FLUVIAL-12 Modeling of Sand Mining Impacts For Lower Hassayampa River

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

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ATTACHMENTS: The following computer files are submitted as attachments:

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EXIST-100.TXT: Listings of input/output for the 100-yr flood and existing conditions
TEXT document
PROP-100.OUT: Listings of input/output for the 100-yr flood and proposed conditions
ESRI Print document
PROP-100.TXT: Listings of input/output for the 100-yr flood and proposed conditions
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EXIST-S.OUT: Listings of input/output for the flood series and existing conditions
ESRI Print document
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EXECUTIVE SUMMARY

The Flood Control District of Maricopa County (FCDMC) intends to identify and develop technical guidance for managing erosion and flooding hazards of the Lower Hassayampa River. A model needs to be developed in order to assess the existing conditions of the river channel and to evaluate new mining permit applications in the future. The purpose of this study is to develop and to maintain a live FLUVIAL-12 model for the river channel to meet the stated objectives. In addition, a visual transient model will be developed as a supplemental tool for this study so that engineers can visualize the transient changes in river morphology induced by mining pits.

For a given flood hydrograph and sediment characteristics, the FLUVIAL-12 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. 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.

The FCDMC provided necessary data for the modeling study including the channel geometry, flood hydrology, sediment characteristics, mining sites, etc. The study covered the river channel under its existing conditions and future conditions with completed mining at the approved sites. River channel behavior is evaluated using the 100-yr flood and a long-term flood series. Simulated results for the dynamic river channel behavior include the water-surface and channel bed profile changes, time and spatial variations of the flow velocity, sediment transport, sediment delivery, sediment budget, changes in cross sectional geometry, etc.

Instream sand mining changes the stream channel geometry, hydraulics of river flow, and sediment transport. Channel responses to such human activities are simulated by the FLUVIAL-12 model and are presented by the changes in channel morphology. Typically, such morphological changes include the following features: (1) patterns of sediment deposition and

erosion in sand pits, (4) head cutting and downstream erosion, and (3) channel width changes during scour and fill. Such morphological changes are analyzed and explained based on the basic principles governing river channel formation and river channel changes.

Impacts caused by instream sand mining are analyzed and presented, covering the following aspects: (1) impacts on flood level and channel-bed profile changes, (2) impacts on spatial variations of flow velocity and sediment transport through sand mining areas, (3) impacts on sediment delivery and sediment budget along the river channel, and (4) scour impacts at infrastructures. Modeling results for the existing and proposed conditions are presented in the report. The differences of the modeling results between the existing and proposed conditions are used to assess the impacts of the mining projects. Sand pits slow down the flow velocity to induce sediment deposition; they cause erosion along the adjacent river channel in the form of head cutting and downstream erosion. The changes in sediment budgets and river channel morphology induced by the mining sites are quantified in the modeling study. In addition, the modeling study evaluates the potential channel-bed scour at the bridge crossings and impacts on bridge stability.

The study results are used to demonstrate the complex nature of dynamic river channel changes. Dynamic equilibrium is the direction toward which each river channel evolves. The Lower Hassayampa River has been disturbed by sand mining. As the river channel adjusts toward establishing dynamic equilibrium, channel bed scour and fill occur concurrently with channel width changes. Since channel bed profile changes affect the changes in channel width and vice versa, both changes must be coupled in modeling river channel changes. For this reason, the Lower Hassayampa River should be modeled using an *erodible boundary model* instead of an *erodible bed model.*

A graphical-user interphase (GUI) model for visualizing the FLUVIAL-12 output of the Lower Hassayampa River has also been developed as a part of the study. The GUI model is used to show the dynamic river channel changes in the form of a time lapse movie. The model provides visual graphical presentation of transient changes covering the following FLUVIAL-12 modeling results:

(1) Transient dynamic changes in water-surface and channel bed profiles during the flow period, and

(2) Transient dynamic changes in cross-sectional profiles during the flow period,

Morphologic changes of the river channel induced by a mining pit include head-cutting and downstream erosion. Such changes exhibit very distinct morphologic features. Visualization of such changes is essential for engineers to assess the mining impacts and to develop mitigation measures.

GLOSSARY OF TERMS

Aggradation: A rise in channel bed elevation, usually caused by sediment deposition.

Alluvial: Relating to, composed of, or found in alluvium

Bank protection: A structure placed on a river bank to protect the bank against erosion. Such structures are usually made of riprap stones, revetments, dikes, etc.

Base flood: The flood having one percent chance of being equaled or exceeded in any given year.

Bed load: That part of the sediment load that travels in contact with the bed by rolling, sliding and saltation. It is also the coarser portion of the sediment load.

cfs: Acronym for cubic feet per second, a measure of the flow discharge.

Channel reach: Any stretch of the channel.

Channelization: To make a channel.

Cross sections: Channel sections that are perpendicular to the flow direction that are used to define the river channel geometry for a river study.

Degradation: A lowering of the channel-bed elevation usually caused by erosion.

Drainage basin: A surface area from which rainfall drains toward a single point.

Drop structure: A rigid structure erected across a river channel through which there is a drop in channel-bed elevation.

Erodible boundary model: A model that considers the changes in channel boundary, including channel-bed scour and fill, changes in channel width and changes related to channel curvature.

Erodible bed model: A model that only considers the changes in channel-bed level by assuming that channel width does not change.

Field calibration: The correlation of modeling results using field data. It usually involves fine adjustments of certain parameters used in modeling to improve the correlation.

Flood hydrograph: A relationship showing how the flood discharge varies with time during its occurrence.

Fluvial processes: Processes that are caused by stream action, including sediment transport, flood flow, erosion, deposition, and river channel changes.

fps: Acronym for feet per second, a measure for the flow velocity.
Grade control structure: A rigid structure constructed across a river channel used to stabilize the bed elevation at the location. A drop structure is also a grade control structure.

Head cutting: Channel-bed erosion occurring upstream of a sand or gravel pit or any other depression.

Model: For this study, a model is a computer software developed to simulate the hydraulics of flow, sediment transport and river channel changes.

Pit capture: A stream is diverted from its normal course into a pit of lower elevation

Power expenditure: The rate of energy dissipation of stream flow

Scour (general and local): Erosion or removal of material caused by stream action. General scour is caused by the imbalance (non-uniformity) in sediment transport along a river channel. Local scour is caused by any local obstruction to flow, such as bridge piers, abutments, tree trunks, etc.

Sediment delivery: The cumulative amount of sediment that is delivered passing a river section in a specified period of time.

Sediment transport/replenishment: Sediment transport is the movement of sediment by flow measured usually in volume or weight per unit time. Replenishment is sediment supply to make up any previous deficit.

Study channel reach: A river channel reach that is covered in a study. Such a reach is defined by a series of cross sections taken along the channel.

Suspended load: Sediment load that travels in suspension, consisting of the finer portion of the transported sediment.

Tractive force: The force exerted by the flow on the channel boundary or on any object in the river channel, usually measured in force per unit surface area.

FLVUIAL-12 MODELING OF SAND MINING IMPACTS FOR LOWER HASSAYAMPA RIVER

I. INTRODUCTION

Alluvial rivers are self-regulatory in that they adjust their characteristics in response to any change in the environment. These environmental changes may occur naturally, as in the case of climatic variation or changes in vegetative cover, or may be a result of such human activities as river training, damming, diversion, sand and gravel mining, channelization, bank protection, and bridge and highway construction. Such changes distort the natural quasi-equilibrium of a river; in the process of restoring the equilibrium, the river will adjust to the new conditions by changing its slope, roughness, bed-material size, cross-sectional shape, or meandering pattern. Within the existing constraints, any one or a combination of these characteristics may adjust as the river seeks to maintain the balance between its ability to transport and the load provided.

The Lower Hassayampa River (see Figs. 1 and 2) is located west of Phoenix, Arizona, The study river reach has an approximate length of 27.5 miles; it extends upstream from the Gila River confluence to the Central Arizona Project (CAP) canal crossing. Jackrabbit Wash joins the Lower Hassayampa River approximately fourteen miles upstream of the Gila River confluence. This reach of the Lower Hassayampa River is highly braided with in-stream mining pits located primarily upstream of the 1-10 Bridges. With existing and future bridges and sand/gravel mining activities, it is important to know the potential impacts, both short term and long term, of such human activities. This study will cover the existing mining sites together with approved mining sites, as well as more potential sand/gravel pits.

The Flood Control District of Maricopa County (FCDMC) intends to identify and develop technical guidance for managing erosion and flooding hazards, lateral migration of the Lower Hassayampa watercourse, and the cumulative impacts of existing and future development or encroachment into the floodplain. The specific project reach of the Lower

Hassayampa River is located west of Phoenix and extends from the Gila River confluence to the Central Arizona Project (CAP) canal crossing.

The purpose of this study is to develop and to maintain a live FLUVIAL-12 model for the Lower Hassayampa River. The model will be used to assess the existing conditions of the river channel and it will also be used to evaluate new mining permit applications in the next two years or so. A visual transient model will be developed as a supplemental tool for this study so that engineers can visualize the transient changes in river morphology induced by mining pits. This study will include the development of the four following FLUVIAL-12 models.

- Model 1 - The first model is a FLUVIAL-12 model that is a pure translation of the existing HEC-6 model provided by FCDMC from the watercourse master plan. This model is for the 100-year flood.
- Model 2 -This model is the same as the first model except it is for the historical flood series.
- Model 3 - The third model is to include all approved pits for 100-year flood.
- Model 4 -The fourth is to include all approved pits for the historical flood series.

II. DATA PREPARATION FOR MODELING STUDY

Hydraulic and sediment studies of the Lower Hassayampa River have been made previously by JE Fuller (2006) and West Consultants (2006). Their river geometry data and flow data are applicable to this study. An existing HEC-6 model was provided by FCDMC together with other data and reports. Data used in the modeling study including the channel geometry, flood hydrology, sediment characteristics, and mining sites are briefly described below.

Channel Geometry Data – Fig. 1 is a location map of the Lower Hassayampa River; Fig. 2 is an aerial photograph of the river channel for the study with the channel stations in river miles. The study channel reach has a total length of almost 28 miles. Jackrabbit Wash is a major tributary that enters the Lower Hassayampa River at river mile 15.49. Cross sections selected along the channel reach are used to define the channel geometry. Points of interest along the channel reach are listed in Table 1.

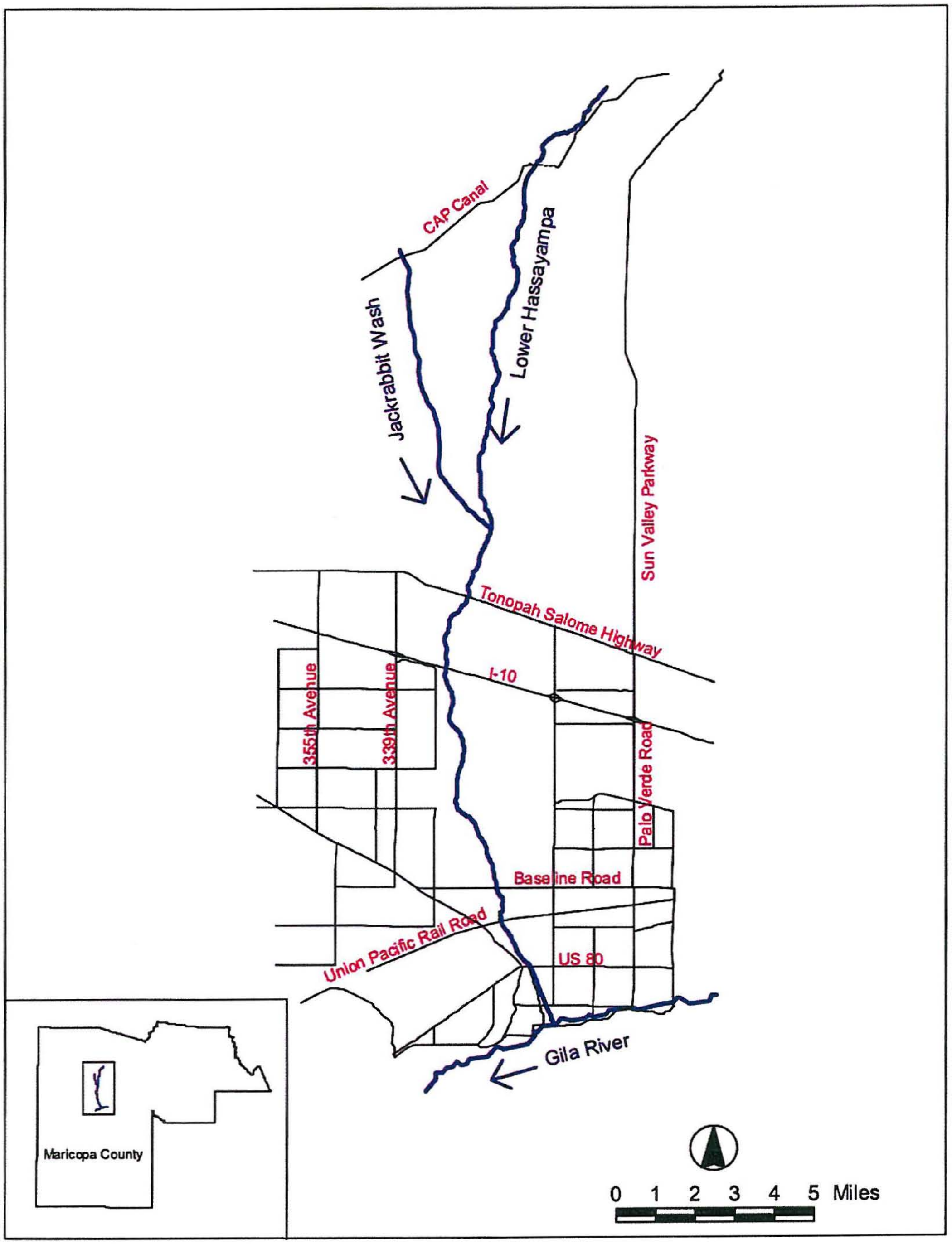


Fig. 1. Project location by WEST Consultants

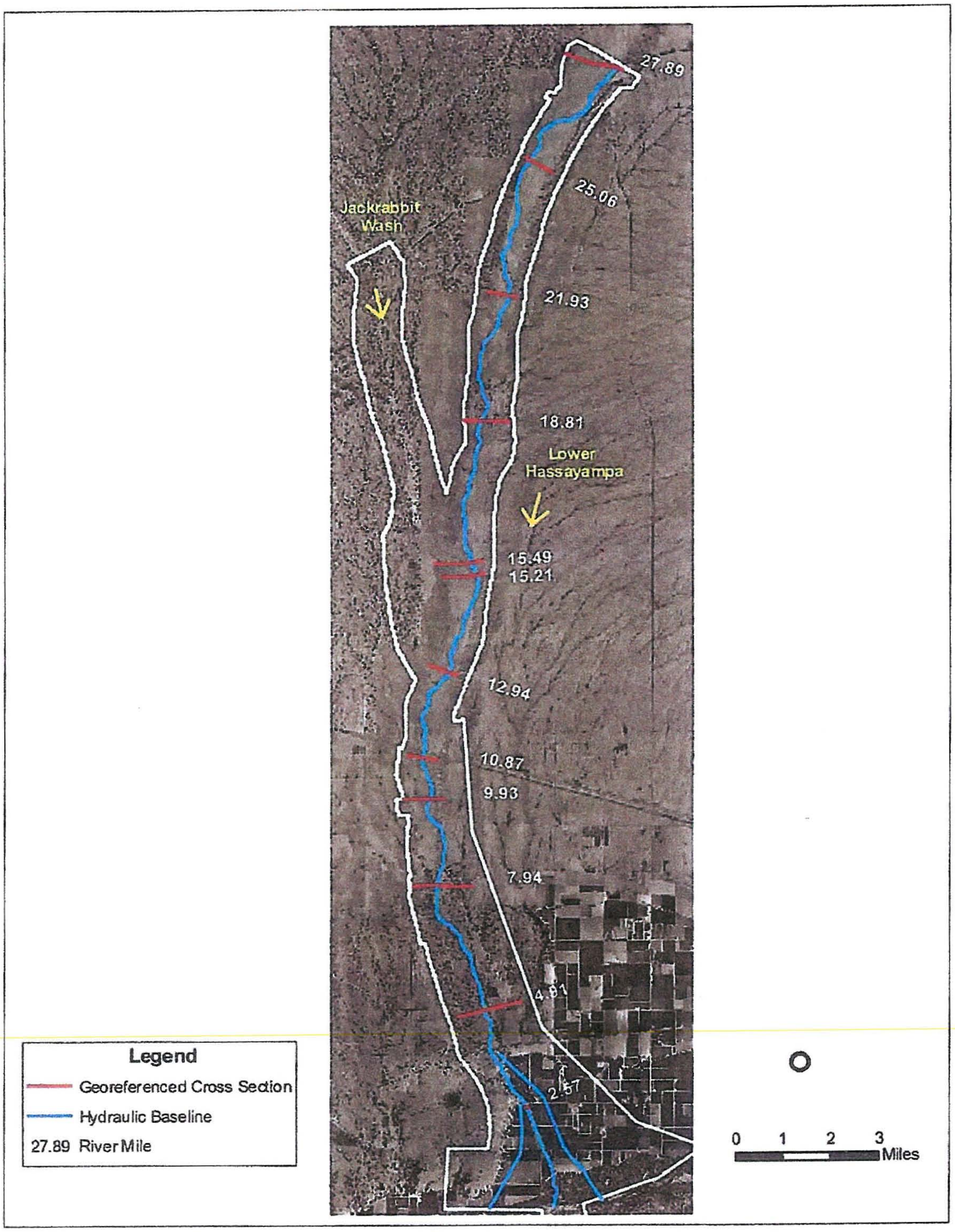


Fig. 2. Aerial view of the Lower Hassayampa River

Table 1. Points of interest along river channel

River station miles	Peak 100-yr discharge Cfs	Location
0.35	72,966	Confluence with Gila River, downstream limit of study
2.65	72,966	U.S. 80 Bridge
4.00	73,500	Railroad Bridge
10.985	74,970	I-10 Bridge
11.005	74,970	I-10 Bridge
15.49	76,120	Confluence of Jackrabbit Wash
27.89	57,854	Upstream limit of study

Sand and Gravel Mining Sites – At this time, some small mining pits are located near river mile 13. The current conditions of excavation are reflected in the cross-sectional data. The approved sand and gravel mining sites together with there locations are listed in Table 2 below.

Table 2. List of approved mining sites

Mining sites	River stations covered by mining site
SG06_006_near XS_0.44	No mine plan has been submitted to the FCDMC. Currently, there is no mining on the property.
SG06_001_near XS_1.01	0.54, 0.63, 0.73, 0.82
SG07_001_nearXS_6.33	5.57, 5.67, 5.78, 5.76, 5.86, 5.95, 6.05, 6.14
SG06_005_near XS_8.51_1	7.37, 7.47, 7.56, 7.66, 7.75, 7.84, 7.94, 8.03, 8.13, 8.22
SG06_005_near XS_8.51_2	7.76, 7.84, 7.94, 8.03, 8.13, 8.22 Separated from effective flow area of river by a berm
FA96_032A_nearXS_12.85	12.09, 12.18, 12.28, 12.37, 12.47, 12.56, 12.66, 12.75, 12.85
SG03_002_nearXS_13.7	13.13, 13.23, 13.32, 13.42, 13.51, 13.61
SG08_001_nearXS_14.38	13.89, 13.98, 14.08, 14.17, 14.27, 14.36, 14.45, 14.55, 14.64, 14.73, 14.83

FA01_113_nearXS_15.97_1	15.02, 15.11, 15.21, 15.30, 15.41, 15.49, 15.59, 15.68, 15.78, 15.87
FA01_113_nearXS_15.97_2	15.49, 15.59, 15.68, 15.78, 15.87, 15.97 Separated from effective flow area of river by a berm
SG05_010_nearXS_27.89	27.23, 27.33, 27.43, 27.52, 27.61, 27.75, 27.89, and beyond Separated from effective flow area of river by a berm

Sediment Data – Sediment data used in the study were taken from the following previous study on the Hassayampa River.

JE Fuller, Hydrology and Geomorphology, Inc., "Lower Hassayampa River Watercourse Master Plan, river Behavior Report," prepared for Maricopa County Flood Control District, April 2006.

Grain size distributions of bed sediment are based on the available data. However, the upstream sediment inflow for the FLUVIAL-12 study was computed using the channel geometry, sediment gradation and flow characteristics of the upstream most cross section at teach time step.

III. HYDROLOGY OF FLOOD FLOW

Flood flows in the arid region are characterized by short durations with the discharge rising and falling rapidly. Hydrographs of the 100-yr flood are shown in Fig. 3. The peak discharge of the flood varies along the river channel. Some of the peak discharges are listed in Table 1.

In the modeling study, the 100-yr flood is used to evaluate the river channel responses to the mining activities. In addition, the long term mining impacts are evaluated using a flood series from the U. S. G. S. stream gage records for the time period from 1937 to 2004 (see Fig. 4). The flood series was developed with gage data that spanned 68 years, but the actual flows, which were used in the modeling, only have duration of around 4,680 hours.

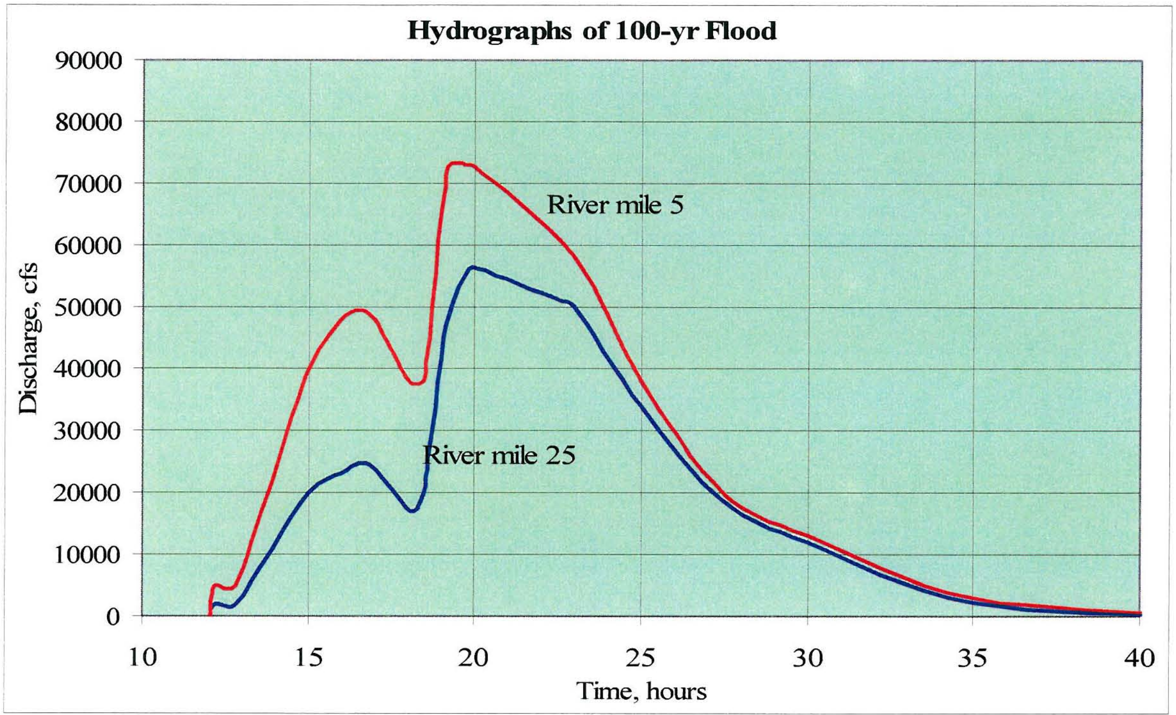


Fig. 3. Hydrographs of the 100-yr flood

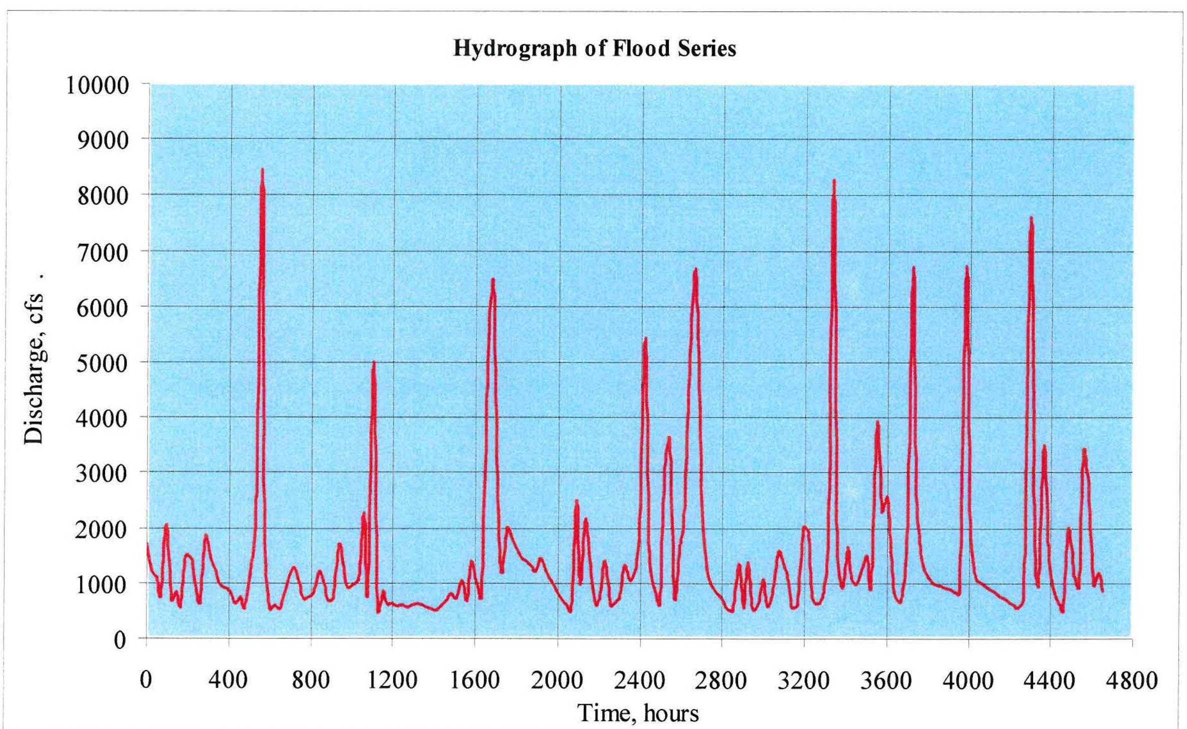


Fig. 4. Hydrograph of the flood series for the period of 1937 to 2004

IV. SEDIMENT TRANSPORT MODELING USING FLUVIAL-12

In Maricopa County, the stream channel scour is generally estimated as the sum of several scour components, which are long-term scour, general scour, bend scour, bed form scour, low flow incisement, and local scour. The long-term scour, general scour, bend scour can be simulated based on the flow and sediment transport in FLUVIAL-12. Normally, the long-term scour is simulated using a long-term flood series. The general scour may be simulated using the 100-yr flood, or estimated by either a sediment transport model or empirical equations (such as Lacey, Blench or Neill equations). The higher value of the general scour, which was calculated from the sediment transport simulation or the empirical equations, is then selected as the final general scour. The bend scour can be computed by some empirical equations, or it can also be simulated together with other scour components by the FLUVIAL-12 model. The bed form scour is calculated from either the antidune or dune equations. Low flow incisement is usually based on field estimates; but when those are not available, a value between 1 to 2 feet is selected. Local scour can be due to bridge piers, bridge abutments, bridge guide banks, culvert outlets, or grade control/drop structures.

Mathematical Model for General Scour - The FLUVIAL-12 model (Chang, 1988) was employed for this project. 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 Lower Hassayampa River was computed in the model using the Engelund-Hansen formula (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.

Comparison of FLUVIAL-12 and HEC-6 Models – The FLUVIAL-12 model is applicable to ephemeral rivers as well as rivers with long-term flow; it has also been tested and calibrated with field data from several rivers, in both semi-arid and humid regions. Because of the transient behavior in dynamic changes, ephemeral rivers require more complicated techniques in model formulation. The FLUVIAL-12 model is an *erodible-boundary model*; it simulated inter-related changes in channel-bed profile, channel width and bed topography induced by the channel curvature. The erodible-boundary model is different from an *erodible-bed model* in the following ways.

(1) An erodible-bed model does not simulate changes in channel width. Since changes in channel-bed profile is closely related to changes in width, these changes may not be separated.

(2) The change in bed profile in an erodible-bed model is assumed to be uniform in the erodible zone. All points adjust up and down by an equal amount during aggradation and degradation. Actual bed changes are by no means uniform and therefore they may not be simulated by an erodible-bed model.

(3) An erodible-bed model does not consider the channel curvature. In reality, the bed topography is highly non-uniform in a curved channel, especially during a high flow.

(4) The erodible zone needs to be specified at all cross sections in an erodible-bed model. This means the model does not provide the extent of erosion in the channel, but the user has to inform the model about the erodible part of the channel bed. The boundary of erosion is computed and provided by the FLUVIAL-12 model, this boundary changes with the discharge and time.

(5) Sediment inflow into the channel reaches needs to be specified for many other models. This requires the sediment rating curve which is usually not available for stream channels. In the FLUVIAL-12 model, the sediment inflow may be specified and it may

also be computed based on the hydraulics of flow at the upstream section at every time step.

(6) The FLUVIAL-12 has been calibrated using many 14 sets of river data. An erodible-bed model may not be calibrated with field data of natural streams.

Field Calibration of the Model - The FLUVIAL-12 model has been calibrated and confirmed using 12 set of field data in the semi-arid region. Many of the streams studied are similar to the Lower Hassayampa River.

Selection of the Engelund-Hansen Formula —The Engelund-Hansen formula was selected for the study for the following reasons:

(1) The selection was based on the most extensive evaluation of formulas made by Brownlie (see Fig. 5); the Engelund-Hansen formula has the best correlation with field data.

(2) The Engelund-Hansen formula was used in many studies in this region. The results of these studies were verified by field data.

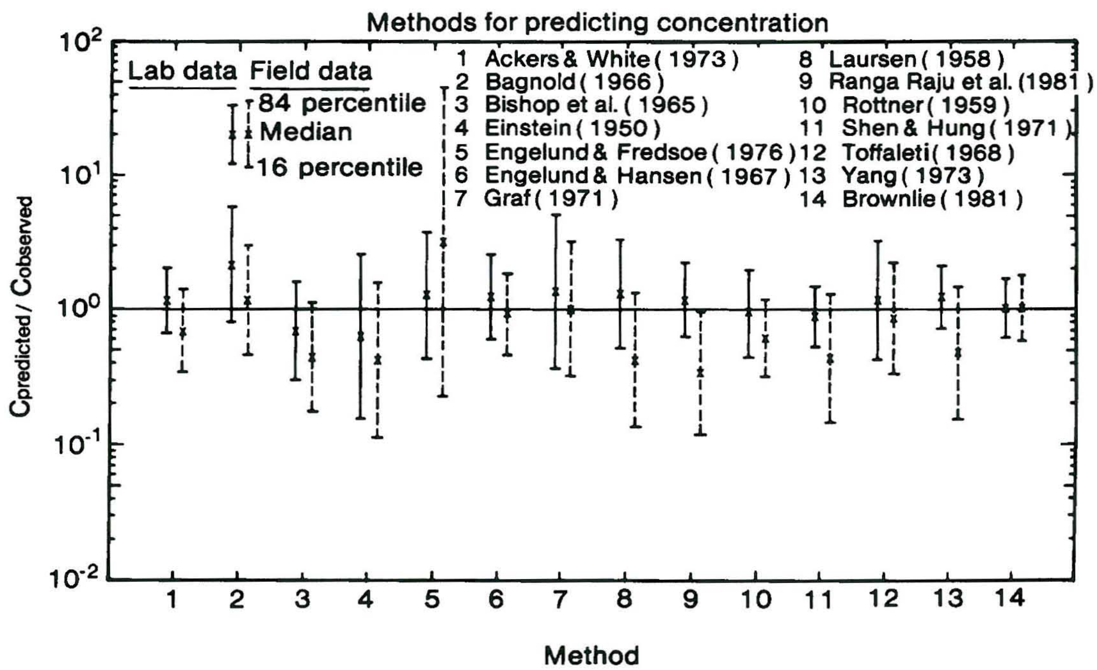


Fig. 5. Evaluation of sediment transport formulas by Brownlie

Engelund-Hansen Formula - Engelund and Hansen (1967) applied Bagnold's stream power concept and the similarity principle to obtain their sediment transport equation:

$$f' \varphi = 0.1 (\tau_*)^{5/2} \quad (1)$$

$$\text{with} \quad f' = \frac{2gRS}{U^2} \quad (2)$$

$$\varphi = \frac{q_s}{\gamma_s [(s - 1) gd^3]^{1/2}} \qquad \tau_* = \frac{\tau_o}{(\gamma_s - \gamma) d} \quad (3)$$

where f' is the friction factor, d is the median fall diameter of the bed material, φ is the dimensionless sediment discharge, s is the specific gravity of sediment, and τ_* is the dimensionless shear stress or the Shields stress. Substituting Eqs. 2 and 3 into Eq. 1 yields

$$C_s = 0.05 \frac{s}{s - 1} \frac{US}{[(s - 1)gd]^{1/2}} \left[\frac{RS}{(s - 1) d}\right]^{1/2} \quad (4)$$

where C_s (= Q_s/Q) is the sediment concentration by weight. This equation relates sediment concentration to the *U-S* product (which is the rate of energy expenditure per unit weight of water) and the *R-S* product (which is the shear stress). Strictly speaking, the Engelund-Hansen formula should be applied to streams with a dune bed in accordance with the similarity principle. However, it can be applied to upper flow regime with particle size greater than 0.15 mm without serious error.

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,

$$Y = \int_T Q_s \, dt \quad (5)$$

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.

V. MODELING RESULTS FOR EXISTING AND PROPOSED CONDITIONS

The FLVUIAL-12 model has been applied to simulate river hydraulics, sediment transport, and river channel changes for the Lower Hassayampa River under the existing and proposed conditions, defined as follows:

(1) Existing conditions: This refers to the conditions of the current river channel with the existing mining pits. The channel geometry is defined at a series of channel cross sections used in the previous HEC-6 study.

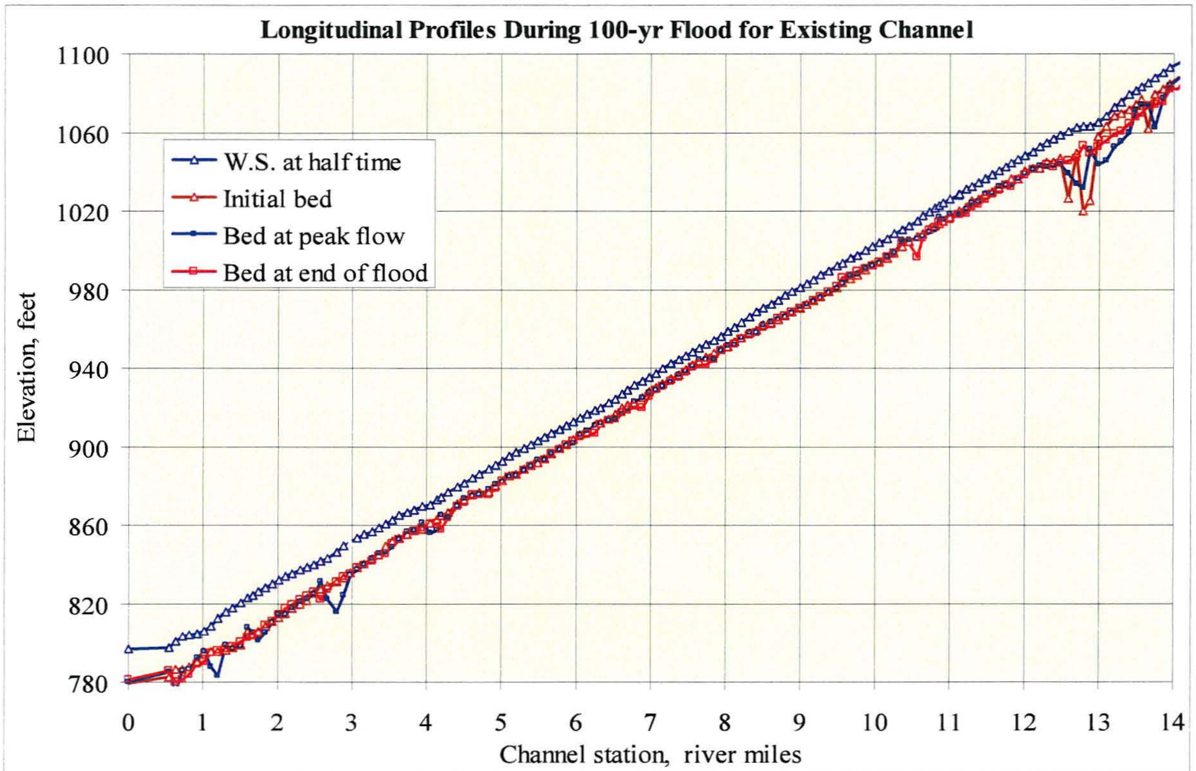
(2) Proposed conditions: This refers to the river channel with the completed excavation at the approved sand mining sites.

Instream sand mining changes the stream channel geometry, hydraulics of river flow, and sediment transport. River channel responses to such human activities are simulated by the FLUVIAL-12 model and are presented by the changes in channel morphology together with other aspects. The 100-yr flood was used to simulate the short-term changes and the flood series was used for long-term changes for both the existing and proposed conditions. Typically, morphological changes associated with instream mining include the following features: (1) patterns of sediment deposition and erosion in sand pits, (4) head cutting and downstream erosion, and (3) channel width changes during scour and fill. Such morphological features are illustrated by simulated results.

Impacts caused by instream sand mining are analyzed and presented covering the following aspects: (1) impacts on flood level and channel-bed profile changes, (2) impacts on spatial variations of flow velocity and sediment transport through sand mining areas, (3) impacts on sediment delivery along the river channel, and (4) scour impacts at infrastructures. The modeling results are used to describe these impacts.

Sand Mining Impacts on Flood Level and Channel Bed Profile Changes for Existing Conditions –Modeling results of water surface and channel bed profile changes for the 100-yr flood are shown in Figs. 6 and 7; those for the flood series are shown in Fig. 8. Sand mining lowers the channel bed; it also lowers the water surface profile of the river flow near the sand pits. In the absence of sand mining, the water surface of the river channel has a more or less uniform profile. The uniformity is disrupted by the presence of sand pits. In response, the river channel will undergo both scour and fill as the water-surface profile gradually readjusts toward uniformity. Depending on the size of the sand pit, the time duration for channel adjustment toward re-establishing new uniformity varies. But the river is constantly adjusting toward uniformity in its water-surface profile, although the true uniformity may never be attained.

Figure 7 shows more detailed water-surface and channel bed profile changes during the 100-yr flood through the existing sand mining area near river mile 13. The channel bed has a non-uniform profile through the sand pits. These sand pits will undergo refill during the flood. It is partially refilled at the peak flood and it is not totally refilled at the end of the flood. In the case of the flood series, these sand pits are more or less refilled at half time through the flood series as shown in Fig. 8.



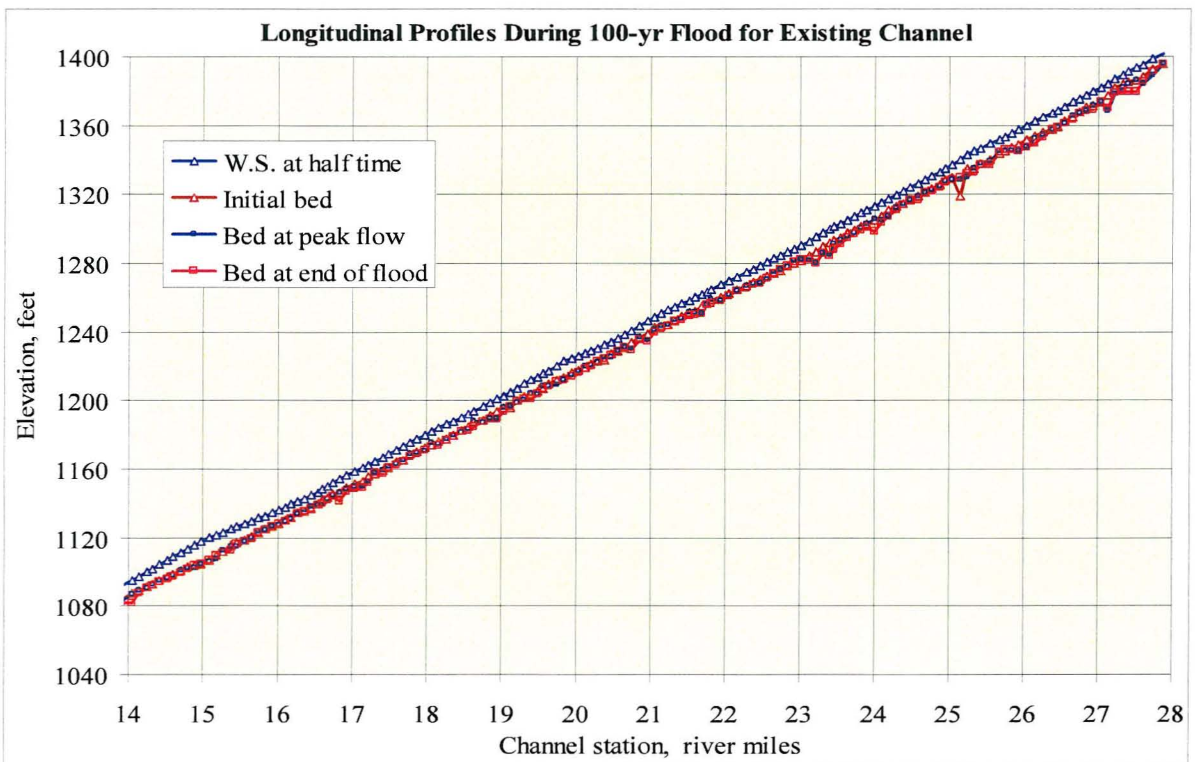


Fig. 6. Simulated water-surface and channel bed profile changes during 100-yr flood for existing conditions

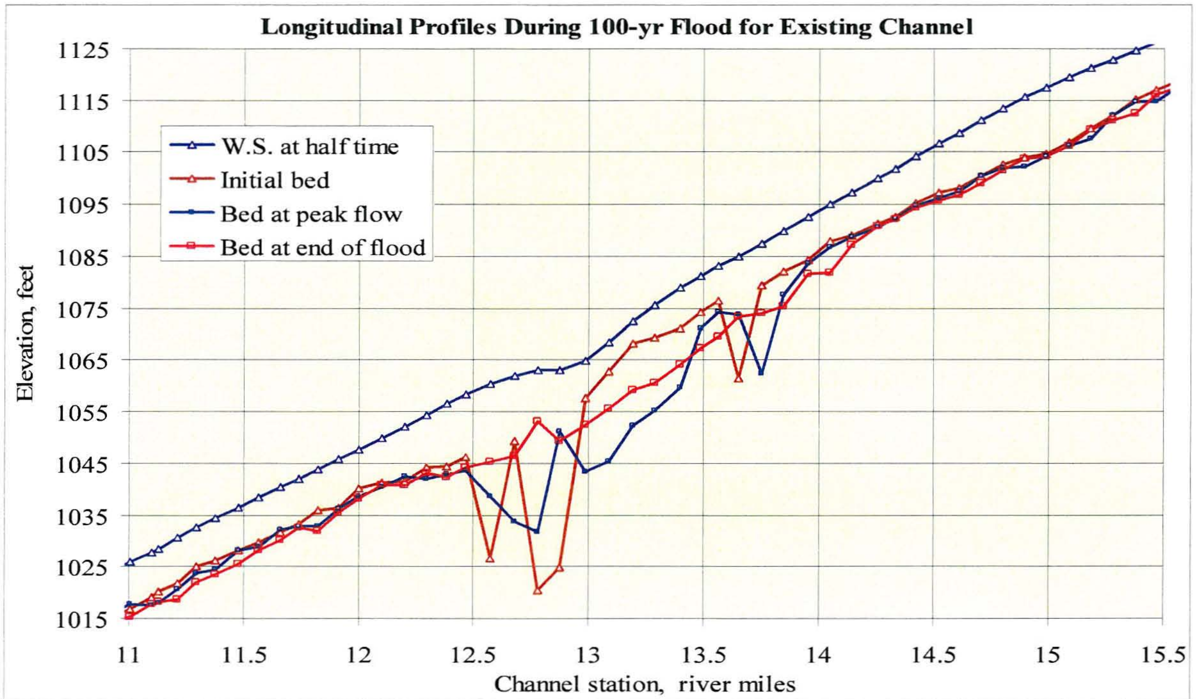


Fig. 7. Simulated water-surface and channel bed profile changes
during 100-yr flood for existing conditions near existing sand mining area

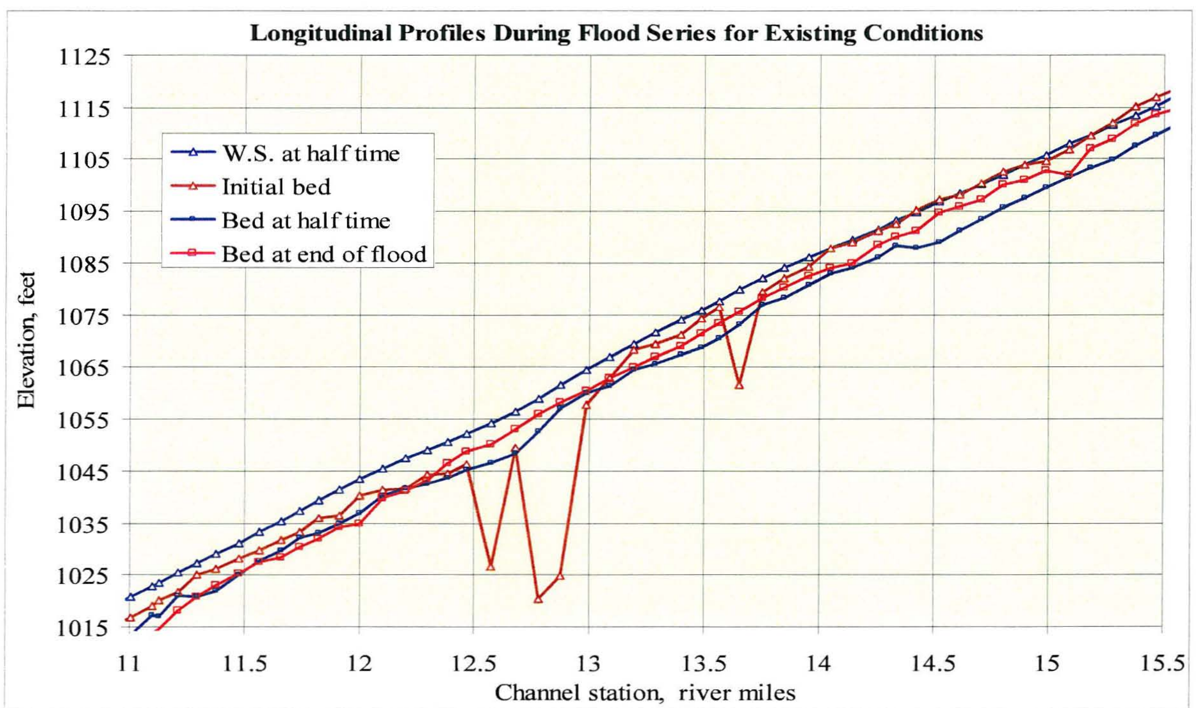


Fig. 8. Simulated water-surface and channel bed profile changes
During flood series for existing conditions near existing sand mining area

Maximum Channel Bed Scour – Minimum channel bed elevations reached by scour during the 100-yr flood and the flood series for the existing and proposed conditions are summarized as listed in Tables 1 and 2 in Appendix B of the report.

Table 1 lists the minimum bed elevations for all channel cross sections at the end of flood events for the following four cases, (1) existing channel conditions and the 100-yr flood, (2) proposed conditions of channel and the 100-yr flood, (3) existing channel conditions and the flood series, and (4) proposed channel conditions and the flood series. Table 2 lists the maximum scour at each cross-section for the same four cases.

Spatial Variations of Flow Velocity and Sediment Transport through Sand Mining Area for Existing Conditions - The presence of sand pits also affects the spatial variations of flow velocity and sediment transport along the channel. Fig. 9 shows the spatial variation of flow velocity at the peak 100-yr flood near the existing mining area. High velocity occurs at the upstream entrance of the sand pit and the dip in velocity is in the sand pit. Fig. 10 shows the spatial variation of sediment load at the peak 100-yr flood along the same channel reach. The flow carries a low sediment load through the sand pit and it has a high sediment transport rate in the upstream channel.

The non-uniformities in flow velocity and sediment load caused by mining pits will gradually disappear as the channel adjusts toward a new equilibrium. For the existing sand mining area, the 100-yr flood alone will not re-establish a new uniformity for the velocity and sediment transport. However, in the case of the long-term flood series, the spatial variation of the sediment load is predicted to become more uniform at half time through the series as shown in Fig. 11. The sediment load becomes more uniform as the sand pits become largely refilled.

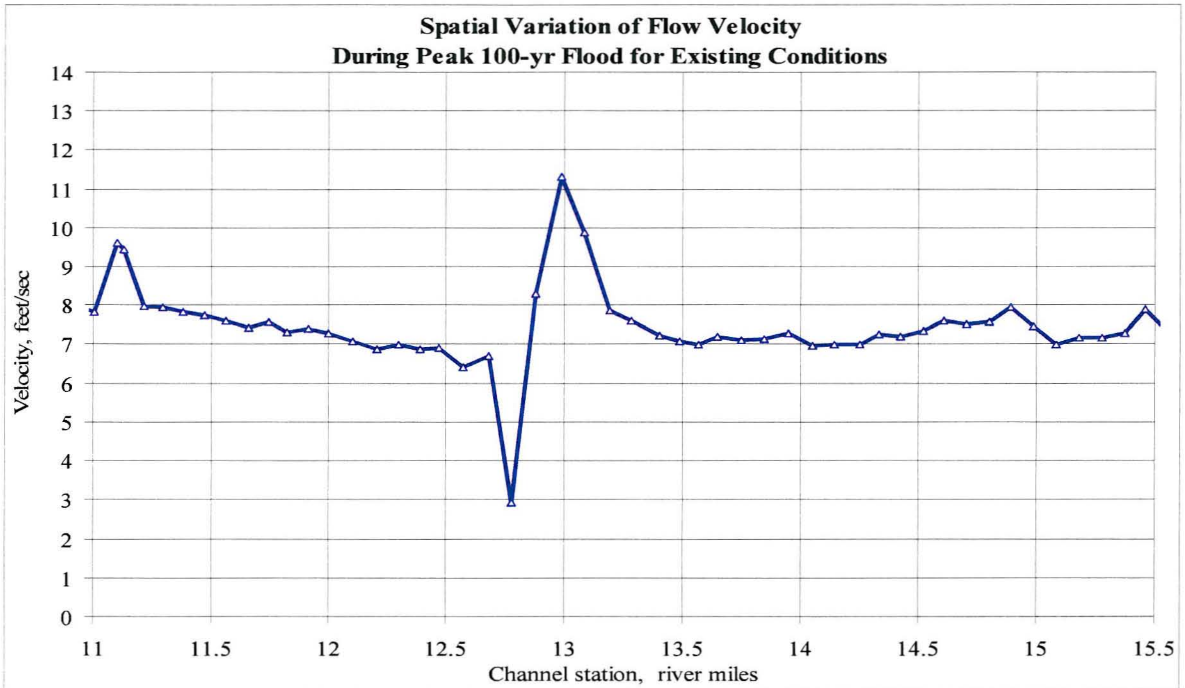


Fig. 9. Spatial variation of flow velocity at peak 100-yr flood along channel reach near existing mining area

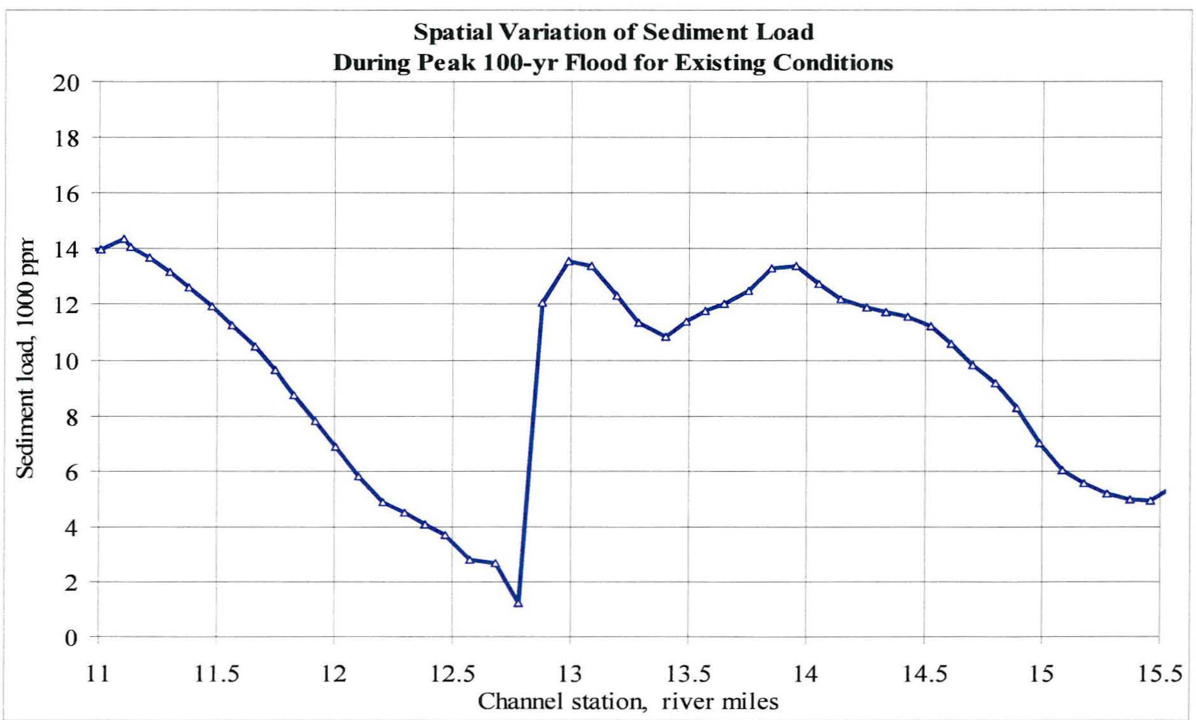


Fig. 10. Spatial variation of flow velocity at peak 100-yr flood along channel reach near existing mining area

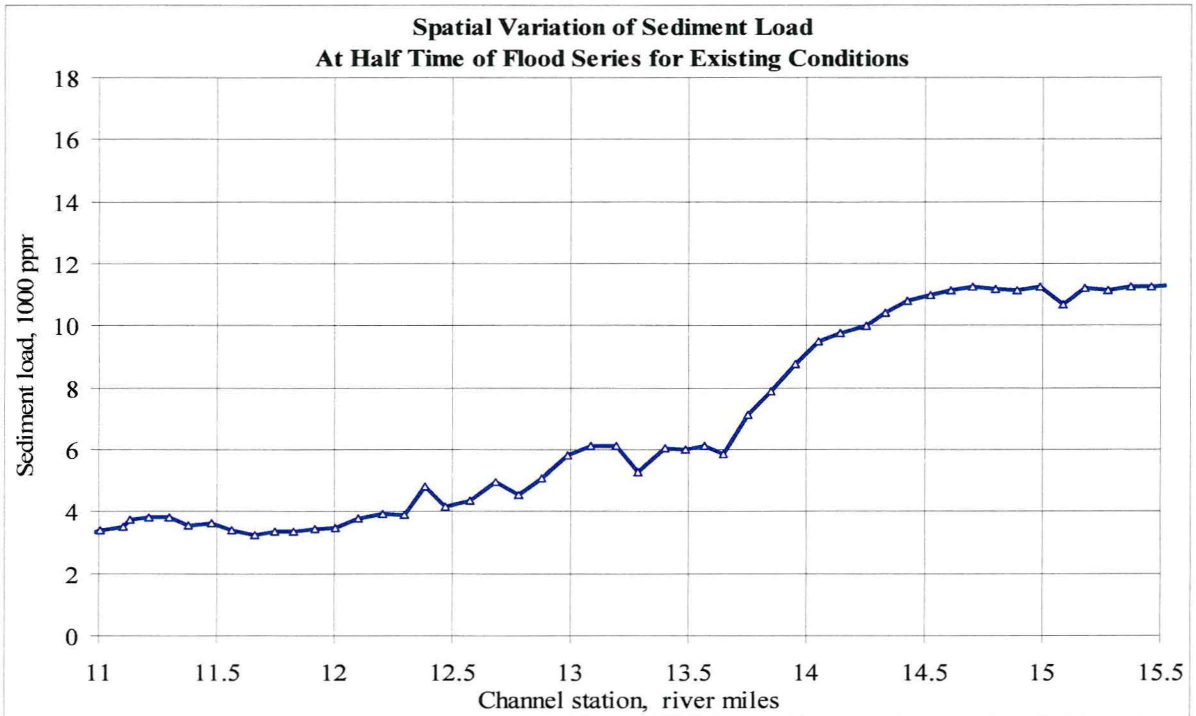
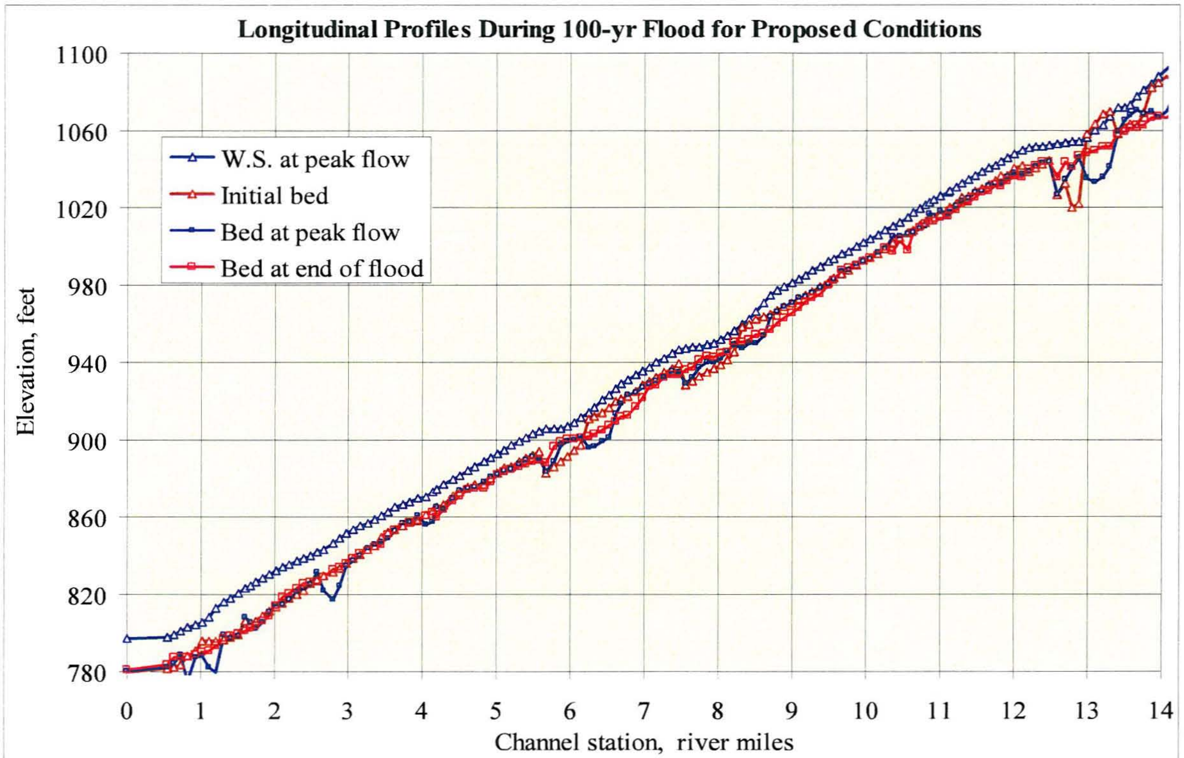


Fig. 11. Spatial variation of flow velocity at half time of flood series along channel reach near existing mining area

Sand Mining Impacts on Flood Level and Channel Bed Profile Changes for Proposed Conditions – The proposed conditions refer to the conditions when final excavation at the approved mining sites are completed. For the proposed conditions, simulated results for the water-surface and channel bed profile changes during the 100-yr flood are shown in Figs. 12 and 13; those for the flood series are shown in Fig. 14. Fig. 12 shows that the channel bed profile at the completion of the mining plans will have several low areas reflecting various depths of excavation. The channel bed profile will undergo adjustments during floods, but one 100-yr flood will not re-establish channel bed uniformity as these mining sites will only be partially refilled.

In the process of river channel changes, the river channel will undergo both scour and fill as the water-surface profile gradually readjusts toward uniformity. These pits will be partially refilled and a more uniform bed profile will eventually develop through the pits as shown in Fig. 14. An incised channel will gradually develop, and in the long term, most of the Lower Hassayampa River will eventually become incised. With channel incision, a somewhat smooth channel bed profile will reach the bottom of the smaller sand pits as such smaller sand pits may eventually disappear. The deeper pits will not disappear even for the duration of the flood series. Sand mining lowers the channel bed; it also lowers the water surface of the river flow near the sand pits.

Figure 15 shows the spatial variation of flow velocity at the peak 100-yr flood for the proposed conditions. The pronounced changes in velocity are characterized by low velocities through sand pits and high velocities along channel reaches approaching the sand pits.



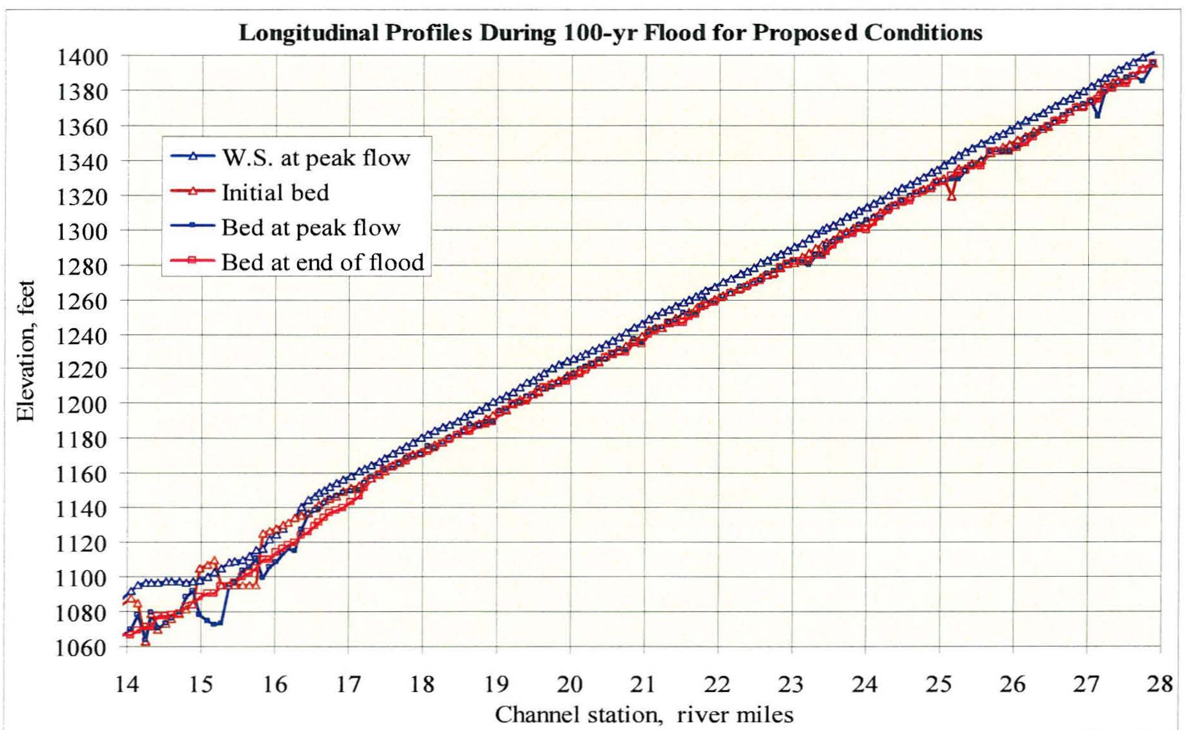
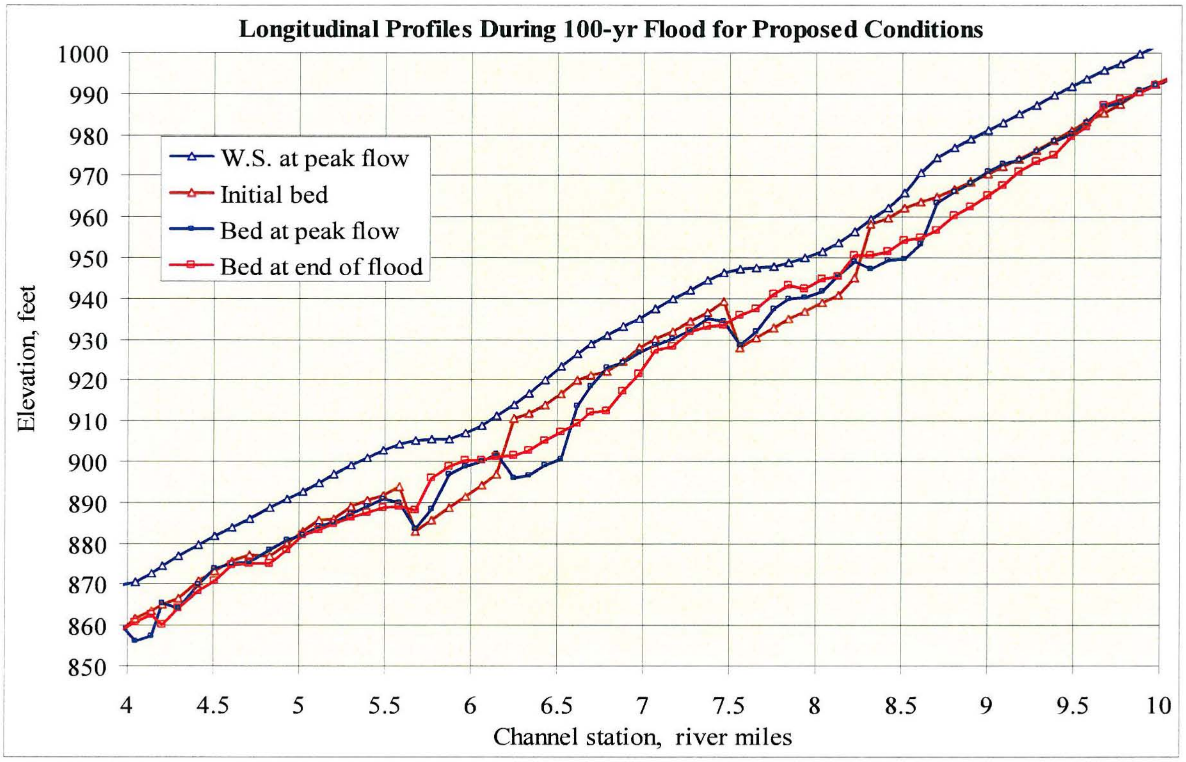


Fig. 12. Simulated water-surface and channel bed profile changes during 100-yr flood for proposed conditions



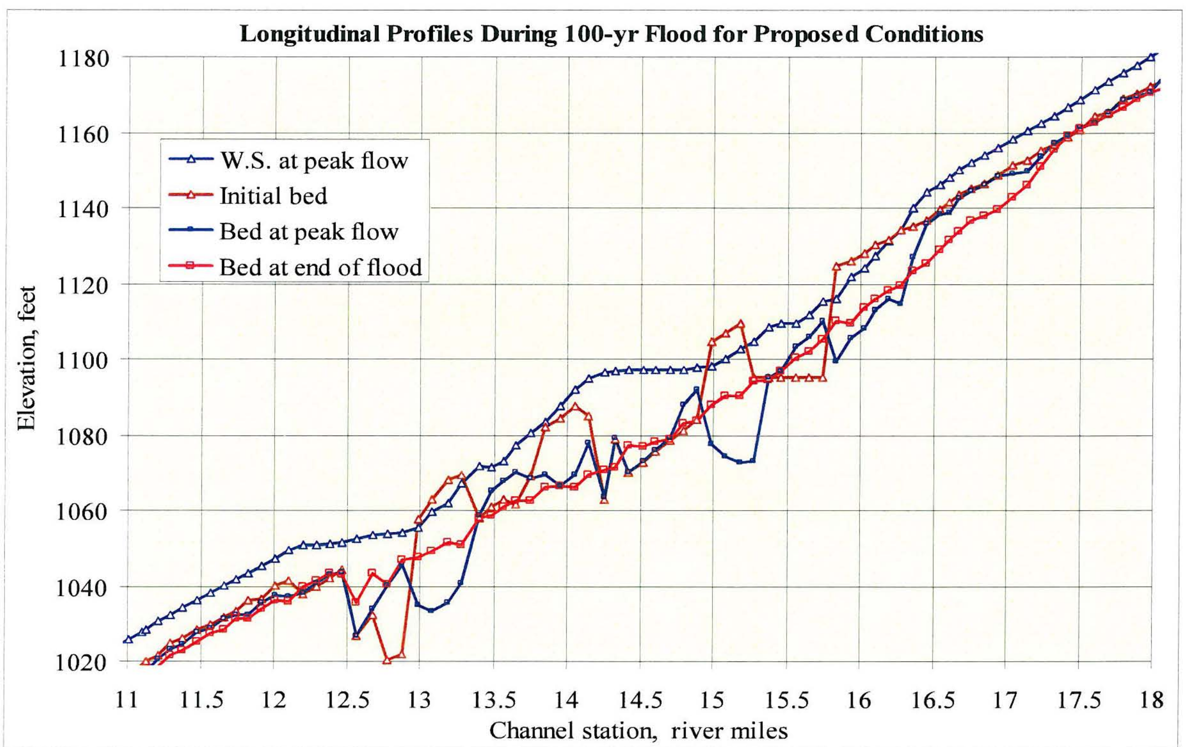
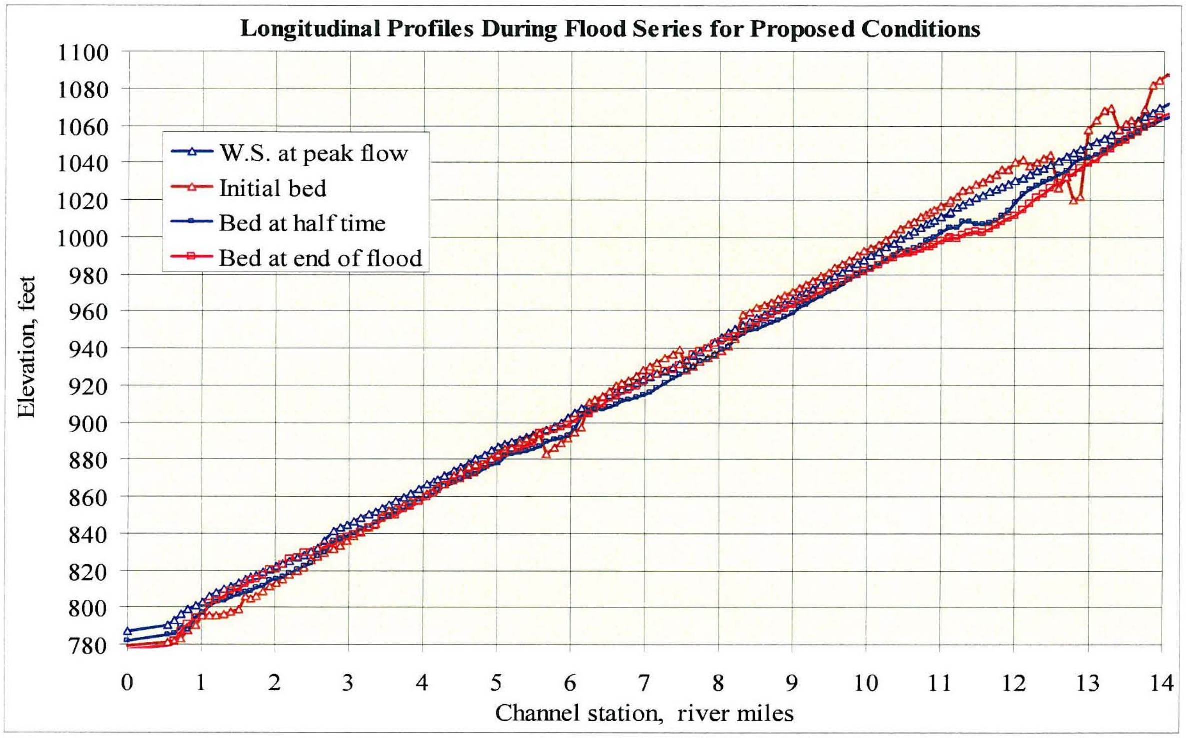


Fig. 13. Water-surface and channel-bed profile changes during 100-yr flood for proposed conditions



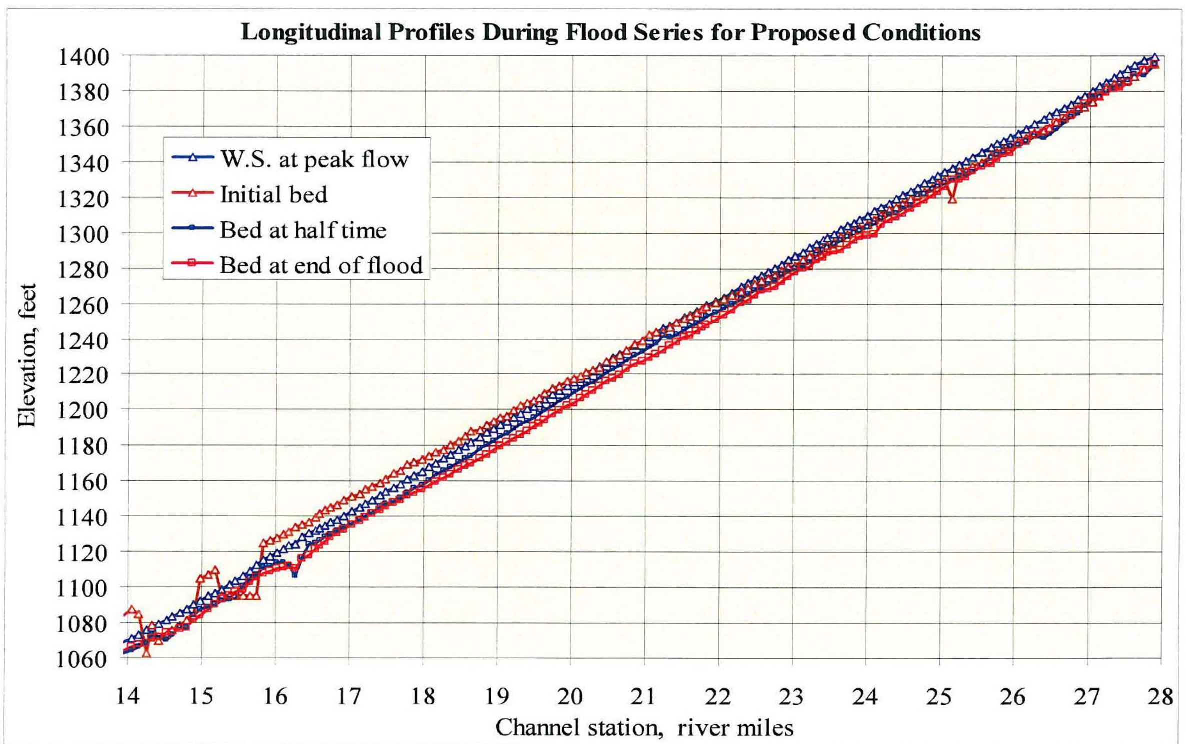
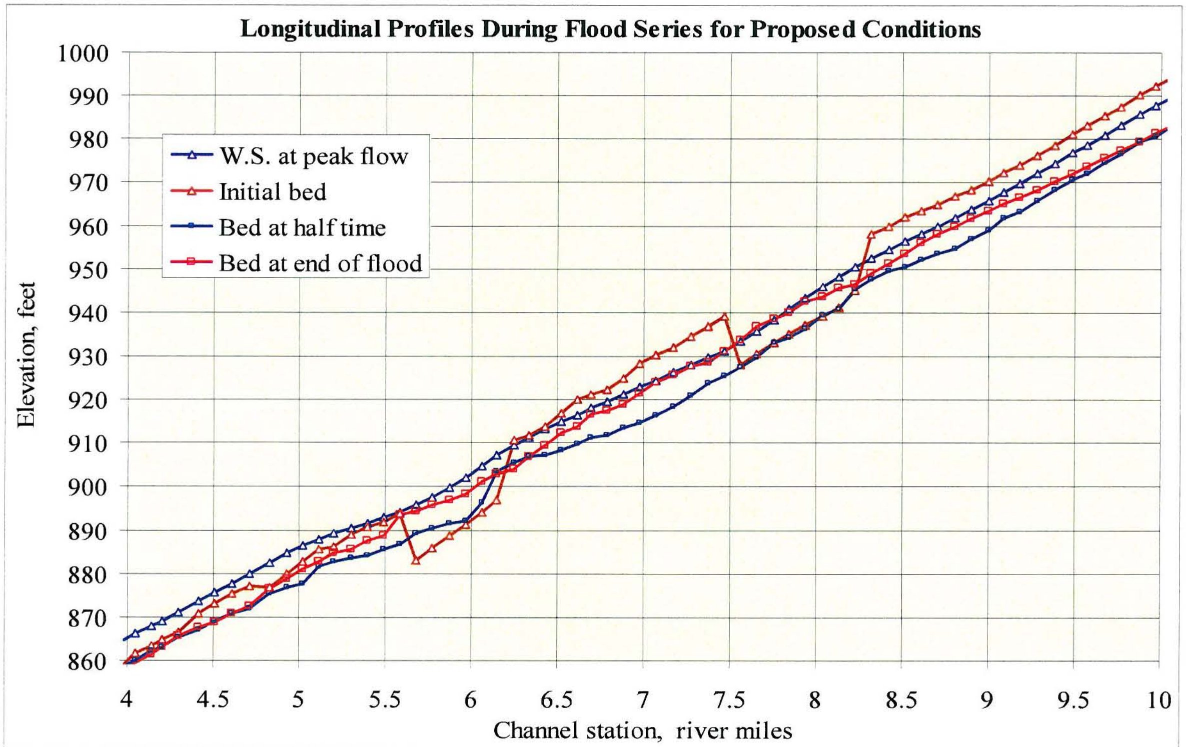


Fig. 14. Water-surface and channel-bed profile changes during flood series for proposed conditions



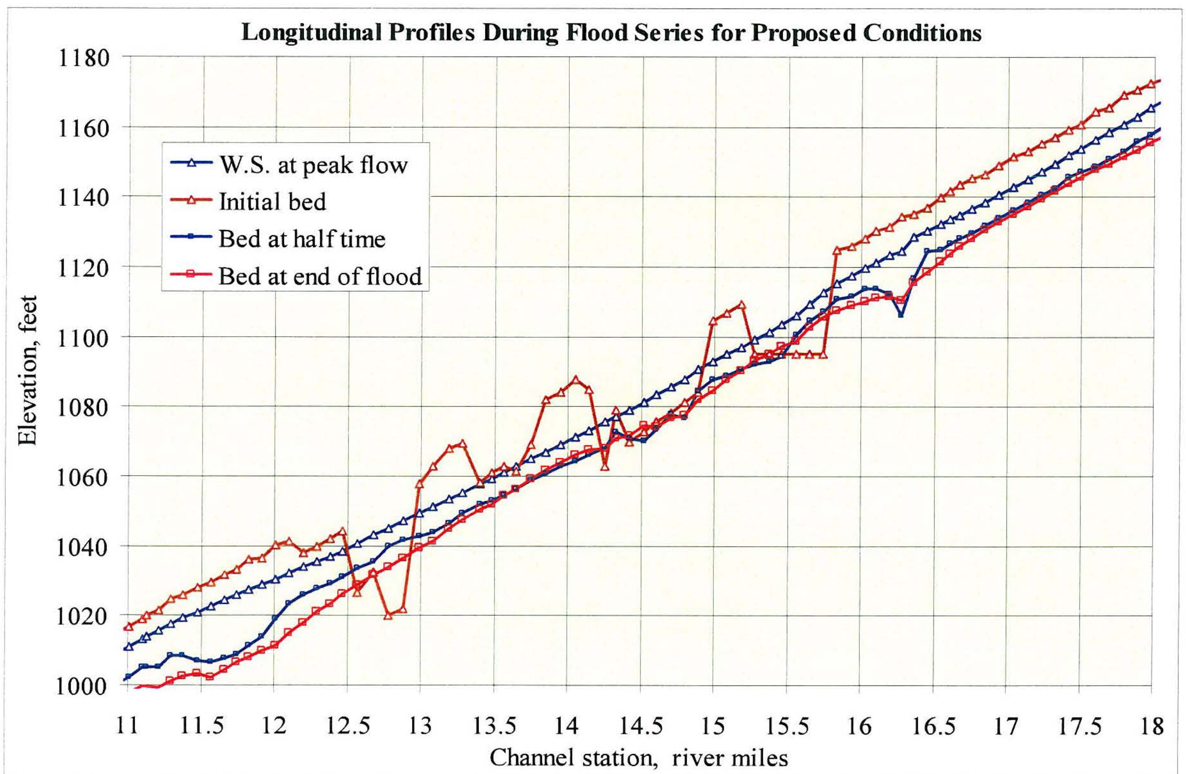


Fig. 14 (continued). Water-surface and channel-bed profile changes during flood series for proposed conditions

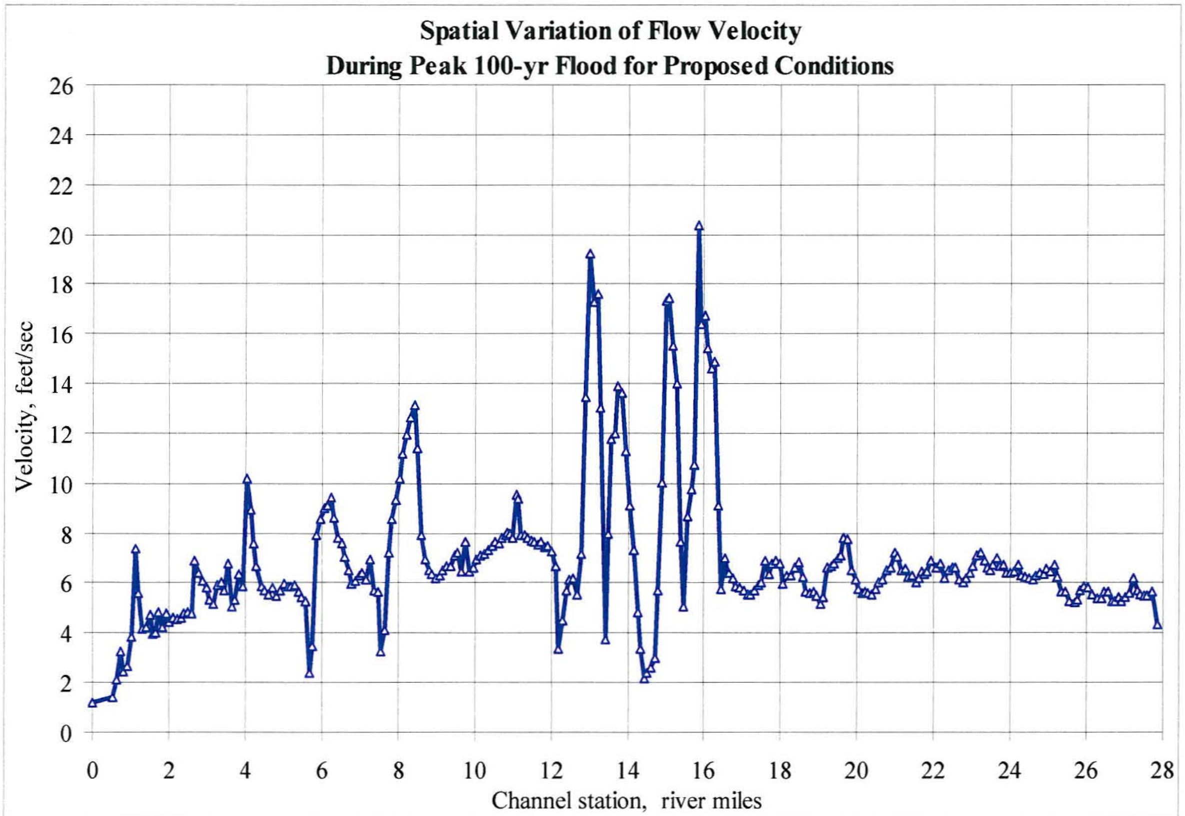


Fig. 15. Spatial variation of flow velocity at peak 100-yr flood for proposed conditions

Sand Mining Impacts on Sediment Delivery along River Channel - 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 as defined in Eq. 5. The time and spatial variations of sediment delivery along the river channel during flood series for the existing conditions are shown in Fig. 16; those for the proposed conditions are shown in Fig. 17. Such spatial variations are characterized by distinct changes along the channel, with an increasing trend of sediment delivery toward downstream along a channel reach approaching a sand pit and a decreasing trend as the flow pass through a sand pit. The increasing trend indicates sediment erosion from the channel boundary and the decreasing trend indicates sediment deposition. The amount of sediment erosion or deposition along a channel reach can be determined from the difference in the amount of delivery from one channel station to the other.

For the existing conditions, the spatial variation of sediment delivery has a major drop toward downstream near river mile 13 and a small drop near the downstream end. The drop in delivery near river mile 13 is related to sediment trapping by the existing mining pits. As a part of the transported sediment settles in the pits, the total delivery toward downstream decreases. The small drop in sediment delivery near the downstream end is related to the backwater from the Gila River, which has induced sediment deposition and delta formation near the Gila River and the Lower Hassayampa River confluence.

For the proposed conditions, the spatial variation of sediment delivery has drops at the mining sites. The variations of sediment delivery near river mile 14 reflect the presence of several mining sites. Fig. 18 shows a more detailed sediment delivery pattern near river mile 14 based on the 100-yr flood. For these sand pits, the short-term changes shown in Fig. 18 are different from the long-term changes shown in Fig. 17.

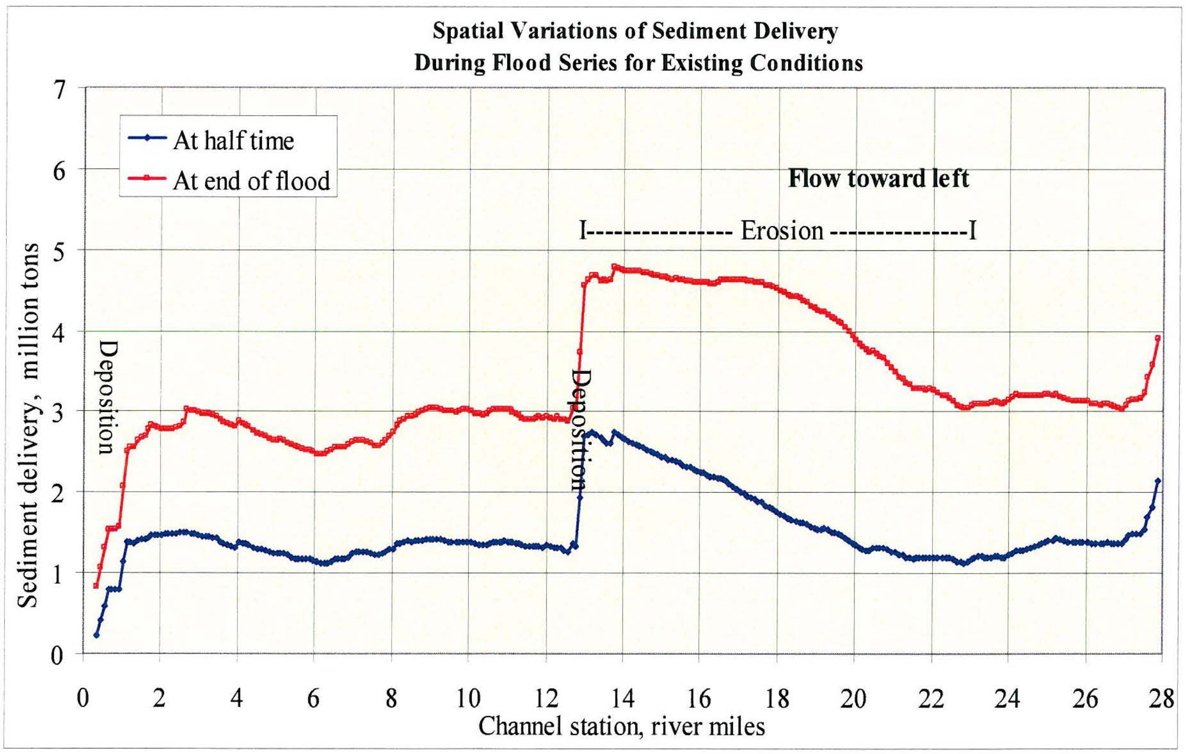


Fig. 16. Time and spatial variations of sediment delivery during the flood series for existing conditions

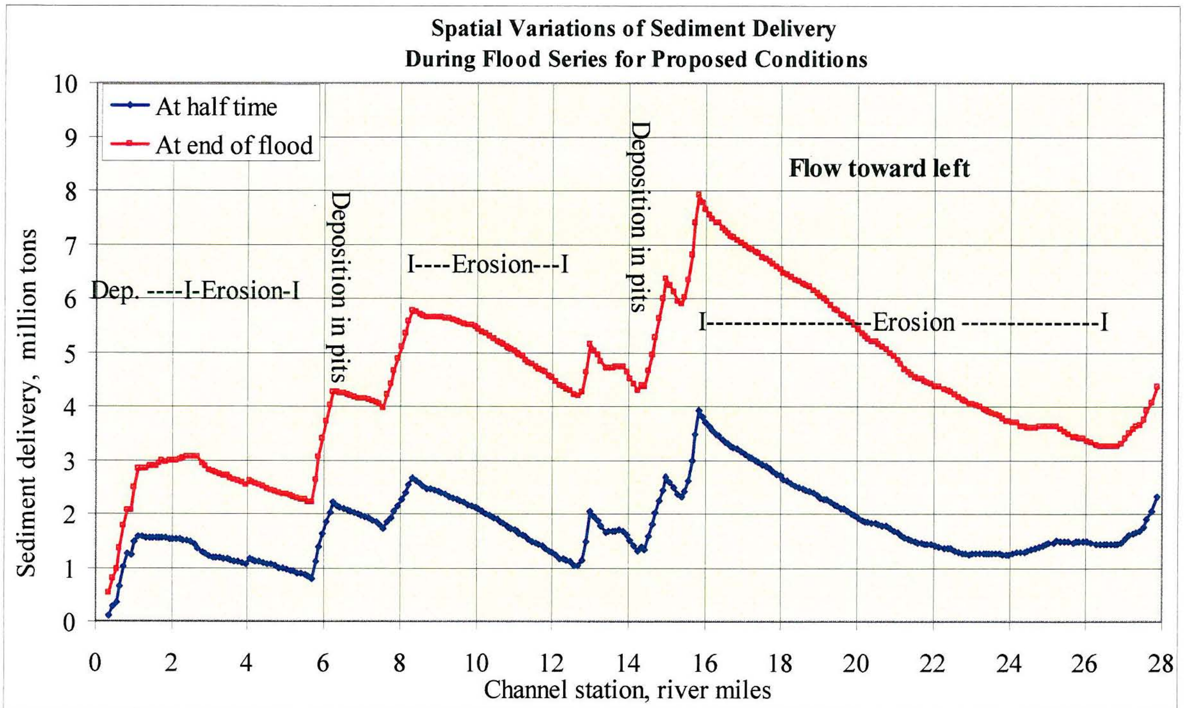


Fig. 17. Time and spatial variations of sediment delivery
during the flood series for proposed conditions

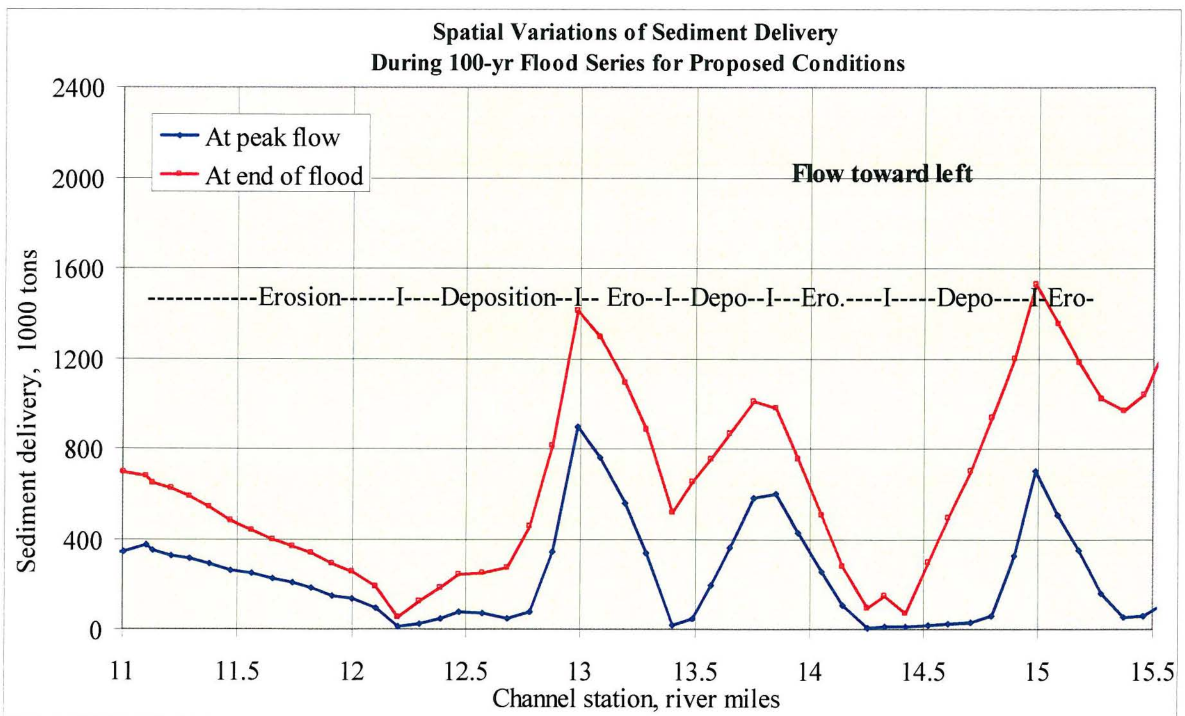


Fig. 18. Time and spatial variations of sediment delivery
during the 100-yr flood near river mile 14 for proposed conditions

The Lower Hassayampa River is divided into several channel reaches, according to the presence of approved sand mining sites. Reaches with approved future mining sites are distinguished from those without future mining. For each channel reach, the inflow and outflow of sediment for the time period of the flood series are used to assess the amount of sediment storage or depletion, i.e., deposition or erosion, along the channel reach for the time period of 68 years covered by the flood series.

For the existing conditions, Table 3 lists channel reaches with future instream sand mining and without mining. For each channel reach, sediment inflow is the sediment delivery passing the channel station at the reach entrance; sediment outflow is the sediment delivery passing the channel station at the reach exit. If the sediment inflow exceeds the outflow, then the net change is increased sediment storage in the reach, and vice versa. For the proposed conditions, Table 4 lists the same channel reaches and their respective sediment inflows, sediment outflows, sediment storages for the duration of the flood series.

In order to assess the impacts of sand mining on the sediment budget, the changes in sediment storage for the existing conditions in Table 3 are compared with those for the proposed conditions in Table 4. The increases or decreases of sediment storage within channel reaches are listed in the last column of Table 5. In which, a negative value for sediment storage indicates increased erosion due to sand mining for channel reach; a positive value indicates decreased erosion due to sand mining for channel reach. It can be seen that the channel reach between 7.37 to 8.22 river mile is predicted to have the largest amount of sediment gain due to the mining projects. On the other hand, the channel reach between 15.87 and 26.38 is predicted to have the largest erosion.

Table 3. Summary of sediment delivery and sediment storage during flood series along river channel for existing conditions

M: Channel reach with future instream mining
N: Channel reaches without future instream mining

River reach River miles	Sediment inflow Million tons	Sediment outflow Million tons	Change in sediment storage, Million tons
0.54 – 0.82 (M)	1.52	1.31	+0.22
0.82 – 5.57 (N)	2.54	1.53	+1.01
5.57 – 6.14 (M)	2.48	2.54	-0.06
6.14 – 7.37 (N)	2.61	2.48	+0.13
7.37 – 8.22 (M)	2.90	2.61	+0.29
8.32 – 12.09 (N)	2.91	2.90	+0.01
12.09 – 12.85 (M)	4.57	2.91	+1.57
12.85 – 13.13 (N)	4.68	4.57	+0.09
13.13 – 14.83 (M)	4.66	4.68	-0.04
14.83 – 15.02 (N)	4.65	4.66	-0.01
15.02 – 15.87 (M)	4.59	4.65	-0.06
15.87 – 26.38 (N)	3.08	4.59	-1.51
26.38 – 27.89 (N)	3.91	3.08	+0.83

Table 4. Summary of sediment delivery and sediment storage during flood series along river channel for proposed conditions

M: Channel reach with instream mining
N: Channel reaches without instream mining

River reach River miles	Sediment inflow Million tons	Sediment outflow Million tons	Change in sediment storage, Million tons
0.54 – 0.82 (M)	2.07	0.97	+1.10
0.82 – 5.57 (N)	2.21	2.07	+0.14
5.57 – 6.14 (M)	4.28	2.21	+2.07
6.14 – 7.37 (N)	4.04	4.28	-0.24
7.37 – 8.22 (M)	5.79	4.04	+1.75
8.22 – 12.09 (N)	4.39	5.79	-1.40
12.09 – 12.85 (M)	5.17	4.39	+0.78
12.85 – 13.13 (N)	4.84	5.17	-0.33
13.13 – 14.83 (M)	6.36	4.84	+1.52
14.83 – 15.02 (N)	6.13	6.36	-0.23
15.02 – 15.87 (M)	7.65	6.13	+1.52
15.87 – 26.38 (N)	3.27	7.65	-4.38
26.38 – 27.89 (N)	4.37	3.27	+1.10

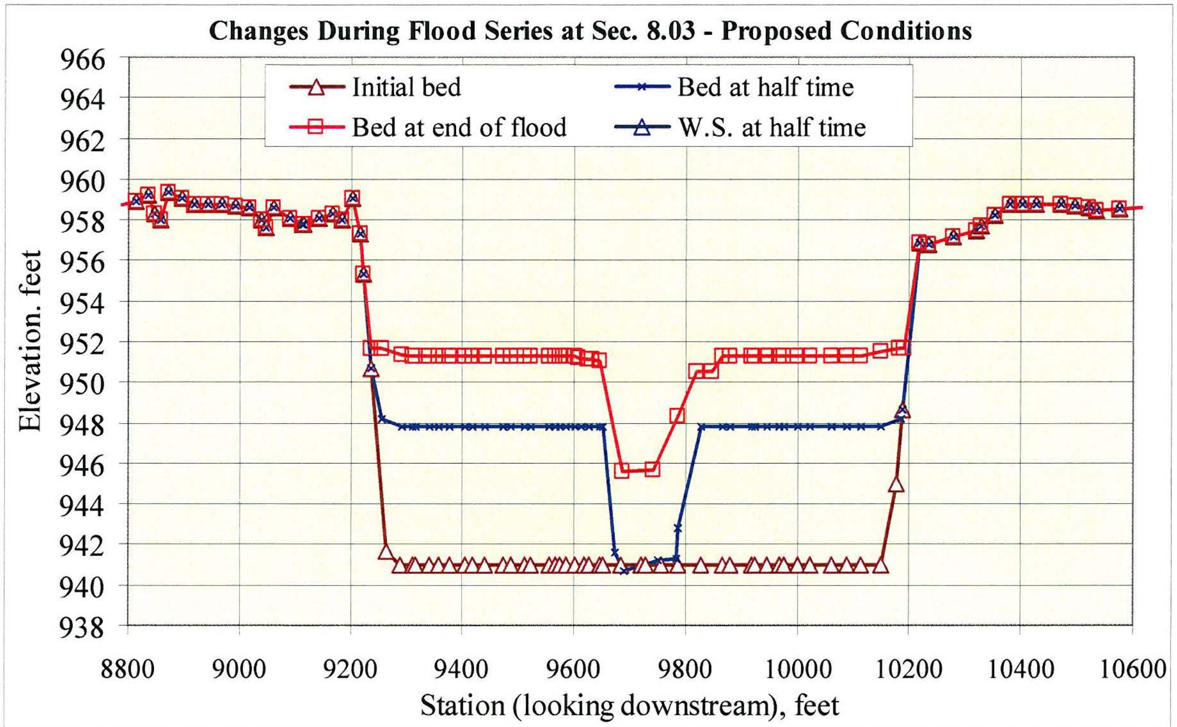
Table 5. Comparison of changes in sediment budget related to mining project

M: Channel reach with instream mining
N: Channel reaches without instream mining

River reach River miles	Change in sediment storage for existing conditions Million tons	Change in sediment storage for proposed conditions Million tons	Impacts of sand mining on sediment budget* Million tons
0.54 – 0.82 (M)	+0.22	+1.10	+0.88
0.82 – 5.57 (N)	+1.01	+0.14	-0.87
5.57 – 6.14 (M)	-0.06	+2.07	+2.13
6.14 – 7.37 (N)	+0.13	-0.24	-0.37
7.37 – 8.22 (M)	+0.29	+1.75	+1.40
8.32 – 12.09 (N)	+0.01	-1.40	-1.41
12.09 – 12.85 (M)	+1.57	+0.78	+0.79
12.85 – 13.13 (N)	+0.09	-0.33	-0.42
13.13 – 14.83 (M)	-0.02	+1.52	+1.54
14.83 – 15.02 (N)	-0.01	-0.23	-0.22
15.02 – 15.87 (M)	-0.01	+1.52	+1.53
15.87 – 26.38 (N)	-1.51	-4.38	-2.87
26.38 – 27.89 (N)	+0.83	+1.10	+0.27

*A negative value indicates increased erosion due to sand mining for channel reach
*A positive value indicates decreased erosion due to sand mining for channel reach

Morphology of Sediment Deposition and Erosion in Sand Pits – As flow passes through a sand pit, the velocity slows down and sediment drops out to settle in the sand pit. Cross-sectional changes depicting sand pit deposition and erosion are exemplified by those shown in Fig. 19 for Secs. 8.03, 12.66, and 15.59. The section numbers represent the cross section locations in river miles. Section 8.03 is located in a sand pit and sections 12.66 and 15.59 are in deeper pits. Changes at these sections are characterized by continued deposition; they also exemplify that as sediment settles in a sand pit, it tends to spread out and to build up the bed in horizontal layers. The wide and flat channel bed continues in the sand pit as long as deposition persists. But as the bed builds up to a high level, the deposition trend may stop, to be followed by erosion. During erosion, the flow tends to converge as the flow slides back into the banks to form deeper and narrower channels, as illustrated by the changes at Sec. 15.59 during the 100-flood and by Sec. 16.22 during the flood series. Such changes in channel morphology demonstrate that the channel undergoing deposition tends to spread out to cover wide areas, while it tends it slide back to the banks during erosion. With continued erosion, the channel may become incised as shown by the changes at Sec. 12.66 during the flood series.



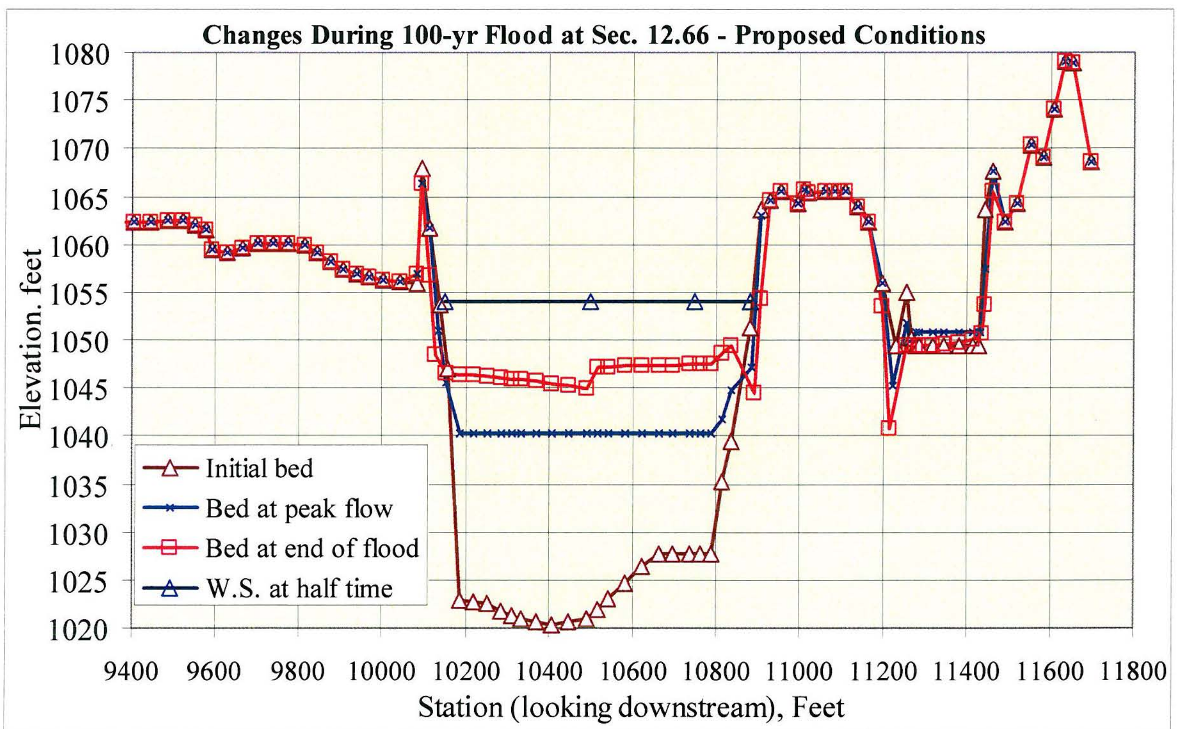
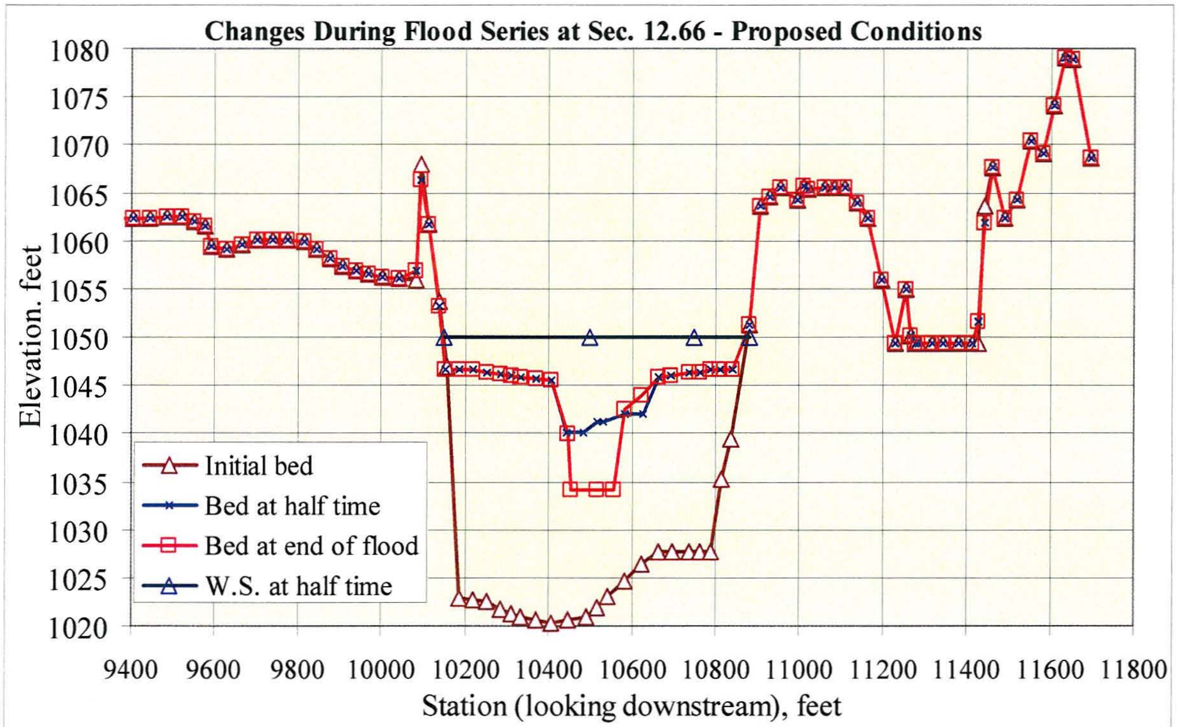


Fig. 19. Sample cross-sectional changes for sediment deposition in sand pit



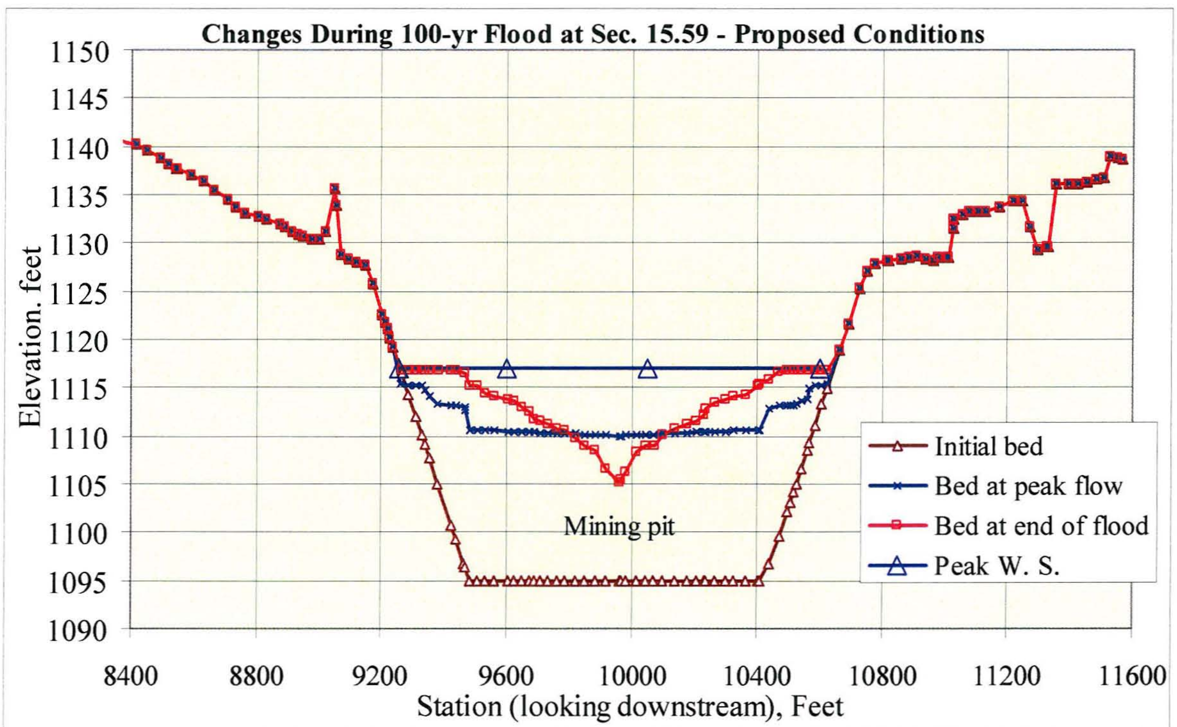


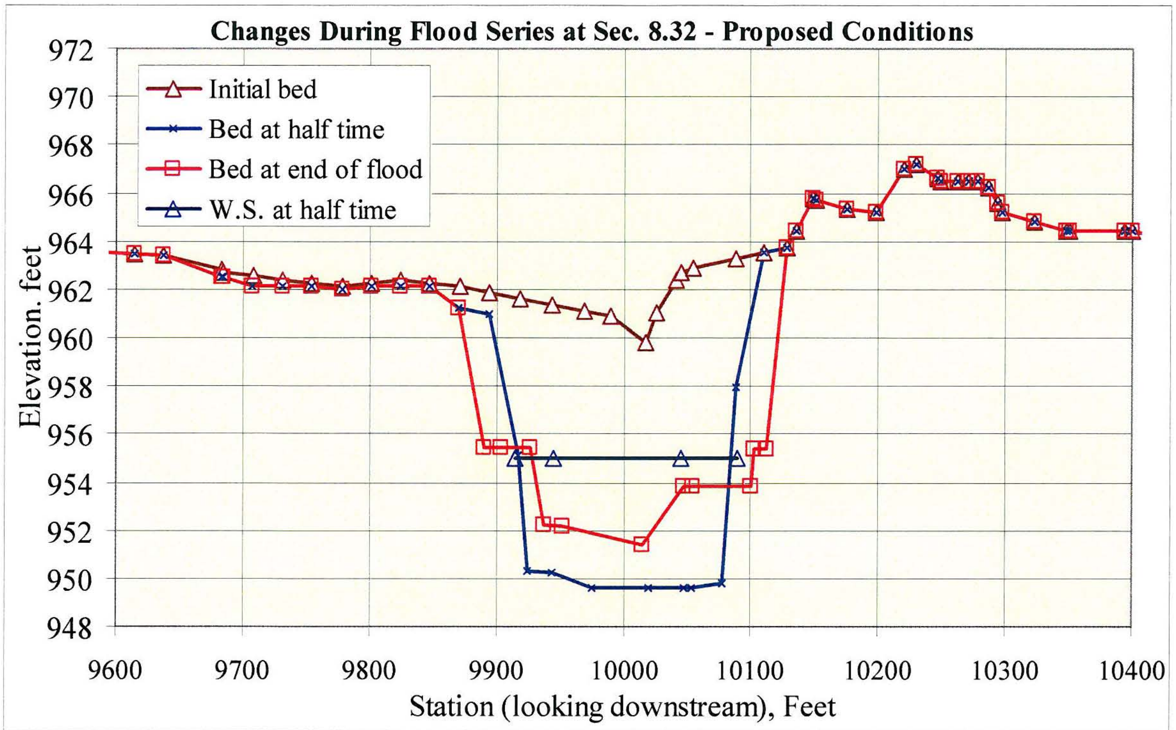
Fig. 19 (continued). Sample cross-sectional changes for sediment deposition in sand pit

Head-Cutting and Downstream Erosion - Sand and gravel mining may induce erosion in both the upstream and downstream directions, referred to as head cutting and downstream erosion, respectively. The fluvial processes are different for these types of channel changes. The occurrence of downstream erosion is due to sediment storage in the 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 in order to satisfy its transport capacity. As long as the tractive force of 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, will remove 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.

Head-cutting is illustrated by the cross-sectional changes shown in Fig. 20 for Secs. 8.32, 14.92, 15.78, and 16.35. These cross-sections are located in the upstream vicinity of a sand pit. Sec. 8.32 is located upstream of the sand pit near river mile 8; Secs. 14.92, 15.78 and 16.35 are located upstream of the shallower pit near river mile 13. Changes at these sections are characterized deep channel bed scour. The scour depth is directly related to the sand pit depth; it diminishes with distance away from the sand pit.

Downstream erosion is illustrated by the cross-sectional changes shown in Fig. 21. These cross sections are located downstream of the sand pit near river mile 13. Channel bed changes are characterized by gradual lowering of the channel bed as inflow sediment is trapped in the sand pit.

The rates of channel change due to head cutting and downstream erosion are different. It can be seen from the longitudinal channel bed profile changes that head-cutting develops more rapidly than downstream erosion. This is because water surface drawdown in the sand pit causes a major increase in velocity in the approach channel and more rapid channel bed erosion.



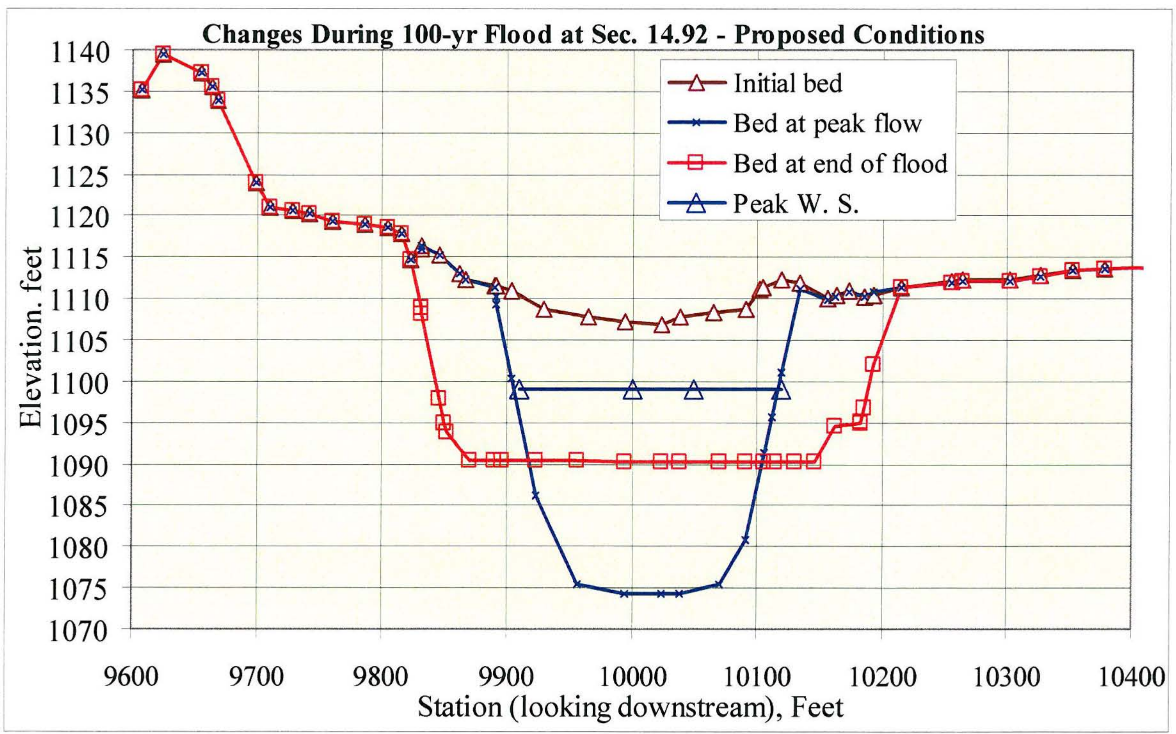
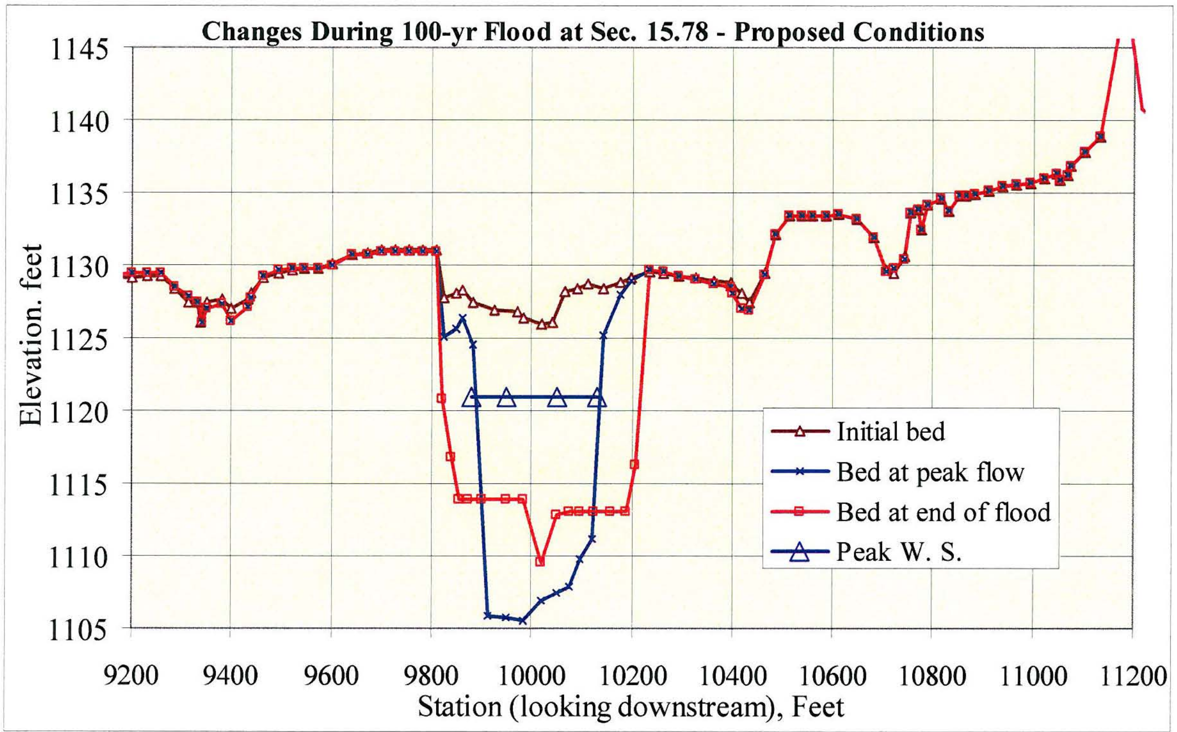


Fig. 20. Sample cross sectional changes due to head cutting



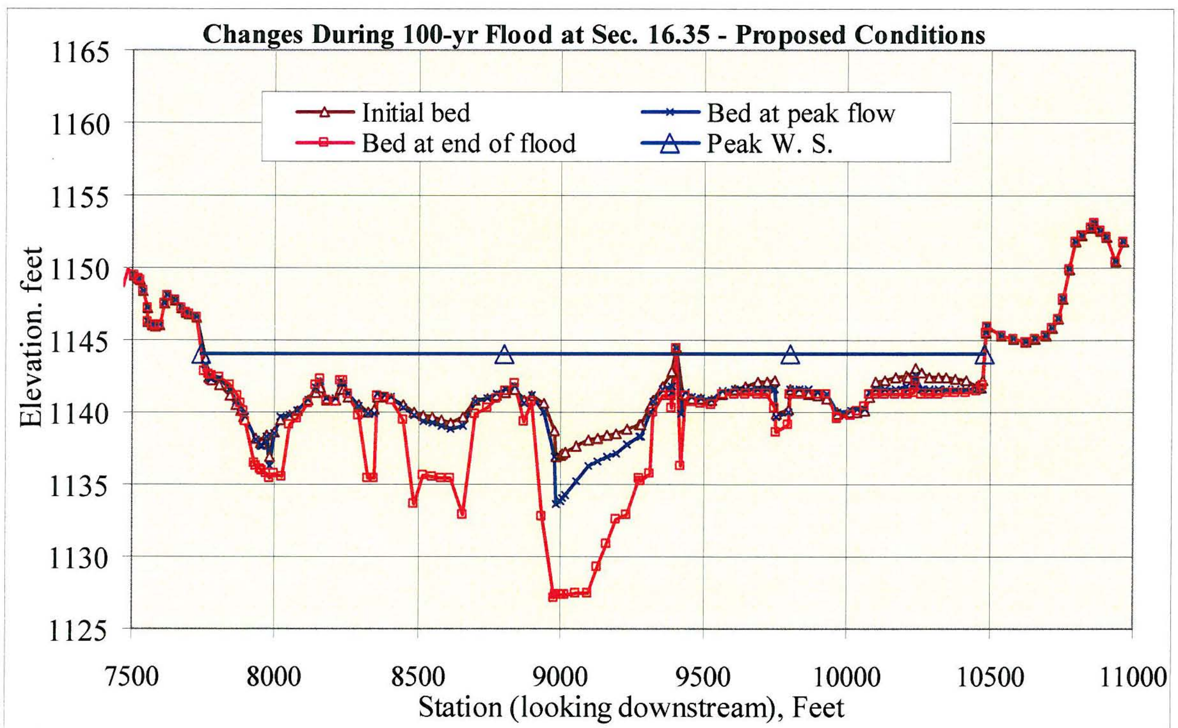
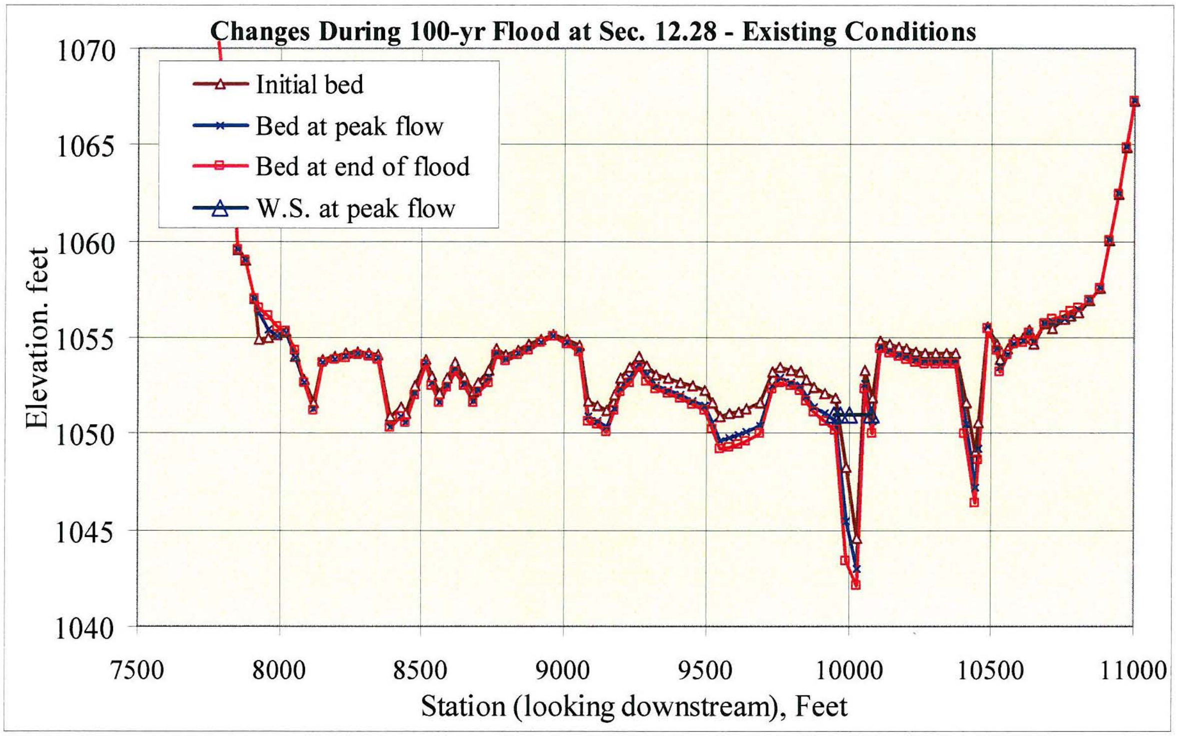


Fig. 20 (continued). Sample cross sectional changes due to head cutting



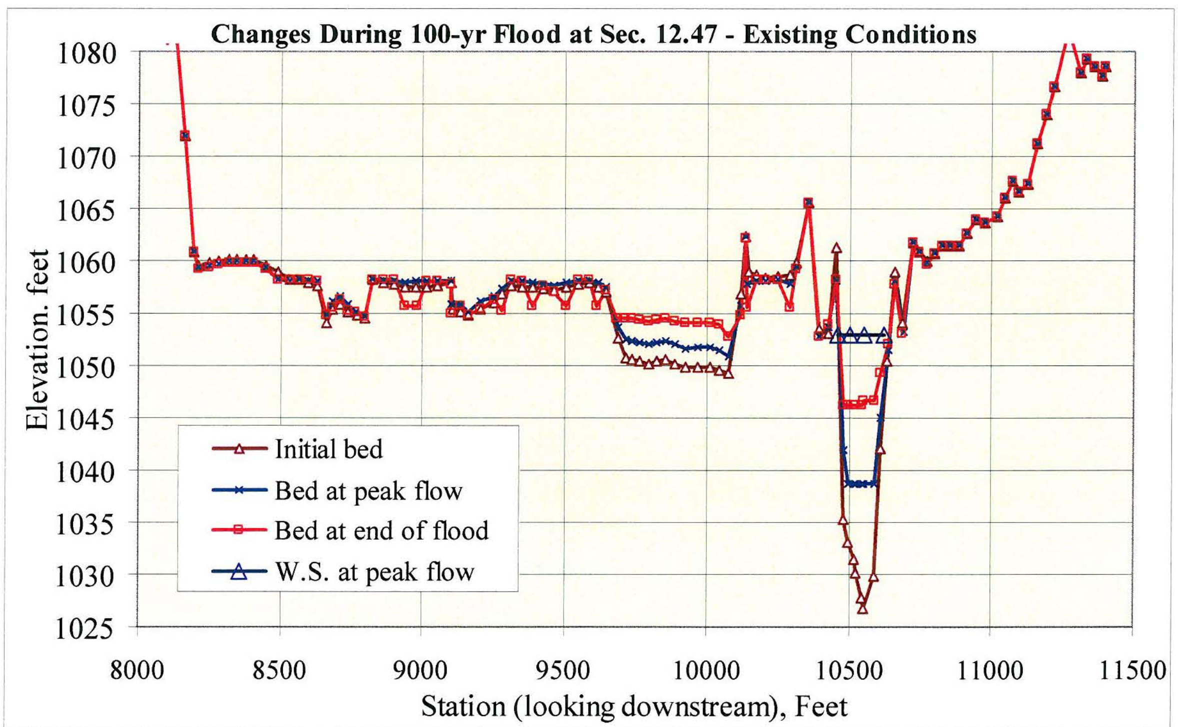


Fig. 21. Sample cross-sectional changed due to downstream erosion caused by an upstream sand pit

Channel Width Changes During Scour and Fill – Channel bed scour and fill are usually accompanied by changes in channel width, as shown in Figs. 19 and 20. These figures have distorted plot scales as the vertical scale is exaggerated in relation to the horizontal scale. The figures give the image that channel-bed changes are greater in magnitude than channel width changes. In fact, width changes are generally greater in magnitude than channel bed scour and fill. For the cross-sectional changes shown in Fig. 20, the maximum changes in bed level from the initial point to the peak flow are compared with the width changes from the peak flow to the end of flood as listed in Table 6 below. The width changes are much greater than the scour depth. The changes in channel width and depth are inter-related; therefore, modeling river channel changes should be based on an erodible boundary model instead of an erodible bed model.

Table 6. Morphological changes related to head-cutting

River station Miles	Maximum scour depth Feet	Maximum width change feet
8.41	26	50
14.92	33	150
15.78	20	50

Modeling Results Explained Based on Basic Principles Governing River Channel Changes - In natural rivers, channel bed scour and fill are usually accompanied by width changes. Such morphologic features can be explained from the basic principles governing river channel changes as described below. Dynamic equilibrium is the condition toward which each river channel evolves. The transient behavior of an alluvial river undergoing changes must reflect its constant adjustment toward dynamic equilibrium, although the true equilibrium may never be attained. For a short river reach of uniform discharge, the conditions for dynamic equilibrium are (1) equal sediment load along the channel and (2) uniformity in power expenditure γQS, where γ is the unit weight of the water-sediment mixture, Q is the volume flow rate, and S is the energy gradient. The term γQS is the energy loss per unit time and unit channel length. If the energy gradient is approximated by the water-surface slope, then a uniform energy gradient is equivalent to a linear (straight-line) water-surface profile along the channel. A river channel undergoing changes usually does not have a linear water-surface profile or uniform sediment load and may have significant non-uniformities. However, river channel adjustments are such that the non-uniformities in water-surface profile and sediment load are effectively reduced. The rate of adjustment is limited by the rate of sediment movement and is subject to the rigid constraints such as grade-control structures, bank protection, abutments, bedrock, and so on.

The energy gradient usually varies significantly along an alluvial channel reach. From the results of a hydraulic computation, such as the HEC-RAS output, the energy gradient exhibits non-uniformity even if it is for a fairly uniform channel. This spatial variation is much more pronounced in disturbed rivers. A mathematical modeler realizes that a river channel will change in order to attain stream-wise uniformity in sediment load. It is equally important to perceive that it will also adjust toward equal energy gradient along the channel. Because sediment discharge is a direct function of γQS, channel adjustment in the direction of equal power expenditure also favors the uniformity in sediment discharge. The sediment discharge in the reach will match the inflow rate when the equilibrium is reached.

A stream channel's adjustment in the direction of equal power expenditure, or linear water-surface profile, provides the physical basis for the modeling of channel width changes. However, this adjustment does not necessarily mean movement toward uniformity in channel width. For one thing, the power expenditure is also affected by channel roughness and channel-bed elevation, in addition to the width. But, more importantly, the adjustment toward uniformity in power expenditure is frequently accomplished by significant stream-wise variation in width. Such spatial width variation generally occurs concurrently with streambed scour or fill, to be illustrated in the following by an example.

The transient behavior can be more clearly demonstrated by more dramatic river channel changes in the short term. For example, as a stream channel first enters a sand pit, it forms a deep and narrow gulley in the entrance channel and it then spreads out to a large width to deposit sediment in the pit. This morphological pattern is selected herein to illustrate how the significant spatial variation in width is related to river channel's adjustment toward uniform power expenditure.

During the initial stage, the channel reach approaching the sand pit has a higher bed elevation and a higher energy gradient. Channel changes are characterized by the formation of a deep and narrow gully. Such a channel change effectively lowers the sediment transport and energy gradient. At the same time, sediment deposition in the pit downstream spreads out to cover a large width. From the approaching channel to the sand pit, the channel has a large spatial variation in width, from a narrow channel to a broad alluvial fan channel in the sand pit. Such spatial variation in width represents the channel adjustments toward uniformity in power expenditure as explained below. Formation of a narrower and deeper channel was effective to reduce the energy gradient due to decreased boundary resistance and lowered streambed elevation. On the other hand, the streambed area undergoing fill had a lower streambed elevation and a flatter energy gradient. Channel widening at this area was effective to steepen its energy gradient due to the increasing boundary resistance and rising streambed elevation. Thus, these adjustments in channel width effectively reduced the spatial variation in power expenditure or non-uniformity in water-surface profile. Because sediment discharge is a direct function of stream power γQS, channel adjustment in the direction of equal power expenditure also favors the equilibrium, or uniformity, in sediment discharge.

The significant spatial width variation is temporary. The small width lasted while streambed scour continued, and the large width persisted with sustained fill. At a later stage when scour and fill ceased, the energy gradient or water-surface slope associated with the small width became flatter than that for the large width. The new profile of energy gradient or water surface became a reversal of the initial profile. Then, the small width started to grow wider while the large width began to slide back into the channel, resulting in a more uniform width along the channel.

The above example illustrates that a regime relationship for channel width may not be used in simulating transient river channel changes. Under the regime relationship, the width is a function of the discharge only; but under transient changes, the channel can have very different widths even though the discharge is essentially uniform along the channel.

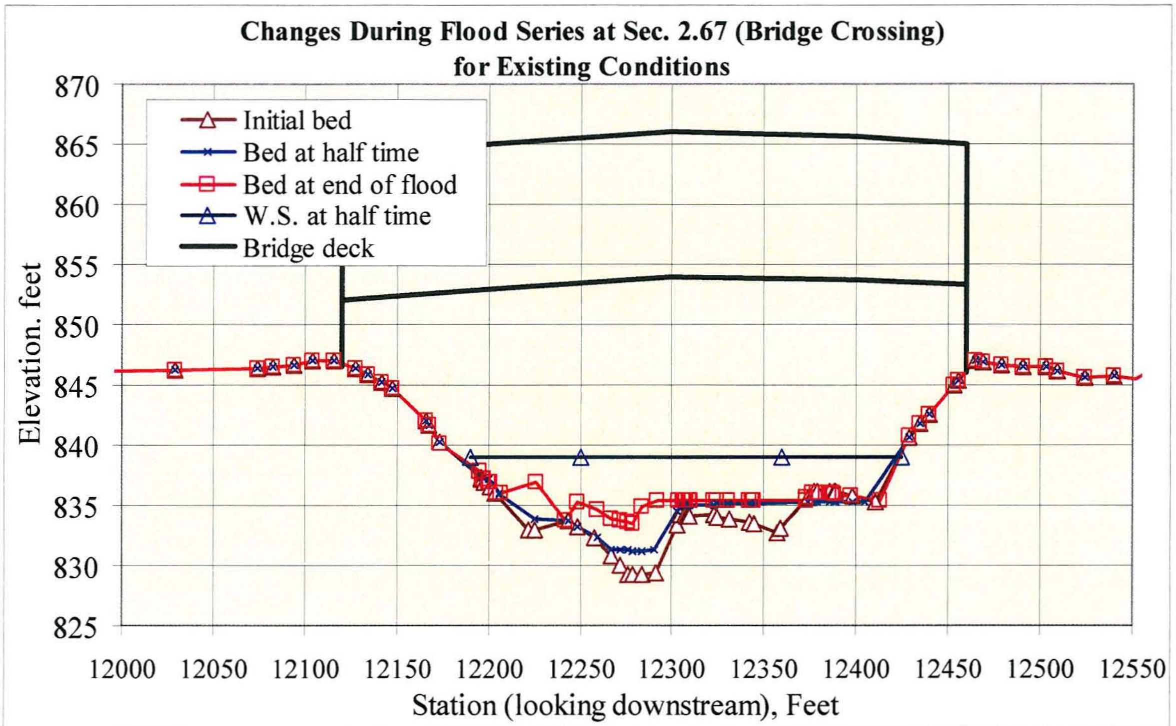
The pattern of sediment deposition in a sand pit can be illustrated by a picture taken for a sediment basin along Pole Creek in Ventura County, California. Fig. 22 shows that as the flow of Pole Creek enters the sediment basin, it deposited the sediment to form an almost flat bed in the wide sediment basin.

Sand Mining Impacts on Infrastructure – Infrastructures, such as bridges, levels, bank protection, pipeline crossings, etc. may be impacted by river channel scour. As a basic principle, any hydraulic structure must be strong enough to withstand the force of flow, and the toe of a structure must entrench beyond the potential channel bed scour.

The most important hydraulic structures along the Lower Hassayampa River are the three bridges. Potential channel bed scour (long-term scour) at these bridge crossings have been simulated for the existing conditions as well as for the proposed conditions, based on the long flood series that has greater impacts on scour. Figs. 23, 24, and 25 show the simulated long term channel bed scour at three bridge crossings for the existing conditions and the proposed conditions. For all bridge crossings, there will be greater long-term channel bed scour for the proposed conditions than for the existing conditions.

The U.S. 80 Bridge crossing at river mile 2.67 is subject to limited long-term channel bed scour that is not a threat to bridge stability. The railroad bridge crossing at river mile 4.005 is subject to minor channel bed scour as depicted in the figure. The I-10 Bridge located between river miles 10.98 and 11.01 is along a river reach between major mining sites. The modeling results show that this bridge crossing is subject to major long-term scour during future floods, as depicted in the figure. Because of the large long-term scour depth, the bridge stability may be jeopardized in the long run.

Fig. 22. Sediment deposition in sediment basin forming a flat bed



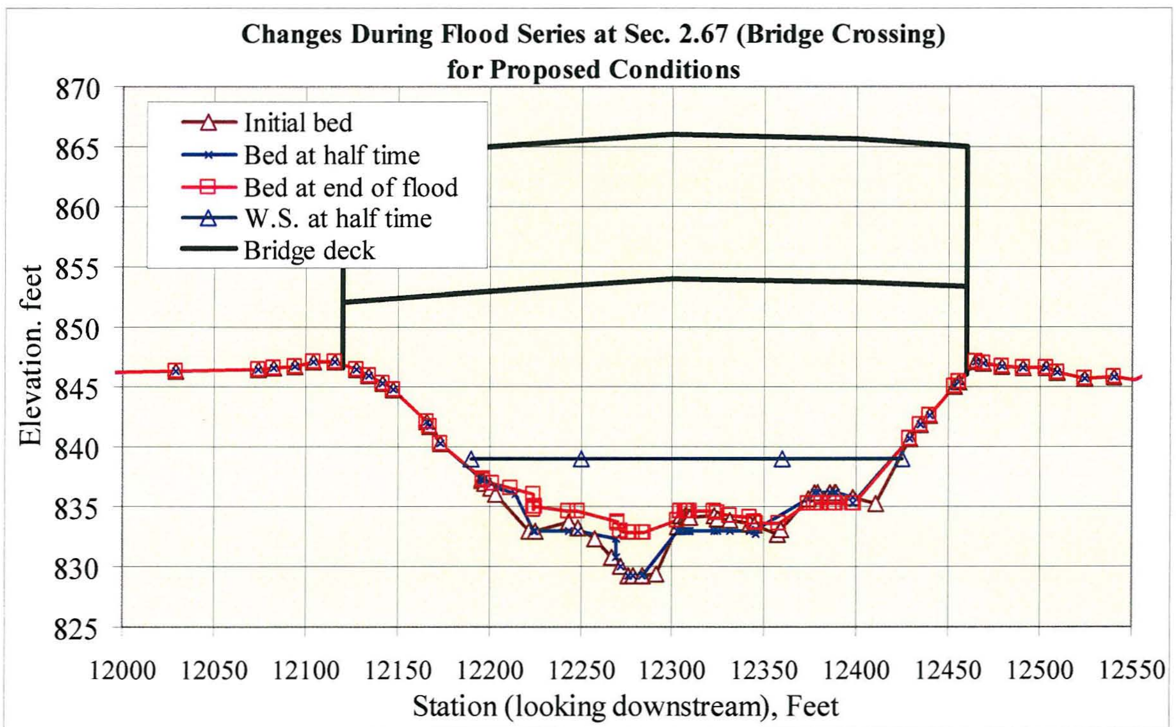
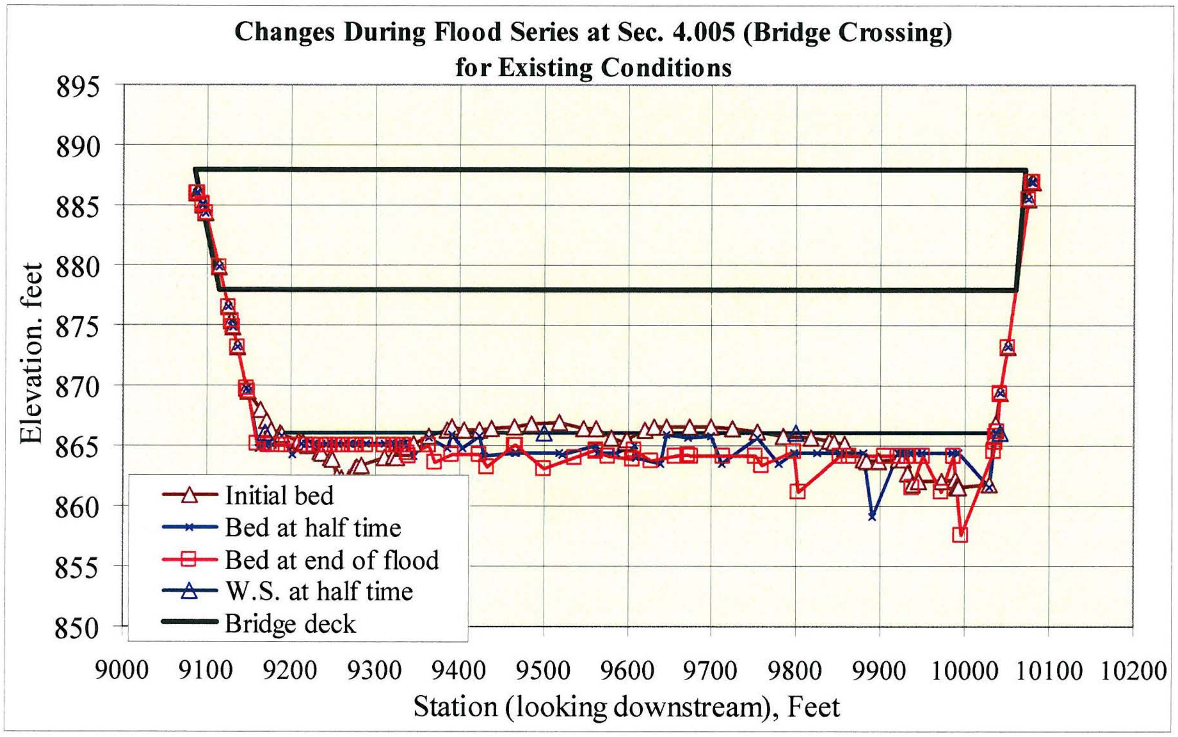


Fig. 23. Simulated channel bed scour at the U.S. 80 Bridge crossing during flood series for existing and proposed conditions



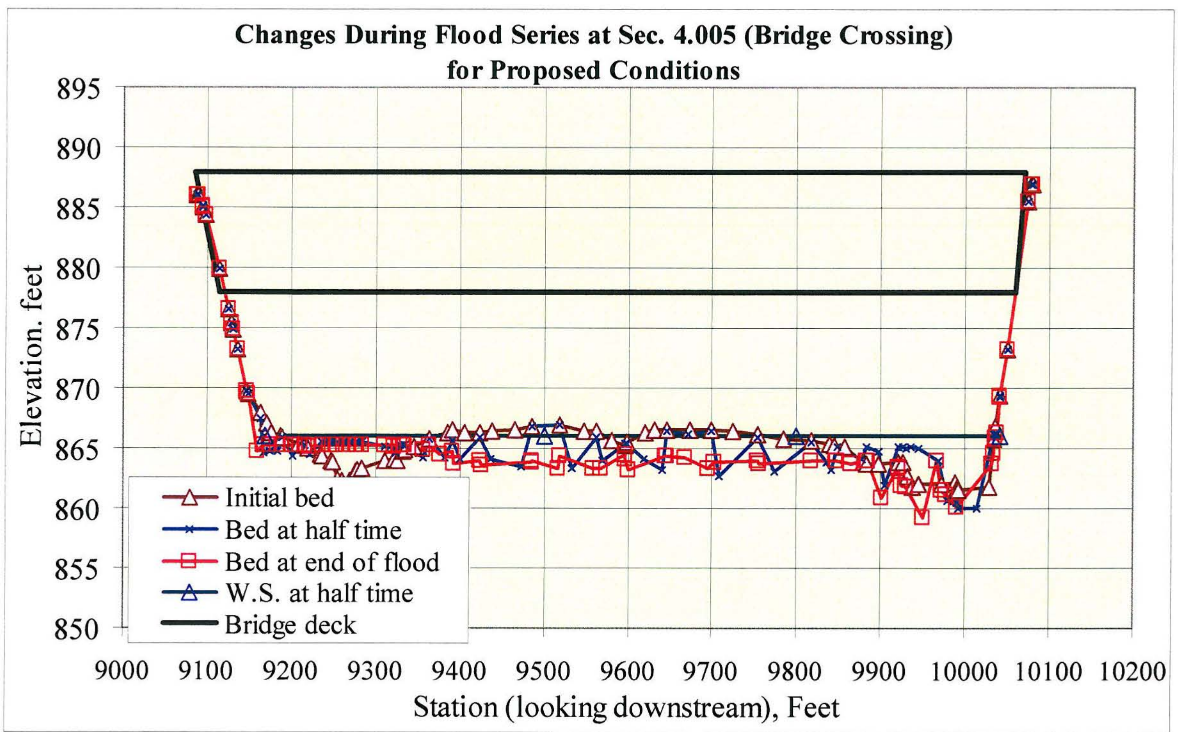
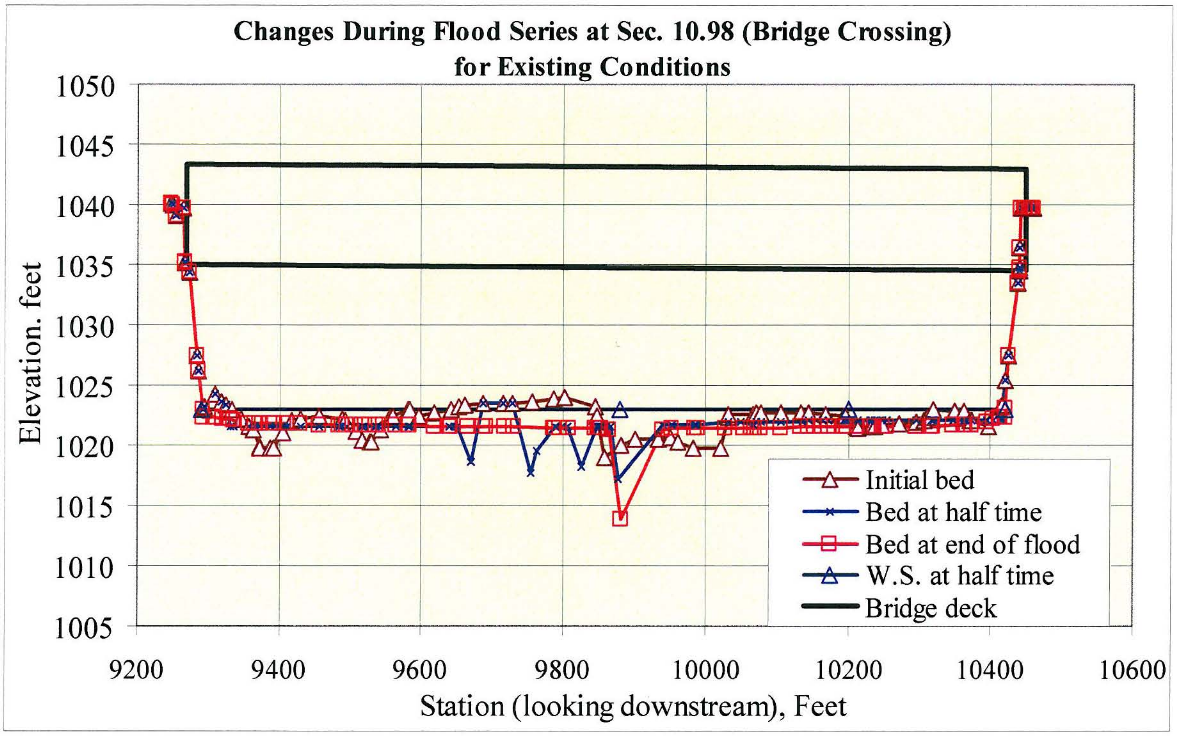


Fig. 24. Simulated channel bed scour at railroad bridge crossing during flood series for existing and proposed conditions



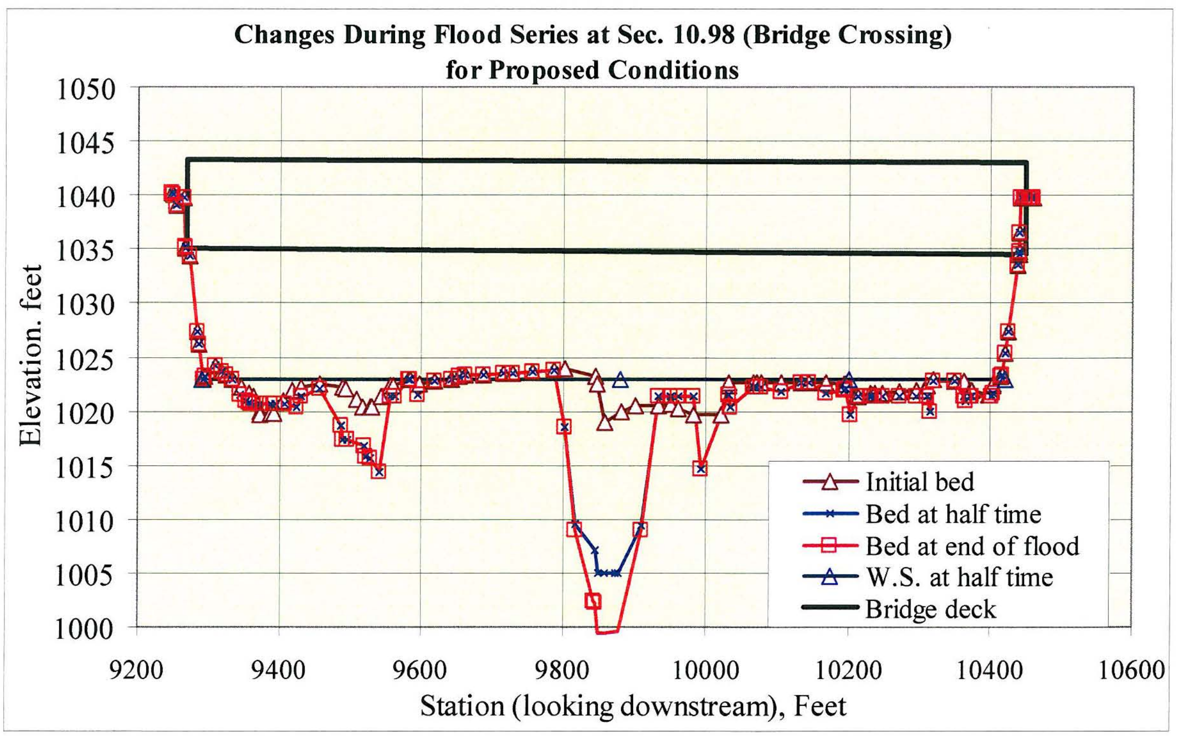


Fig. 25. Simulated channel bed scour at the I-10 Bridge crossing during flood series for existing and proposed conditions

REFERENCES

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.

Chang, H. H., *Fluvial Processes in River Engineering*, John Wiley & Sons, New York, NY, 1988, 432 pp.

Engelund, F. and Hansen, E., A Monograph on Sediment Transport in Alluvial Streams, Teknisk Vorlag, Copenhagen, Denmark, 1967.

JE Fuller, Hydrology and Geomorphology, Inc., "Lower Hassayampa River Watercourse Master Plan, river Behavior Report," prepared for Maricopa County Flood Control District, April 2006.

Vanoni, V., *Sedimentation Engineering*, ASCE Manual 54, 1975.

WEST Consultants, Final Hydraulics Report, Hassayampa River", prepared for JE Fuller, Hydrology and Geomorphology, Inc., February 2006

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 down-stream 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.
		$\pm$	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

APPENDIX B. SUMMARY OF BED ELEVATIONS REACHED BY SCOUR

Table 1. List of minimum bed elevations at end of events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
0.35	780.87	780.78	771.76	780.12
0.44	781.12	780.35	778.02	777.15
0.54	785.92	783.47	784.26	779.3
0.63	781.99	787.18	787.49	782.17
0.73	781.42	786.93	790.94	787.25
0.82	785.33	787.47	793.48	791.38
0.92	788.17	788.63	796.87	794.29
1.01	791.36	789.85	799.11	795.01
1.11	795.27	790.43	803.22	802.19
1.2	796.73	793.3	804.86	803.62
1.3	798.85	797.23	806.94	805.84
1.39	800.68	798.39	808.8	808.32
1.49	801.62	799.67	809.95	809.78
1.58	802.74	800.8	812.81	812.67
1.65	802.99	801.81	814.58	814.24
1.72	804.53	803.38	815.46	815.4
1.81	807.32	806.01	817.35	817.28
1.91	809.35	808.48	819.6	820.01
2	813.76	813.78	820.57	820.39
2.1	817.06	818.12	822.43	822.8
2.19	819.22	820.42	824.27	826.4
2.29	821.51	822.99	826.08	826.82
2.38	823.6	825.8	827.21	829.31
2.48	825.39	826.34	828.81	829.18
2.57	824.37	825.98	833.58	830.88
2.67	827.4	828.88	833.7	832.75
2.78	832.03	832.44	834.87	833.75
2.87	834.08	833.96	837.03	836.36
2.96	835.44	835.85	838.84	838.21
3.06	838.53	838.75	840.5	838.89
3.15	840.73	840.84	841.42	840.8
3.25	842.29	842.19	844.64	842.85
3.34	844.35	844.56	845.86	843.92
3.44	845.81	845.95	847.45	847.57
3.53	850.31	850.7	848.19	849.02
3.63	853.18	853.53	850.18	849.8
3.72	854.34	854.71	852.44	852.62
3.81	856.55	857.08	855.04	854.45
3.91	857.85	858.33	856.31	856.75

Table 1 (contnued). List of minimum bed elevations at end of events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
4.01	861.12	860.74	859.72	859.29
4.09	861.85	862.64	861.77	861.48
4.15	861.13	860.14	863.62	863.14
4.25	864.39	864.14	865.91	865.73
4.34	868.09	868.16	868.11	867.67
4.44	870.96	870.77	870.06	868.86
4.53	874.83	874.63	872.2	870.89
4.63	875.26	874.95	874.44	872.39
4.72	875.6	875.13	876.41	876.6
4.82	878.84	878.46	878.74	878.67
4.91	882.02	882	881.21	881.05
5	885.18	883.26	884.39	882.65
5.1	885.66	884.67	885.25	884.68
5.19	888.5	886.13	886.83	885.59
5.29	890.37	887.61	888.29	887.49
5.38	892.4	888.67	889.23	888.64
5.48	894.67	888.95	892.69	893.58
5.57	896.47	888.24	893.73	894.45
5.67	897.91	896.15	895.6	895.89
5.76	899.81	898.8	897.87	897.04
5.86	903.28	900.42	899.45	898.52
5.95	904.15	900.21	903.52	901.3
6.05	904.41	901.13	905.25	902.89
6.14	906.69	901.45	906.49	904.08
6.23	909.58	902.7	910.09	906.94
6.33	911.28	905.09	912.17	909.57
6.42	913.99	907.39	913.54	912.42
6.52	917.32	909.37	917.35	913.81
6.61	918.8	912.11	919.5	916.53
6.71	919.81	912.38	921.33	917.56
6.8	920.13	917.25	922.57	918.98
6.9	926.68	921.78	925.59	921.6
6.99	929.18	927.57	926.58	924.07
7.09	930.65	928.38	927.61	925.71
7.18	933.15	931.92	932.12	927.71
7.28	935.11	933.28	934.39	928.57
7.37	936.78	933.47	936.26	931.07
7.47	940.15	935.84	937.87	933.61
7.56	940.5	937.51	941.09	936.88
7.66	941.57	941.17	942.94	938.48

Table 1 (continued). List of minimum bed elevations at end of events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
7.75	944.62	943.18	945.44	939.83
7.84	948.89	942.31	947.72	942.45
7.94	949.52	944.67	949.06	943.6
8.03	953.15	945.37	951.47	945.64
8.13	954.97	950.71	953.98	946.64
8.22	956.24	950.53	955.97	949.01
8.32	957.74	951.61	959.42	951.4
8.41	960.37	954.35	961.66	953.7
8.51	961.42	954.95	962.39	956.06
8.6	964.92	956.72	963.74	958.21
8.7	966.96	960.46	964.93	959.94
8.79	968.87	962.62	967.52	961.76
8.89	970.19	965.35	968.83	963.68
8.98	972.15	967.83	971.25	965.25
9.08	974.67	970.92	973.52	966.73
9.17	976.66	973.38	974.87	968.39
9.27	978.97	974.99	977.53	970.38
9.36	981.22	979.66	979.77	972.25
9.45	984.3	982.09	981.41	973.83
9.55	986.97	987.28	983.41	975.8
9.64	989.71	988.77	985.81	977.58
9.74	990.18	990.25	987.94	979.58
9.83	991.87	992.08	989.68	981.38
9.93	993.4	993.79	992.51	983.15
10.02	995.18	995.53	995.19	985.18
10.12	998.6	999.05	996.55	987.39
10.21	1002.7	997.26	998.45	988.75
10.31	1003.67	1003.01	1000.84	990.56
10.4	999.6	998.03	1003.2	991.16
10.5	1006.79	1006.8	1004.47	992.22
10.59	1009.94	1009.71	1008.32	993.46
10.69	1011.37	1011.86	1009.38	994.61
10.73	1012.92	1012.79	1013.07	994.57
10.77	1013.32	1013.05	1013.13	996.18
10.87	1015.06	1014.87	1014.54	997.82
10.98	1015.16	1015.15	1015.94	999.46
11.01	1018.7	1017.93	1016.98	999.76
11.09	1018.77	1018.74	1018.71	999.43
11.16	1021.85	1021.7	1019.98	1001.26
11.24	1022.83	1022.82	1021.12	1002.68

Table 1 (contnued). List of minimum bed elevations at end of events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
11.33	1025.45	1025.3	1024.02	1003.16
11.43	1027.41	1027.61	1026.84	1002.36
11.52	1029.27	1028.52	1028.86	1004.25
11.62	1032.22	1031.44	1031.38	1006.48
11.71	1031.86	1031.24	1033.44	1008.1
11.81	1035.47	1033.95	1035.41	1010.04
11.9	1038.29	1036.14	1037.12	1011.45
12	1040.71	1035.92	1039.85	1014.98
12.09	1040.49	1039.78	1040.98	1018.02
12.18	1043.45	1041.46	1043.29	1021.04
12.28	1042.08	1043.34	1046.12	1023.24
12.37	1044.55	1043.22	1048.28	1026.52
12.47	1046.19	1035.63	1050.82	1028.97
12.56	1043.62	1043.41	1053.37	1031.71
12.66	1053.14	1040.63	1055.88	1034.09
12.75	1048.59	1046.87	1058.3	1036.64
12.85	1052.82	1047.69	1060.03	1039.53
12.94	1055.84	1049.18	1063.14	1041.44
13.04	1060.63	1051.41	1065.45	1045.13
13.13	1060.15	1050.96	1067.47	1047.47
13.23	1062.84	1057.94	1070.32	1050.38
13.32	1068.39	1058.8	1072.04	1051.9
13.42	1069.59	1061.03	1073.44	1054.39
13.51	1071.95	1062.58	1075.13	1056.43
13.61	1074.59	1062.46	1077.78	1059.1
13.7	1075.46	1066.16	1080.44	1061.73
13.79	1079.37	1066.57	1082.64	1063.92
13.89	1080.52	1066.28	1084.5	1066.25
13.98	1086.73	1069.31	1086.7	1067.67
14.08	1090.33	1070.84	1088.92	1068.05
14.17	1091.64	1071.34	1089.83	1070.95
14.27	1094.01	1077.08	1092.44	1071.78
14.36	1096.23	1076.97	1092.13	1074.65
14.45	1097.39	1078.18	1095.11	1074.4
14.55	1099.65	1078.73	1096.28	1076.82
14.64	1100.62	1083	1099.84	1077.39
14.73	1103.33	1083.82	1102.04	1081.79
14.83	1104.69	1088	1102.97	1084.33
14.92	1106.86	1090.24	1104.11	1087.82
15.02	1108.49	1090.38	1105.22	1090.35

Table 1 (contnued). List of minimum bed elevations at end of events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
15.11	1109.94	1094.25	1105.95	1093.32
15.21	1111.62	1094.55	1109.61	1095.12
15.3	1115.31	1096.82	1114.2	1097.31
15.4	1116.94	1100.31	1115.04	1098.8
15.49	1118.4	1102.06	1117.26	1102.65
15.59	1122.35	1105.09	1119.85	1105.86
15.68	1124.5	1109.92	1120.64	1107.72
15.78	1125.72	1109.54	1123.67	1108.89
15.87	1127.56	1113.64	1125.64	1110.13
15.97	1128.95	1115.94	1127.06	1111.14
16.06	1130.52	1118.36	1129.42	1111.63
16.16	1133.49	1119.54	1130.99	1110.44
16.25	1134.52	1123.42	1133.09	1115.72
16.35	1136.26	1125.32	1135.52	1118.36
16.44	1138.84	1128.86	1137.22	1121.48
16.53	1139.84	1131.39	1139.12	1123.73
16.63	1141.69	1133.88	1140.22	1125.8
16.72	1143.93	1136.63	1142	1128.09
16.82	1144.05	1138.09	1144.08	1130.44
16.91	1145.86	1139.74	1145.79	1132.82
17.01	1146.89	1143.01	1147.21	1135.09
17.1	1149.7	1146.31	1150.77	1137.29
17.2	1151.98	1151	1152.49	1139.41
17.29	1156.89	1155.75	1154.07	1141.47
17.39	1157.79	1159.12	1156.97	1143.64
17.48	1159.92	1161.25	1158.26	1145.55
17.58	1161.57	1162.85	1159.83	1147.64
17.67	1164.65	1164.78	1161.89	1149.45
17.77	1166.59	1166.53	1163.9	1151.63
17.86	1169.1	1169.04	1165.15	1153.4
17.95	1170.59	1170.54	1167.74	1155.44
18.05	1171.86	1171.79	1169.78	1157.25
18.14	1174.22	1174.12	1171.51	1159.23
18.24	1176.87	1176.76	1172.89	1161.28
18.33	1178.55	1178.64	1175.22	1163.57
18.43	1181.64	1181.56	1177.63	1166.1
18.52	1183.62	1183.58	1180.65	1168.36
18.62	1184.14	1183.5	1181.92	1169.88
18.71	1187.62	1187.43	1181.88	1172.45
18.81	1188.48	1187.86	1186.41	1174.45

Table 1 (contnued). List of minimum bed elevations at end of events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
18.9	1189.11	1188.95	1188.65	1177.25
19	1193.87	1193.74	1190.17	1179.86
19.09	1196.47	1196.43	1191.19	1181.72
19.19	1199.35	1199.38	1193.1	1183.84
19.28	1200.51	1200.51	1195.55	1185.64
19.38	1201.2	1200.98	1197.6	1188.05
19.47	1204.28	1204.31	1199.3	1190.41
19.56	1206.23	1206.36	1201.24	1192.29
19.66	1209	1208.97	1202.47	1193.86
19.75	1210.65	1210.57	1204.82	1197.26
19.85	1211.02	1211	1207.3	1199.57
19.94	1212.46	1212.66	1209.42	1202.07
20.14	1215.29	1215.38	1211.42	1204.01
20.23	1216.81	1217.15	1213.81	1206.54
20.3	1218.7	1218.82	1214.97	1208.66
20.32	1222.18	1222.22	1216.82	1210.82
20.42	1224.4	1224.07	1219.79	1213.34
20.51	1226.32	1226.3	1221.74	1215.85
20.61	1228.41	1228.38	1222.89	1217.37
20.7	1229.3	1229.58	1225.29	1219.83
20.8	1228.92	1228.97	1227.48	1222.91
20.89	1235.15	1235.18	1228.93	1225.62
20.98	1233.75	1233.89	1232.37	1227.35
21.08	1239.57	1239.6	1234.96	1229.46
21.17	1241.73	1241.76	1237.25	1231.39
21.27	1243.15	1243.23	1238.49	1233.52
21.36	1246.21	1246.28	1241.14	1236.1
21.46	1246.94	1246.64	1243.29	1238.37
21.55	1247.41	1246.93	1244.99	1240.75
21.65	1250.24	1250.29	1247.52	1242.04
21.74	1251.53	1251.38	1249.32	1244.34
21.84	1255.16	1255.23	1250.86	1246.27
21.93	1256.35	1256.36	1252.57	1247.91
22.03	1258.42	1258.56	1255.76	1250.65
22.12	1260.89	1260.98	1257.29	1253.29
22.21	1264.01	1263.98	1259.46	1256.17
22.31	1265.56	1265.44	1262.74	1260.17
22.4	1267.58	1267.39	1264.56	1261.84
22.5	1269.65	1269.36	1266.23	1264.49
22.59	1270.75	1270.87	1269.13	1267.01

Table 1 (contnued). List of minimum bed elevations at end of events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
22.69	1273.75	1273.55	1271.72	1268.19
22.78	1275.44	1274.35	1274.45	1269.23
22.88	1278.37	1278.39	1277.22	1272.15
22.97	1280.3	1280.4	1279.21	1275.09
23.07	1281.68	1281.69	1280.95	1277.42
23.16	1281.45	1281.57	1283.2	1279.69
23.26	1282.4	1282.13	1284.43	1280.54
23.35	1285.46	1285.55	1288.22	1284.28
23.45	1284.76	1284.98	1290.38	1286.22
23.54	1287.18	1287.28	1292.03	1288.8
23.63	1290.87	1290.85	1292.87	1289.46
23.73	1294.58	1294.57	1295.25	1290.26
23.82	1296.66	1296.7	1296.26	1293.19
23.92	1298.22	1298.02	1298.01	1295.44
24.01	1300.46	1300.44	1299.98	1297.56
24.11	1298.76	1299.64	1302.65	1298.57
24.2	1302.46	1303.63	1306.1	1298.86
24.3	1307.7	1307.39	1307.68	1304.86
24.39	1310.93	1310.99	1308.81	1307.72
24.49	1313.46	1313.5	1311.39	1308.86
24.58	1316.35	1316.37	1313.84	1310.59
24.68	1316.48	1316.46	1316.6	1313.6
24.77	1320.69	1320.78	1317.82	1316.34
24.87	1321.82	1321.83	1320.56	1318.32
24.96	1323.36	1323.3	1324.06	1321.08
25.06	1326.71	1326.73	1324.64	1322.97
25.15	1327.53	1327.53	1328.05	1326.39
25.24	1330.71	1330.63	1329.02	1329.97
25.34	1332.17	1331.95	1330.82	1330.26
25.43	1333.9	1333.76	1332.51	1331.79
25.53	1336.19	1336.17	1334.39	1334.88
25.62	1336.72	1336.62	1337.66	1337.6
25.72	1344.54	1344.43	1340.22	1339.44
25.81	1345.07	1344.98	1341.82	1342.26
25.91	1344.96	1344.87	1344.51	1344.91
26	1345.05	1344.72	1346.27	1345.75
26.1	1347.39	1347.12	1348.59	1349.48
26.19	1349.73	1349.67	1351.23	1351.74
26.29	1352.48	1353.31	1354.78	1354.8
26.38	1357.22	1357.21	1357.33	1356.45

Table 1 (contnued). List of minimum bed elevations at end of events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
26.48	1359.15	1359.11	1357.84	1358.46
26.57	1361.7	1361.77	1362.65	1361.77
26.67	1362.33	1362.51	1365.15	1365.04
26.76	1366.94	1367.01	1368.32	1366.25
26.85	1369.18	1369.26	1370.49	1369.58
26.95	1369.04	1369.31	1371.78	1372.93
27.04	1373	1373.2	1374.4	1376.29
27.14	1373.3	1374.1	1377.4	1377.33
27.23	1379.04	1379.28	1378.6	1379.59
27.33	1380.08	1380.41	1381.4	1381.23
27.43	1379.88	1383.74	1383.53	1382.35
27.52	1382.77	1383.69	1385.96	1384.86
27.61	1387.4	1387.55	1388.12	1387.64
27.75	1391.52	1390.75	1392.04	1392.04
27.89	1395.5	1395.5	1395.5	1395.5

Table 2. List of bed elevations reached by maximum scour during events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
0.35	780.4	780.4	769.4	777
0.44	779.5	779.5	776.8	779.5
0.54	782.4	781	776.8	777.7
0.63	774.6	782	780.8	781.3
0.73	781	783	783.2	781
0.82	779.3	771.4	786.4	779.6
0.92	788.3	775.6	790.2	784.7
1.01	790.2	779.1	792.9	787.3
1.11	787.7	782.2	794.9	790
1.2	782.8	778.3	795.6	792.4
1.3	787.8	785	796.5	795
1.39	794.2	788.4	797.5	797.3
1.49	798	798	798.7	798.7
1.58	803.9	801.2	803.7	800.5
1.65	803.9	801.1	804.2	800.6
1.72	801.4	801.7	805.4	802.5
1.81	801.2	801.1	807.2	801.3
1.91	808.5	808	808.4	805.1
2	813.1	811.8	812.2	805.7
2.1	813.8	814.7	814.3	808.3
2.19	816.9	816.6	816.4	810.5
2.29	819.7	819.7	819.7	815.1
2.38	821.4	821.4	821.4	817.7
2.48	823.7	823.1	823.1	819.4
2.57	822.4	821.3	825.1	821.1
2.67	821.6	820.4	829	829
2.78	815.5	816.8	830	830.2
2.87	816.1	817.1	833.4	831.8
2.96	828.9	828.4	834.2	834.7
3.06	830.8	830.7	837.4	837.8
3.15	836.2	836.3	839.1	839
3.25	837.8	838.7	840.8	841.2
3.34	843.7	843.8	842.4	842.6
3.44	845	845.3	843.2	842.7
3.53	848.9	848.8	847.1	846.8
3.63	852.5	852.5	846	847.8
3.72	854.4	854.7	849.3	850.2
3.81	856.6	856.9	852.1	852.9
3.91	857.8	857.8	853.9	855.7
4.01	856.2	856.1	854.4	856.1

Table 2 (continued). List of bed elevations reached by maximum scour during events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
4.09	857.1	857	857.4	856.4
4.15	858	857.9	859.7	857.5
4.25	863.7	863.5	861.8	860.8
4.34	868.1	868.1	864.3	865
4.44	870.9	870.7	867.9	864.6
4.53	874.7	874.6	870	867.6
4.63	874.9	874.6	870.9	869.8
4.72	875.6	875.1	871.3	870.4
4.82	878	878.2	877.1	871
4.91	881.9	881.6	878.9	873.7
5	884.3	882.9	881.5	873.4
5.1	885.1	884.2	882.6	873.9
5.19	887	885.9	884.9	876.4
5.29	888.8	887	886.1	879.3
5.38	890.7	888.7	887.9	879.6
5.48	892.6	888.9	889.6	879.6
5.57	896.1	883	893.3	882.8
5.67	897.7	885.8	895	885.8
5.76	899.9	888.6	894.8	886.8
5.86	901.6	891.4	895.3	887.8
5.95	904.2	894.2	900.2	892.1
6.05	904.4	897	902.7	894.2
6.14	904.4	894.1	903.2	896.9
6.23	909.3	896.6	905.3	899.6
6.33	911.1	896.8	910.6	902.2
6.42	913.5	896.6	909.8	904.5
6.52	916.6	901.6	914.4	906.1
6.61	918	907.3	916.5	907.8
6.71	919.6	909.9	916	909.6
6.8	918.6	906.6	919.6	908.7
6.9	925.8	920.9	923.1	908.6
6.99	929	926.7	923.6	913.2
7.09	930.6	927.5	927.4	911.6
7.18	932.8	931.7	930.3	912.7
7.28	935.1	933.3	929.7	914.9
7.37	936.5	933.5	929.6	916.4
7.47	940.1	928	936.4	924.4
7.56	940.5	930.5	936.4	925.4
7.66	941.6	933	939.4	925.4
7.75	943.6	935	942.5	928.5

Table 2 (continued). List of bed elevations reached by maximum scour during events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
7.84	948.9	937	944.4	929.2
7.94	949.6	939	947.5	931.4
8.03	951.3	941	949.8	936.7
8.13	954.1	945	950.3	936.6
8.22	955.8	947	953	942.2
8.32	957.5	946.7	955.2	944.2
8.41	960.2	949.7	956.6	946.2
8.51	961.3	947.8	957.5	948.4
8.6	964.8	950.2	962	951.7
8.7	966.1	954.8	964.2	954.2
8.79	968	960.4	965.8	956.4
8.89	970	964	967.5	958.2
8.98	972	966.7	969.1	960.4
9.08	973.5	969.7	971	963
9.17	975.8	972.8	972.1	965.4
9.27	978.1	974.7	973	967.8
9.36	980.3	978.9	976.2	969.9
9.45	981.5	980.5	978.5	970.5
9.55	985.4	985.4	981	974.2
9.64	987.4	987.5	982.6	976.3
9.74	989.8	990	984.4	976.4
9.83	991.7	991.7	988	978.8
9.93	993.2	993.2	988.3	981.6
10.02	994.5	994.5	990.8	983.7
10.12	998.4	998.4	994.6	984.4
10.21	1001.7	1001.7	996.4	986.1
10.31	1003.3	1003.5	997.7	987.2
10.4	996.6	997.9	997.8	988.1
10.5	1006.4	1006.3	1001.5	988.7
10.59	1008.5	1008.1	1001.6	987.8
10.69	1009.9	1009.7	1004.6	990.2
10.73	1012.7	1012.6	1006.9	990.8
10.77	1012.8	1013.1	1007	991.8
10.87	1015	1014.8	1007.2	994.1
10.98	1015.5	1014.7	1009.2	996.3
11.01	1017.6	1016.8	1013.7	997.2
11.09	1018.1	1017.3	1016.7	998
11.16	1021.7	1021.4	1017.8	999.5
11.24	1023	1022.6	1018.9	1001.4
11.33	1025.3	1025.3	1020.2	1000.4

Table 2 (continued). List of bed elevations reached by maximum scour during events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
11.43	1027.3	1027.1	1022.1	997.9
11.52	1029	1029.1	1025.6	998.4
11.62	1031.5	1032.1	1027.8	1000.5
11.71	1031.6	1031.3	1029.6	1002.1
11.81	1035.4	1034	1031.2	1005.9
11.9	1038.1	1036.1	1032	1007.9
12	1040.4	1035.9	1034.2	1011.3
12.09	1040.5	1038	1035.2	1013
12.18	1042	1040	1035.3	1018.2
12.28	1042	1042.1	1034.3	1020.3
12.37	1043.2	1043.2	1035.2	1021.4
12.47	1026.7	1026.7	1026.7	1025.9
12.56	1033.7	1032.5	1030.9	1028.3
12.66	1020.3	1020.3	1020.3	1020.3
12.75	1024.9	1022	1024.9	1022
12.85	1043	1025.8	1037.7	1029.5
12.94	1043	1024.8	1040.3	1033.7
13.04	1049.1	1034	1041.7	1034
13.13	1054.7	1033.5	1047.6	1038.4
13.23	1049.1	1058	1052.8	1046
13.32	1061.4	1059	1055.9	1046.4
13.42	1058.9	1060.9	1050.4	1046.8
13.51	1061.6	1061.6	1057.4	1045.8
13.61	1061.3	1061.8	1058.3	1051.7
13.7	1073.9	1064.6	1060.1	1054.2
13.79	1080.1	1064.3	1067	1051.2
13.89	1080.7	1064.2	1071.2	1049.5
13.98	1086.8	1065.6	1073.9	1049.1
14.08	1090.1	1063	1077.9	1063
14.17	1091.7	1072.1	1080.4	1065.7
14.27	1094.1	1070	1081.4	1066.7
14.36	1095.4	1072.8	1084.3	1069
14.45	1096.8	1075.6	1085.6	1070.3
14.55	1099	1078.4	1088.9	1071.4
14.64	1100.8	1081.2	1090	1071.6
14.73	1101.7	1083.9	1090.9	1074
14.83	1103.4	1078	1091.3	1063.8
14.92	1105.6	1073	1096.1	1081.1
15.02	1107.5	1070.5	1097.1	1082.3
15.11	1110.3	1072.6	1092.8	1087.9

Table 2 (continued). List of bed elevations reached by maximum scour during events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
15.21	1111.7	1093.9	1101.8	1084.2
15.3	1114.7	1094.6	1104	1084.8
15.4	1116.8	1095	1107.6	1084.3
15.49	1118.2	1095	1110.1	1092.8
15.59	1122.2	1095	1112.3	1095
15.68	1123.9	1095.9	1113.6	1099.5
15.78	1125.7	1099.9	1116.5	1097
15.87	1127.4	1103.6	1118.6	1103.6
15.97	1128.8	1107.8	1121.1	1101.9
16.06	1130.2	1110.2	1122.4	1106.6
16.16	1133.6	1112.9	1125.1	1105
16.25	1134.6	1111	1126.9	1110.8
16.35	1136.1	1120.6	1129	1115.3
16.44	1138.9	1124.1	1131.4	1117
16.53	1138.7	1125.7	1133.1	1119.7
16.63	1141.5	1130.3	1134.3	1119.9
16.72	1143.5	1133.7	1136.7	1115.4
16.82	1139.6	1134.6	1139.3	1122.1
16.91	1145.8	1139.7	1141	1127.3
17.01	1147.2	1140.7	1142.6	1130.8
17.1	1148.6	1144.9	1146.2	1135
17.2	1151	1150.2	1147.7	1137.4
17.29	1156.8	1155.1	1149.5	1139
17.39	1156	1158.9	1150.9	1142.5
17.48	1159.7	1160.7	1152.7	1144.6
17.58	1161.5	1162.4	1155.4	1147.2
17.67	1164.6	1164.6	1157.3	1148.7
17.77	1166.3	1166.5	1159.3	1150.9
17.86	1168.9	1169	1161.7	1152.8
17.95	1169.9	1170	1163.9	1154.5
18.05	1171.8	1171.8	1166.2	1156.4
18.14	1173.9	1173.5	1168.3	1159.3
18.24	1176.9	1176.8	1170.7	1161.7
18.33	1178.4	1178.4	1172.3	1164.2
18.43	1180.9	1181	1174.7	1166.3
18.52	1182.2	1182	1177.1	1168.7
18.62	1183.9	1183.6	1178.5	1169.9
18.71	1187.4	1187.3	1178.9	1173
18.81	1188.5	1187.9	1183	1175.3
18.9	1189.3	1188.5	1183.9	1177.8

Table 2 (continued). List of bed elevations reached by maximum scour during events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
19	1193.8	1193.9	1187.9	1179.7
19.09	1196	1196	1189.4	1181.6
19.19	1198.7	1198.8	1190.5	1184.4
19.28	1199.6	1199.6	1193	1186.3
19.38	1200.8	1200.8	1195.9	1188.3
19.47	1203.3	1203.2	1197.2	1191
19.56	1206.4	1206.3	1199.8	1193.3
19.66	1207.9	1207.9	1201.5	1194.9
19.75	1208.6	1208.4	1204.1	1197.8
19.85	1210.5	1210.4	1204.6	1199.8
19.94	1212.3	1212.3	1208.5	1202
20.14	1215.2	1215.1	1208.7	1204.4
20.23	1217	1216.7	1211.1	1205.4
20.3	1218.7	1218.7	1214.2	1207
20.32	1222.2	1222	1216.1	1209.9
20.42	1223.9	1223.9	1217.4	1212.2
20.51	1225	1224.8	1220.3	1214.8
20.61	1228.2	1228.3	1222.6	1216.8
20.7	1229.3	1229.3	1223.1	1218.5
20.8	1228.8	1228.7	1226.3	1221.1
20.89	1235.1	1235.1	1226.7	1224.1
20.98	1233.4	1233.5	1230.7	1226.2
21.08	1239.5	1239.6	1229.3	1228.7
21.17	1241.7	1241.8	1232.7	1230.5
21.27	1243.1	1243.2	1238.1	1233
21.36	1246.2	1246.3	1239.6	1235.4
21.46	1246.3	1246.3	1241.3	1237.9
21.55	1246.8	1246.9	1244.2	1240.5
21.65	1250.2	1250.2	1245.1	1242.1
21.74	1250.3	1250.3	1247.7	1244.1
21.84	1255.1	1255.2	1249.4	1245.4
21.93	1256.2	1256.3	1251.1	1248.1
22.03	1257.6	1257.5	1253.7	1250.7
22.12	1260.7	1261	1255	1252.6
22.21	1263.4	1263.3	1257.8	1255.5
22.31	1264.2	1264.3	1260.5	1258.8
22.4	1267.1	1267	1261.8	1261
22.5	1268.1	1267.9	1263.2	1263.5
22.59	1270.6	1270.4	1266.5	1265.5
22.69	1273.6	1273.6	1268.4	1267.5

Table 2 (continued). List of bed elevations reached by maximum scour during events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
22.78	1275.1	1274.2	1270	1269.1
22.88	1277.8	1277.8	1272.7	1271.3
22.97	1280	1280.1	1273.7	1271.7
23.07	1281.1	1281.1	1277.2	1276.1
23.16	1281.7	1281.8	1279.8	1276.4
23.26	1279.6	1279.8	1281.8	1279.2
23.35	1285.2	1285.2	1283	1282
23.45	1284.5	1284.6	1285	1285.4
23.54	1287.3	1287.3	1287.5	1286.9
23.63	1291	1290.1	1290.1	1288.4
23.73	1294.7	1294.4	1291.4	1289.7
23.82	1296.5	1296.1	1294.4	1292.5
23.92	1298.1	1298	1296	1294.4
24.01	1300.3	1300.3	1298.8	1295.1
24.11	1296.6	1296.6	1298.9	1298.3
24.2	1302.3	1301.8	1300.7	1298.1
24.3	1306.7	1306.4	1301.4	1301.3
24.39	1310.5	1310.6	1304.9	1306.6
24.49	1312.9	1313.5	1310	1308.5
24.58	1315.8	1315.9	1309.9	1309.2
24.68	1316.1	1316.4	1313.8	1310
24.77	1320.7	1320.8	1316	1314.7
24.87	1321.7	1321.8	1317.6	1318
24.96	1323.1	1323.2	1319.4	1320.9
25.06	1326.6	1326.6	1322.1	1322.4
25.15	1327.5	1327.6	1323.6	1323.8
25.24	1318.9	1318.9	1318.9	1318.9
25.34	1329.5	1328.4	1327.2	1327.2
25.43	1332.6	1331.9	1330.3	1328.6
25.53	1336.2	1336.1	1332.7	1332.1
25.62	1336.5	1336.6	1335.4	1335.1
25.72	1343.9	1343.9	1337.7	1335.4
25.81	1345	1344.9	1340.1	1339.3
25.91	1344.6	1344.7	1341	1341.1
26	1344.9	1344.4	1342.6	1341.8
26.1	1346.8	1346.6	1343.9	1344.2
26.19	1349.8	1349.6	1346.5	1347.2
26.29	1352.3	1353.4	1349.6	1350.7
26.38	1357.1	1357.1	1353.9	1350
26.48	1358.8	1358.9	1355.9	1354.7

Table 2 (continued). List of bed elevations reached by maximum scour during events

Channel Station River miles	100-yr flood Existing Feet	100-yr flood Proposed Feet	Flood series Existing Feet	Flood series Proposed Feet
26.57	1360.7	1360.7	1356.4	1355.3
26.67	1362.4	1362.2	1360.1	1359.1
26.76	1367	1367.1	1361.2	1363.2
26.85	1368.4	1368.3	1365.4	1364.4
26.95	1368.9	1368.8	1366.5	1364.6
27.04	1373	1372.7	1370.6	1371.1
27.14	1367.8	1364.7	1370	1372.9
27.23	1376.9	1377.6	1375.3	1376
27.33	1379.6	1379.4	1377.5	1379.1
27.43	1379.4	1380.9	1379	1379.1
27.52	1378.4	1377.8	1379.4	1381.7
27.61	1383.8	1381.3	1385.8	1380.6
27.75	1385.6	1382	1387.9	1387.8
27.89	1395.5	1395.5	1395.5	1395.5

Flood Control District
of Maricopa County

MEMORANDUM

Date: May 13, 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: Final Report for the Fluvial-12 Modeling of Sand Mining Impacts for the Lower Hassayampa 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 (and digital copy) to these comments to the FCD. Comments, which have been resolved, have been shown in a gray font. All comments have now been resolved.

1) **FCD Comment (April 17, 2009):** On page 13, could the first paragraph be revised so that it is in better agreement with the FCDMC's methodology to estimate total scour? Please consider modifying this paragraph based on the following paragraph (shown below) or adding the following paragraph below the first paragraph on page 13:

   In Maricopa County, the stream channel scour is generally estimated as the sum of several scour components, which are long-term scour, general scour, bend scour, bed form scour, low flow incisement, and local scour. A sediment transport simulation can be used to estimate the long-term scour component when the input flow hydrograph is from a long-term historical flood series. The general scour can be estimated by either a sediment transport model or empirical equations (such as Lacey, Blench or Neill equations). When a sediment transport simulation is used to calculate the general scour, the input flow hydrograph is normally the 100-year flood hydrograph. The higher value of the general scour, which was calculated from the sediment transport simulation or the empirical equations, is then selected as the final general scour. The bend scour can be computed by some empirical equations. The bed form scour is calculated from either the antidune or dune equations. Low flow incisement is usually based on field estimates; but when those are not available, a value between 1 to 2 feet is selected. Local scour can be due to bridge piers, bridge abutments, bridge guide banks, culvert outlets, or grade control/drop structures.

Chang Consultants Response (April 22, 2009): Revised as: In Maricopa County, the stream channel scour is generally estimated as the sum of several scour components, which are long-term scour, general scour, bend scour, bed form scour, low flow incisement, and local scour. The long-term scour, general scour, bend scour can be simulated based on the flow and sediment transport in FLUVIAL-12. Normally, the long-term scour is simulated using a long-term flood series. The general scour may be simulated using the 100-yr flood, or estimated by either a sediment transport model or empirical equations (such as Lacey, Blench or Neill equations). The higher value of the general scour, which was calculated from the sediment transport simulation or the empirical equations, is then selected as the final general scour. The bend scour can be computed by some empirical equations, or it can also be simulated together with other scour components by the FLUVIAL-12 model. The bed form scour is calculated from either the antidune or dune equations. Low flow incisement is usually based on field estimates; but when those are not available, a value between 1 to 2 feet is selected. Local scour can be due to bridge piers, bridge abutments, bridge guide banks, culvert outlets, or grade control/drop structures

FCD Response (April 29, 2009): The paragraph has been revised. Comment resolved.

2) FCD Comment (April 17, 2009): Please consider revising the last two paragraphs on page 44. The following are suggested revisions:

The most important hydraulic structures along the Lower Hassayampa River are the three bridges. Potential channel bed scour (long-term scour) at these bridge crossings have been simulated for the existing conditions as well as for the proposed conditions, based on the long flood series that has greater impacts on scour. Figs. 23, 24, and 25 show the simulated long term channel bed scour at three bridge crossings for the existing conditions and the proposed conditions. For all bridge crossings, there will be greater long-term channel bed scour for the proposed conditions than for the existing conditions.

The U.S. 80 Bridge crossing at river mile 2.67 is subject to limited long-term channel bed scour that is not a threat to bridge stability. The railroad bridge crossing at river mile 4.005 is subject to scour, with a simulated maximum long-term scour depth of about 10 feet. The I-10 Bridge located between river miles 10.98 and 11.01 is along a river reach between major mining sites. The modeling results show that this bridge crossing is subject to major long-term scour during future floods, as depicted in the figure. Because of the large long-term scour depth, the bridge stability may be jeopardized in the long run.

Chang Consultants Response (April 22, 2009): The two paragraphs on page 44 have been modified in accordance to the suggested wording.

FCD Response (April 29, 2009): The paragraphs have been modified. Comment resolved.

3) **FCD Comment (April 17, 2009):** For the final report, a DVD with all the data (which were used in the study) should be provided. Some examples of this data would be input/output files, mine plan sheets, etc.

Chang Consultants Response (April 22, 2009): A CD with the required files will be submitted.

FCD Response (April 29, 2009): A CD has been provided. Comment resolved.

4) **FCD Comment (April 17, 2009):** A table, which shows the sediment data used to develop the Fluvial-12 input files, and a discussion about the sediment data should be included in the report. These items could be added to Section H of the report.

Chang Consultants Response (April 22, 2009): The following section has been added to Section F.

Sediment Data – Sediment data used in the study were taken from previous studies on the Hassayampa River. Such studies include the following:

JE Fuller, Hydrology and Geomorphology, Inc., "Lower Hassayampa River Watercourse Master Plan, river Behavior Report," prepared for Maricopa County Flood Control District, April 2006.

WEST Consultants, Final Hydraulics Report, Hassayampa River", prepared for JE Fuller, Hydrology and Geomorphology, Inc., February 2006

WEST Consultants, Final Hydraulics Report, Hassayampa River (II)", Volume 3, prepared for JE Fuller, Hydrology and Geomorphology, Inc., February 2006

Grain size distributions of bed sediment are based on the available data. However, the upstream sediment inflow for the FLUVIAL-12 study was computed using the channel geometry, sediment gradation and flow characteristics of the upstream most cross section at teach time step.

FCD Response (April 29, 2009): A sediment data section has been added. However, West's "Final Hydraulics Report" does not contain the sediment data. Therefore, these two references do not need to be shown in the sediment data section. Also, the last WEST reference can be removed (from the References section) since both WEST references refer to the Final Hydraulics Report.

Chang Consultants Response (May 5, 2009): The following too references by WEST consultants have been deleted from Section II.

WEST Consultants, Final Hydraulics Report, Hassayampa River", prepared for JE Fuller, Hydrology and Geomorphology, Inc., February 2006

WEST Consultants, Final Hydraulics Report, Hassayampa River (II)", Volume 3, prepared for JE Fuller, Hydrology and Geomorphology, Inc., February 2006

Also, the last WEST reference has been removed from the References section.

FCD Response (May 13, 2009): The modifications have been made. Comment resolved.

5) **FCD Comment (April 17, 2009):** Some figures are continued on multiple pages with Figures 14 and 19 being two examples. Would it be clearer to split these figures into separate ones?

Chang Consultants Response (April 22, 2009): There are two ways to treat this problem, either to split a figure into multiple parts or to keep them together. In this case, these figures were kept together as one number because each figure pertains to one channel reach of the same river channel for the same conditions. There are for different reaches within the same river channel and for the same conditions.

FCD Response (April 29, 2009): This comment is deferred to the author. However, to remain consistent with the other figures, Figure 19 on page 38 should have "(continued)" in the title.

Chang Consultants Response (May 5, 2009): Figure 19 on the second sheet has been changed into Fig. 19 (continued).

FCD Response (May 13, 2009): On page 38, Figure 19 now has the additional text. Comment resolved.

6) **FCD Comment (April 17, 2009):** In the second paragraph on page 6, there is a sentence fragment, which begins "With existing and future…" that should be removed.

Chang Consultants Response (April 22, 2009): Revised as: With existing and future bridges and sand/gravel mining activities, it is important to know the potential impacts, both short term and long term, of such human activities.

FCD Response (April 29, 2009): The sentence has been revised. Comment resolved.

7) **FCD Comment (April 17, 2009):** On page 11, the flood series is said to have a time duration of 68 years. However, this sentence could be confusing. Could the report be clarified to indicate that the flood series was developed with gage data that spanned 68 years, but the actual flows, which were used in the modeling, only have a duration of around 4680 hours?

Chang Consultants Response (April 22, 2009): Revised as: In the modeling study, the 100-yr flood is used to evaluate the river channel responses to the mining activities. In addition, the long term mining impacts are evaluated using a flood series from the U. S. G. S. stream gage records for the time period from 1937 to 2004 (see Fig. 4). The flood series was developed with gage data that spanned 68 years, but the actual flows, which were used in the modeling, only have duration of around 4,680 hours.

FCD Response (April 29, 2009): This section has been revised. Comment resolved.

8) **FCD Comment (April 17, 2009):** In the first sentence on page 13, it is indicated that stream channel scour is comprised of only general scour and local scour. Could this sentence be revised to indicate that there are other types of scour, such as long-term scour, bedform scour, and low-flow incisement?

Chang Consultants Response (April 22, 2009): Revised as: In Maricopa County, the stream channel scour is generally estimated as the sum of several scour components, which are long-term scour, general scour, bend scour, bed form scour, low flow incisement, and local scour. The long-term scour, general scour, bend scour can be simulated based on the flow and sediment transport in FLUVIAL-12. Normally, the long-term scour is simulated using a long-term flood series. The general scour may be simulated using the 100-yr flood, or estimated by either a sediment transport model or empirical equations (such as Lacey, Blench or Neill equations). The higher value of the general scour, which was calculated from the sediment transport simulation or the empirical equations, is then selected as the final general scour. The bend scour can be computed by some empirical equations, or it can also be simulated together with other scour components by the FLUVIAL-12 model. The bed form scour is calculated from either the antidune or dune equations. Low flow incisement is usually based on field estimates; but when those are not available, a value between 1 to 2 feet is selected. Local scour can be due to bridge piers, bridge abutments, bridge guide banks, culvert outlets, or grade control/drop structures.

FCD Response (April 29, 2009): The section has been revised. Comment resolved.

9) **FCD Comment (April 17, 2009):** The second full sentence at the top of page 17 is unclear. Could this sentence be revised to clarify its meaning?

Chang Consultants Response (April 22, 2009): Revised as: 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.

FCD Response (April 29, 2009): The initial comment was referring to the following sentence:

Channel reaches with net sediment storage or depletion may be designated on the basis of the gradient.

Could this sentence be clarified? What does it mean by "on the basis of the gradient?" Is the gradient the slope of the delivery function shown on the "Spatial Variations of Sediment Delivery" figure? What may the channel reaches be designated as? Does it mean designated as "aggrading or degrading"?

Please keep the revised wording for the sentence that was already revised.

Chang Consultants Response (May 5, 2009): Revised as: 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.

FCD Response (May 13, 2009): The paragraph has been revised. Comment resolved.

10) **FCD Comment (April 17, 2009):** In the figure title on page 25, "continued" appears unnecessary.

Chang Consultants Response (April 22, 2009): Revised as: Fig. 13. Water-surface and channel-bed profile changes during 100-yr flood for proposed conditions

FCD Response (April 29, 2009): The figure has been revised. Comment resolved.

11) **FCD Comment (April 17, 2009):** In the first sentence on page 28, it appears that the sentence should refer to equation 5, rather than equation 1.

Chang Consultants Response (April 22, 2009): Revised as: 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 as defined in Eq. 5.

FCD Response (April 29, 2009): The sentence has been revised. Comment resolved.

12) **FCD Comment (April 17, 2009):** On page 31, could Table 3 be completely shown on one page?

Chang Consultants Response (April 22, 2009): Changes have been made so that Table 3 is shown on one page.

FCD Response (April 29, 2009): The table has been shown on one page. Comment resolved.

13) **FCD Comment (April 17, 2009):** The last sentence on page 32 does not appear correct. The reach between river miles 7.37 to 8.22 shows deposition in Table 5, rather than a sediment loss.

Chang Consultants Response (April 22, 2009): Revised as: It can be seen that the channel reach between 7.37 to 8.22 river mile is predicted to have the largest amount of sediment gain (deposition) due to the mining projects.

FCD Response (April 29, 2009): The sentence has been corrected. However, could the sentence "On the other hand, channel reaches with mining sites are predicted to gain sediment storage" be removed? Also, at the end of this section, could a sentence, such as: "On the other hand, the channel reach between 15.87 and 26.38 is predicted to have the largest erosion.", be added?

Chang Consultants Response (May 5, 2009): Revised as: It can be seen that the channel reach between 7.37 to 8.22 river mile is predicted to have the largest amount of sediment gain due to the mining projects. On the other hand, the channel reach between 15.87 and 26.38 is predicted to have the largest erosion.

FCD Response (May 13, 2009): The sentence has been revised. Comment resolved.

14) **FCD Comment (April 17, 2009):** Figure 9 appears to have an erroneous data label. Also, Figure 4 appears to have erroneous symbols.

Chang Consultants Response (April 22, 2009): Figure 9 is revised as follows.

I am not clear about the erroneous symbols for Figure 4 shown below.

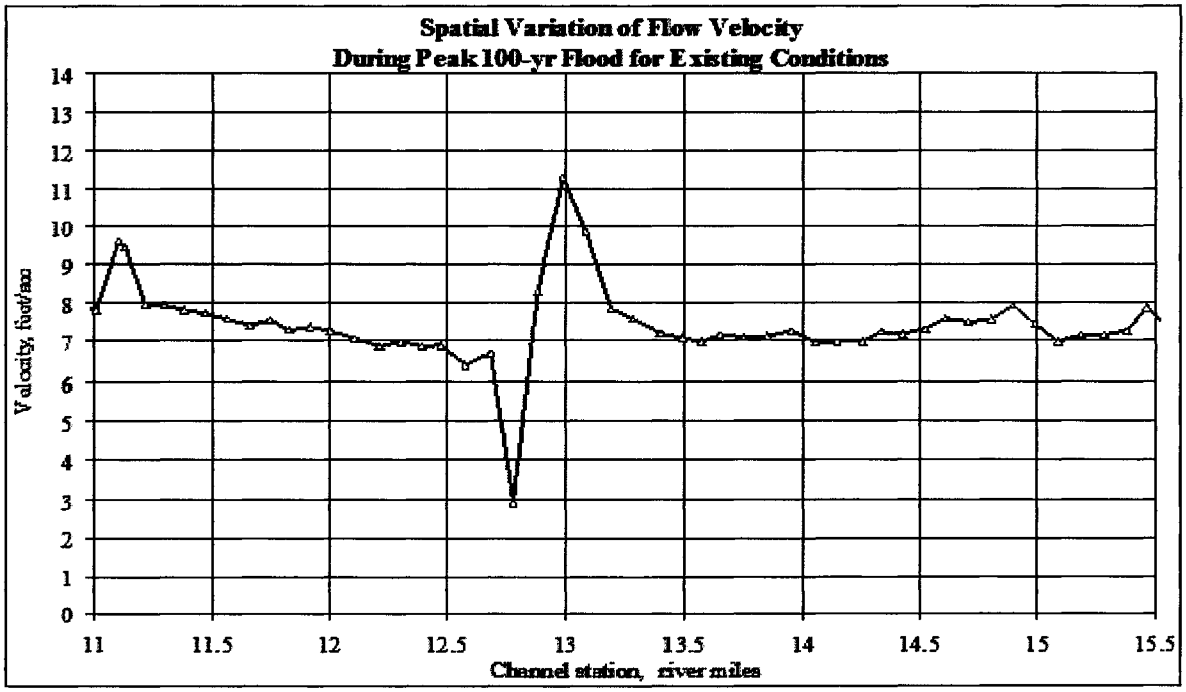


Fig. 9. Spatial variation of flow velocity at peak 100-yr flood along channel reach near existing mining area

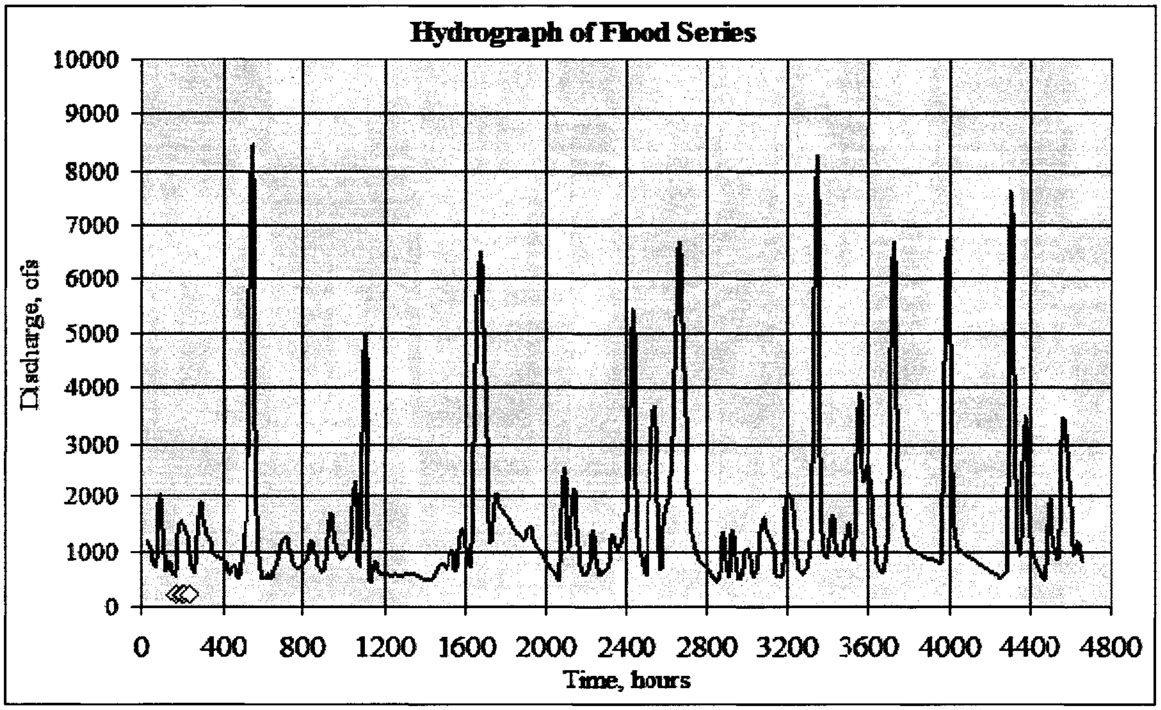


Fig. 4. Hydrograph of the flood series for the period of 1937 to 2004

FCD Response (April 29, 2009): Figure 9 has been revised. Figure 4 has been revised. Comment resolved.

15) **FCD Comment (April 17, 2009):** JE Fuller's "River Behavior Report" should be added to the references, since this report was the source of the HEC-6 model.

Chang Consultants Response (April 22, 2009): The following references are included in the report.

JE Fuller, Hydrology and Geomorphology, Inc., "Lower Hassayampa River Watercourse Master Plan, river Behavior Report," prepared for Maricopa County Flood Control District, April 2006.

WEST Consultants, Final Hydraulics Report, Hassayampa River", prepared for JE Fuller, Hydrology and Geomorphology, Inc., February 2006

West Consultants, Inc. "Final Hydraulics Report, Hassayampa River (II), Volume 3", Lower Hassayampa River Watercourse Master Plan, Prepared for JE Fuller/Hydrology & Geomorphology, Inc., February 2006.

FCD Response (April 29, 2009): The Fuller report has been added to the references. Comment resolved.

16) **FCD Comment (April 17, 2009):** Could a table, which shows the maximum scour at each cross-section for both the proposed and existing conditions, be prepared and added to the report? Similarly, could another table, which compares the scour at the end of the hydrograph for both the proposed and existing conditions, be prepared and added to the report?

Chang Consultants Response (April 22, 2009): The maximum scour includes the scour depths as well as cross-sectional profiles are given in the following files. These files are submitted as attachments to the report as stated in the table of contents.

ATTACHMENTS: The following FLVUIAL-12 files are attached to the report:
EXIST-100.OUT: Listings of input/output for the 100-yr flood and existing conditions
PROP-100.OUT: Listings of input/output for the 100-yr flood and proposed conditions
EXIST-S.OUT: Listings of input/output for the flood series and existing conditions
PROP-S.OUT: Listings of input/output for the flood series and proposed conditions
HASSAMAX-100E.DAT: Maximum scour profile for the 100-yr flood and existing conditions
HASSAMAX-100P.DAT: Maximum scour profile for the 100-yr flood and proposed conditions
HASSAMAX-SE.DAT: Maximum scour profile for the flood series and existing conditions
HASSAMAX-SP.DAT: Maximum scour profile for the flood series and existing conditions

FCD Response (April 29, 2009): The listed files are included on the CD. However, there are a total of 14 files contained on the CD. Please list all 14 files in the attachment list and provide a description of each file. A screen capture of the provided files is shown below (the files listed as ESRI files are the .out files):

EXIST-100	ESRI Print Document
EXIST-100	Text Document
EXIST-S	ESRI Print Document
EXIST-S	Text Document
HASSA	FLU File
HASSAMAX-100E	DAT File
HASSAMAX-100P	DAT File
HASSAMAX-SE	DAT File
HASSAMAX-SP	DAT File
HASSAP	FLU File
PROP-100	ESRI Print Document
PROP-100	Text Document
PROP-S	ESRI Print Document
PROP-S	Text Document

Also, it would be useful to see a table, which shows the maximum scour at each cross-section for both the proposed and existing conditions, and another table, which compares the scour at the end of the hydrograph for both the proposed and existing conditions. Perhaps these tables can be added to an appendix (Appendix C) of the report. Similarly, if the comments/responses are attached to the report, please separate them into Appendix B and list this Appendix in the Table of Contents.

Chang Consultants Response (May 5, 2009): Revised as: The listed files are included on the CD. There are a total of 14 files contained on the CD. (The files listed as ESRI files are the .out files):

EXIST-100.OUT: Listings of input/output for the 100-yr flood and existing conditions
ESRI Print document

EXIST-100.TXT: Listings of input/output for the 100-yr flood and existing conditions
TEXT document

PROP-100.OUT: Listings of input/output for the 100-yr flood and proposed conditions
ESRI Print document

PROP-100.TXT: Listings of input/output for the 100-yr flood and proposed conditions
TEXT document

EXIST-S.OUT: Listings of input/output for the flood series and existing conditions
ESRI Print document

EXIST-S.OUT: Listings of input/output for the flood series and existing conditions
TEXT document

PROP-S.OUT: Listings of input/output for the flood series and proposed conditions
ESRI Print document

PROP-S.OUT: Listings of input/output for the flood series and proposed conditions
TEXT document

HASSAMAX-100E.DAT: Maximum scour profile for the 100-yr flood and existing conditions
DAT File

HASSAMAX-100P.DAT: Maximum scour profile for the 100-yr flood and proposed conditions
DAT File

HASSAMAX-SE.DAT: Maximum scour profile for the flood series and existing conditions
DAT File

HASSAMAX-SP.DAT: Maximum scour profile for the flood series and existing conditions
DAT file
HASSA.FLU: Input file for existing conditions of Hassayampa River
FLU File
HASSA.FLU: Input file for proposed conditions of Hassayampa River
FLU File

Two tables have been added to Appendix B. Table 1 lists the minimum bed elevations for all channel cross sections at the end of flood events for the following four cases, (1) existing channel conditions and the 100-yr flood, (2) proposed conditions of channel and the 100-yr flood, (3) existing channel conditions and the flood series, and (4) proposed channel conditions and the flood series.

Table 2 lists the maximum scour at each cross-section for the proposed and existing conditions as well as the 100-yr flood and the flood series.

Comments/responses are not included in the report.

FCD Response (May 13, 2009): The CD contains all the files. The files have been listed in the Table of Contents, and the Tables have been added to Appendix B. However, as a note, there is one EXIST-S.OUT file and one EXIST-S.TXT (on the CD). However, the attachments list in the Table of Contents shows two EXIST-S.OUT files. Similarly, there are two PROP-S.OUT files in the attachment list in the Table of Contents, while there is actually one PROP-S.OUT file and one PROP-S.TXT file on the CD. However, this issue is minor and does not affect the content of the report. Comment resolved.

17) **FCD Comment (April 17, 2009):** On page 44, there is a discussion regarding the scour at the three bridges. Were the three bridge pier/decks included in the four Fluvial-12 models? The BT or SB cards could not be located inside the models. Also, the discussion mentions the scour for long flood series. Was the general scour (from the 100-year flood) also calculated?

Chang Consultants Response (April 22, 2009): At the three bridge crossings, the bridge decks are above the calculated flood level; therefore, they do no affect the flood flow. The bridge abutments are treated as bank protections. The flow resistance due to bridge piers for each case is very small; their effects are considered by the channel roughness coefficients.

The scour presented in the report pertains to long-terms scour during the long-term flood series. In this case, the general scour due to the 100-r flood is less hat the long-term scour.

FCD Response (April 29, 2009): Since only the long-term scour (at the bridges) is presented in this section of the report, the piers do not need to be simulated. The comment is resolved.

18) **FCD Comment (April 17, 2009):** In the third paragraph, it is indicated that the bridge (at station 4.005) is subject to scour of 10 feet, but in Figure 24, the maximum scour appears to be ~5 feet.

Chang Consultants Response (April 22, 2009): Revised as: The railroad bridge crossing at river mile 4.005 is subject to minor channel bed scour as depicted in the figure.

FCD Response (April 29, 2009): The sentence has been revised. However, the sentence would be clearer if it referred to the specific figure, i.e., Figure 24.

Chang Consultants Response (May 5, 2009): Revised as: The railroad bridge crossing at river mile 4.005 is subject to minor channel bed scour as depicted in Fig. 24.

FCD Response (May 13, 2009): The sentence has not been revised. However, even though the sentence has not been revised, the content of the report is not affected and the comment is resolved.