# VERIFICATION OF AN UNCALIBRATED TWO-DIMENSIONAL HYDRAULIC MODEL WITH VELOCITY AND REMOTE IMAGERY

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**Abstract** Observed velocities and remote imagery were used to verify the predictions of an uncalibrated two-dimensional hydraulic model. The initial hydraulic model was used to assess the flood hazard posed to the Moab uranium mill tailings near Moab, Utah, by flooding in the Colorado River. Velocity measurements acquired at a discharge of 33,300 cubic feet per second were compared to model simulated velocities at the same discharge. At this discharge, vegetated submerged islands, which were assigned roughness characteristics equal to the main channel materials, created discrepancies in the relation of observed and simulated velocities at four of the eight cross sections examined. To test this, the islands were delineated and assigned the roughness characteristics associated with the vegetated overbank regions of the study reach. The relation of observed and simulated velocities improved following the delineation. In regards to verifying the initial model, it is likely that the position of these islands in the main channel would cause their roughness characteristics to be minimized at the range of discharges simulated with that model. The topographic setting of the study reach in Moab Valley presented a unique opportunity to compare flooding captured by space-based imagery with model generated predictions. The extent of flooding captured by a Landsat-5 image from 1984 at a discharge of 61,500 cubic feet per second was compared to model predicted flooding extents. Both methods of verification appear to validate the predictions generated by the initial hydraulic model.

## INTRODUCTION

More than 11.5 million tons of uranium tailings were generated by the Moab uranium mill which operated near Moab, Utah, from 1956 to 1984. These tailings are adjacent to the Colorado River in Moab Valley, and questions remain as to whether they are susceptible to scour processes during extreme discharge events in the Colorado River. The steward for the Moab uranium mill tailings, the U.S. Department of Energy, published the draft environmental impact statement (DEIS) for the remediation of the site in 2004. The DEIS outlined two principle alternatives for the tailings: on-site disposal and off-site disposal (U.S. Department of Energy, 2004). The comment period for the DEIS ended in spring of 2005. To aid those tasked with determining the fate of the Moab uranium mill tailings, the U.S. Geological Survey (USGS), in cooperation with the Utah Department of Environmental Quality and the U.S. Environmental Protection Agency, applied an uncalibrated two-dimensional hydrodynamic model to assess the potential hazard posed to the tailings by flooding in the Colorado River (Kenney, 2005). In this assessment three critical parameters were examined near the tailings pile: water-surface elevation, velocity distribution, and shear-stress distribution. These parameters were evaluated for discharge estimates of the 100-year (97,600 $ft^3/s$) and 500-year (120,000 $ft^3/s$) recurrence intervals, and the Probable Maximum Flood (PMF) (300,000 $ft^3/s$).

## BACKGROUND

Moab Valley marks one of the only points within the Colorado Plateau where the Colorado River is not confined laterally by bedrock. The study reach of the Colorado River within Moab Valley has a sophisticated morphology including a substantial bend occupied by several channel bars

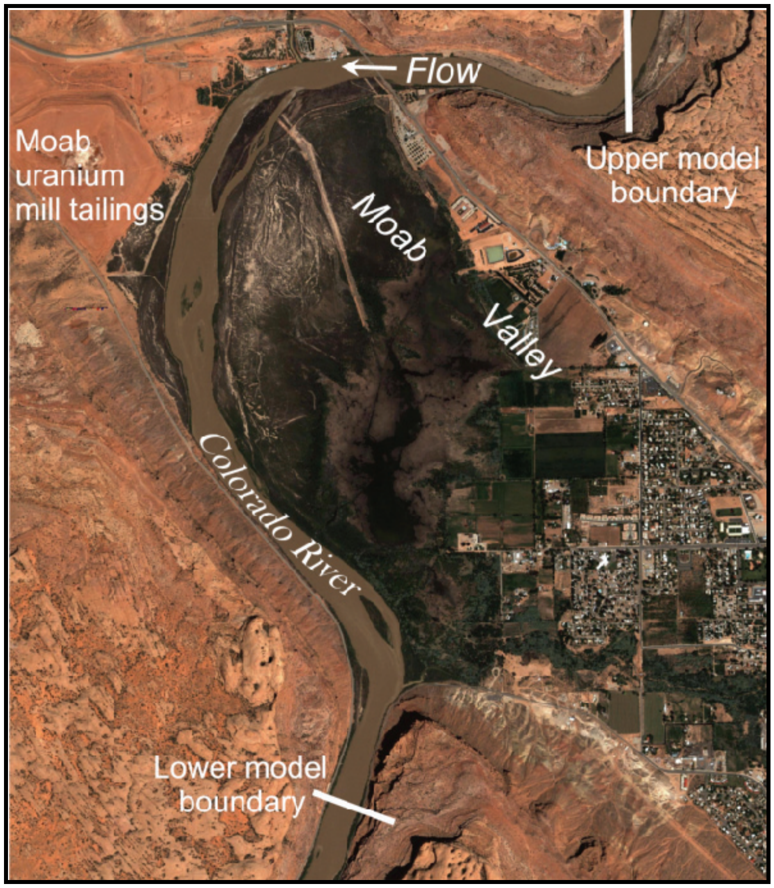

Figure 1. Moab uranium mill tailings study area, Moab Valley, Grand County, Utah. Aerial photograph taken May, 2004. Discharge is estimated to be between 15,000 and 20,000 cubic feet per second.

and islands. The Moab uranium mill tailings are located approximately 650 ft from the main channel along the outer edge of the bend in the river (fig. 1). The USGS Multi-Dimensional Surface Water Modeling System (MD_SWMS), which incorporates the Flow and Sediment Transport and Morphological Evolution of Channels (FASTMECH) 2- and 2.5-dimensional flow models, was used to model the study reach.

A curvilinear orthogonal grid that generally followed the direction of the Colorado River was developed for the study area. The grid was defined with 310 cross-stream, and 450 stream-wise points or nodes. The cross-stream width of the grid was 1.74 mi, and the centerline stream-wise distance was about 3.6 mi. Cell size varied with the curvilinear grid, but the steam-wise increment along the centerline was 42.3 ft, and the cross-stream increment was 32.8 ft.

The initial hydraulic model used to examine the flood hazard posed to the Moab uranium mill tailings by flooding in the Colorado River is an uncalibrated one. Observed water-surface elevations, aside from those collected during the baseflow bathymetric survey, or velocity data were not available. Furthermore, the flows simulated with the model have not been observed during the period of record at the nearest USGS streamflow-gaging station 09180500, Colorado River near Cisco, Utah.

Critical to modeling overland flow is the accurate representation of energy losses related to the frictional characteristics of channel materials. For the modeling system chosen, energy losses are computed from input drag coefficients. For the initial modeling effort, an extremely limited calibration of the in-channel drag coefficient was conducted. This calibration was based upon water-surface elevations acquired throughout most of the reach when channel topography was surveyed. The mean streamflow discharge during the 2 days of data collection that was used in this calibration was about 3,550 $ft^3/s$. Because the discharges simulated with this model are orders of magnitude greater than the discharge used for calibrating the in-channel drag coefficient, the model is considered uncalibrated. The extensive presence of tamarisk (*Tamarix chinensis*), an invasive shrub that grows along the banks of many waterways in the Western United States, in the over-bank regions of the study reach presented further challenges to the initial modeling effort.

## INITIAL MODEL FINDINGS

All discharges examined exceeded the capacity of the main channel of the Colorado River. Water-surface elevations for the three discharge simulations at the base of the tailings pile, which is at an elevation of about 3,970 ft, ranged from 3,975 to about 3,995 ft. Water-surface elevation differences between the inlet and outlet of Moab Valley were about 3 to 4 ft for each simulation, equating to a water-surface slope roughly equal to the main-channel slope of about 0.0002 ft/ft.

Main-channel vertically averaged velocities within Moab Valley for the three discharge simulations reached a maximum of between 6 and 8 ft/s. Modeled velocities for the 100- and 500-year discharges in Moab Valley were within 1 ft/s of each other. Predicted velocities at the most streamward edge of the tailings pile were about 1 to 2 ft/s for the 100-year discharge, but increased to between 2 and 4 ft/s for the PMF. Model results indicate that this progression is the result of accumulating over-bank flow from upstream being forced around the front of the tailings pile.

Shear-stress values exceeding the critical shear stress of coarse sands were identified in the region unoccupied by tamarisk on the right bank upstream and adjacent to the tailings pile for the 100-year discharge. Predicted shear stresses for the PMF discharge in this region and the entire study reach increased in both magnitude and spatial extent over those predicted for the 100- and 500-year discharges.

From the initial uncalibrated modeling effort, some important observations regarding the relation between extreme discharge events in the Colorado River and the Moab uranium mill tailings can be made. The degree of inundation together with the progression of velocities along the streamward edge of the tailings pile indicates that the tailings pile plays a role in obstructing the natural flow of over-bank flood discharges through the reach. The predicted path of flow along the existing Colorado River channel indicates that the current distribution of tamarisk in the over-bank region may determine how flood-flow velocities are spatially distributed. The tamarisk appear to constrain the highest velocities to the main channel.

## MODEL VERIFICATION

Due to the lack of model calibration and uncertainties associated with the tamarisk, some degree of model verification would substantiate the results of the initial model. When simulating extreme discharge events, such as those related to flood hazard assessments, quantitative observations are often lacking. This was the case for the initial modeling effort. Since that time, velocity measurements for a discharge greater than the average annual peak were obtained. Unfortunately, water-surface elevation data were not acquired during this flow event, which would have allowed for a true calibration of the in-channel roughness. The unique morphology of the study reach presented an opportunity to try and compare a remote image taken during one of the larger discharge events experienced in the Colorado River during the past century to model predictions at the same discharge. Two methods were used in an attempt to verify the predictions generated by the initial model used to assess the hazard posed to the Moab uranium mill tailings by flooding in the Colorado River.

**<u>Verification With Observed Velocities</u>** Velocity data were acquired at eight cross sections during the snowmelt runoff period of 2005 (fig. 2). These data were obtained at a discharge of 33,300 $ft^3/s$ from a moving boat using an acoustic Doppler current profiler (ADCP) interfaced with a differential global positioning system. To improve sampling accuracy, 4 transects across the river were made at each cross section. A straightened transect perpendicular to the mean flow direction was computed at each of the eight cross sections by using the four measurement transects (R.L, Dinehart, U.S. Geological Survey, written commun., 2003). The measured three-dimensional velocity components were then assigned to this straightened transect and vertically averaged to obtain two-dimensional velocity components.

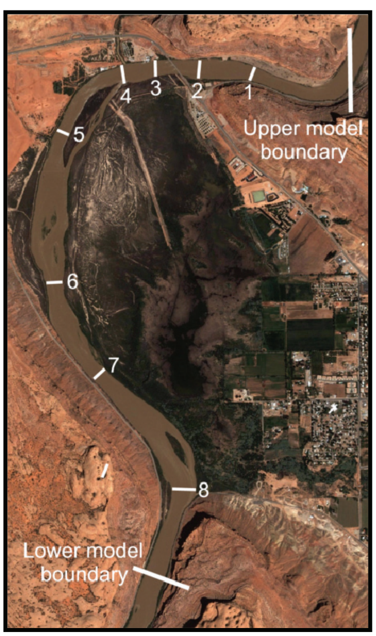


Figure 2. Location of cross section velocity measurements, Colorado River, Moab Valley, Utah.

The observed discharge of 33,300 $ft^3/s$ was simulated with the previously developed model. Aside from adjusting the lateral eddy viscosity and the upstream and downstream water surface elevations, all input parameters used in the initial model remained the same. Following the guidelines of MD_SWMS, the lateral eddy viscosity for a discharge of 33,300 $ft^3/s$ was initially estimated to be between 0.01 and 0.11 $ft^2/s$. However, the minimum lateral eddy viscosity that allowed for a stable solution using the initial model input parameters was 0.32 $ft^2/s$ ft. Upstream and downstream boundary water-surface elevations were solved for using the one-dimensional U.S. Army Corps of Engineers' River Analysis System (HEC-RAS) model previously developed for the study reach.

The relation between observed and simulated velocities for a discharge of 33,300 $ft^3/s$, plotted as a function of cross-stream distance, at the eight cross sections is shown in figure 3. The acquired velocity data allow for an examination of how well the model is simulating the spatial distribution of velocity throughout the selected cross sections. The model predicts the greatest velocities to be located in the center of flow, but this

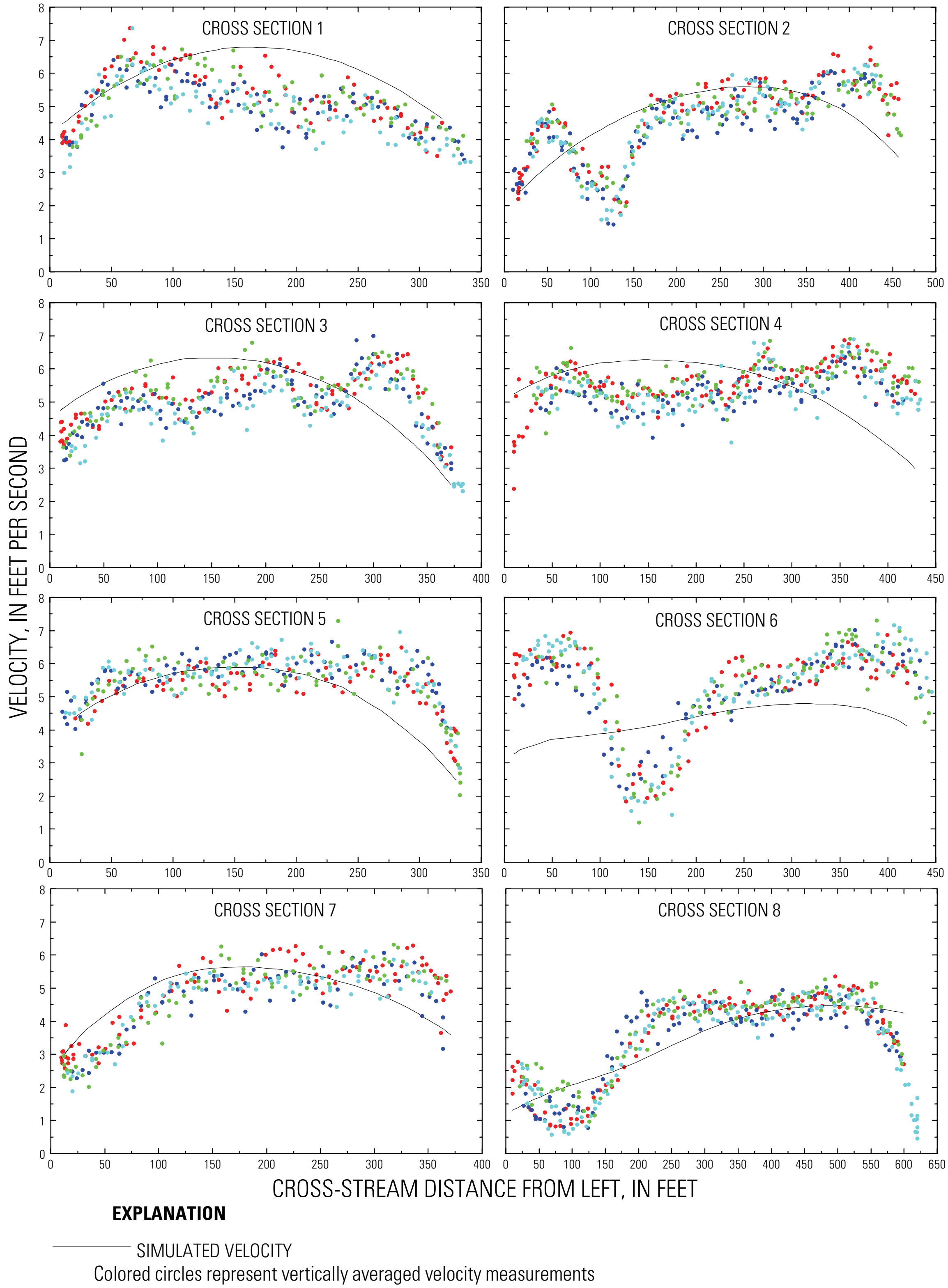


Figure 3. Relation of observed and simulated velocities for a discharge of 33,300 cubic feet per second at eight cross sections in the Colorado River, Moab Valley, Utah. Four transects, denoted by color, were made at each cross section.

distribution does not seem to be always true from the observed velocities. The simulated velocities represent steady-state average conditions, while the observed data were collected under somewhat unsteady conditions. Moreover, four transects may not provide enough measurements to capture truly average conditions. Because some streamwise distance is needed for flow to fully organize itself with the modeled topography, care must be taken when comparing observed and simulated velocities near the upstream model boundary. Observed and simulated velocity discrepancies may be inherent at cross section 1, and possibly cross sections 2 and 3, due to their proximity to the upstream model boundary. Disagreement between the predicted and simulated spatial distribution of velocity is evident at cross section 3. The observed velocity data shows two regions of slower velocities located between higher velocities. This is likely caused by two bridge piers located just upstream, that were not represented in the model. Observed and simulated velocities at cross section 5, which is adjacent to the tailings pile, and 7 are in strong agreement. Deviations between the observed and simulated velocities at cross sections 2, 4, 6, and 8 are believed to be associated with roughness caused by upstream vegetated islands that was not represented in the initial model.

Cross-stream regions of substantially smaller observed velocities can be seen at cross sections 2, 4, 6, and 8. This may be related to the presence of vegetation on submerged islands, located upstream, which were not characterized as possessing more flow resistance, or drag, in the initial model. In the model these islands were assigned the drag coefficient equal to the main channel materials and not the drag coefficient associated with the tamarisk. An aerial photograph taken during low flow conditions on October 1, 2004, at a discharge of about 2,800 $ft^3/s$ (fig. 4) shows these vegetated islands. As part of this verification effort, the islands were delineated and assigned the drag coefficient associated with tamarisk in the study reach, and the 33,000 $ft^3/s$ discharge was re-simulated. The relation between observed and simulated velocities at cross sections 2, 4, 6, and 8 with and without the delineation of the islands is shown in figure 5.

Figure 4. Aerial photograph taken on October 1, 2004, at a discharge of about 2,800 cubic feet per second, showing islands upstream from cross sections 2, 4, 6 and 8.

Delineating the islands generally improved the relation of observed and simulated cross-stream velocity at the four cross sections. The lowest observed velocities at three of the four cross sections are in close agreement with the simulated velocities with the islands delineated. At cross section 2, both sets of simulated velocities near the left edge appear to be much smaller than those observed. Because shallow conditions were encountered during the channel topographic survey, this area along the left edge was not directly measured. It is likely that the poor relation of observed and simulated velocities on the left side of the channel is caused by a lack of topographic definition. Assigning the drag coefficient to the small island upstream of cross section 4 improved the relation of observed and simulated velocities on the right and left sides of the channel. However, the simulated velocities in the center, directly downstream of the island, are much smaller than those observed. It is likely that the drag coefficient assigned to this island may be too

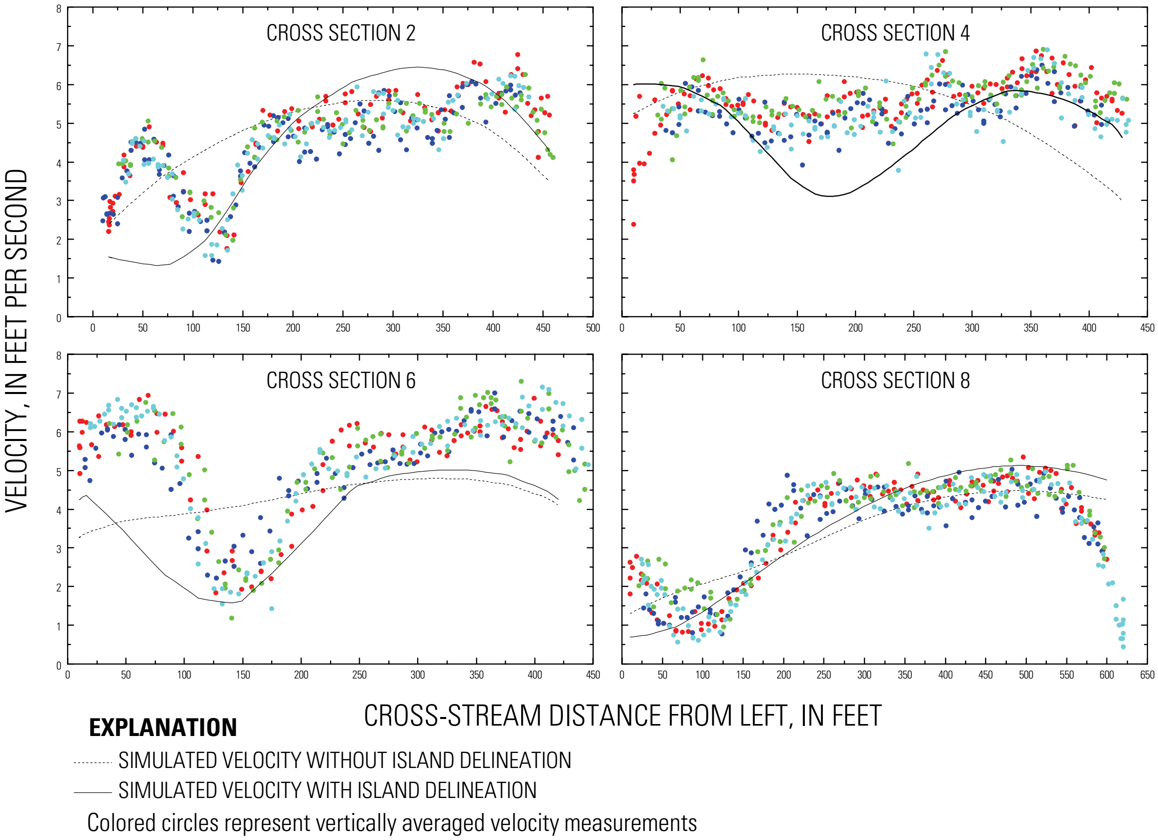


Figure 5. Relation of observed and simulated velocities with and without the delineation of upstream submerged vegetated islands for a discharge of 33,300 cubic feet per second at cross sections 2, 4, 6, and 8. Four transects, denoted by color, were made at each cross section.

large. The elevation of the island upstream from cross section 4 is the lowest of those delineated, which indicates that it is inundated more frequently and likely colonized by younger, less mature, tamarisk. Simulated velocities following the delineation of the islands at cross section 6 are generally under-predicting the observed velocities. The discrepancies at cross section 6 may be the result of poor topography and (or) overestimated energy losses, or drag, upstream. Because shallow conditions were encountered during the survey, a substantial area of the channel in the vicinity of the islands upstream of cross section 6 was not surveyed from the boat. The relation of observed to simulated velocities at cross section 8 improved with the island delineation. Differences shown are likely associated with the difficulty in capturing true average conditions with four transects during somewhat unsteady conditions.

**Verification With Remote Imagery** The topography of the study reach is such that flow expansion occurs at the upstream end, discharge changes correlate to flow width, and flow contracts at the downstream end. Reaches with these characteristics are ideal for space-based flow measurement (Brakenridge and others, 2005). The spring snowmelt runoff of 1984 in the Upper Colorado River Basin was the highest since 1917, and the study reach in Moab Valley experienced considerable overbank flooding. A few days prior to the runoff peak, a Landsat-5 image of the study reach was taken at a discharge of about 61,500 $ft^3/s$ (fig. 6). As the image

Figure 6. Landsat-5 image of the Colorado River, Moab Valley, Utah, at a discharge of about 61,500 cubic feet per second, May 26, 1984.

was taken at a discharge associated with considerable overbank flooding, and the reach possesses ideal characteristics for spaced-based flow measurement, some degree of verification of the model can be attempted.

A discharge of 61,500 $ft^3/s$ was simulated with the model and the extent of flooding was delineated from the Lansat-5 image. A comparison of the predicted inundation and the observed extent of flooding is shown in figure 7. Uncertainty related to the resolution of the Landsat-5 image makes determining the exact position of the edge of water difficult. From a qualitative perspective this uncertainty is represented by the thickness of the black line denoting the inundation from the 1984 image. The model predicted a much greater extent of flooding to the north, east of the tailings pile. Since 1984, considerable land topography changes related to the removal of contaminated soils, and the demolition of the old uranium mill have occurred in this area. Because overbank flow is confined by bedrock to the west of the river, the extent of inundation to the south and east should be related to the river discharge. In general, a strong relation of observed to predicted flooding can be seen.

## CONCLUSIONS

Two different methods were examined in an effort to verify the uncalibrated two-dimensional hydraulic model used to assess the hazard posed to the Moab uranium mill tailings by flooding in the Colorado River. From the two methods of verification used, the predictions generated by the uncalibrated model appear valid. The good relation of observed to simulated velocities for a flow of 33,300 $ft^3/s$ at four of the eight cross sections indicates a fair estimation of the in-channel drag coefficient. Discrepancies in observed and simulated velocities at the other four cross sections appear to be related to the roughness characteristics of vegetation on submerged islands that was not accounted for. After delineating these islands and assigning them the drag coefficient associated with areas occupied by tamarisk, the relation improved. In regards to verifying the initial model, it is likely that the position of these islands in the main channel would cause their roughness characteristics to be minimized at the range of discharges simulated with that model. Agreement between the observed flooding from the Landsat-5 image and the predicted flooding validates the roughness characteristics chosen to represent the tamarisk occupied areas of the study reach.

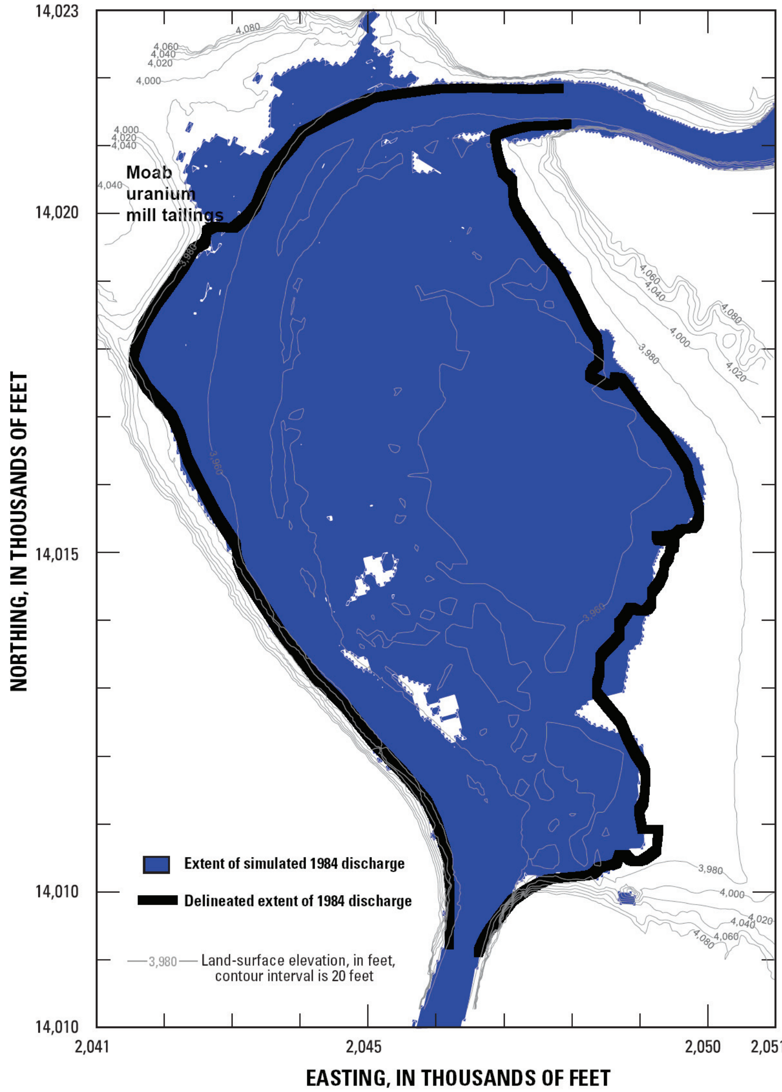


Figure 7. Relation of observed to predicted flow inundation for a discharge of 61,500 cubic feet per second in the Colorado River, Moab Valley, Utah.

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