FLUVIAL-12 SIMULATION OF SALT RIVER NEAR GILBERT ROAD CROSSING

Prepared for
Engineering Application Development and River Mechanics Branch
Engineering Division
Flood Control District of Maricopa County

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The following computer files are attached to the report:

SALT.FLU: FLUVIAL-12 input file for the Salt River study

SALT2005-CAPTURE.OUT: FLUVIAL-12 output file for the 2005 flood with pit capture

SALT2005-NO CAPTURE.OUT: FLUVIAL-12 output file for the 2005 flood without pit capture

SALT-S.OUT: FLUVIAL-12 output file for the flood series without pit capture

SALT-S-CAPTURE.OUT: FLUVIAL-12 output file for the flood series with pit capture

SALT-MIN.DAT: FLUVIAL-12 output file for maximum scour during the flood series without pit capture

SALT-MIN-CAPTURE.DAT: FLUVIAL-12 output file for maximum scour during the flood series with pit capture

THE FOLLOWING ARE COMPUTER FILES FROM OTHERS

2001 topoHECRAS_JEFuller

Hydrograph

XSlocationsCAD

2001RASXSfortF12.DWG

2001topoHECRAS_JRFuller.zip (HEC6T is included)

GILBERT2007.dat

Gilbert Road Topo Data from 2007.msg

Gilbert_2ft_Contours.dwg

EXECUTIVE SUMMARY

Sand and gravel has been extracted from the Salt River in Maricopa County for decades. The mining activities have disturbed the natural equilibrium of the river channel to induce river channel changes. The channel geometry for a long river reach was surveyed in 2001 and those cross sections near the Gilbert Road Bridge crossing were surveyed in 2007. The geometric data and the flood hydrology provide the data basis that is useful for testing and calibration of computer models for river sedimentation. This scope of the study has the following tasks: (1) to simulate the river channel changes caused by floods occurred after 2001, (2) to compare the simulated results with the channel geometry surveyed in 2007, and (3) to predict long-term river channel changes in the future. Sediment transport and river channel changes for the Salt were simulated using the FLUVIAL-12 computer model. The data used for the Salt River study are taken from previous studies covering the hydrology, hydraulics and geomorphology of the stream channel.

Pit capture refers to a stream that is diverted from its normal course into a pit at a lower elevation. During the 2005 flood, flood water in the main channel of the Salt River was diverted into the Gilbert mining pit north of the channel. As a result of pit capture, the flow made a 90-degree turn toward the north into the deep Gilbert mining pit. The diverted water traveled through the Gilbert pit and reentered the main channel at a downstream location.

River Channel Changes during the 2005 Flood - The 2005 flood has the peak discharge exceeding 40,000 cfs and a long duration over three months; it was the most important event for the period from 2001 to 2007. Other events for the same period are much smaller in discharge and shorter in duration.

River channel changes during the 2005 flood with pit capture were simulated for the 2005 flood. The simulated river channel changes were compared with the measured changes. The short channel reach near the Gilbert Road crossing is between two major mining pits. This channel reach is simulated to undergo major channel bed degradation of about 10 feet.

The simulated results for river stations near the Gilbert Road crossing are presented together with the measured post-flood cross-sectional profiles. The comparisons of cross-sectional area changes and the maximum scour depths are summarized in the two following tables.

Comparison of simulated and measured cross-sectional area changes

River Station River miles	Cross-Sectional Area Change due to Scour, Square feet	
	Measured by Survey	Simulated by Model
7.28	2,990	3,070
7.32	3,480	3,710
7.36	1,620	1,910
7.40	2,000	1,730
7.44	3,970	3,800
7.47	3,350	3,350
7.55	2,890	2,910
7.62	2,450	2,345

Comparison of simulated and measured maximum scour depths

River Station River miles	Maximum Scour Depths, feet	
	Measured by Survey	Simulated by Model
7.28	9.8	13.8
7.32	18.0	15.4
7.36	14.1	12.2
7.40	16.9	14.2
7.44	13.2	14.1
7.47	12.8	14.8
7.55	13.8	14.0
7.62	13.5	13.0

The total amount of channel bed scour as simulated is similar to the measured amount as shown in the above table. The total depth of channel bed degradation is also similar. However, the simulated and measured cross-sectional profiles have significant differences. The simulated channel bed scour is near the thalweg; the measured scour may be away from the thalweg. The causes for such discrepancy may be due to lateral migration of the thalweg, which is not considered in the model simulation; or it may be due to survey inaccuracy. In fact, the overbank areas for the cross sections from the 2001 survey do no always match the corresponding ones from the 2007 survey. The overbank areas were not affected by river channel scour; there should be no big differences in geometry. However, such differences do exist at several river stations.

The simulated cross-sectional profiles may have an uneven channel bed, while those from the 2007 topographic survey are quite smooth. One possible reason why there are differences is that the 2007 topography was developed from contours. In the process, local variations in bed elevation may be ignored and wide flat area may thus be shown as flat bed.

Long-Term River Channel Changes - The Gilbert mining pit is separated from the main channel of the Salt River by a berm. There also exist instream mining pits located both upstream and downstream of the Gilbert Road crossing. The long-term river channel changes for this reach of the Salt River have been simulated for the two following cases: (1) without pit capture (by the Gilbert mining pit) and (2) with pit capture. The hydrograph for a long-term flood series was used. For the case of no pit capture, the study river reach is predicted to undergo major changes. The changes are characterized by refill of the mining pits and erosion of their adjacent river reaches. The river reach near the Gilbert Road crossing is simulated to undergo changes in both channel bed scour and refill (or degradation and aggradation). The channel bed profile at the end of flood series is lower than the initial channel bed profile. However, the channel bed profile at the end of flood series is higher than the maximum channel bed scour profile. The difference between these two profiles indicate refill would occur during the later part of the flood series.

The downstream mining pit induces head cutting on this reach and the upstream pit causes tail-cutting on the reach. This process continues as the adjacent mining pits undergo refill. After the refill, these adjacent mining pits no longer cause head-cutting and tail-cutting. By that time, this river reach is expected to undergo refill as sediment supply resumes to this reach. Long-term changes with pit capture (by off-stream the Gilbert mining pit) have also been simulated. Pit capture will increase potential river channel scour. However, it should be noted that the long-term simulations only simulate the existing geometries of the sand and gravel pits and that any future or continued excavation is not simulated.

The computer output files for the study have the complete information for the longitudinal profile changes and cross-sectional changes. This study has its focus on the Salt River near the Gilbert Road crossing; therefore, only those cross-sectional changes near the Gilbert Road crossing are presented graphically. Each figure has the initial cross-sectional profile based on the 2001 survey, the simulated cross-sectional profile at the of the flood series, the simulated maximum scour profile together with the post flood 100-yr water surface. The predicted long-term changes at these river stations are greater in magnitude than those that occurred during the 2005 flood.

FLUVIAL-12 SIMULATION OF SALT RIVER NEAR GILBERT ROAD CROSSING

I. INTRODUCTION

Sand and gravel has been extracted from the Salt River in Maricopa County for decades. The mining activities have disturbed the natural equilibrium of the river channel to induce river channel changes. Figure 1 is an aerial photograph of the Salt River near the Gilbert Road Bridge. Because of sand and gravel mining, the river channel near the bridge crossing has undergone major channel bed scour. Changes in river channel geometry in recent years have been recorded by topographic surveys. The Maricopa County Flood Control District has the channel geometry data from a 2001 topographic survey. The channel geometry is defined at channel cross sections shown in Figure 2.

Since 2001, major river channel scour has occurred, primarily caused by the 2005 flood. Figure 3 is an aerial photograph showing the post-flood river channel near the Gilbert Road crossing. Figure 4 is a 2009 picture of the river channel and the bridge.

The channel geometry at those cross sections near the bridge crossing was surveyed in 2007. The geometric data and the flood hydrology provide the data basis that is useful for testing and calibration of computer models for river sedimentation. The purpose of this study was to test and calibrate the FLUVIAL-12 computer model using the Salt River data. Because of the existing and future sand and gravel mining, it is essential to develop methods to determine impacts of such activities and to develop measures for channel stabilization. A calibrated model is useful for predicting future stream channel changes, both short-term and long-term. It is also useful for developing counter-measures for channel stabilization and for the design of future bridges and other hydraulic structures.

This scope of the study has the following tasks: (1) to simulate the river channel changes caused by floods occurred after 2001, (2) to compare the simulated results with the channel geometry surveyed in 2007, and (3) to predict long-term river channel changes in the future.

Figure 1. Aerial photograph of the Salt River near the Gilbert Road crossing

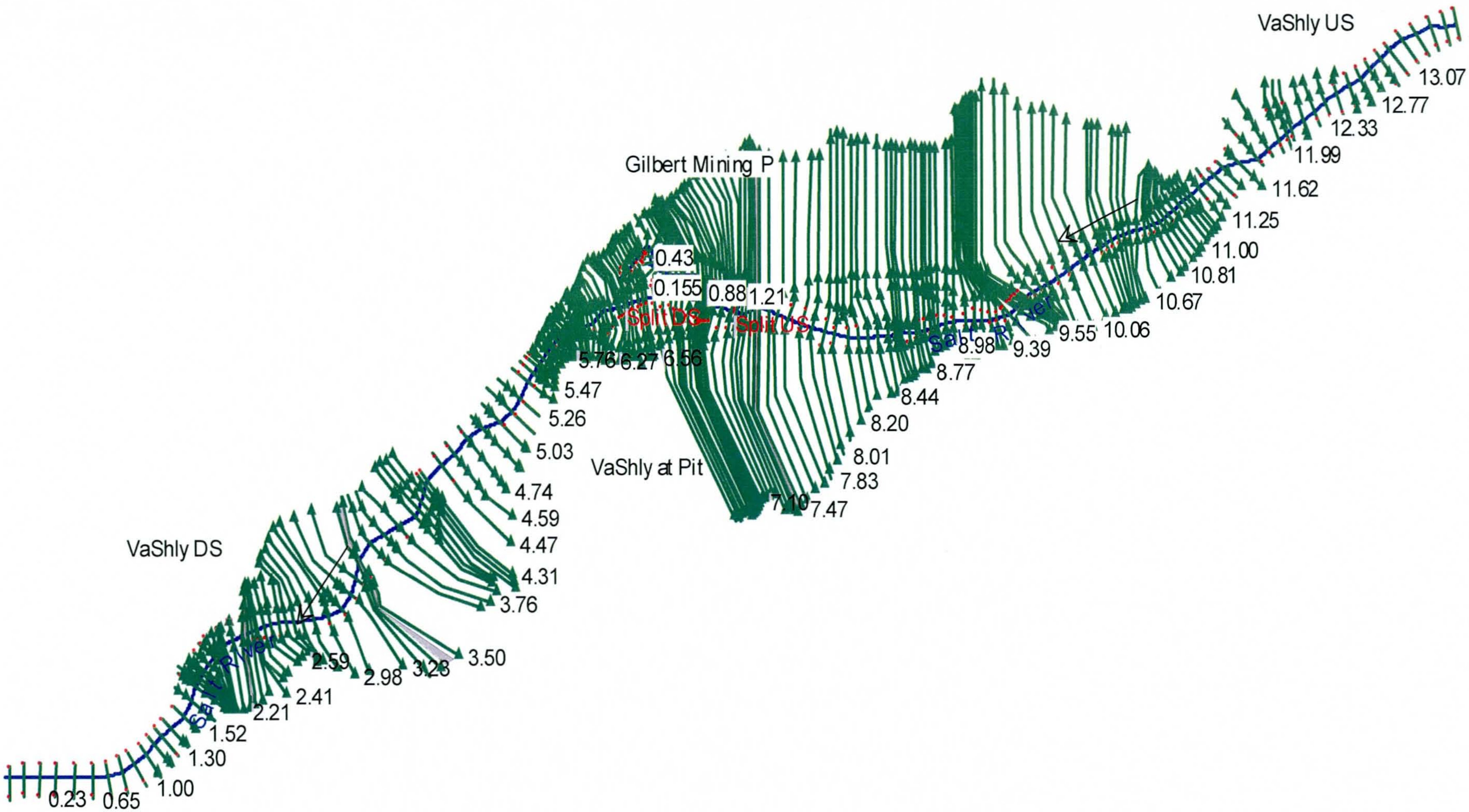


Figure 2. Cross section lines for the Salt River

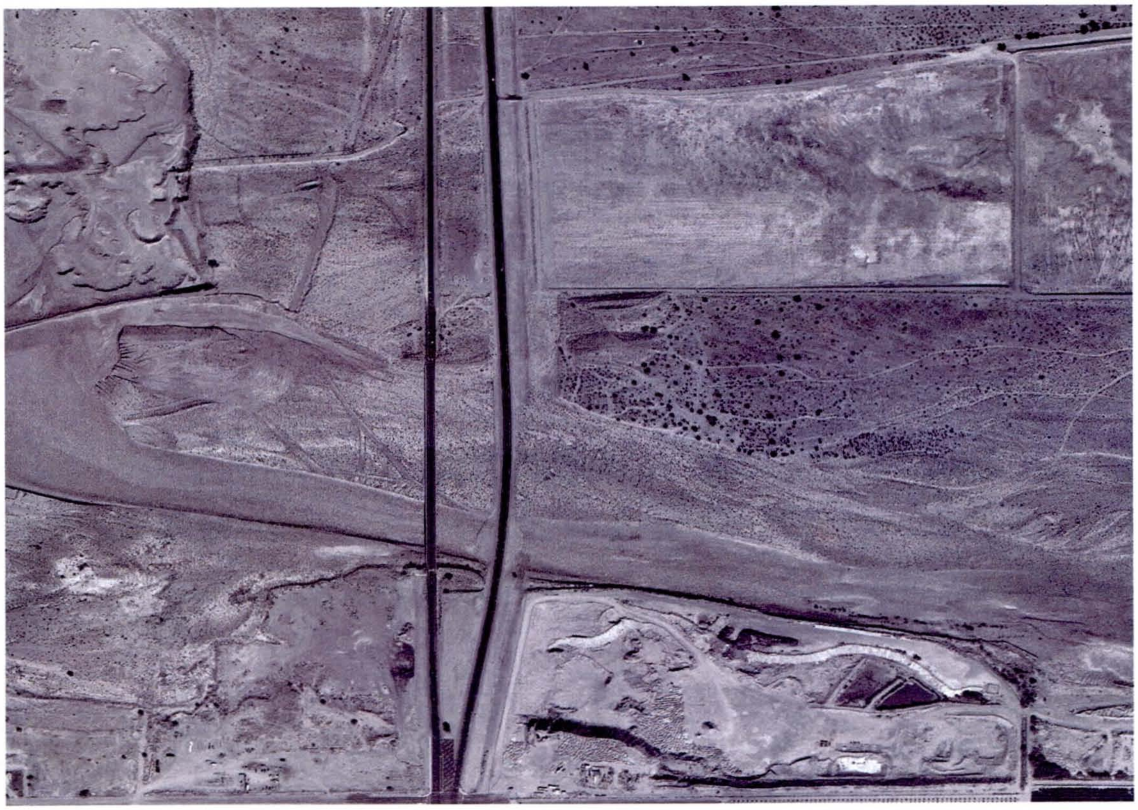


Figure 3. Aerial view of the Salt River near Gilbert Road crossing after the 2005 flood

Figure 4. View of the Salt River at Gilbert Road crossing after the 2005 flood

II. COMPILATION OF RIVER DATA

The data used for the Salt River study are taken from previous studies covering the hydrology, hydraulics and geomorphology of the stream channel. The most important data set for the study is the cross-sectional data of the stream channel including the mining pits. Such cross-sectional data are the data basis for hydraulic computations and river channel modeling. Specifically, the following data were compiled and used for the study:

Channel Geometry Data - The channel geometry data are based on the 2001 topographic survey used in a 2008 hydraulic study by JE Fuller (2008). Figure 2 is taken from the HEC-RAS study by JE Fuller. For this study, the cross sections from river station 2.04 to 13.64 are used. The cross sections downstream from river station 2.04 are not used because they are located downstream of a grade control structure at river station 2.33; they do not affect the hydraulic of flow and sediment transport along the river channel upstream of the grade control structure. Important locations along the river channel and their respective river stations are listed in Table 1. A grade control structure as shown in Figure 5 is located at river station 2.33. The bridge crossing at Gilbert Road is located between river stations 7.44 and 7.47. The data set covers the main channel of the Salt River and the Gilbert mining pit located downstream of Gilbert Road and north of the main channel. Another survey of the channel geometry was made by the County in 2007. The County survey provides the post-flood channel geometry at river stations: 7.28, 7.32, 7.44, 7.47, 7.55, and 7.62. These channel stations are on both sides of the bridge crossing.

Table 1. River stations for important locations along the Salt River

Location	River station 100-yr flood in river miles	
	Without pit capture	With pit capture
Downstream limit of study	2.04	2.04
Grade control structure	2.33	2.33
Downstream side of Gilbert Rd.	7.44	8.00
Upstream side of Gilbert Rd.	7.47	8.03
Upstream limit of study	13.64	14.20

Figure 5. Grade control structure at river mile 2.33

Data on Flood Hydrology – The established flood discharges of the Salt River at two locations for different return periods are listed in the following table.

Peak flows for the Salt River

Return periods	Flood discharges in cfs	
	River mile 13.64	River mile 7.55
5 year	22,000	21,000
10 year	60,000	58,000
20 year	100,000	95,000
50-year	150,000	145,000
100-year	175,000	172,000
200-year	210,000	207,000
500-year	250,000	246,000

The data for the 2005 flood was used in the current study. Figure 6 shows the hydrograph for the 2005 compiled from the USGS gaging records at Priest. The flood has the peak discharge exceeding 40,000 cfs and a long duration over three months; it was the most important event for the period from 2001 to 2007. Other events for the same period are much smaller in discharge and shorter in duration, as shown in Figure 7.

The hydrograph for a long-term flood series is shown in Figure 8. The series covers the time period from 1891 to 1993. This flow data was used to simulate potential river channel changes in the long-term future.

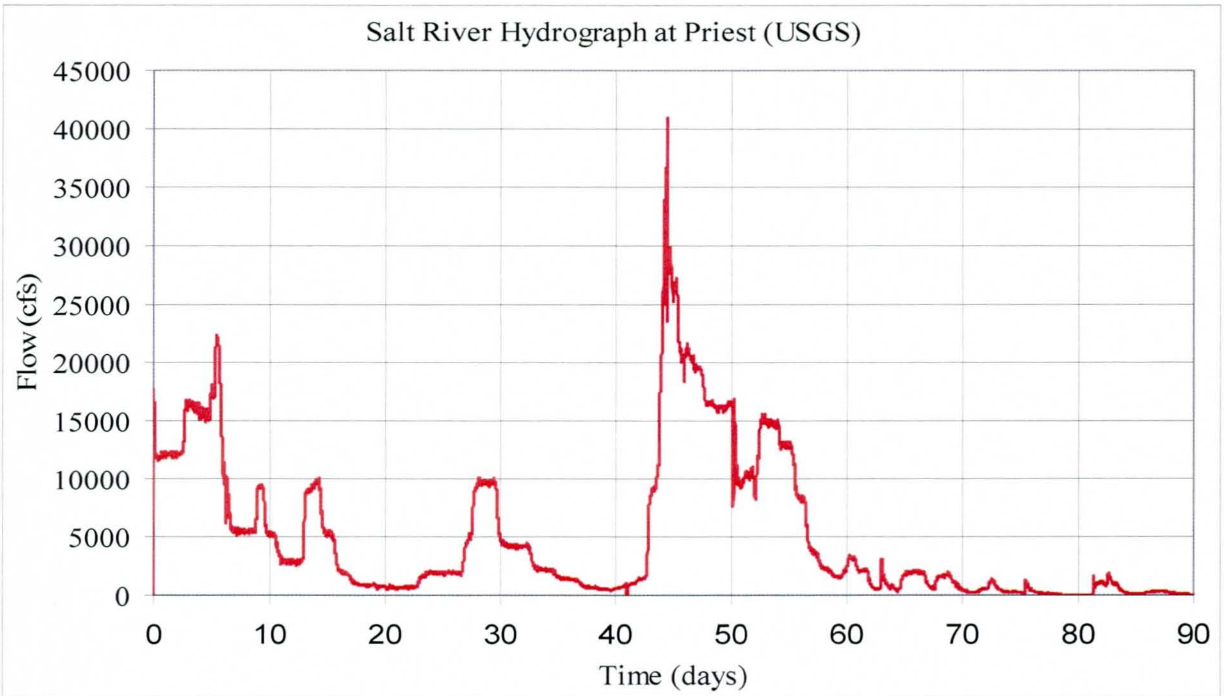


Figure 6. Hydrograph of the 2005 flood

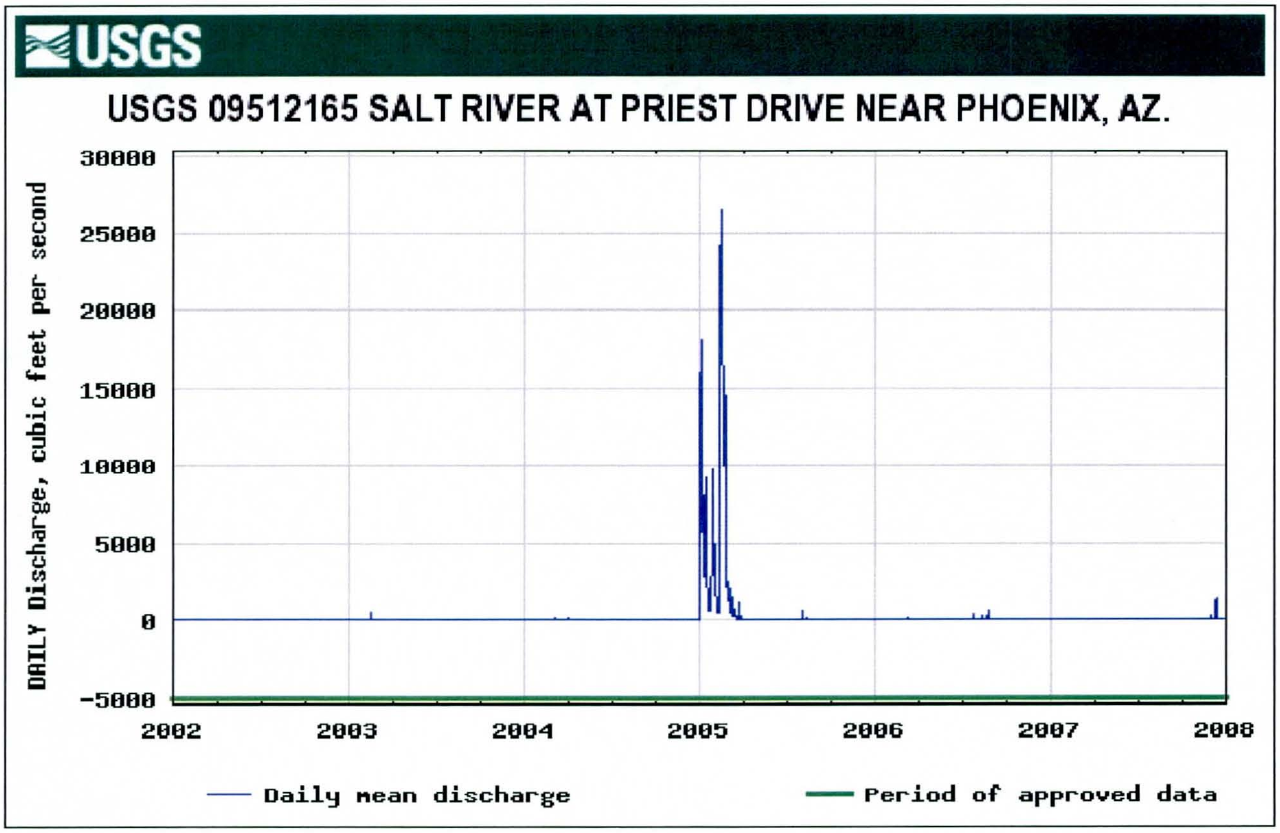


Figure 7. Flow records for the period from 2002 to 2008

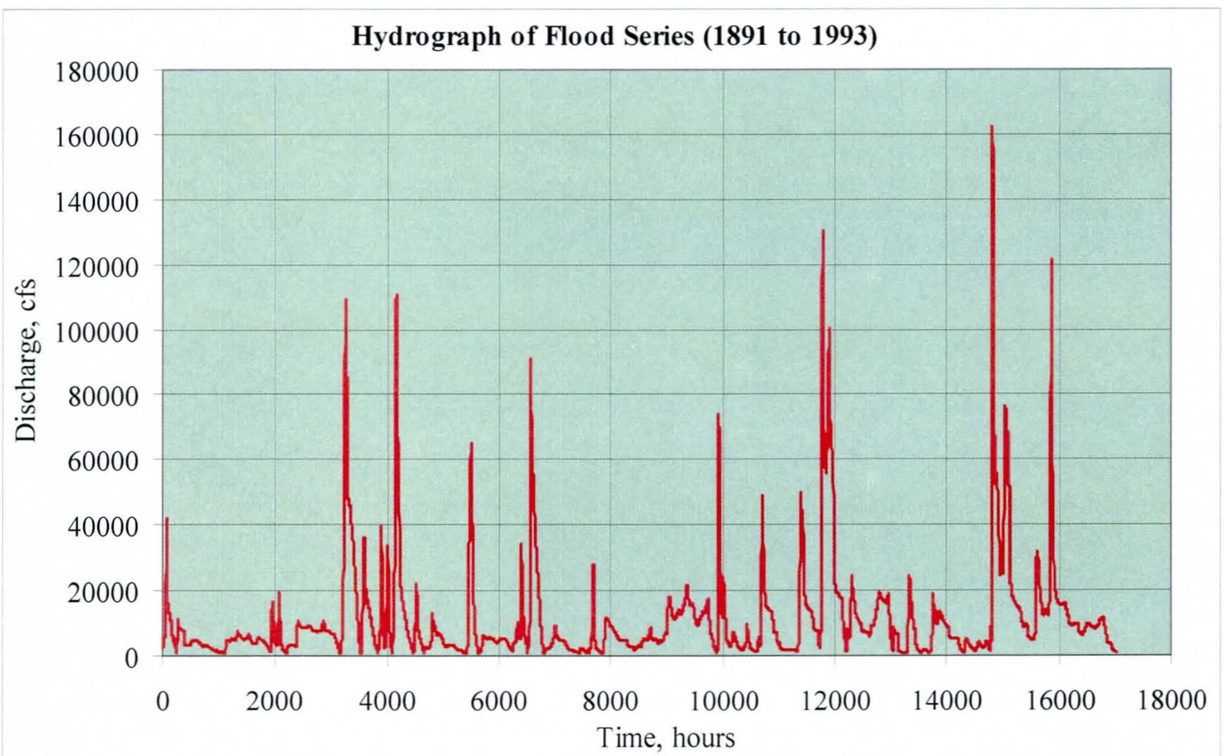


Figure 8. Hydrograph for a long-term flood series

Data on Sediment Gradation - The Salt River study by WEST Consultants (2002) has a large number of gradation curves. Sample gradation curves are shown in the figure. For gradation curves used in the study, five size fractions were used for each curve. The geometric mean of each size fraction is adopted as the size for the fraction.

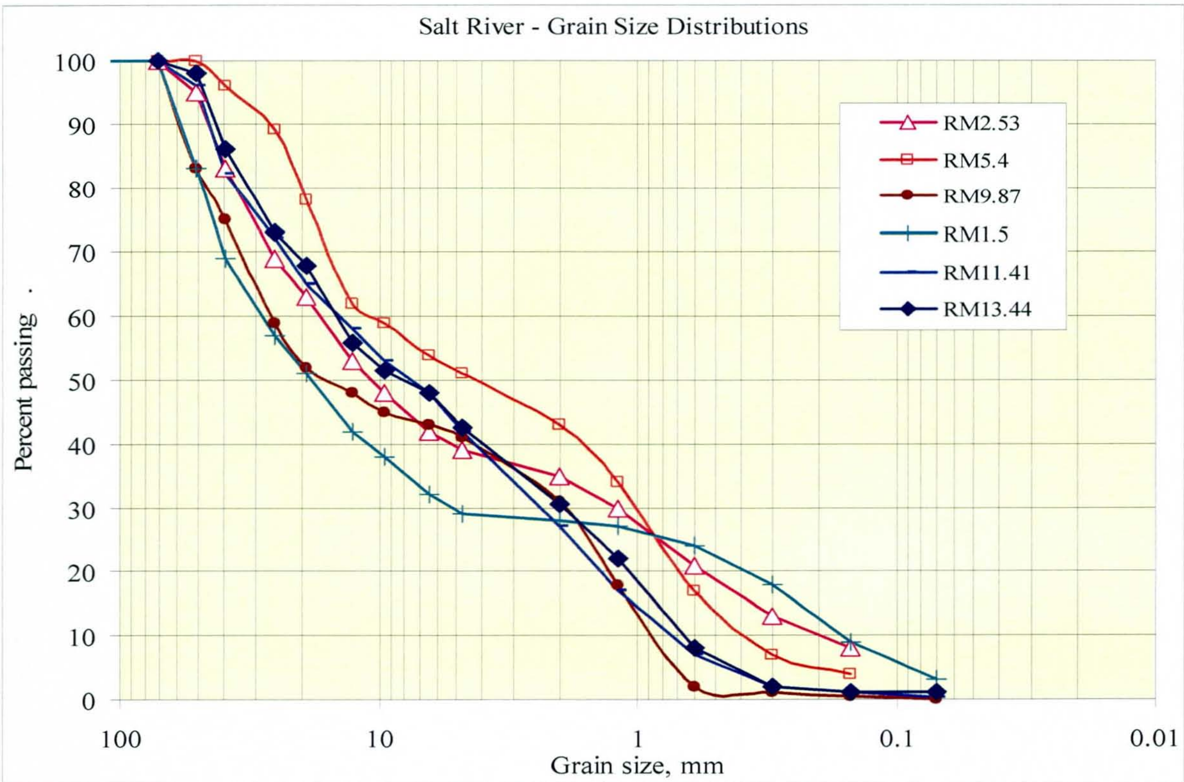


Figure 9. Sample grains size distributions of bed sediment

III. PIT CAPTURE

Pit capture is a geological term. It refers to a stream that is diverted from its normal course into a pit at a lower elevation. During the 2005 flood, flood water in the main channel was diverted into the Gilbert mining pit north of the channel as shown in Figure 10. As a result of pit capture, the flow made a 90-degree turn toward the north into the deep Gilbert mining pit. The diverted water traveled through the Gilbert pit and reentered the main channel at a downstream location. The time of occurrence for pit capture is not available. However, the HEC-RAS study by West Consultants (2002) shows that flow in the main channel starts to split into the Gilbert mining pit at about 20,000 cfs, which is close to the 5-yr flood. The water level in the Gilbert pit was much lower than the river stage. The split flow dropped down into the Gilbert pit at a much lower elevation with a very steep gradient; it should have caused rapid scour and enlargement of the flow path. It can be seen from the aerial photograph that the entire river flow was diverted into the pit as a result of pit capture. In this study, it is assumed that the flow diversion occurred after the flood discharge reached above 20,000 cfs. It is also assumed that the subsequent flood flow was diverted into the Gilbert pit in its entirety. During the 2005 flood, the discharge reached above 20,000 cfs in the early days of the flood event. For this reason, most of the flood flow in 2005 entered the Gilbert mining pit.

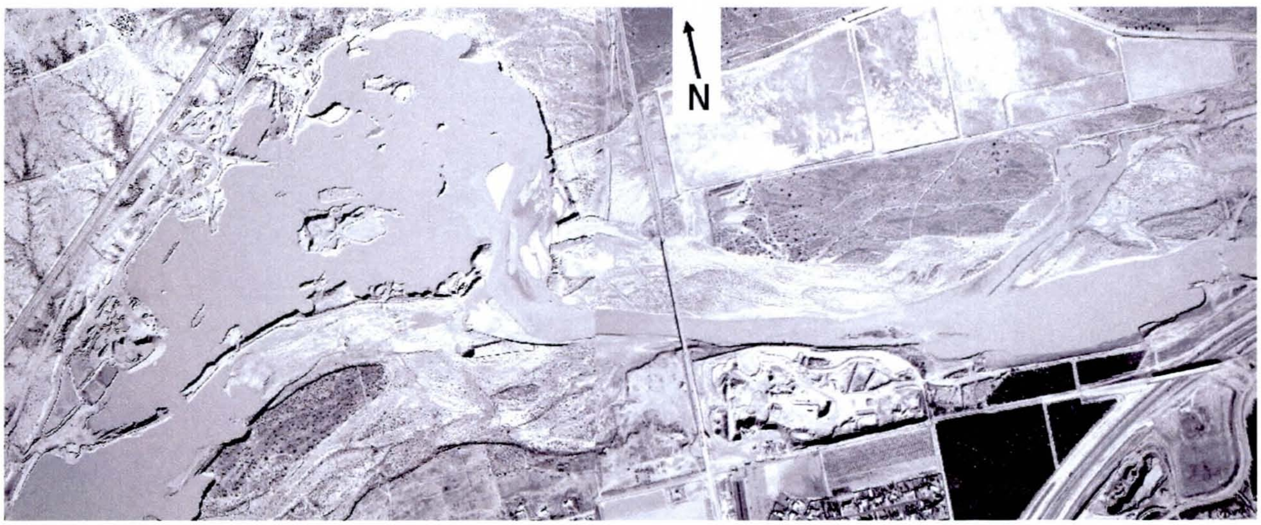


Figure 10. Aerial photograph of the Salt River during the 2005 flood showing pit capture of the river flow by the Gilbert mining pit

IV. SEDIMENT TRANSPORT MODELING USING FLUVIAL-12

Sediment transport and river channel changes for the Salt River during the 2005 flood were simulated using the FLUVIAL-12 computer model. For a given flood hydrograph, the model simulates spatial and temporal variations in water-surface elevation, sediment transport and stream channel changes. Scour and fill of the stream bed are coupled with width variation in the prediction of stream channel changes. Computations are based on finite difference approximations to energy and mass conservation that are representative of open channel flow. Sediment transport for the Salt River was computed in the model using the Meyer-Peter--Muller formula (Meyer-Peter and Muller, 1948, also see Chang, 1988) for sediment.

The model simulates the inter-related changes in channel-bed profile and channel width, based upon a stream's tendency to seek uniformities in sediment discharge and power expenditure. At each time step, scour and fill of the channel bed are computed based on the spatial variation in sediment discharge along the channel. Channel-bed corrections for scour and fill will reduce the non-uniformity in sediment discharge. Width changes are also made at each time step, resulting in a movement toward uniformity in power expenditure along the channel. Because the energy gradient is a measure of the power expenditure, uniformity in power expenditure also means a uniform energy gradient or linear water surface profile. A stream channel may not have a uniform power expenditure or linear water-surface profile, but it is constantly adjusting itself toward that direction.

Meyer-Peter--Muller Formula – A sediment transport formula is employed in the FLUVIAL-12 model. For the Salt River with a gravel bed, the Meyer-Peter--Muller formula (MPM formula) was used. The two most widely used sediment formulas for gravel are the MPM formula and the Parker-Coleman formula (1986). The MPM formula has been in use for a long period of time and it is generally considered as the most accurate formula for gravel transport. Most professionals in the U. S and Europe apply the MPM formula in their studies.

The dimensionless Meyer-Peter--Muller formula and the physical meanings for its respective terms normalized by $(\gamma_s - \gamma)\, d_m$ are given by

$$\underbrace{\left[\frac{q_b\,(\gamma_s-\gamma)}{\gamma_s}\right]^{2/3} (\gamma/g)^{1/3}\,\frac{0.25}{(\gamma_s-\gamma)\,d_m}}_{\text{I}} = \underbrace{\frac{(k/k')^{3/2}\,\gamma RS}{(\gamma_s-\gamma)\,d_m}}_{\text{II}} - \underbrace{0.047}_{\text{III}} \qquad (1)$$

The left-hand side of the equation (Term I) is the bed load discharge in its dimensionless form; the first term on the right-hand side (Term II) is the effective shear stress; the second term (Term III) on the right-hand side is the critical shear. In this basically empirical equation, the bed-load discharge q_b is in weight per unit time and unit channel width. Being dimensionally homogeneous, it may be used under any consistent set of units. It is applicable to graded sediments, for which the effective diameter d_m of the sediment mixture is defined as

$$d_m = \sum_i p_i d_i$$

where i is the size fraction index, d_i is the mean size of a fraction of the bed material, and p_i is its fraction by weight. The quantities k and k', which are reciprocals of Manning's roughness coefficient, are given by

$$U = k R^{2/3} S^{1/2}$$
$$U = k' R^{2/3} S'^{1/2}$$

where U is the cross-sectionally averaged velocity, R is the hydraulic radius, S is the total energy gradient, and S' is the energy gradient caused by grain roughness. The value of k' can be obtained from Strickler's formula for grain roughness, that is,

$$k' = \frac{26}{D_{90}^{1/6}}$$

where D_{90} is the grain size of the bed material for which 90% is finer, in meters. Note that this formula is valid only if D_{90} is in meters and time is in seconds.

Term I in Eq. 1 represents the bed-load discharge per unit channel width measured in submerged weight and normalized by $(\tau_s - \tau)d_m$; it is related to the shear stress caused by grain roughness (term II) subtracted by the critical shear stress (term III). The grain shear stress is considered directly responsible in moving the particles. The form roughness also affects the shear stress because of its influence on the depth. The ratio k/k' is used to provide the grain shear stress as a portion of the total (grain plus form) shear stress. The value of k/k' varies between 0.5 and 1; it is 0.5 for strong bedforms and 1 in the absence of bedforms. Bedforms such as dunes and ripples are usually characteristic to the sand bed and are usually poorly developed in coarse sediments for which the total roughness is essentially caused by grain roughness. Term III as the dimensionless critical shear is similar to the critical Shields stress.

The experiments in developing the formula were made in laboratory flumes with widths ranging between 15 cm and 2 m, water depth between 1 and 120 cm, effective diameter of sediments between 0.4 and 30 mm, and specific gravity for sediments from 1.25 to over 4. This formula is therefore more applicable to coarse sediments with little suspended load. It has enjoyed considerable popularity in Europe.

V. MODELED RESULTS ON RIVER CHANNEL CHANGES DURING THE 2005 FLOOD

The river channel geometry for the entire study river reach was surveyed in 2001 and digitized in the HEC-RAS data file. Another survey was made in 2007 covering the channel geometry at those stations near the Gilbert Road crossing. River channel changes were simulated using the FLUVIAL-12 model for the 2005 flood. The simulated river channel changes would then be compared with the measured changes.

Simulation of the Salt River changes during the 2005 flood was made for the two following scenarios: (1) river channel without pit capture, and (2) river channel with pit capture. For the first case, the river stations follow the original studies by WEST and JE Fuller. For the second case, the river flow passes through the Gilbert mining pit with a longer channel length, the river stations for those cross sections upstream of the Gilbert pit are increased by 0.56 river mile. River stations at a few locations including the Gilbert Road crossing are listed in Table 1 for both cases.

Simulated results are presented below. Figure 11 shows the simulated water-surface and channel bed profile changes during the 2005 flood for the case of no pit capture. In the figure, the drop structure at river mile 2.33 is the downstream grade control for the channel bed. The Gilbert Road crossing is located between river miles 7.44 and 7.47. The uneven channel bed profile reflects the presence of several existing mining pits. The Gilbert Road crossing is located along a river reach between two major mining pits. The figure shows that the 2005 flood would only cause minor channel bed scour near the Gilbert Road crossing. The channel bed scour as simulated is much less than the measured change in bed level. The 2005 flood had a long duration. However, its peak discharge has a return period less than 10 years. Since the actual channel bed scour was much greater than the simulated changes for this case, there must be other reasons not yet accounted for.

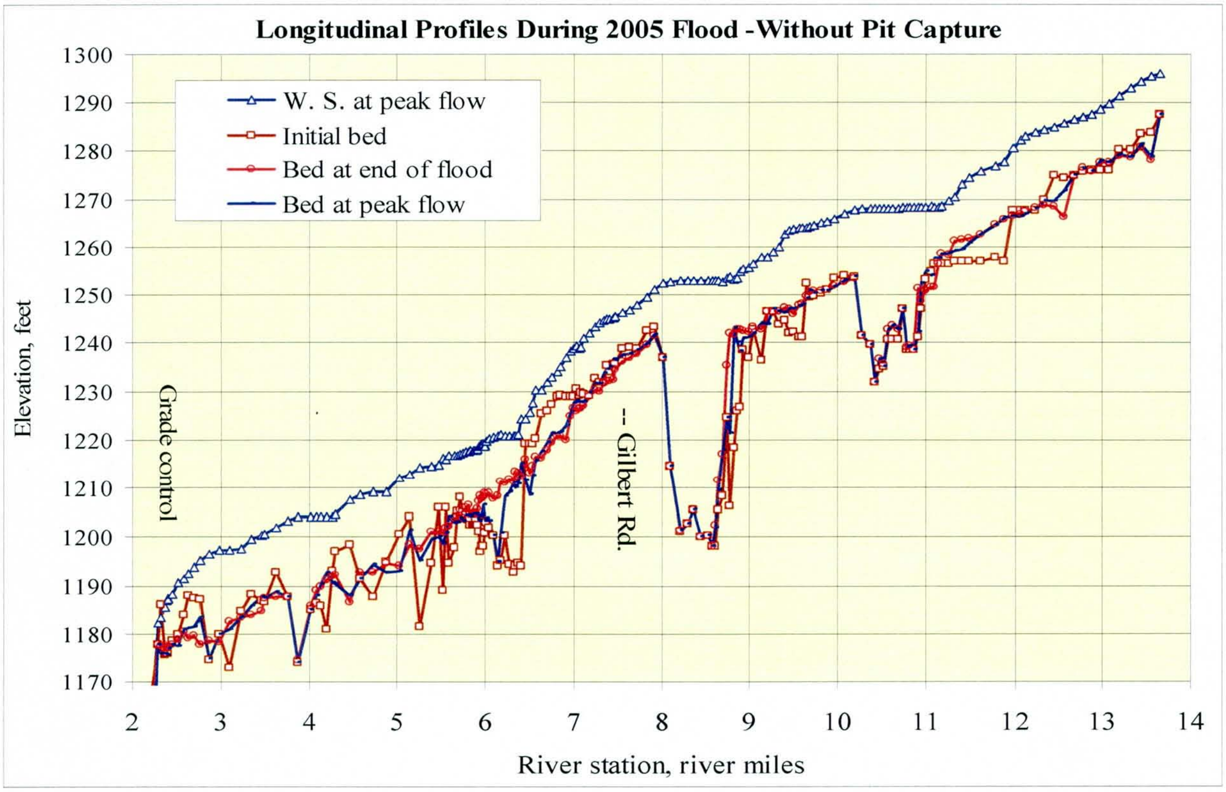


Figure 11. Water surface and channel bed profile changes
during the 2005 flood assuming no pit capture

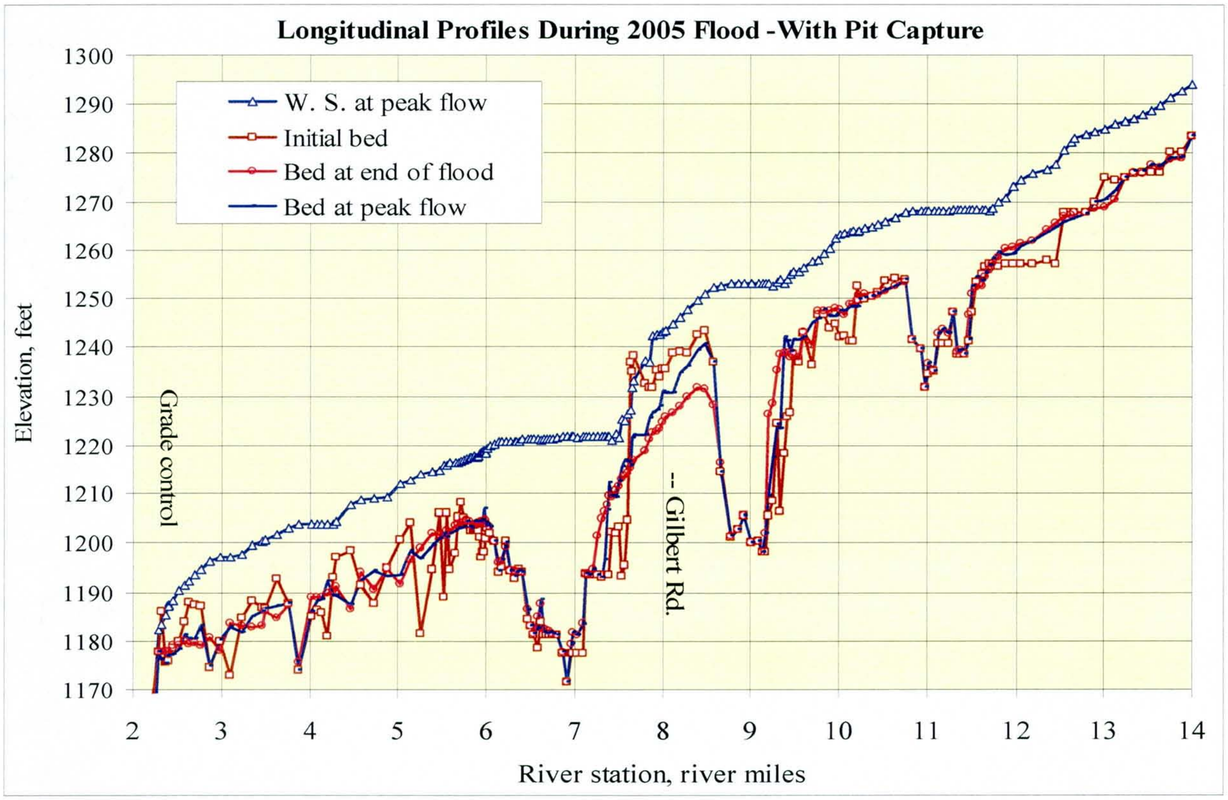
For the case scenario of pit capture, it is assumed that pit capture occurred when the flood discharge exceeded 20,000 cfs in the very early stage of the flood event. Simulated water-surface and channel bed profile changes for this case are shown in Figure 12. The short channel reach near the Gilbert Road crossing is between two major mining pits. This channel reach is simulated to undergo major channel bed degradation of about 10 feet.

Simulated changes at those channel stations near the bridge crossing are shown in Figure 13. The figure at each river station has the following cross-sectional profiles:

Bed before flood: Cross-sectional profile from the 2001 survey

Bed after flood: Simulated cross-sectional profile at the end of the 2005 flood

Bed measured after flood: Cross-sectional profile from the 2007 survey.



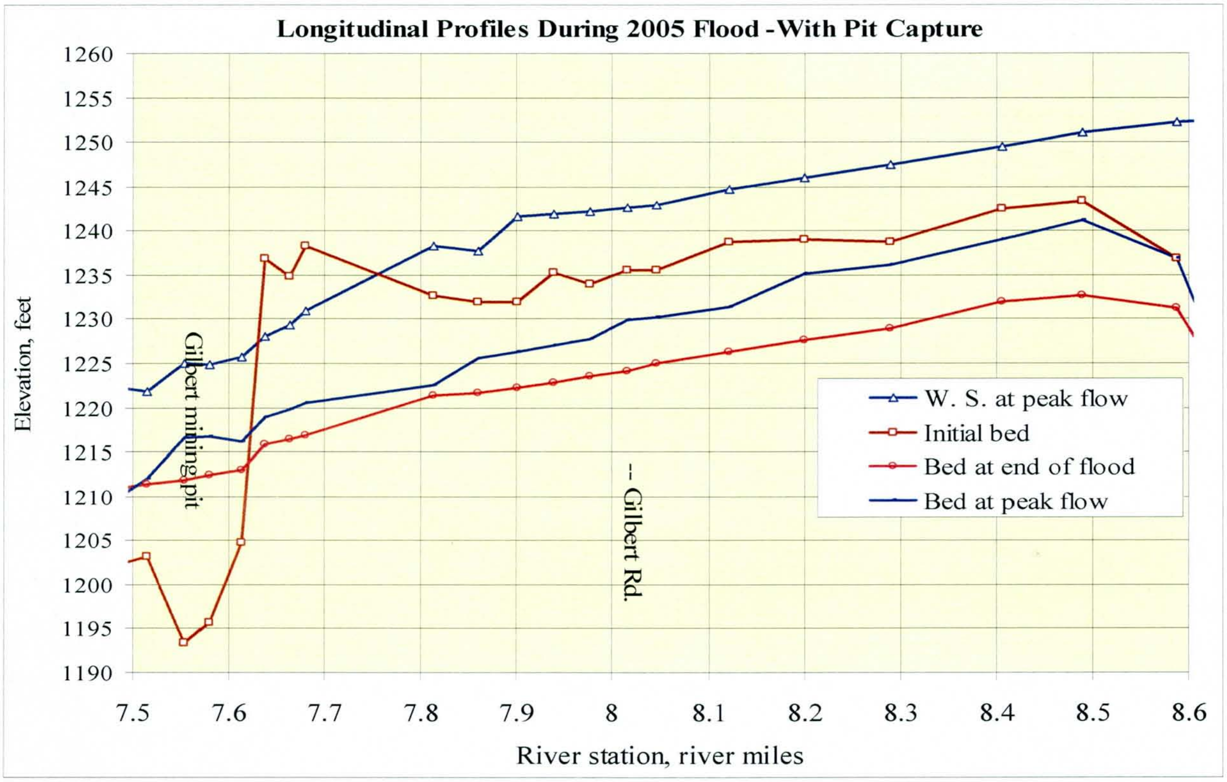
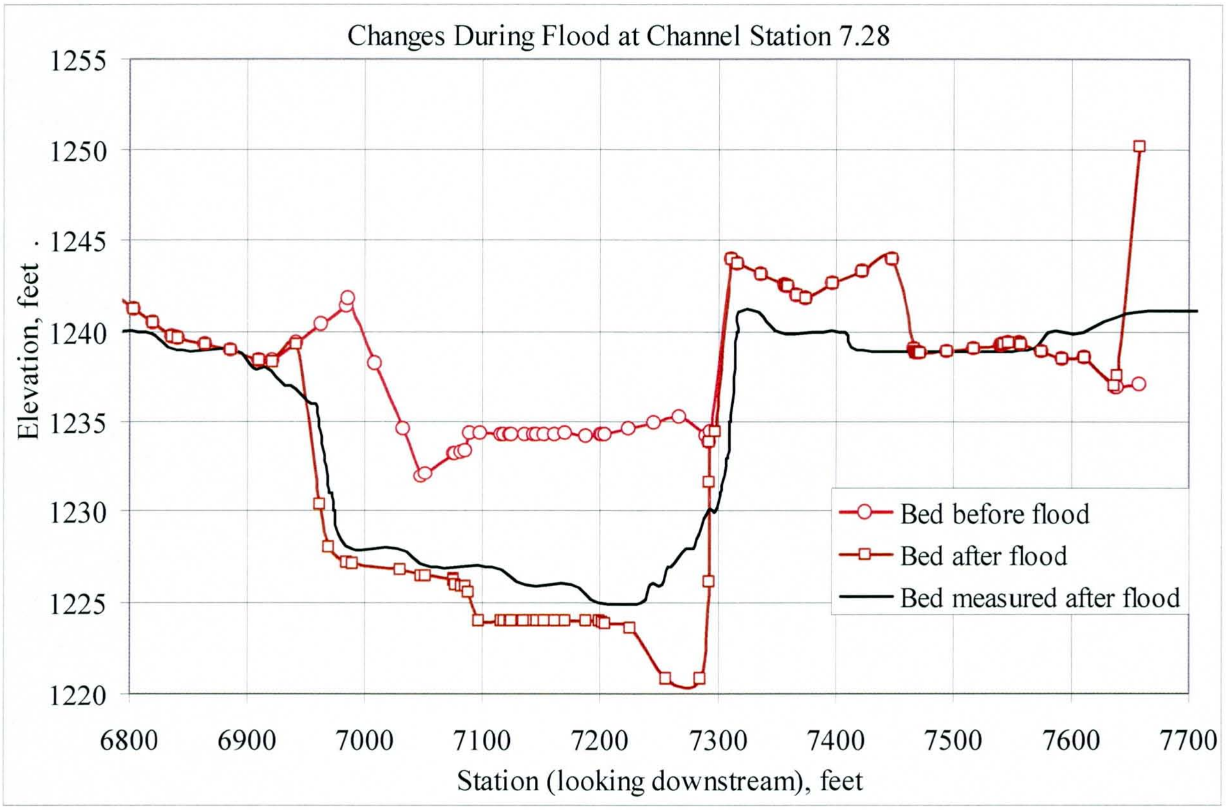


Figure 12. Simulated water surface and channel bed profile changes. The upper figure shows the entire study river reach. The lower figure shows a short reach near Gilbert Road.



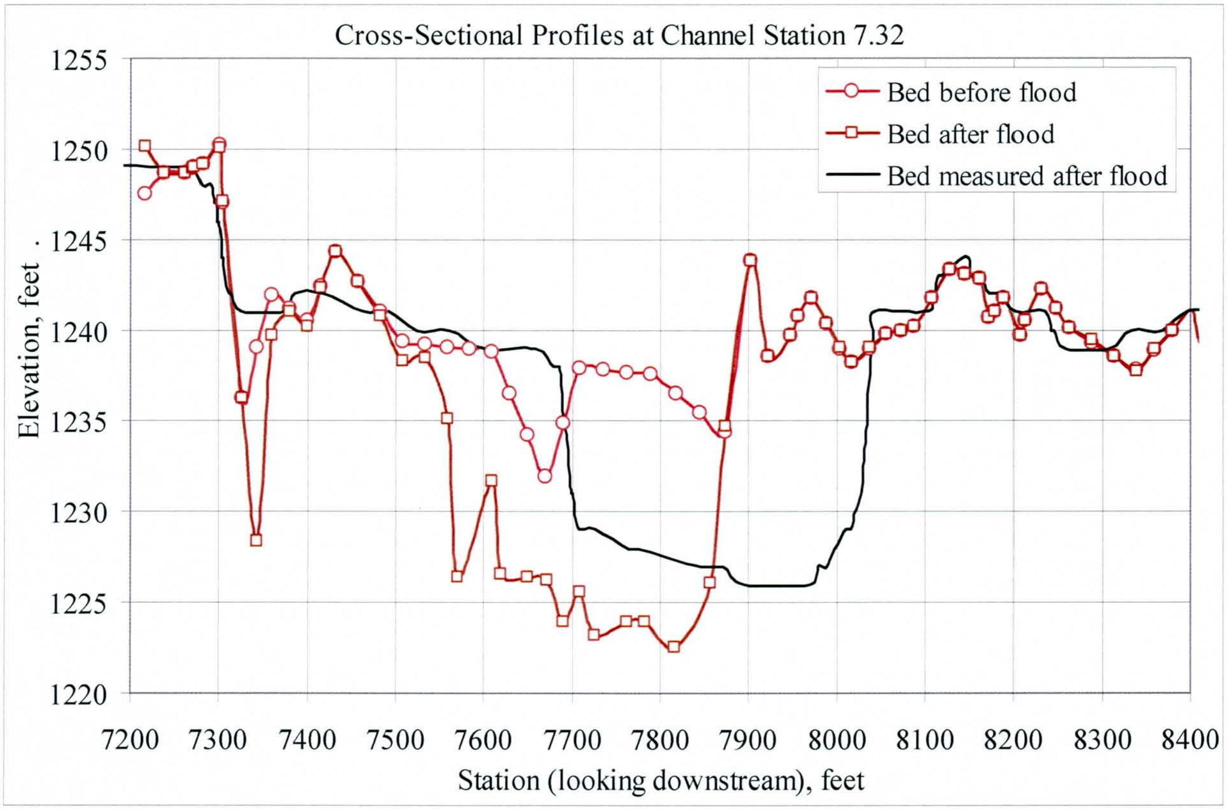
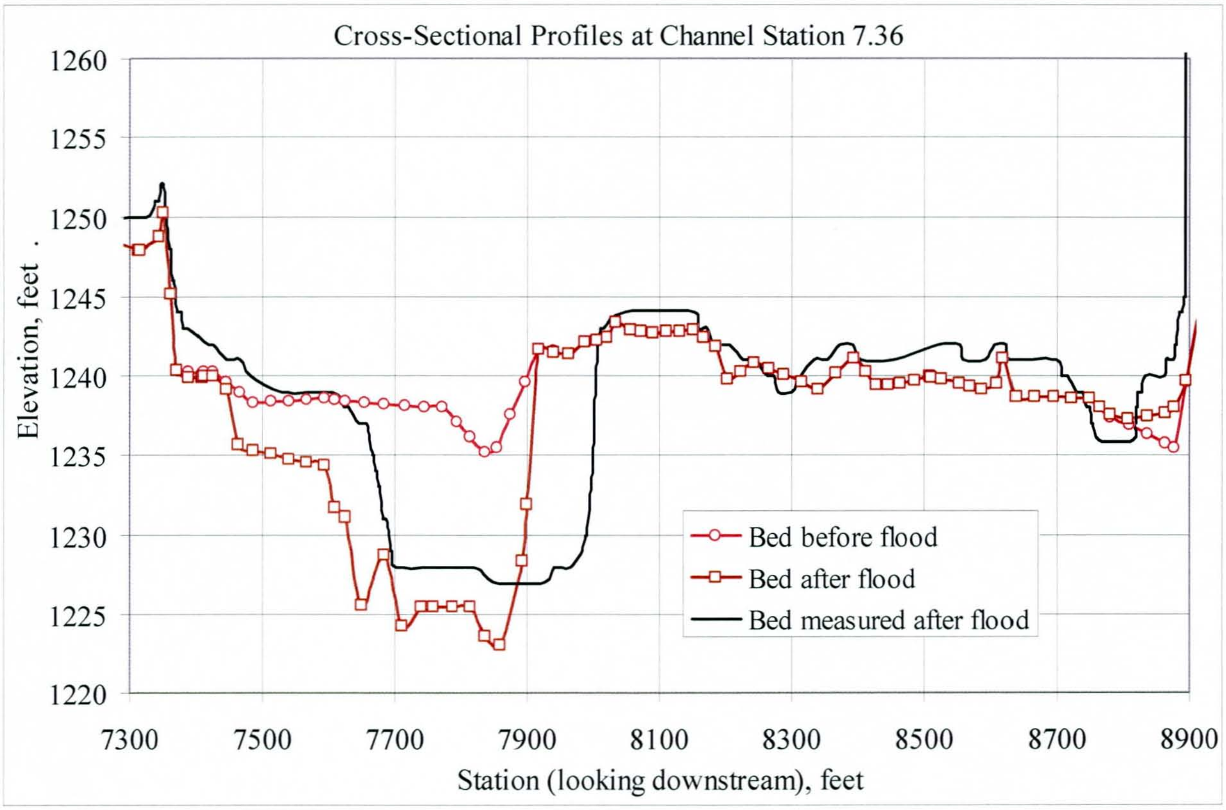


Figure 13. Cross-sectional profiles



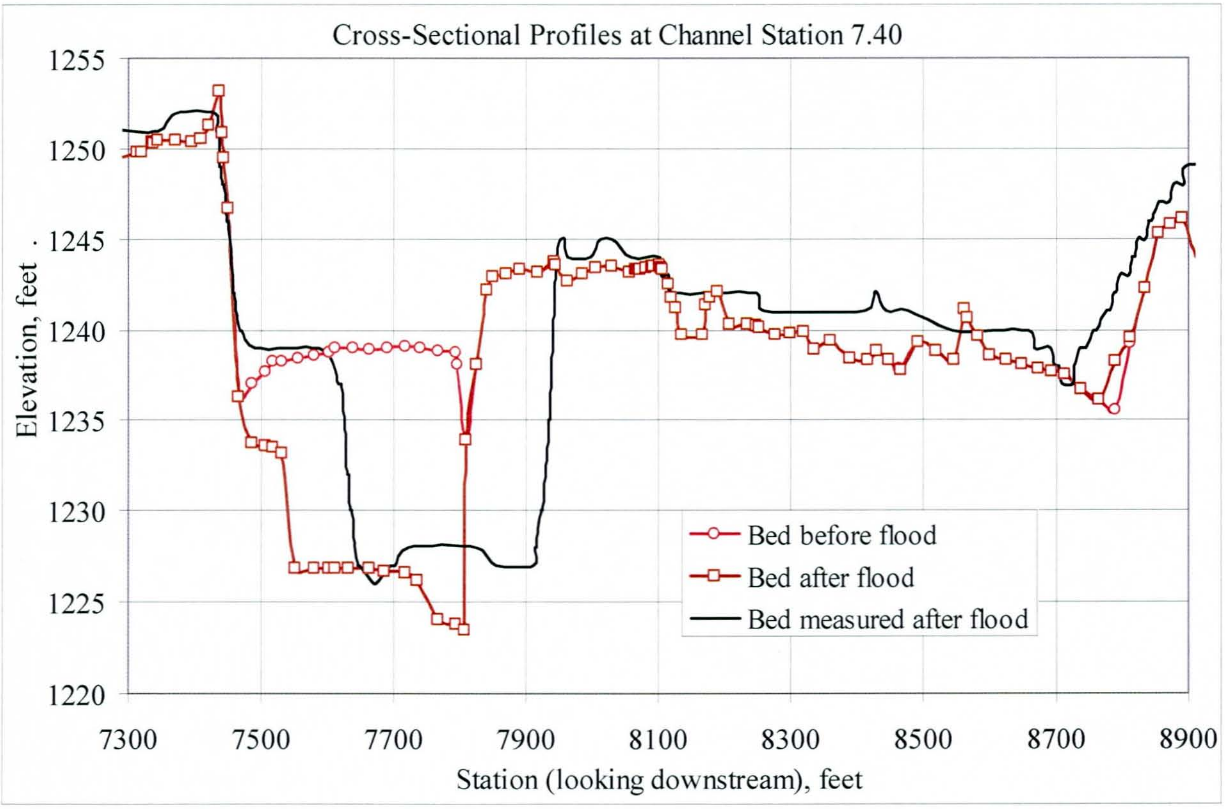
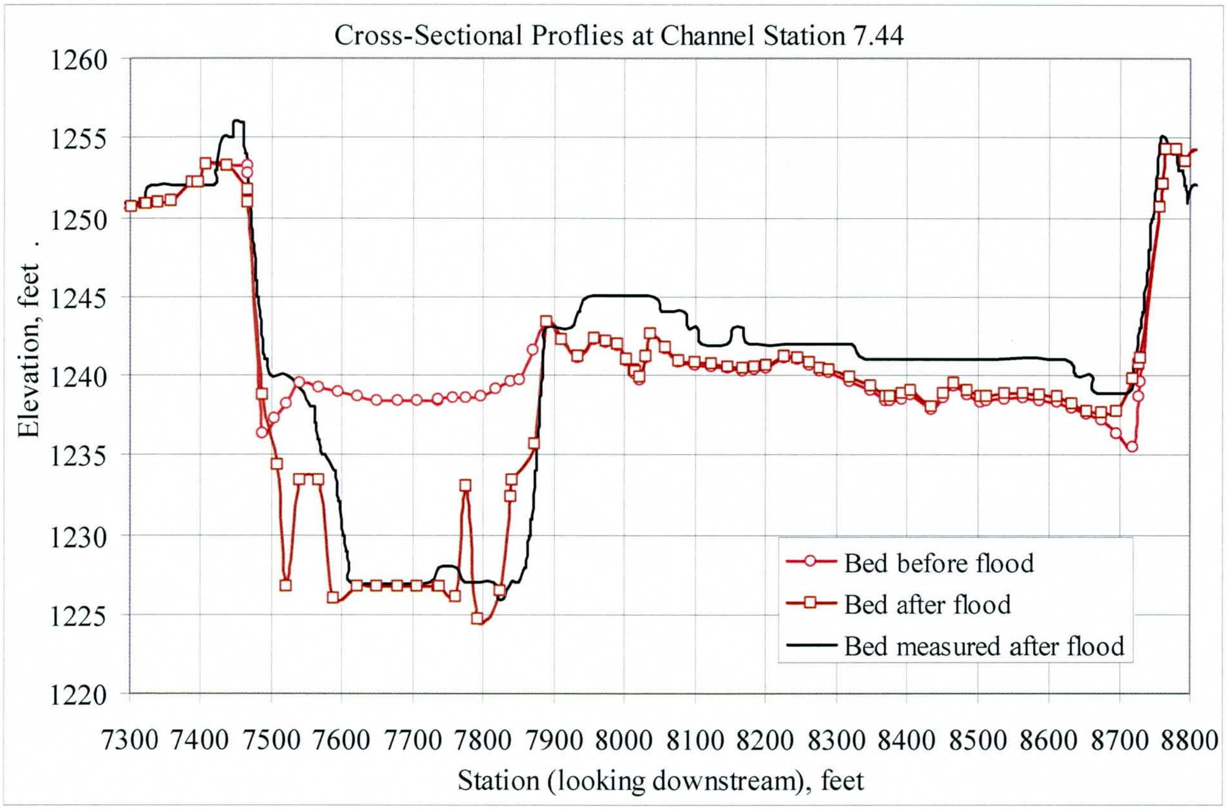


Figure 13 (continued). Cross-sectional profiles



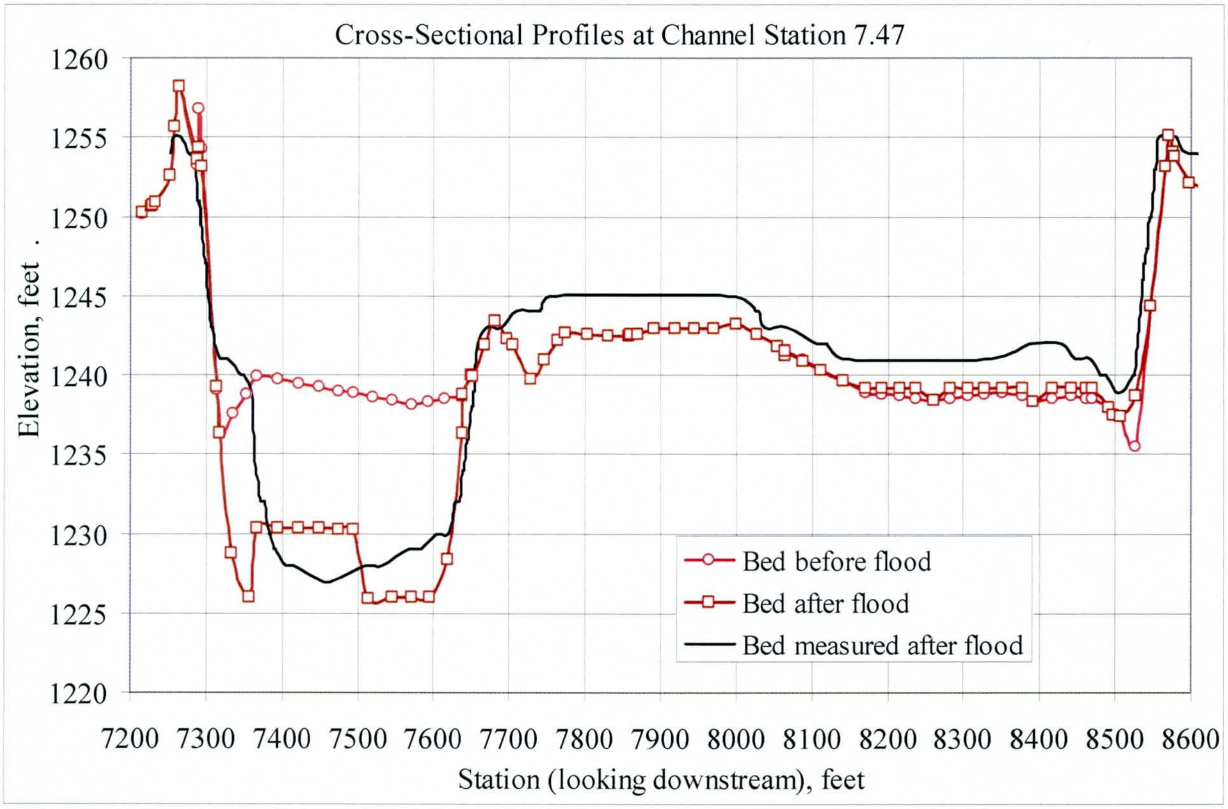
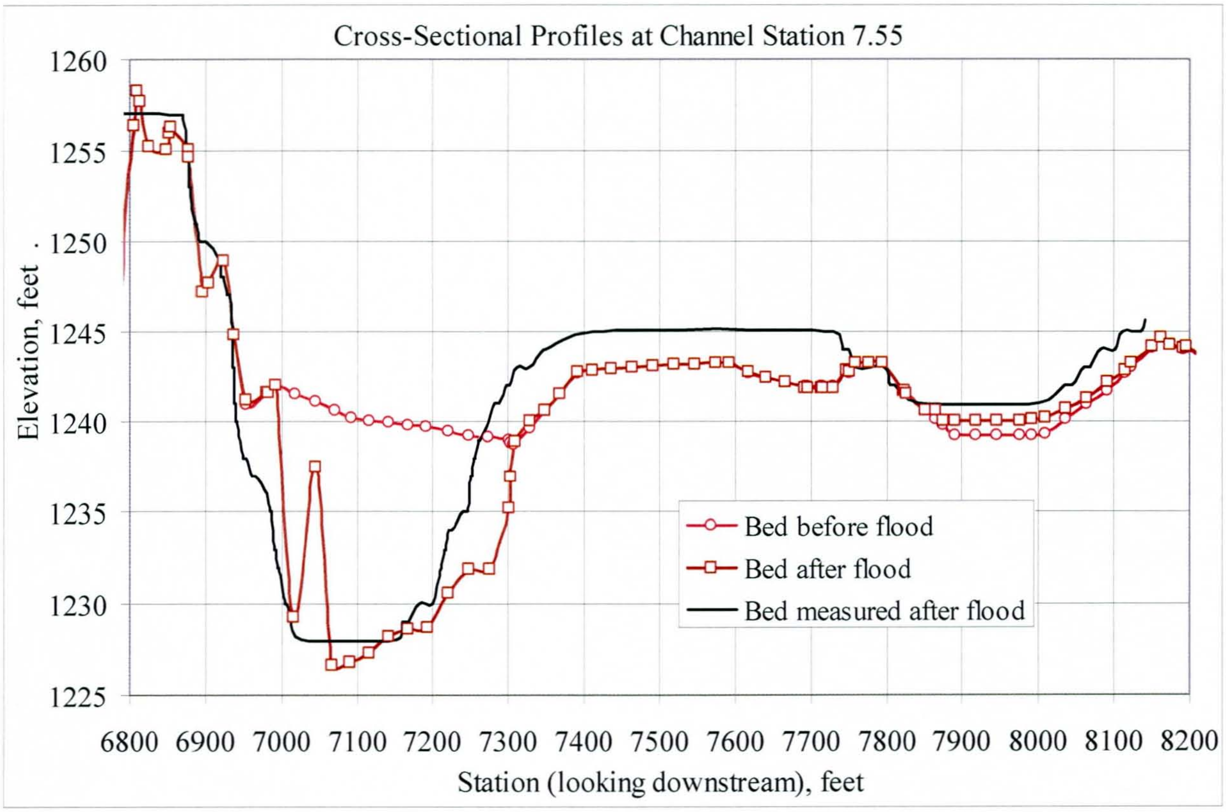


Figure 13 (continued). Cross-sectional profiles



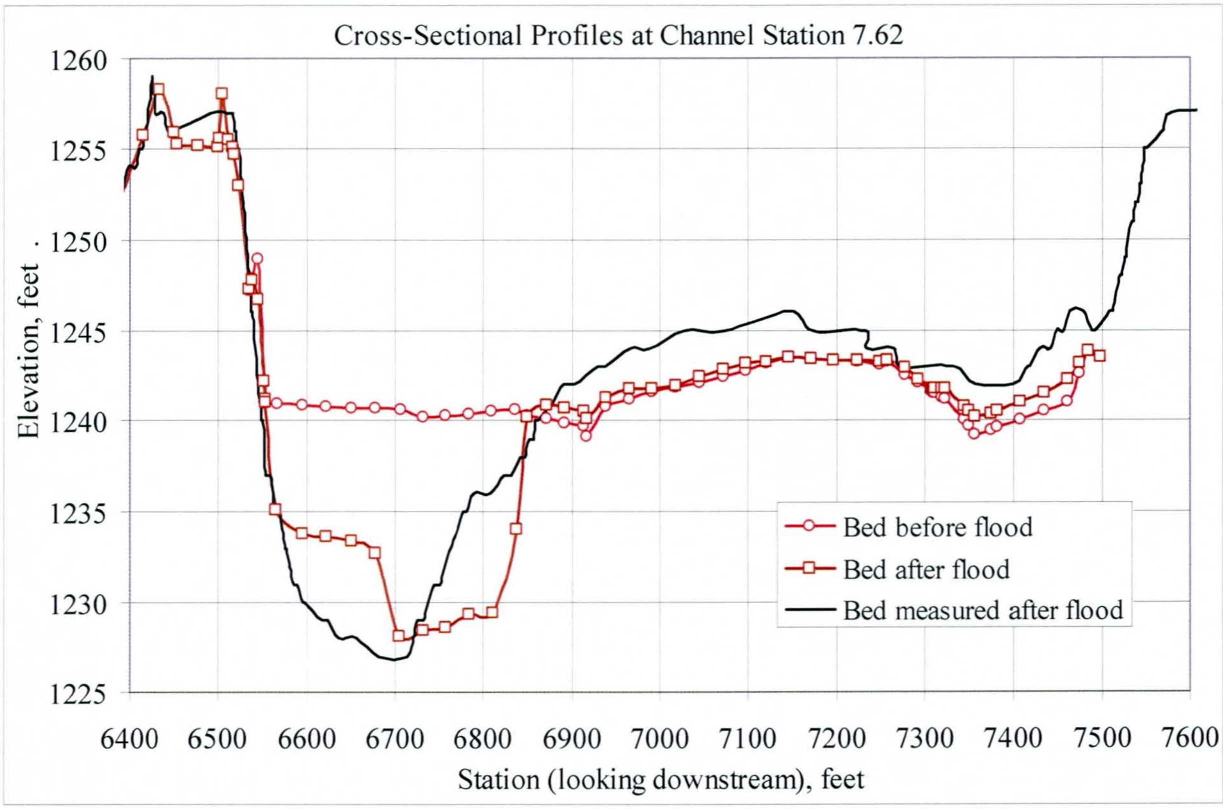


Figure 13 (continued). Cross-sectional profiles

The FLUVIAL-12 model has been used to simulate general scour of the channel reach near the Gilbert Road crossing. The simulated results for river stations near the Gilbert Road crossing are shown in Figure 13 together with the measured post-flood cross-sectional profiles. Now the cross-sectional profiles as simulated are compared with the measured profiles. Changes along this channel reach are characterized by channel bed scour along the main channel. Simulated cross-sectional area changes due to scour are compared with the measured changes as summarized in Table 2.

Table 2. Comparison of simulated and measured cross-sectional area changes

River Station	Cross-Sectional Area Change due to Scour, Square feet	
River miles	Measured by Survey	Simulated by Model
7.28	2,990	3,070
7.32	3,480	3,710
7.36	1,620	1,910
7.40	2,000	1,730
7.44	3,970	3,800
7.47	3,350	3,350
7.55	2,890	2,910
7.62	2,450	2,345

The total amount of channel bed scour as simulated is similar to the measured amount. The total depth of channel bed degradation is also similar. However, the simulated and measured cross-sectional profiles have significant differences. The simulated channel bed scour is along the thalweg. At channel stations 7.28, 7.44, 7.55 and 7.62, the measured channel bed scour also occur along the thalweg. But at channel stations 7.32, 7.36 and 7.40, the simulated channel bed scour occur at different locations from the measured scour. While the simulated and measured scours are similar in pattern, they have somewhat different locations. The simulated channel bed scour is near the thalweg; the measured scour may be away from the thalweg. The causes for such discrepancy may be due to lateral migration of the thalweg, which is not considered in the model simulation; or it may be due to survey inaccuracy. In fact, the overbank areas for the cross sections from the 2001 survey do no always match the corresponding ones from the 2007 survey. The overbank areas were not affected by river channel scour; there should be no big differences in geometry. However, such differences do exist at several river stations.

The simulated cross-sectional profiles may have an uneven channel bed, while those from the 2007 topographic survey are quite smooth. The 2007 topography was developed from contours. In the process, local variations in bed elevation may be ignored and wide area may thus be shown as flat bed.

VI. MODELED RESULTS ON LONG-TERM RIVER CHANNEL CHANGES

Since the Salt River has been disturbed by sand and gravel mining, it is expected to undergo changes in the future. For this reason, the potential long-term river channel changes have been simulated using the flood series shown in Figure 8. The flood series has the time span of about 100 years. For long-term changes, the following two scenarios are assumed:

(1) The berm separating the Gilbert mining pit from the main channel of the Salt River will be restored and pit capture in the future will be prevented.

(2) The berm separating the Gilbert mining pit from the main channel of the Salt River will not be restored and pit capture will continue in the future.

Simulated results on sediment delivery and river channel changes are presented below.

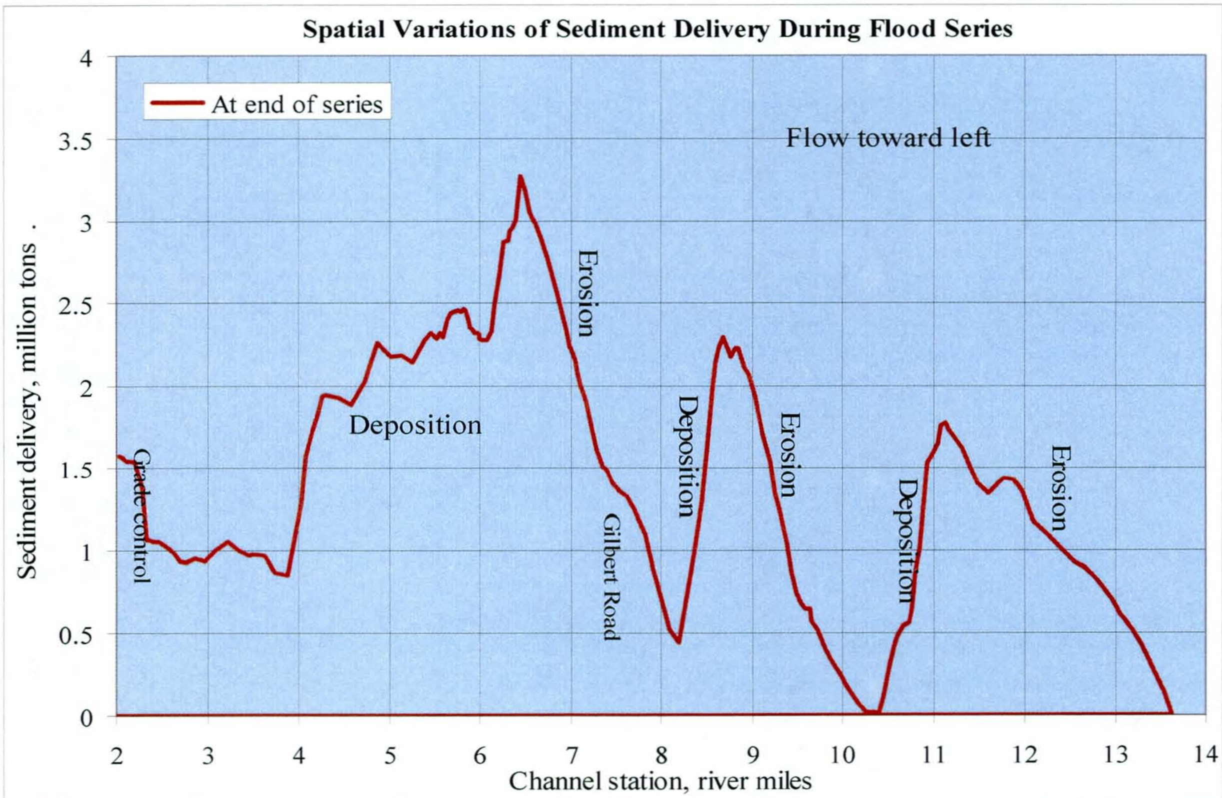
Sediment Delivery - Sediment delivery is defined as the cumulative amount of sediment that has been delivered passing a certain channel section for a specified period of time, that is,

$$Y = \int_T Q_s \, dt \qquad (2)$$

Where Y is sediment delivery (yield); Q_s is sediment discharge; t is time; and T is the duration. The sediment discharge Q_s pertains only to bed-material load of sand, gravel and cobble. Fine sediment of clay and silt constituting the wash load may not be computed by a sediment transport formula. Sediment delivery is widely employed by hydrologists for watershed management; it is used herein to keep track of sediment supply and removal along the channel reach.

Spatial variations in sediment delivery are manifested as channel storage or depletion of sediment associated stream channel changes since the sediment supply from upstream may be different from the removal. The spatial variation of sediment delivery depicts the erosion and deposition along a stream reach. A decreasing delivery in the downstream direction, i.e. downward gradient for the delivery-distance curve, signifies that sediment load is partially stored in the channel to result in a net deposition. On the other hand, an increasing delivery in the downstream direction (upward gradient for the delivery-distance curve) indicates sediment removal from the channel boundary or net scour. A uniform sediment delivery along the channel (horizontal curve) indicates that sediment inflow and outflow are in balance, i.e., no net erosion or deposition along the reach. Channel reaches with net sediment storage or depletion may thus be designated on the basis of the gradient. From the engineering viewpoint, it is best to achieve a uniform delivery, the non-silt and non-scour condition, for dynamic equilibrium.

The simulated spatial variation in sediment delivery along the study river reach is shown in Figure 14. The total amount of sediment delivered during the flood series varies considerably along the river channel. For the case of no pit capture, the upstream river reach from river mile 11.6 to river mile 11.2, the delivery shows an increase toward downstream of about 1.75 million tons. This amount represents the sediment eroded from the reach during the long-term time span. This reach is subject to long-term erosion because sediment supply to the reach from upstream is cut off by the diversion dam.



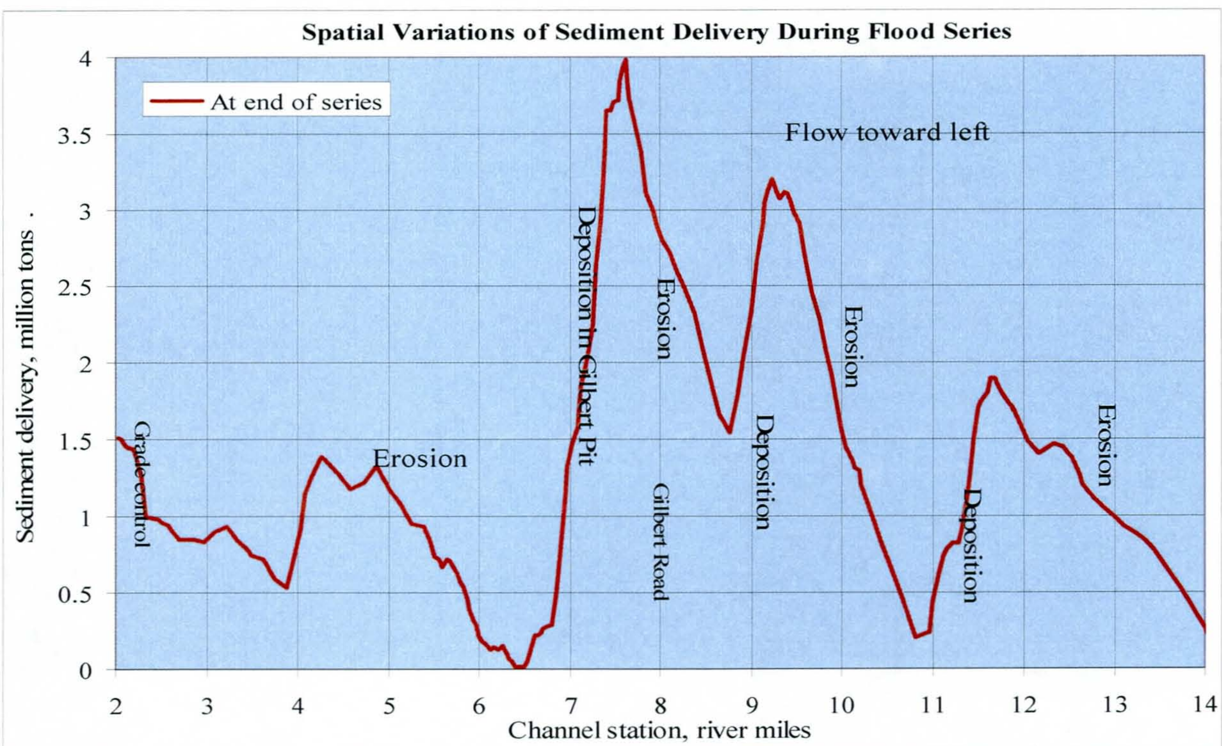
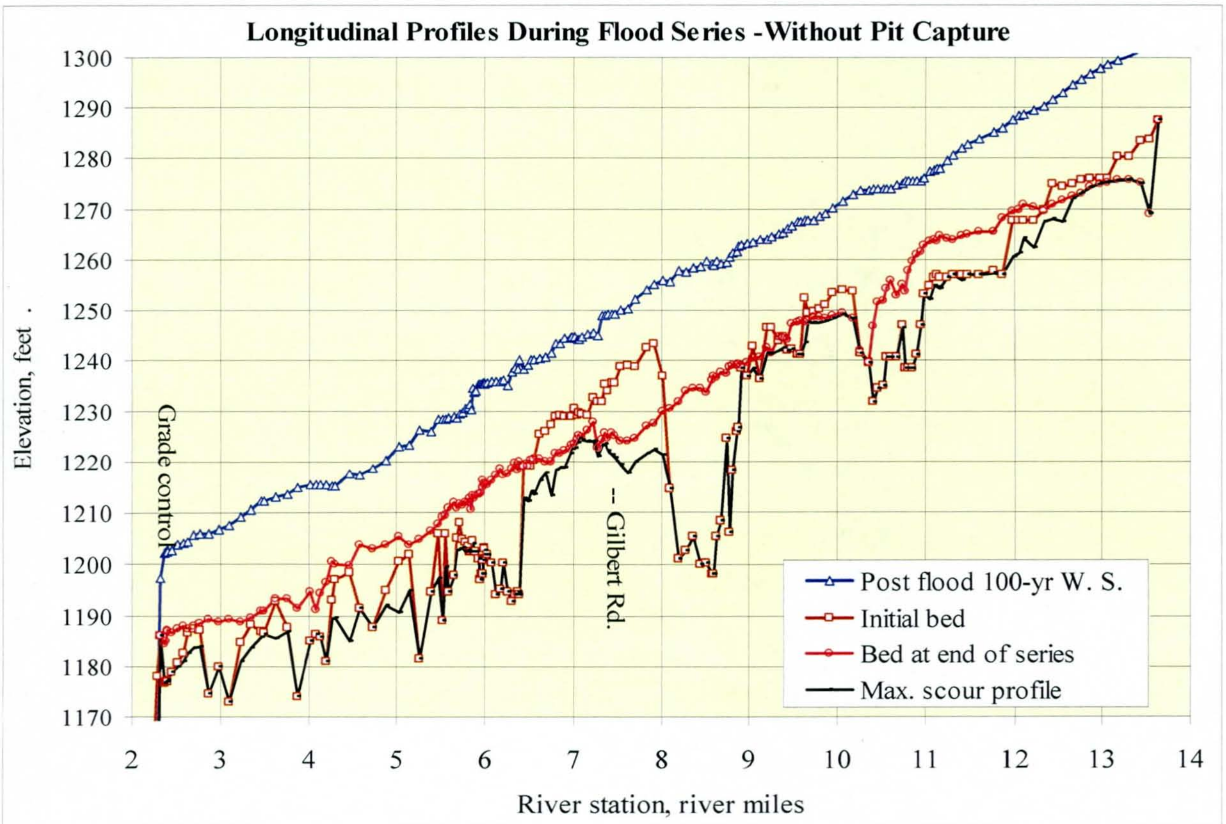


Figure 14. Spatial variation of sediment delivery along the Salt River
Upper figure: Without pit capture Lower figure: With pit capture

For other downstream river reaches, a drop in sediment delivery in the downstream direction is related to the presence of mining pits, which detain sediment to cause a decrease of delivery. The river reach from near Gilbert Road is between two mining sites. This river reach is subject to long term erosion. For the case of no pit capture, the sediment supply to the reach is the delivery at river mile 8.2 of 0.45 million tons; the sediment removal from the reach is the delivery at river mile 6.4 of 3.25 million tons. The difference of 2.8 million tons (3.25 million tons minus 0.45 million tons) is the sediment eroded from the reach of 1.8 miles in the long-term time span. For the case of pit capture, the sediment supply to the reach is the delivery at river mile 8.8 of 1.55 million tons; the sediment removal from the reach is the delivery at river mile 7.6 of 4.0 million tons. The difference of 2.45 million tons is the sediment eroded from the reach of 1.2 miles in the long-term time span. The erosion rate for the case of no pit capture is 1.56 million tons per mile for the case of no pit capture; it is 2.04 million tons per mile for the case of pit capture. In other words, pit capture will increase the erosion at the Gilbert Road crossing.

Simulated Changes in Longitudinal Profiles - Simulated longitudinal profiles along the river channel during the flood series are shown in Figure 15. The profiles consists of the post flood 100-yr water surface profile, the initial channel bed profile from the 2001 survey, the simulated channel bed profile at the end of flood series, and the channel bed profile for the maximum extent of channel bed scour. It is easy to see that pit capture will increase river channel scour in the long run.



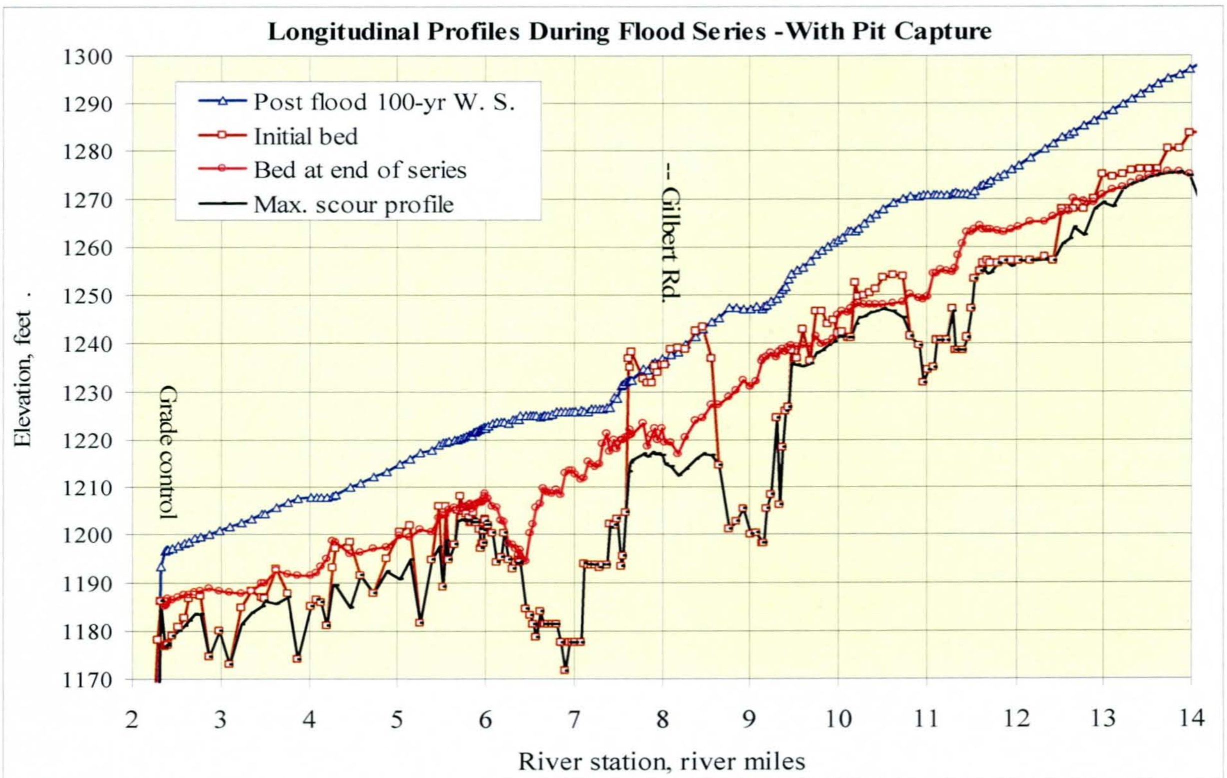
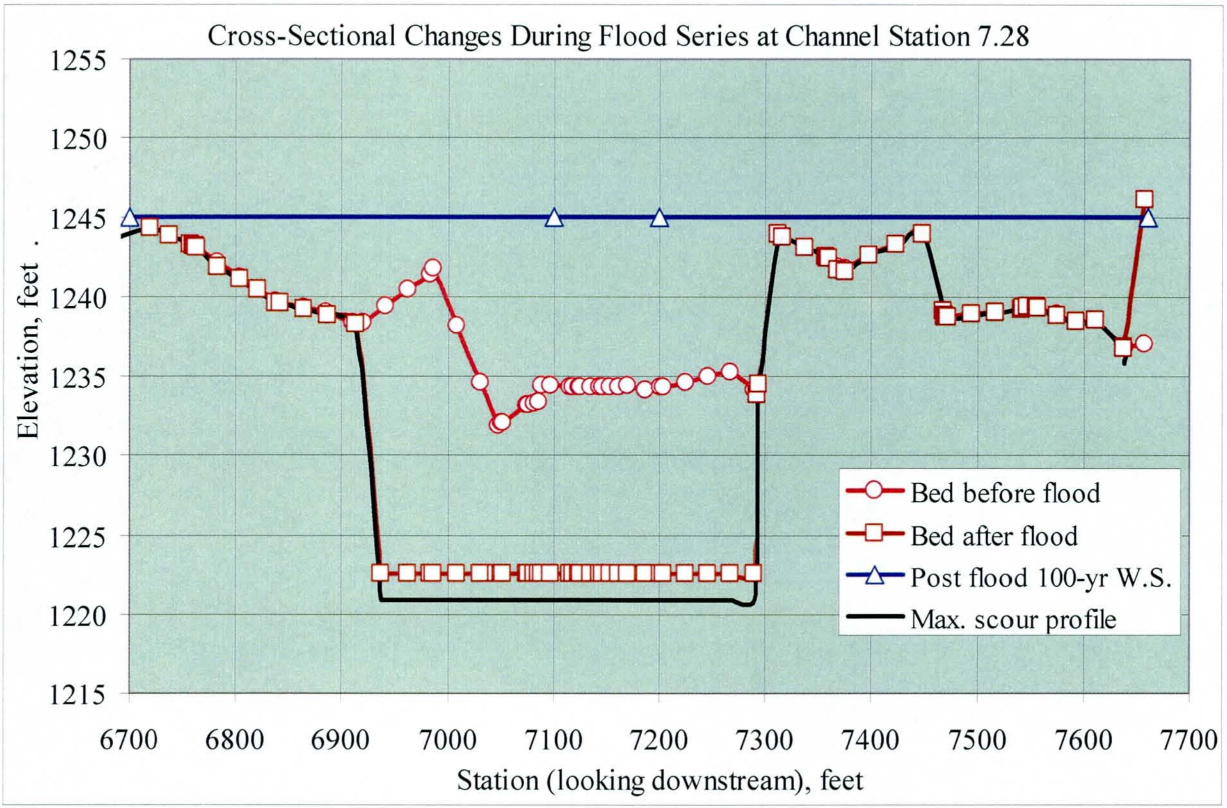


Figure 15. Water-surface and channel bed profile changes during the flood series
Upper figure: Without pit capture   Lower figure: With pit capture

It can be seen from Figure 15 that the study river reach is predicted to undergo major changes in channel bed profile in the long term even in the absence of pit capture. The changes are characterized by refill of the mining pits and erosion of their adjacent river reaches. The river reach from river mile 8 down to river mile 6.5 is simulated to undergo changes in both channel bed scour and refill (or degradation and aggradation). The channel bed profile at the end of flood series is lower than the initial channel bed profile; therefore, there would be channel bed scour. However, the channel bed profile at the end of flood series is higher than the maximum channel bed scour profile. The difference between these two profiles indicate refill that would occur during the later part of the flood series. This river reach is between two large mining pits. The downstream mining pit induces head cutting on this reach and the upstream pit causes tail-cutting on the reach. This process continues as the adjacent mining pits undergo refill. After the refill, these adjacent mining pits no longer cause head-cutting and tail-cutting. By that time, this river reach is expected to undergo refill as sediment supply resumes to this reach.

Changes in Cross-Sectional Profiles – In order to see the complete picture of channel changes, one also needs to view the changes in channel cross sections in addition to the longitudinal profiles. The computer output files for the study have the complete information for the longitudinal profile changes and cross-sectional changes. This study has its focus on the Salt River near the Gilbert Road crossing; therefore, only those cross-sectional changes near the Gilbert Road crossing are presented graphically below.

Figure 16 shows the cross-sectional changes during the flood series for those channel stations near the Gilbert Road crossing. Each figure has the initial cross-sectional profile based on the 2001 survey, the simulated cross-sectional profile at the of the flood series, the simulated maximum scour profile together with the post flood 100-yr water surface. The predicted long-term changes at these river stations are greater in magnitude than those occurred during the 2005 flood. When the simulated results for the case of no pit capture are compared with those for the case of pit capture, it is easy to see that more scour develops under the case of pit capture.



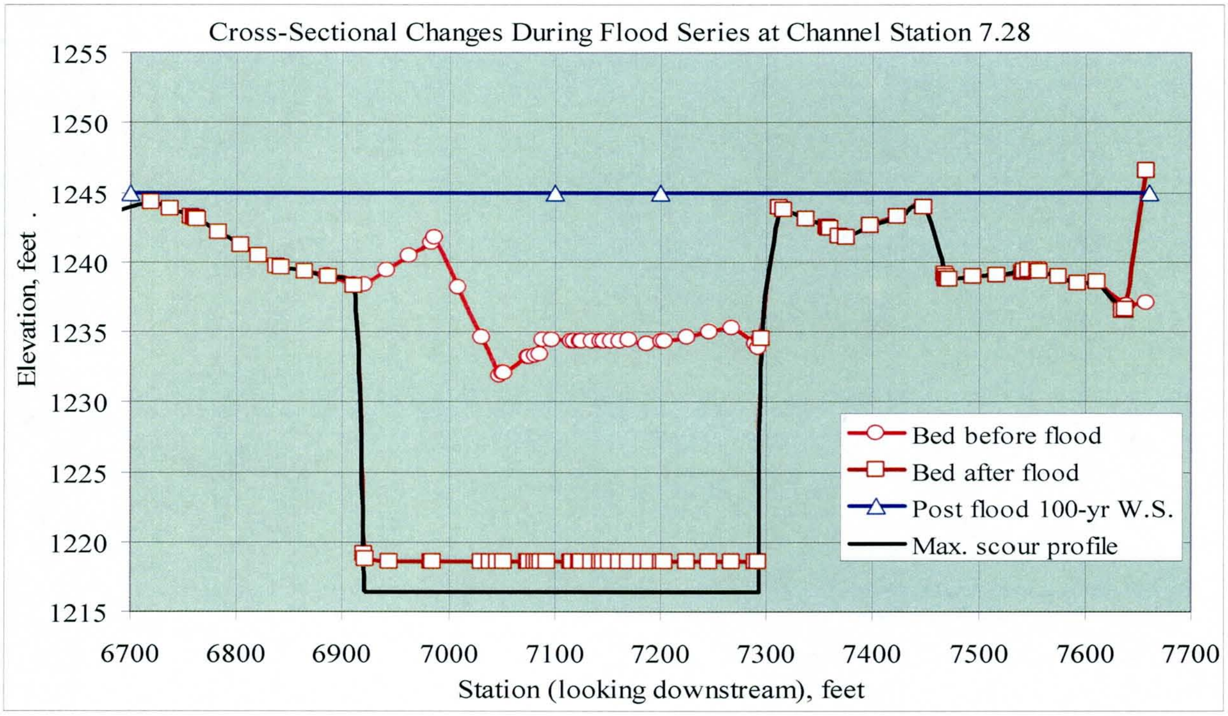
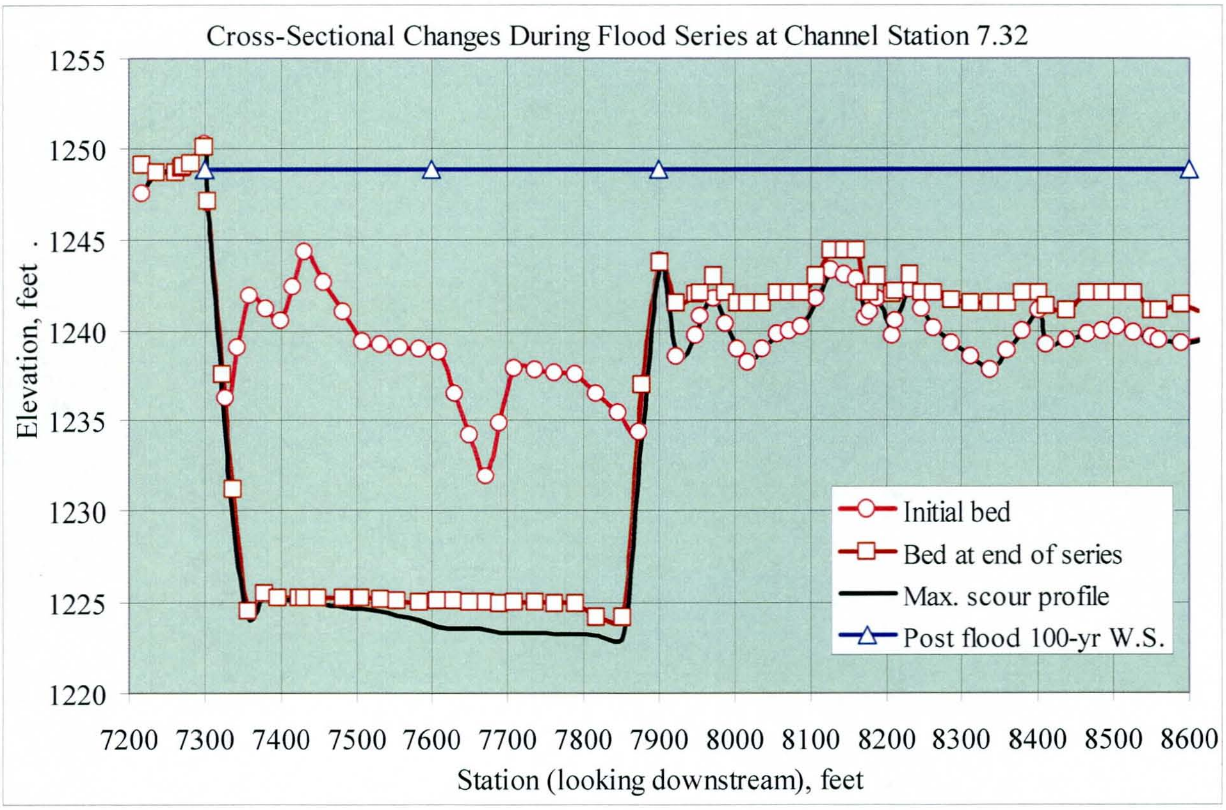


Figure 16. Sample cross-sectional profile changes during the flood series
Upper figure: Without pit capture Lower figure: With pit capture



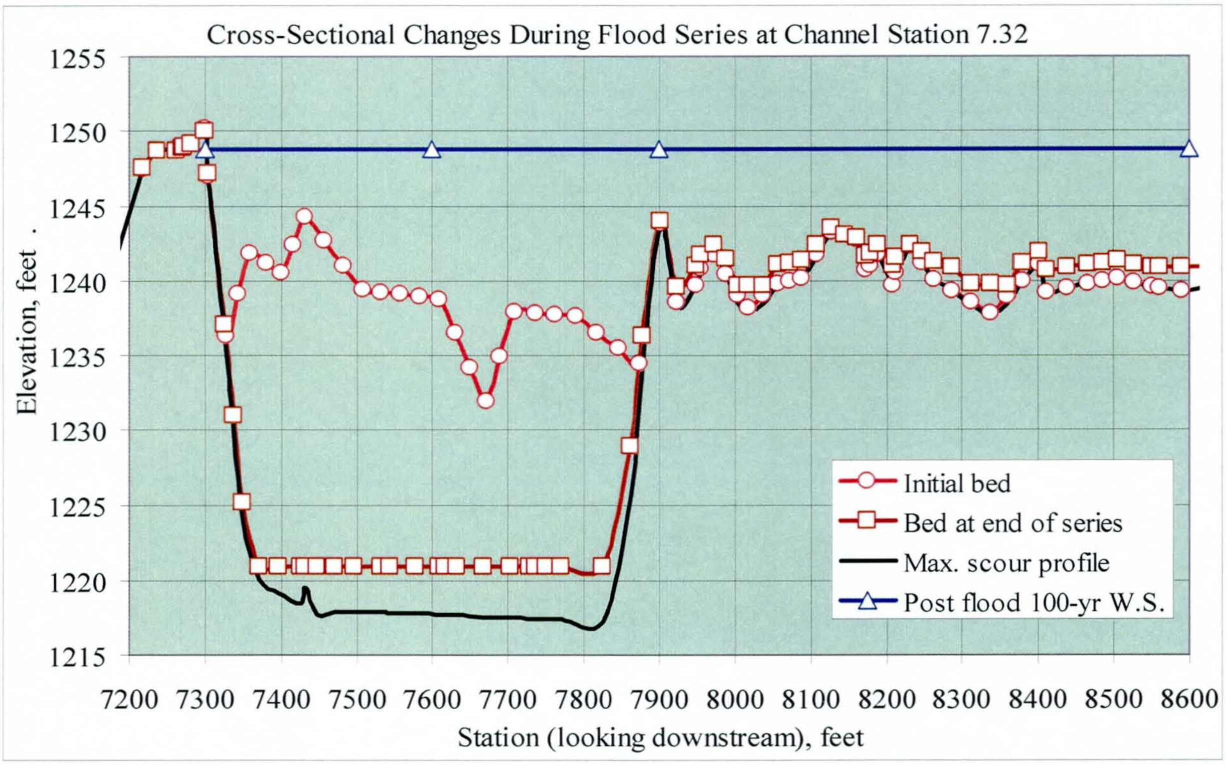
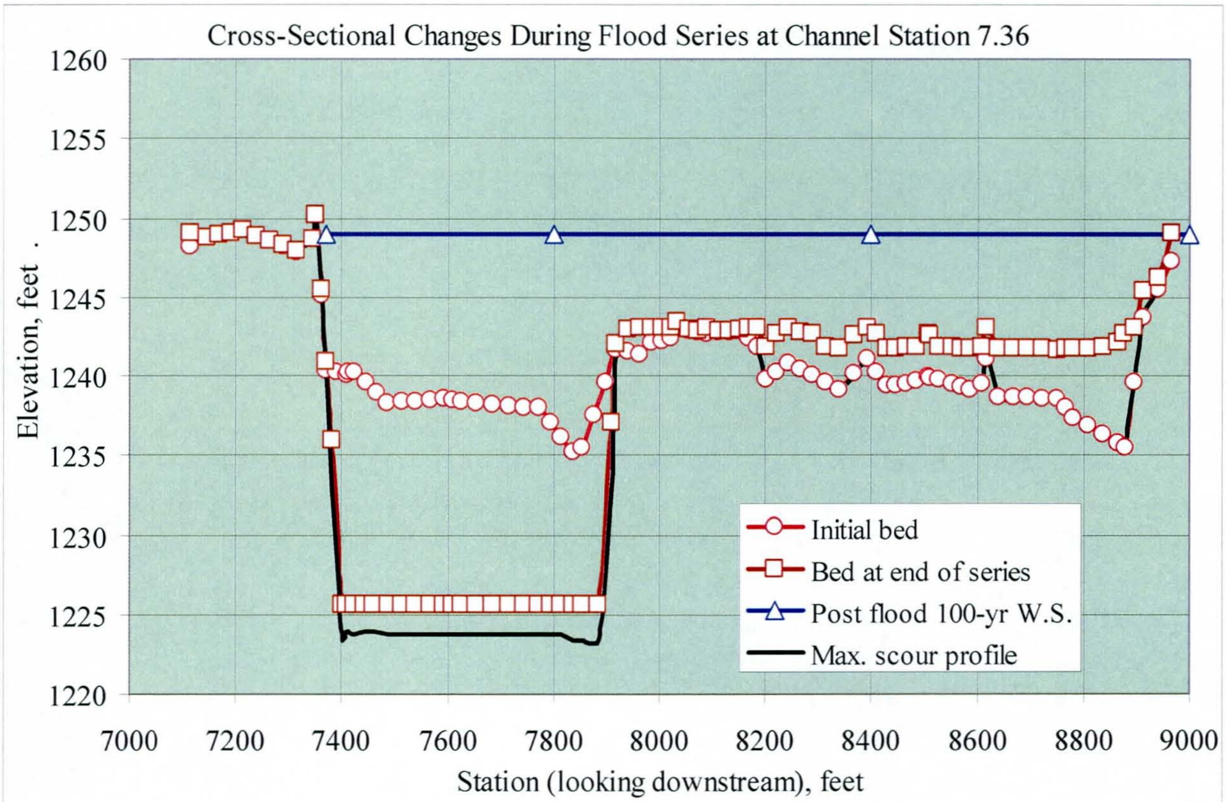


Figure 16 (continued). Sample cross-sectional profile changes during the flood series
Upper figure: Without pit capture Lower figure: With pit capture



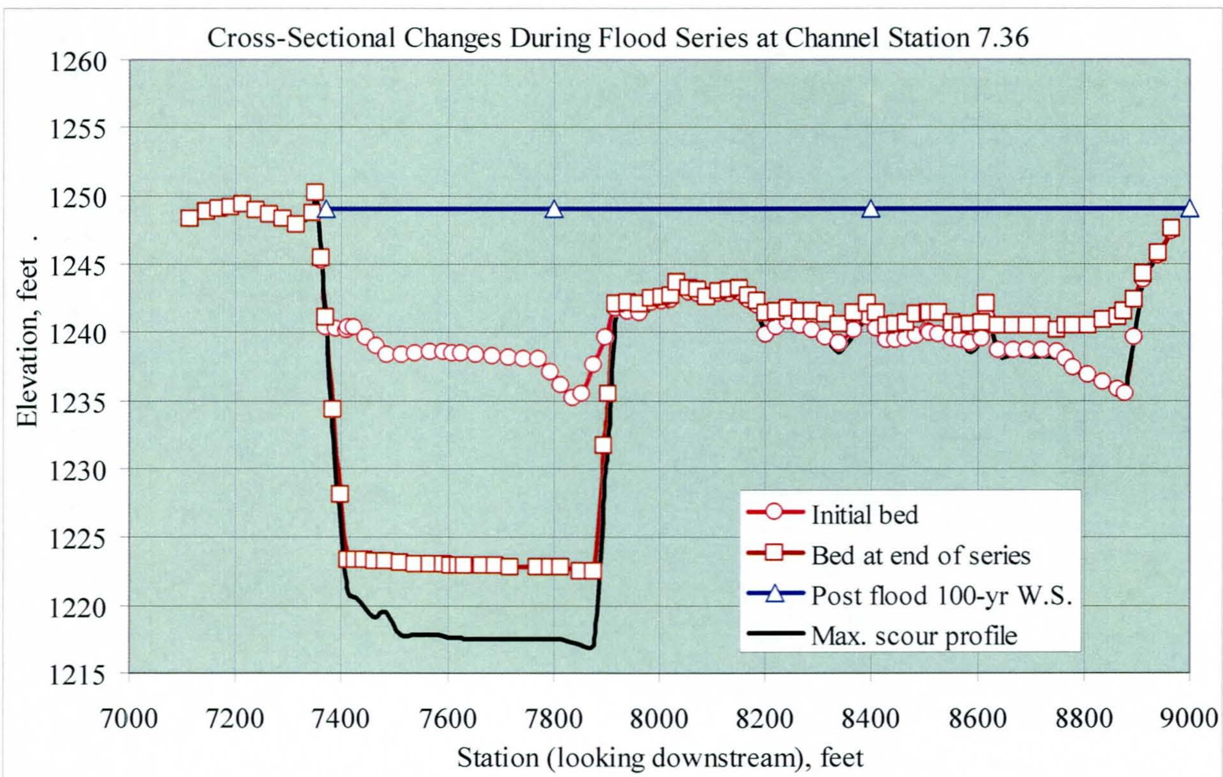
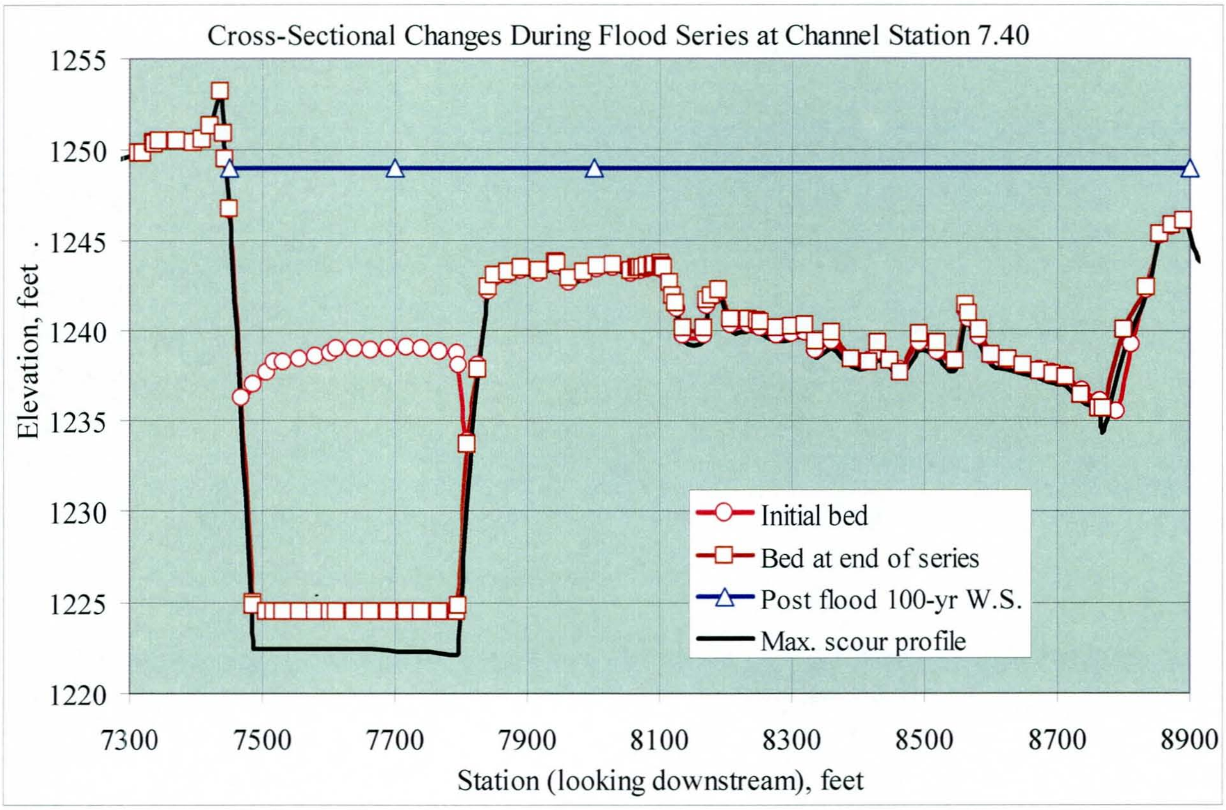


Figure 16 (continued). Sample cross-sectional profile changes during the flood series
Upper figure: Without pit capture Lower figure: With pit capture



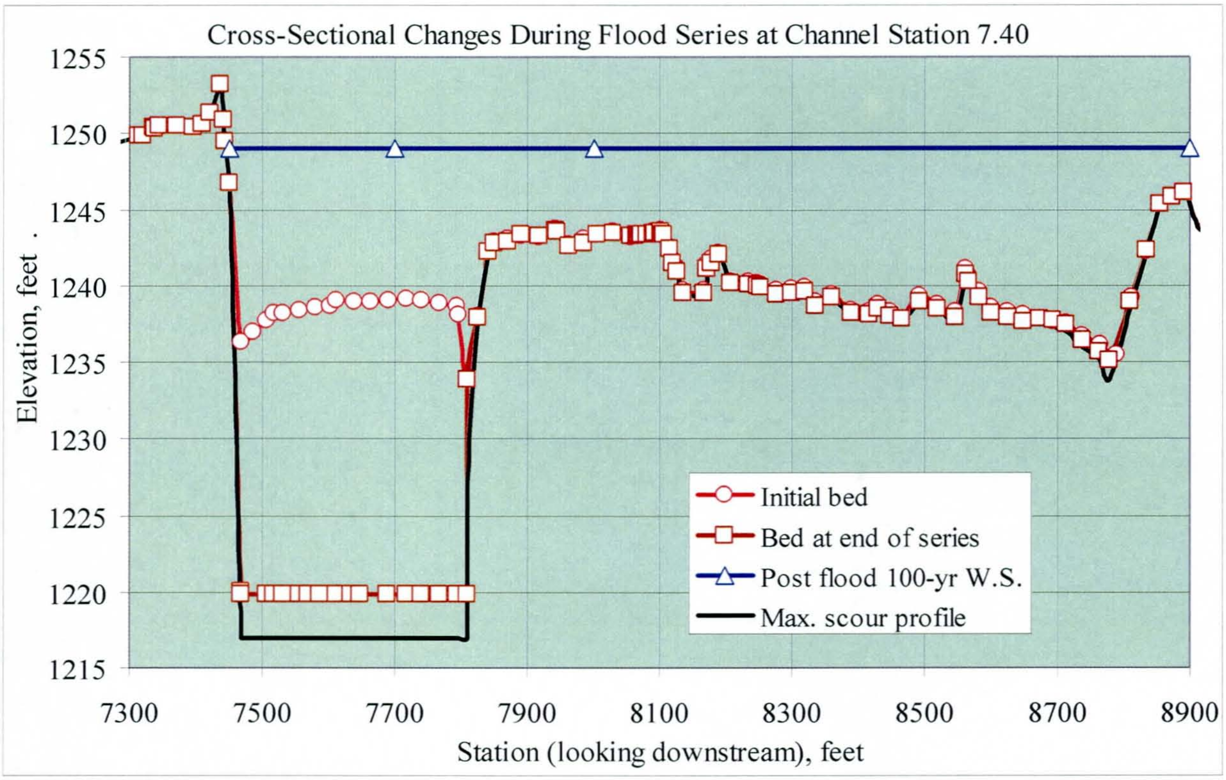
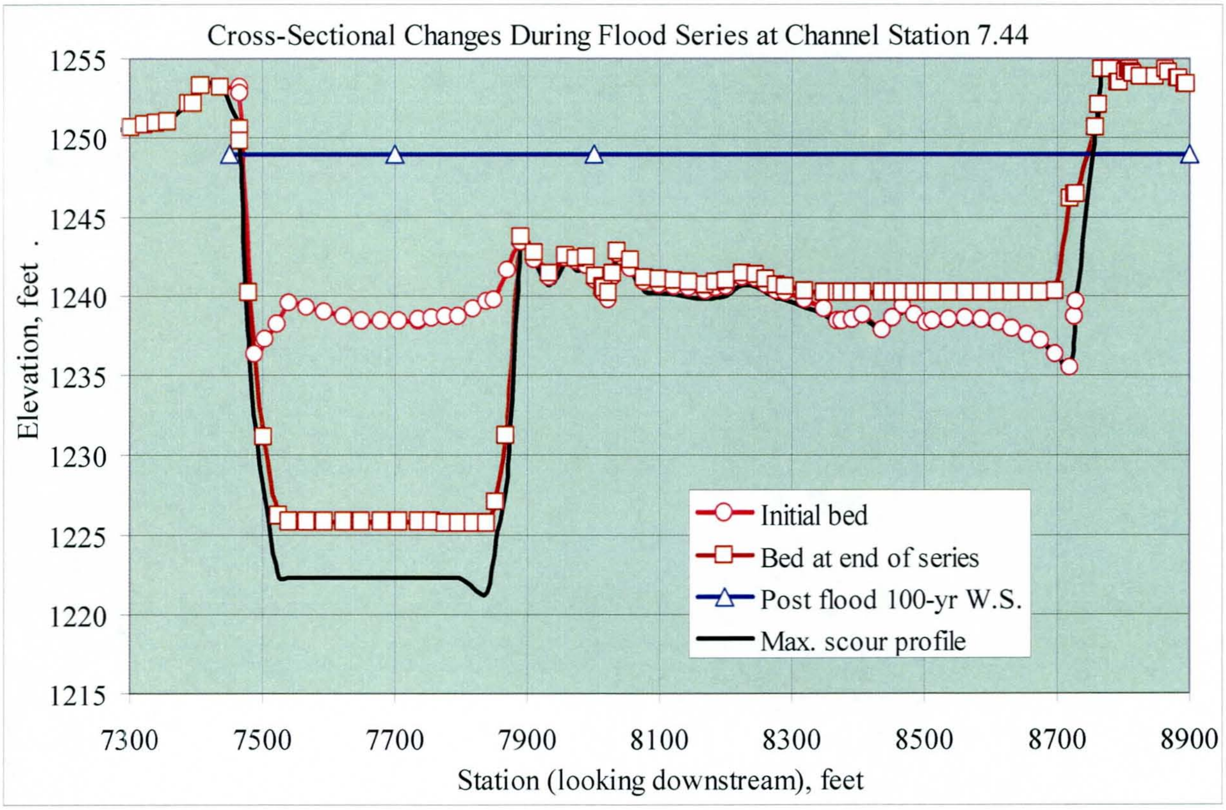


Figure 16 (continued). Sample cross-sectional profile changes during the flood series
Upper figure: Without pit capture Lower figure: With pit capture



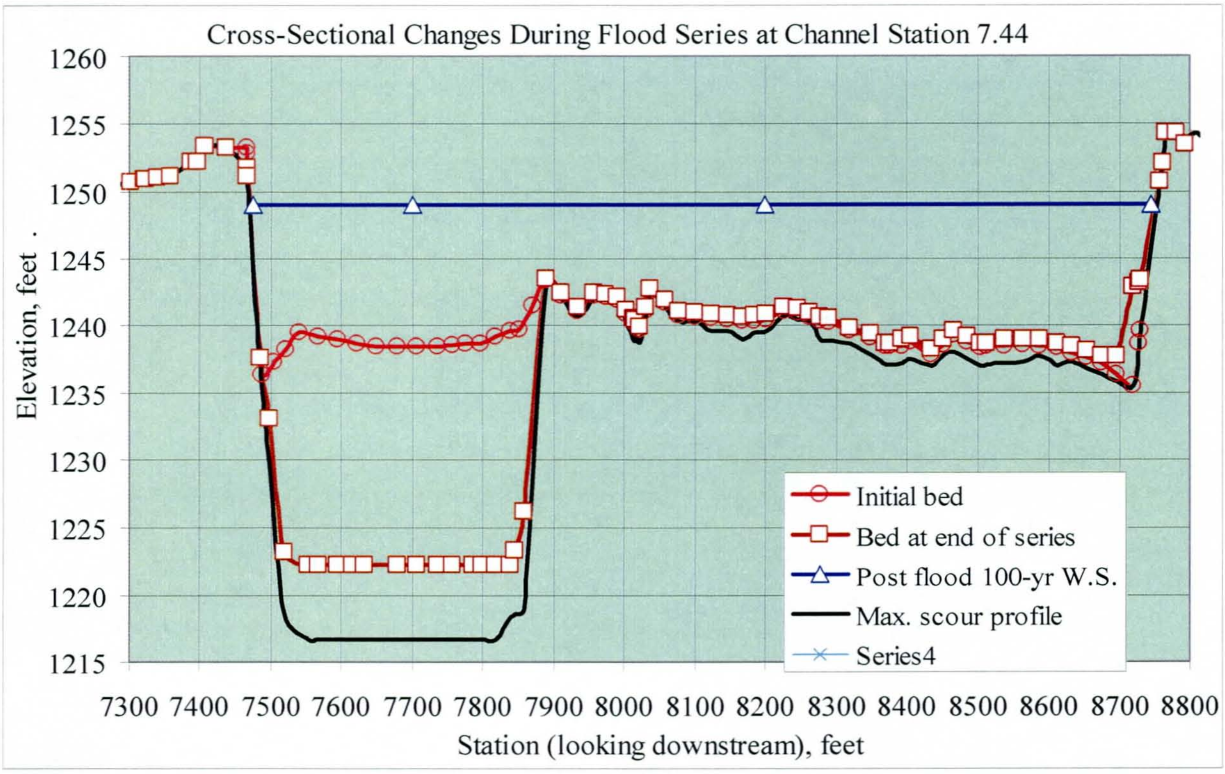
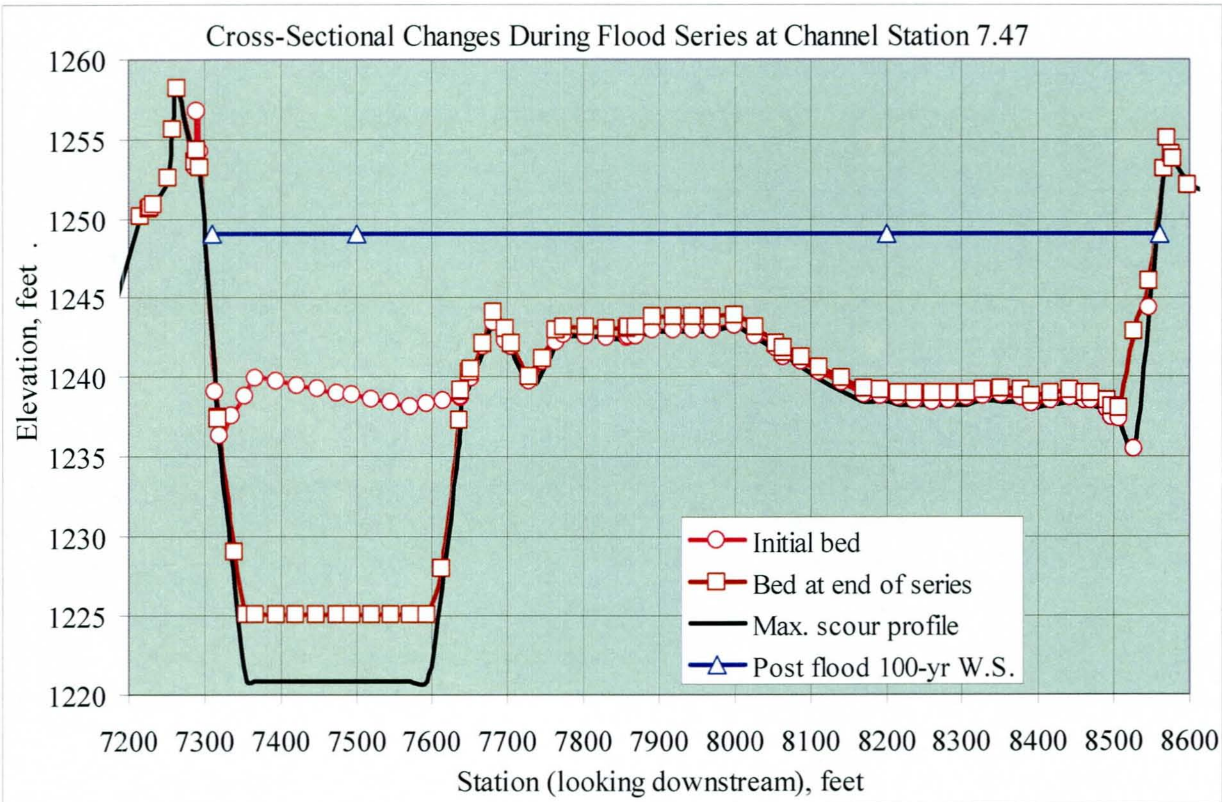


Figure 16 (continued). Sample cross-sectional profile changes during the flood series
Upper figure: Without pit capture Lower figure: With pit capture



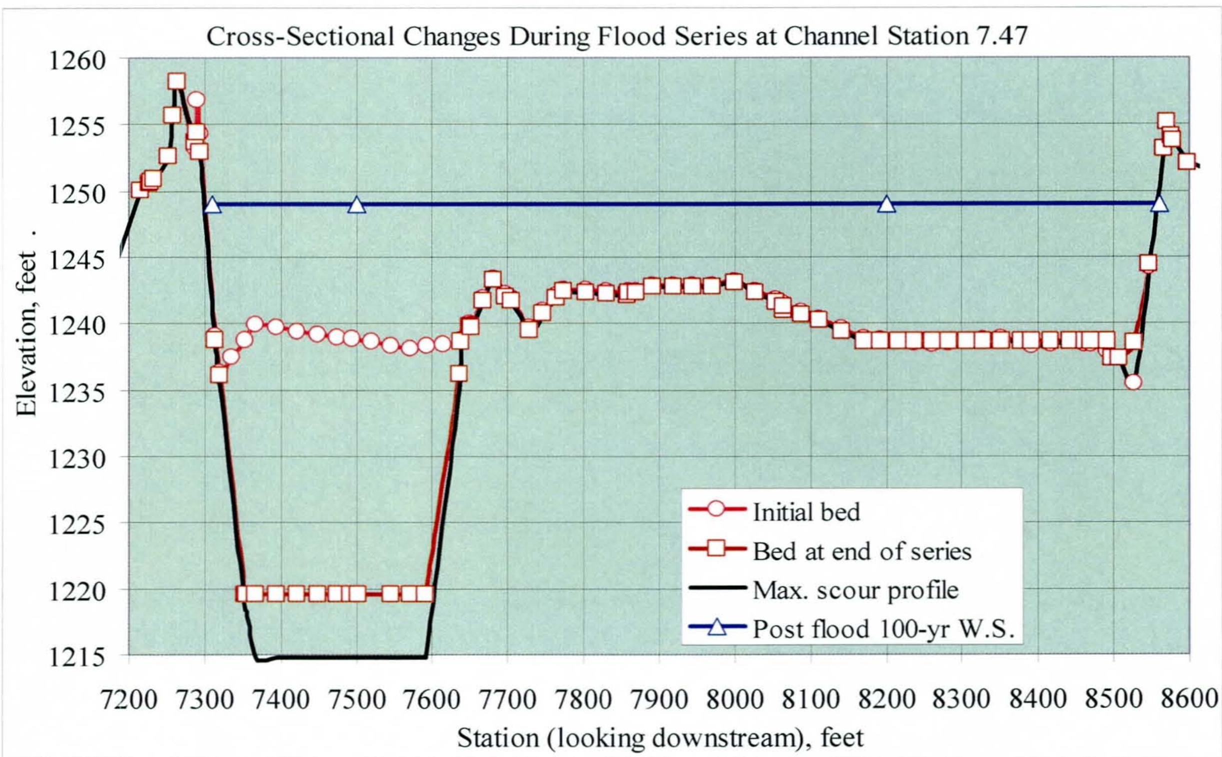
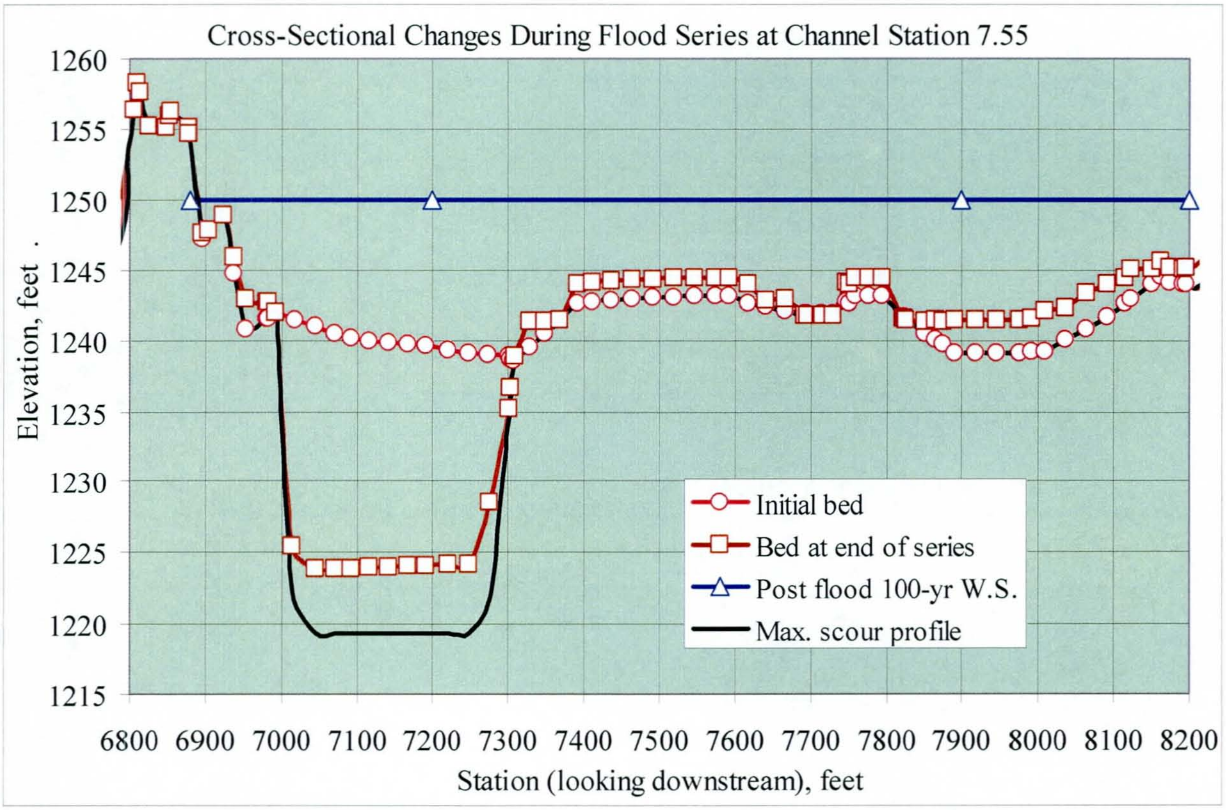


Figure 16 (continued). Sample cross-sectional profile changes during the flood series
Upper figure: Without pit capture Lower figure: With pit capture



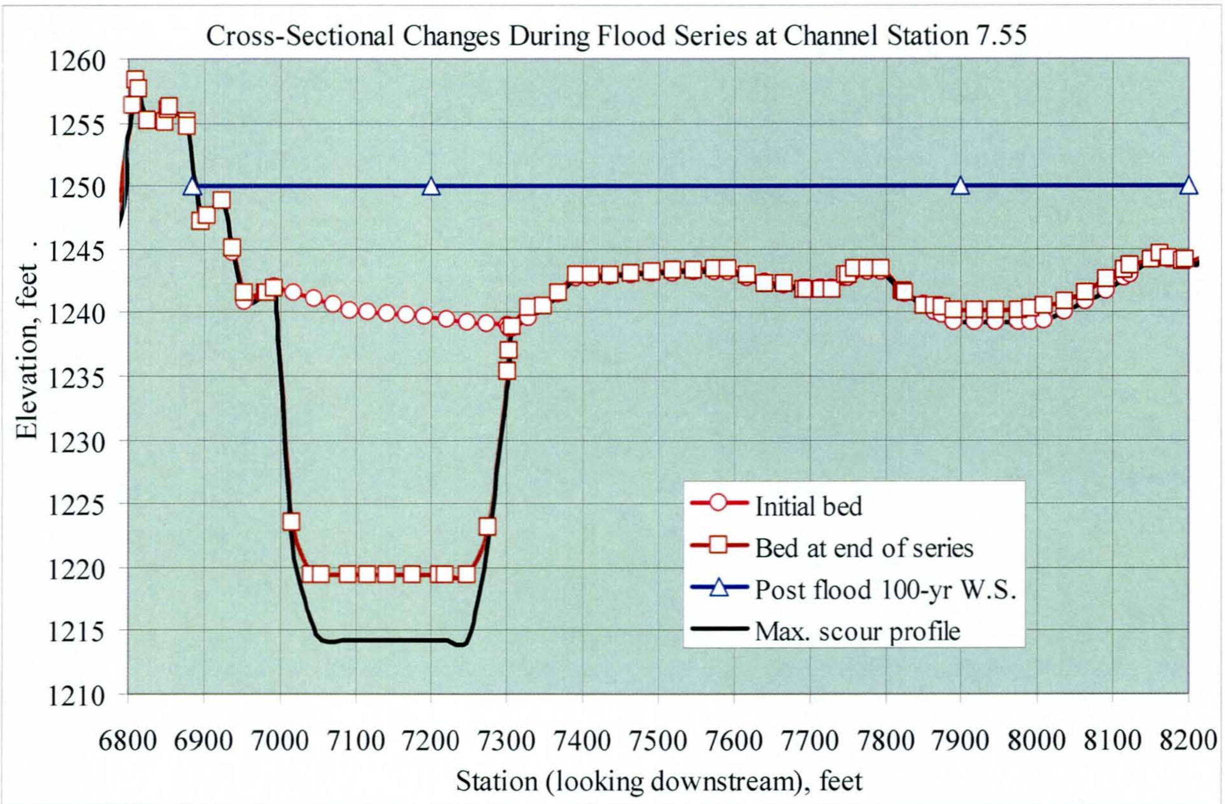
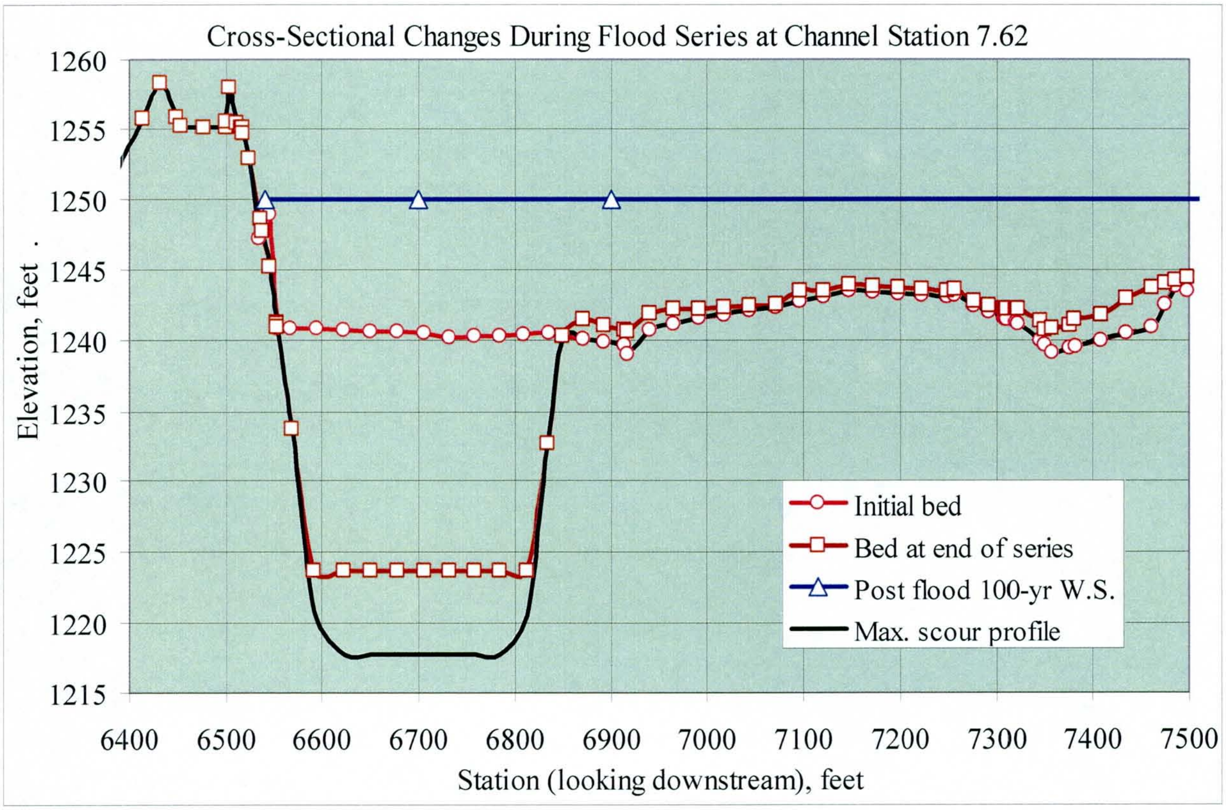


Figure 16 (continued). Sample cross-sectional profile changes during the flood series
Upper figure: Without pit capture Lower figure: With pit capture



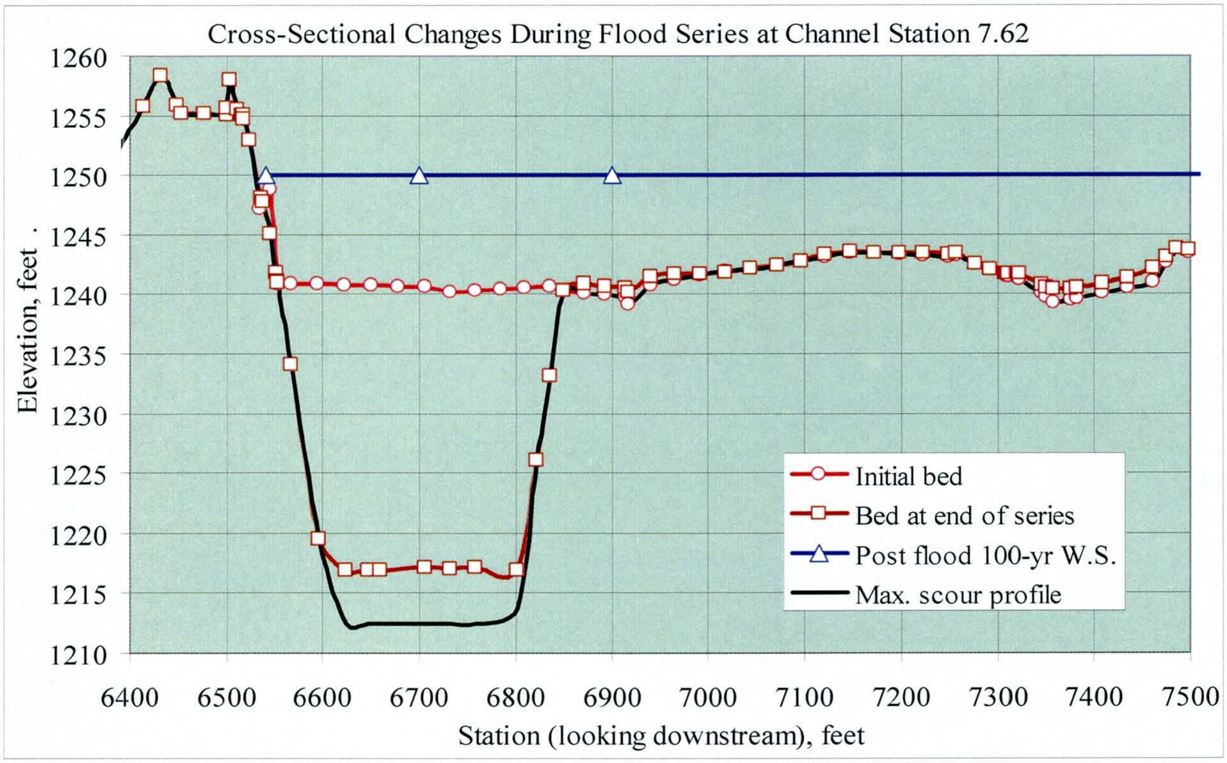


Figure 16 (continued). Sample cross-sectional profile changes during the flood series
Upper figure: Without pit capture Lower figure: With pit capture

VII. SUMMARY AND CONCLUSIONS

The Salt River near Gilbert Road in Maricopa County, Arizona underwent major changes in channel geometry during the 2005 flood. Such changes in channel geometry are related to pit capture, which occurred as flood water overtopped the berm separating the main channel from the deep Gilbert mining pit. The channel geometry data before and after the flood event are available together with the flood hydrograph.

Sediment transport and river channel changes for the Salt River has been simulated using the FLUVIAL-12 computer model. This scope of modeling covers the following tasks: (1) simulation of river channel changes caused by the 2005 flood, (2) comparison of simulated results with the surveyed channel geometry, and (3) prediction of long-term river channel changes in the future. The data used for the Salt River study are taken from previous studies covering the hydrology, hydraulics and geomorphology of the stream channel.

River Channel Changes during the 2005 Flood - The 2005 flood has the peak discharge exceeding 40,000 cfs and a long duration over three months; it was the most important event for the period from 2001 to 2007. Other events for the same period are much smaller in discharge and shorter in duration.

River channel changes during the 2005 flood with pit capture were simulated for the 2005 flood. The simulated river channel changes were compared with the measured changes. The short channel reach near the Gilbert Road crossing is between two major mining pits. This channel reach is simulated to undergo major channel bed degradation of about 10 feet.

The simulated results for river stations near the Gilbert Road crossing are presented together with the measured post-flood cross-sectional profiles. The cross-sectional profiles as simulated are compared with the measured profiles. Changes along this channel reach are characterized by channel bed scour along the main channel. The total amount of channel bed scour as simulated is similar to the measured amount. The total depth of channel bed degradation is also similar. However, the simulated and measured cross-sectional profiles have significant differences. While the simulated and measured scours are similar in pattern, they have somewhat different locations. The simulated channel bed scour is near the thalweg; the measured scour may be away from the thalweg. The causes for such discrepancy may be due to lateral migration of the thalweg, which is not considered in the model simulation; or it may be due to survey inaccuracy. In fact, the overbank areas for the cross sections from the 2001 survey do no always match the corresponding ones from the 2007 survey. The overbank areas were not affected by river channel scour; there should be no big differences in geometry. However, such differences do exist at several river stations.

The simulated cross-sectional profiles may have an uneven channel bed, while those from the 2007 topographic survey are quite smooth. One possible reason why there are differences is that the 2007 topography was developed from contours. In the process, local variations in bed elevation may be ignored and wide flat area may thus be shown as flat bed.

Long-Term River Channel Changes - The Gilbert mining pit is separated from the main channel of the Salt River by a berm. There also exist instream mining pits located both upstream and downstream of the Gilbert Road crossing. The long-term river channel changes for this reach of the Salt River have been simulated for the two following cases: (1) without pit capture (by the Gilbert mining pit) and (2) with pit capture. The hydrograph for a long-term flood series was used. For the case of no pit capture, the study river reach is predicted to undergo major changes. The changes are characterized by refill of the mining pits and erosion of their adjacent river reaches. The river reach near the Gilbert Road crossing is simulated to undergo changes in both channel bed scour and refill (or degradation and aggradation). The channel bed profile at the end of flood series is lower than the initial channel bed profile. However, the channel bed profile at the end of flood series is higher than the maximum channel bed scour profile. The difference between these two profiles indicate refill would occur during the later part of the flood series.

The downstream mining pit induces head cutting on this reach and the upstream pit causes tail-cutting on the reach. This process continues as the adjacent mining pits undergo refill. After the refill, these adjacent mining pits no longer cause head-cutting and tail-cutting. By that time, this river reach is expected to undergo refill as sediment supply resumes to this reach. Long-term changes with pit capture (by off-stream the Gilbert mining pit) have also been simulated. Pit capture will increase potential river channel scour. However, it should be noted that the long-term simulations only simulate the existing geometries of the sand and gravel pits and that any future or continued excavation is not simulated.

In summary, the computer output files for the study have the complete information for the longitudinal profile changes and cross-sectional changes. This study has its focus on the Salt River near the Gilbert Road crossing; therefore, only those cross-sectional changes near the Gilbert Road crossing are presented graphically. Each figure has the initial cross-sectional profile based on the 2001 survey, the simulated cross-sectional profile at the of the flood series, the simulated maximum scour profile together with the post flood 100-yr water surface. The predicted long-term changes at these river stations are greater in magnitude than those that occurred during the 2005 flood.

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APPENDIX A. INPUT/OUTPUT DESCRIPTIONS FOR FLUVIAL-12

I. INPUT DESCRIPTION

The basic data requirements for a modeling study include (1) topographic maps of the river reach from the downstream end to the upstream end of study, (2) digitized data for cross sections in the HEC-2 format with cross-sectional locations shown on the accompanying topographic maps, (3) flow records or flood hydrographs and their variations along the study stream reach, it any, and (4) size distributions of sediment samples along the study reach. Additional data are required for special features of a study river reach.

The HEC-2 format for input data is used in all versions of the FLUVIAL model. Data records for HEC-2 pertaining to cross-sectional geometry (X1 and GR), job title (T1, T2, and T3), and end of job (EJ), are used in the FLUVIAL model. If a HEC-2 data file is available, it is not necessary to delete the unused records except that the information they contain are not used in the computation. For the purpose of water- and sediment-routing, additional data pertaining to sediment characteristics, flood hydrograph, etc., are required and supplied by other data records. Sequential arrangement of data records are given in the following.

Records	**Description of Record Type**
T1,T2,T3	Title Records
G1	General Use Record
G2	General Use Records for Hydrographs
G3	General Use Record
G4	General Use Record for Selected Cross-Sectional Output
G5	General Use Record
G6	General Use Record for Selecting Times for Summary Output
G7	General Use Record for Specifying Erosion Resistant Bed Layer
GS	General Use Records for Initial Sediment Compositions
GB	General Use Records for Time Variation of Base-Level
GQ	General Use Records for Stage-Discharge Relation of Downstream Section
GI	General Use Records for Time Variation of Sediment Inflow
X1	Cross-Sectional Record
XF	Record for Specifying Special Features of a Cross Section
GR	Record for Ground Profile of a Cross Section
SB	Record for Special Bridge Routine
BT	Record for Bridge Deck Definition
EJ	End of Job Record

Variable locations for each input record are shown by the field number. Each record has an input format of (A2, F6.0, 9F8.0). Field 0 occupying columns 1 and 2 is reserved for the required record identification characters. Field 1 occupies columns 3 to 8; Fields 2 to 10 occupy 8 columns each. The data records are tabulated and described in the following.

T1, T2, T3 Records - These three records are title records that are required for each job.

Field	Variable	Value	Description
0	IA	T1	Record identification characters
1-10	None		Numbers and alphameric characters for title

G1 Record - This record is required for each job, used to enter the general parameters listed below. This record is placed right after the T1, T2, and T3 records.

Field	Variable	Value	Description
0	IA	G1	Record identification characters
1	TYME	+	Starting time of computation on the hydrograph, in hours
2	ETIME	+	Ending time of computation on the hydrograph, in hours
3	DTMAX	+	Maximum time increment Δt allowed, in seconds
4	ISED	1	Select Graf's sediment transport equation.
		2	Select Yang's unit stream power equation. The sediment size is between 0.063 and 10 mm.
		3	Select Engelund-Hansen sediment equation.
		4	Select Parker gravel equation.
		5	Select Ackers-White sediment equation.
		6	Select Meyer-Peter Muller equation for bed load.
5	BEF	+	Bank erodibility factor for the study reach. This value is used for each section unless otherwise specified in Field 9 of the XF and 1 may be used.
6	IUC	0	English units are used in input and output.
		1	Metric units are used in input and output.
7	CNN	+	Manning's *n* value for the study reach. This value is used for a section unless otherwise specified in Field 4 of the XF record. If bed roughness is computed based upon alluvial bedforms as specified in Field 5 of the G3 record, only an approximate *n* value needs to be entered here.
8	PTM1	+	First time point in hours on the hydrograph at which summary output and complete cross-sectional output are requested. It is usually

			the peak time, but it may be left blank if no output is requested.
9	PTM2	+	Second time point on the hydrograph in hours at which summary usually the time just before the end of the simulation. This field may be left blank if no output is needed.
10	KPF	+	Frequency of printing summary output, in number of time steps.

G2 Records - These records are required for each job, used to define the flow hydrograph(s) in the channel reach. The first one (or two) G2 records are used to define the spatial variation in water discharge along the reach; the succeeding ones are employed to define the time variation(s) of the discharge. Up to 10 hydrographs, with a maximum of 120 points for each, are currently dimensioned. See section II for tributaries. These records are placed after the G1 record.

Field	**Variable**	**Value**	**Description**
First G2			
0	IA	G2	Record identification characters
1	IHP1	+	Number of last cross section using the first (downstream most) hydrograph. The number of section is counted from downstream to upstream with the downstream section number being one. See also section II.
2	NP1	+	Number of points connected by straight segments used to define
3	IHP2	+	Number of last section using the second hydrograph if any. Otherwise leave it blank.
4	NP2	+	Number of points used to define the second hydrograph if any. Otherwise leave it blank.
5	IHP3	+	Number of last section using the third hydrograph if any. Otherwise leave it blank.
6	NP3	+	Number of points used to define the third hydrograph if any. Otherwise leave it blank.
7	IHP4	+	Number of last section using the fourth hydrograph if any. Otherwise leave it blank.
8	NP4	+	Number of points used to define the fourth hydrograph if any. Otherwise leave it blank.
9	IHP5	+	Number of last section using the fifth hydrograph if any. Otherwise leave it blank.

10	NP5	+	Number of points used to define the fifth hydrograph if any. Otherwise leave it blank.

Second G2: Note that this record is used only if more than 5 hydrographs are used for the job. It is necessary to place a negative sign in front of NP5 located in the 10th field of the first G2 record as a means to specify that more than 5 hydrographs are used.

0	IA	G2	Record identification characters
1	IHP6	+	Number of last cross section using the sixth hydrograph if any. Otherwise leave it blank.
2	NP6	+	Number of points connected by straight segments used to define
3	IHP7	+	Number of last section using the seventh hydrograph if any. Otherwise leave it blank.
4	NP7	+	Number of points used to define the seventh hydrograph
5	IHP8	+	Number of last section using the eighth hydrograph if any. Otherwise leave it blank.
6	NP8	+	Number of points used to define the eighth hydrograph
7	IHP9	+	Number of last section using the ninth hydrograph if any. Otherwise leave it blank.
8	NP9	+	Number of points used to define the ninth hydrograph
9	IHP10	+	Number of last section using the tenth hydrograph if any. Otherwise leave it blank.
10	NP10	+	Number of points used to define the tenth hydrograph

Succeeding G2 Record(s)

1	Q11, Q21 Q31	+	Discharge coordinate of point 1 for each hydrograph, in ft^3/sec or m^3/sec
2	TM11,TM21 TM31	+	Time coordinate of point 1 for each hydrograph, in hours
3	Q12, Q22 Q32	+	Discharge coordinate of point 2 for each hydrograph, in cfs or cms
4	TM12,TM22 TM32	+	Time coordinate of point 2 for each hydrograph, in hours

Continue with additional discharge and time coordinates. Note that time coordinates must be in increasing order.

G3 Record - This record is used to define required and optional river channel features for a job as listed below. This record is placed after the G2 records.

Field	Variable	Value	Description
0	IA	G3	Record identification characters
1	S11	+	Slope of the downstream section, required for a job
2	BSP	0	One-on-one slope for rigid bank or bank protection
		+	Slope of bank protection in BSP horizontal units on 1 vertical unit. for all cross sections unless otherwise specified in Field 8 of the XF record for a section.
3	DSOP	0	Downstream slope is allowed to vary during simulation.
		1	Downstream slope is fixed at S11 given in Field 1.
4	TEMP	0	Water temperature is 15°C.
		+	Water temperature in degrees Celsius
5	ICNN	0	Manning's n defined in Field 7 of the G1 record or those in Field 4 of the XF records are used.
		1	Brownlie's formula for alluvial bed roughness is used to calculate Manning's n in the simulation.
6	TDZAMA	0	Thickness of erodible bed layer is 100 ft (30.5 m).
		+	Thickness of erodible bed layer in ft or m. This value is applied to
7	SPGV	0	Specific gravity of sediment is 2.65.
		+	Specific gravity of sediment
8	KGS	0	The number of size fractions for bed material is 5.
		+	The number of size fractions for bed material. It maximum value is 8.
9	PHI	0	The angle of repose for bed material is 36°.
		+	Angle of repose for bed material

G4 Record - This is an optional record used to select cross sections (up to 4) to be included at each summary output. Each cross section is identified by its number which is counted from the downstream section. This record also contains other options; it is placed after the G3 record.

Field	Variable	Value	Description
0	IA	G4	Record identification characters

1	IPLT1	+	Number of cross section
2	IPLT2	+	Number of cross section
3	IPLT3	+	Number of cross section
4	IPLT4	+	Number of cross section
5	IEXCAV	+	A positive integer indicates number of cross section where sand/gravel excavation occurs.
6	GIFAC	+	A non-zero constant is used to modify sediment inflow at the upstream section.
7	PZMIN	0	Minimum bed profile during simulation run is not requested.
		1	Output file entitled TZMIN for minimum bed profile is requested.
10	REXCAV	+	A non-zero value specifies rate of sand/gravel excavation at Section IEXCAV.

G5 Record - This is an optional record used to specify miscellaneous options, including unsteady-flow routing for the job based upon the dynamic wave, bend flow characteristics. If the unsteady flow option is not used, the water-surface profile for each time step is computed using the standard-step method. When the unsteady flow option is used, the downstream water-surface elevation must be specified using the GB records.

Field	Variable	Value	Description
0	IA	G5	Record identification characters
1	DT	0	The first time step is 100 seconds.
		+	Size of the first time step in seconds.
2	IROUT	0	Unsteady water routing is not used; water-surface profiles are computed using standard-step method.
		1	Unsteady water-routing based upon the dynamic wave is used to compute stages and water discharges at all cross sections for each
3	PQSS	0	No output of gradation of sediment load
		3	Gradation of sediment load is included in output in 1,000 ppm by weight.
5	TSED	0	Rate of tributary sediment inflow is 1 times the discharge ratio.
		+	Rate of tributary sediment inflow is TSED times the discharge ratio.

6	PTV	0	No output of transverse distribution of depth-averaged velocity
		1	Transverse distribution of depth-averaged velocity is printed. The velocity distribution is for bends with fully developed transverse flow.
10	DYMAX	0	No GR points are inserted for cross sections.
		+	Maximum value of spacing between adjacent points at a cross

G6 Record - This is an optional record used to select time points for summary output. Up to 30 time points may be specified. The printing frequency (KPF) in Field 10 of the G1 Record may be suppressed by using a large number such as 9999.

Field	Variable	Value	Description
First G6 Record			
0	IA	G6	Record identification characters
1	NKPS	+	Number of time points
Succeeding G6 Record(s)			
0	IA	G6	Record identification characters
1	SPTM(1)	+	First time point, in hours
2	SPTM(2)	+	Second time point, in hours

Continue with additional time points.

G7 Record - This is an optional record used to specify erosion resistant bed layer, such as a caliche layer, that has a lower rate of erosion.

Field	Variable	Value	Description
First G7 Record			
0	IA	G7	Record identification characters
1	KG7	+	Number of time points used to define the known erosion rate in relation to flow velocity
2	THICK	+	Thickness of erosion resistant layer, in feet
Succeeding G7 Record(s)			
0	IA	G7	Record identification characters
1	ERATE(1)	+	Erosion rate, in feet per hour

2	G7V(2)	+	Velocity, in feet per second

Continue with additional time points.

GS Record - At least two GS records are required for each job, used to specify initial bed-material compositions in the channel at the downstream and upstream cross sections. The first GS record is for the downstream section; it should be placed before the first X1 record and after the G4 record, if any. The second GS record is for the upstream section; it should be placed after all cross-sectional data and just before the EJ record. Additional GS records may be inserted between two cross sections within the stream reach, with the total number of GS records not to exceed 15. Each GS record specifies the sediment composition at the cross section located before the record. From upstream to downstream, exponential decay in sediment size is assumed for the initial distribution. Sediment composition at each section is represented by five size fractions.

Field	Variable	Value	Description
0	IA	GS	Record identification characters
1	DFF	+	Geometric mean diameter of the smallest size fraction in mm
2	PC	+	Fraction of bed material in this size range

Continue with other DFF's and PC's.

GB Records - These optional records are used to define time variation of stage (water-surface elevation) at a cross section. The first set of GB records is placed before all cross section records (X1); it specifies the downstream stage. When the GB option is used, it supersedes other methods for determining the downstream stage. Other sets of GB records may be placed in other parts of the data set; each specifies the time variation of stage for the cross section immediately following the GB records.

Field	Variable	Value	Description
First GB Record			
0	IA	GB	Record identification characters
1	KBL	+	Number of points used to define base-level changes
Succeeding GB Record(s)			
0	IA	GB	Record identification characters
1	BSLL(1)	+	Base level of point 1, in ft or m
2	TMBL(1)	+	Time coordinate of point 1, in hours
3	BSLL(2)	+	Base level of point 2, in ft or m

4	TMBL(2)	+	Time coordinate of point 2, in hours

Continue with additional elevations and time coordinates, in the increasing order of time.

GQ Records - These optional records are used to define stage-discharge relation at the downstream section. The GQ input data may not used together with the GB records.

Field	Variable	Value	Description
First GQ Record			
0	IA	GQ	Record identification characters
1	KQL	+	Number of points used to define base-level changes
Succeeding GQ Record(s)			
0	IA	GQ	Record identification characters
1	BSLL(1)	+	Base level of point 1, in ft or m
2	TMQ(1)	+	Discharge of point 1, in cfs or cms
3	BSLL(2)	+	Base level of point 2, in ft or m
4	TMQ(2)	+	Discharge of point 2, in cfs or cms

Continue with additional elevations and discharges, in the increasing order of discharge.

GI Records - These optional records are used to define time variation of sediment discharge entering the study reach through the upstream cross section. The GI input data, if included, will supersede other methods for determining sediment inflow. The sediment inflow is classified into the two following cases: (1) specified inflow at the upstream section, such as by a rating curve; and (2) sediment feeding, such as from a dambreach or a sediment feeder. These two cases are distinguished by DXU in Field 2 of this record. For the first case, sediment discharge at the upstream section is computed using size fractions of bed-material at the section, but for the second case, the size fractions of feeding material need to be specified using the PCU values in this record. The upstream section does not change in geometry for the first case but it may undergo scour or fill for the second case.

Field	Variable	Value	Description
First GI Record			
0	IA	GI	Record identification characters
1	KGI	+	Number of points used to define time variation of sediment inflow.

2	DXU	+ or 0	Channel distance measured from the upstream section to the and KGI signify case 2, for which PCU values are required.
3-10	PCU	+	Size fractions of inflow material. The number of size fractions is given in Field 8 of the G3 record and the sizes for the fractions are given in the second GS record.

Succeeding GI Record(s)

0	IA	GI	Record identification characters
1	QSU(1)	+	Sediment discharge of point 1, in cubic ft or m (net volume) per second
2	TMGI(1)	+	Time coordinate of point 1, in hours
3	QSO(2)	+	Sediment discharge of point 2
4	TMGI(2)	+	Time coordinate of point 2.

Continue with additional sediment discharges and time coordinates, in the increasing order of time coordinates.

X1 Record - This record is required for each cross section (175 cross sections can be used for the study reach); it is used to specify the cross-sectional geometry and program options applicable to that cross-section. Cross sections are arranged in sequential order starting from downstream.

Field	**Variable**	**Value**	**Description**
0	IA	X1	Record identification characters
1	SECNO	+	Original section number from the map
2	NP	+	Total number of stations or points on the next GR records for
7	DX	+	Length of reach between current cross section and the next downstream section along the thalweg, in feet or meters
8	YFAC	0	Cross-section stations are not modified by the factor YFAC.
		+	Factor by which all cross-section stations are multiplied to increase or decrease area. It also multiplies YC1, YC2 and CPC in the XF record, and applies to the CI record.
9	PXSECE	0	Vertical or Z coordinate of GR points are not modified.
		±	Constant by which all cross-section elevations are raised or lowered
10	NODA	0	Cross section is subject to change.

		1	Cross section is not subject to change.

XF Record - This is an optional record used to specify special features of a cross section.

Field	Variable	Value	Description
0	IA	XF	Record identification characters
1	YC1	0	Regular erodible left bank
		+	Station of rigid left bank in ft or m, to the left of which channel dinates in GR records but not the first Y coordinate.
2	YC2	0	Regular erodible right bank
	+		Station of rigid right bank, to the right of which channel is non-erodible. Note: This station is located at toe of rigid bank; its value must be equal to one of the Y coordinates in GR records but not the last Y coordinate.
3	RAD	0	Straight channel with zero curvature
		+	Radius of curvature at channel centerline in ft or m. Center of radius is on same side of channel where the station (Y-coordinate) starts.
		-	Radius of curvature at channel centerline in ft or m. Center of radius is on opposite side of zero station. Note: RAD is used only if concave bank is rigid and so specified using the XF record. RAD produces a transverse bed scour due to curvature.
4	CN	0	Roughness of this section is the same as that given in Field 7 of the G1 record.
		+	Manning's *n* value for this section
5	CPC	0	Center of thalweg coincides with channel invert at this section.
		+	Station (Y-coordinate) of the thalweg in ft or m
6	IRC	0	Regular erodible cross section
		1	Rigid or nonerodible cross section such as drop structure or road crossing. There is no limit on the total number of such cross sections.
8	BSP	0	Slope of bank protection is the same as that given in Field 2 of the G3 record.
		+	Slope of bank protection at this section in BSP horizontal units
		5	Slope of rigid bank is defined by the GR coordinates.
9	BEFX	0	Bank erodibility factor is defined in Field 5 of the G1 record.
		+	A value between 0.1 and 1.0 for BEFX specifies the bank

			erodibility factor at this section.
	RWD	+	RWD is the width of bank protection of a small channel in the specified by a value greater than 1 (ft or m) in this field. When RWD is used, BEFX is not specified.
10	TDZAM	0	Erodible bed layer at this section is defined by TDZAMA in Field
		+	Thickness of erodible bed layer in ft or m. Only one decimal place is allowed for this number.
	ENEB	±	Elevation of non-erodible bed, used to define the crest elevation of a grade-control structure which may be above or below the existing channel bed. In order to distinguish it from TDZAM, ENEB must have the value of 1 at the second decimal place. For example, the ENEB value of 365 should be inputted as 365.01 and the ENEB value of -5.2 should be inputted as -5.21. When ENEB is specified, it supersedes TDZAM and TDZAMA

CI Record - This is an optional record used to specify channel improvement options due to excavation or fill. The excavation option modifies the cross-sectional geometry by trapezoidal excavation. Those points lower than the excavation level are not filled. The fill option modifies the cross-sectional geometry by raising the bed elevations to a prescribed level. Those points higher than the fill level are not lowered. Excavation and fill can not be used at the same time. This record should be placed after the X1 and XF records but before the GR records. The variable ADDVOL in Field 10 of this record is used to keep track of the total volume of excavation or fill along a channel reach. ADDVOL specifies the initial volume of fill or excavation. A value greater or less than 0.1 needs to be entered in this field to keep track of the total volume of fill or excavation until another ADDVOL is defined.

Field	Variable	Value	Description
0	IA	G5	Record identification characters
1	CLSTA	+	Station of the centerline of the trapezoidal excavation, expressed according to the stations in the GR records, in feet or meter.
2	CELCH	+	Elevation of channel invert for trapezoidal channel, in feet or meters.
4	XLSS	+	Side slope of trapezoidal excavation, in XLSS horizontal units for 1 vertical unit.
5	ELFIL	+	Fill elevation on channel bed, in feet or meters.
6	BW	+	Bed width of trapezoidal channel, in feet or meters. This width is measured along the cross section line; therefore, a larger value should be used if a section is skewed.
10	ADDVOL	0	Volume of excavation or fill, if any, is added to the total volume already defined.

+	Initial volume of fill on channel bed, in cubic feet or cubic meters.
-	Initial volume of excavation from channel bed, in cubic feet or meters.

GR Record - This record specifies the elevation and station of each point for a digitized cross section; it is required for each X1 record.

Field	Variable	Value	Description
0	IA	GR	Record identification characters
1	Z1	"	Elevation of point 1, in ft or m. It may be positive or negative.
2	Y1	"	Station of point 1, in ft or m
3	Z2	"	Elevation of point 2, in ft or m
4	Y2	"	Station of point 2, in ft or m

Continue with additional GR records using up to 79 points to describe the cross section. Stations should be in increasing order.

SB Record - This special bridge record is used to specify data in the special bridge routine. This record is used together with the BT and GR records for bridge hydraulics. This record is placed between cross sections that are upstream and downstream of the bridge.

Field	Variable	Value	Description
0	IA	SB	Record identification characters
1	XK	+	Pier shape coefficient for pier loss
2	XKOR	+	Total loss coefficient for orifice flow through bridge opening
3	COFQ	+	Discharge coefficient for weir flow overtopping bridge roadway
4	IB	+	Bridge index, starting with 1 from downstream toward upstream
5	BWC	+	Bottom width of bridge opening including any obstruction
6	BWP	0	No obstruction (pier) in the bridge
		i	Total width of obstruction (piers)
7	BAREA	+	Net area of bridge opening below the low chord in square feet
9	ELLC	+	Elevation of horizontal low chord for the bridge
10	ELTRD	+	Elevation of horizontal top-of-roadway for the bridge

BT Record - This record is used to compute conveyance in the bridge section. The BT data defines the top-of -roadway and the low chord profiles of bridge. The program uses the BT, SB and GR data to distinguish and to compute low flow, orifice flow and weir flow.

Field	Variable	Value	Description
0	IA	BT	Record identification characters
1	NRD	+	Number of points defining the bridge roadway and bridge low Chord to be read on the BT records
2	RDST(1)	+	Roadway station corresponding to RDEL(1) and XLCEL(1)
3	RDEL(1)	+	Top of roadway elevation at station RDST(1)
4	XLCEL(1)	+	Low chord elevation at station RDST(1)
5	RDST(2)	+	Roadway station corresponding to RDEL(2) and XLCEL(2)
6	RDEL(2)	+	Top of roadway elevation at station RDST(2)

7	XLCEL(2)	+	Low chord elevation at station RDST(2)

Continue with additional sets of RDST, RDEL, and XLCEL.

EJ Record - This record is required following the last cross section for each job. Each group of records beginning with the T1 record is considered as a job.

Field	Variable	Value	Description
0	IA	EJ	Record identification characters
1-10			Not used

II. OUTPUT DESCRIPTION

Output of the model include initial bed-material compositions, time and spatial variations of the water-surface profile, channel width, flow depth, water discharge, velocity, energy gradient, median sediment size, and bed-material discharge. In addition, cross-sectional profiles are printed at different time intervals.

Symbols used in the output are generally descriptive, some of them are defined below:

SECTION	Cross section
TIME	Time on the hydrograph
DT	Size of the time step or Δt in sec
W.S.ELEV	Water-surface elevation in ft or m
WIDTH	Surface width of channel flow in ft or m
DEPTH	Depth of flow measured from channel invert to water surface in ft or m
Q	Discharge of flow in cfs or cms
V	Mean velocity of a cross-section in fps or mps
SLOPE	Energy gradient
D50	Median size or d_{50} of sediment load in mm
QS	Bed-material discharge for all size fractions in cfs or cms
FR	Froude number at a cross section
N	Manning's roughness coefficient
SED.YIELD	Bulk volume or weight of sediment having passed a cross section since beginning of simulation, in cubic yards or tons.
WSEL	Water-surface elevation, in ft or m
Z	Vertical coordinate (elevation) of a point on channel boundary at a cross-section, in ft or m
Y	Horizontal coordinate (station) of a point on channel boundary at a cross-section, in ft or m
DZ	Change in elevation during the current time step, in ft or m
TDZ	Total or accumulated change in elevation, in ft or m

Flood Control District
of Maricopa County

MEMORANDUM

Date: August 12, 2009

To: Howard Chang, PhD, PE, Chang Consultants

From: Richard Waskowsky, Hydrologist, Engineering Application Development and River Mechanics Branch, Engineering Division

CC: Bing Zhao, PhD, PE, Engineering Application Development and River Mechanics Branch Manager, Engineering Division

Subject: Draft Report for the FLUVIAL-12 Simulation of Salt River near Gilbert Road Crossing

The Engineering Application Development and River Mechanics Branch (EADRM) has finished its review and has the following comments. The consultant should submit written responses (with digital copy) to these comments to the FCD. The comments that have been resolved have been shown in a gray font. All comments have been resolved.

1) **FCD Comment (June 22, 2009):** The attached computer files should include all files, which are relevant to the study. These files would include the input/output Fluvial-12 files, the 2007 topography, the 2001 topography, and any other data that was used in the study. This is important because the report should be self-contained. If five years in the future someone wanted to repeat the study, all necessary files would be included with the report.

   Chang Consultants Response (June 29, 2009): Additional files have been added to the package of computer files. The list includes the input/output Fluvial-12 files, the 2007 topography, the 2001 topography, and other data that was used in the study. The package will be sent to the County in a CD after the review is finalized.

   In addition, modeling study has also been made for the case of long-term river channel changes with pit capture. Computer files for this case include the following:
   SALT-S-CAPTURE.OUT: FLUVIAL-12 output file for the flood series with pit capture
   SALT-MIN-CAPTURE.DAT: FLUVIAL-12 output file for maximum scour during the flood series with pit capture

FCD Response (July 8, 2009): All relevant files will be added to the final CD. The comment will be resolved once the CD is received.

Chang Consultants Response (July 16, 2009): I agree.

FCD Response (July 22, 2009): From the CD that was included with the current submittal, it appears that most of the relevant data has been included. The only data file that is still missing is the hydrograph for the long-term simulation. Also, to be consistent with the format of the report, each file that is on the CD should be included in the Attachments portion of the Table of Contents.

Chang Consultants Submittal (July 24, 2009)

FCD Response (July 29, 2009): The files have been added to the Attachments portion of the Table of Contents.

2) **FCD Comment (June 22, 2009):** A discussion, which explains why the MPM sediment transport formula was used (rather than another formula), needs to be shown in the report.

Chang Consultants Response (June 29, 2009): The following discussion on the MPM formula has been added to the report:

> The study reach of the Salt River is basically a gravel bed river. The two most widely used sediment formulas for gravel are the MPM formula and the Parker-Coleman formula (Parker, G. and Coleman, N. L., "Simple Model of Sediment-Laden Flows," *J. Hydraul. Eng.* ASCE, 112(5), pp. 356-375, May 1986.). The MPM formula has been in use for a long period of time and it is generally considered as the most accurate formula for gravel transport. Most professionals in the U. S and Europe apply the MPM formula in their studies.

FCD Response (July 8, 2009): A discussion has been added. Comment resolved.

3) **FCD Comment (June 22, 2009):** On page 8 of the report, it is indicated that JE Fuller did the hydraulic study in 2001. However, this statement is not true. JE Fuller did their study in 2008, and WEST did their study in 2002. The JE Fuller HEC-RAS model was an updated version of the WEST model, which used the 2001 topography. In the area of Gilbert Road, both models used the 2001 topography.

Chang Consultants Response (June 29, 2009): The statement on page 8 has been revised to read as follows:

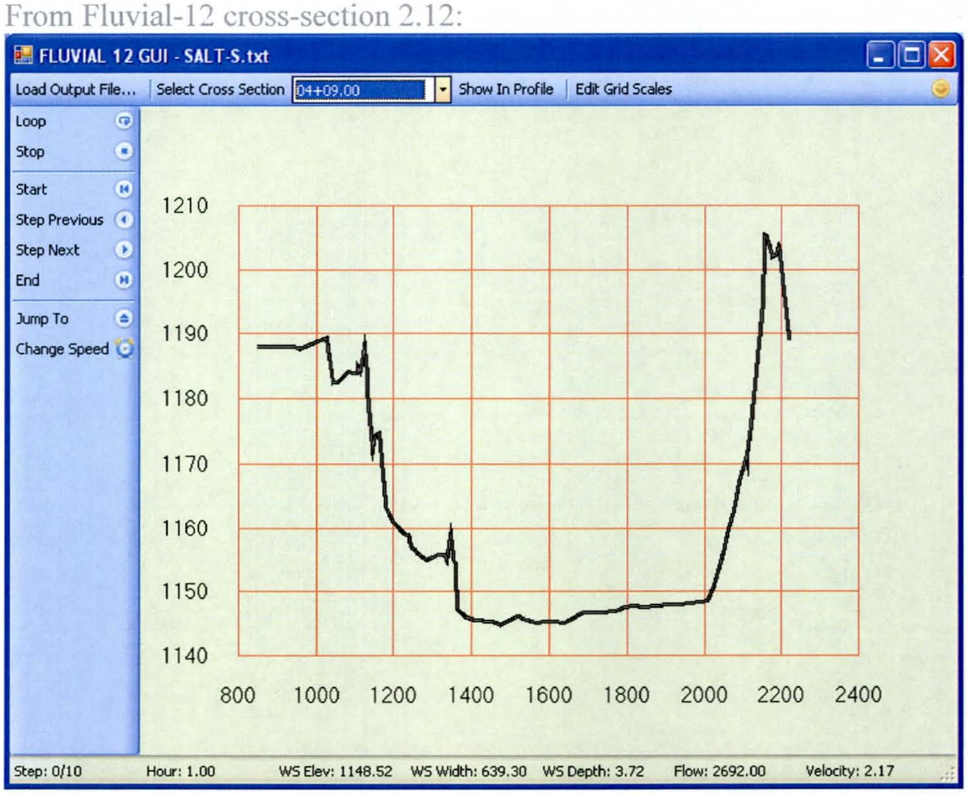
> **Channel Geometry Data** - The channel geometry data are based on the 2001 topographic survey used in a 2008 hydraulic study by JE Fuller.

FCD Response (July 8, 2009): The Fuller report should be cited in the statement on page 8, and the reference added to the References section. The reference is as follows

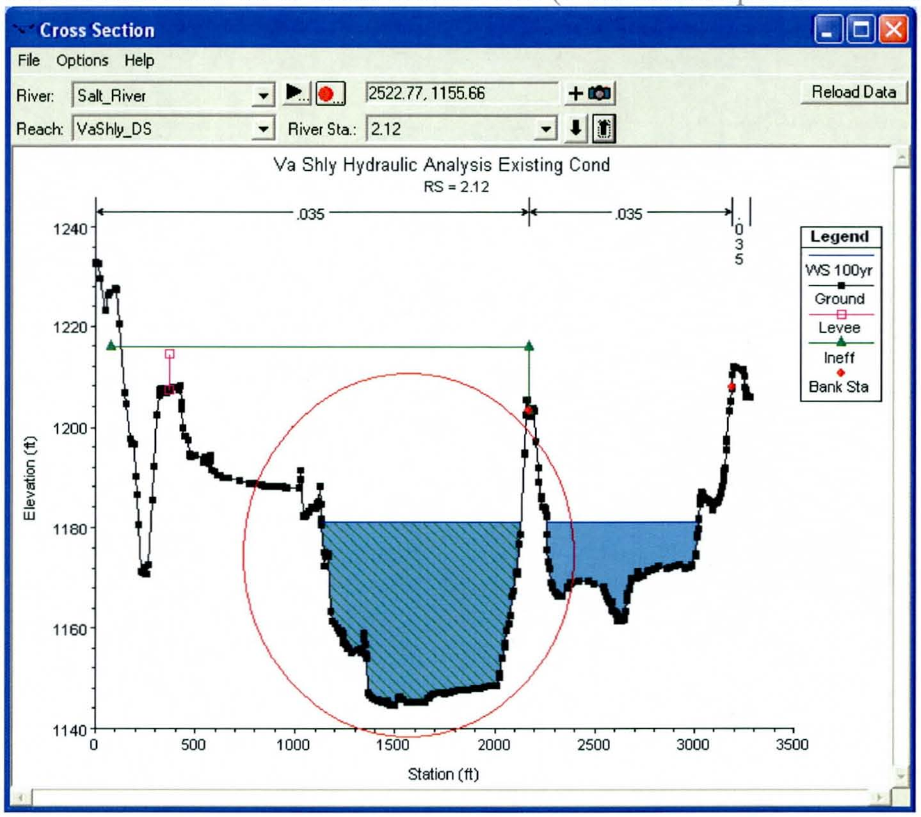
JE Fuller/ Hydrology & Geomorphology, Inc. (Fuller), "Va Shly' Ay Akimel Salt River Ecosystem Restoration Project – Phase I: DRAFT Design Documentation Report Hydrologic and Hydraulic Analysis Appendix", May 2008.

Also, there appears to be errors with multiple cross-sections in the Fluvial-12 simulations. For example, at cross-section 2.12, Fluvial-12 models an ineffective flow area as the main channel. At cross-sections 2.12 and 5.15, only a small portion of the Salt River cross-section is modeled, which may cause the flow to be artificially contained in a smaller area (e.g. cross-section 5.15). Please correct these errors and verify that all the cross-section have been converted correctly. Please see the screen captures below for the examples. As a note, in cross-sections 2.65 to 2.04, the ineffective areas along the south portion of the cross-section belong to a south channel, which is not part of the main channel and will be blocked by a levee in the future.

From Fluvial-12 cross-section 2.12:

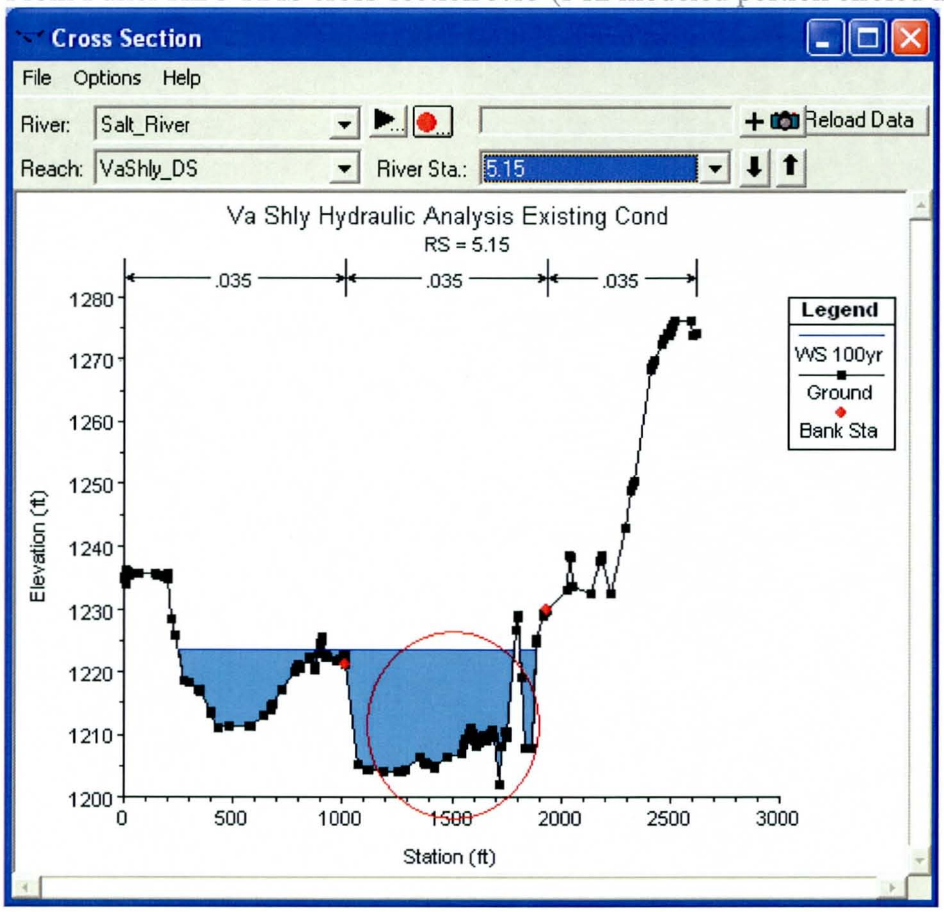


From Fuller HEC-RAS cross-section 2.12 (F12 modeled portion circled in red):



From Fluvial-12 cross-section 5.15:

From Fuller HEC-RAS cross-section 5.15 (F12 modeled portion circled in red):



Chang Consultants Response (July 16, 2009): The reference for JE Fuller is now cited in the report text. The reference is also included in the list of references.

I have gone through the data file to check the channel cross sections against the HEC-RAS data prepared by JE Fuller. Revisions have been made to those cross sections where the channel geometries were not properly coded to represent the effective flow areas. As a result of the revisions, all modeling cases have also been changed and corrected. The graphics have also been corrected.

The corrections made to the cross-sectional data have resulted in small changes to the simulated results for the 2005 flood. The correlation of the simulated and measured cross-sectional area changes actually show small improvements as shown in Table 2 below.

Table 2. Comparison of simulated and measured cross-sectional area changes

River Station	Cross-Sectional Area Change due to Scour, Square feet	
River miles	Measured by Survey	Simulated by Model
7.28	2,990	3,075
7.32	3,480	3,780
7.36	1,620	1,970
7.40	2,000	1,745
7.44	3,970	3,737
7.47	3,350	3,340
7.55	2,890	2,925
7.62	2,450	2,355

FCD Response (July 22, 2009): The reference has been added, and the cross-sections have been corrected. Comment resolved.

4) **FCD Comment (June 22, 2009):** It is stated that that the results from the study predict long-term river channel changes in the future and that the results are adequate. In order to make this assessment, a quantitative comparison of the results must be included and discussed. Since "adequate" is a relative term, a measure to differentiate what is adequate and what is not adequate should also be included.

Chang Consultants Response (June 29, 2009): The word of description "adequate" is no longer used since it is qualitative. A quantitative comparison of cross-sectional area changes due to scour for the simulated and measured results are presented in the report.

FCD Response (July 8, 2009): A table, which compares the change in cross-sectional area due to scour, has been added to the report. However, in addition to the cross-sectional area table, could a table, which compares the magnitude of scour, also be added to the report?

Chang Consultants Response (July 16, 2009): The minimum bed elevation reached by channel bed scour from the modeling study and from the measurement can also be compared. However, such a comparison is not as good as a comparison of cross-sectional area changes for the reasons give below. Channel bed scour usually develops an uneven channel bed profile. The minimum bed elevation reached by scour may be a sharp point. The comparison can be skewed by the sharp point. It is not a good measure of the magnitude of channel bed scour. The cross-sectional area change is a better measure of the magnitude for channel bed scour.

FCD Response (July 22, 2009): The cross-sectional area changes may be a better measure than the magnitude of scour for the overall scour comparison. However, the FCD is also very interested in the magnitude of scour because the regulation for utility crossings such as gas lines and sewer lines is based the magnitude of scour measured from the minimum bed elevation in the cross-section. Therefore, please add a table, which compares the magnitude of scour. The magnitude of scour can be calculated with the minimum bed elevation change between the pre-flood and post-flood cross-sections. The text of the report can emphasize the cross-section area changes, but it should also mention that the magnitude of scour was compared.

Chang Consultants Response (July 24, 2009): The comparison of the maximum scour depths is also included. The paragraph has been revised as follows.

The simulated results for river stations near the Gilbert Road crossing are presented together with the measured post-flood cross-sectional profiles. The comparisons of cross-sectional area changes and the maximum scour depths are summarized in the two following tables.

Comparison of simulated and measured cross-sectional area changes

River Station River miles	Cross-Sectional Area Change due to Scour, Square feet	
	Measured by Survey	Simulated by Model
7.28	2,990	3,075
7.32	3,480	3,780
7.36	1,620	1,970
7.40	2,000	1,745
7.44	3,970	3,737
7.47	3,350	3,340
7.55	2,890	2,925
7.62	2,450	2,355

Comparison of simulated and measured maximum scour depths

River Station River miles	Maximum Scour Depths, feet	
	Measured by Survey	Simulated by Model
7.28	9.8	13.7
7.32	18.0	15.5
7.36	14.1	12.3
7.40	16.9	14.4
7.44	13.2	14.1
7.47	12.8	15.1
7.55	13.8	14.1
7.62	13.5	13.1

FCD Response (July 29, 2009): A comparison of the maximum scour depths has been given in the Executive Summary. Comment resolved.

5) **FCD Comment (June 22, 2009):** The sentence on page 2 in the first paragraph, which reads "the simulated and measured cross-sectional profiles are similar but also with significant differences," could be made clearer. The sentence is confusing because it is indicating that the profiles are both similar while being dissimilar. Please revise the sentence to indicate what is similar about the profiles and what is different.

Chang Consultants Response (June 29, 2009): These sentences have been revised to read as follows:

> The total amount of channel bed scour as simulated is similar to the measured amount (see Table 2). The total depth of channel bed degradation is also similar. However, the simulated and measured cross-sectional profiles have significant differences.

FCD Response (July 8, 2009): This revision has been made to the text on page 23. However, the first sentence, which reads "The total amount of channel bed scour as simulated is similar to the measured amount", should also be added to the text just below the table on page 2.

Chang Consultants Response (July 16, 2009): The sentence on page 2 below the table has been revised to read as follows:

> The total amount of channel bed scour as simulated is similar to the measured amount as shown in the above table. The total depth of channel bed degradation is also similar. However, the simulated and measured cross-sectional profiles have significant differences. The simulated channel bed scour is near the thalweg; the measured scour may be away from the thalweg. The causes for such discrepancy may be due to lateral migration of the

thalweg, which is not considered in the model simulation; or it may be due to survey inaccuracy. In fact, the overbank areas for the cross sections from the 2001 survey do no always match the corresponding ones from the 2007 survey. The overbank areas were not affected by river channel scour; there should be no big differences in geometry. However, such differences do exist at several river stations.

FCD Response (July 22, 2009): The sentence has been added. Comment resolved.

6) **FCD Comment (June 22, 2009):** At the bottom of page 23, it is indicated that during the long-term simulation pit capture will not occur. Another test, which assumes pit capture, should be run, and the results compared with the run without pit capture.

Chang Consultants Response (June 29, 2009): For long-term changes, the following two scenarios are assumed:

a. The berm separating the Gilbert mining pit from the main channel of the Salt River will be restored and pit capture in the future will be prevented.
b. The berm separating the Gilbert mining pit from the main channel of the Salt River will not be restored and pit capture will continue in the future.

Simulated results on sediment delivery and river channel changes are presented for both case scenarios. Such results include the spatial variations of sediment delivery, changes in longitudinal channel profiles and changes in cross sectional profiles. Several figures for the case of pit capture have been added to the report. Comparisons of the results are also made.

FCD Response (July 8, 2009): The second case (with pit capture) has been simulated. However, could it be noted that the long-term simulations only simulate the existing geometries of the sand and gravel pits and that any future or continued excavation is not simulated.

Chang Consultants Response (July 16, 2009): The following sentence has been added for the case of long term changes with pit capture.

Long term changes with pit capture have also been simulated. Pit capture will increase potential river channel scour. However, it should be noted that the long-term simulations only simulate the existing geometries of the sand and gravel pits and that any future or continued excavation is not simulated.

FCD Response (July 22, 2009): The notation has been added to the Executive Summary and the Summary and Conclusions sections. Comment resolved.

7) **FCD Comment (June 22, 2009):** In the report, there are many graphs showing the results (e.g., Figure 13 pages 19-22). However, the discussion on page 22 is qualitative. Please discuss the results considering a quantitative comparison of the results.

Chang Consultants Response (June 29, 2009): The simulated and measured cross-sectional area changes due to scour are compared as listed in Table 2.

Table 2. Comparison of simulated and measured cross-sectional area changes

River Station	Cross-Sectional Area Change due to Scour, Square feet	
River miles	Measured by Survey	Simulated by Model
7.28	2,990	3,090
7.32	3,480	4,020
7.36	1,580	2,060
7.40	2,000	1,730
7.44	3,970	3,730
7.47	3,350	3,250
7.55	2,890	2,920
7.62	2,450	2,350

FCD Response (July 8, 2009): A quantitative comparison has been given. Comment resolved.

8) **FCD Comment (June 22, 2009):** On page 2, the paragraph that reads

> The simulated cross-sectional profiles may have an uneven channel bed, while those from the survey are quite smooth. The real flood flow moved sediment in the longitudinal direction, it also have small lateral components that move sediment laterally to produce a smooth bed profile. The simulation does not have this feature.

is misleading. The 2007 topography was developed from a TIN, which was developed from contours. Because the topography was developed from contours, wide flat areas are shown perfectly flat. Therefore, the paragraph should be revised or removed.

Chang Consultants Response (June 29, 2009): The paragraph has been revised to read as follows:

> The simulated cross-sectional profiles may have an uneven channel bed, while those from the 2007 topographic survey are quite smooth. The 2007 topography was developed from contours. In the process, local variations in bed elevation may be ignored and wide area may thus be shown as flat bed.

FCD Response (July 8, 2009): The paragraph has been revised. However, the portion that reads "…wide area may…" should be revised to "… wide flat areas may…". The paragraph may read better if the first two sentences were replaced with one, such as "One possible reason why there are differences is that the 2007 topography was developed from contours." The report may also flow better if this paragraph was combined with the preceding paragraph.

These revisions can also be made to the text at the top of page 39.

Chang Consultants Response (July 16, 2009): The paragraph at two places has been revised to read as follows:

> The simulated cross-sectional profiles may have an uneven channel bed, while those from the 2007 topographic survey are quite smooth. One possible reason why there are differences is that the 2007 topography was developed from contours. In the process, local variations in bed elevation may be ignored and wide flat area may thus be shown as flat bed.

FCD Response (July 22, 2009): The paragraph has been revised. Comment resolved.

9) **FCD Comment (June 22, 2009):** On the top of page 11 (at the bottom of page 23), please add text, which clarifies that Figure 8 is the gage data that was collected from 1891 to 1993. The current text seems to indicate that the flow hydrograph has a flow duration of ~100 years, which is not correct.

Chang Consultants Response (June 29, 2009): The sentences have been revised to read as follows:

> The hydrograph for a long-term flood series is shown in Fig. 8. The series covers the time period from 1891 to 1993. This flow data was used to simulate potential river channel changes in the long-term future.

FCD Response (July 8, 2009): The paragraph has been revised by removing the reference to "a total duration very close to 100-years." Comment resolved.

10) **FCD Comment (June 22, 2009):** The labeling of the figures is incorrect. The figure number on page 26 is 15, while the subsequent figure on page 27 is also 15. The figures on pages 28-31 are numbered 13. Also, the figures, which extend multiple pages, would be clearer if shown as separate figures.

Chang Consultants Response (June 29, 2009): The figure on page 27 is labeled as Fig. 16. The subsequent figures have also been revised.

FCD Response (July 8, 2009): The labeling has been corrected. Comment resolved.

11) **FCD Comment (June 22, 2009):** A summary or conclusions section needs to be added to the report.

Chang Consultants Response (June 29, 2009): In response, the following new section has been added

VII. SUMMARY AND CONCLUSIONS

The Salt River near Gilbert Road in Maricopa County, Arizona underwent major changes in channel geometry during the 2005 flood. Such changes in channel geometry are related to pit capture, which occurred as flood water overtopped the berm separating the main channel from the deep Gilbert mining pit. The channel geometry data before and after the flood event are available together with the flood hydrograph.

Sediment transport and river channel changes for the Salt River has been simulated using the FLUVIAL-12 computer model. This scope of modeling covers the following tasks: (1) simulation of river channel changes caused by the 2005 flood, (2) comparison of simulated results with the surveyed channel geometry, and (3) prediction of long-term river channel changes in the future. The data used for the Salt River study are taken from previous studies covering the hydrology, hydraulics and geomorphology of the stream channel.

River Channel Changes during the 2005 Flood - The 2005 flood has the peak discharge exceeding 40,000 cfs and a long duration over three months; it was the most important event for the period from 2001 to 2007. Other events for the same period are much smaller in discharge and shorter in duration.

River channel changes during the 2005 flood with pit capture were simulated for the 2005 flood. The simulated river channel changes were compared with the measured changes. The short channel reach near the Gilbert Road crossing is between two major mining pits. This channel reach is simulated to undergo major channel bed degradation of about 10 feet.

The simulated results for river stations near the Gilbert Road crossing are presented together with the measured post-flood cross-sectional profiles. The cross-sectional profiles as simulated are compared with the measured profiles. Changes along this channel reach are characterized by channel bed scour along the main channel. The total amount of channel bed scour as simulated is similar to the measured amount. The total depth of channel bed degradation is also similar. However, the simulated and measured cross-sectional profiles have significant differences. While the simulated and measured scours are similar in pattern, they have somewhat different locations. The simulated channel bed scour is near the thalweg; the measured scour may be away from the thalweg. The causes for such discrepancy may be due to lateral migration of the thalweg, which is not considered in the model simulation; or it may be due to survey inaccuracy. In fact, the overbank areas for the cross sections from the 2001 survey do no always match the corresponding ones from the 2007 survey. The overbank areas were not affected by river channel scour; there should be no big differences in geometry. However, such differences do exist at several river stations.

The simulated cross-sectional profiles may have an uneven channel bed, while those from the 2007 topographic survey are quite smooth. The 2007 topography was developed from contours. In the process, local variations in bed elevation may be ignored and wide area may thus be shown as flat bed.

Long-Term River Channel Changes - The hydrograph for a long-term flood series was used to simulate potential river channel changes in the long-term future under the assumption that future pit capture will be prevented. The study river reach is predicted to undergo major changes in the long term even in the absence of pit capture. The changes are characterized by refill of the mining pits and erosion of their adjacent river reaches. The river reach near the Gilbert Road crossing is simulated to undergo changes in both channel bed scour and refill (or degradation and aggradation). The channel bed profile at the end of flood series is lower than the initial channel bed profile; therefore, there would be channel bed scour. However, the channel bed profile at the end of flood series is higher than the maximum channel bed scour profile. The difference between these two profiles indicate refill would occur during the later part of the flood series. This river reach is between two large mining pits. The downstream mining pit induces head cutting on this reach and the upstream pit causes tail-cutting on the reach. This process continues as the adjacent mining pits undergo refill. After the refill, these adjacent mining pits no longer cause head-cutting and tail-cutting. By that time, this river reach is expected to undergo refill as sediment supply resumes to this reach.

The computer output files for the study has the complete information for the longitudinal profile changes and cross-sectional changes. This study has its focus on the Salt River near the Gilbert Road crossing; therefore, only those cross-sectional changes near the Gilbert Road crossing are presented graphically. Each figure has the initial cross-sectional profile based on the 2001 survey, the simulated cross-sectional profile at the of the flood series, the simulated maximum scour profile together with the post flood 100-yr water surface. The predicted long-term changes at these river stations are greater in magnitude than those occurred during the 2005 flood. When the simulated results for the case of no pit capture are compared with those for the case of pit capture, it is easy to see that more scour develops under the case of pit capture

FCD Response (July 8, 2009): A Summary and Conclusions section has been added. One recommendation, however, is to add the phrase "In summary" to the beginning of the first sentence of the last paragraph on page 39. This addition would set this paragraph apart from the "Long-term River Channel Changes" portion of the report.

Chang Consultants Response (July 16, 2009): It is a good way to improve it. It has been done.

FCD Response (July 22, 2009): The phrase has been added. Comment resolved.

12) **FCD Comment (June 22, 2009):** There is a file, which is named SALT-OLD.out, with the computer files. This file should be included in the Attachments section of the Table of Contents.

Chang Consultants Response (June 29, 2009): The computer file SALT-OLD.FLU: was accidently included in the package of computer files. This file does not belong to the report. It has since been removed from the package of computer files.

FCD Response (July 8, 2009): The file has been removed from the list of attachments. Comment resolved.

13) **FCD Comment (June 22, 2009):** The cross-sections, which are shown in Figure 2, do not match the cross-sections in the Salt.flu file. Please revise Figure 2 so that the figure only shows the modeled cross-sections.

Chang Consultants Response (June 29, 2009): The following explanation for Fig. 2 has been added in the report:

Fig. 2 was taken from the HEC-RAS study. For this study, the cross sections from river station 2.04 to river station 13.64 are used. The cross sections downstream from river station 2.04 are not used because they are located downstream of the grade control structure at river station 2.33; they do not affect the hydraulic of flow and sediment transport along the river channel upstream of the grade control structure.

FCD Response (July 8, 2009): The explanation has been added to page 8 of the report. Comment resolved.

14) **FCD Comment (June 22, 2009):** There are some grammatical mistakes in the report. For example, in the first paragraph on page 1, the third sentence reads, "cross sections near the Gilbert Road Bridge crossing was surveyed in 2007." However, 'was' should be 'were.' Please revise this sentence and check the report for similar errors.

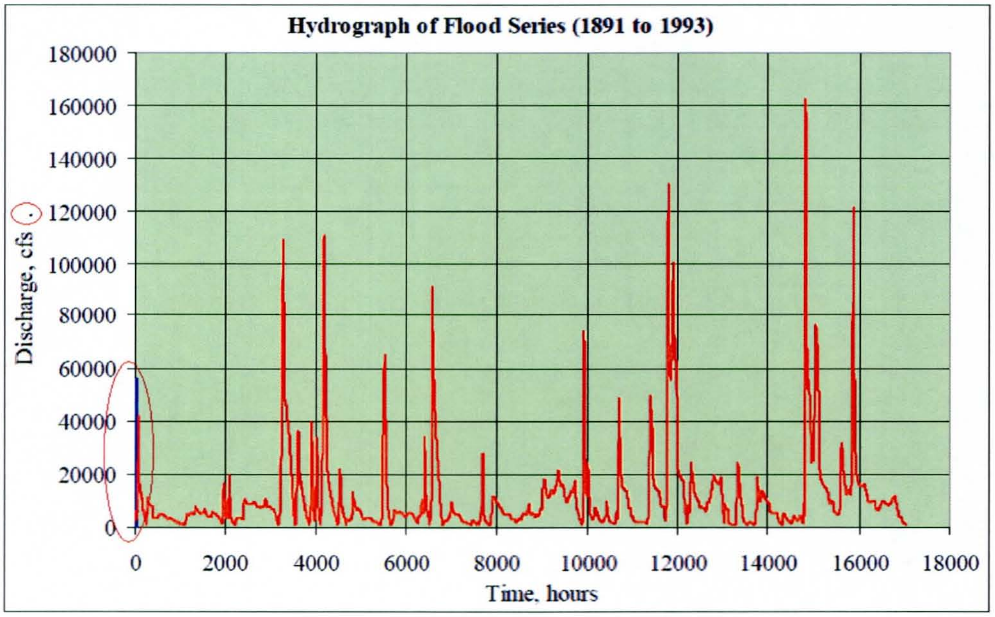
Chang Consultants Response (June 29, 2009): The sentence has been revised as follows:

The channel geometry for a long river reach was surveyed in 2001 and those cross sections near the Gilbert Road Bridge crossing were surveyed in 2007.

FCD Response (July 8, 2009): The sentence has been revised. However, there are some other grammatical mistakes in the report. The following is a brief list of recommendations that may improve the report. They are

1. at the top of page 3, the first two paragraphs could be combined and modified to reflect that long-term simulations were run for both cases, with and without pit capture,
2. on page 3 in the first sentence of the last paragraph, "has" should be "have" (this also occurs on page 39),
3. at the bottom of page 3, "that" should be added between "those" and "occurred" in the last sentence (this also occurs on page 40),
4. on page 4 in the second paragraph, "primacy" should be "primarily",
5. in general, the abbreviation "Fig." appears awkward when it occurs at the beginning of a sentence (or in the Figure title when period is used after the figure number); therefore it is recommended that "Fig." be replaced with "Figure",
6. on page 14, the second bracket in the MPM formula could be revised,
7. on page 14 in the first sentence after the MPM formula, "right-and" should be "right-hand",
8. on page 15, the second period should be removed after "time is in seconds",

9. on page 16 in the third paragraph, the sixth sentence should have a "the" before Gilbert Road,
10. Figure 3 needs a period after 3, and
11. Figure 8 could be revised by removing the period and extraneous blue line (circled in red below).



Chang Consultants Response (July 16, 2009): The following actions have been taken:

a. At the top of page 3, the first two paragraphs have been combined and modified to reflect that long-term simulations were run for both cases.

b. The sentence, with "has" replaced by "have", has been revised to read as follows:

> "The computer output files for the study have the complete information for the longitudinal profile changes and cross-sectional changes."

c. I made no change to the following sentence. Please advise again.

> "The predicted long-term changes at these river stations are greater in magnitude than those occurred during the 2005 flood."

d. "Primacy" has been changed into "primarily".

e. All "Fig."s have been revised into "Figure"s.

f. "right-and" has been replaced by "right-hand".

g. I can not find the following statement "time in seconds" on page 15.

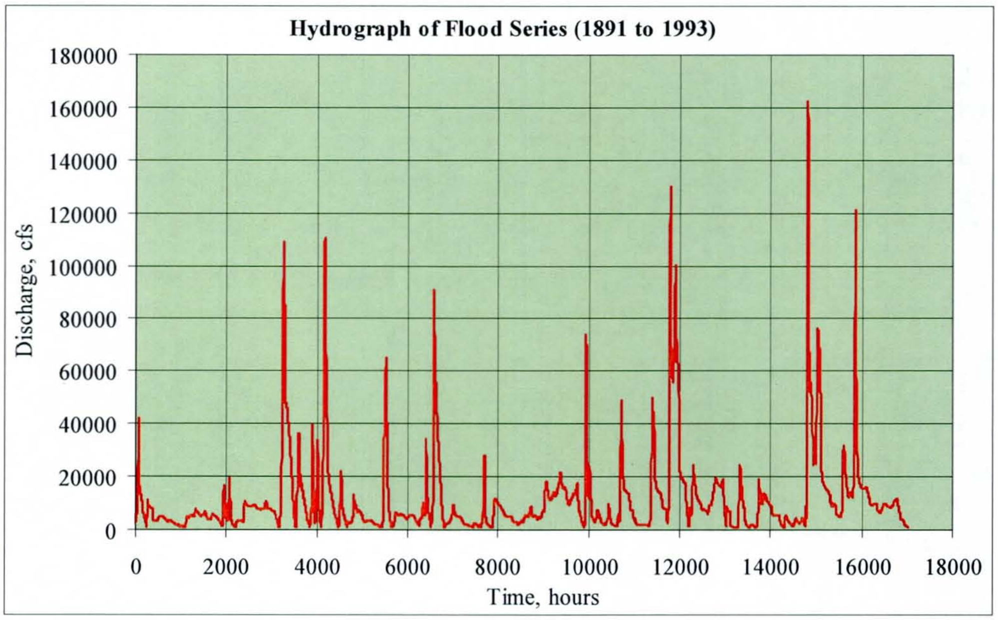
h. On page 16 in the third paragraph, the sixth sentence should have a "the" before Gilbert Road.

Corrected.

i. The period is added to Figure 3:

Figure 3. Aerial view of the Salt River near Gilbert Road crossing after the 2005 flood

j. Figure 8 has been revised by removing the period and extraneous blue line



FCD Response (July 22, 2009): Six of the eleven recommendations have been resolved. Please see the list below for the five remaining recommendations.

i. The first paragraph in the Long-Term River Channel Changes section of both the Executive Summary and the Summary and Conclusions should be rewritten. As it is written now, the first sentence indicates that pit capture will be prevented, but later in the paragraph it is indicated that the reach is between two large mining pits, which induce erosion in this reach. These statements are contradictory. Also, the bulk of the paragraph explains the "no pit capture" simulation while only a minor portion is used to explain the "pit capture" simulation. Please revise this paragraph to better document the "pit capture" simulation and to remove or to better explain the seemingly contradictory statements. One recommendation for the format of this paragraph is to use an introductory sentence, such as "The long-term river channel changes for this reach of the Salt River have been simulated for two cases, 1) with pit capture and 2) without pit capture." The results for both simulations can then be presented in the rest of the paragraph.

ii. On the bottom of page 3 in the Executive Summary, the sentence

> "The predicted long-term changes at these river stations are greater in magnitude than those occurred during the 2005 flood."

should be revised to

> "The predicted long-term changes at these river stations are greater in magnitude than those that occurred during the 2005 flood."

This change can also be made on page 41.

iii. On page 15, the right bracket in the MPM formula should be revised such that it is clearer.

iv. On page 16, the second period should be removed after the sentence "Note that this formula is valid only if D_{90} is in meters and time is in seconds.."

v. On page 17, "the" should be added before "Gilbert Road crossing…" in the last paragraph.

Also, here are two additional, minor comments on the report.

i. The page number should not be shown on the title page. Also for the Table of Contents and the Executive Summary, it may be better to use lower case Roman numerals.

ii. There is one extra blank page (labeled as page 3) after the Table of Contents that should be removed. This page will probably not have to be deleted once all the computer files have been included in the Attachments.

Chang Consultants Response (July 24, 2009):

i. This paragraph has been rewritten. The revised paragraph is given below.

Long-Term River Channel Changes - The Gilbert mining pit is separated from the main channel of the Salt River by a berm. There also exist instream mining pits located both upstream and downstream of the Gilbert Road crossing. The long-term river channel changes for this reach of the Salt River have been simulated for the two following cases: (1) without pit capture (by the Gilbert mining pit) and (2) with pit capture. The hydrograph for a long-term flood series was used. For the case of no pit capture, the study river reach is predicted to undergo major changes. The changes are characterized by refill of the mining pits and erosion of their adjacent river reaches. The river reach near the Gilbert Road crossing is simulated to undergo changes in both channel bed scour and refill (or degradation and aggradation). The channel bed profile at the end of flood series is lower than the initial channel bed profile. However, the channel bed profile at the end of flood series is higher than the maximum channel bed scour profile. The difference between these two profiles indicate refill would occur during the later part of the flood series.

The downstream mining pit induces head cutting on this reach and the upstream pit causes tail-cutting on the reach. This process continues as the adjacent mining pits undergo refill. After the refill, these adjacent mining pits no longer cause head-cutting and tail-cutting. By that time, this river reach is expected to undergo refill as sediment supply resumes to this reach. Long-term changes with pit capture (by off-stream the Gilbert mining pit) have also been simulated. Pit capture will increase potential river channel scour. However, it should be noted that the long-term simulations only simulate the existing geometries of the sand and gravel pits and that any future or continued excavation is not simulated.

ii. The changes have been made.

iii. The right bracket has been revised.

iv. The second period has been removed.

v. The affected sentence has been revised as follows.

The Gilbert Road crossing is located along a river reach between two major mining pits.

The additional comments are shown below:

i. The page number is no longer on the title page. Roman numerals are used for page numbering of the Table of Contents.

ii. The blank page will not be in the final version.

FCD Response (July 29, 2009): All of the above recommendations have been implemented. Comment resolved.

15) **FCD Comment (July 8, 2009):** On page 12, the sediment gradations are shown. How were these curves developed? They could not be verified when compared with the Appendix 4 of the WEST (2002) report.

Chang Consultants Response (July 16, 2009): All the gradations were taken from the WEST study report of 2002. Entitled "VA SHLY' AY AKIMEL, Hydraulic & Sedimentation Analysis, Salt River Pima-Maricopa Indian Community adjacent to the City of Mesa, Maricopa County, Arizona", Prepared for Los Angeles District, U.S. Army Corps of Engineers.

The WEST report has a large number of gradation curves. Sample gradation curves are shown in the figure. For gradation curves used in the study, five size fractions were used for each curve. The geometric mean of each size fraction is adopted as the size for the fraction.

BORING 3: RM1.5 PLACED AT DOWNSTREAM END OF STUDY REACH
GS 0.13 0.09 0.45 0.15 3.16 0.15 17.3 0.22 49.0 0.38

BORING 5: RM3.7 PLACED JUST AFTER X13.64
GS 0.15 0.08 0.55 0.17 2.83 0.19 14.4 0.25 45.6 0.30

BORING 8: RM6.3 PLACED JUST AFTER X16.27 AND X16.4
GS 0.18 0.10 0.65 0.20 2.00 0.20 8.94 0.22 40.0 0.28

BORING 8 (THE SECOND): PLACED JUST BEFORE X17.28 AND AFTER 7.55
GS 0.23 0.10 0.81 0.20 2.84 0.20 13.6 0.25 49.9 0.25

BORING 10: RM7.91 PLACED JUST AFTER X7.91
GS 0.17 0.10 0.42 0.28 0.77 0.16 2.45 0.19 51.9 0.27

BORING 10 (THE SECOND): PLACED JUST AFTER X8.85
GS 0.17 0.11 0.39 0.20 0.71 0.24 2.65 0.20 23.7 0.25

BORING 12: RM9.59 PLACED JUST AFTER X19.59
GS 0.55 0.12 1.41 0.20 4.47 0.15 17.3 0.19 49.0 0.34

BORING 14: RM12.2 PLACED AT UPSTREAM END OF STUDY REACH
GS 0.40 0.10 1.26 0.17 31.6 0.15 10.0 0.25 40.0 0.33

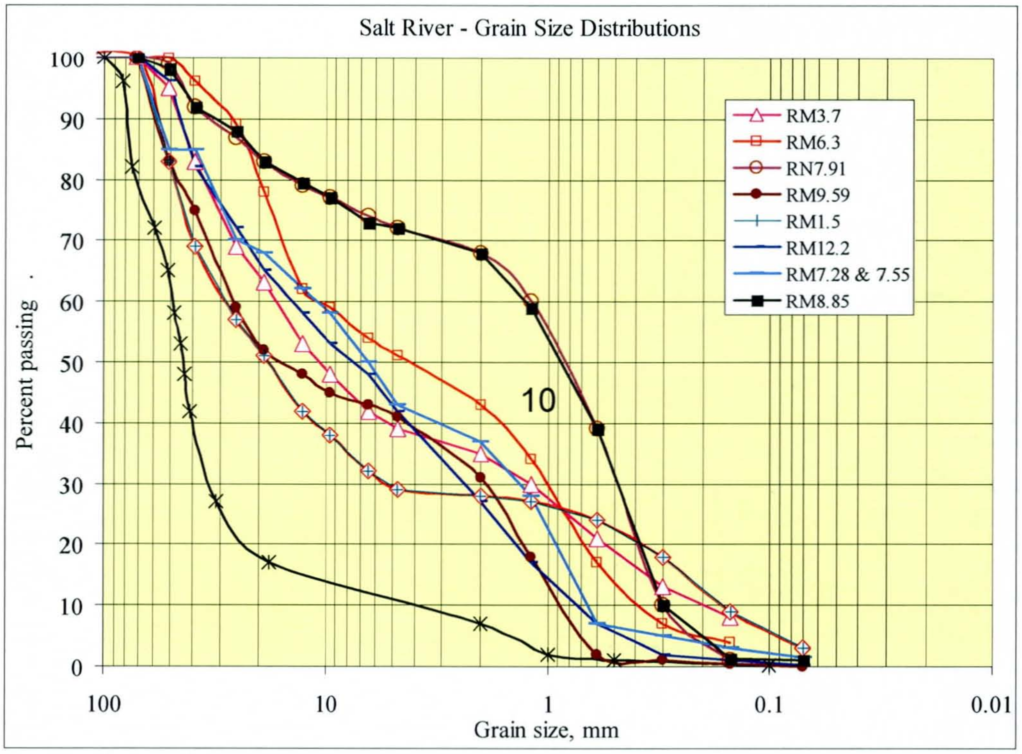
The second boring 8 and 10 from the WEST report were selected in view of the presence of coarse gravel (see report cover) near the Gilbert Bridge crossing.

FCD Response (July 22, 2009): The development of the sediment gradations, which were used in the study, has been clarified. However, all the data labels are not shown in Figure 9 (on page 13). There are 8 data series plotted in the figure, but only 6 labels are shown. Also, it appears that one data series is plotted twice. Please revise this figure.

Chang Consultants Response (July 24, 2009): Figure 9 shows only sample gradation curves but not all the gradation curves since they are also available from existing data. To make it complete for this study, two additional curves have been added to the figure. These are:

BORING 8 (THE SECOND): PLACED JUST BEFORE X17.28 AND AFTER 7.55
GS 0.23 0.10 0.81 0.20 2.84 0.20 13.6 0.25 49.9 0.25

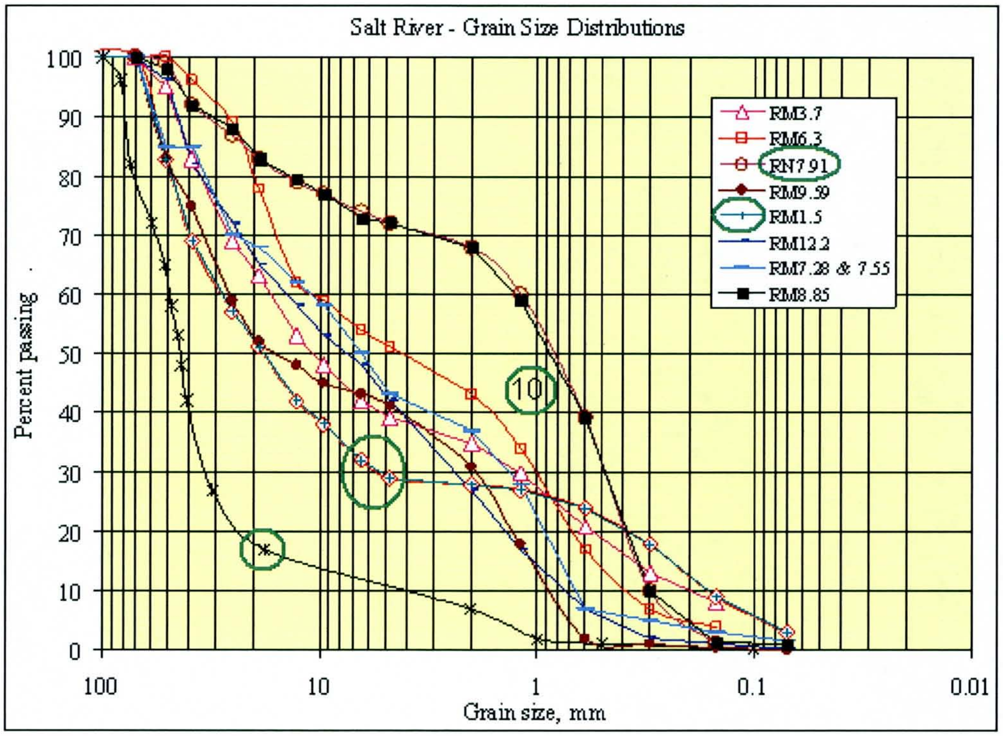
BORING 10 (THE SECOND): PLACED JUST AFTER X8.85
GS 0.17 0.11 0.39 0.20 0.71 0.24 2.65 0.20 23.7 0.25



FCD Response (July 29, 2009): Additional gradations have been shown on the figure. However, there are still some minor discrepancies with the figure. These discrepancies are circled in green in the figure below. A brief list is as follows:

1. Two additional lines are shown in the figure, but not in the legend.
2. One extra symbol (for RM 1.5) is shown in the legend but not in the plot.
3. A numeral "10" is shown in the middle of the figure.
4. RN7.91 should be RM7.91.

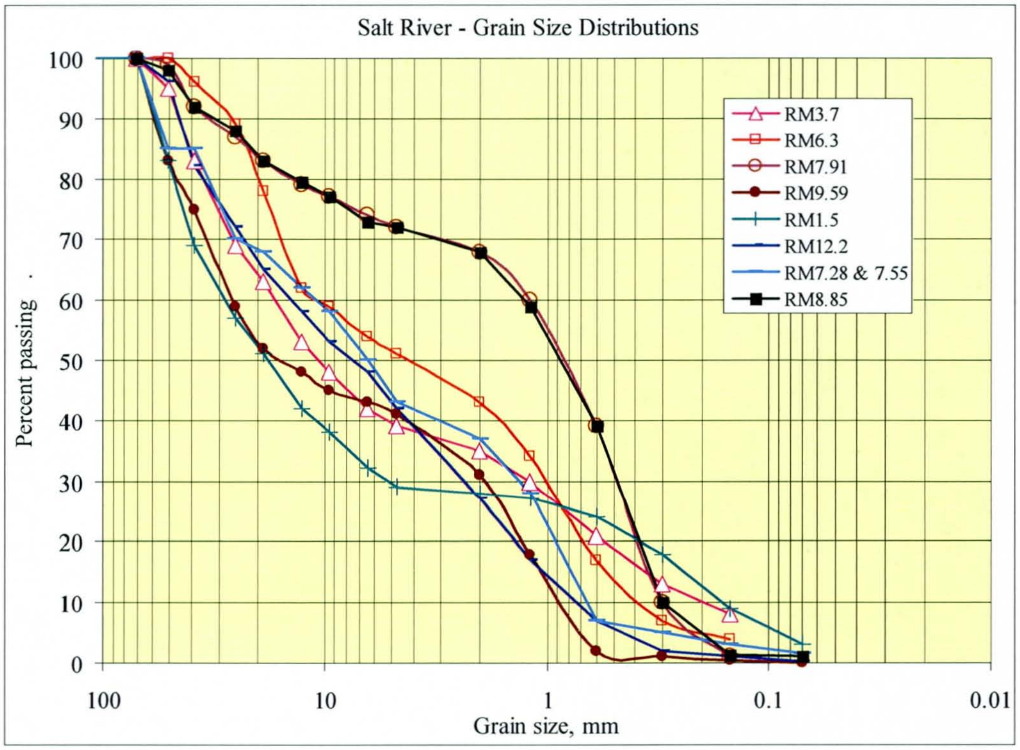
Also, some of the data labels do not match either the Fluvial-12 cross-section or the WEST (2002) cross-section. For example, "RM12.2" is shown in the figure, but the last sediment gradation in Fluvial-12 is at cross-section 13.64 and the last gradation in the WEST report is at cross-section 13.44. Please make sure the data labels correspond to either the Fluvial-12 model or the WEST report, and place a note, which indicates the source of the labeling, in the report. Once this figure has been revised, the final report can be submitted.



Chang Consultants Response (July 30, 2009):

1. The lines and legends are matched after two redundant lines are deleted.
2. The plot for RM1.5 is now in the plot.
3. The numeral "10" is deleted.
4. RN7.91 is now RM7.91.

In response, it is necessary to define the sediment gradation at both ends (downstream end and upstream end) of the study reach. Since there is no sediment gradation curve at the upstream end, the data at the nearest channel station (RM12.2) was used.



Revised figure for sediment gradation curves

Chang Consultants Submittal (August 7, 2009)

FCD Response (August 12, 2009): Figure 9 on page 13 of the final report has been revised to match the cross-sections from the WEST (2002) report. As a note, this figure plots the data directly from the WEST report, and these gradation curves (shown in Figure 9) were adjusted to fit the Fluvial-12 format requirements of five size fractions. Comment resolved.

16) **FCD Comment (July 8, 2009):** On page 9, the flow rates for the Salt River near Gilbert Road are given. However, these flow rates do not correspond to the flow rates at Gilbert Road given in Table 3.1 in the WEST (2002) study (see below). Please give a reference for the flow rates and revise the table to match the WEST table.

Table 3-1. Peak flows used in the hydraulic analysis and inundation area delineation.

Return Period	Flow at CP-40 (upstream limit at River Station 13.64, in cfs)	Flow at CP-109 (River Station 7.55 just upstream of Gilbert Road, in cfs)
5-year	22,000	21,000
10-year	60,000	58,000
20-year	100,000	95,000
50-year	150,000	145,000
100-year	175,000	172,000
200-year	210,000	207,000
500-year	250,000	246,000

Chang Consultants Response (July 16, 2009): The paragraph has been revised as follows:

Data on Flood Hydrology – The established flood discharges of the Salt River at two locations for different return periods are listed in the following table.

Peak flows for the Salt River

Return periods	Flood discharges in cfs	
	River mile 13.64	River mile 7.55
5 year	22,000	21,000
10 year	60,000	58,000
20 year	100,000	95,000
50-year	150,000	145,000
100-year	175,000	172,000
200-year	210,000	207,000
500-year	250,000	246,000

FCD Response (July 22, 2009): The table has been added to the report. Comment resolved.

17) **FCD Comment (July 8, 2009):** For both the long-term simulation and the 2005 flood simulation, only a portion of the cross-section is used in Fluvial-12. For some cross-sections, the shortened cross-section results in high flows being artificially contained. Please review and revised the cross-sections to make sure the high flows are not being artificially contained (see comment 3).

Chang Consultants Response (July 16, 2009): I have gone through the data file to check the channel cross sections against the HEC-RAS data prepared by JE Fuller. Revisions have been made to those cross sections where the channel geometries were not properly coded to represent the effective flow areas. As a result of the revisions, all modeling cases have also been rerun. However, revisions of the cross sectional data have little effects on long-term channel changes near Gilbert Road.

FCD Response (July 22, 2009): There are some cross-sections where the channel widens and is contained by the last point in the cross-section (see one example below). Would it be worthwhile to extend these cross-sections so that the channel can widen, if necessary? Would the overall results change much? If the overall results would not change much, the cross-sections do not have to be extended.

Chang Consultants Response (July 24, 2009): The right bank of this sample cross section (and several others) is along the berm that separates the main channel from the Gilbert mining pit. Under the assumption of no pit capture, the right bank is assumed stable. For the other case of pit capture, the river flow would breach the berm to enter the mining pit.

FCD Response (July 29, 2009): These cross-sections have been clarified. No new simulations need to be performed. Comment resolved.

References:

WEST, 2002, *Va Shly' Ay Akimel Hydraulic & Sediment Analysis – Final Without Project Analysis Report*, prepared for the Los Angeles District U.S. Army Corps of Engineers; September 20, 2002.