Simulations of Lakes Mills Drawdown Experiment Using SRH2D Model

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Abstract

The removal of Elwha Dam and Glines Canyon Dam in Washington State has caused considerable sediment release to the lower reach of Elwha River. A reliable sediment transport model is needed for predicting post-dam removal sediment transport. This presentation reports the verification of SRH2D model for simulating fluvial sediment transport processes during the 1994 Lake Mills drawdown experiment on the Elwha River. SRH2D model is a depth-averaged two-dimensional model for flow and sediment transport in alluvial rivers developed by the Bureau of Reclamation. The experiment drawdown was performed in April 1994 by gradually lowering the Lake level by 18 feet over one week period. Flow discharge, cross sectional data, and sediment size distributions were collected at the reservoir reach during the experiment. This study simulated flow hydrodynamic and sediment transport during the experimental drawdown. The simulation used surveyed cross section data to reconstruct the lake bathymetry. Surveyed flow discharge and sediment load are used as the upstream boundary conditions for flow and sediment. Observed lake level in the reservoir was the downstream boundary condition. Multiple simulation runs using different sediment transport formulas, computational meshes, and various Manning's roughness are compared with field surveyed data. Results showed the importance of initial channel bathymetry, non-equilibrium sediment transport, locally induced turbulence, and bank erosion for simulating the morphodynamic processes of reservoir sedimentation delta. Additionally, the simulation results also demonstrated the applicability of SRH2D model in simulating complex sediment transport processes.

1 Introduction

The objective of this study is to simulate fluvial processes during the 1994 Lake Mills drawdown experiment in the Elwha River, Washington. The experiment drawdown was performed in April 1994 by gradually lowering the Lake level by 18 feet over one week period. Flow

discharge, cross sectional data, and sediment size distribution were collected at the reservoir reach during the drawdown experiment (Childers *et al.* 2000). This study simulated the experimental drawdown using SRH2D model and compared the simulated results of cross sectional changes with measurements. SRH-2D, Sedimentation and River Hydraulics – Two Dimensional model, is two-dimensional hydraulic, sediment, temperature, and vegetation model for river systems developed at the Bureau of Reclamation (BOR 2008). We conducted two series of simulations: one is to use the measured data to extract cross sections, and then test the sensitivities of modeling results to meshes, roughness coefficient, various sediment transport formulas, and different methods of adaptive lengths; the other is to use a refined mesh with many breaklines to pre-define the channel flow.

2 Model Set-up

2.1 Computational Grid

The simulation domain is the Lake Mills reservoir reach covering the reservoir delta from Section 3 to Section 17 as shown in Fig.1 and 2. The simulation boundary including the left and right banks is obtained from the boundaries of measured cross sections. The bathymetry in the simulated reach is interpolated using the surveyed bed elevation at each cross sections in 1994.

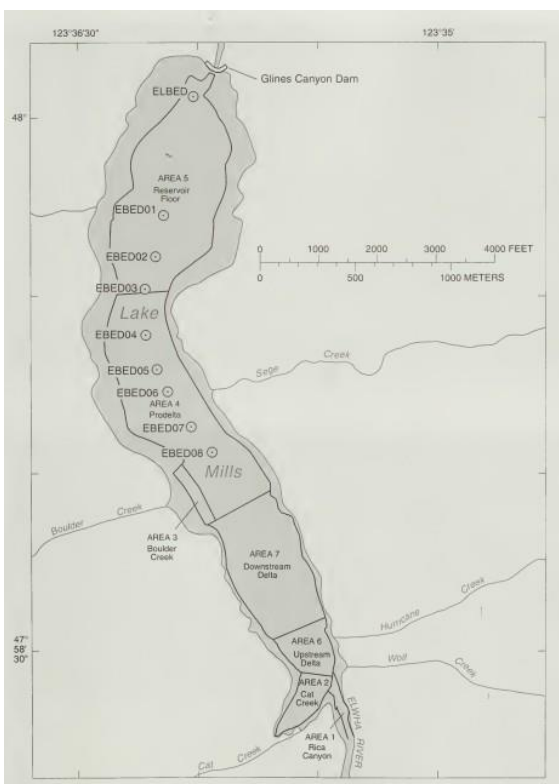
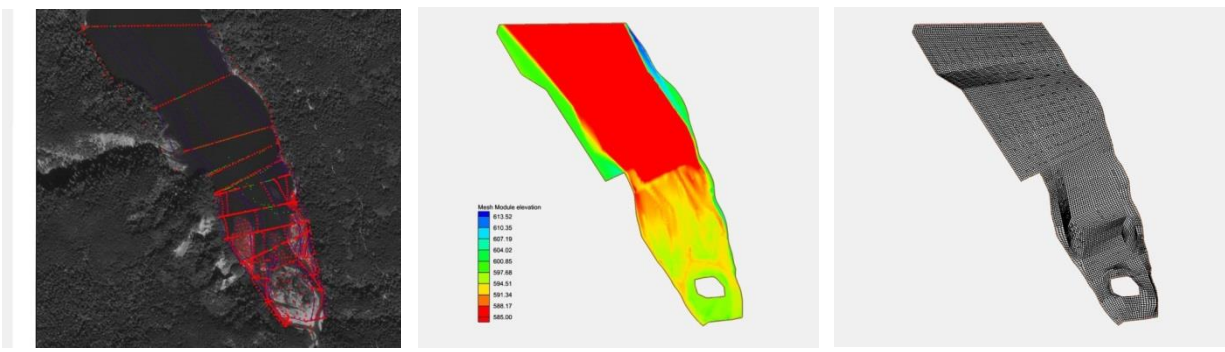


Fig.1 Location of the simulation reach.

Fig.2 Location of surveyed cross sections

The simulation domain is the Lake Mills reservoir reach covering the reservoir delta from Section 3 to Section 17 as shown in Fig.2. The simulation boundary including left and right banks

is obtained from the boundaries of measured cross sections at April 8th. All other measured data points on the delta from USGS GIS shape files are also used (Fig.3a). The bathymetry in the simulated reach is interpolated using the surveyed cross sections and all other measured points on the delta. The measured data points in the tables of USGS report is based on the local coordinates. Conversions are needed to change the elevations to the NAD88 datum. The local elevation was added 0.9 ft to the NGVD29 system, and added 3.625 ft to the NAD88 datum. Therefore, the recorded elevations in the USGS report were added 4.525 ft to the NAD88 datum. The initial bed bathymetry showed two small side channels near both banks (Fig.3b). Cross sections, 16 and 17, are used as the inlets. This study used an improved quadrilateral mesh, shown in Fig.3c, to accommodate the complex geometry of the delta channels at the beginning of the drawdown experiment.

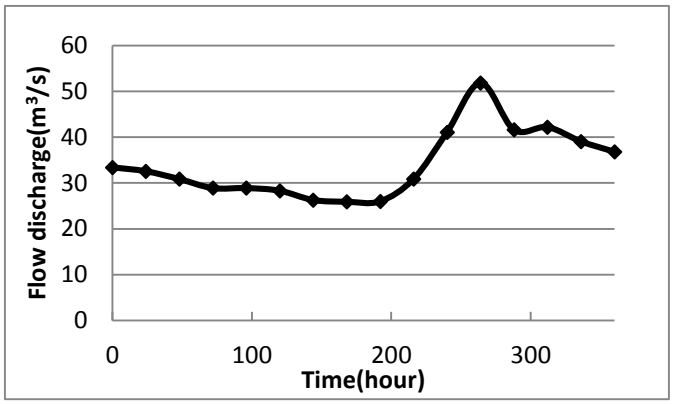


(a) **(b)** **(c)**

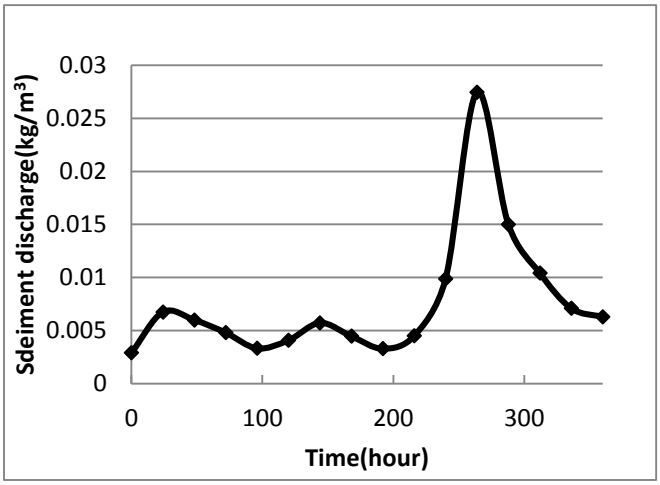
Fig.3 Scatter data points, initial bed elevations, and computational grid

2.2 Simulation Data

Stream flow data were collected at five sites. Stream flow data were collected at five sites. Daily flows at ELWW, a gaging station that was established just a few weeks prior to the beginning of the drawdown experiment. The stream flow discharge (Fig.4a) at ELWW gauge is used. The measured discharge is divided into two parts: one part is 40% of the total discharge at the cross section #16, and the rest is at the cross section #17. Both suspended and bed load sediment discharges measured at ELWW gauge (Fig.4b) are used as sediment upstream boundary condition.



(a)



(b)

Fig.4 Stream flow and sediment discharge

The lake drawdown began with a full lake at 8:00 am on April 9, 1994. During the experiment, the lake's water level was lowered 18 feet over a 1-week period from April 9 to 16. Drawdown rates were about 3 feet per day for the first 5 days, for a total of 15 feet. The lake was drawn down 2 feet between April 14 and 15 and 1 foot between April 15 and 16. A drawn down of 18 feet was reached 8:00 am on April 16, and then held at constant elevation for a week. The changes of lake level are shown in Fig.5, and were used as the downstream boundary condition. The particle-size distribution collected at ELD1 station was used. The distribution curve is shown in Fig.6.

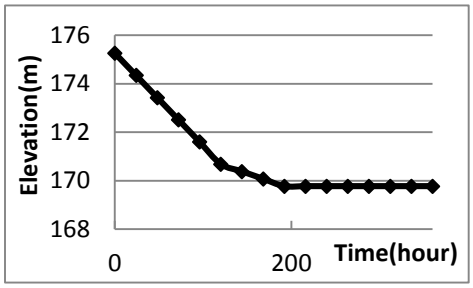


Fig.5 Downstream boundary conditions

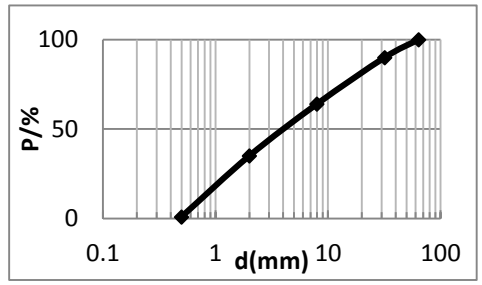


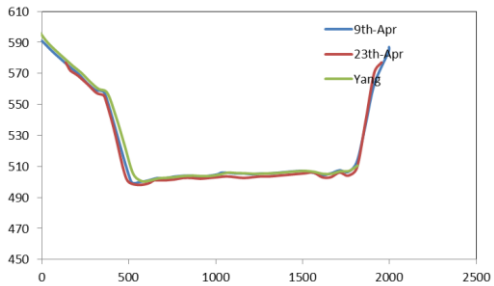
Fig.6 Particle-size distribution

The time step used for the three computational meshes is 5.0 s. The total simulation time is 360 hours. When the mesh size is decreased to 8 m, the SRH2D doesn't converge even reducing the time step to 0.01 s.

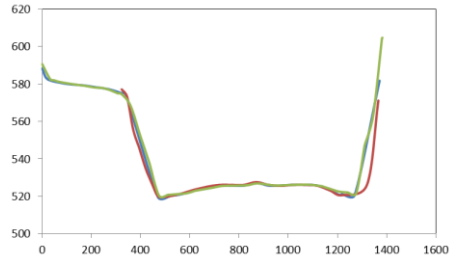
3 Simulation Results

The simulated bed elevations using the new mesh were compared with the measurements on April 23th, and shown in Fig.7. Only Yang's equation was used in this calculation in order to compare with the previous results by using only measured cross sections on April 8th, 1994. The final results at Section 3, 4, and 5 showed no erosion or deposition, the same as the measurements. At Section 6, the simulated results underestimated the deposition. From Section 7 to 11, two large channels are formed at both sides of the delta, while the simulated results also showed two channels formed on the delta, but the channel sizes cannot match the observed ones. The sizes of both channels are smaller than the observed ones. From Section 12 to 15, the simulated results considerably over-estimated the deposition comparing to observed bed elevation.

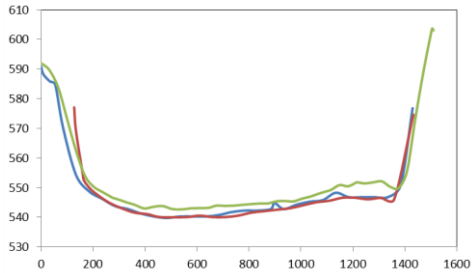
7a. Cross-section 3.



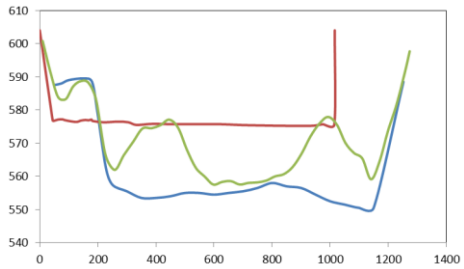
7b. Cross-section 4



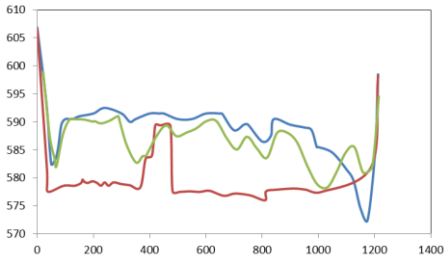
7c. Cross-section 5.



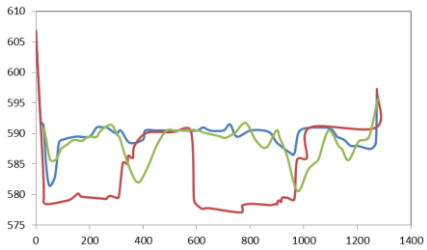
7d. Cross-section 6.



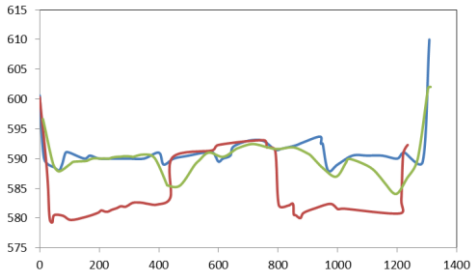
7e. Cross-section 7.



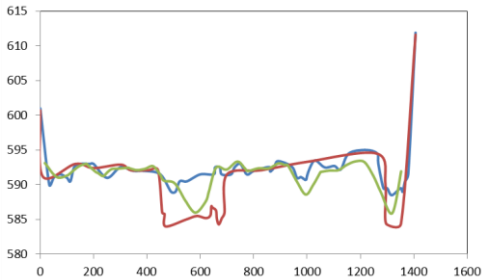
7f. Cross-section 8.



7g. Cross-section 9.

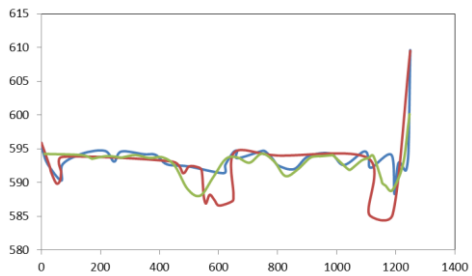


7h. Cross-section 10.

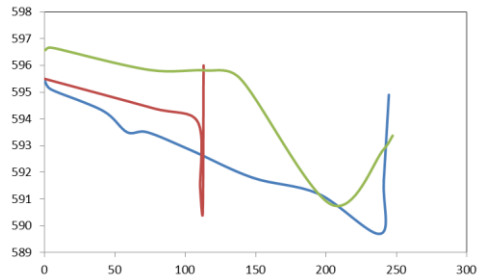


7i. Cross-section 11.

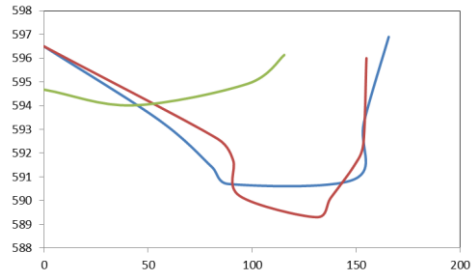
7j. Cross-section 12.



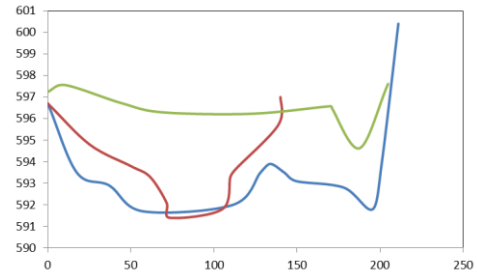
7k. Cross-section 13.



7l. Cross-section 14.



7m. Cross-section 15.



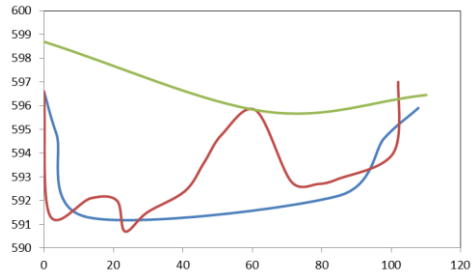


Fig.7 Simulated and measured bed elevation changes

The errors of simulated bed elevation changes may due to 1) local turbulence due to woody debris; 2) bank erosion induced channel changes have not been simulated; 3) avulsion or bifurcation processes may also need to be considered.

4. Conclusion

This study first applies the SRH2D model to simulate the experimental drawdown of Lake Mills in 1994. The simulated results showed no erosion or deposition within the reservoir at Section 3, 4, and 5, the same as the measurements. At the edge of exposed delta (Section 6), the simulated results underestimated the deposition. From Section 7 to 11 where delta is scoured by the drawdown flow, the simulated results showed two channels formed on the delta, but underestimated erosion occurred in the channels. At the delta upstream (Section 12 to 15), the simulated results considerably over-estimated the deposition comparing to observed bed elevation changes.

To test the sensitivities of modeling results to selected parameters, we chose three different mesh sizes using pure triangular, pure quadrilateral, and mixed triangular and quadrilateral meshes,

six different sediment transport equations, three different adaptation lengths, six combinations of roughness coefficients ranging from 0.02-0.06. The results showed that the modeling results are sensitive to sediment equations. Among selected equations, Yang (1973) relation yielded the maximum sedimentation and erosion at sections upstream of the delta, and the results are also sensitive to roughness coefficients. As roughness is increased, more erosion is predicted. However, the maximum roughness value in the simulation reach cannot exceed 0.06 according to field observations. The calibration of roughness coefficients will not lead to accurate results that match the observations. The modeling results are not sensitive to the selection of adaptation length, mesh types, and sizes.

In summary, SRH2D model approximately predicted the erosion in the delta front, in particularly, two side channels formed on the delta. However, the results of SRH2D underestimated the erosion due to water level drawdown that makes the simulated channel erosion much less than the observed.

5. Discussion

As seen from the simulated results, both SRH2D cannot accurately predicted the observed erosion due to lake level drawdown. As water withdraws from a lake, sediment erosion at channel bottom and bank collapse are visible. The model only predicted very small sediment transport rate due to very small bed shear stresses on the streamwise direction. Bed shear stress relates to both mean and near-bed turbulence flow (Biron *et al.* 2004, 2005; Huthnance *et al*. 2002, Kim et al., 2000). At present, we cannot tell if the under-predicted bed shear stress is due to the hydrodynamic model because there is no measured flow field that can verify the simulated flow velocity and water surface elevations. Whether or not the simulated flow fields, especially shear stress field, are accurate requires further experimental or field data verification. Therefore, we strongly recommend to verify SRH2D using a laboratory experimental case with measured flow field.

Secondly, currently sediment transport equations may not be able to predict sediment transport rate due to water surface drawn down. Water surface is down vertically that will cause an acceleration of vertical flow (Stelling 1984, Stelling and van Kester 1994). This vertical accelerated flow either directly entrains sediment from bottom or generates drag force that cause sediment transport. The erosion due to the vertical accelerated flow is the major erosion mechanism in lake level drawdown scenario. However, this mechanism was not considered in any sediment transport formula. The sediment transport rate in the model is determined by the horizontal shear stress, which is a function of depth-averaged horizontal velocity. Therefore, the model under-predicts or is unable to predict observed erosion.

Therefore, we recommend to verify the flow simulation of SRH2D model using a well-

defined laboratory experiment of lake level drawdown. If there is an existing laboratory experiment, it will be ideal. The physical experiment conducted at University of Minnesota can be a good choice, but needs to check if flow field measurements are available. After the simulated flow field is verified, we recommend modifications to sediment transport equations to account for the effect of vertical accelerated flow on sediment transport.

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