# BANK EORISON MODELING WITH SRH-2D ON THE RIO GRANDE, NEW MEXICO

**Yong G. Lai, Ph.D., Hydraulic Engineer, Technical Service Center,**
**U.S. Bureau of Reclamation, Denver, CO, ylai@urbr.gov**

**Abstract** A number of sites along the Rio Grande in New Mexico have been experiencing significant bank erosion. A good understanding of bank erosion along the river is necessary for habitat restoration projects and river maintenance planning. This includes the ability to estimate future bank erosion location and its rate. The new geofluvial model SRH-2D, which couples lateral bank erosion modules with the original vertical mobile-bed erosion model, has been developed recently. The model has been verified elsewhere as a useful numerical model that simulates simultaneously the vertical stream bed erosion and lateral bank erosion. In this study, the new SRH-2D is used to evaluate whether the new model is applicable to Rio Grande bank erosion modeling, and the study also establishes the modeling procedure. A specific site at RM 111 on the Rio Grande, New Mexico, is selected for the purpose.

## INTRODUCTION

Stream bank erosion is a natural geomorphic process occurring in all alluvial channels; it can be an important form of channel adjustment in unstable alluvial environments. Hence bank erosion should be accounted for in geomorphic analyses, river restoration, dam removal, and channel maintenance projects. Along the Rio Grande in New Mexico, for example, many sites have been experiencing bank erosion. These sites need frequent river maintenance work and the cost can be prohibitive if unmanaged. A good understanding of the bank erosion locations and retreat rates is necessary for river maintenance prioritization, planning and project design. Numerical modeling assessment is a viable alternative for these purposes.

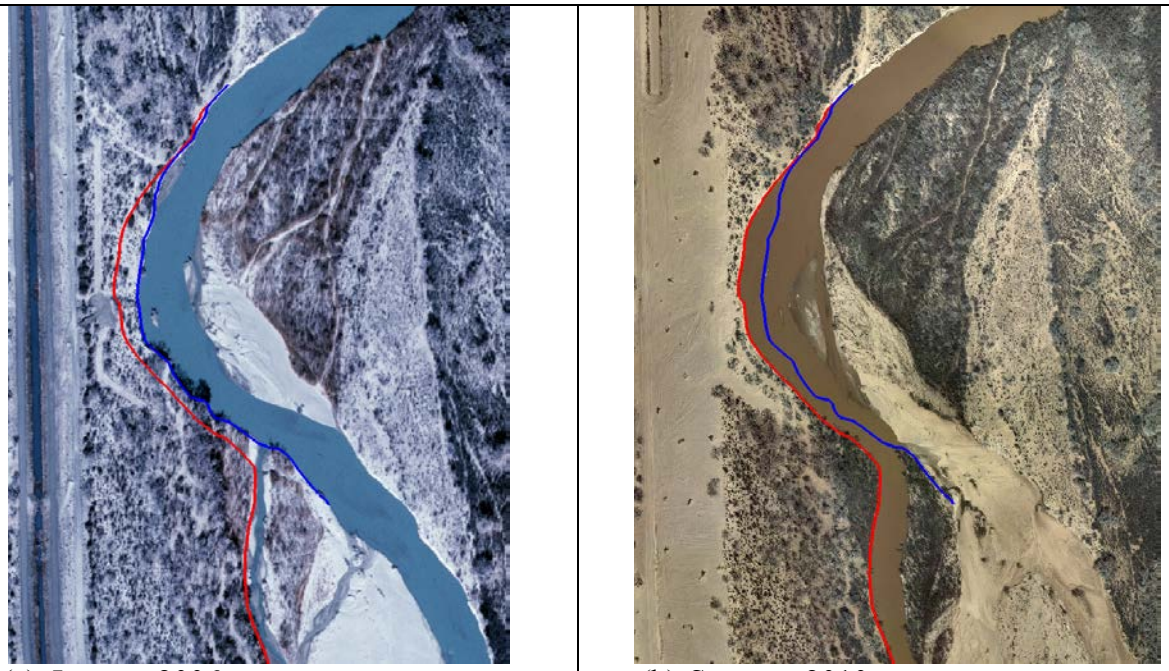
In recent years, one-dimensional (1D) and two-dimensional (2D) numerical models have become important tools for predicting channel responses. For example, a number of stream-specific mobile-bed sediment transport models are becoming available for project applications such as HEC-RAS, SRH-1D, CONCEPTS, CCHE2D and SRH-2D. They are versatile and offer extensive capabilities and choices in modeling the vertical stream bed changes (a few also have the lateral erosion modeling capability). Recently, SRH-2D has been extended to include the bank erosion modules; this new geofluvial capability has been tested, validated and applied to a number of rivers (Lai and Wu 2013; 2014; Lai 2014; Lai et al. 2015a; 2015b). This new development motivated the present study; and it intends to answer the question of whether the current state-of-the-art multi-dimensional geofluvial model SRH-2D can be useful in predicting bank erosion on the Rio Grande. In the past, a few bank erosion sites on the Rio Grande were assessed through field study and using a point-based bank erosion model (Bankhead et al. 2012). However, the point-based models have limited use for predicting future changes. More advanced geofluvial modeling was sought by the Bureau of Reclamation Albuquerque Area Office. In this study, I report the application of SRH-2D to a particular bank erosion site on the Rio Grande, New Mexico (River Mile 111). The study has the following objectives: (a) establish the application and calibration procedure of SRH-2D to the field case, and (b) assess the model performance by comparing the model results with the field data. The study paves the way for future potential applications of SRH-2D to the Rio Grande for bank erosion assessment; it also

adds to the list of successful applications of SRH-2D for combined vertical and lateral erosion modeling.

## ABOUT THE STUDY SITE

The bank erosion site selected for the present study is located at River Mile (RM) 111, downstream of the San Acacia Diversion Dam, on the Rio Grande, New Mexico. A series of historical aerial photographs are available between 2002 and 2012 and they are used to help delineate the bank erosion processes at the study site. In particular, the bank retreat distance is obtained and is used to calibrate the numerical model in this study.

The modeling starts from October 2005 and ends in September 2010, about a 5-year modeling period. The aerial photographs from January 2006 and in the summer of 2010 are shown in Figure 1. In the plot, the 5-year bankline retreat is also displayed. The October 2005 terrain used by the model is reconstructed from the July-August 2005 cross sectional data surveyed by Tetra Tech., Inc., and the 2003 DTM data and 2012 LiDAR in dry areas such as bank tops and floodplains. Photos taken at the RM 111 site during a field trip by the author on February 6, 2013 are shown in Figure 2.



(a) January 2006 (b) Summer 2010

Figure 1. Aerial photographs between January 2006 and summer 2010 at RM 111; also shown are the banklines: Blue=2006; Red=2010

(a) Looking Upstream (b) Looking Downstream

Figure 2. Photos taken at RM 111 during the February 6, 2013 field trip

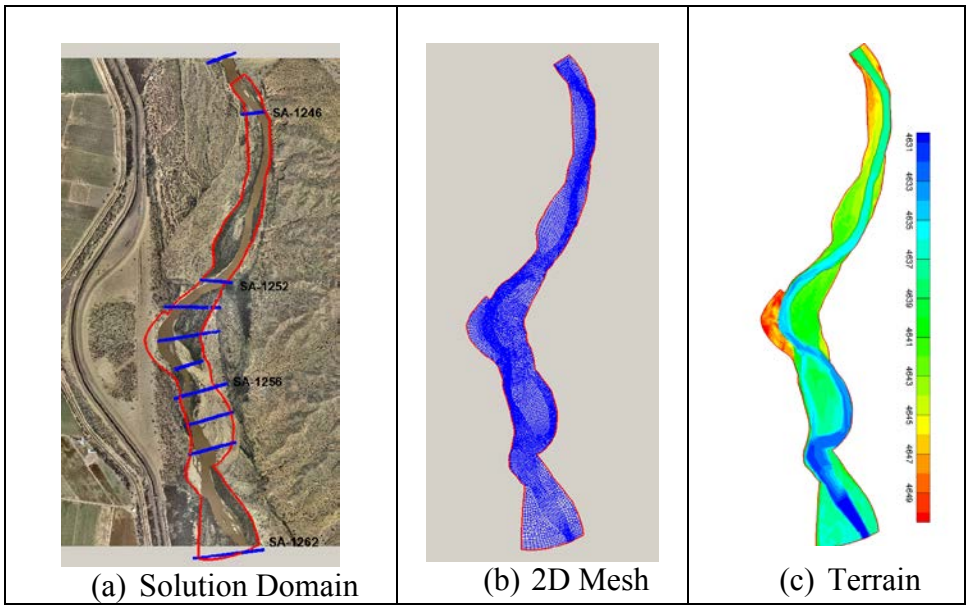
## NUMERICAL MODEL AND MODELING DETAILS

**SRH-2D Model Description** SRH-2D is a teo-dimensional, depth-averaged, hydraulic and sediment transport model for river systems under development at the Bureau of Reclamation. The hydraulic flow model, documented by Lai (2008; 2010), has been widely used by internal and external users. The sediment transport mobile-bed module is used to predict stream-bed vertical changes and has been described by Lai and Greimann (2008; 2010) and Lai et al. (2011). The sediment module tracks multi-size, non-equilibrium sediment transport for suspended, mixed, or bed load for both cohesive and non-cohesive materials. In recent years, SRH-2D has been developed to include bank erosion modules. Two bank modules are developed: the uniform retreat module and the mechanistic failure module. The two adopt the same basal erosion (lateral erosion) algorithm given a shear stress distribution on a wetted bank. The main difference lies in the mass failure algorithm. The uniform retreat module assumes that the bank is retreating uniformly as a whole. The mass failure process is computed by assuming that a constant bank angle (e.g., the angle of repose) is maintained, and the loss of the bank material equals to the basal erosion. The uniform retreat module is developed primarily for uniform non-cohesive banks undergoing the dry granular and shallow slide processes. It may also be applied to cohesive banks or banks with other mass failure processes if only gross bank retreat amount is of the interest, when actual physical processes are too complex to model, or if there is a lack of measured bank data. The mechanistic failure module is developed primarily for multi-layer cohesive banks; the development is based on t he Bank Stability and Toe Erosion Model (BSTEM) as reported by Simon et al. (2000; 2011) and Langendoen and Simon (2008). The integration of key BSTEM algorithms into SRH-2D was documented by Lai et al. (2013; 2015a).

The technical details of the geofluvial modeling capability of SRH-2D are not reported herein; interested readers are referred to the review by Lai (2014), along with other works by Lai and Wu (2013; 2014) and Lai et al. 2015a. With the latest SRH-2D, main channel fluvial processes may be solved with the regular 2D depth-averaged mobile-bed module, while the lateral bank erosion processes are solved with bank modules. In this study, the latest geofluival SRH-2D model is used and the uniform retreat bank module is used.

**Modeling Procedure** Modeling is carried out in two stages: hydraulic analysis and bank erosion mobile-bed analysis. Hydraulic analysis is a necessary step to check and verify the model development and setup; the results are needed as the initial condition for bank erosion modeling. Often it also helps guide a proper selection of the solution domain (model boundaries) and the development of the mesh. Bank erosion modeling is carried out after the hydraulic analysis is completed. SRH-2D modeling, in general, is carried out in the following steps: (1) Selection of the solution domain; (2) Mesh generation for the solution domain; (3) Topography and flow roughness and bed gradation representations on the mesh; (4) Model calibration; and (5) Model application. Steps 1-3 are discussed first; followed by hydraulic analysis and bank erosion modeling for model calibration. In this study, model application is not carried out due to limited scope of the study.

**Solution Domain, Mesh and Initial Terrain** The solution domain may be limited by the availability of terrain data and the area of interest. For this study the solution domain is shown in Figure 3a. It runs from cross sections SA-1243 to SA-1262 and has a longitudinal extent of about 1.8 miles. The upstream boundary is located upstream of SA-1246 and the downstream boundary is located near SA-1262. A 2D mesh is generated with the Surface Water Modeling System software (SMS). It consists of a total of 11,722 mixed quadrilateral and triangular cells and 11,584 nodes (Figure 3b). Once the 2D mesh is generated, the October 2005 terrain and bathymetric survey data are interpolated onto the 2D mesh. The terrain represented by the 2D mesh is shown in Figure 3c.

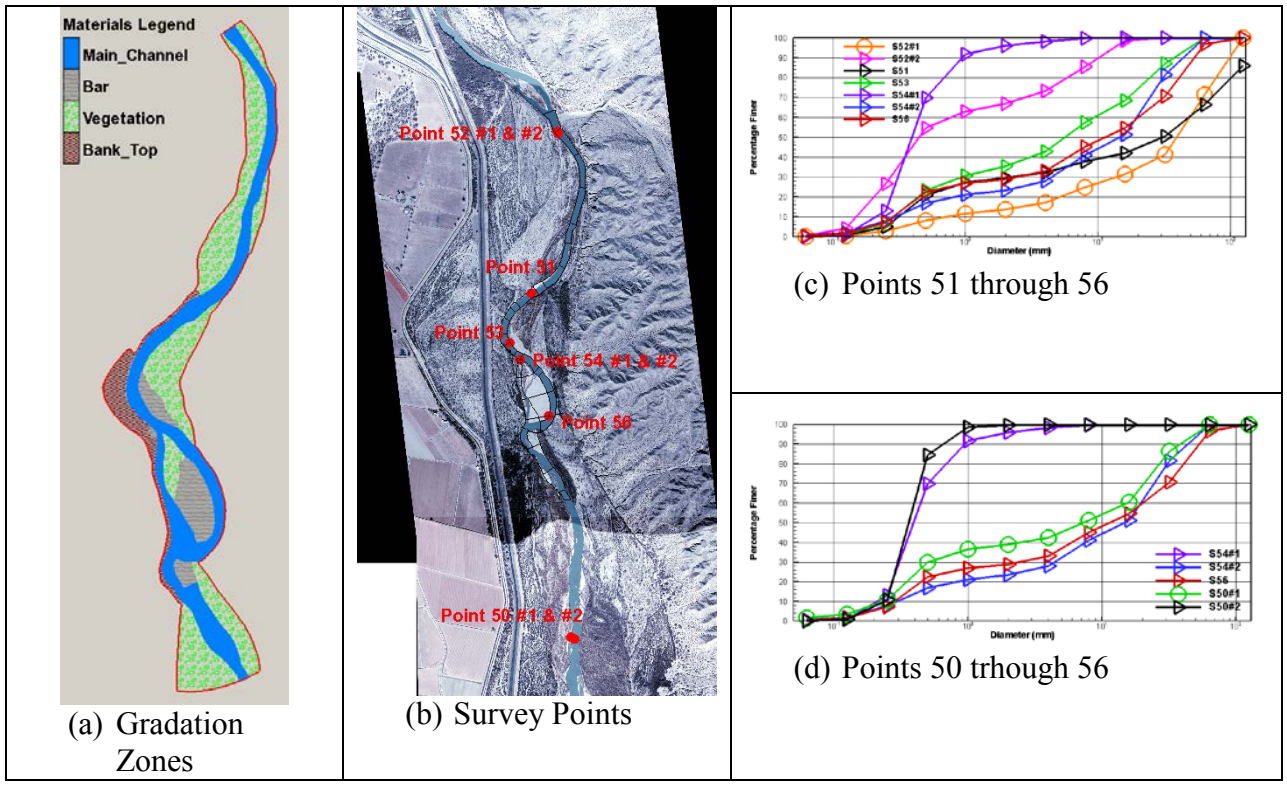



(a) Solution Domain (b) 2D Mesh (c) Terrain

Figure 3. Solution domain (Left), 2D mesh (Middle) and terrain (Right) at RM 111 study site

**Flow Resistance and Bed Gradation** The flow resistance and initial bed/subsurface sediment gradations are two major model inputs. The flow resistance is computed with the Manning's roughness equation. In this study, the Manning's coefficient of 0.026 is used in the main channel and bare bars based on the study carried out in the reach upstream of San Acacia Diversion Dam (Lai, 2007). No separate calibration for the roughness coefficient is carried out due to lack of data.

Initial bed and subsurface sediment gradations are represented by four bed zones as shown in Figure 4a. Each zone is assigned with thickness of the surface and sub-surface layers along with the sediment gradation (cumulative sediment size distribution). Sediment gradation surveys were carried out by Bauer (2006) between June 15-20, 2006 and again between July 17-19, 2006. These survey data are used for the present modeling. The survey points within the study area are displayed in Figure 4b while the gradations of these survey points are plotted in Figure 4c and d.




(a) Gradation Zones

(b) Survey Points

(c) Points 51 through 56

(d) Points 50 through 56

Figure 4. Zonal partition of the solution domain for bed gradation, survey points and the measured cumulative distribution at survey points

**Boundary Conditions and Other Model Inputs** A time-series flow hydrograph from July 2005 to the end of 2010 is used for the simulation; the data are based on the runoff data recorded at the USGS San Acacia Floodway station (#08354900) (Figure 5a). The time series discharges are used as the upstream boundary condition. The upstream sediment supply is based on the capacity equation of Parker (1990) since the measured sediment flux data are unavailable. Discharges less than 1,000 cfs are excluded from sediment modeling as done by Lai (2009) and Lai (2011) for the Rio Grande since low flows do not change the channel morphology appreciably and the exclusion reduces the computing time. At the downstream boundary, the normal depth boundary condition is applied. The normal depth assumption is adequate for the present study since the selected downstream boundary is located quite far away from the RM 111 bend which is the zone of interest of the study; the outlet is also located in a relatively straight channel.

A total of seven sediment size classes are used, from 0.002 to 125 mm, to represent the bed material load. The partition of the seven classes is shown in Table 1. The sediment erosional rate

potential uses the Parker (1990) sediment transport equation. The bedload adaptation length is chosen to be 170 ft (about the average channel width of the study reach), and the active layer thickness is 30 mm which is about twice the mean particle diameter in the main channel.

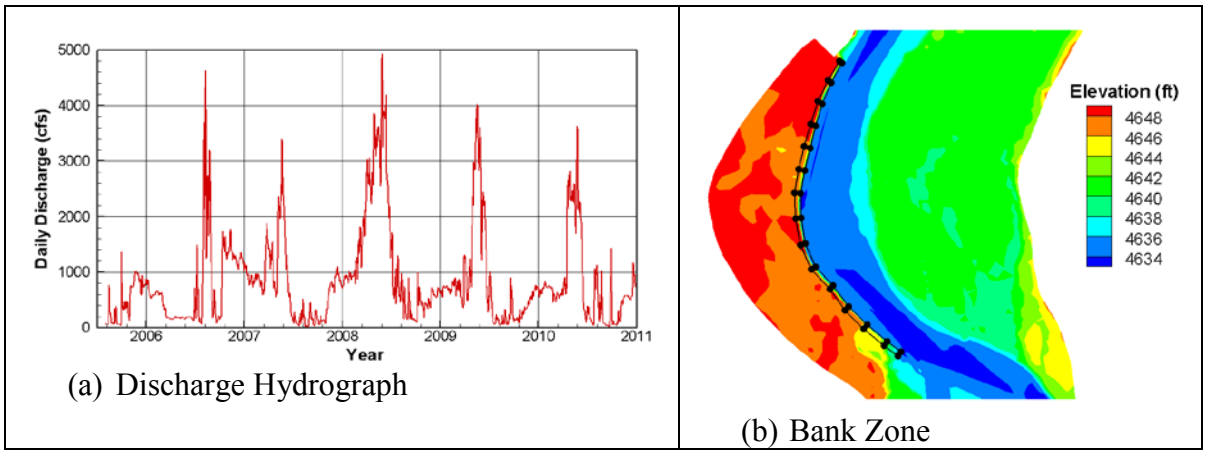
Table 1. Size ranges of each sediment size class

| Sediment Size Class | Size Range (mm) |
|---|---|
| 1 | .002 to .0625 |
| 2 | .0625 to .25 |
| 3 | .25 to .5 |
| 4 | .5 to 2.0 |
| 5 | 2.0 to 8.0 |
| 6 | 8.0 to 32 |
| 7 | 32 to 125 |

**Bank Module Inputs** Additional input parameters are related to the bank properties for a coupled geofluvial modeling; the right bank within the bend is simulated as shown in Figure 5b. In the figure, both bank toe and top lines are displayed. The mesh within the bank zone consists of quadrilateral cells and has a total of five lateral nodes. Longitudinally, fifteen (15) bank profiles are simulated; the toe and top nodes of each bank profile are displayed in Figure 5b as black dots.

A separate input file is used for the bank erosion module and it contains bank erosion input parameters for each of the 15 banks. The input parameters are summarized below:

- A constant time step of 1 hour is used for the bank erosion module (as compared with 5 seconds time step for the flow and sediment transport modeling);
- Each bank is simulated using the uniform retreat module with the following input parameters;
    - All banks have the same bank porosity of 0.4 and critical shear stress of 0.0 Pa, with the initial angle of the bank profile unchanged;
    - The volumetric composition of the bank sediment in terms of the seven size classes in Table 1 is specified as: 13%, 29%, 29%, 29%, 0%, 0%, and 0%; and
    - The erodibility coefficient is calibrated and the final values were: 2.0e-5 for banks 2 to 10; 5.0e-6 for banks 11 to 12; 2.0e-6 from banks 13 to 15.




(a) Discharge Hydrograph

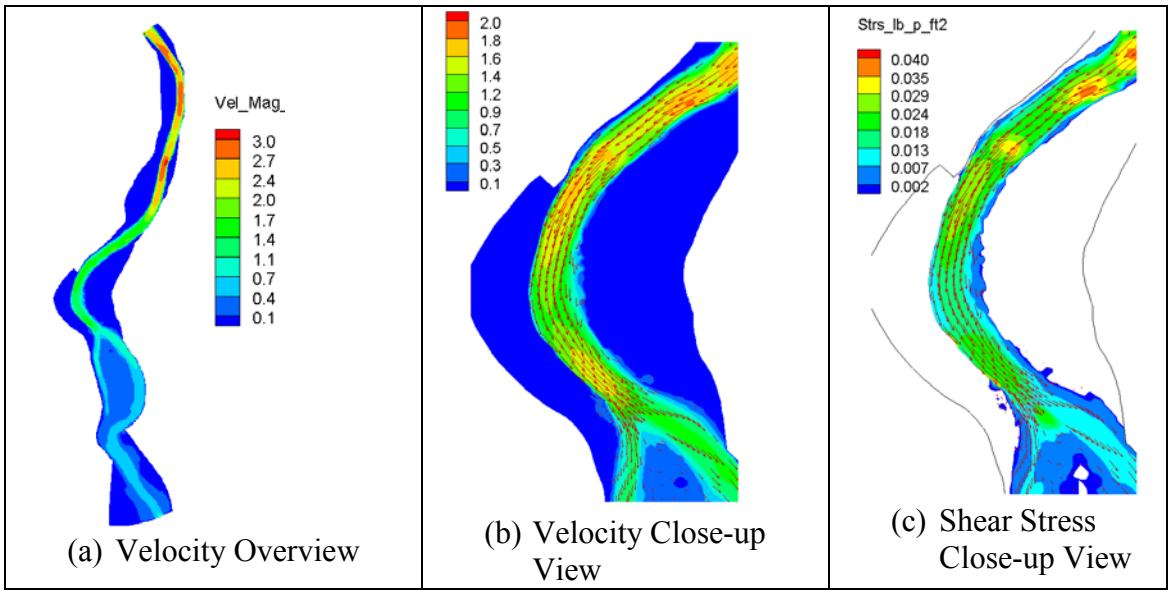
(b) Bank Zone

Figure 5. Daily flow discharge data (Left) and bank zone (black polygon on the Right) along the outer bank of the bend (right black circles represent bank toes of all bank profiles and left ones are top nodes)

## RESULTS AND DISCUSSION

Simulation is carried out from October, 2005 to September, 2010. First a constant discharge of 1,000 cfs is simulated without the bank erosion module. The flow results are discussed first since it is used as the initial condition. It is also used as the cutoff discharge for the bank erosion mobile-bed modeling. The bank erosion modeling results are presented and discussed afterwards.

**Flow Results** The predicted flow velocity and shear stress for the 1,000 cfs discharge are shown in Figure 6 (shear stress unit conversion: $lb/ft^2$ = 47.838 Pa). The results show that flow in the upstream section above the bend has higher velocity and shear stress than the downstream section, due possibly to narrower upstream cross sections. The RM 111 bend is only subject to moderate fluvial loading with shear stress around 1.0 Pa at the 1,000 cfs flow. This is a bit surprising considering that this bend has been subject to bank erosion over the study period. Without bank erosion modeling, the hydraulic flow results alone may be used infer the bank erosion mechanisms. First, the bank at the bend might consist of weaker materials than those upstream, owing to geological reasons or vegetation roots, as the shear stress is not very high. The field observation by the author in February, 2013 seemed to confirm the above conjecture. It was found that the banks at RM 111 composed of very fine, unconsolidated, easily erodible materials. Also, the banks were mostly bare without much vegetation presence except near the downstream section. Second, non-fluvial processes such as seepage and/or piping may contribute to bank erosion. If this is the case, rainfall events would also influence the erosion process and a fluvial based method alone might be insufficient to capture all processes. At the best, the erodibility coefficient used by SRH-2D model needs to take the non-fluvial processes into consideration. Without detailed field study and monitoring data, I could not identify the processes for sure.




(a) Velocity Overview (b) Velocity Close-up View (c) Shear Stress Close-up View

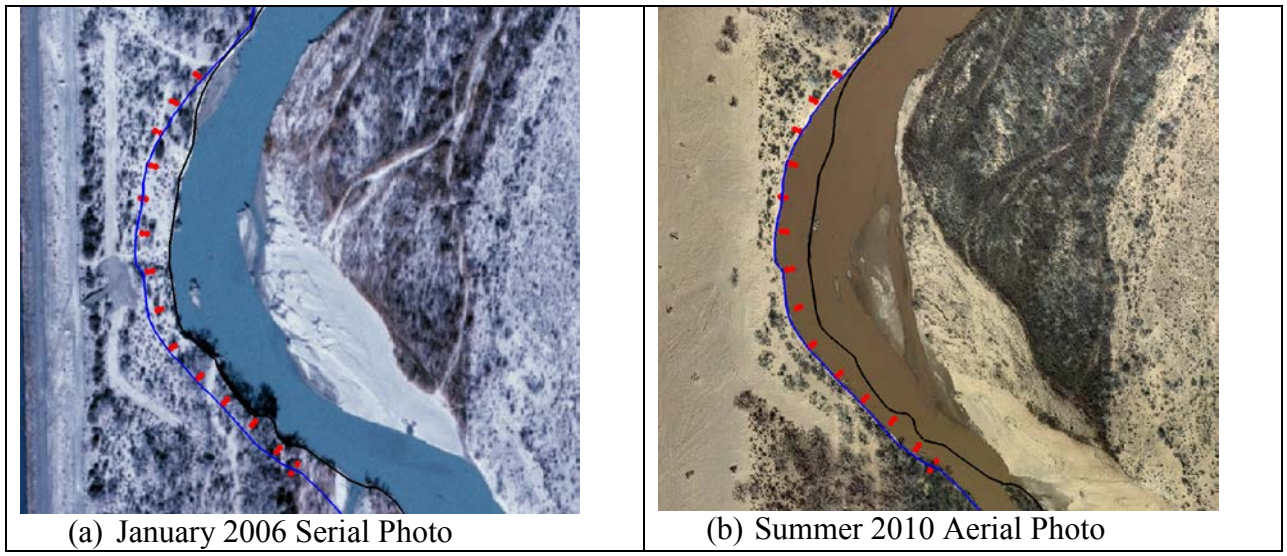
Figure 6. Simulated velocity and shear stress at 1,000 cfs discharge with the 2005 terrain

**Bank Erosion Modeling Results** Bank erosion mobile-bed modeling is carried out in an attempt to calibrate the model using the bank retreat data computed from the historical aerial photographs. The modeling study assumes that fluvial processes are responsible for the bank erosion at the RM 111 site. For the modeling, the erodibility coefficient is chosen as the main calibration parameter.

All model input parameters and initial and boundary conditions have been discussed above. The calibration model run starts the simulation in October 2005 and ends in September 2010. The final 2010 bankline predicted by the model is plotted in Figure 7 and it is represented by the red dots of both bank toe and top points. In the figure, the January 2006 and summer 2010 historical aerial photographs are also shown for comparison. It is seen that the calibrated model did a reasonably good job in capturing the bank retreat over the 5-year period; up to about 78 feet of bank retreat distance is predicted at a few cross sections which is in agreement with the historical data.

With the calibration model, erodibility coefficient is chosen as the primary calibration parameter. However, its value has to be changed along the outer bank with a large reduction of erodibility at the downstream section of the bank. The calibrated model uses the following erodibility values: 2.0e-5 for banks 2 to 10; 5.0e-6 for banks 11 to 12; and 2.0e-6 from banks 13 to 15. A reduction of erodibility for banks 11-15 is justified as the banks in this area were reinforced by the presence of the vegetation as shown in Figure 7a as well as the photos shown in Figure 2.

During calibration it is found that a very small critical shear was required in order to simulate the bank erosion reasonably. This may or may not be physically correct. I attribute the cause to the poor representation of the terrain in the bend area.



(a) January 2006 Serial Photo (b) Summer 2010 Aerial Photo

Figure 7. Comparison of bankline location and the historical bankline changes. Black line: January 2006 bankline; Blue line: summer 2010 bankline; Red dots: Predicted 2010 bankline

## CONCLUDING REMARKS

The new geofluvial SRH-2D model, which coupled bank erosion modules with the mobile-bed model, is applied to predict the bank erosion at RM 111 on the Rio Grande, New Mexico. The simulation starts with the reconstructed river terrain representing the October 2005 river condition, and ends in September 2010. The 5-year simulation is carried out by using the actual, recorded daily discharge at the USGS gaging station 08354900, the Rio Grande Floodway at San Acacia, NM. The study finds that SRH-2D model is robust and ready to use with its uniform retreat bank erosion module for engineering applications. The main bank erosion calibration parameter is the erodibility coefficient that quantifies the rate of retreat at each simulated bank. The erodibility coefficient is used to represent primarily the fluvial processes. The effect of vegetation protection may also be included. However, the erodibility coefficient may also be used to represent non-fluvial processes if they are identified and quantified in the field. Once calibrated, the numerical model can perform a reasonable job in predicting the right amount of bank retreatment.

Despite the success, there are areas that need further attention and improvements in the future. They include the following:

- Field study is recommended at bank erosion sites focusing on identifying the dominant bank erosion mechanisms. SRH-2D is developed primarily for fluvial processes. If non-fluvial processes are also important, the model would be less accurate, although the erodibility coefficient can be adjusted to take non-fluvial processes into account to a certain extent.
- The terrain data, mainly in the main channel of the retreating banks, are too scarce in the present study. We believe the October 2005 terrain reconstructed from the available data is not accurate enough for this study. High uncertainty in the terrain may cause doubts on

the reasonableness of the calibrated erodibility coefficient. Erodibility should be a physical parameter; however, it is possible that the calibrated value of this study may also contain a non-physical portion that is necessary to compensate the high uncertainty of the terrain data. In the future, a bathymetric survey near the banks is recommended for SRH-2D bank erosion modeling in order to predict potential future bank changes more reliably if such data are not already available or too sparse.

## ACKNOWLEDGEMENT

The author acknowledges the technical assistance and peer review provided by Paula Makar at the Bureau of Reclamation.

## REFERENCES

Bankhead, N., Simon, A., Klimetz, L., and Klimetz, D. (2012). Application of the Bank-Stability and Toe-Erosion model (BSTEM) at Sites along the Rio Grande, New Mexico. U.S. Department of Agriculture – Agricultural Research Service. National Sedimentation Laboratory.

Bauer, T.R., (2006). 2006 Bed Material Sampling on the Middle Rio Grande, NM, U.S. Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group, Denver, CO.

Lai, Y.G. (2007). Erosion Analysis Upstream of the San Acacia Diversion Dam on the Rio Grande River. Technical Report. Technical Service Center, U.S. Bureau of Reclamation.

Lai, Y.G. (2008). SRH-2D Theory and User's Manual version 2.0, Technical Service Center, Bureau of Reclamation, Denver, CO.

Lai, Y.G. and Greimann, B.P. (2008). "Modeling of erosion and deposition at meandering channels," World Environmental & Water Resources Congress, ASCE, May 12-16, 2008, Honolulu, Hawaii.

Lai, Y.G. (2009). Sediment Plug Prediction on the Rio Grande with SRH-2D Model. Technical Report No. SRH-2009-41. Technical Service Center, Bureau of Reclamation.

Lai, Y.G. (2010). "Two-Dimensional Depth-Averaged Flow Modeling with an Unstructured Hybrid Mesh." J. Hydraul. Eng., ASCE, 136(1): 12-23.

Lai, Y.G. and Greimann, B.P. (2010). "Predicting contraction scour with a two-dimensional depth-averaged model." J. Hydraulic Research, IAHR, 48(3), 383-387.

Lai, Y.G. (2011). Prediction of Channel Morphology Upstream of Elephant Butte Reservoir on the Middle Rio Grande. Technical Report No. SRH-2011-04, Technical Service Center, Bureau of Reclamation.

Lai, Y.G., Greimann, B.P., and Wu, K. (2011). "Soft bedrock erosion modeling with a two-dimensional depth-averaged model," J. Hydraul. Eng., ASCE, 137(8): 804-814.

Lai, Y.G. 2013. A Coupled Stream Bank Erosion and Two-Dimensional Mobile-Bed Model. Technical Report No. SRH-2013-07, Technical Service Center, Bureau of Reclamation, Denver, CO.

Lai, Y.G. and Wu, K. (2013). “Modeling of Vertical and Lateral Erosion on the Chosui River, Taiwan,” ASCE World Environmental and Water Resources Congress, Cincinnati, Ohio, May 19-23.

Lai, Y.G. (2014) “Advances in Geofluvial Modeling: Methodologies and Applications.” Advances in Water Resources Engineering, Handbook of Environmental Engineering, Volume 14, C.T. Yang and L. K. Wang (eds), Humana Press, Springer Science and Business Media.

Lai, Y.G., and Wu, K. (2014). “Combined Vertical and Lateral Channel Evolution Modeling.” Proc. 11th International Conference on Hydroinformatics, New York City, USA.

Lai, Y.G., Thomas, R., Ozeren, Y., Simon, A., Greimann, B.P., Wu, K. (2015a). “Modeling of multi-layer cohesive bank erosion with a coupled bank stability and mobile-bed model.” To appear in Geomorphology.

Lai, Y.G., Gaeuman, D, Bandrowski, D.J. (2015b). “Morphological impact of a rehabilitation project: SRH-2D modeling assessment.” Joint 10th Federal Interagency Sedimentation Conference and 5th Federal Interagency Hydrologic Modeling Conference, Reno, Nevada, April 19 –23, 2015.

Langendoen, E.J. and Simon, A. (2008). “Modeling the evolution of incised streams. II: Streambank erosion.” J. Hydraul. Eng., ASCE, 134(7): 905-915.

Parker, G., (1990). “Surface-Based Bedload Transport Relation for Gravel Rivers.” J. Hydraulic Research, 28(4):417-436.

Simon, A., Curini, A., Darby, S.E., and Langendoen, E.J. (2000). “Bank and near-bank processes in an incised channel.” Geomorphology, 35(3-4): 193–217.

Simon, A., Pollen-Bankhead, N., and Thomas, R.E. (2011). “Development and application of a deterministic bank stability and toe erosion model for stream restoration.” In: Stream Restoration in Dynamic Fluvial Systems: Scientific Approaches, Analyses, and Tools, American Geophysical Union, Geophysical Monograph Series 194. pp. 453-474.