APPLICATION OF GSTAR-1D SEDIMENT TRANSPORT MODEL ON THE MIDDLE RIO GRANDE, NM - SAN ACACIA DIVERSION DAM TO ELEPHANT BUTTE RESERVOIR

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Abstract: Sediment transport was modeled for an 80 mile reach of the Rio Grande from San Acacia Diversion Dam to Elephant Butte Reservoir. Operation and maintenance options were evaluated to determine which option would most likely result in a stable river channel and minimize future maintenance requirements, thus improving the effectiveness of the river maintenance program. Future hydraulic geometry and morphology projections are valuable for assessment of river operations, maintenance, and restoration activities such as varying Low Flow Conveyance Channel diversions, adding sediment to degrading reaches, and bank stabilization or terrace lowering. The Generalized Sediment Transport for Alluvial Rivers - One Dimension (GSTAR-1D) computer program, developed by Reclamation, was used to develop the sediment transport model.

Data from two periods, 1972 through 1992 and 1992 through 2002, were available to calibrate the model using historical hydrology and cross-section geometry. These two periods were typical of dry and wet hydrologic conditions, respectively. The general shape and magnitude of the historical cumulative erosion and deposition curves in the main channel and the total cross-section for both calibrations were generally reproduced by the GSTAR-1D model.

The calibrated model was then used to predict future sedimentation for a 20-year period using 2002 data as the starting point with three predicted hydrologic scenarios: wet, average, and dry. Additionally, the predictive model was used to investigate sediment augmentation to assist in channel stabilization along the reach. The predictive model results reveal that additional channel incision may take place in the upper portion of the study reach if the future hydrology is relatively wet or has many high peak flows and that bed material coarsening may continue. The main channel appears to be relatively stable through the middle of the study reach with a general trend towards channel incision in the lower portion of the study reach. The most likely causes of the projected erosion in the main channel are attributed to the large unregulated peak flows present in the predictive hydrology combined with low reservoir levels, the existence of a perched channel system, and the uncertainty of sediment transport and mixing in a bi-modal system.

From these results it is apparent that additional research would help refine the sediment transfer between the main channel and floodplains in a perched system. Similarly, refinement of bed material mixing and armor layer development in a bi-modal system should also be investigated.

INTRODUCTION

The Generalized Sediment Transport for Alluvial Rivers - One Dimension (GSTAR-1D) computer program, developed by Reclamation, and customized specifically for the Middle Rio Grande (Yang et al, 2004), was used to develop a comprehensive calibrated sediment transport model of the Middle Rio Grande from San Acacia Diversion Dam to Elephant Butte Reservoir (Figure 1). The resulting comprehensive sediment model was used to predict future sediment transport trends and provides a valuable tool to analyze the impacts to channel geometry and sediment size from various future operation and maintenance alternatives
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This paper focuses on sediment models for the Middle Rio Grande for two calibration periods from 1972 through 1992 and 1992 through 2002, and future analysis for a twenty year period assumed to run from 2002 through 2022.

The purpose of modeling time periods 1972 through 1992 and 1992 through 2002 was to calibrate parameters for the predictive model using historical hydrology and cross-section geometry. Following calibration of the study reach, an analysis of future sediment trends on the Middle Rio Grande was performed using a sediment transport model based on 2002 data. The projected aggradation/degradation and streambed characteristics provide information to aid management planning to achieve goals regarding effective water delivery to Elephant Butte Reservoir and improving habitat for the Rio Grande silvery minnow (RGSM) and southwestern willow flycatcher (SWFL). Scenarios for the prediction of future sediment conditions used dry, wet, and average hydrologic regimes.

Figure 1 Site map of the Middle Rio Grande and the study area.

DATA ANALYSIS AND MODEL CALIBRATION

Data available for use in the model consisted of suspended sediment data, bed material samples, cross-section surveys, flow hydrology, reservoir elevations, lateral sediment inputs, and aerial photography.

USGS gages at San Acacia and San Marcial were used to generate inflow sediment rating curves, bed gradations, and flow hydrology. Data at Elephant Butte Reservoir were used to determine reservoir pool elevations for the downstream boundary condition. Aerial photography from 1972, 1992, and 2002 were used to generate cross-section geometry, calculate depositional/erosional changes, and identify bank locations, levee locations, ineffective flows, and changes in channel and overbank roughness. Elephant Butte Reservoir surveys were used to provide additional cross-section data downstream of cross section 1792 (Agg/Deg#1792) to provide reservoir water surface elevations used as down stream boundary condition.

Historical (1962, 1972, 1992) and current (2002) cross-section data comparisons were used to determine aggradation/degradation trends along the study reach. Computing the volume change between cross-sections and then generating a cumulative sediment volume plot allowed comparison with the model results. This comparison provided a method for calibrating the sediment model to produce similar results to the measured data. Model calibration also included comparison of model results and field data parameters such as bed material, slope, and mean bed elevations. The model was calibrated for two time periods, 1972-1992 and 1992-2002. Calibration over these two time periods provided verification that the model could be used consistently for two different hydrologic time periods (dry and wet) and provided calibration parameters for the future predictive models.

CALIBRATION RESULTS

The overall results of the final calibration runs reproduce the general shape and magnitude of the cumulative erosion and deposition in both the main channel and the total channel including the floodplains (Figure 2). The results from both sediment models reasonably matched the total historical deposition within the reach (16,741 acre-feet historical vs. 12,036 acre-feet simulated for the 1972 to 1992 model and 4,274 acre-feet historical vs. 4,745 acre-feet simulated for the 1992 to 2002 model) and predicted the overall geometry changes along the reach fairly well. Though the base runs show the deposition for the entire reach is similar to that of the historical record, the reach by reach volumes of deposition differ slightly from the historical volumes of deposition (Figure 3).

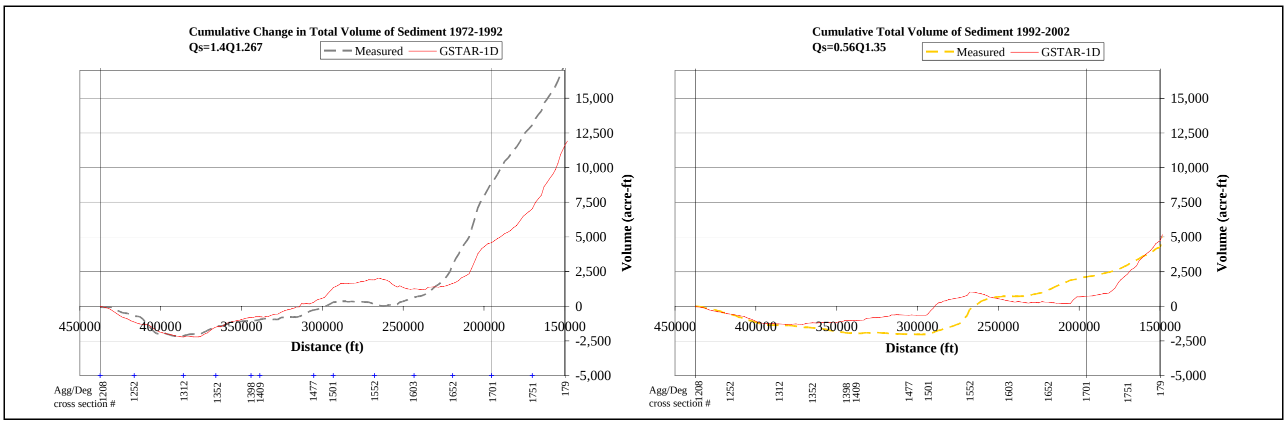

Figure 2 Comparison of cumulative change in total volume of sediment.

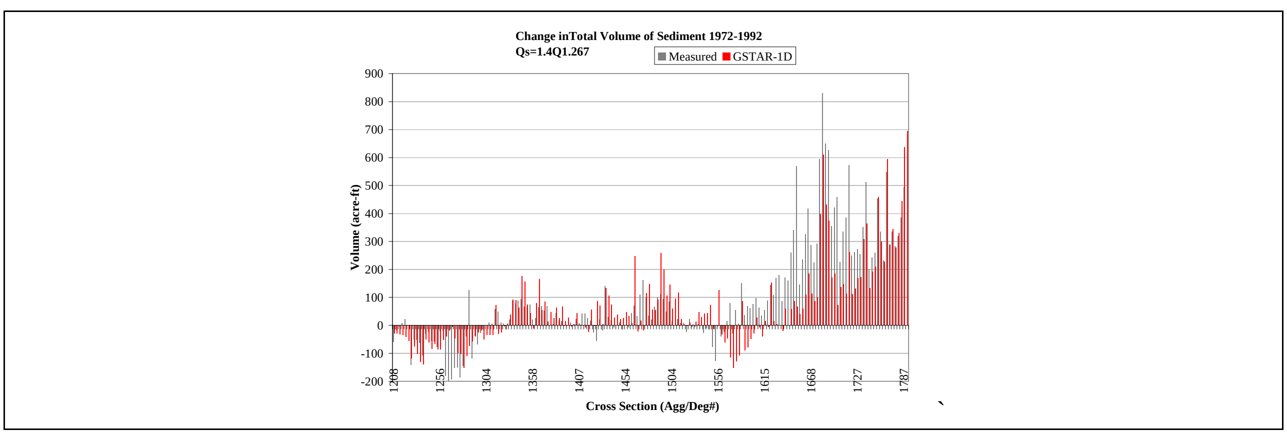

Figure 3 Comparison of change in total volume of sediment.

Figure 4 shows the change in mean bed from the start of each simulation to the end. Overall, the numerical model reproduces the mean bed profile change along the reach. The average difference in mean bed between 1992 measured and the 20 year simulation (1972 to 1992) is 0.26 ft. and has a standard deviation of 1.75 ft. The average difference in mean bed between the 2002 measured and the 10 year simulation (1992 to 2002) is 0.94 ft. and has a standard deviation of 2.05 ft. The degradation of the channel downstream from San Acacia Diversion Dam and the channel aggradation in the reach upstream from Elephant Butte Reservoir has resulted in an overall decrease in channel slope.

While the numerical model reproduces the deposition in the main channel induced by the downstream reservoir fairly well, it tends to over predict the floodplain deposition as a result of the slightly perched channel causing complex interactions between the main channel and the floodplains. In a perched channel system, the interaction between the floodplain and main channel cannot be modeled properly with a 1-dimensional model because a 1-D model assumes a constant water surface for the entire cross-section resulting in a sediment transport capacity that is too low. Additionally, the 1-D model is not able to replicate the tendency to decant overbank flows.

Overall, there is a trend for coarsening, but the model results do not show as much coarsening as the measured data. There are two likely reasons for not capturing the coarsening of the bed: 1) the initial bed material and incoming load does not contain enough coarse sediment, and/or 2) the bed mixing processes may not be represented correctly in the model. Erosion during high flows may leave armoring layers of coarse sediment. As low flows follow a period of high flows, the model will mix the fines with the coarser material. However, in reality the fines may pass over the top of the coarser material and not mix.

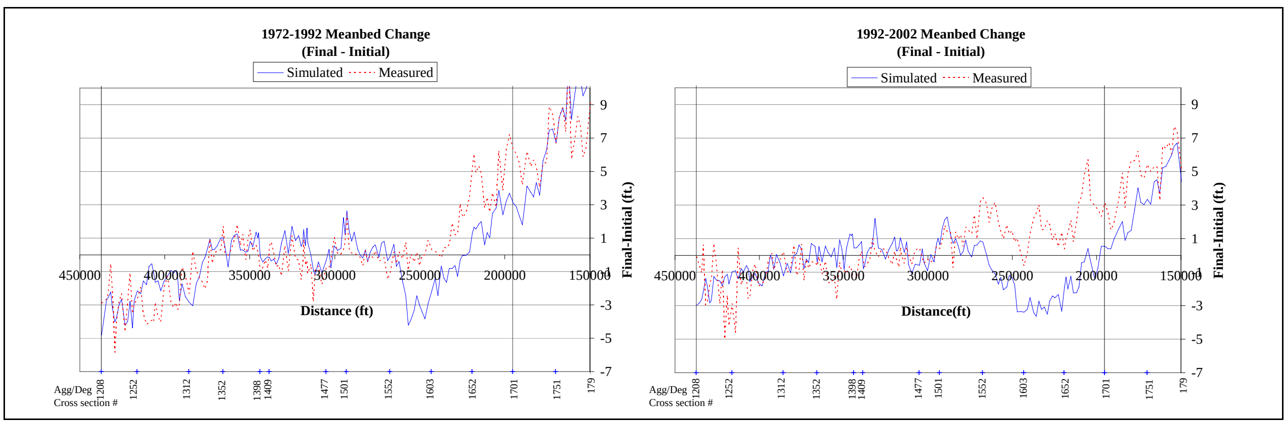

Figure 4 Mean bed change comparison.

PREDICTIVE MODEL RESULTS

No Action Option: The predicted erosion and deposition for the 20-year period are, in general, greater than historical trends (Figure 5). The numerical model shows the main channel to be relatively stable downstream from Agg/Deg#1327 with a general trend towards channel erosion at the furthest downstream cross sections (Figure 6).

The major difference between the different hydrologic scenarios is in the overbanks and the main channel just downstream of San Acacia Diversion Dam at the upper portion of the modeled reach (Figure 7). Floodplain aggradation increases with higher flows as a result of additional channel-floodplain interaction. The lower portion of the study reach exhibits excessive amounts of aggradation in the floodplain for the wet hydrology due to the complex interaction between the floodplain and main channel in a perched channel system (Figure 5).

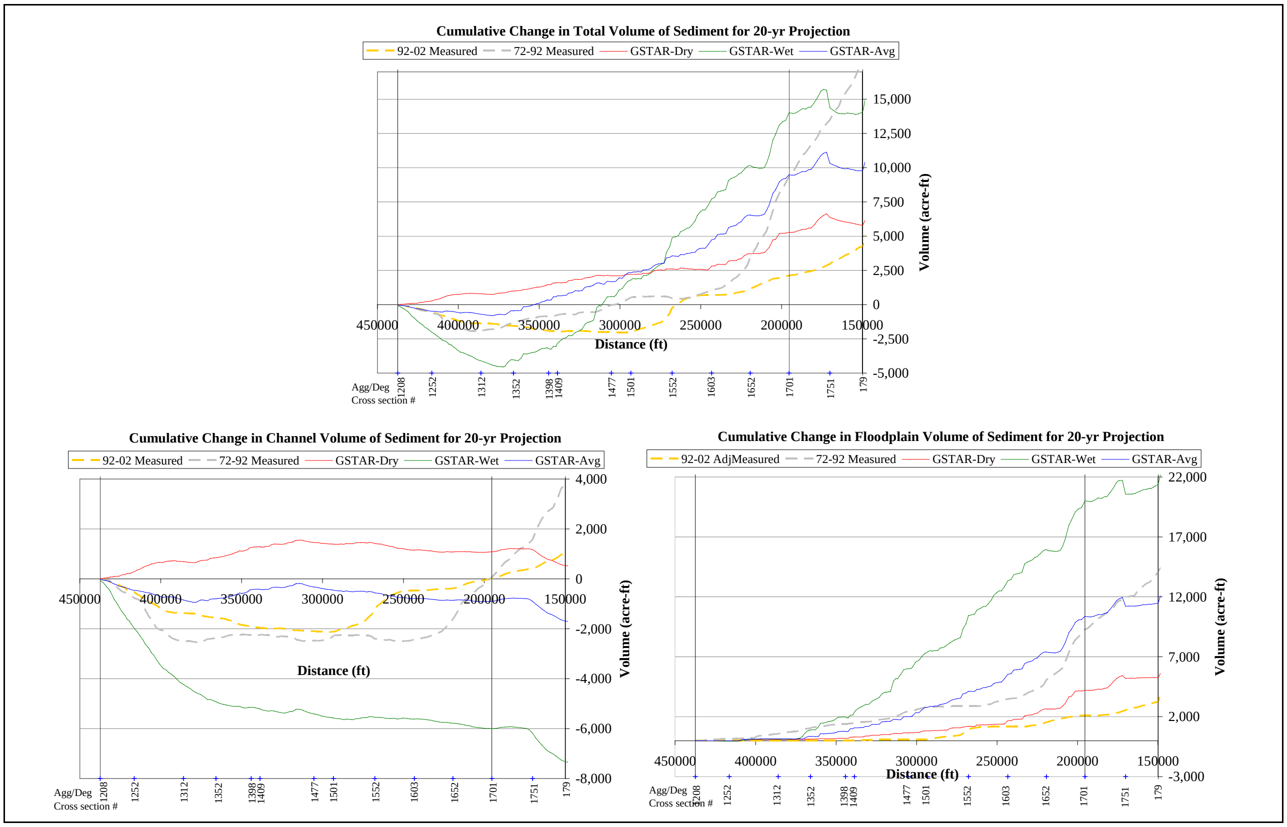

Figure 5 20-Comparison of 20-yr projection of cumulative change in volume of sediment.

Sediment Augmentation Option: It is difficult to predict the effect of sediment augmentation because the sediment loads at the San Acacia floodway gage have not been measured above 4,000 ft^3/s. If the current loads are unknown it is difficult to predict the effect of incremental change. Since the predictive hydrology contains flows up to 21,000 ft^3/s and a large number of flows greater than 5,000 ft^3/s, it is necessary to determine the incoming load for the discharges ranging from 4,000 – 21,000 ft^3/s. Augmentation of fine sediment (fine sand, silt and clay) will increase the aggradation in the floodplains in the lower reaches and augmentation of coarse sand and gravel may prevent some erosion in the upper reaches. Therefore, further work could compute the volume of gravel necessary to maintain the current bed elevations downstream of San Acacia Diversion Dam.

CONCLUSION

The project developed a comprehensive sediment transport model of the Middle Rio Grande from San Acacia Diversion Dam to Elephant Butte Reservoir. The model was calibrated with the data from two time periods: 1972 through 1992 and 1992 through 2002. From the calibration results it was found that the modified GSTAR-1D model was capable of reproducing the general river geometry changes caused by sediment transport. After the model was calibrated for these two time periods, the model was used to predict future sedimentation for three hydrologic regimes: wet, average, and dry. The following can be concluded:

Summary of Calibration Model Results:

- The numerical model reproduced the general shape and magnitude of the cumulative erosion and deposition in the main channel and the total cross-section for both calibration time periods; 1972 through 1992 and 1992 through 2002.

- For both calibration time periods, the numerical model reproduced the degradation in the mean bed profile downstream of San Acacia Diversion Dam as well as the aggradation in the mean bed profile near the reservoir.

- For both calibration time periods, the numerical model reproduced the cross-section geometry changes such as channel width, water surface width, thalweg elevation, and mean bed elevation fairly well. However, due to the limitations of a one-dimensional model, the model cannot predict the uneven deposition in the floodplains, main channel, or the channel meandering and migration.

Summary of 20-year Predictive No Action Model Results:

- The 20-year predictive model results are impacted by the greater magnitude and duration of peak flows in the predictive hydrology and the perched system causing increased floodplain deposition.

- The 20-year predictive model produces deposition in the main channel with the dry hydrology, and main channel erosion with the average and wet hydrology just downstream of San Acacia Diversion Dam.

- Upstream of Agg/Deg#1352, additional channel erosion may take place if the future hydrology is relatively wet or many peak flows are encountered. If large flows are encountered, the coarsening of bed material may continue. Further work could define more precisely the magnitude of flows required to extend the erosion and coarsening of bed material in the upstream reach.

- The 20-year predictive model produces floodplain deposition for all three hydrologic scenarios (dry, average, and wet) due to the unregulated peak flows in the predictive hydrology and the complex interaction of overbank flows in a perched channel system.

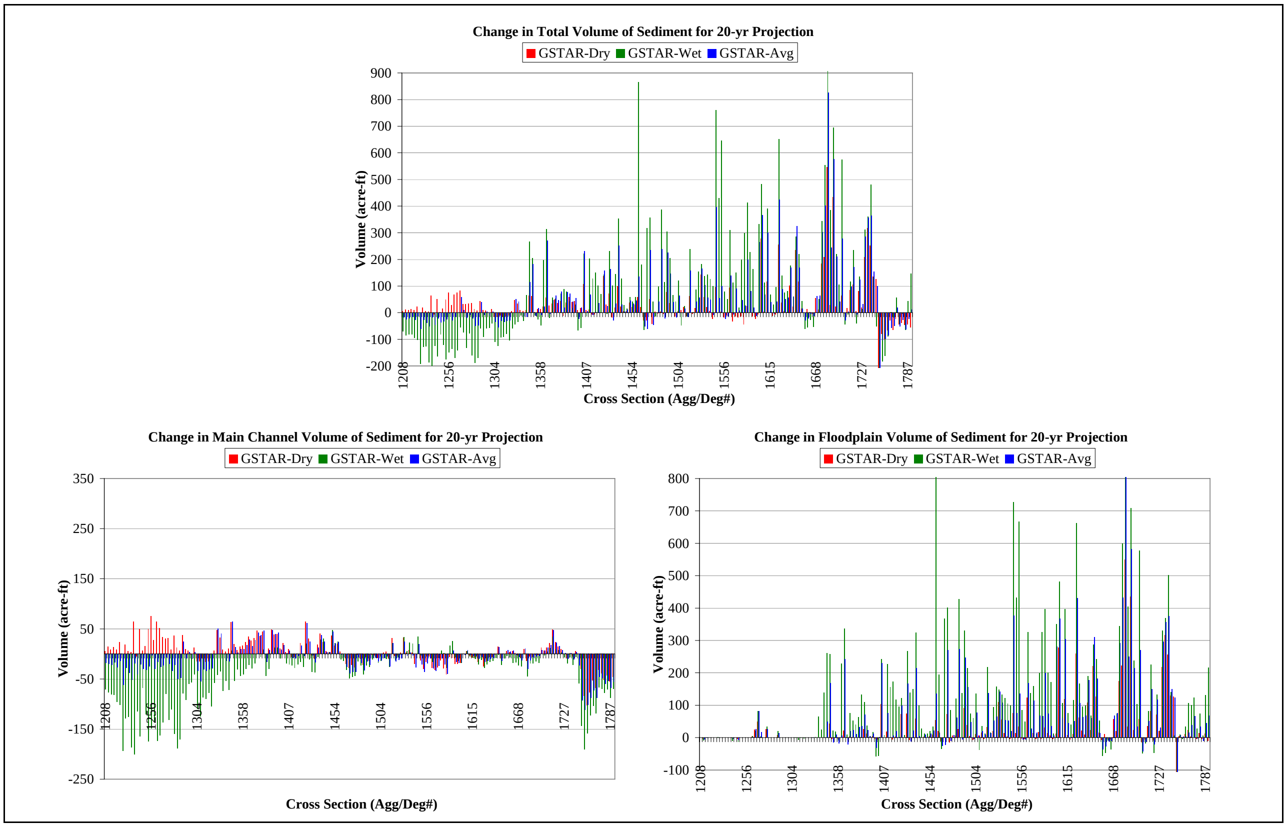

Figure 6 Comparison of change in volume of sediment for 20-year projection.

Figure 7 shows the total change in mean bed from the start (2002) of the simulation to the end of the 20-year modeling period for each hydrology.

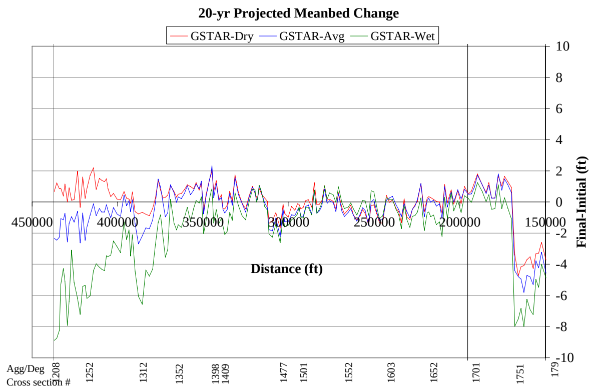

Figure 7   20-year projected change in mean bed.

<u>Summary of 20-year Predictive Sediment Augmentation Model Results</u>:

- Increasing the sand load at San Acacia Diversion Dam has the potential to stop or reverse the erosion occurring in the upper reach. For dry hydrological conditions, no additional sediment may be necessary. For average to wet hydrology, however, the increase in sand load would have to be up to several thousand acre-ft. However, additional modeling of the upper reach is required to predict the volume of sediment currently entering the reach. If fine sediment is added to the system, additional floodplain deposition may occur in the downstream reach, and/or additional deposition will occur in Elephant Butte Reservoir.

<u>Recommendations for future analysis</u>:

- The overall bed changes in the predictive models differ from the historical trends due to the magnitude and duration of the unregulated discharges present in the predictive hydrology. Therefore, additional analysis of the predictive hydrology should be conducted to determine if flow regulation should be included in generating future flows.
- Collection of additional sediment data (suspended and bed material) to further define the incoming sediment rating curve, especially at higher discharges, and further define the bed material gradation variation along the reach.
- Additional calibration work to more closely simulate the change in channel slope and the coarsening of the river bed.
- Additional capabilities that could be introduced into the model would include: refining the sediment diffusion between the main channel and floodplains to better predict the main channel floodplain interaction in a perched system, and refinement of bed material mixing and armor layer development for Rio Grande conditions.

REFERENCES

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