TWO DIMENSIONAL MODELING OF THE UPPER NORTH FORK SEDIMENTATION PLANE

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Abstract The Portland District of the U.S. Army Corps of Engineers is evaluating several measures to manage sediment deposition in the Cowlitz River downstream from the Mount Saint Helens area. One part of this effort is to develop and utilize a two dimensional model to predict the long term response of the sediment plane upstream from the Sediment Retention Structure (SRS) and to help understand how much sediment (by size fraction) will pass the SRS between now and 2035. A 2-dimensional model was developed to represent the Toutle River from the N1 (the original sediment retention structure) to the SRS. The model of this 6.5 mile reach of the Toutle River is being used to evaluate the evolution of the sediment plane upstream from the mostly full SRS and to provide insight into the volume of sand and gravel expected to pass over the SRS and enter into the Cowlitz River.

The coupled and fully dynamic 2-dimensional hydrodynamic model was calibrated by running it with channel and sediment plane geometry from a 2003 LIDAR survey and water and sediment inflow representing historic hydrology from that period. After the three year run, the resulting model surface was compared to the channel geometry from a 2006 LIDAR survey. After validating the 2-D model with the 2003-2006 results, the model was then run with 28 year water and sediment inflow hydrographs which represent a design basis sequence.

Preliminary results indicate that the SRS structure will pass an increasing amount of sediment to the Toutle River downstream as the sediment plane reaches its equilibrium slope and the trapping efficiency of the existing SRS decreases. The existing conditions model of the Toutle River above SRS 2-D model can be used to study alternative management concepts including an SRS raise, island building, and flow lengthening structures.

INTRODUCTION

The North Fork of the Toutle River is tributary to the Cowlitz and ultimately the Columbia River near Kelso, WA. After the 1980 eruption of Mount Saint Helens, this area became inundated with sediment running off of the resulting debris avalanche. The Sediment Retention Structure (SRS) was constructed to manage sediment introduction to the Toutle, Cowlitz, and Columbia Rivers.

Construction of the SRS after the eruption reduced the depositional nature of the Cowlitz and caused sediment to stay in the upper watershed. In the late 1990's the stored sediment reached the spillway of the SRS. Strategies are being evaluated at this time to determine how to best manage the sediment within the Toutle and Cowlitz River system.

A number of options are being considered including raising the SRS and constructing grade building structures above the SRS to store sediment further upstream within the existing Toutle River Sediment Plane. A two-dimensional model of the North Fork of the Toutle River existing condition will ultimately provide decision support for selecting an appropriate sediment management strategy. Figure 1 shows the modeled reach of the North Fork of the Toutle River between N1 and the SRS.

Figure 1 Toutle River above SRS 2-D Model Study Reach.

MODEL DESCRIPTION

The numeric model MIKE21-C (DHI Software) was used for the depth averaged hydrodynamic simulations. MIKE21-C is a two dimensional, depth averaged hydraulic model well suited to modeling water and sediment transport through sandbed rivers. The hydrodynamic module simulates water surface level and lateral and longitudinal velocity variations in response to a variety of forcing functions, including incoming flow volume from the Toutle River upstream, Halstead Creek and 3 other northern tributaries as well as 2 from the south. Bottom shear stress, and other influences including momentum dispersion, sources and sinks, evaporation, flooding and drying, and wave radiation stresses are factored into the solution.

Model Grid MIKE21-C operates exclusively in SI units and is based on a curvilinear grid. A curvilinear grid is similar to a structured grid in that each cell has four sides, however, the cells can be non-orthogonal - allowing them to follow irregular river channel alignments. The grid for the Toutle River Above SRS study includes the lower a 6.5 mile river section varying between

approximately one half and three quarters of a mile wide. The 6,888 cell grid (164 cells in the flow direction x 42 cells in the cross stream direction) representing this area is shown in Figure 2. Grid resolution varies spatially but is roughly 20 m x 30 meters (in the direction of flow).

Since run times for the 2003 - 2006 calibration period take six to eight hours, a portion of the cells above modeled discharge levels was computationally disabled. Approximately 800 cells (11% of the entire grid) representing the overbanks and two major southern islands were disabled by assigning them a high elevation (616 meters) to designate them as land during all flow levels. These cells are colored red in Figure 3. The cell centered grid elevations ranging from 943.9 feet (287.7 meters) above sea level at the SRS spillway to over 1230 feet (375 meters) upstream of N1 are shown as well in Figure 3.

Roughness in the model from Manning's n = 0.035 for sand to n = 0.043 for backwater areas south of the main island and n = 0.060 for heavily vegetated bank and island areas. Figure 4 shows the model roughness distribution where yellow cells have n = 0.035, green cells have n = 0.043, and blue cells (heaviest vegetation) have n = 0.060.

Topography Three sets of surface data were used to build the calibration surfaces (2003 and 2006) and the long term Toutle River model surface (2007). All surveys were originally provided in feet (Washington South State Plane Coordinate System, NAD83/NAVD88 datum). Since MIKE21-C operates in meters only, all the survey points were converted to meters. The 2003 survey was conducted in October of 2003, the 2006 was conducted October 21, 2006, and the 2007 survey was conducted between October 22 and October 27, 2007.

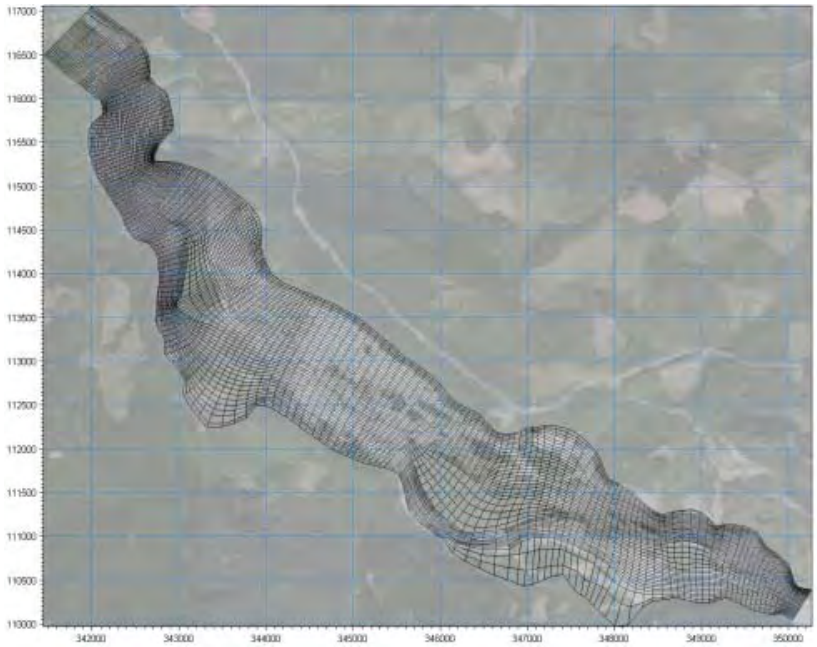


Figure 2 Toutle River Above SRS Model MIKE21-C Mesh.

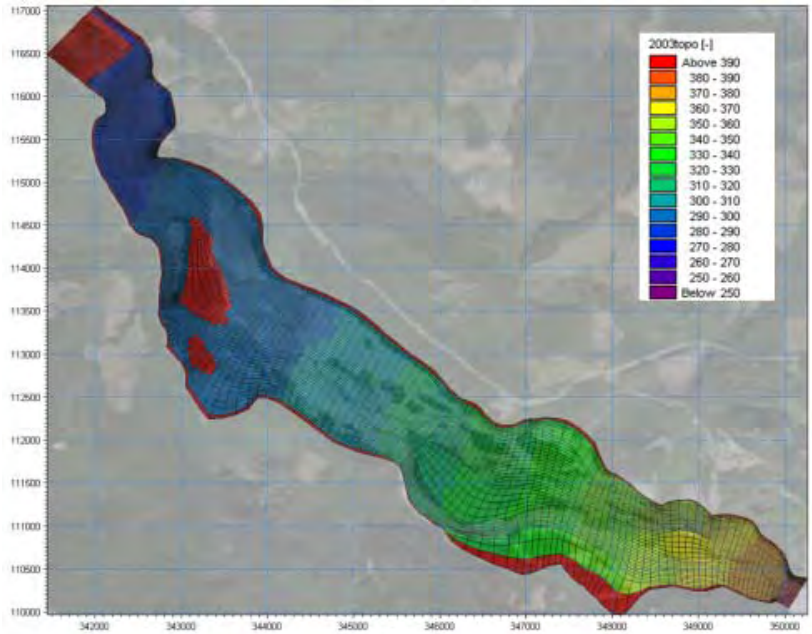


Figure 3 Toutle River 2003 Bathymetry (MIKE21-C color coded elevations are in meters).

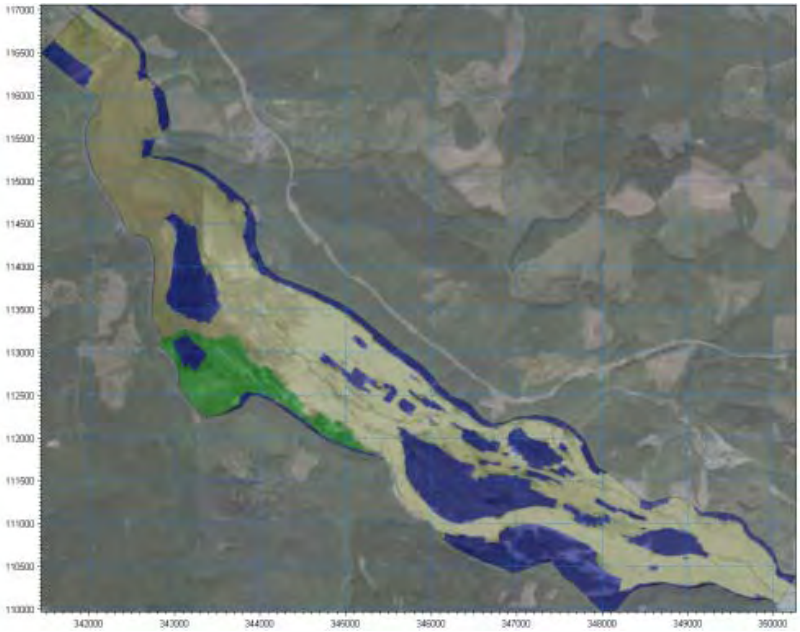


Figure 4 Model Reach Roughness.

Sediment Two kinds of sediment information are necessary for input into the hydrodynamic sediment transport model:

- Bed material gradation
- Inflowing sediment volume and gradation

Since the majority of the sediment filling in the SRS is coming from upstream of N1, the model bed material was selected as an average of the Elk Rock and SRS 5 samples shown in Figure 5. Some scour is expected in the upper reaches of the model where the bed material will be well represented by this gradation . The lower reaches of the model are depositional and will be covered with incoming sediment as the model is initiated.

The inflowing sediment for the calibration period of water years 2004 through 2006 is based on a concurrent sediment budget study. The sediment inflow curve in cubic meters per second relative to the daily average discharge of the Toutle River below the SRS is shown in Figure 6. MIKE21-C allows an input hydrograph containing sediment by size class. For the water year 2004 through 2006 calibration run, this is shown in Figure 7.

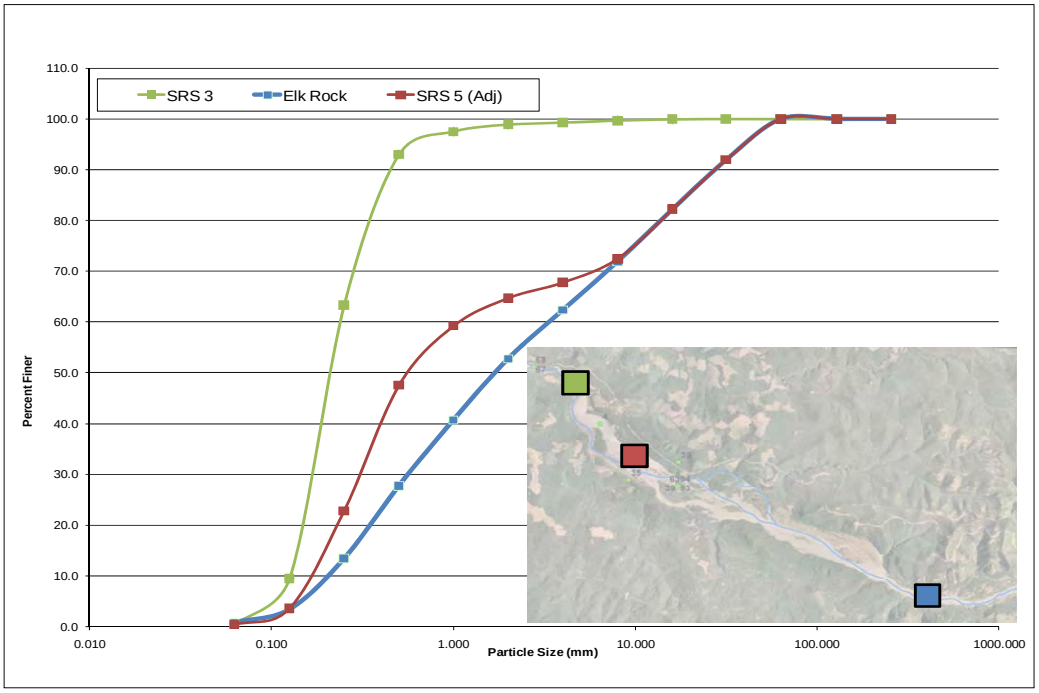


Figure 5 Toutle River Bed Material Gradation Curves - Samples, Biedenharn Group, 2007.

The gradation of inflowing sediment is adjusted to reflect how sediment concentration varies by size fraction for different discharges. The sediment gradation per inflowing sediment volume in tons/day is shown in Figure 8. The sediment gradation curves of the samples in Figure 5 are duplicated in Figure 5 (bold blue, red, and green lines) along with the model bed material (dotted line). The coarsening of inflowing sediment can be observed as the total tons per day of incoming increases.

Hydrology River flow data for the Toutle River at N1, inflow from 3 major tributaries to the north and 2 tributaries to the south, and downstream water surface are all necessary as inputs for the 2-dimensional model.

Flow data was taken from available mean daily records at the North Fork of the Toutle River Gage below the SRS (Gage 5 in Figure 9). Periods of time without gage records below the SRS

were estimated by a gage correlation between the Toutle River Gage at Tower Road Gage (Gage 2) and the Toutle River Gage below the SRS.

Inflow Hydrograph The North Fork of the Toutle River watershed was broken down into upstream inflowing area (US), and six tributaries (see Figure 10). Flow into the river was ratioed by the contributing area

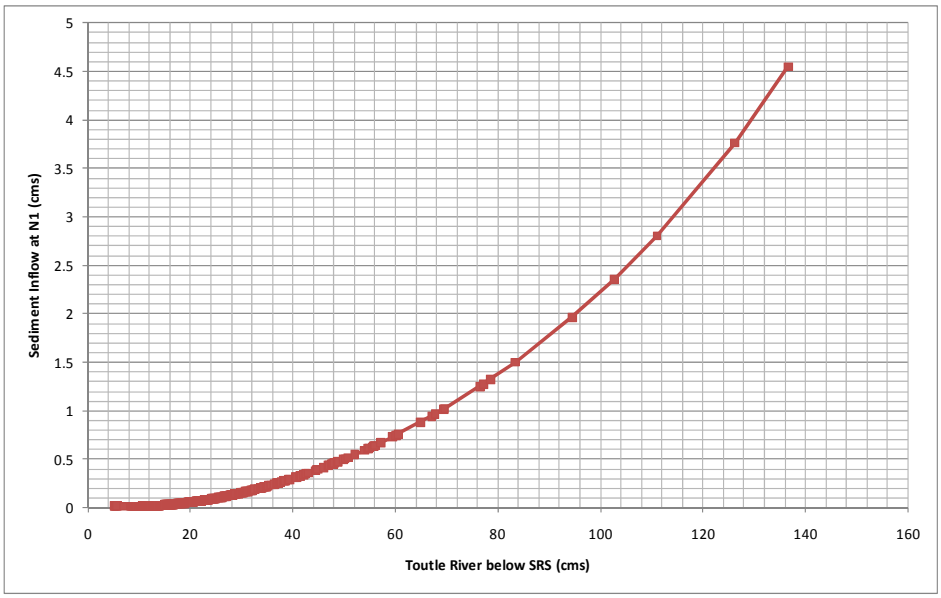


Figure 6 Sediment Inflow Rating Curve.

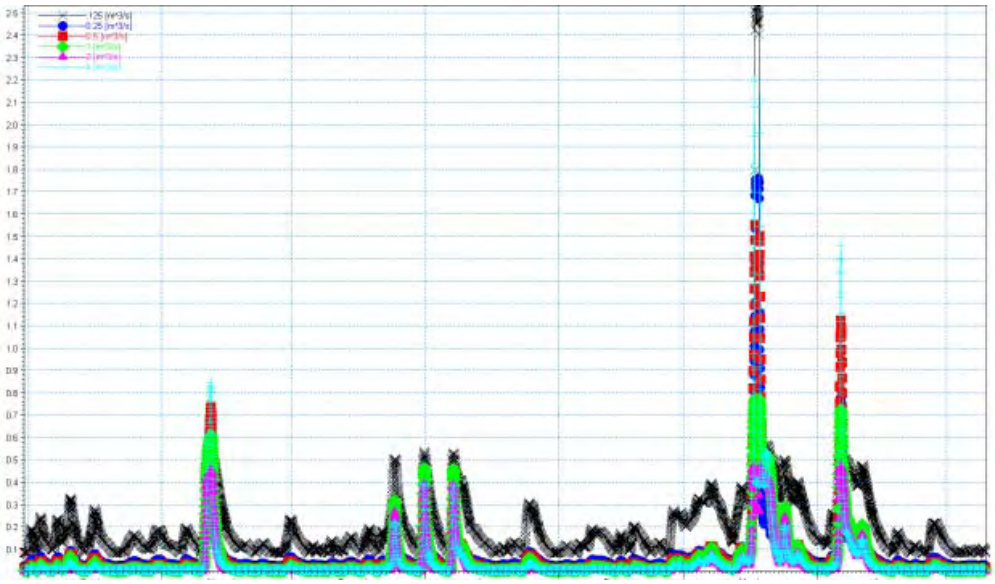


Figure 7 Sediment Inflow (cubic meters per second by size class) - Calibration Run.

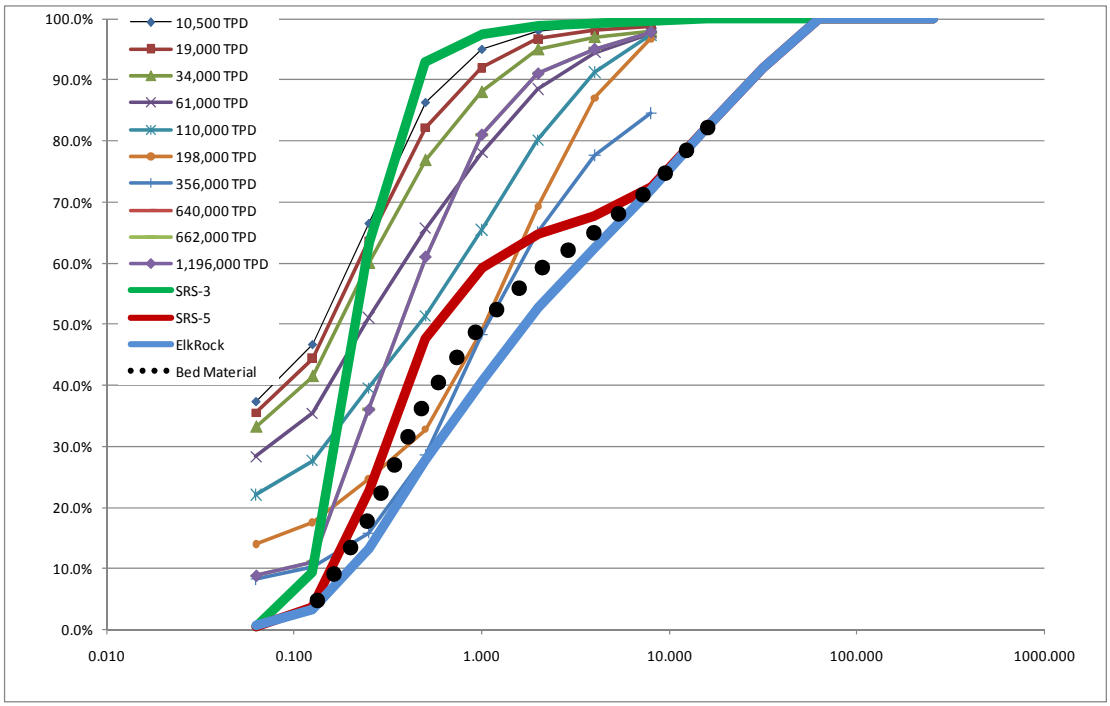


Figure 8 Sediment Gradation Curves for Inflowing Sediment.

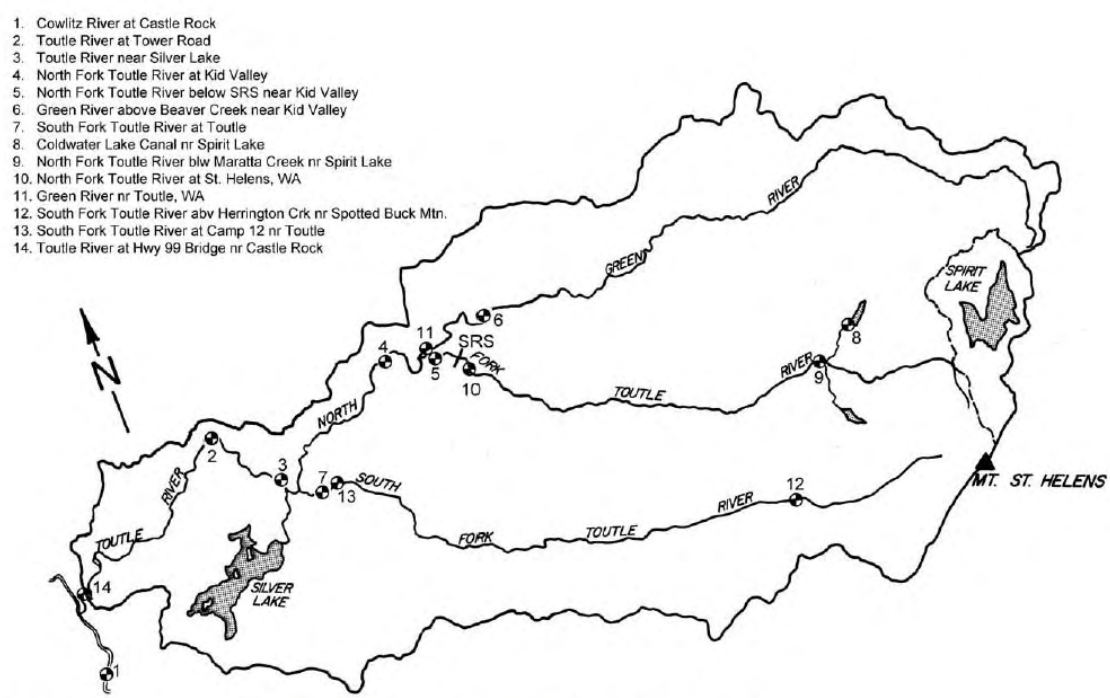
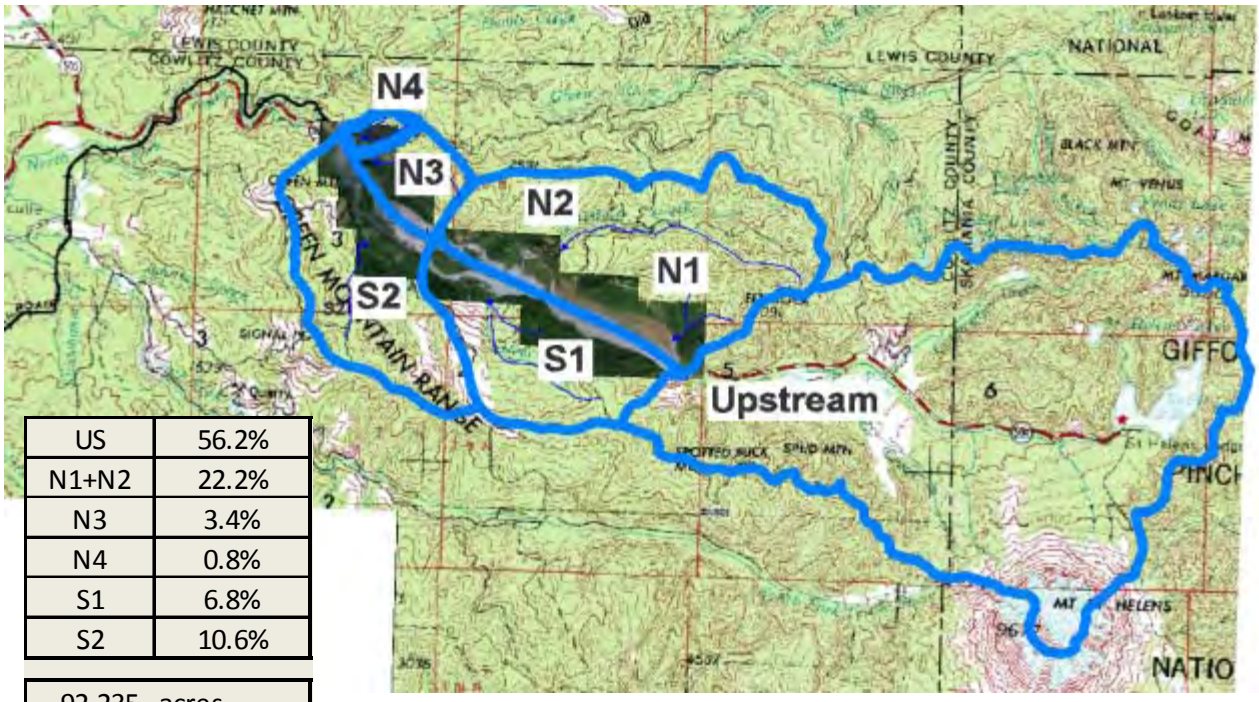


Figure 9 Toutle River Drainage Basin Showing Streamflow Gage Locations.pdf (WEST Consultants, 2002).



US	56.2%
N1+N2	22.2%
N3	3.4%
N4	0.8%
S1	6.8%
S2	10.6%

92,235 acres

Figure 10 Model Hydrologic Basin Delineation.

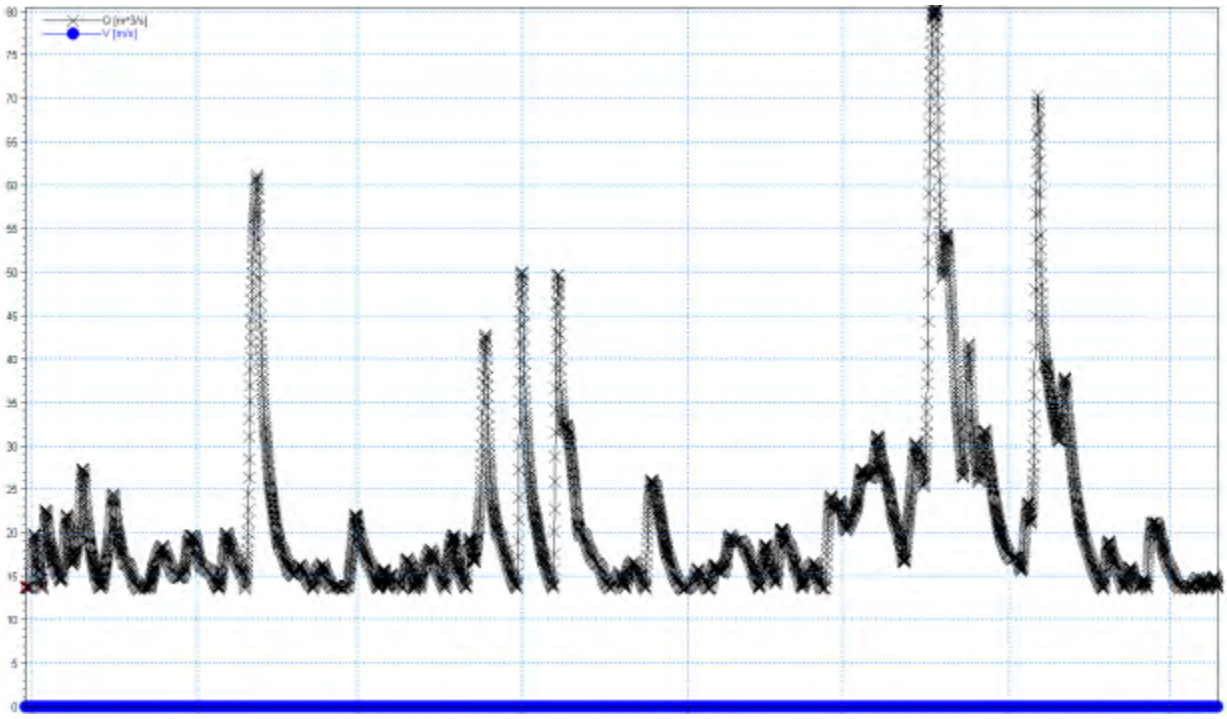


Figure 11 Three Year Calibration Inflow Hydrograph (US + N1) in cubic meters per second.

of each tributary (ranging from 0.8% of the total area and flow for Tributary N1 to 56% of inflow from the area upstream on the North Fork of the Toutle River). The combined inflow hydrograph at N1 or the upstream model boundary is shown in Figure 11.

For the calibration run, the 3 years of inflow were reduced to minimize run times. Over 26,300 hours of inflow data (sediment and water) were reduced to 5,300 by eliminating flows less than 850 cfs at the SRS. This simplifying assumption reduced run time by 80% but retained over 70% of the inflowing sediment. Each hourly sediment inflow value was hyperconcentrated by multiplying by a factor of 1.4 to incorporate the entire sediment inflow hydrograph in only 20% of the time steps. This reduces the computer time required for a 3 year run 28 hours to 7 hours. Figure 12 shows a lengthwise comparison of the 3 year inflow hydrographs - the full 3 years is in the lower half of the figure, the compressed hydrograph with flow values over 850 cfs at the SRS is shown in the upper half. A similar simplification was made with the 28 year inflow hydrograph allowing a 54 hour compressed run representing 8% of the flow days and 60% of the inflowing sediment. The 28 year sediment hydrograph was hyperconcentrated by a factor of 1.7 to incorporate the entire sediment inflow hydrograph in the compressed time period.

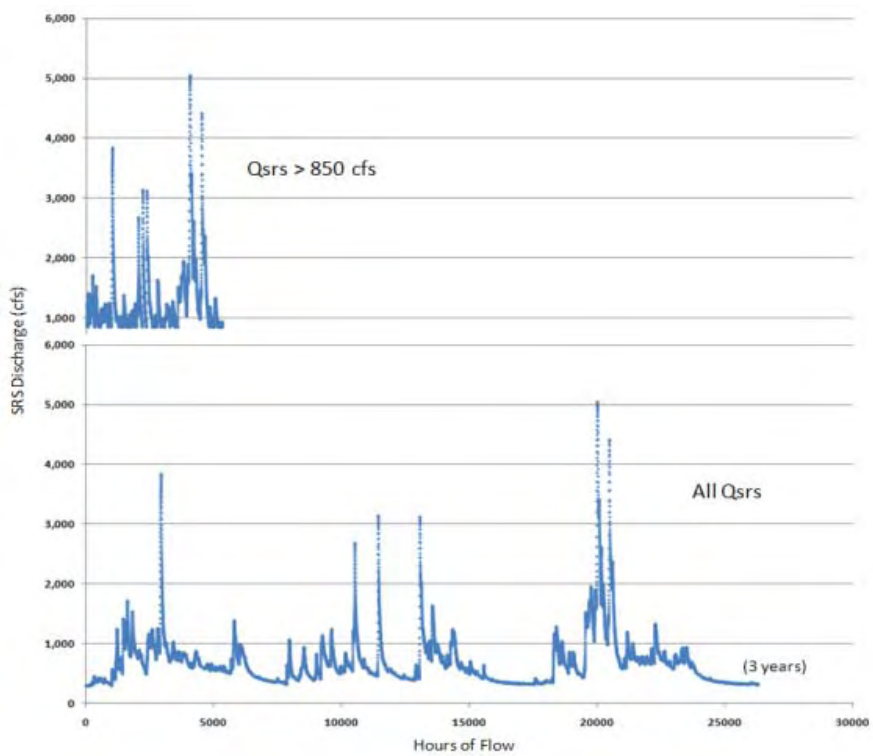


Figure12 Inflow - 3 Water Years vs Flows Above 850 cfs at the SRS Comparison for Calibration Period.

RESULTS

Over the three year calibration period, about 14 million tons of sediment enter the study reach at N1. The 2-D model results indicate that the SRS, which by 1998 was full of sediment to the spillway crest, is approximately 20% efficient at trapping sediment. The calibration results, which agree volumetrically with the observed difference between the 2003 and 2006 LIDAR

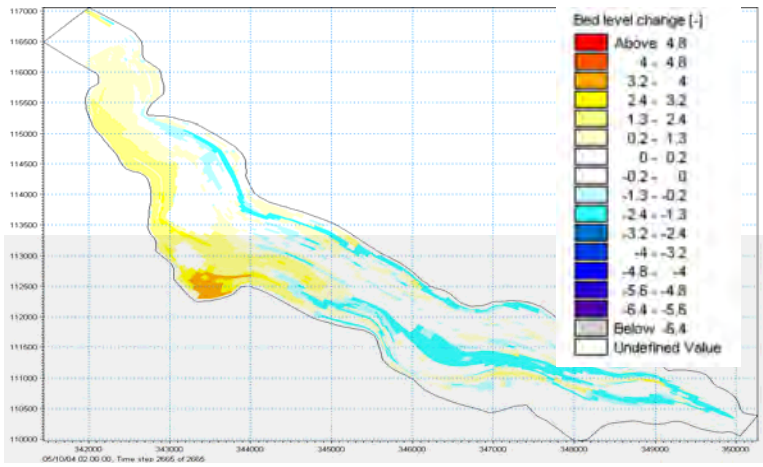


Figure 13 Bed Level change (Calibration Period).

surveyed surfaces, show over 11 million tons of sediment passing over the SRS between water years 2004 and 2006. Figure 13 shows the modeled change in bed level for the calibration run.

The 28 year model projection of future performance of the SRS through 2035 shows the SRS sediment trapping efficiency decreasing to 10% over that period. The sediment plane will continue to trap some sediment until it reaches an equilibrium slope. However the model indicates that about 90% of the 230 million tons of sediment projected to enter the system at N1 over the next 28 years can be expected to enter the Toutle River below the SRS. Figure 14 shows the modeled bed level change over the 28 year run through 2035.

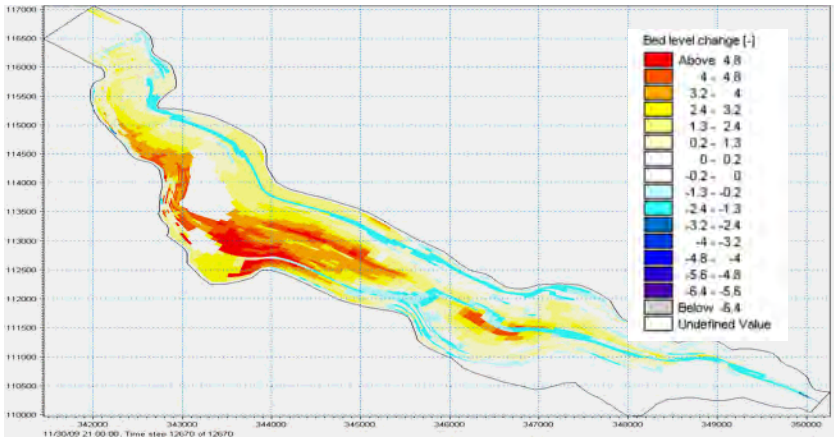


Figure 14 Bed Level Change (28 Year Run).

CONCLUSIONS

A two-dimensional model has been developed and used to predict the evolution of the North Fork of the Toutle River sediment plane above the SRS. This model will be used to evaluate sediment management strategies in this area along the North Fork of the Toutle River adjacent to Mount Saint Helens.

The preliminary results, which model the existing SRS structure through 2035, show that the sediment plane is expected to increase in size (depth of sedimentation and longitudinal extent of channel aggradations), but as time passes the SRS will not be able to trap as much sediment as it is presently trapping. (The SRS trapping efficiency is decreasing over time). With decreased trapping efficiency in the SRS, more sediment can be expected to reach the Toutle River below the SRS.

Sediment management strategies can be evaluated with the 2-D model of the North Fork of the Toutle River. Output from this model will be used as input on a 1-D model of the Lower Cowlitz River which will serve as input for another 2-D model of the Lower Cowlitz Rover just upstream from the Columbia River Confluence. The suite of Toutle and Cowlitz CFD models will provide support for sediment management in the Cowlitz River basin moving forward.