The Impact of Initial Water Surface Elevation inside Mining Pit on Head-Cutting and Downstream Erosion in Gila River

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ATTACHMENTS: The following computer files are attached to the report.

GILA.FLU: FLUVIAL-12 input file for the Gila River study

GILA-SED-FILL.OUT: FLUVIAL-12 output file for proposed mining pit filled with sediment

GILA-HIGH-WATER.OUT: FLUVIAL-12 output file for proposed mining pit filled with groundwater

GILA-INITIAL.FLU: FLUVIAL-12 input file for the Gila River study covering the initial filling of sand pit by flood water.

GILA-INITIAL.OUT: FLUVIAL-12 output file for the Gila River study covering the initial filling of sand pit by flood water.

EXECUTIVE SUMMARY

Mining pits in a river channel may cause erosion in both the upstream and downstream directions, referred to as head-cutting and tail-cutting, respectively. The fluvial processes are different for these types of channel changes. The occurrence of downstream erosion is due to sediment storage in an upstream excavation which causes a deficit of sediment supply to the downstream channel. With a sediment deficit, river flow erodes materials from the channel boundary to satisfy its transport capacity. As long as the tractive force by the flow exceeds the permissible force of the channel boundary, materials are being scoured away to become a part of the sediment load. In the case of head cutting, the downstream excavation has the effect of lowering the water-surface profile to induce a higher velocity in the adjacent upstream channel. The higher velocity, with it greater sediment transport capability, removes sediment from the upstream channel boundary to result in scour. Some of the scoured material will then be deposited in the excavation site where the velocity slows down.

There are existing and proposed mining sites in the Gila River. The river is in a region where the groundwater is very close to the river bed surface. Mining impacts on the adjacent river channel may be mitigated if the mining pit is backfilled with sediment. Several mining permit applicants in the past wanted to assume groundwater level in a mining pit would have similar effects as dirt fill in the pit. It is therefore important to determine if ground water would have the same effects as dirt fill in checking river channel erosion. The purpose of this study is to determine if groundwater in the proposed mining pit has the same effects as dirt fill on head-cutting and downstream erosion in the Gila River.

The flow velocity, sediment delivery, and river channel changes during the 100-yr flood have been simulated using the FLUVIAL-12 model for the cases of (1) pits filled with water, (2) pits filled with sediment, and (3) initially dry pit. The results are presented and compared. The river flow has lower velocities through the pits for the case of pits filled with water. On the other hand, pits filled with sediment to the same level would cause higher flow velocities. Since sediment transport is directly related to the flow velocity, more sediment deposition can be expected in the mining pits filled with groundwater. Sediment refill, on the other hand, would reduce sediment deposition in the sediment-filled pits. More sediment deposition in

groundwater-filled pits also means more sediment trapping or more sediment storage in the pits. This has the direct effects of reducing sediment supply to the downstream channel.

Sediment deliveries by the 100-yr flood for the cases of (1) pits filled with water, (2) pits filled with sediment, and (3) initially dry pit have been simulated in modeling. Total amounts of sediment flow entering the proposed mining pit from the upstream channel during the 100-yr flood are summarized in the table below.

Summary of sediment flow entering mining pit
during 100-yr flood

Case scenario	Sediment flow entering mining pit
High groundwater	680,000 tons
Sediment-filled pit	372,000 tons
Initially dry pit	684,000 tons

The proposed mining pit filled with groundwater traps much more sediment than the sediment-filled pit. The pit will continue to trap inflow sediment for a long time until it is filled with sediment. Sediment trapping and sediment storage in the pits in turn cause deficit of sediment supply along the downstream channel. The hungry flood water will continue to erode sediment from the channel boundary to result in scour. The downstream erosion caused by sediment deficit is a slow process; major downstream erosion usually develops in the long term in a gravel bed river, such as the Gila River.

Computed changes in cross-sectional area due to head-cutting for river stations near the pit entrance are listed in the table below. The minimum bed elevations reached by channel bed scour due to head cutting are listed in another table. Among them, river station 197.07 is at the upstream entrance of the proposed mining pit. From the listed sets of numbers, it is easy to see that more head-cutting would develop for the case of groundwater-filled pit than for the case of sediment-filled pit. The magnitude of head-cutting is the largest at the pit entrance (station 197.07). The difference in head-cutting for these three cases is also the largest at the pit entrance.

The magnitude of head-cutting becomes smaller and the difference in head-cutting for these cases also decreases toward upstream.

Cross-sectional area changes due to head-cutting
during the 100-yr flood for three cases

River station River miles	Cross-sectional area change due to scour during the 100-yr flood Square feet		
	Pits filled with sediment	Pits filled with water	Initially dry pits
197.07	499	5,900	6,045
197.16	1,178	3,573	3,570
197.26	1,325	2,970	2,967
197.35	1,243	1,710	1,710
197.45	365	1,414	1,415

Minimum bed elevation reached by head-cutting
during the 100-yr flood for three cases

River station River miles	Minimum bed elevation reached by head-cutting during the 100-yr flood Feet		
	Pits filled with sediment	Pits filled with water	Initially dry pits
197.07	910.2	901.4	901.0
197.16	914.1	904.3	904.3
197.26	915.1	915.1	915.1

The simulated results demonstrate that mining pits induce head-cutting in the upstream channel. High groundwater level in the mining pit does not reduce head-cutting. The effects of high groundwater level are not the same as sediment level in the mining pit.

The Impact of Initial Water Surface Elevation inside Mining Pit on Head-Cutting and Downstream Erosion in Gila River

I. INTRODUCTION

Sand and gravel mining in river channels has been going on in Maricopa County, Arizona. Such mining activities may cause erosion in both the upstream and downstream directions, referred to as head-cutting and tail-cutting, respectively. The fluvial processes are different for these types of channel changes. The occurrence of downstream erosion is due to sediment storage in an upstream excavation which causes a deficit of sediment supply to the downstream channel. With a sediment deficit, river flow erodes materials from the channel boundary to satisfy its transport capacity. As long as the tractive force by the flow exceeds the permissible force of the channel boundary, materials are being scoured away to become a part of the sediment load. In the case of head cutting, the downstream excavation has the effect of lowering the water-surface profile to induce a higher velocity in the adjacent upstream channel. The higher velocity, with it greater sediment transport capability, removes sediment from the upstream channel boundary to result in scour. Some of the scoured material will then be deposited in the excavation site where the velocity slows down.

The reach of the Gila River selected in the study is an alluvial channel consisting of predominantly sand with some gravel and cobbles. There are existing and proposed mining sites in the Gila River. Figure 1 shows two aerial photographs of the Gila River. The proposed mining site is marked by a red rectangle; the existing mining pit is marked by a yellow circle. This reach of the Gila River is in a region where the groundwater is very close to the surface.

Mining impacts on the adjacent river channel may be mitigated if the mining pit is backfilled with sediment. Several mining permit applicants in the past wanted to assume groundwater level in a mining pit would have similar effects as dirt fill in the pit. It is therefore important to determine if the ground water would have the same effects as dirt fill in checking river channel erosion. This purpose of this study is to determine if the groundwater in the proposed mining pit has the same effects as dirt fill to mitigate head-cutting and downstream erosion in the river channel.

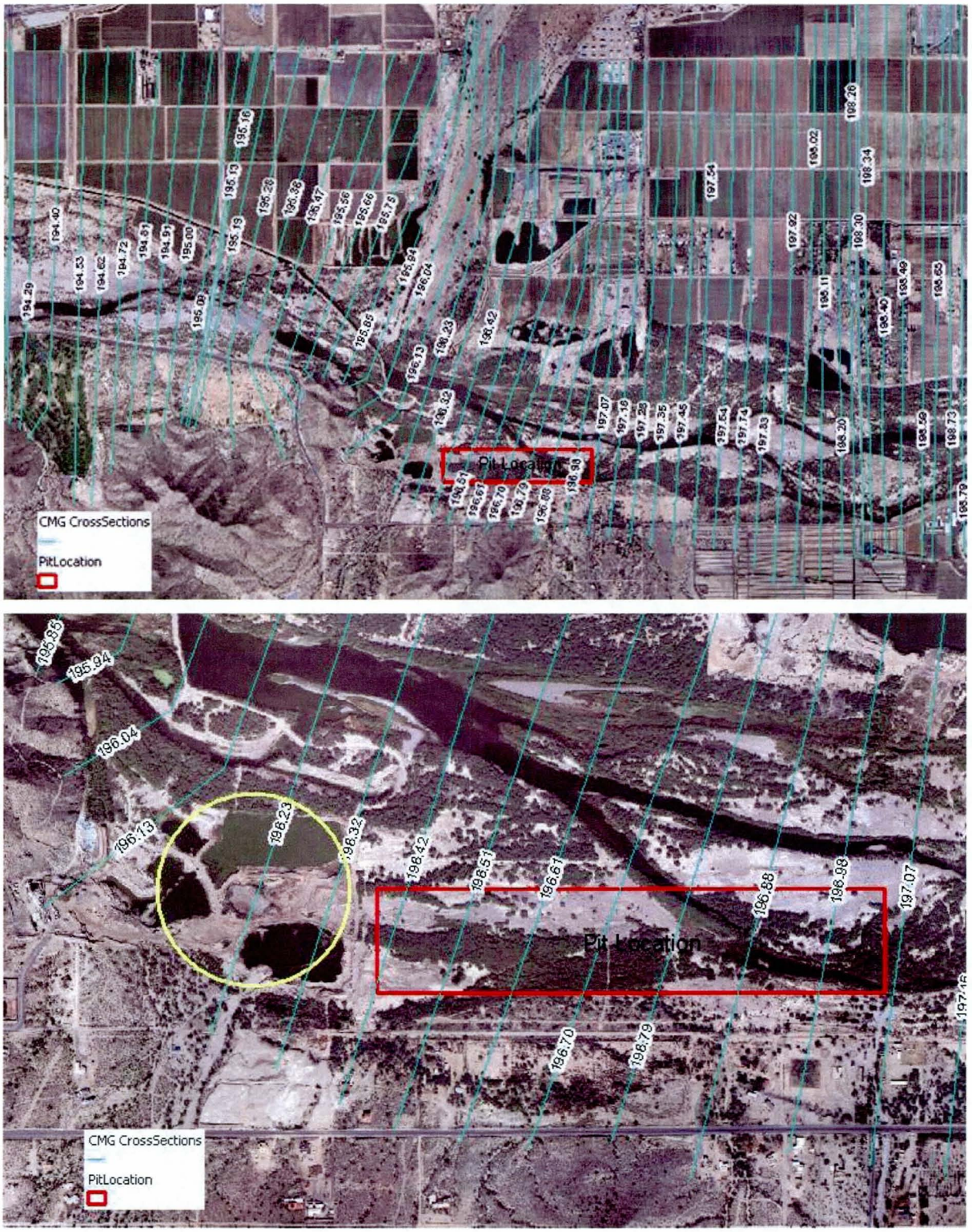


Figure 1. Aerial photographs of the Gila River with mining sites

II. COMPILATION OF RIVER DATA

The data set for the Gila River study has the following items:

(1) Aerial maps of the Gila River as shown in Figure 1. The maps show locations of cross sections used for the hydraulic and sediment studies.

(2) Available digitized cross-sectional data for the river reach.

(3) The 100-yr flood hydrograph as shown in Figure 2.

(4) Exiting and proposed sand and gravel mining sites.

(5) Sediment samples taken along the study river reach as shown in Figure 3. Size distributions of such samples were obtained based on sieve analysis.

Data for the current study are from the Gila River study by Stantec Consulting, Inc. (2006) for the El Rio Watercourse Master Plan 82000240, prepared for Flood Control District of Maricopa County. Channel geometry data is from the 1999 Floodplain Delineation Study by Baker Engineers. The sediment gradations are from the HEC-6T model, for which Stantec developed the PF and PFC cards for river station 199.07. The other river stations were developed by CMG Drainage Engineering, Inc., as part of the sand and gravel permit application.

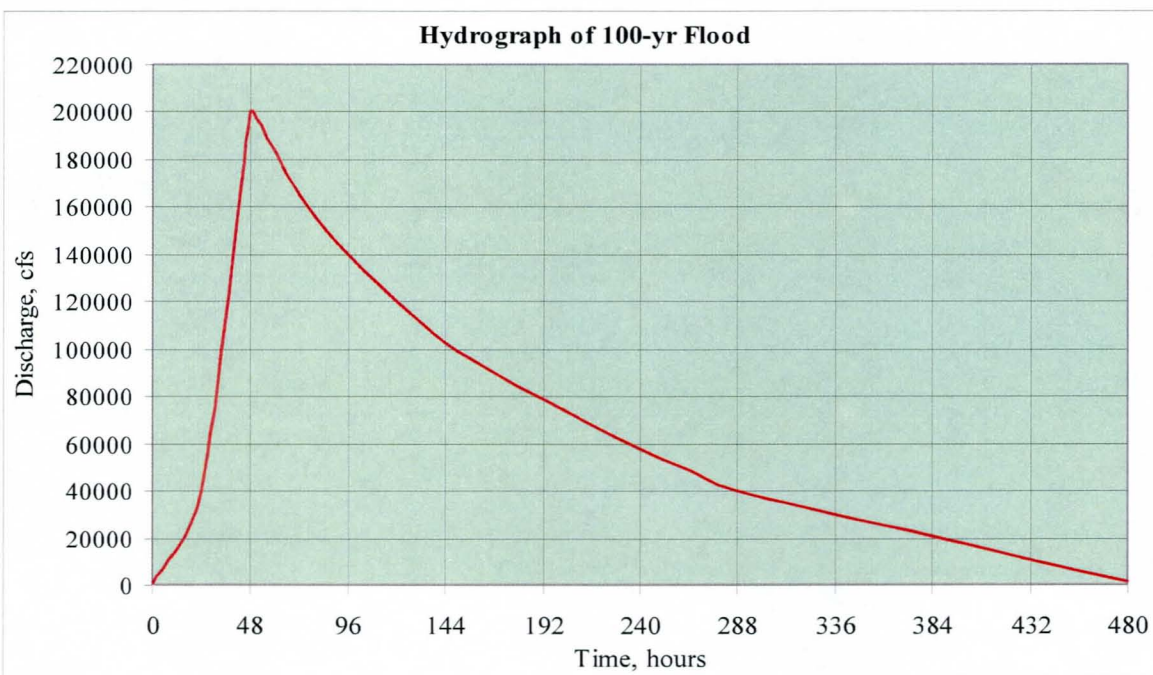


Figure 2. Hydrograph of the 100-yr flood

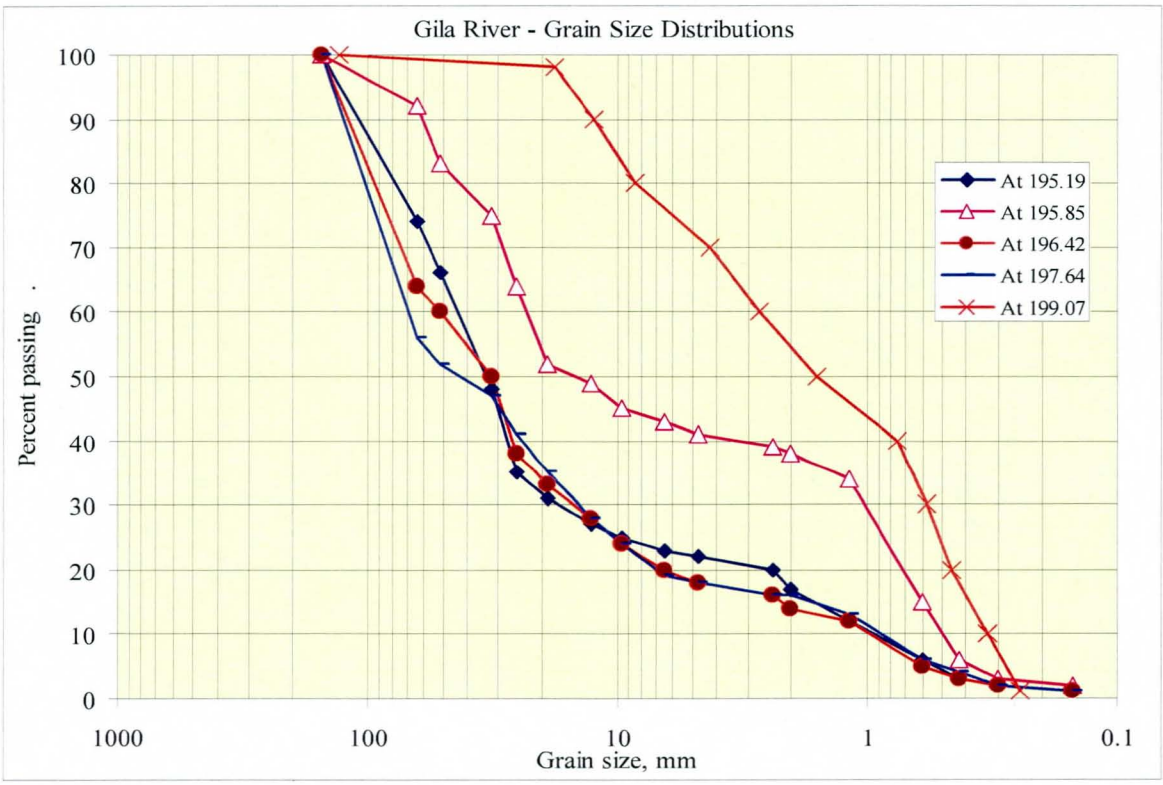


Figure 3. Gradations of sediment samples

III. HEAD-CUTTING DURING INITIAL MINING PIT REFILL BY FLOOD WATER

The study is general in scope. The proposed mining pit is used as a sample to verify that a pit filled with sediment is not equivalent to a pit filled with groundwater. The proposed mining pit has a bottom width of about 470 feet, 3 to 1 side slopes, and a total length of about 3,000 feet. The bottom elevation of 840 feet is about 70 feet below the upstream channel bed. For an initially dry pit, floodwater drops down into the pit during the initial refill. High velocity develops in the upstream channel due to the steep gradient to cause head cutting. On the other hand, a high initial groundwater level in the pit tends to reduce the approaching flow velocity as well as head-cutting.

Time Variation of Water-Surface Elevation in Mining Pit - An initially empty pit gets refilled by floodwater during the initial stage of flood flow. The rise of water level in the pit during the refill can be determined based on the time variation of the flood discharge and the

elevation - storage volume relation for the pit. Time variation of the flood discharge is given by the flood hydrograph shown in Figure 2. The storage volume versus water level relation for the pit has been established from the geometric data for the pit as shown in Figure 4. Table 1 shows the time intervals in column 1; their corresponding flood discharges in column 2. The volume of floodwater for each time increment is computed by the product of the average discharge with time duration. The accumulated volumes of water at the time intervals are shown in column 3. For each storage volume, the stage or water-surface elevation in the pit in Table 1is then obtained from Figure 4. From the tabulated values in Table 1, the time variation of water-surface elevation is established as show in Figure 5. It shows that the mining pit is filled to the brink level of 950 feet in 6.5 hours. This relation serves as the downstream boundary condition is simulating the sediment process during the initial refill of the mining pit.

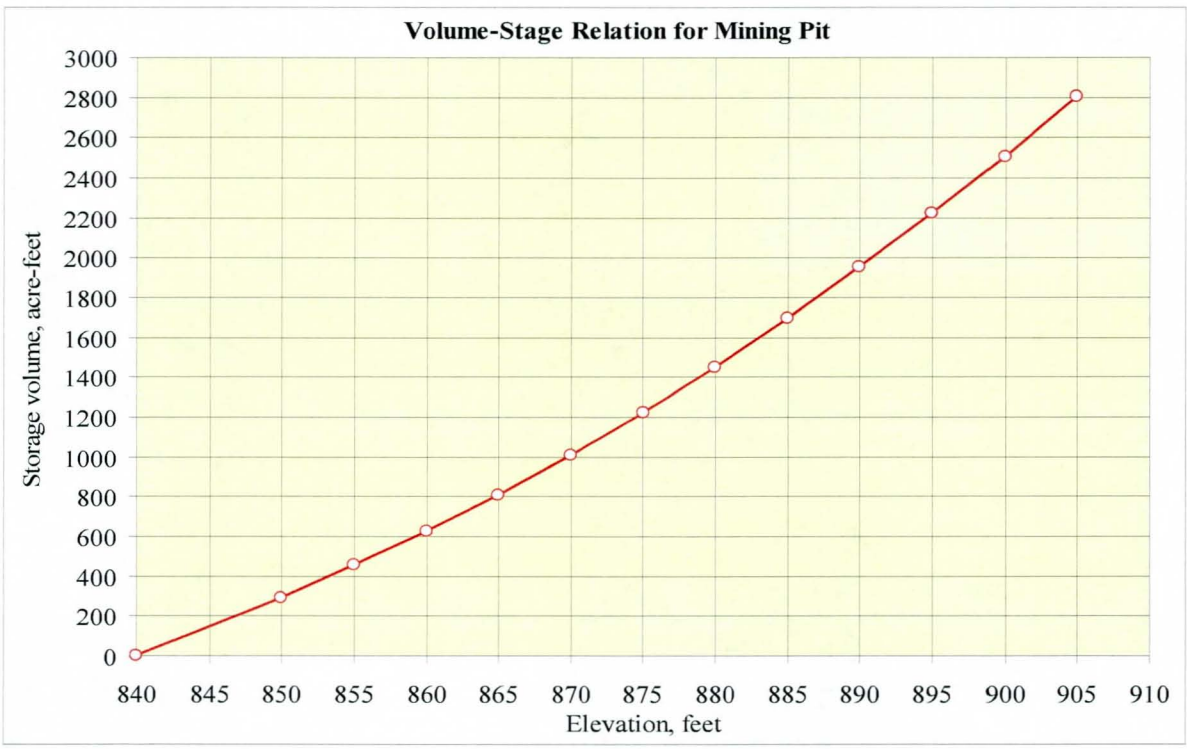


Figure 4. Storage volume of proposed mining pit in relation to water-surface elevation

Table 1. Time variations of flood discharge, accumulated volume of pit inflow, and stage in pit

Time hours	Flood discharge cfs	Accu. Flow Vol. acre-feet	Stage in pit, feet
0.81	1,351	45.2	841.5
1.74	2,907	209	846
2.64	4,407	481	857
3.94	6,574	1,070	872
4.61	7,685	1,445	881.3
5.18	8,629	1,847	888
5.78	9,629	2,300	896.8
6.34	10,574	3,770	904
6.64	11,074	3,038	907

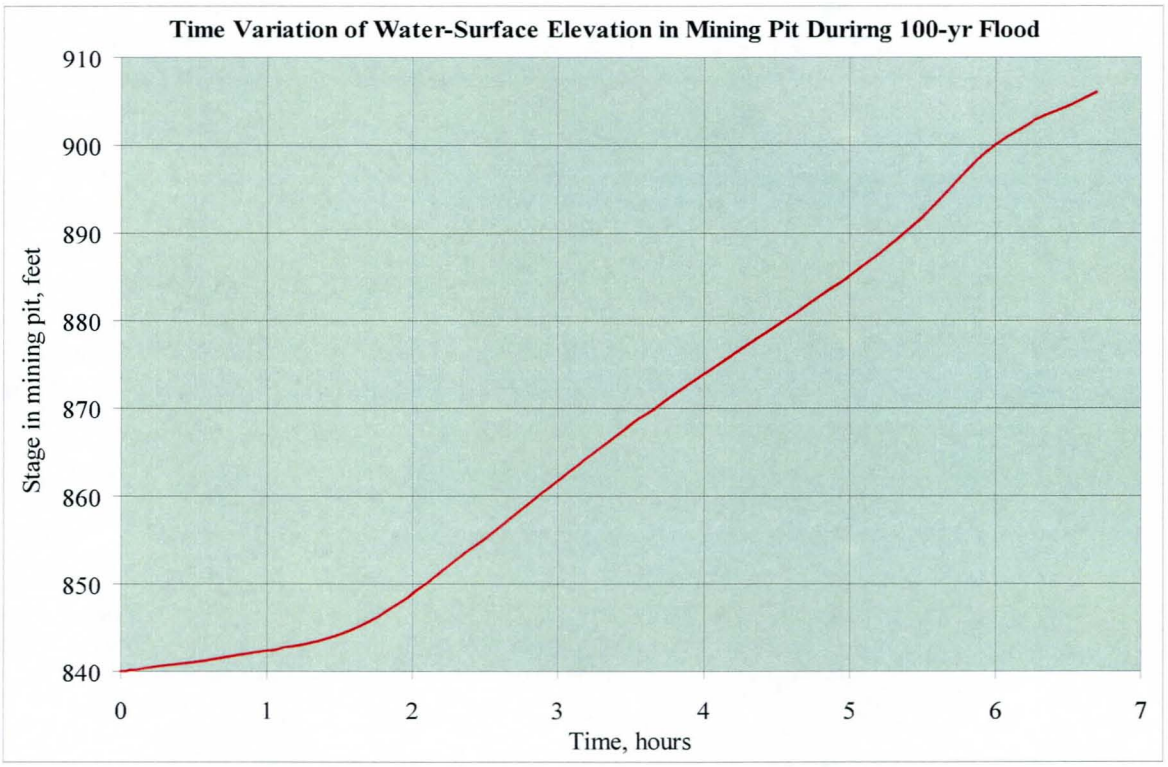


Figure 5. Time variation of stage in mining pit during initial refill

IV. SEDIMENT TRANSPORT MODELING USING FLUVIAL-12

Sediment transport and river channel changes for the Gila River 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 Gila River was computed in the model using the Meyer-Peter--Muller formula (Meyer-Peter - Muller, 1948; 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 Gila River, the Meyer-Peter--Muller formula was used. The dimensionless Meyer-Peter--Muller formula and the physical meanings for its respective terms normalized by $(\gamma_s - \gamma)\, d_m$ are given by

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

I----------I I----------I I-----I

I II III

The left-had side of the equation (Term I) is the bed load discharge in its dimensionless form. The first term on the right-and side (Term II) is the effective shear stress, defined as that part of the shear stress applied to sediment grains excluding the part due to bed forms. The second term (Term III) on the right-hand side is the critical shear to initiate sediment motion. 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.

Spatial Variations of Sediment Delivery through Mining Pits - For the purposes of resources planning and management, it is necessary to determine the amount of sediment delivery toward downstream affected by the proposed sand and gravel mining. The Gila River will undergo changes as some sediment is deposited or removed from the river channel boundary. Sediment delivery is defined as the accumulated amount of sediment that has been delivered passing a certain channel section for a specified period of time, that is,

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

In which, 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. negative 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 (positive 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 sediment balance, i.e., zero storage or depletion. Channel reaches with net sediment storage or depletion may 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.

Sediment delivery will be used to keep track of the sediment budget in order to assess the effects on sediment budget due to groundwater and dirt refill. Figure 8 shows the spatial variations of sediment delivery along the river channel in the vicinity of the mining sites for the cases of pits filled with groundwater and pits filled with sediment. Major differences in sediment delivery occur in the upstream entrance of the proposed mining pit. The total amounts of sediment delivery by the 100-yr flood for the cases are summarized in Table 2.

V. HEAD-CUTTING DURING INITIAL MINING PIT REFILL

The mining pit has a bed elevation that is about 70 feet lower than the upstream channel bed. During the initial refill of the mining pit, floodwater drops down into the pit from upstream. Head-cutting develops in the upstream channel at the pit entrance. Simulated water-surface and channel-bed profile changes during initial head cutting are shown in Figure 6. It takes 6.5 hours for the sand pit to be refilled. The changes in cross-sectional profile due to head-cutting at the pit entrance (station 197.07) are shown Figure 7. The maximum scour depth at the location is 0.46 foot.

Simulated spatial variations of sediment delivery along the channel during the initial pit refill are shown in Figure 8. Total sediment delivery reaching the pit entrance at river station 197.07 is 4,060 tons. The delivery in the pit is less than 1 ton. The total amount of sediment storage in the pit during the initial refill is therefore 4,060 tons. The total sediment refill in the pit is also the sediment removed by scour from the upstream channel due to head-cutting.

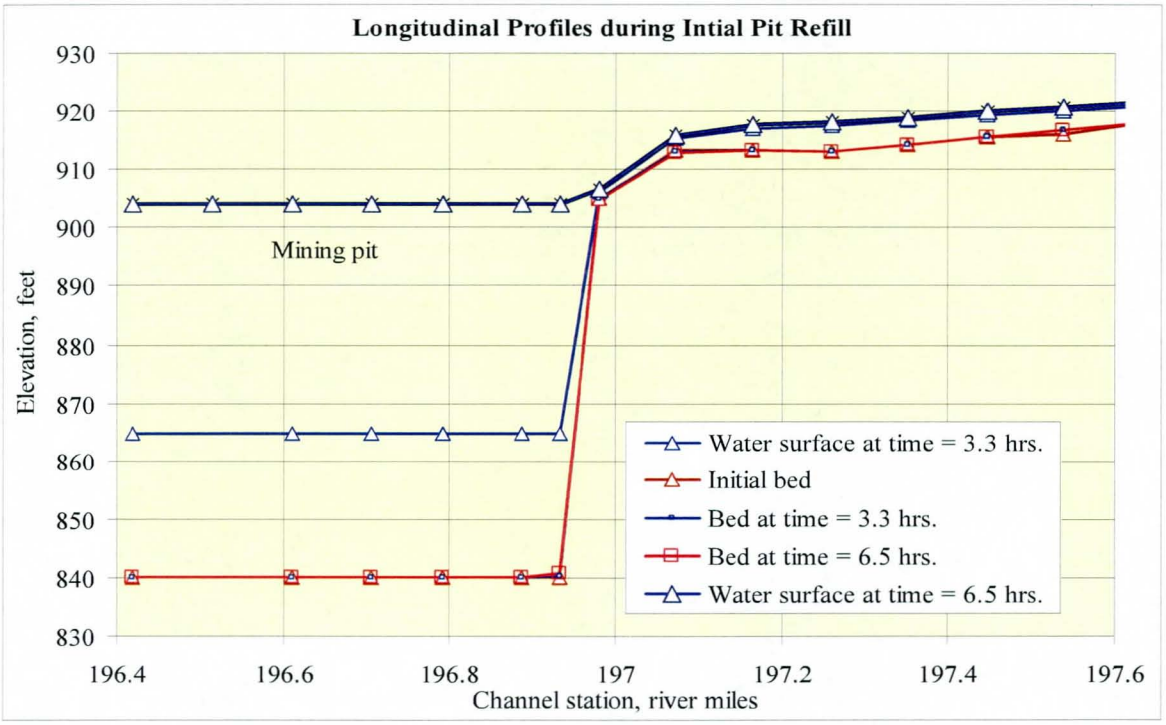


Figure 6. Water-surface and channel bed profile change during the initial pit refill

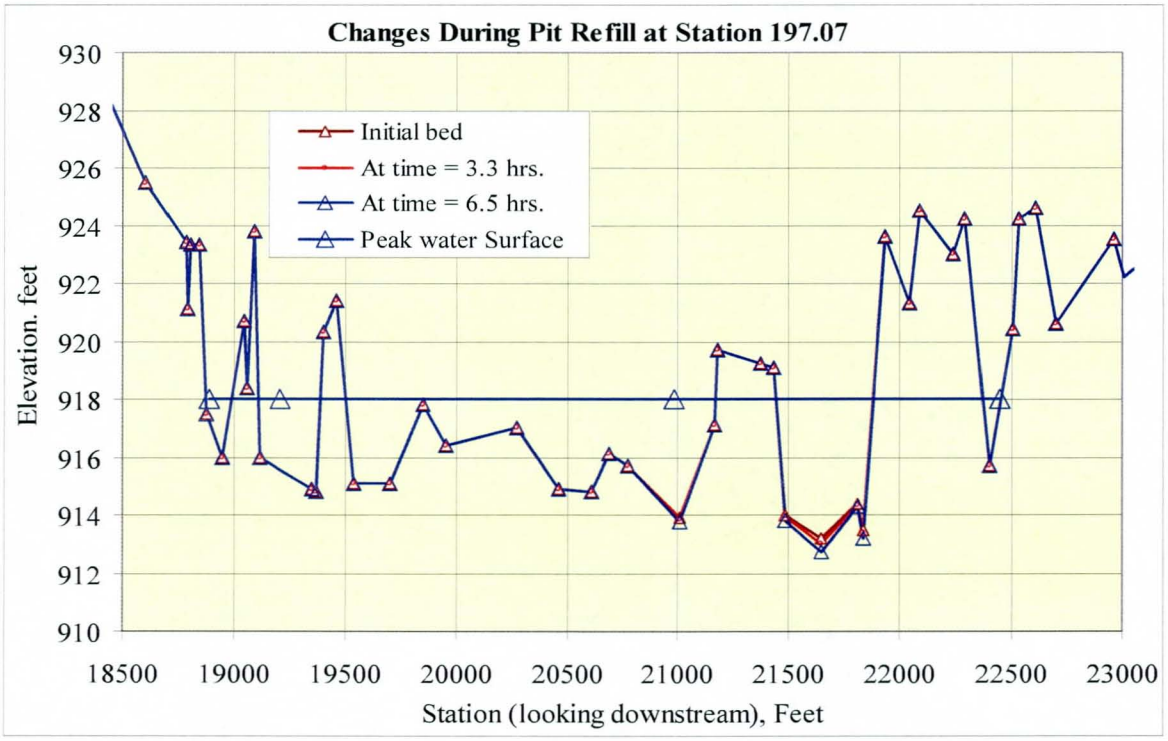


Figure 7. Simulated cross-sectional changes at river station 197.07 during initial pit refill

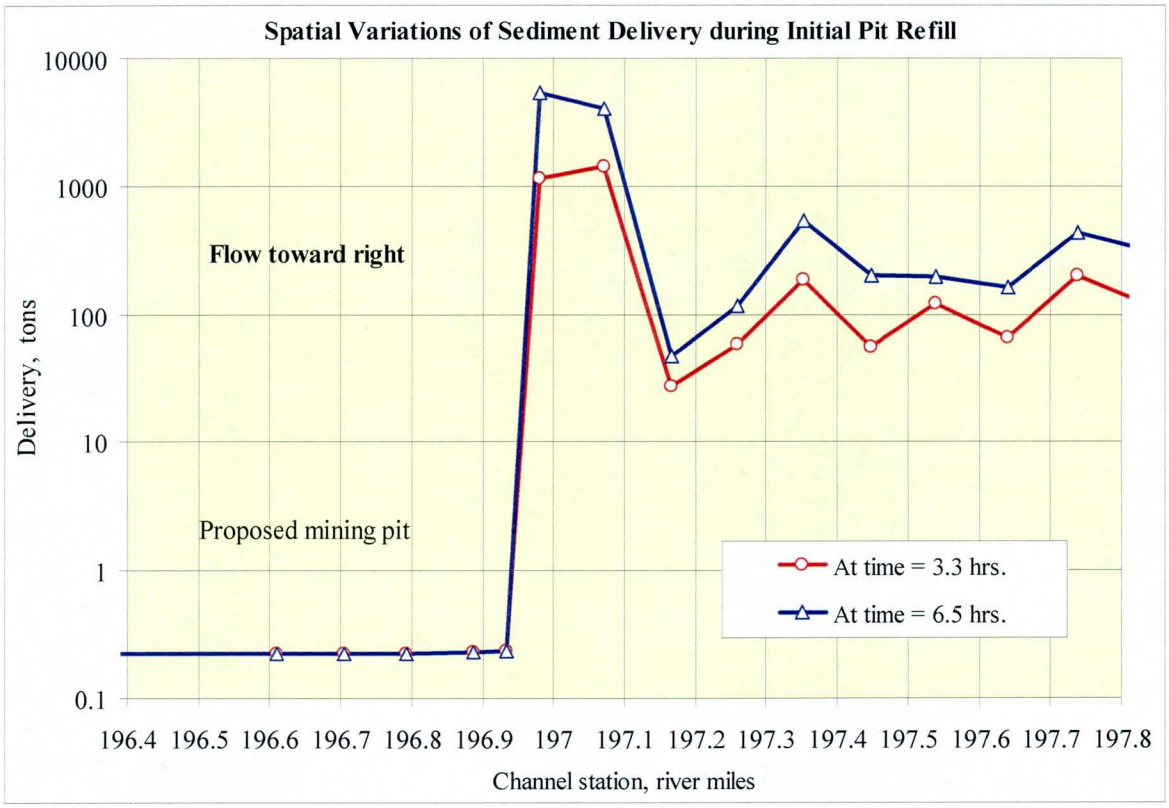


Figure 8. Spatial variations of sediment delivery during initial pit refill

VI. MODELED RESULTS ON FLOW VELOCITY AND SEDIMENT DELIVERY

River channel flow, sediment delivery, and changes in geometry have been simulated using the 100-yr flood for the three following conditions: (1) mining pits filled with groundwater to the brink level, (2) mining pits filled with sediment, and (3) initially dry mining pit. It is assumed that the groundwater is at the elevation of 905 feet. For the existing pit, groundwater can reach the elevation of 885 feet without spilling; and for the proposed pit, the brink level is 905 feet.

Spatial Variations of Flow Velocity through Mining Pits - The simulated flow velocities at the peak flow and their spatial variations along the channel near the pits for the two conditions are shown in Figure 9. The river flow has lower velocities through the pits for the case of pits filled with water. On the other hand, pits filled with sediment to the same level would cause higher flow velocities. Since sediment transport is directly related to the flow

velocity, more sediment deposition can be expected in the mining pits filled with groundwater. Sediment refill, on the other hand, would reduce sediment deposition in the sediment-filled pits. More sediment deposition in groundwater-filled pits also means more sediment trapping or more sediment storage in the pits. This has the direct effects of reducing sediment supply to the downstream channel. Sediment trapping by mining pits is the direct cause of erosion downstream of a mining pit.

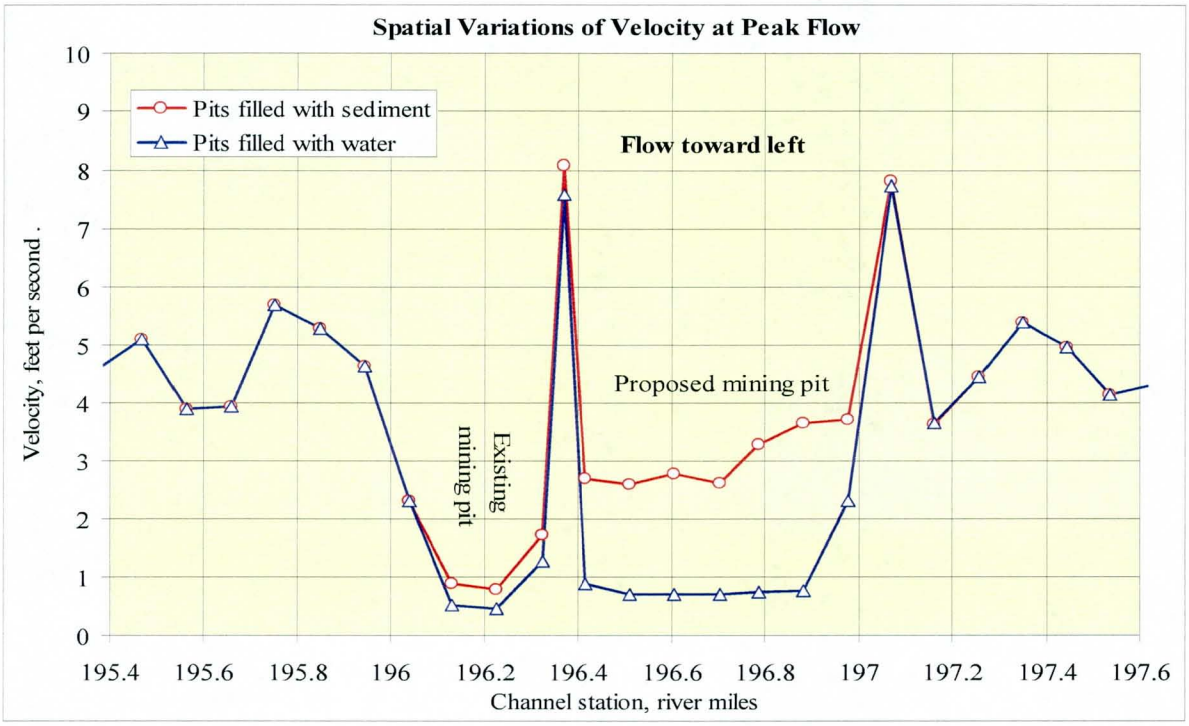


Figure 9. Spatial variations of flow velocities at peak flow

Total sediment deliveries by the 100-yr flood for the cases of (1) pits filled with water, (2) pits filled with sediment, and (3) initially dry pit have been simulated in modeling. The results are presented in Figure 10 and Table 2. It can be seen that much more sediment would be transported along the channel reach in the upstream vicinity of the proposed mining pit for the case of pits filled with groundwater. For this reason, pits filled with groundwater do not mitigate head-cutting; the effects of groundwater are not the same as sediment refill in the pits.

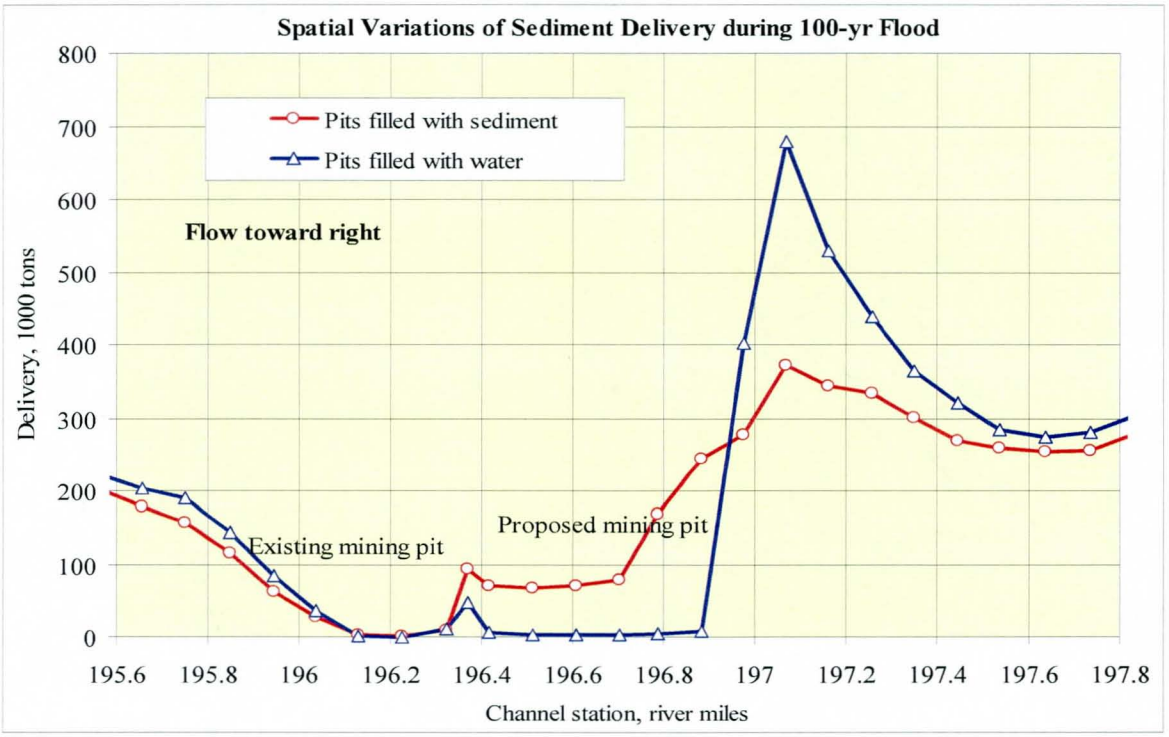


Figure 10. Spatial variations of sediment delivery by the 100-yr flood for two cases

Table 2. Comparison of sediment deliveries during the 100-yr flood for two cases

River station River miles	Total sediment delivery during the 100-yr flood Tons	
	Pits filled with sediment	Pits filled with groundwater
196.98	278,000	402,000
197.07	372,000	680,000
197.16	364,000	529,000
197.26	334,000	438,000
197.35	301,000	364,000
197.45	269,000	320,000
197.54	260,000	285,000

The sediment delivery passing river station 197.07 is the amount of sediment eroded from the upstream channel; it is also the amount of sediment entering the proposed mining pit. This

amount is 372,000 tons for the case of high initial groundwater level and 680,000 tons for the case of the sediment-filled pit. For the case of the initially dry pit, sediment delivery passing river station 197.07 is 4,060 tons during the initial refill of the mining pit by floodwater. From these numbers, the following amounts of sediment delivery entering the mining pit can be summarized below:

Table 3. Summary of sediment flow entering mining pit during 100-yr flood

Case scenario	Sediment flow entering mining pit
High groundwater	680,000 tons
Dirt-filled pit	372,000 tons
Initially dry pit	684,000 tons

Mining pits filled with groundwater will continue to trap inflow sediment. Sediment trapping and sediment storage in the pits in turn cause deficit of sediment supply along the downstream channel. The hungry flood water will continue to erode sediment from the channel boundary to result in scour. The downstream erosion caused by sediment deficit is a slow process; major downstream erosion usually develops in the long term in a gravel bed river, such as the Gila River.

VII. MODELED RESULTS ON RIVER CHANNEL SCOUR

Potential changes in river chance geometry have been mathematically simulated using the FLUVIAL-12 model for the two conditions. The computer simulation for general scour was made for the 100-yr flood, covering the following features: (1) changes in longitudinal channel profiles and (2) changes in channel cross sections. The effects of groundwater on head-cutting and downstream erosion can be assessed based on the simulated results.

Simulated water-surface and channel bed profile changes for the case of pits filled with groundwater are shown in Figure 11; those for the case of pits filled with sediment are shown in

Figure 12. Simulated cross-sectional changes for both cases are shown in Figure 13. For the first case, floodwater flows through the pits at low velocities. For the second case, floodwater flows through the pits over the sediment-filled bed at higher velocities. Head-cutting develops at the entrance of the proposed mining pit for both cases. Changes in longitudinal channel bed profiles show that head-cutting occurs in the upstream entrance of the pit. Its magnitude is the largest at the pit entrance and it tapers off towards upstream away from the pit entrance. While the extent of head-cutting is inhibited by the coarse gravel, it is easy to see there is more head-cutting for the case of groundwater filled pits.

The cross-sectional changes shown in Figure 13 are used to show the head-cutting developments as well as the comparison of head-cuttings for these cases. Changes in cross – sectional area due to head-cutting for the river stations near the pit entrance are listed in Table 4. Station 197.07 is at the upstream entrance of the proposed mining pit. There is more head-cutting for the case of groundwater-filled pit than for the case of sediment-filled pit. For other upstream channel stations, the head-cutting becomes smaller and the difference in head-cutting for these cases also diminishes.

Table 4. Cross-sectional area changes due to scour during the 100-yr flood for three cases

River station River miles	Cross-sectional area change due to scour during the 100-yr flood Square feet		
	Pits filled with sediment	Pits filled with water	Initially dry pits
197.07	499	5,900	6,045
197.16	1,178	3,573	3,570
197.26	1,325	2,970	2,967
197.35	1,243	1,710	1,710
197.45	365	1,414	1,415

The cross-sectional area change during initial refill of the dry pit is 145 square feet at river station 197.07; it becomes very small at other upstream river stations. For the duration of the

100-yr flood, the total cross-sectional area change due to scour at river station 197.07 is then 6,045 square feet (the sum of 145 and 5,900).

The simulated results demonstrate that mining pits induce head-cutting in the upstream channel. High groundwater level in the mining pit does not reduce head-cutting. The effects of high groundwater level are not the same as sediment level in the mining pit.

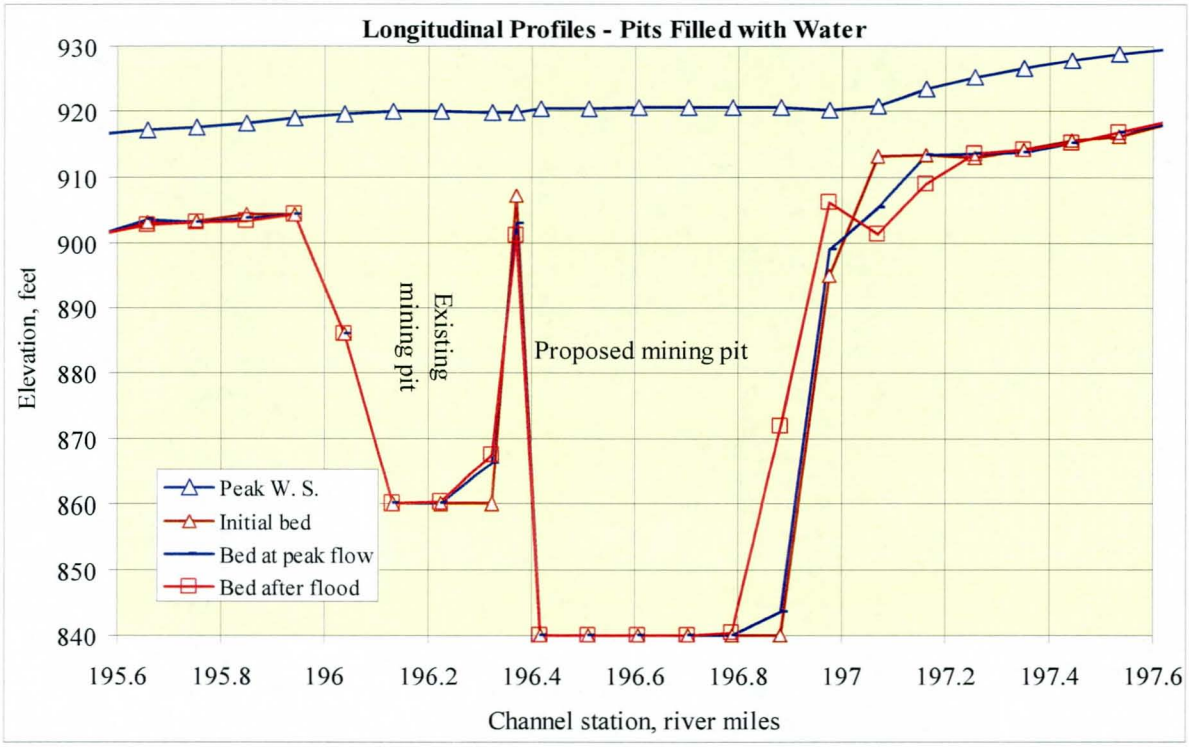


Figure 11. Simulated water-surface and channel bed profile changes during 100-yr flood for pits filled with groundwater

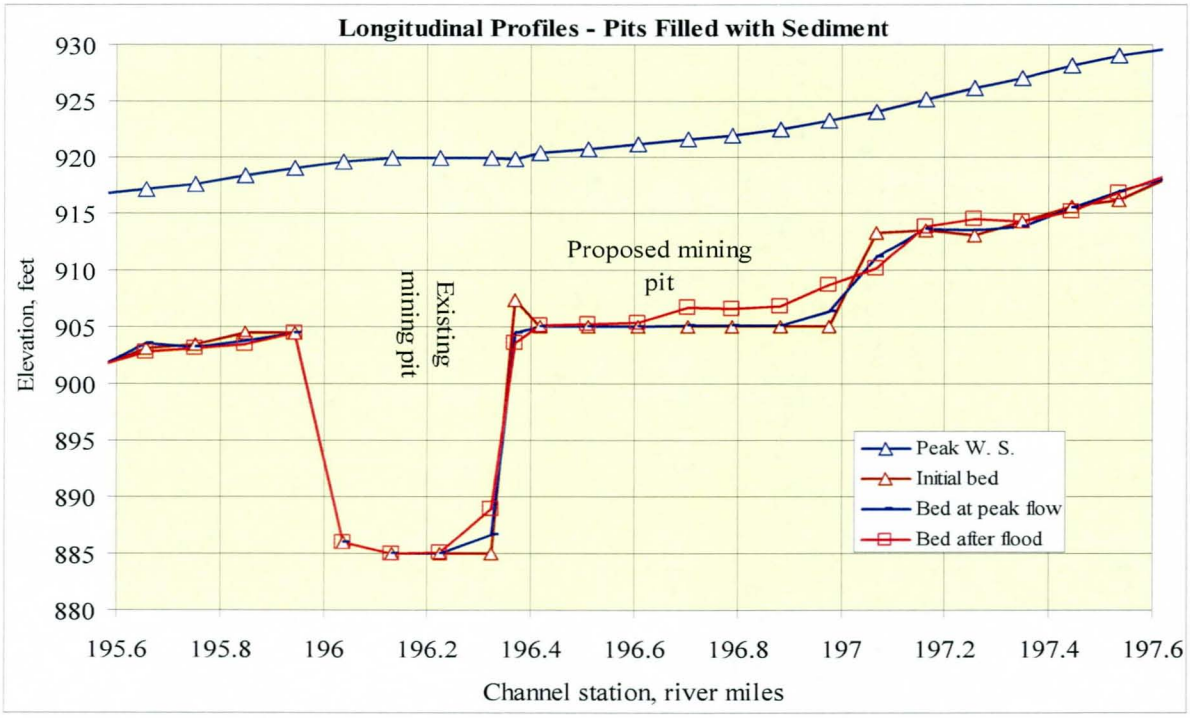
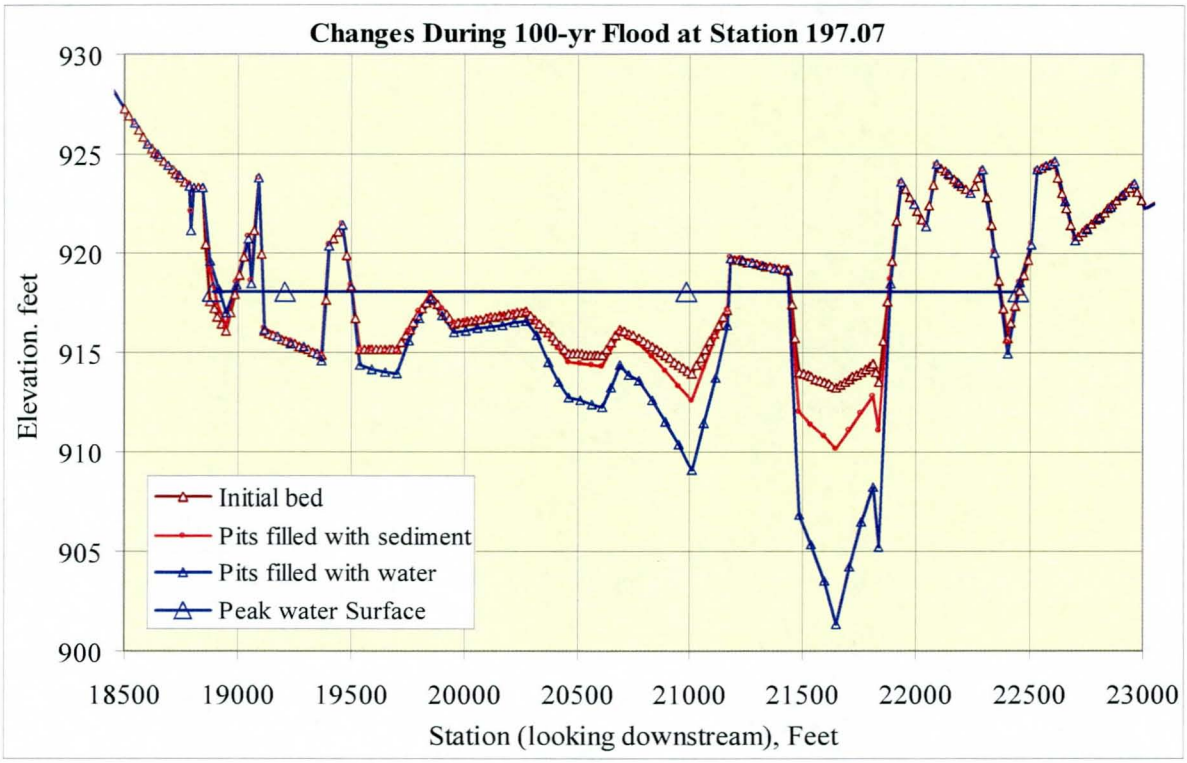


Figure 12. Simulated water-surface and channel bed profile changes during 100-yr flood for pits filled with sediment



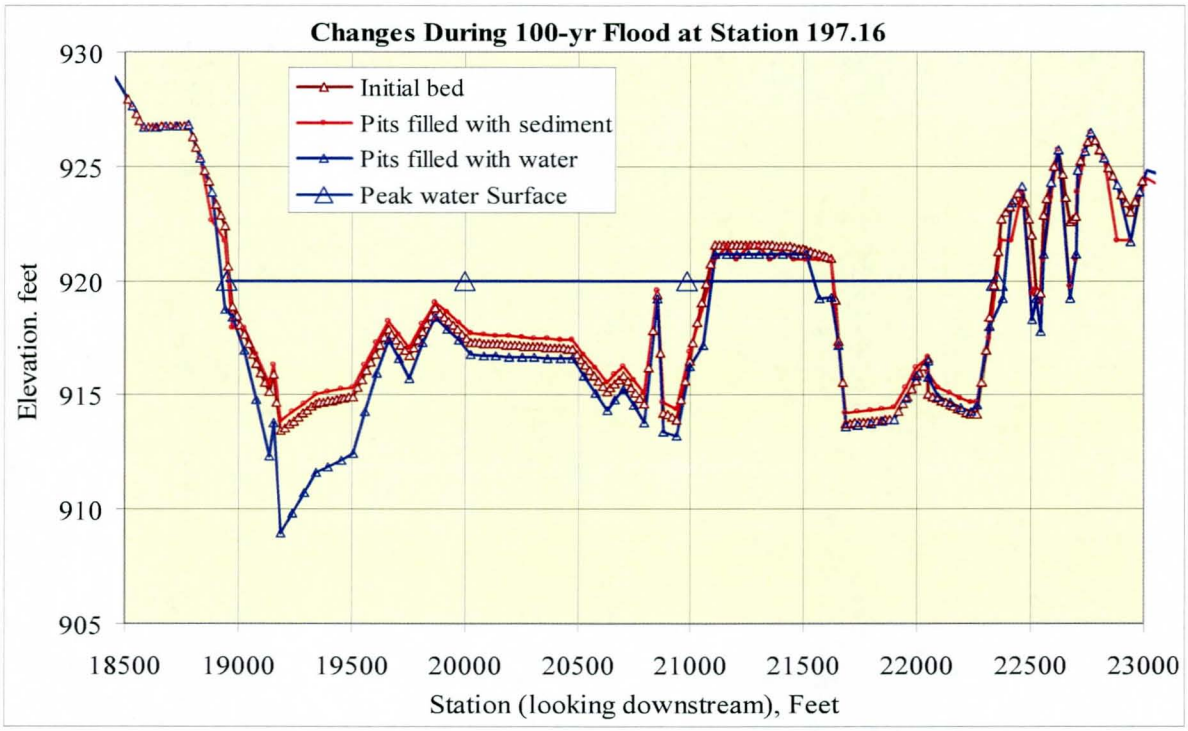


Figure 13. Simulated changes in channel cross sections

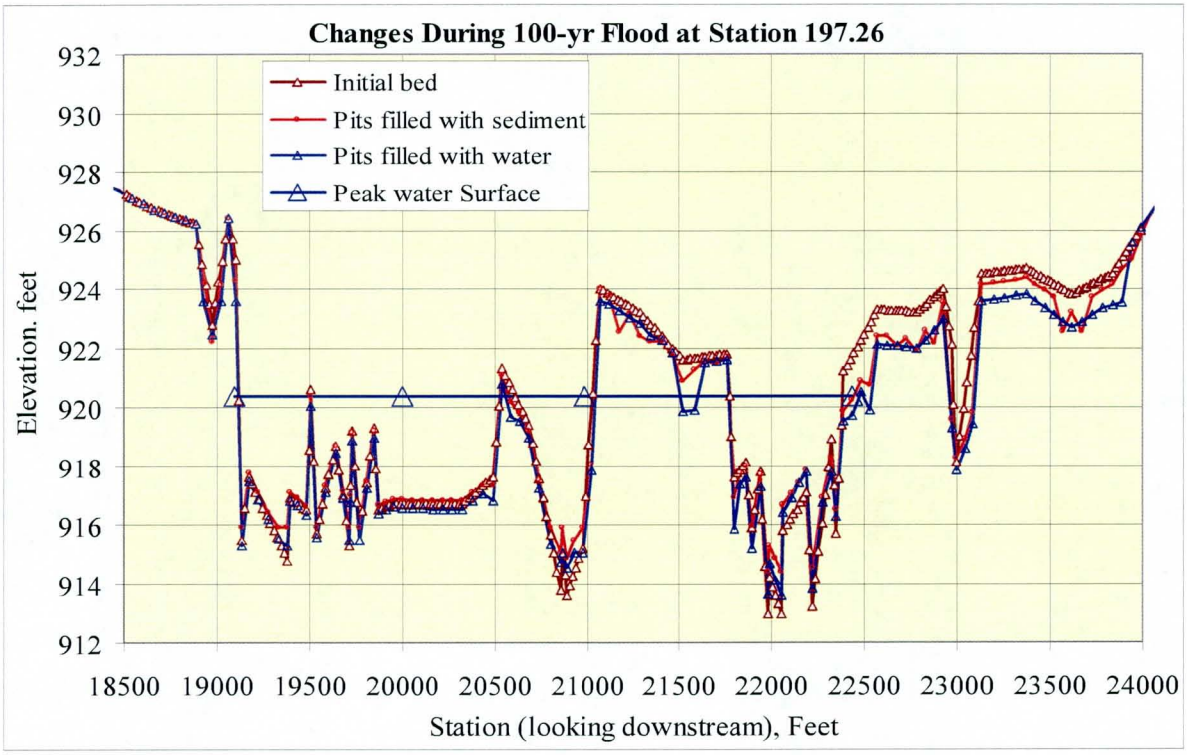


Figure 13 (continued). Simulated changes in channel cross sections

VIII. SUMMARY AND CONCLUSIONS

There are existing and proposed mining sites in the Gila River. The river is in a region where the groundwater is very close to the river bed surface. Mining impacts on the adjacent river channel may be mitigated if the mining pit is backfilled with sediment. Several mining permit applicants in the past wanted to assume groundwater level in a mining pit would have similar effects as dirt fill in the pit. It is therefore important to determine if ground water would have the same effects as dirt fill in checking river channel erosion. The purpose of this study is to determine if groundwater in the proposed mining pit has the same effects as dirt fill on head-cutting and downstream erosion in the Gila River.

The flow velocity, sediment delivery, and river channel changes during the 100-yr flood have been simulated using the FLUVIAL-12 model for the cases of (1) pits filled with water, (2) pits filled with sediment, and (3) initially dry pit. The results are presented and compared. The river flow has lower velocities through the pits for the case of pits filled with water. On the other

hand, pits filled with sediment to the same level would cause higher flow velocities. Since sediment transport is directly related to the flow velocity, more sediment deposition can be expected in the mining pits filled with groundwater. Sediment refill, on the other hand, would reduce sediment deposition in the sediment-filled pits. More sediment deposition in groundwater-filled pits also means more sediment trapping or more sediment storage in the pits. This has the direct effects of reducing sediment supply to the downstream channel.

Sediment deliveries by the 100-yr flood for the cases of (1) pits filled with water, (2) pits filled with sediment, and (3) initially dry pit have been simulated in modeling. Total amounts of sediment flow entering the proposed mining pit from the upstream channel during the 100-yr flood are summarized in the table below.

Summary of sediment flow entering mining pit
during 100-yr flood

Case scenario	Sediment flow entering mining pit
High groundwater	680,000 tons
Sediment-filled pit	372,000 tons
Initially dry pit	684,000 tons

The proposed mining pit filled with groundwater traps much more sediment than the case of sediment-filled pit. The pit will continue to trap inflow sediment for a long time until it is filled with sediment. Sediment trapping and sediment storage in the pits in turn cause deficit of sediment supply along the downstream channel. The hungry flood water will continue to erode sediment from the channel boundary to result in scour. The downstream erosion caused by sediment deficit is a slow process; major downstream erosion usually develops in the long term in a gravel bed river, such as the Gila River.

Computed changes in cross-sectional area due to head-cutting for river stations near the pit entrance are listed in the table below. The minimum bed elevations reached by channel bed scour due to head cutting are listed in another table. Among them, river station 197.07 is at the

upstream entrance of the proposed mining pit. From the listed sets of numbers, it is easy to see that more head-cutting would develop for the case of groundwater-filled pit than for the case of sediment-filled pit. The magnitude of head-cutting is the largest at the pit entrance (station 197.07). The difference in head-cutting for these three cases is also the largest at the pit entrance. The magnitude of head-cutting becomes smaller and the difference in head-cutting for these cases also decreases toward upstream.

Cross-sectional area changes due to head-cutting
during the 100-yr flood for three cases

River station River miles	Cross-sectional area change due to scour during the 100-yr flood Square feet		
	Pits filled with sediment	Pits filled with water	Initially dry pits
197.07	499	5,900	6,045
197.16	1,178	3,573	3,570
197.26	1,325	2,970	2,967
197.35	1,243	1,710	1,710
197.45	365	1,414	1,415

Minimum bed elevation reached by head-cutting
during the 100-yr flood for three cases

River station River miles	Minimum bed elevation reached by head-cutting during the 100-yr flood Feet		
	Pits filled with sediment	Pits filled with water	Initially dry pits
197.07	910.2	901.4	901.0
197.16	914.1	904.3	904.3
197.26	915.1	915.1	915.1

The simulated results demonstrate that mining pits induce head-cutting in the upstream channel. High groundwater level in the mining pit does not reduce head-cutting. The effects of high groundwater level are not the same as sediment level in the mining pit.

REFERENCES

Chang, H. H., *Fluvial Processes in River Engineering*, John Wiley & Sons, 1988.

Meyer-Peter, E. and Muller, R., "Formulas for Bed-Load Transport," Paper No. 2, Proceedings of the Second Meeting, IAHR, 1948, pp. 39-64.

Stantec Consulting, Inc. (Stantec), 2006. *El Rio Watercourse Master Plan, El Rio Sedimentation Analysis, Book 1 El Rio Existing Condition Sedimentation Analysis*. Prepared for the Flood Control District of Maricopa County.

Vanoni, V. (ed.), 2006. Sedimentation Engineering, ASCE Manual 54, ASCE, Reston, VA.

Flood Control District
of Maricopa County

MEMORANDUM

Date: August 6, 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

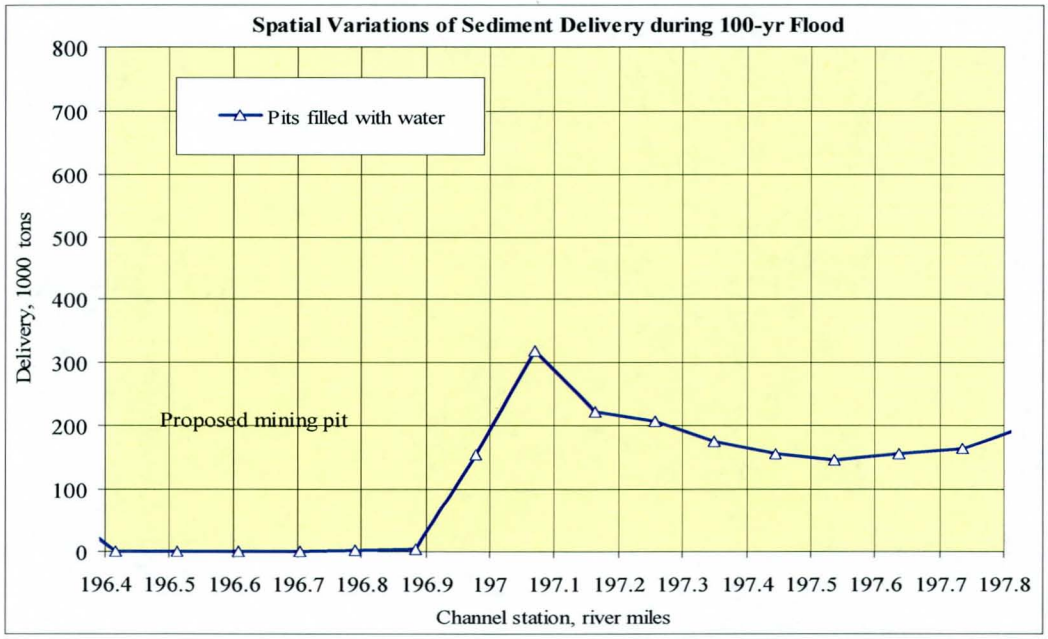
Subject: Draft Report for the FLUVIAL-12 Simulation of the Impact of Initial Water Surface Elevation inside Mining Pit on Head-Cutting and Downstream Erosion in Gila River

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 FCDMC. The comments that have been resolved have been shown in a gray font. All comments have been resolved.

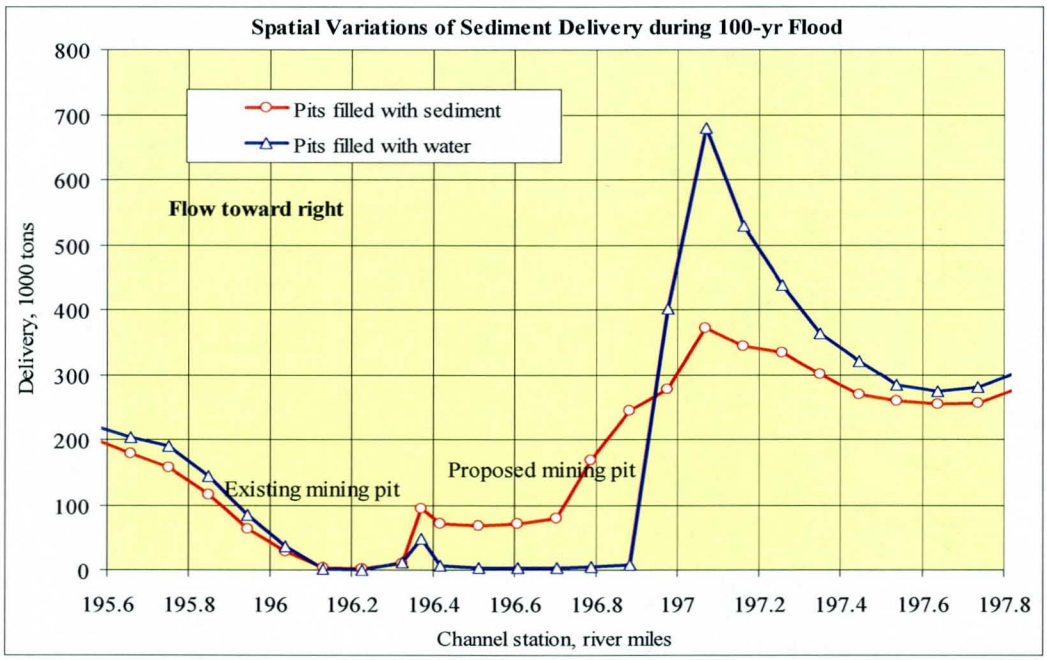
1) **FCD Comment (July 16, 2009):** In this study, the Yang sediment transport formula should also be considered to provide a bracket to the MPM sediment transport formula.

   Chang Consultants Response (July 25, 2009): The Yang formula has also been considered for the study since others used the Yang formula in their studies of the Salt River and other rivers in Maricopa County. The Yang formula was not adopted for the Gila River study for the following reasons.

   A test modeling run for the Gila River was made using the Yang formula. The simulated spatial variation of sediment delivery during the 100-yr flood is shown in the figure below and it is also compared with the corresponding delivery curve based on the MPM formula. It is easy to see that the Yang formula predicts less sediment delivery (and therefore less head-cutting) than the MPM formula.

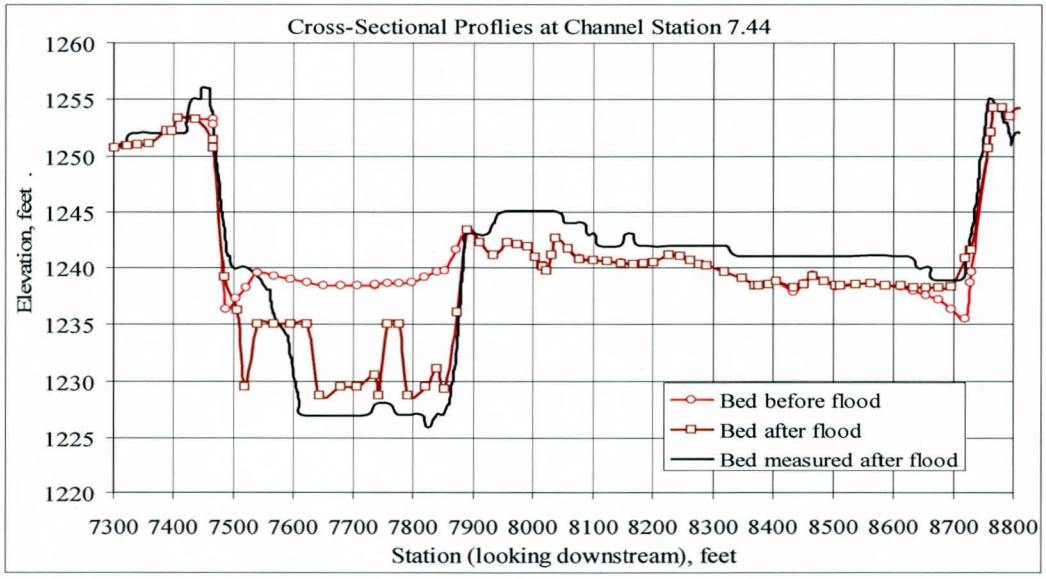


Spatial variations of sediment delivery during the 100-yr flood simulated using the Yang formula

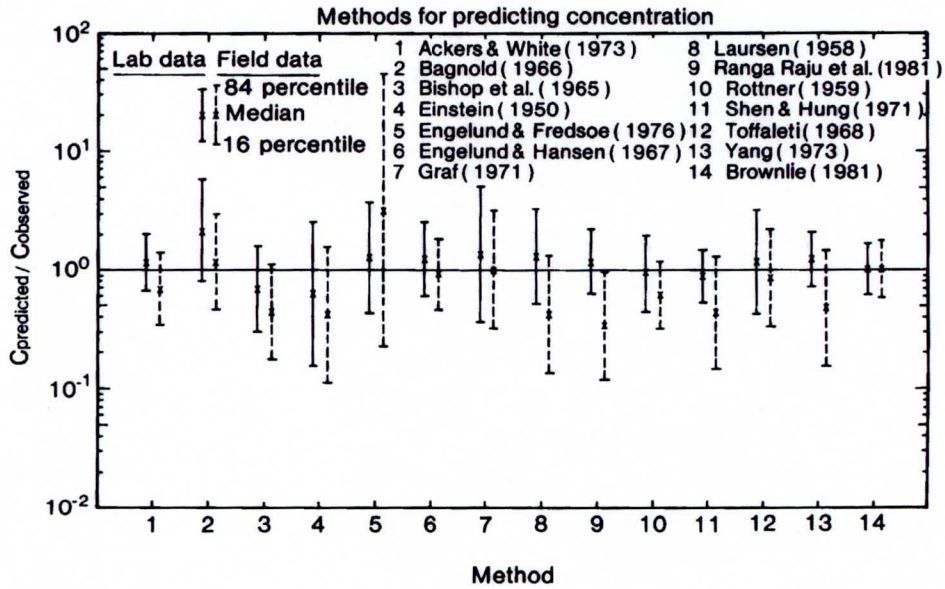


Spatial variations of sediment delivery during the 100-yr flood simulated using the MPM formula

A test run using the Yang formula has also been made for the Salt River study. The figure shown below is used to exemplify that channel bed scour predicted by the Yang formula is less than the measured channel bed scour.



The suitability of a formula must be judged by the physical foundation, generality of the basic assumptions used, and most of all, by the comparison of sediment discharge prediction with the measurement. One apparent way to judge the accuracy of a formula is by graphical comparison. The ratio of concentration calculated by a sediment formula to observed concentration is plotted as a function of the observed concentration for field data by Brownlie (Brownlie, W. R., "Prediction of Flow Depth and Sediment Discharge in Open Channels," Rept. No. KH-R-43A, W.M. Keck Laboratory of Hydraulics and Water Resources, California Institute of Technology, Pasadena, California, November 1981). The median line for the ratio is shown together with those for the 16th and 84th percentile. The comparison of 14 formulas by Brownlie (1981) is shown in the figure below. The bars show the 16th and 84th percentile of the values of the predicted-concentration--measured-concentration ratio for flume data (solid lines) and field data (dashed lines). The median value is indicated by x. It can be seen from the comparisons that the Yang formula has the tendency to under-predict the rate of sediment transport, especially for field conditions. Brownlie's evaluation of sediment formulas is based on the most extensive collection of laboratory and field data.



FCD Response (August 4, 2009): Test runs for the Yang formula have been run. Based upon the above discussion and results, the MPM formula provides a better estimate of scour. Comment resolved.

2) **FCD Comment (July 16, 2009):** On page 6, it is indicated that the sediment gradations were developed by Stantec Consulting. However, in the HEC-6 models, Stantec developed the PF and PFC cards for only one river station, station 199.07. The other river stations were developed by CMG Drainage Engineering, Inc., as part of the sand and gravel permit application.

Chang Consultants Response (July 25, 2009): The paragraph has been revised as follows:

Data for the current study are from the Gila River study by Stantec Consulting, Inc. in 2005 for the El Rio Watercourse Master Plan 82000240, prepared for Flood Control District of Maricopa County. Channel geometry data is from the 1999 Floodplain Delineation Study by Baker Engineers. The sediment gradations are from the HEC-6 model, for which Stantec developed the PF and PFC cards for river station 199.07. The other river stations were developed by CMG Drainage Engineering, Inc., as part of the sand and gravel permit application.

FCD Response (August 4, 2009): The data has been clarified on page 7. However, one minor comment is that Stantec developed the PF and PFC cards for the HEC-6T, rather than HEC-6. Please change HEC-6 to HEC-6T.

Chang Consultants Response (August 5, 2009): HEC-6 has been changed into HEC-6T.

FCD Response (August 6, 2009): The text has been revised. Comment resolved.

3) **FCD Comment (July 16, 2009):** On page 3, the title for the table should be modified such that it is set apart from the report's text. Perhaps splitting the title into two lines, similar to what was done on page 2, would be useful.

   Chang Consultants Response (July 25, 2009): The title has been revised as follows:

   Cross-sectional area changes due to head-cutting
   during the 100-yr flood for three cases

   FCD Response (August 4, 2009): The title has been modified. Comment resolved.

4) **FCD Comment (July 16, 2009):** In addition to the cross-section area and the sediment flow tables, could tables, which compare the maximum scour for each cross-section in each case be prepared?

   Chang Consultants Response (July 25, 2009): The suggested information has been added to the report and the updated paragraph is reproduced in the following:

   Computed changes in cross-sectional area due to head-cutting for river stations near the pit entrance are listed in the table below. The minimum bed elevations reached by channel bed scour due to head-cutting are listed in another table. Among them, river station 197+07 is at the upstream entrance of the proposed mining pit. From the listed sets of numbers, it is easy to see that more head-cutting would develop for the case of groundwater-filled pit than for the case of sediment-filled pit. The magnitude of head-cutting is the largest at the pit entrance (station 197.07). The difference in head-cutting for these three cases is also the largest at the pit entrance. The magnitude of head-cutting becomes smaller and the difference in head-cutting for these cases also decreases toward upstream.

Cross-sectional area changes due to head-cutting
during the 100-yr flood for three cases

River station River miles	Cross-sectional area change due to scour during the 100-yr flood Square feet		
	Pits filled with sediment	Pits filled with water	Initially dry pits
197.07	499	5,900	6,045
197.16	1,178	3,573	3,570
197.26	1,325	2,970	2,967
197.35	1,243	1,710	1,710
197.45	365	1,414	1,415

Minimum bed elevation reached by head-cutting
during the 100-yr flood for three cases

River station River miles	Minimum bed elevation reached by head-cutting during the 100-yr flood Feet		
	Pits filled with sediment	Pits filled with water	Initially dry pits
197.07	910.2	901.4	901.0
197.16	914.1	904.3	904.3
197.26	915.1	915.1	915.1

FCD Response (August 4, 2009): The tables have been added. Comment resolved.

5) **FCD Comment (July 16, 2009):** The page number should be removed from the title page.

Chang Consultants Response (July 25, 2009): It is done.

FCD Response (August 4, 2009): The page number has been removed. Comment resolved.

6) **FCD Comment (July 16, 2009):** A summary or conclusions section needs to be added to the report.

Chang Consultants Response (July 25, 2009): A section on Summary and Conclusions has been added, which is reproduced below.

VIII. SUMMARY AND CONCLUSIONS

There are existing and proposed mining sites in the Gila River. The river is in a region where the groundwater is very close to the river bed surface. Mining impacts on the adjacent river channel may be mitigated if the mining pit is backfilled with sediment. Several mining permit applicants in the past wanted to assume groundwater level in a mining pit would have similar effects as dirt fill in the pit. It is therefore important to determine if ground water would have the same effects as dirt fill in checking river channel erosion. The purpose of this study is to determine if groundwater in the proposed mining pit has the same effects as dirt fill on head-cutting and downstream erosion in the Gila River.

The flow velocity, sediment delivery, and river channel changes during the 100-yr flood have been simulated using the FLUVIAL-12 model for the cases of (1) pits filled with water, (2) pits filled with sediment, and (3) initially dry pit. The results are presented and compared. The river flow has lower velocities through the pits for the case of pits filled with water. On the other hand, pits filled with sediment to the same level would cause higher flow velocities. Since sediment transport is directly related to the flow velocity, more sediment deposition can be expected in the mining pits filled with groundwater. Sediment refill, on the other hand, would reduce sediment deposition in the sediment-filled pits. More sediment deposition in groundwater-filled pits also means more sediment trapping or more sediment storage in the pits. This has the direct effects of reducing sediment supply to the downstream channel.

Sediment deliveries by the 100-yr flood for the cases of (1) pits filled with water, (2) pits filled with sediment, and (3) initially dry pit have been simulated in modeling. Total amounts of sediment flow entering the proposed mining pit from the upstream channel during the 100-yr flood are summarized in the table below.

Summary of sediment flow entering mining pit
during 100-yr flood

Case scenario	Sediment flow entering mining pit
High groundwater	680,000 tons
Sediment-filled pit	372,000 tons
Initially dry pit	684,000 tons

The proposed mining pit filled with groundwater traps much more sediment than sediment-filled pit. The pit will continue to trap inflow sediment for a long time until it is filled with sediment. Sediment trapping and sediment storage in the pits in turn cause deficit of sediment supply along the downstream channel. The hungry flood water will continue to erode sediment from the channel boundary to result in scour. The downstream erosion caused by sediment deficit is a slow process; major downstream erosion usually develops in the long term in a gravel bed river, such as the Gila River.

Computed changes in cross-sectional area due to head-cutting for river stations near the pit entrance are listed in the table below. The minimum bed elevations reached by channel bed scour due to head-cutting are listed in another table. Among them, river station 197+07 is at the upstream entrance of the proposed mining pit. From the listed sets of numbers, it is easy to see that more head-cutting would develop for the case of groundwater-filled pit than for the case of sediment-filled pit. The magnitude of head-cutting is the largest at the pit entrance (station 197.07). The difference in head-cutting for these three cases is also the largest at the pit entrance. The magnitude of head-cutting becomes smaller and the difference in head-cutting for these cases also decreases toward upstream.

Cross-sectional area changes due to head-cutting
during the 100-yr flood for three cases

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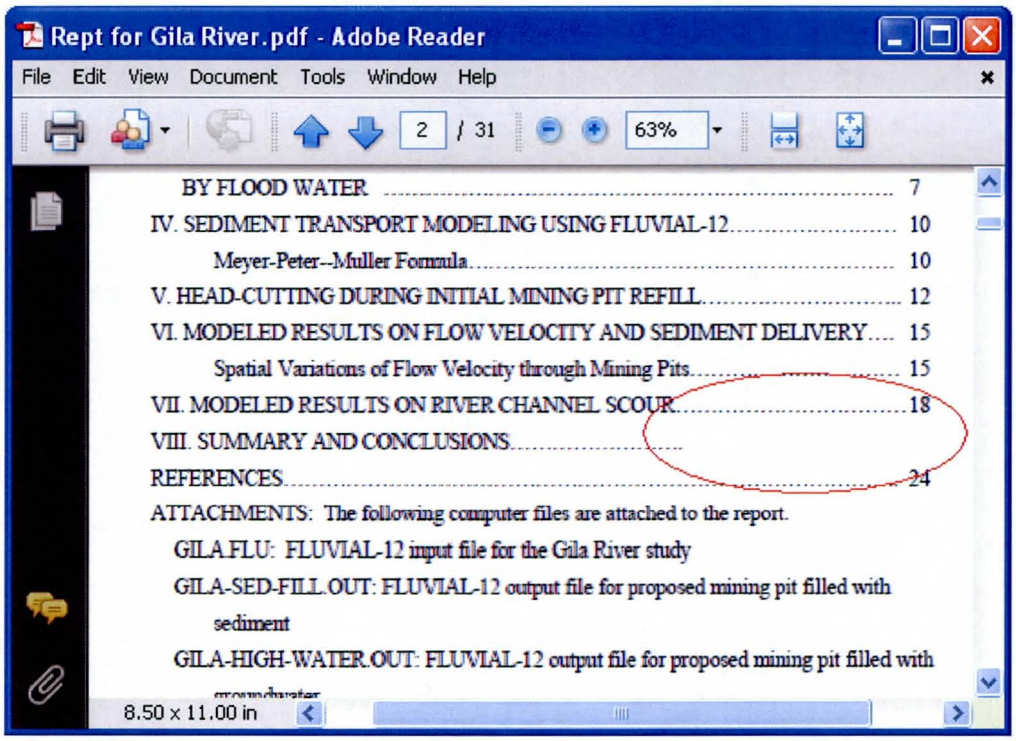
197.26	915.1	915.1	915.1

The simulated results demonstrate that mining pits induce head-cutting in the upstream channel. High groundwater level in the mining pit does not reduce head-cutting. The effects of high groundwater level are not the same as sediment level in the mining pit.

FCD Response (August 4, 2009): A Summary and Conclusions section has been added. However, the page number of this section should be given in the Table of Contents (TOC). Currently, the page number is not shown in the TOC (see below).



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IV. SEDIMENT TRANSPORT MODELING USING FLUVIAL-12..... 10

Meyer-Peter--Muller Formula..... 10

V. HEAD-CUTTING DURING INITIAL MINING PIT REFILL..... 12

VI. MODELED RESULTS ON FLOW VELOCITY AND SEDIMENT DELIVERY.... 15

Spatial Variations of Flow Velocity through Mining Pits..... 15

VII. MODELED RESULTS ON RIVER CHANNEL SCOUR.....18

VIII. SUMMARY AND CONCLUSIONS.....

REFERENCES..... 24

ATTACHMENTS: The following computer files are attached to the report.

GILA.FLU: FLUVIAL-12 input file for the Gila River study

GILA-SED-FILL.OUT: FLUVIAL-12 output file for proposed mining pit filled with sediment

GILA-HIGH-WATER.OUT: FLUVIAL-12 output file for proposed mining pit filled with groundwater

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Chang Consultants Response (August 5, 2009): A page number is given to this section in the Table of Contents as follows:

VIII. SUMMARY AND CONCLUSIONS.....26

FCD Response (August 6, 2009): The page number is now shown, but the number is incorrect. The page number for the Summary and Conclusions should be 23, rather than 26. Also, the page number for Section V should be 13, rather than 12. However, since the incorrect page numbers do not affect the overall conclusion of the report, the comment is resolved.

7) **FCD Comment (July 16, 2009):** On page 1 of the Executive Summary, the first sentence should be modified from "… referred to as head-cutting and downstream erosion (or tail-cutting)…" to "…referred to as head-cutting and tail-cutting…". This change can also be made in the second sentence on page 4.

Chang Consultants Response (July 25, 2009): The sentence at two places has been revised to read as follows:

Mining pits in a river channel may cause erosion in both the upstream and downstream directions, referred to as head-cutting and tail-cutting, respectively.

FCD Response (August 4, 2009): The sentence has been revised. Comment resolved.

8) **FCD Comment (July 16, 2009):** In multiple places in the report, the term "fill dirt" is used. Would this be clearer as "dirt fill"?

Chang Consultants Response (July 25, 2009): "Fill dirt" has been replaced by dirt fill at several placers.

FCD Response (August 4, 2009): The suggestion has been implemented. Comment resolved.

9) **FCD Comment (July 16, 2009):** In the first sentence after the table on page 2 of the Executive Summary, it is indicated that the pit filled with groundwater traps much more sediment than other cases. However, from the preceding table, the initially dry pit traps more sediment. The sentence contradicts the results shown in the table. Also, the results from the table are somewhat misleading. How can the initially dry pit and the groundwater-filled pit have different sediment volumes when they should have the same volume for sediment storage?

Chang Consultants Response (July 25, 2009): The sentence in the Executive Summary has been revised as follows:

The proposed mining pit filled with groundwater traps much more sediment than the sediment-filled pit.

The initially dry pit has slightly different sediment effects than the pit filled with groundwater as explained below. Floodwater enters the initially dry pit with a higher velocity because of the big drop in bed elevation. The flow erodes more bed material during the elevation drop. On the other hand, the inflow velocity is lower for the case of the pit filled with water due to backwater effects. Less sediment is eroded from the approaching channel bed and less sediment gets in the pit.

FCD Response (August 4, 2009): The sentence has been revised. Comment resolved.

10) **FCD Comment (July 16, 2009):** After the table on page 2 of the Executive Summary, "that" should be "than" in the first sentence.

Chang Consultants Response (July 25, 2009): The sentence in the Executive Summary has been revised as follows:

The proposed mining pit filled with groundwater traps much more sediment than the sediment-filled pit.

FCD Response (August 4, 2009): The sentence has been revised. Comment resolved.

11) **FCD Comment (July 16, 2009):** At the bottom of page 2, the river station should be shown as 197.07, rather than 197+07.

Chang Consultants Response (July 25, 2009): The river station has been revised as shown in the following sentence:

Among them, river station 197.07 is at the upstream entrance of the proposed mining pit.

FCD Response (August 4, 2009): On page 2, the river station has been corrected. However, this error also occurs on pages 21 and 26 and on Figure 3. Please correct the river stations. Also, the title for Figure 5 has some spelling errors. Please correct the spelling.

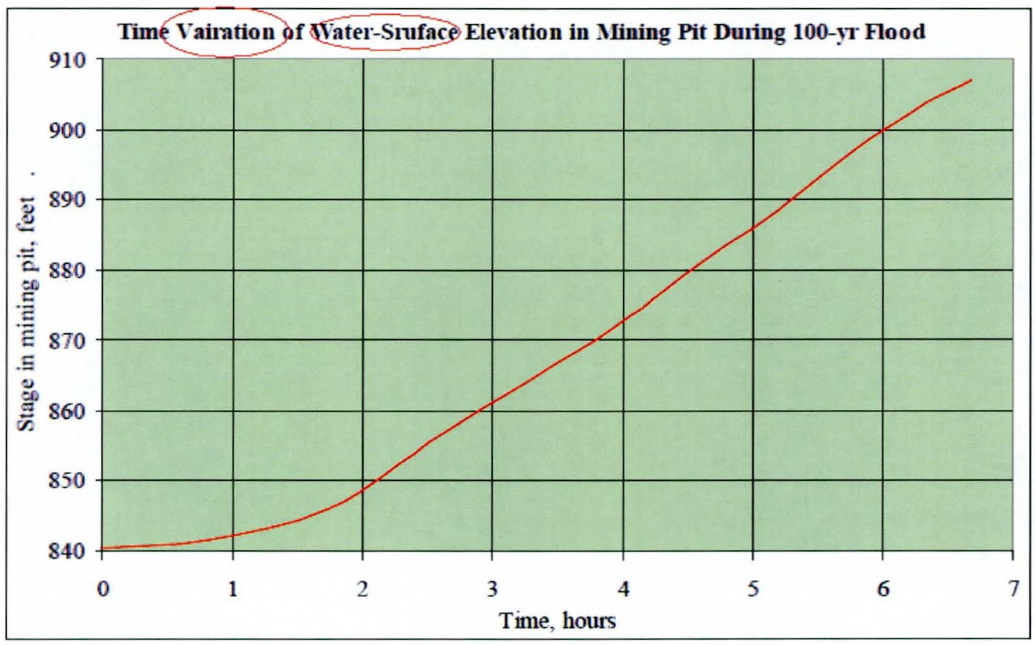


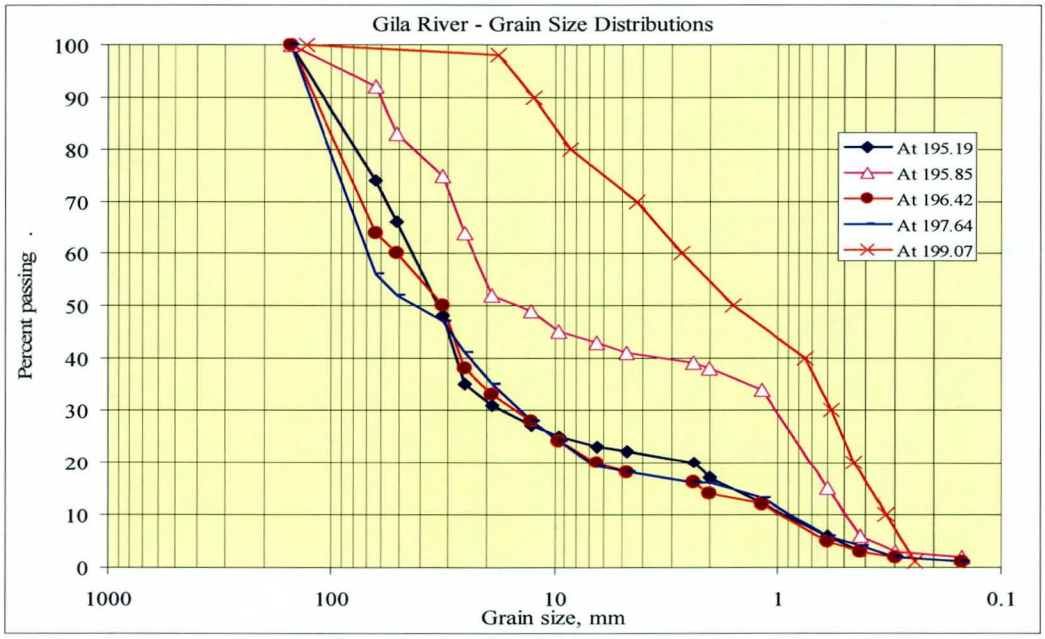
Figure 5. Time variation of stage in mining pit during initial refill

Chang Consultants Response (August 5, 2009): Changes have been made to the stations as given below:

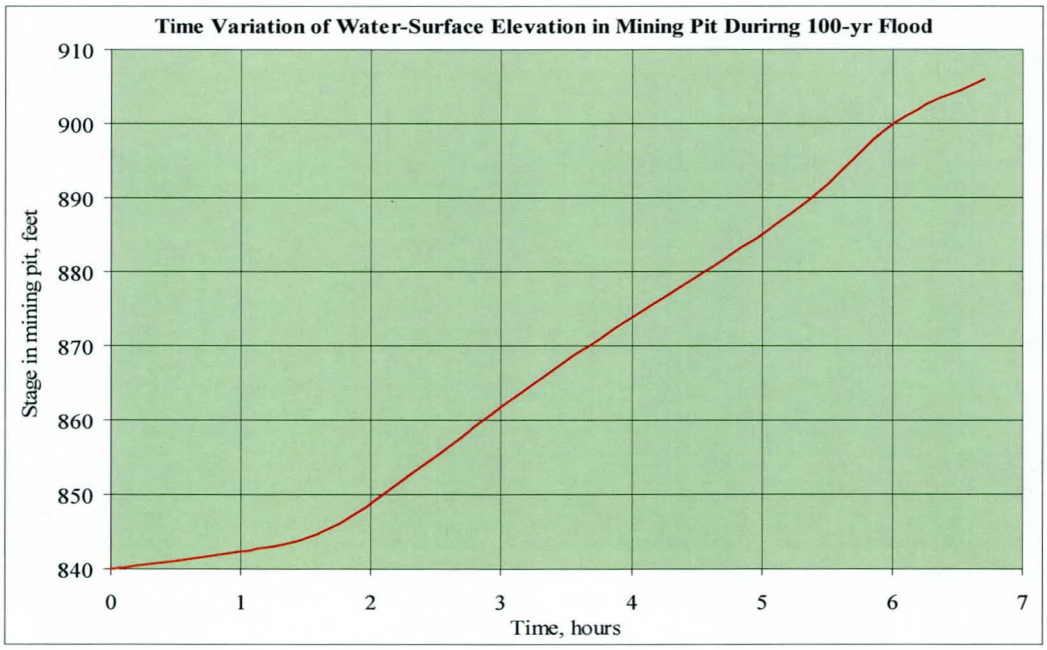
On page 22: Station 197.07 is at the upstream entrance of the proposed mining pit.

On page 27: Among them, river station 197.07 is at the upstream entrance of the proposed mining pit.

The stations in Figure 3 have been revised as shown below:



The title in Figure 3 has been changed as shown below:



FCD Response (August 6, 2009): The changes have been made. Comment resolved.

12) **FCD Comment (July 16, 2009):** After the table on page 3, "simulate" should be "simulated" in the first sentence. This change also occurs in the first sentence of the last paragraph on page 20.

Chang Consultants Response (July 25, 2009): Revisions have been made and the sentence now reads as follows:

The simulated results demonstrate that mining pits induce head-cutting in the upstream channel.

FCD Response (August 4, 2009): The sentence has been revised. Comment resolved.

13) **FCD Comment (July 16, 2009):** At the beginning of the last sentence of the second paragraph on page 4, the text "This reach of" should be added.

Chang Consultants Response (July 25, 2009): A revision has been made and the sentence now reads as follows:

This reach of the Gila River is in a region where the groundwater is very close to the surface.

FCD Response (August 4, 2009): The text has been added. Comment resolved.

14) **FCD Comment (July 16, 2009):** At the beginning of Section III, a paragraph or sentence should be added, which clarifies that the study is general in scope and that the proposed pit is simulated as a representative case to verify that assuming a pit is filled with sediment is not equivalent to a pit filled with groundwater.

Chang Consultants Response (July 25, 2009): A sentence has been added in Section III, which reads as follows:

The study is general in scope. The proposed mining pit is used as a sample to verify that a pit filled with sediment is not equivalent to a pit filled with groundwater.

FCD Response (August 4, 2009): The sentence has been added. Comment resolved.

15) **FCD Comment (July 16, 2009):** The second sentence of the Meyer-Peter—Muller Formula section indicates that the Gila River has a gravel bed. However, this is not true everywhere. This reach of the Gila River has more gravel, but also has sand. Further downstream, the Gila River becomes sandier. Also, on page 18

(in the last sentence of the paragraph after the table), the Gila River is indicated to be a gravel bed river. Please revise the sentences to indicate that this reach of the Gila River is "an alluvial channel consisting of predominantly sand with some gravel and cobbles." (Stantec, 2006)

Chang Consultants Response (July 25, 2009): The following sentence has been added to clarify the point:

The reach of the Gila River selected in the study is an alluvial channel consisting of predominantly sand with some gravel and cobbles.

FCD Response (August 4, 2009): The sentence has been added on page 5. However, on page 11, the second sentence of the Meyer-Peter—Muller Formula section still indicates that the Gila River has a gravel bed. The phrase could be revised from "For the Gila River with a gravel bed…" to "For these simulations…".

Chang Consultants Response (August 5, 2009): The sentence has been revised as follows:

For the Gila River, the Meyer-Peter--Muller formula was used.

FCD Response (August 6, 2009): The sentence has been revised. Comment resolved.

16) **FCD Comment (July 16, 2009):** On page 10, could the right bracket (of the MPM formula) be made clearer?

Chang Consultants Response (July 25, 2009): The right bracket of the MPM formula has been fixed. Also, more explanations are given to describe the terms on the right-hand side of the formula.

The first term on the right-and side (Term II) is the effective shear stress, defined as that part of the shear stress applied to sediment grains excluding the part due to bed forms. The second term (Term III) on the right-hand side is the critical shear to initiate sediment motion.

FCD Response (August 4, 2009): The bracket has been made clearer. Comment resolved.

17) **FCD Comment (July 16, 2009):** On page 10, τ is used in the text, but in the MPM formula γ is used. Please use one consistent symbol. This revision should also occur in the Salt River study.

Chang Consultants Response (July 25, 2009): The revision has been made to both reports.

FCD Response (August 4, 2009): The revision has been made. Comment resolved.

18) **FCD Comment (July 16, 2009):** On page 11, the extra period (after the sentence after Strickler's formula) can be deleted.

Chang Consultants Response (July 25, 2009): The extra period has been removed from the following sentence.

Note that this formula is valid only if D_{90} is in meters and time is in seconds.

FCD Response (August 4, 2009): The period has been removed. Comment resolved.

19) **FCD Comment (July 16, 2009):** In the Meyer-Peter—Muller Formula section, does the (k/k′) term need a 3/2 exponent in the formula on page 10? Also, on page 12, does the range of effective diameters extend from 0.4 mm to 30 mm, rather than 6.4 mm to 30 mm? These questions also apply to the Salt River study. As a note, this section was compared with data from Vanoni (2006).

Chang Consultants Response (July 25, 2009): The Meyer-Peter—Muller Formula, the (k/k′) term does need a 3/2 exponent in the formula. Also, the range of effective diameters extends from 0.4 mm to 30 mm, rather than 6.4 mm to 30 mm. Corrections have been [made] to both reports.

FCD Response (August 4, 2009): The corrections have been made. Comment resolved.

20) **FCD Comment (July 16, 2009):** On page 12, the sentence which reads "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" is confusing. It appears that the second part of the above sentence may be part of another sentence. Please revise this sentence such that it is clearer.

Chang Consultants Response (July 25, 2009): The sentences have been revised as follows:

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.

FCD Response (August 4, 2009): On pages 13 and 14, the sentences (given in the above response) have been revised. However, the above sentences are still confusing. Therefore, it is recommended that the first sentence, "Spatial variations in sediment delivery are manifested as channel storage or depletion of sediment associated stream channel changes" be removed. Also, the phrase "Since the sediment supply from upstream may be different from the removal" can be removed from the second sentence.

Chang Consultants Submittal (August 5, 2009)

FCD Response (August 6, 2009): The sentences have not been revised. However, since this comment is only a grammatical recommendation and does not affect the conclusion of the report, the text of the report is deferred to the author. Comment resolved.

21) **FCD Comment (July 16, 2009):** On page 15, the first sentence indicates there are only two cases. However, from earlier tables and text, there are three cases; a dry pit, a groundwater-filled pit and a sediment-filled pit. Please revise this sentence to be consistent with other parts of the report.

Chang Consultants Response (July 25, 2009): The sentence has been revised as follows:

The difference in head-cutting for these three cases is also the largest at the pit entrance. The magnitude of head-cutting becomes smaller and the difference in head-cutting for these cases also decreases toward upstream.

FCD Response (August 4, 2009): The first sentence (now on page 17) has not been revised to be consistent with other sections of the report. Also, the first sentence on page 18 should be revised to be consistent with other sections of the report. The sentences are listed below:

On page 17:
River channel flow, sediment delivery, and changes in geometry have been simulated using the 100-yr flood for the two following conditions: (1) mining pits filled with groundwater to the brink level, and (2) mining pits filled with sediment.

On page 18:
Total sediment deliveries by the 100-yr flood for the cases of (1) pits filled with water and (2) pits filled with sediment have been simulated in modeling.

These sentences should be revised to indicate that three cases have been simulated. Also, please check Section VI to verify that the section is consistent with the entire report. Currently, pages 17-19 indicate that two cases are simulated, while pages 20-22 indicate that three cases are simulated.

Chang Consultants Response (August 5, 2009): Changes have been made as given below:

On page 17: River channel flow, sediment delivery, and changes in geometry have been simulated using the 100-yr flood for the three following conditions: (1) mining pits filled with groundwater to the brink level, (2) mining pits filled with sediment, and (3) initially dry mining pit.

On page 18: Total sediment deliveries by the 100-yr flood for the cases of (1) pits filled with water, (2) pits filled with sediment, and (3) initially dry pit have been simulated in modeling.

FCD Response (August 6, 2009): The two sentences have been revised. However, Section VI still contains places where the report is inconsistent in the number of cases simulated, whether it be two or three. Since this comment is only a grammatical recommendation and does not affect the conclusion of the report, the text of the report is deferred to the author. Comment resolved.

As a note, three total cases have been simulated, (1) an initially dry pit, (2) a pit filled with groundwater and (3) a pit filled with sediment. The first case was simulated to estimate the amount of erosion that occurs when the pit is being filled with water, but the second and third cases were the focus of the report.

References:

Stantec Consulting, Inc. (Stantec), 2006. *El Rio Watercourse Master Plan, El Rio Sedimentation Analysis, Book 1 El Rio Existing Condition Sedimentation Analysis*. Prepared for the Flood Control District of Maricopa County.

Vanoni, V. (ed.), 2006. Sedimentation Engineering, ASCE Manual 54, ASCE, Reston, VA.