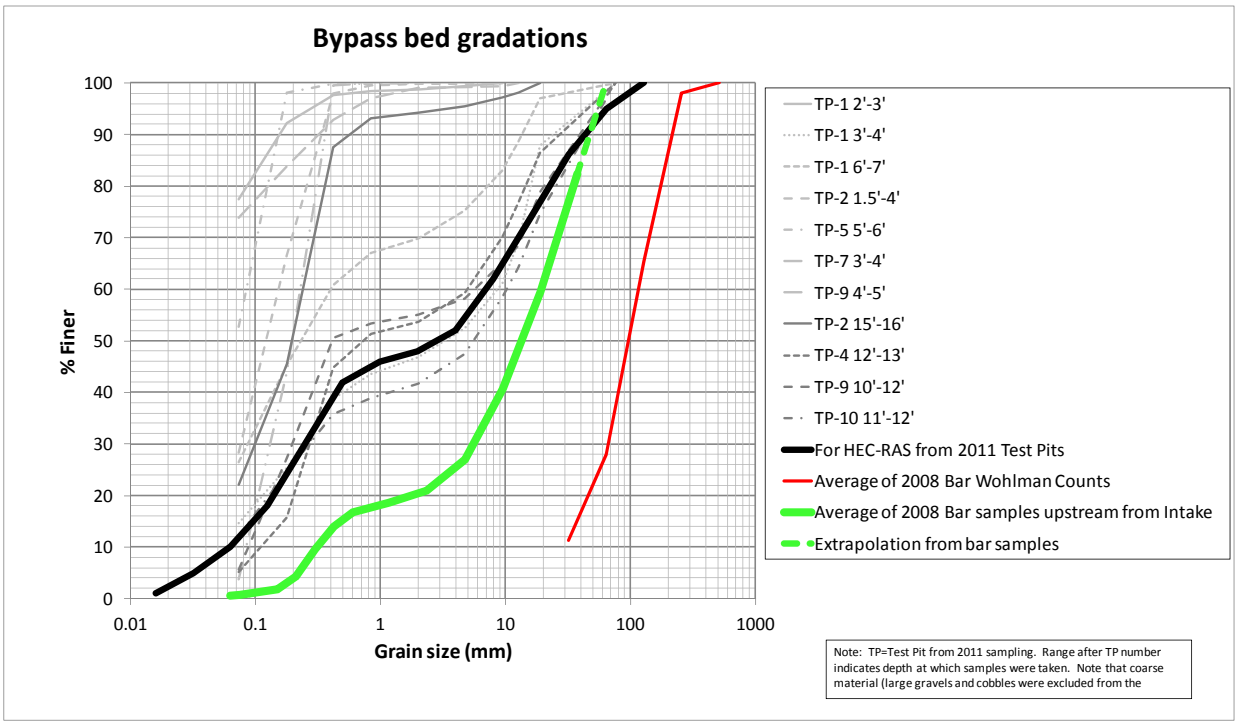

Figure 6 Bypass bed gradations

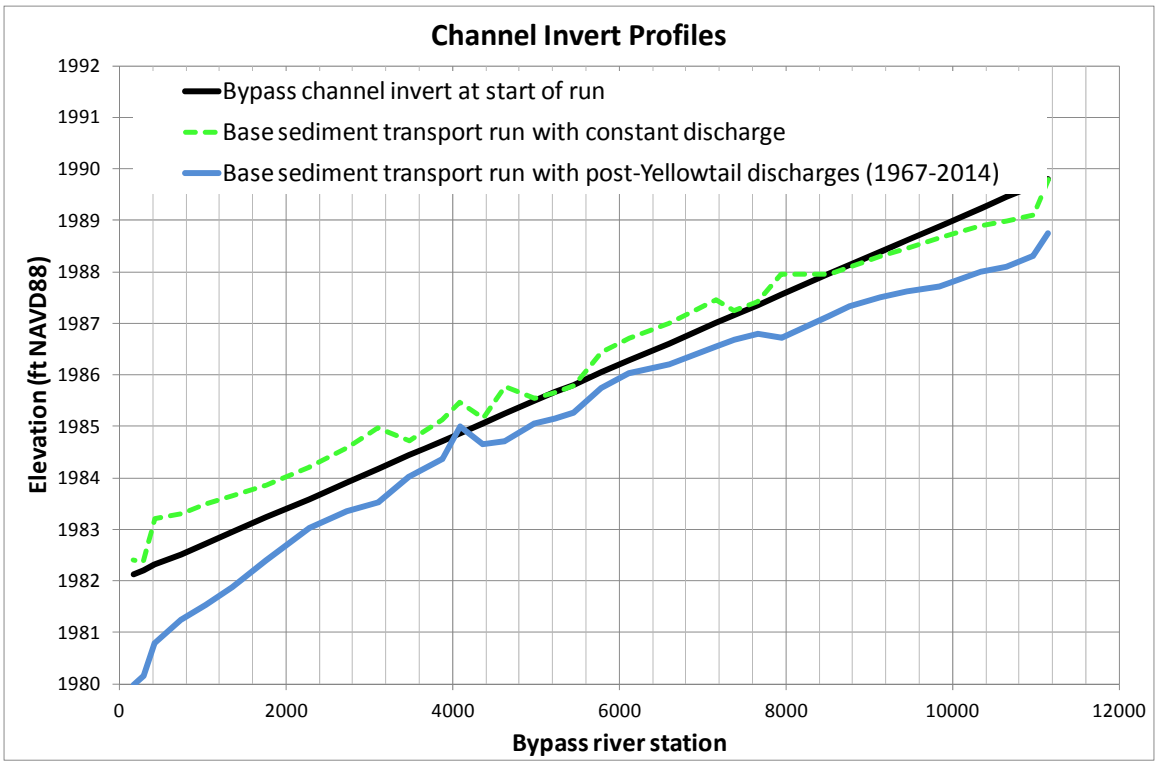

Figure 7 Invert Comparison – Base Runs

SENSITIVITIES

Numerous sensitivity analyses were run on the proposed bypass channel. Sensitivity runs on multiple sediment loading values, incoming gradation, bed gradation, transport functions, sorting methods, discharges and channel slopes were completed.

In general, the model shows high sensitivity to the incoming gradation and transport function; moderate sensitivity to the incoming load, bed gradation, discharge, and sorting method; and low to moderate sensitivity to the channel slope within the ranges considered.

The model shows particularly high sensitivity to the largest size of the incoming material, especially for certain transport functions. In addition to Laursen (Copeland), Yang (1973, 1984), Toffaleti (1968), and Ackers-White (1973) transport functions were used. When using medium gravel (8-16 mm) as the largest incoming material, Yang, Toffaleti, and Ackers-White showed unrealistic aggradation (on the order of 100+ ft). However, when the maximum size of incoming material was limited to very coarse sand (1-2 mm), results with the alternative transport functions were much more realistic. This trend was similar with the main channel of the Yellowstone River, indicating that limitations of the various transport functions are the cause rather than actual physical predictions of extreme aggradation. Figure 8 shows results from multiple runs using various transport functions and maximum incoming material size.

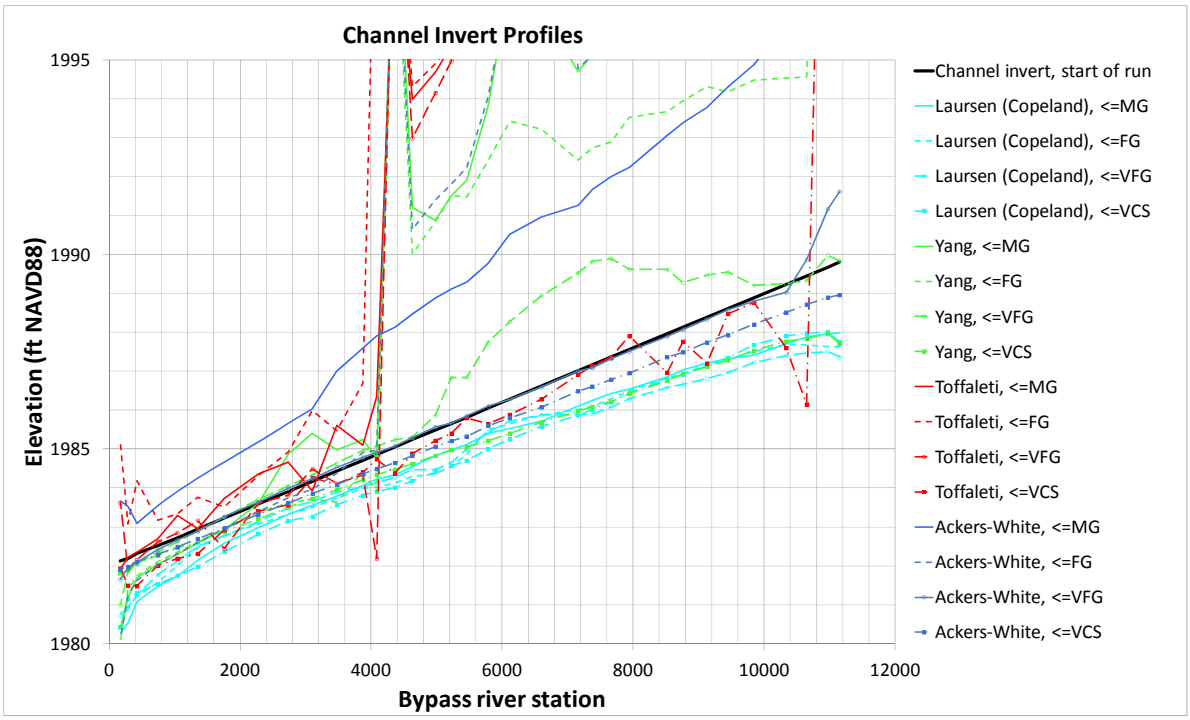

Figure 8 Transport Function and Incoming Gradation Sensitivity (s=0.0007ft/ft)

Figure 8 shows the bypass channel bed invert following the post-Yellowtail Dam flow record (47 years, 1967-2014) limited to a bypass flow of 9,000 cfs. For all runs, the initial channel slope was 0.0007 ft/ft and bed gradation is the Wolman count gradation described above. The legend in the figure indicates which transport function was used, along with the maximum material size of the incoming load (i.e. <=MG indicates the maximum size was medium gravel; FG=Fine Gravel, VFG=Very Fine Gravel, and VCS=Very Coarse Sand).

Figure 9 shows the base runs for slopes of 0.0006 ft/ft and 0.0007 ft/ft. The model shows low sensitivity to the channel slope in this range.

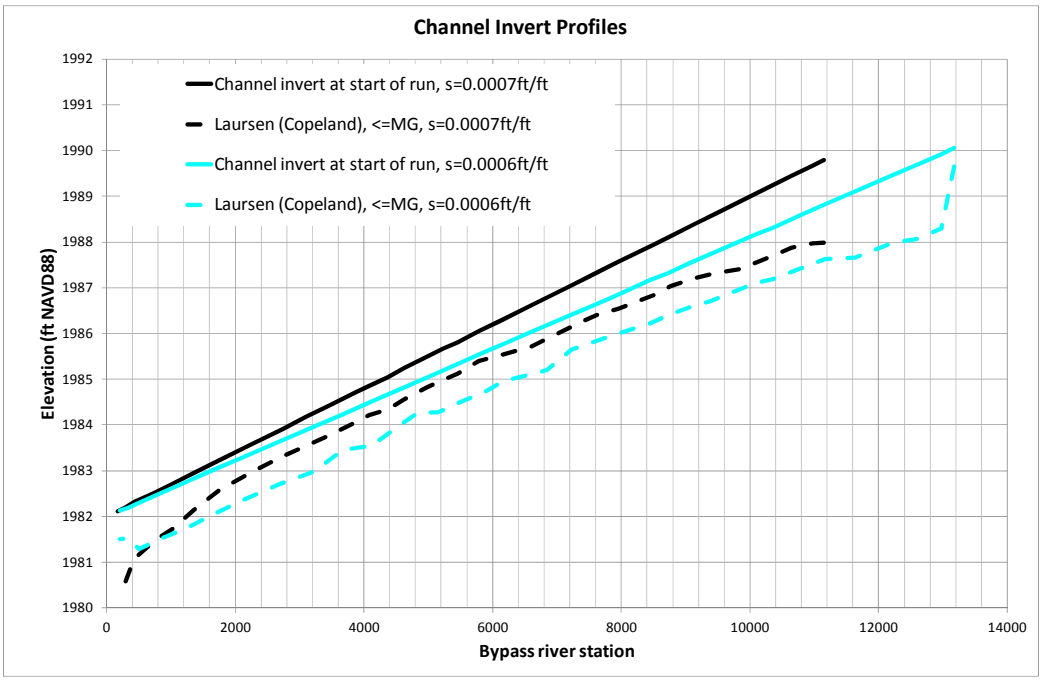

Figure 9 Slope Sensitivity

Sensitivity to the incoming load was evaluated by running the model using the high and low end loads shown in Figure 3. Results of the sensitivity analysis are shown in Figure 10. Unrealistic aggradation at the upstream end of the bypass occurs with the high incoming sediment load which is approximately nine times greater than the base load. This unrealistic aggradation also occurs in the main channel model, indicating that limitations of the transport functions, rather than physical processes are the cause. As shown in Figure 10, a second run was executed with an incoming load of approximately three times the base load.

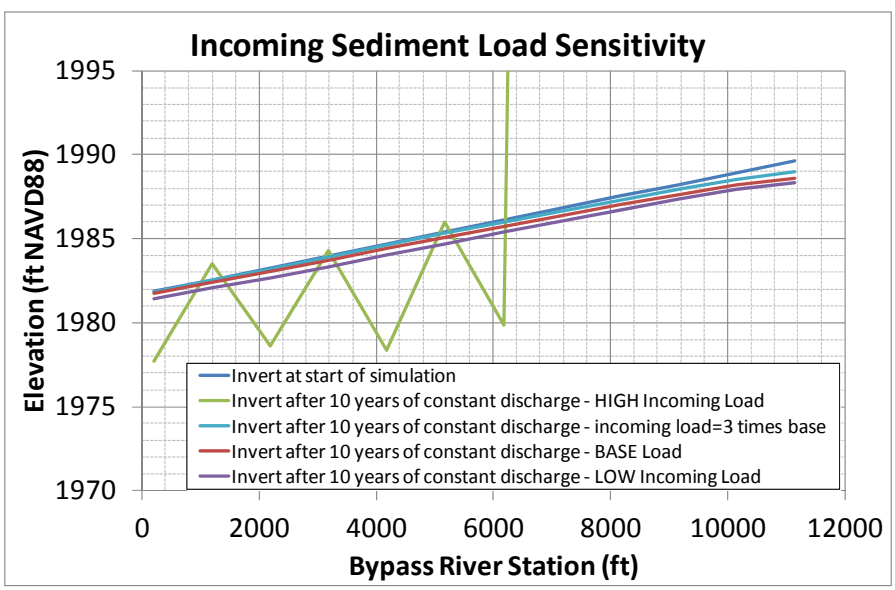

Figure 10 Incoming Sediment Load Sensitivity

Sensitivity to selected sorting method was evaluated by running the model with all three available sorting methods (Brunner 2010): Thomas (Ex5), Active Layer, and Copeland (Ex7). Results of the sensitivity analysis are shown in Figure 11. Runs using the Thomas (Ex5) and Copeland (Ex7) sorting methods produce similar results. The Active Layer method run produced unrealistic aggradation (on the order of 130 ft). Again, this unrealistic aggradation also occurs in the main channel model, indicating that limitations of the sorting method, rather than physical processes are the cause.

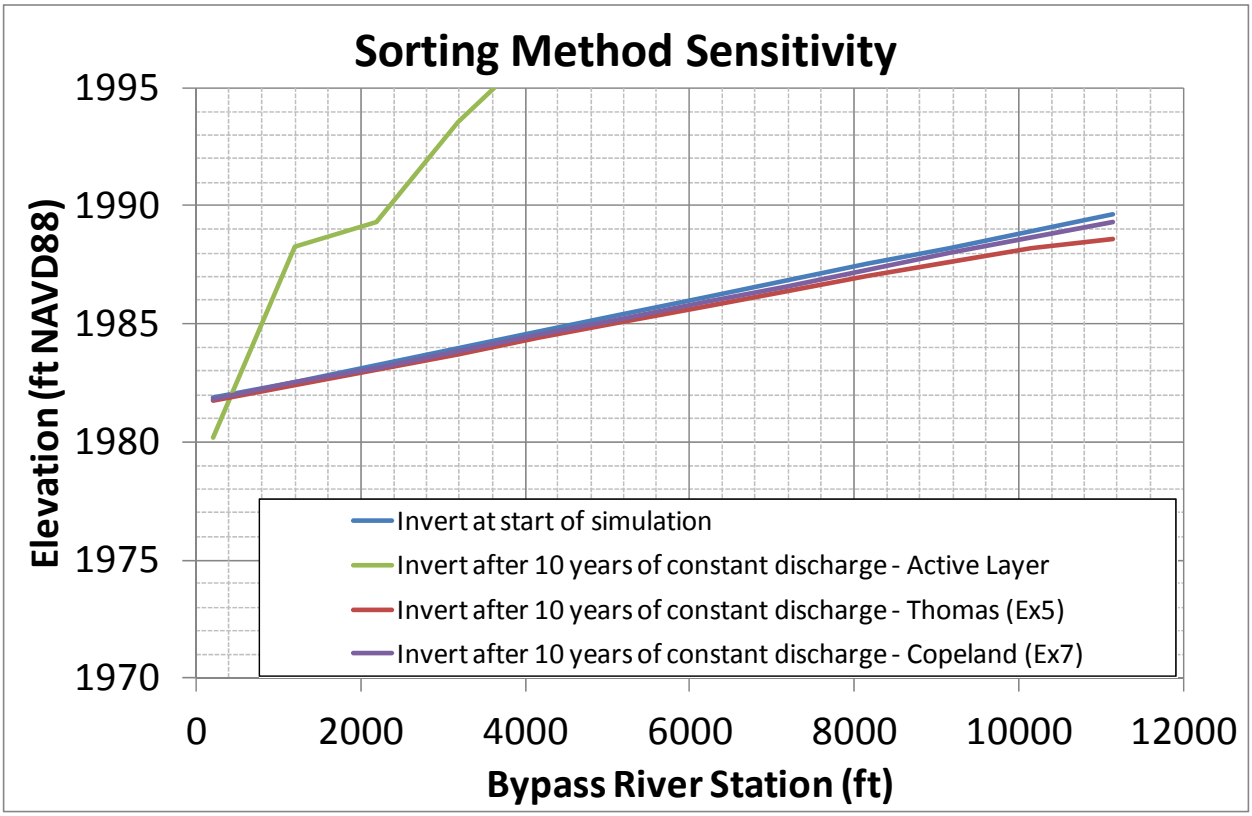

Figure 11 Sorting Method Sensitivity

Because of the large number of alternatives considered, initial sediment runs used uniform cross section shapes and channel slopes. However, the final design includes natural channel elements (varied cross section shapes and inverts). Once the final geometry was selected, the base sediment data were run to evaluate response to the proposed natural channel elements. Figure 12 compares results of the uniform channel vs. the "natural" channel. Figure 13 further compares the results shown in Figure 12. While the general trend of degradation is similar between the uniform and varied channel, HEC-RAS results indicate that some of the pool cross sections may tend to be slightly depositional.

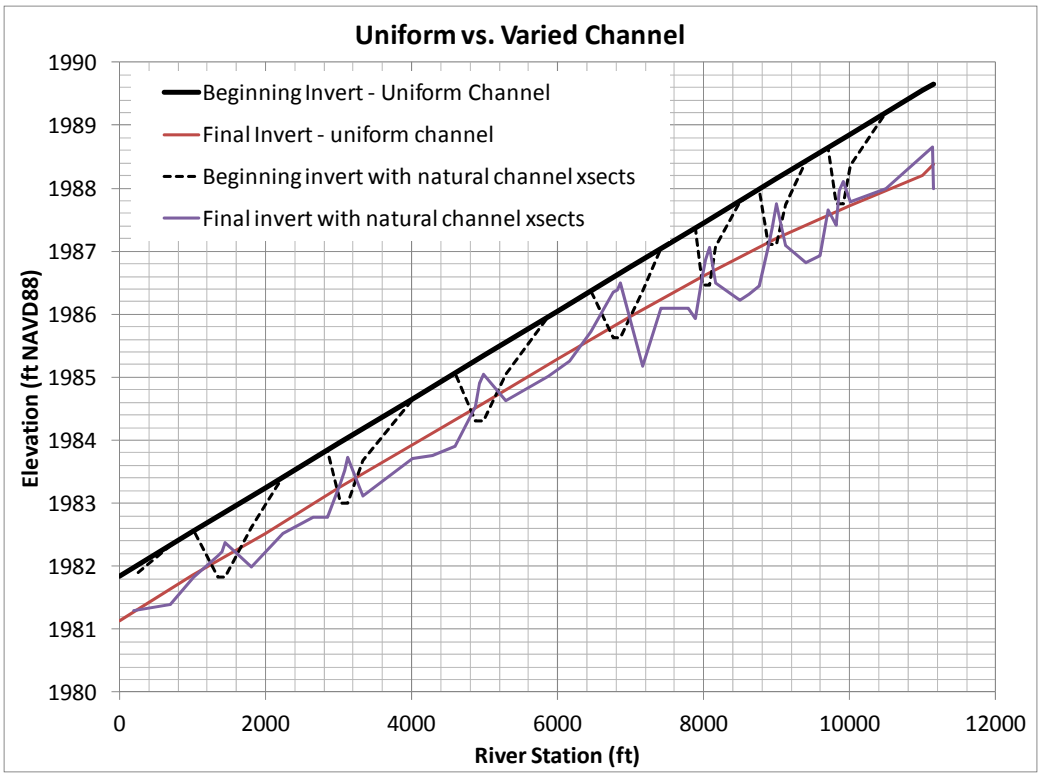

Figure 12 Uniform vs. Varied Channel

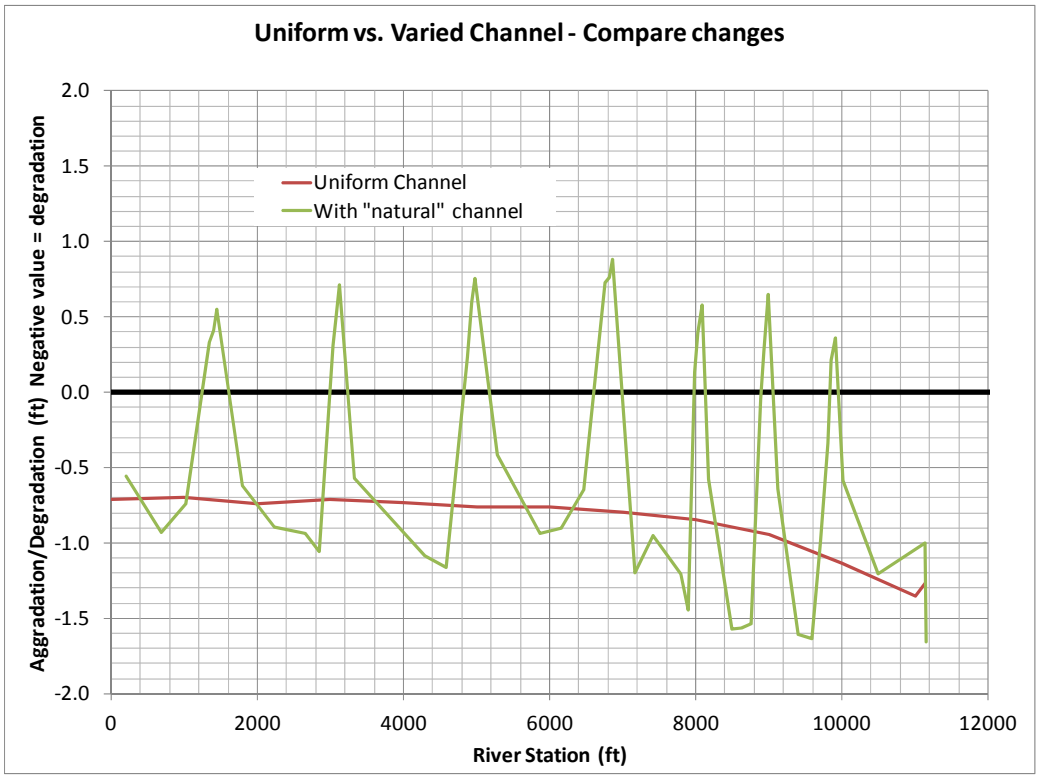

Figure 13 Comparison of Aggradation/Degradation Between Uniform and Varied Channel

SUMMARY AND CONCLUSIONS

Sediment modeling was completed with HEC-RAS to evaluate long term stability of a proposed bypass channel at Intake Dam on the Yellowstone River. Because no calibration data is available, multiple sensitivity analyses were completed to reduce uncertainty.

In general, the model shows high sensitivity to the incoming gradation and transport function; moderate sensitivity to the incoming load, bed gradation, discharge, and sorting method; and low to moderate sensitivity to the channel slope within the ranges considered.

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