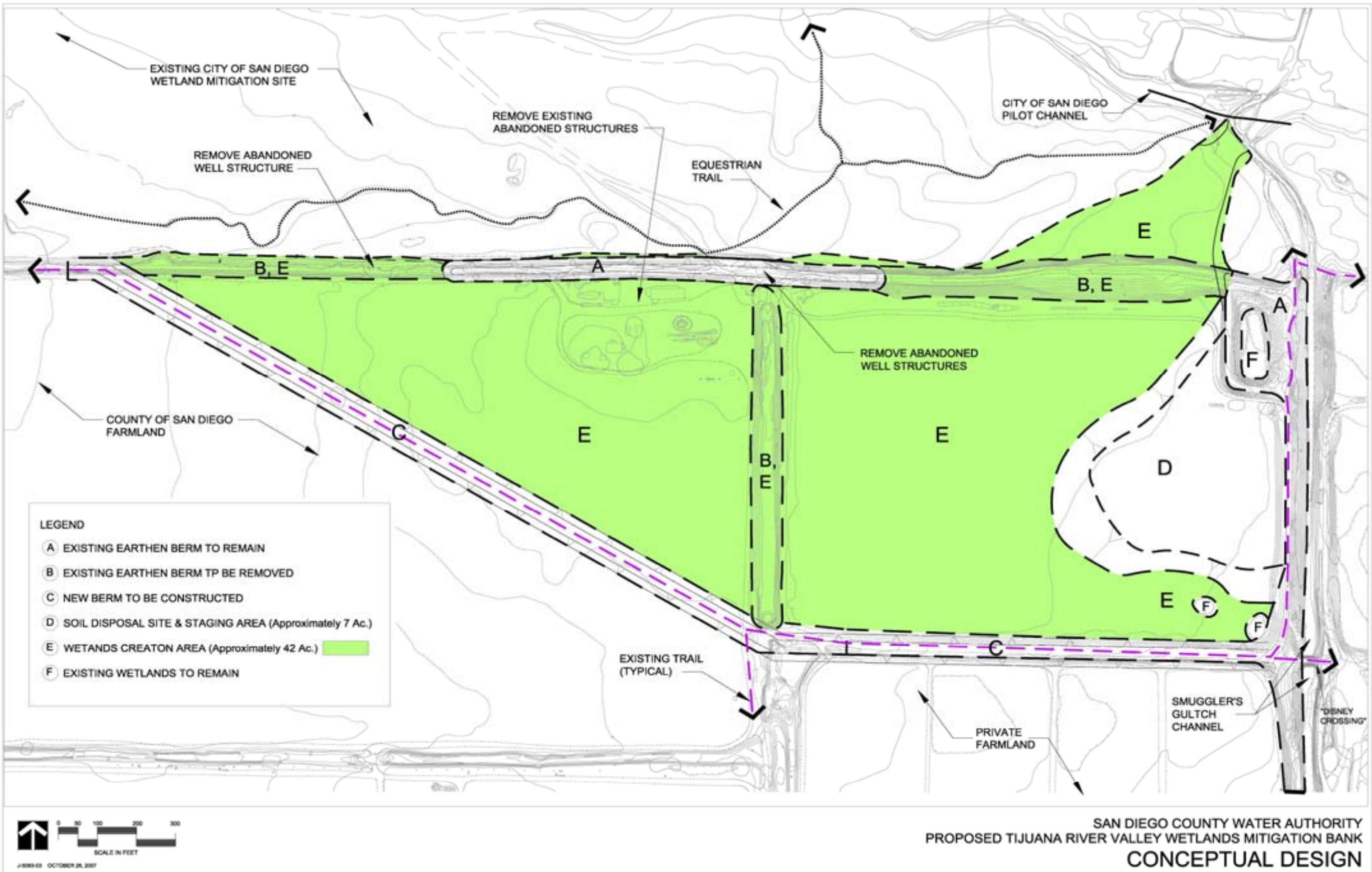
Hydraulic and Sedimentation Study for Wetland Restoration in the Tijuana River Floodplain



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JUANA07E.OUT: Input/output listings of FLUVIAL-12 for the existing conditions

JUANA07P.OUT: Input/output listings of FLUVIAL-12 for the proposed conditions

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 riverbank to protect the bank against erosion. Such structures are usually made of riprap stones, revetments, dikes, etc.

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.

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.

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 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

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.

EXECUTIVE SUMMARY

Wetland restoration has been proposed in the floodplain of the Tijuana River. A hydraulic and sedimentation study has been made for the proposed project. The purpose of the study is to provide the necessary information for wetland development that will also mitigate adverse impacts on river flow and sedimentation. The feasibility for wetland creation relies on the availability of storm water; therefore, frequent flooding of the area is a requirement. The Tijuana River has been severely disturbed by human activities, including the upstream dams, berms in the floodplain, channelization in Mexico, the energy dissipater, and sand and gravel mining in the river channel. Because of such activities, the river channel is expected to undergo changes that may affect the wetland restoration project. The past and future river channel changes must be well understood for the project.

Measures and Effectiveness for Wetland Restoration - For the purpose of wetland restoration, the project site must be subject to frequent flooding since water is essential for wetland health. In order to achieve frequent flooding, the following measures will be made:

(1) Blocking low flow to the north branch channel.
(2) Removing parts of the existing berm that separates the wetland site from the river channel.
(3) Minor grading at the wetland site.
(4) Grading in the main channel to allow low flow into the wetland site.

The functions of these measures are detailed in the report.

The flooding potential and flooding frequency of the project site by river water has been analyzed by a hydraulic modeling study. The HEC-RAS model developed by the U. S. Army Corps of Engineers was used for the hydraulic study. Graphical and numerical results from the hydraulic modeling study are used to show the flow pattern through the wetland site. The proposed wetland site will be subject to flooding from the Tijuana River during the 2-yr event. Since the 2-ye flood is a frequent event, it may therefore be concluded that the project site will receive river water frequently and it may therefore be suitable for wetland development.

Evaluation of Project Impacts - Since the project site is in the floodplain of the Tijuana River; it may have important hydrological impacts on the river channel, including:

(1) flood level,

(2) river channel scour, and

(3) sediment delivery to the beach.

In order to evaluate these impacts, it is necessary to apply an erodible boundary model with capabilities for river hydraulics, sediment transport, and river channel changes. The FLUVIAL-12 model was employed for this project.

Project Impacts on Flood Level – Under existing conditions, the project site is separated from the effective flow area of the river channel by a berm. Parts of the existing berm will be removed under the proposed plan so that the project site will be within the effective flow area. This measure enlarges the effective flow area of the river channel and it thus lowers the flood level. Evaluations of the project impacts on the flood level were made using the HEC-RAS model and the FLUVIAL-12 model. The modeling results show that the proposed project will not raise the flood level; therefore, the project will have no flooding impacts.

Project Impacts on Flow Velocity – Peak 100-yr flow velocities were computed for the existing and proposed conditions. The results show that the river channel has very high velocities near the river mouth. The high velocities are also responsible for the severe scour development. The velocities are higher than 6 feet per second from the river mouth to channel station 20+00. For the rest of the river channel, the flow velocities are generally lower than 6 feet per second. When the velocities for the existing and proposed conditions are compared, it can be seen that the velocities for the proposed plan are closely similar to those for the existing conditions. The proposed project will not raise the velocities at the bridge crossings during the peak 100-yr flood.

Bridge Hydraulics – The lower Tijuana River has two bridge crossings at the Hollister Street Bridge and the Dairy Mart Road Bridge, respectively. The proposed project is at large distances away from these bridges; it does not affect the hydraulics of river flow nor sediment transport at these bridge crossings. Therefore, the proposed project has no impacts at these bridges.

Project Impacts on River Channel Scour - River channel changes were simulated for the existing and proposed conditions. The river reach near the mouth is subject to severe scour during the 100-yr flood. The simulated results show that the proposed project will have insignificant effects on river channel scour.

Project Impacts on Beach Sand Supply - Sediment deliveries along the river channel were simulated for the existing and proposed conditions. The net amount of sand delivered to the river mouth is the sand supply to the beach. The proposed project will have insignificant effects on beach sand supply by the Tijuana River.

Hydraulic and Sedimentation Study for
Wetland Restoration in the Tijuana River Floodplain

I. INTRODUCTION

Wetland restoration has been proposed in the Tijuana River Valley. The project site for wetland restoration is located in the floodplain of the Tijuana River, south of the current main channel and just west of Smuggler's Gulch. Fig. 1 is an aerial photograph of the Tijuana River Floodplain near the project site. This report presents a hydraulic and sedimentation study for the wetland restoration project.

The Tijuana River has been severely disturbed by human activities, including the upstream dams, berms in the floodplain, channelization in Mexico, the energy dissipater, and sand and gravel mining in the river channel. Because of such activities, the river channel is expected to undergo dynamics changes that may affect the wetland restoration project. In addition, meandering development is a natural process. The past and future river channel changes must be well understood for the project.

The feasibility for wetland creation relies on the availability of storm water; frequent flooding of the area is a requirement. The project site is in the floodplain of the Tijuana River; it may have important hydrological impacts on the river channel, including:

(1) flood level,
(2) river channel scour, and
(3) sediment delivery to the beach.

In order to evaluate these impacts, it is necessary to apply an erodible boundary model with capabilities for river hydraulics, sediment transport, and river channel changes.

Fig. 1. Aerial photograph of the Tijuana River Floodplain near the project site

II. WATERSHED AND CHANNEL CHARACTERISTICS

The Tijuana River drains about 1,700 square miles, 73 percent of which lie in Mexico. Runoff in the watershed is partially stored in three reservoirs. Morena Dam, completed in 1910, and Barrett Dam, completed in 1921, are located in the United States. Rodriguez Dam, completed in 1937, is located in Mexico. These dams, with a combined capacity of 206,000 acre-feet (Rodriguez Reservoir has an 110,000 acre-foot capacity), regulate about 71 percent of the total drainage area. The reservoirs were designed for water storage and have only limited capacity for flood control purposes. However, the three reservoirs control most flows resulting from small storms in the upstream portions of the drainage basin. Rodriguez Dam, equipped with floodgates on the spillway, is capable of regulating the flow rate of a major flood to a certain extent.

More importantly, the reservoirs detain nearly all the bed sediment to result in a sediment deficit for the Tijuana River downstream. The dynamic equilibrium of river channel relies upon the balance between sediment supply and transport. For this reason, sediment equilibrium of the Tijuana River has been distorted by the reservoirs. Water overflowing the dam spillway is basically depleted of bed sediment. Since the river flow has the natural tendency to transport sediment to its full capacity, it will try to make up the deficit in supply by removing sediments from the downstream channel boundary, i.e., scour.

In the following, other river channel characteristics, including bed materials, flood hydrographs, existing extraction sites, and hydraulic structures are described.

Bed Materials - The riverbed of the lower Tijuana River has bed materials of clay, silt, sand and gravel, but the dominant bed material is sand. Soil investigations have been made by Geofon Inc. for the Clean Water Program in 1991 and by Amec in 2003. Sediment samples were collected from the riverbed from the energy dissipater to the river mouth; their size distributions are shown in Fig. 2. Such size distributions also show a slight decrease in sediment size from upstream toward downstream.

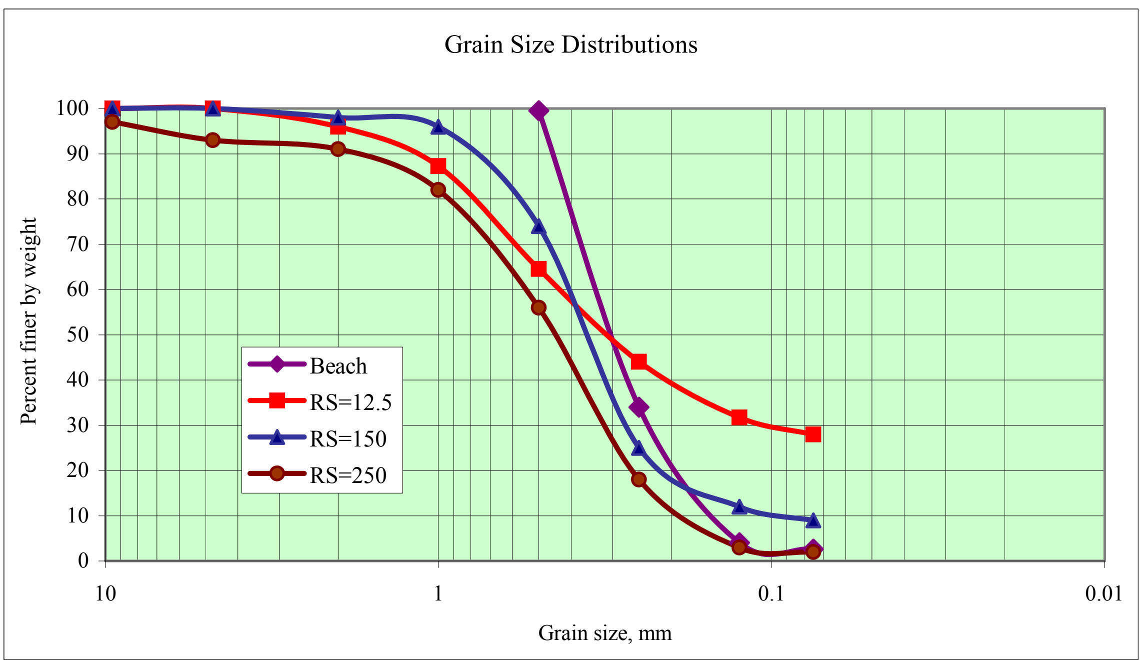


Fig. 2. Grain size distributions

Flood Hydrographs - The flood hydrographs for the study river reach is shown in Fig. 3.

This hydrological information is typical for the San Diego County (Department of Water Resources, 1976). A typical flood has relatively short duration with discharge rising and falling rapidly, as is characteristic of semi-arid areas. Sediment delivery rates in the river closely follow the flow pattern since water is the agent for sediment transport.

The flood discharges for the 100-, 50- and 10-yr floods that have been adopted by the Federal Emergency Management Agency (FEMA) are given in the floodplain study of the Tijuana River; these values as listed in Table 1 are also used in this study. The 25-yr flood is obtained in this study based on the log-probability distribution of flood discharges. Peak discharges of other floods may be estimated based the assumption that the distribution of peak discharges follows a lognormal distribution. In this study, the 100-yr flood was used together with the 10-yr flood; their hydrographs are shown in Fig. 4.

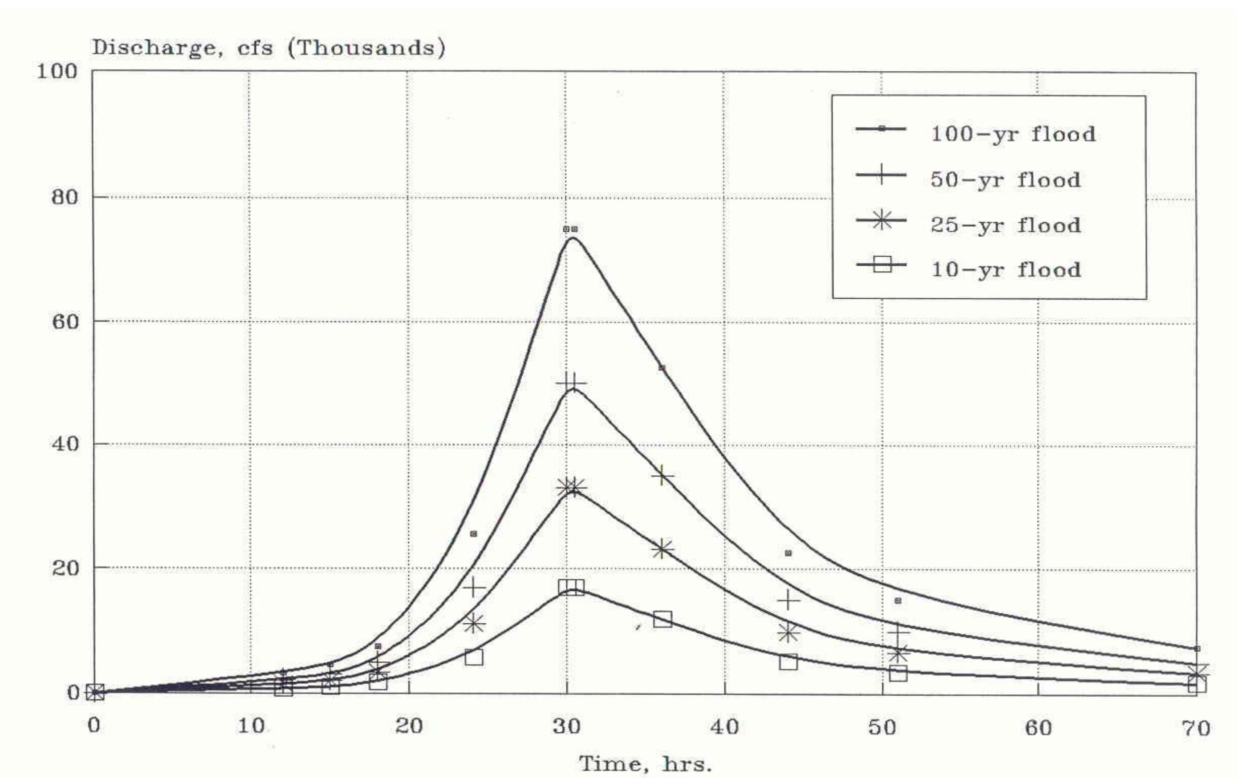


Fig. 4. Flood hydrographs

Table 1. Flood discharges for the Tijuana River

Flood event	Peak Discharge, cfs
2-yr	3,000
5-yr	9,400
10-yr	17,000
25-yr	34,000
50-yr	50,000
100-yr	75,000

Channel Data - Figure 5 is a map of the Tijuana River from the river mouth to the energy dissipater. The channel geometry is defined at selected cross sections. Locations of cross sections used in the study for the river channel from the river mouth to the energy dissipater are shown in the figure; channel stations are shown along the line near the center of river flow. Important locations and their respective channel stations are listed in Table 2.

Table 2. List of important locations along the river channel

Points of interest	Location River miles
River mouth	0
19th Street	120
Hollister Street	148
Dairy Mart Road	210.6
Exit of Energy Dissipater	250
Upstream limit of study	261.6

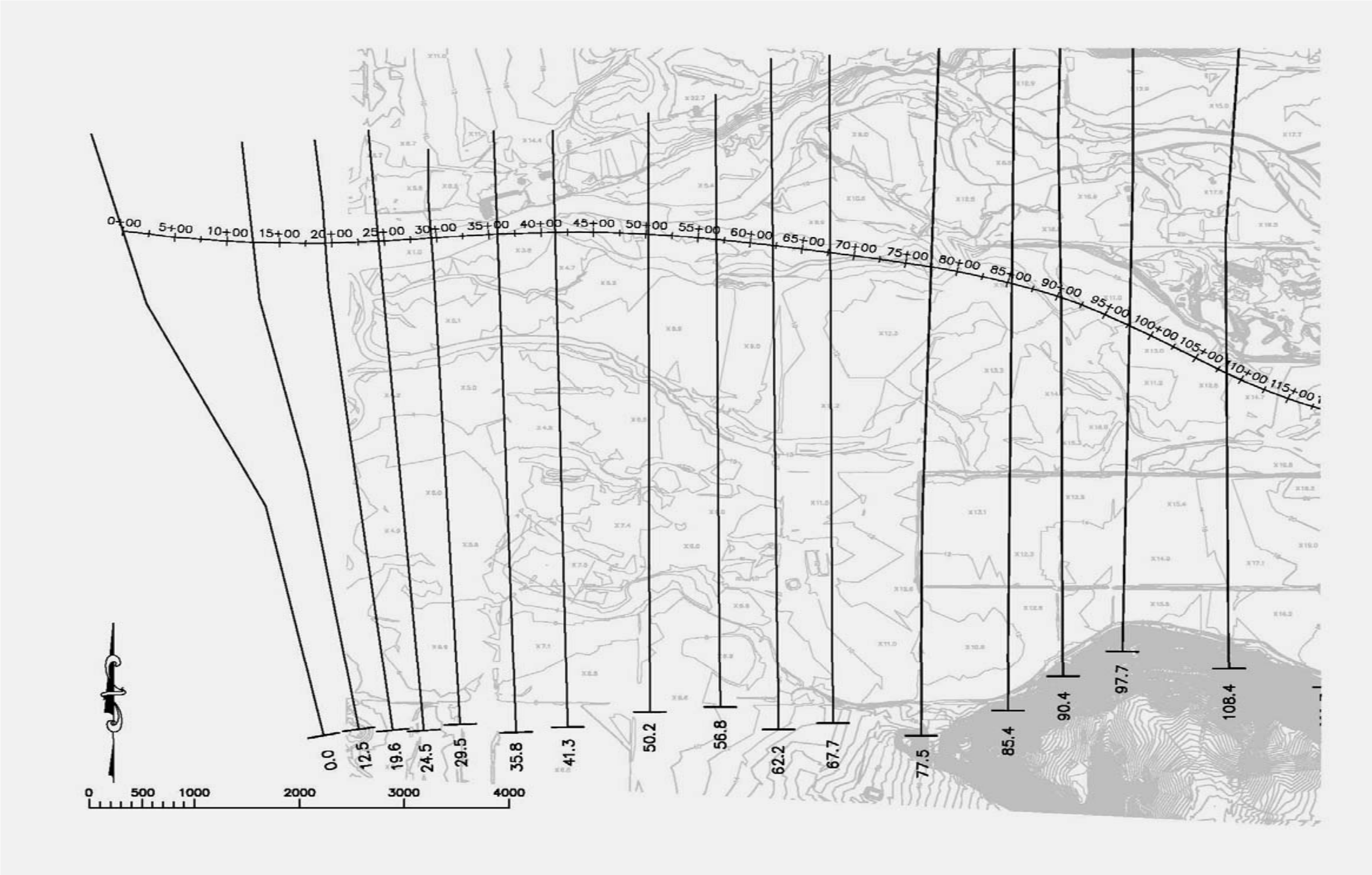


Fig. 5. Map of the Tijuana River

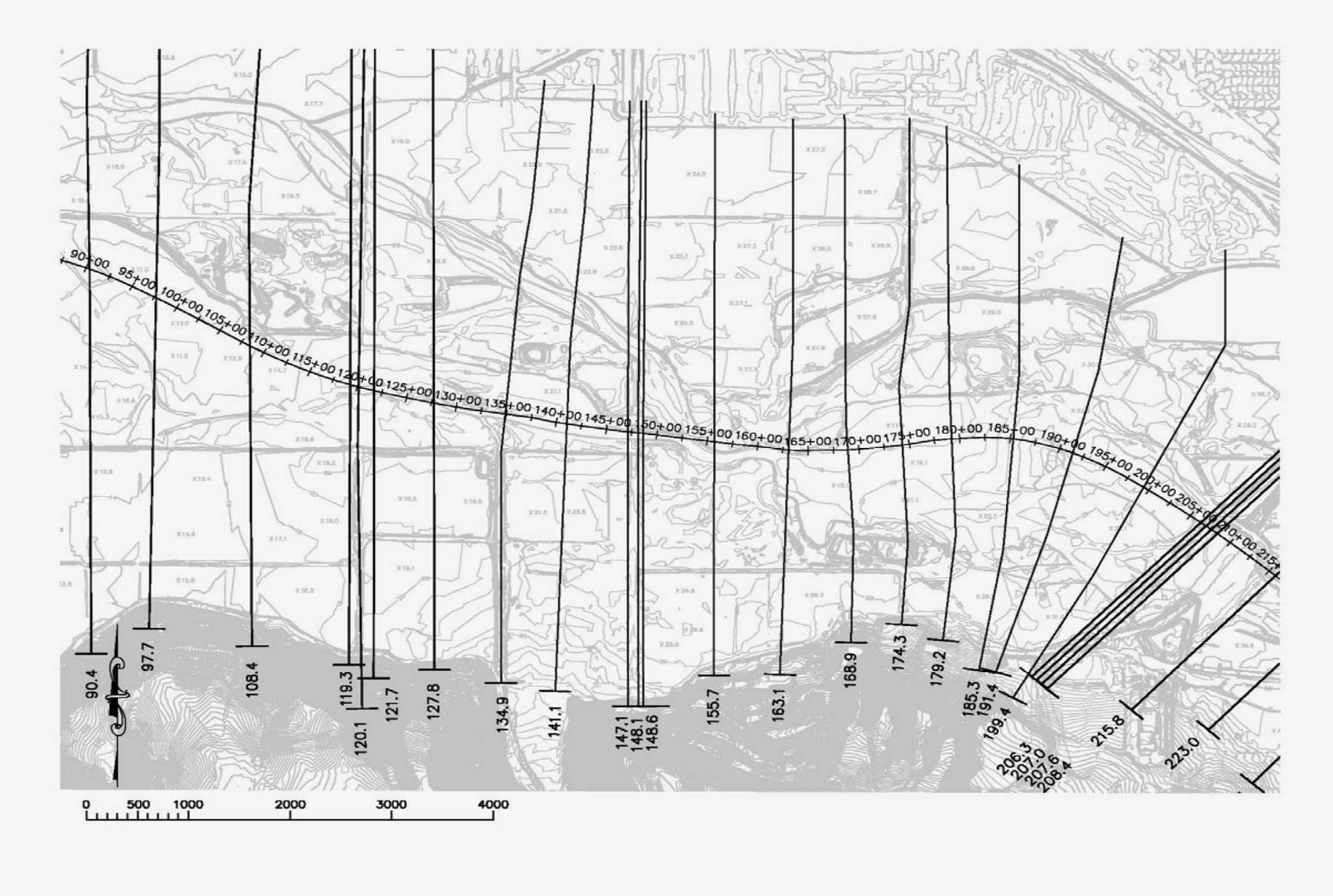


Fig. 5 (continued). Map of the Tijuana River

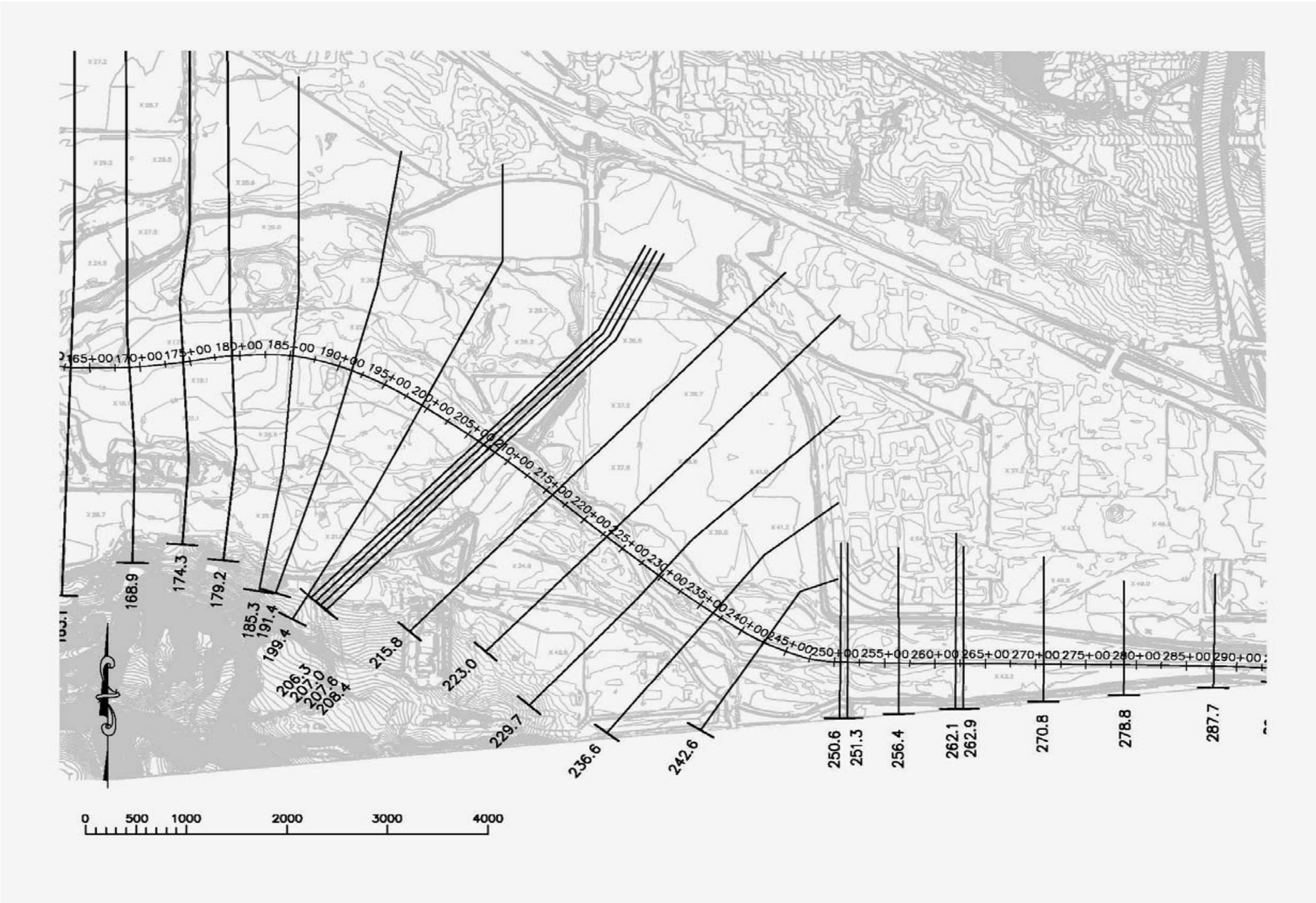


Fig. 5 (continued). Map of the Tijuana River

Effective Flow Area and Ineffective Flow Area - The Tijuana River has a main channel and a broad floodplain. Distribution of flow velocity in the floodplain is not uniform. The main channel tends to have higher flow velocities than the overbank areas in the floodplain. The flow is also significantly affected by the bridges, road crossings and existing berms in the floodplain. Major berms are located in the south part of the floodplain. Areas behind the berms are assumed to be ineffective flow areas. The ineffective flow areas may be under water during a flood, but they have very small flow velocities and they do not contribute significantly to the conveyance of the flow discharge. Fig. 6 illustrates the concept of the effective flow area and ineffective flow area. Flow in the ineffective flow area has very small velocities and they form eddies. The discharge of flow is conveyed through the effective flow area but not by the ineffective flow area.

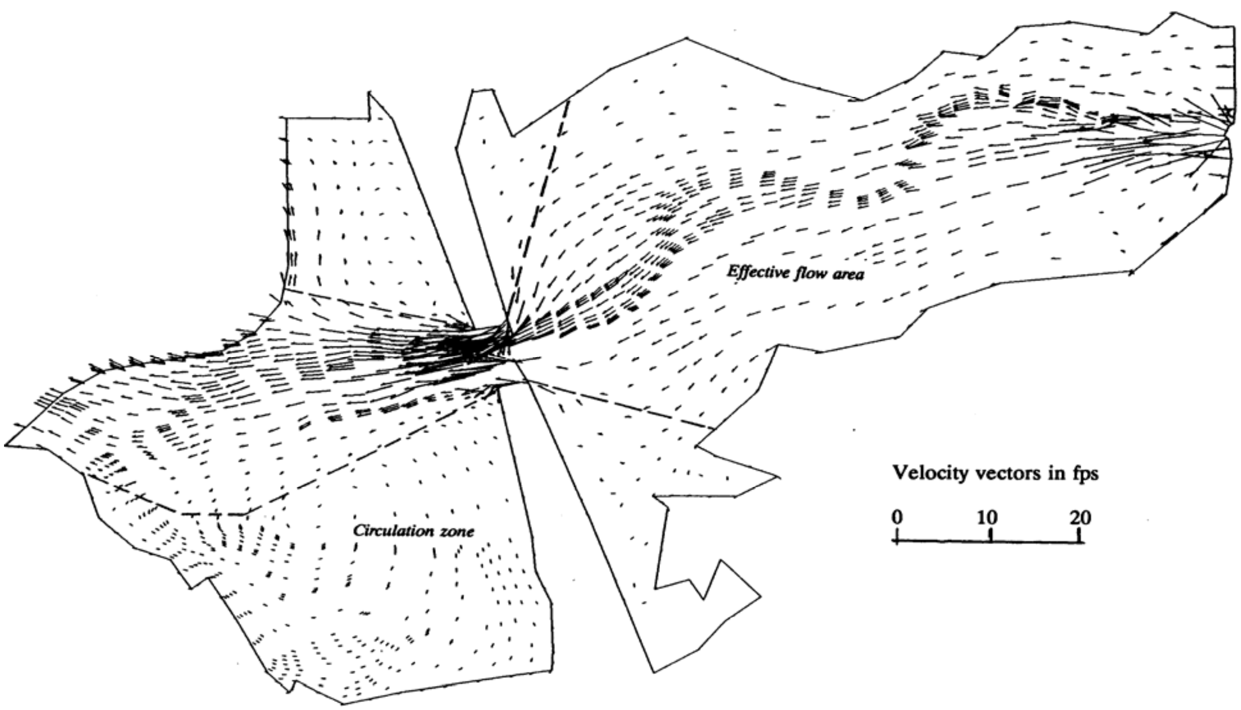


Fig. 6. Effective flow area and ineffective flow area in a floodplain

III. WETLAND CREATION

Figure 7 is a map showing the proposed wetland site in the Tijuana River floodplain. Fig. 8 is a map of the area under the existing conditions. The geometry of the floodplain is defined at the cross-section lines shown. These cross sections are used in the hydraulic modeling of river flow near the project site. Under the proposed plan, the wetland will be created at the previous Amsod site located south of the main channel. Smugglers' Gulch, which has berms on both sides, is along the east boundary of the wetland site. Under the existing conditions, the project site is separated from the main channel by a berm.

Measures for Wetland Creation – For the purpose of wetland creation, the project site must be subject to frequent flooding since water is essential for wetland health. In order to achieve frequent flooding, the following measures will be made:

(1) Blocking low flow to the north branch channel.

(2) Removing parts of the existing berm that separates the wetland site from the river channel.

(3) Minor grading at the wetland site.

(5) Grading in the main channel to allow low flow into the wetland site.

The functions of these measures are described below.

(1) Blocking Low Flow to the North Branch Channel – The main channel of the Tijuana River splits into two branches at a point just east of the Hollister Street Brdige. The south branch is the original low flow channel. The north branch was formed during the 1993 flood when flood flow through the bridge opening was partially blocked by the horse ranch. At this time, the new north branch has greater flow capacity and it would therefore convey more flow than the south branch. In order to restore river flow to the original south branch channel, an earth berm has been built to block low flows from entering the north branch. The earth berm is erodible and hence disposable. Without the berm, most, if not all, the low flow would enter the north channel branch leaving little or no flow for the south channel branch. The proposed wetland relies on water supply from frequent floods in the south channel branch, it is therefore necessary to maintain the berm blocking low flows to the north. Otherwise, there would be inadequate water supply to the wetland area.

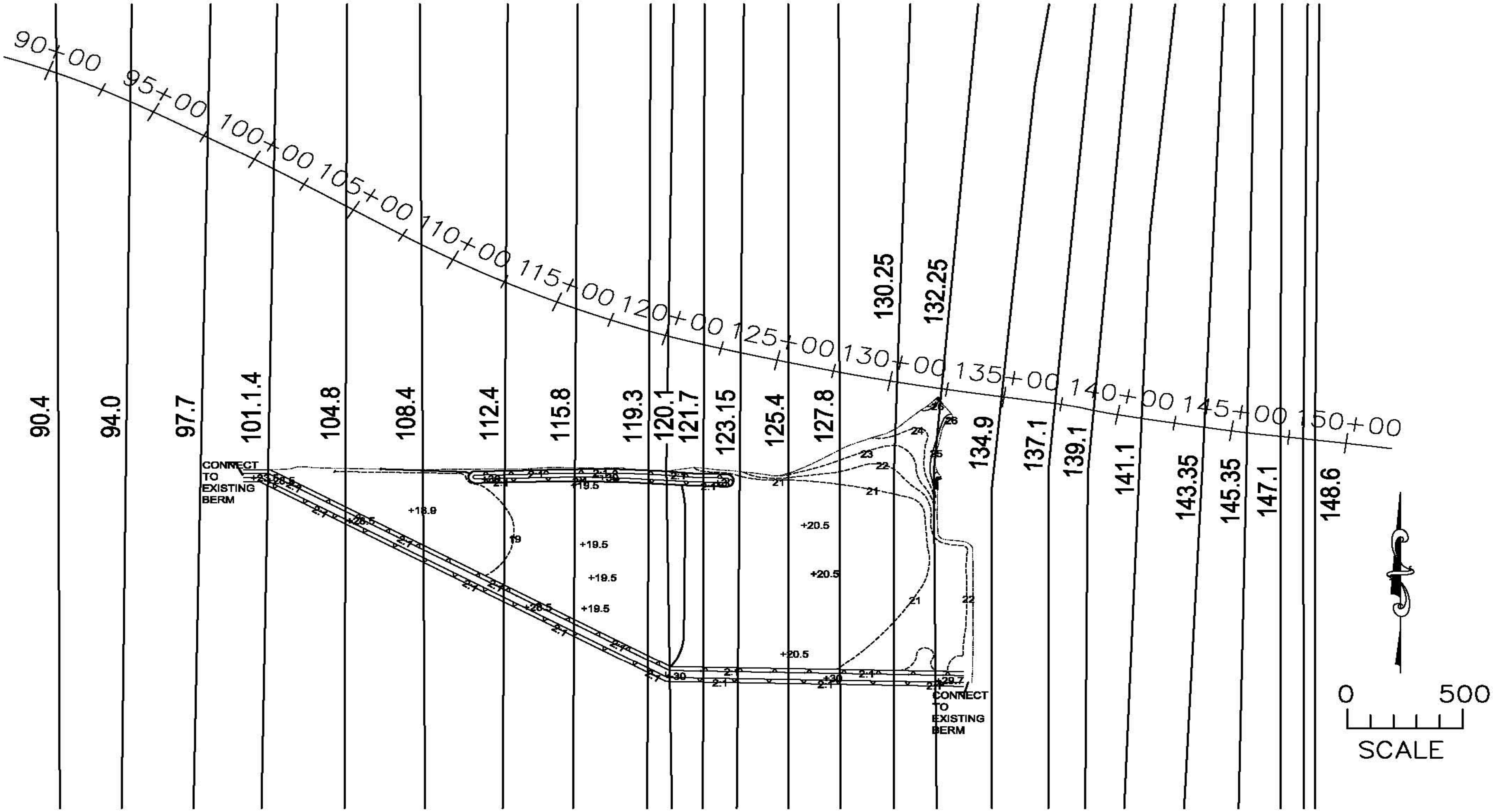


Fig. 7. Topography showing the proposed plan for wetland creation

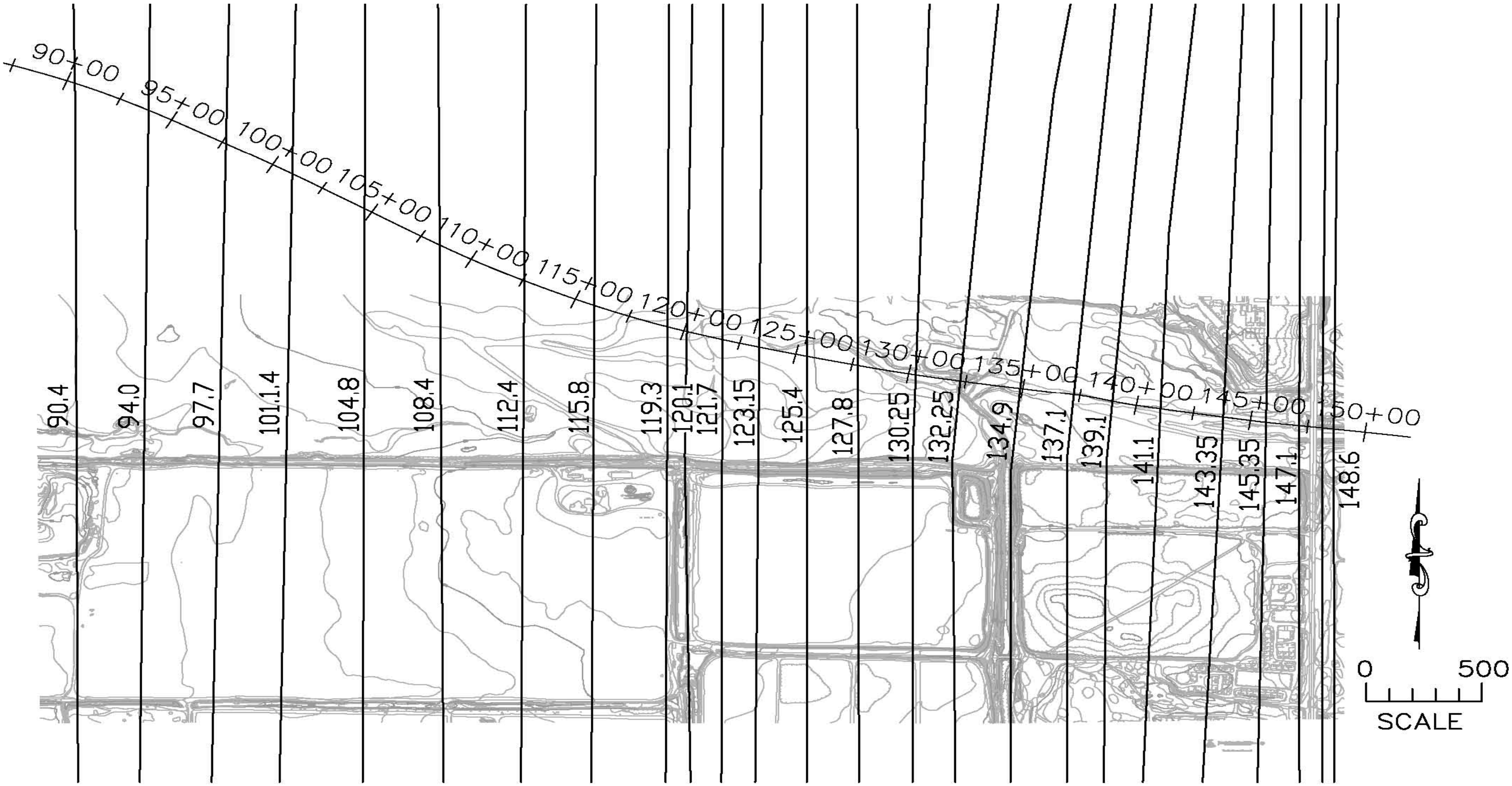


Fig. 8. Topography of the project area under existing conditions

(2) Removing parts of the existing berm that separates the wetland site from the river channel – Two segments of the existing berm between the main channel and the wetland site will be removed. The first segment is from channel station 123+00 to 132+25; the second segment is from station 101+20 to 110+00 as shown in Fig. 7.

(3) Minor grading at the wetland site – Existing ground topography at the wetland site will be lowered. The proposed ground elevation is 21 feet at the east end and it gradually drops down to 18.5 feet at the west end.

(4) Grading in the main channel to allow low flow into the wetland site – The main channel at the north east end of the wetland site will be graded to create a lower passage to allow low flow into the wetland site as shown in Fig. 7.

Analysis of River Flow through the Wetland Site - The flooding potential and flooding frequency of the project site by river water has been analyzed by a hydraulic modeling study. The HEC-RAS model developed by the U. S. Army Corps of Engineers was used for the hydraulic study. The channel geometry is defined by a series of channel cross sections selected along the channel reach. Locations of the cross sections are shown in Fig. 7. Among these cross sections, Section 101.1 is located at the downstream end of the project site and Section 132.25 is at the upstream end or the downstream boundary of Smuggler's Gulch.

River flow is from east toward west. Any flow entering the east or upstream end the wetland area must first passes through the Hollister Street Bridge opening. From the Hollister Street Bridge crossing to the project site, the floodplain width is constrained by berms along the south side of the main channel. At the west end of the project site, the floodplain width is also constrained by the berm south of the main channel. With the flow width constraints at the upstream and downstream ends, the flow expands in width after entering the project site from the upstream end and then the flow width converges toward the west end. While the floodwater may cover the entire lowland area, the effective flow width expands gradually as it enters into the wetland site at the east end.

Modeled results are presented in Figs. 9, 10 and 11. Longitudinal profiles of the water surface and channel bed during the 2-yr, 5-yr, and 10-yr floods near the project site for the existing conditions are shown in Fig. 9; those for the proposed conditions are shown in Fig. 10.

The cross-sectional profiles for the existing and proposed conditions are shown in Fig. 11. These cross sections are viewed toward downstream.

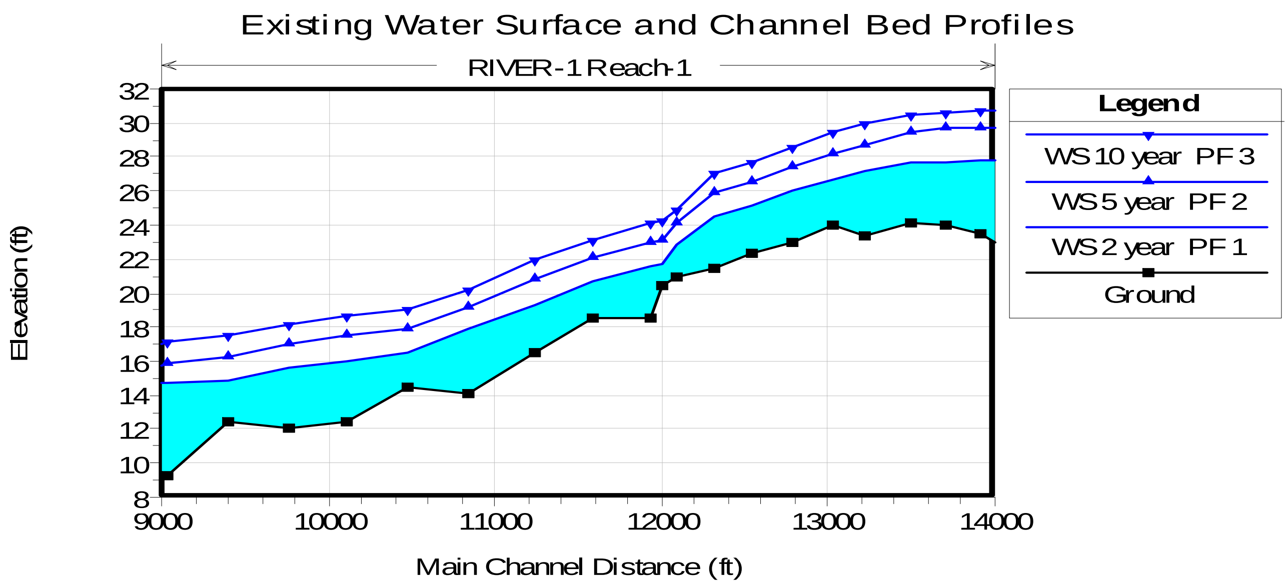


Fig. 9. Longitudinal profiles of the water surface and channel bed near project site for the existing conditions

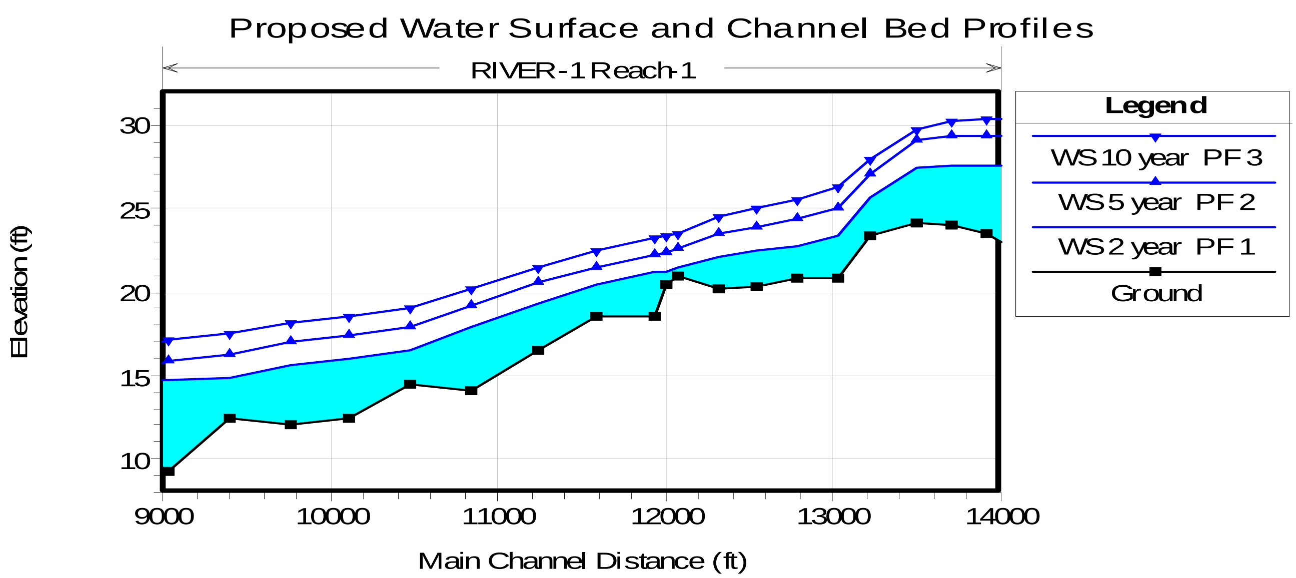
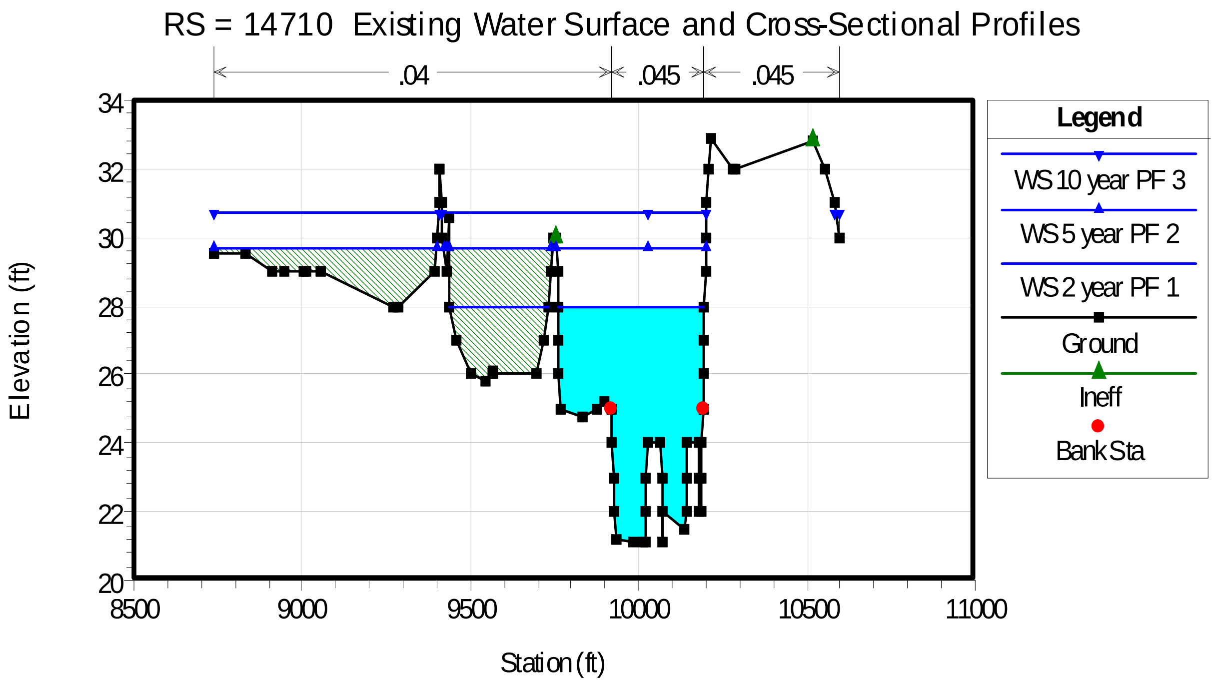


Fig. 10. Longitudinal profiles of the water surface and channel bed near project site for the proposed conditions



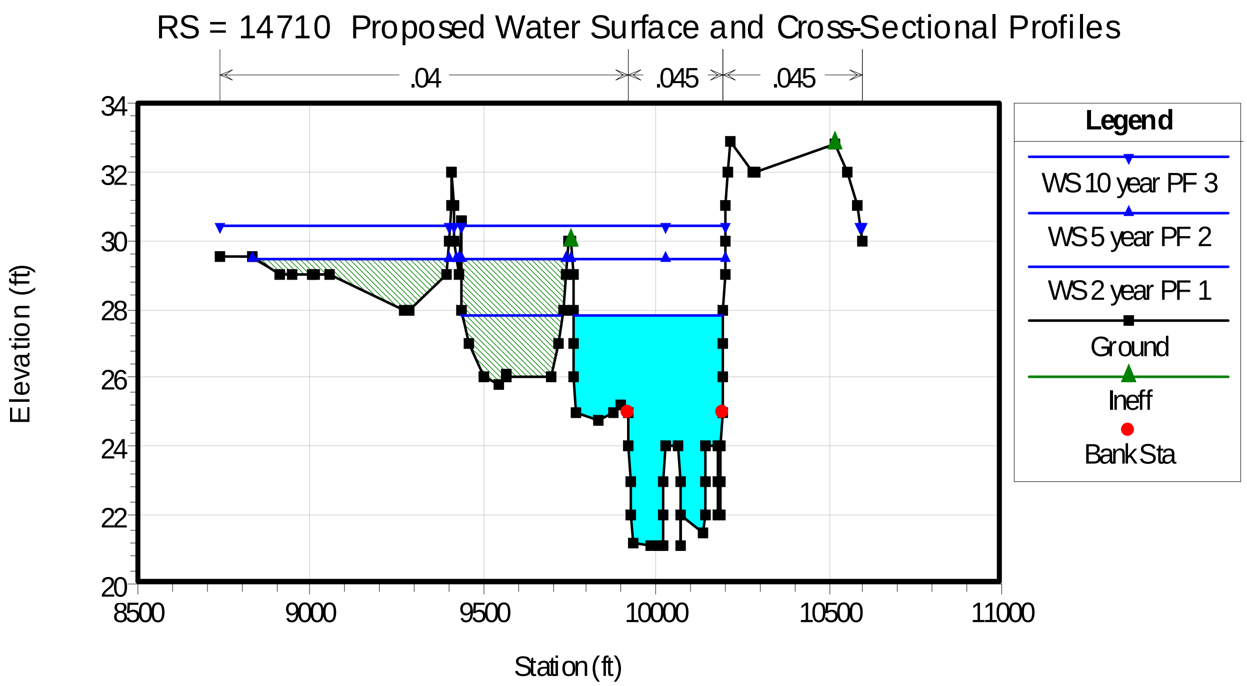
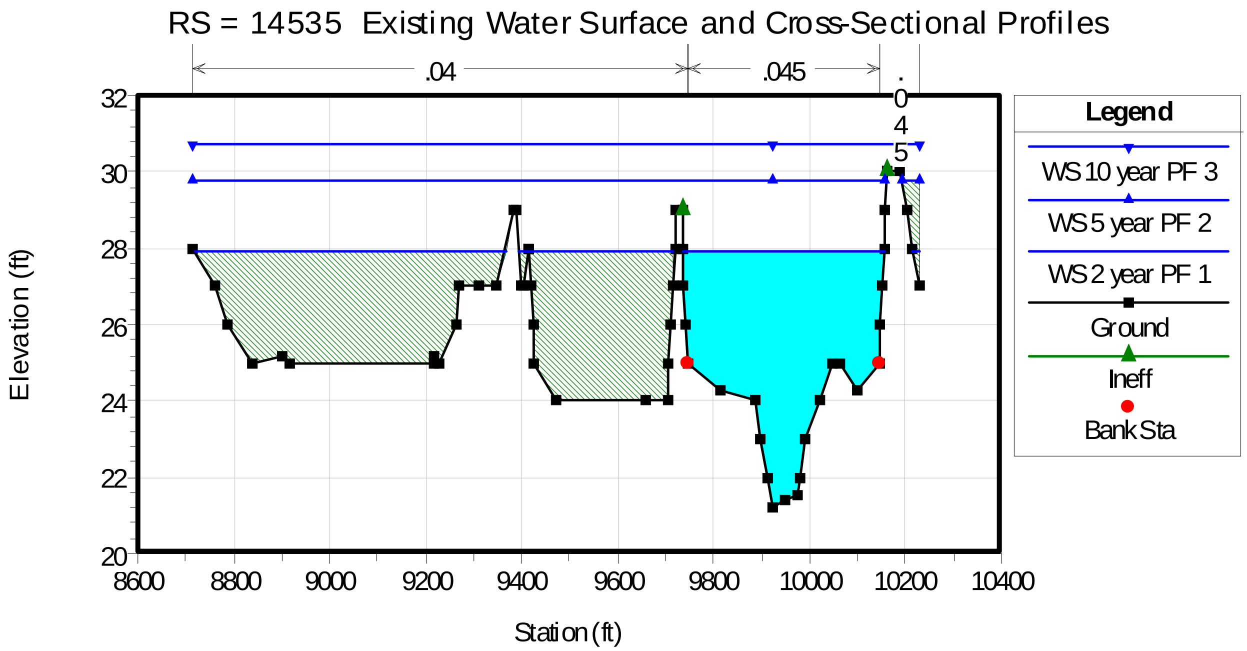


Fig. 11. Water-surface and cross-sectional profiles
for existing and proposed conditions near wetland site



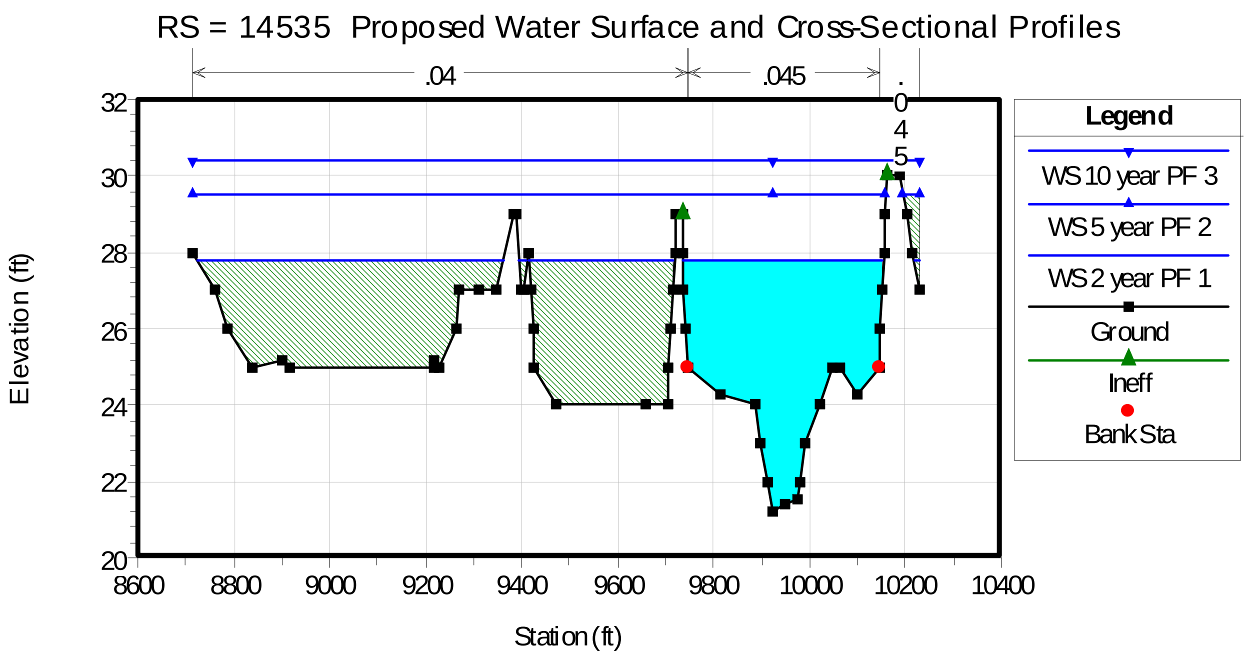
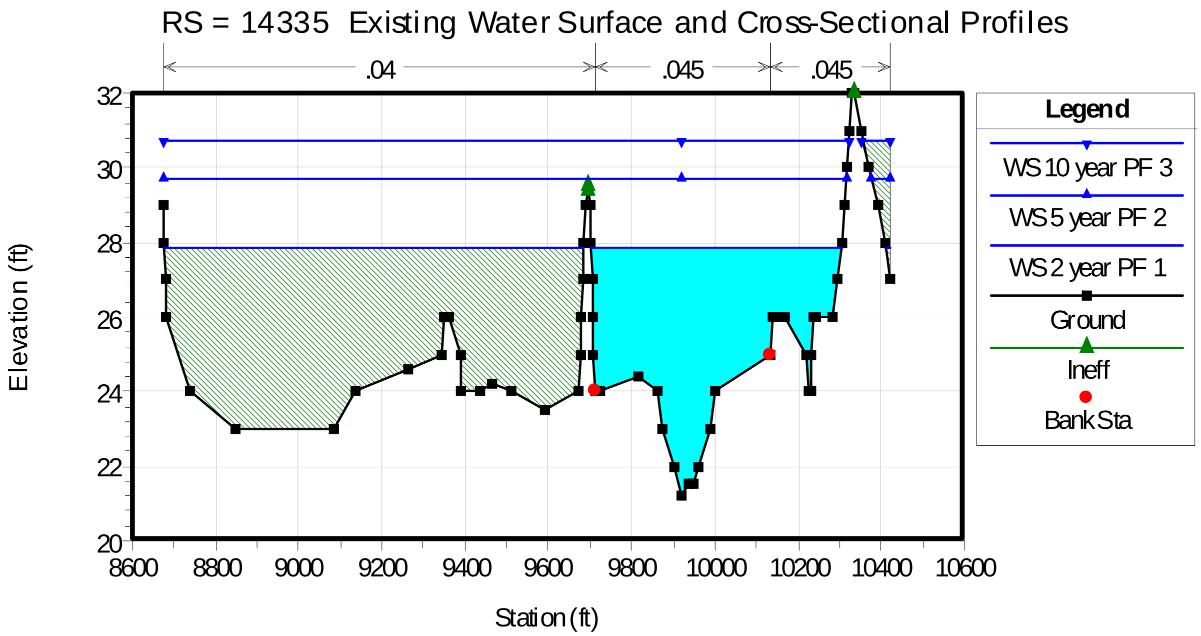


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site



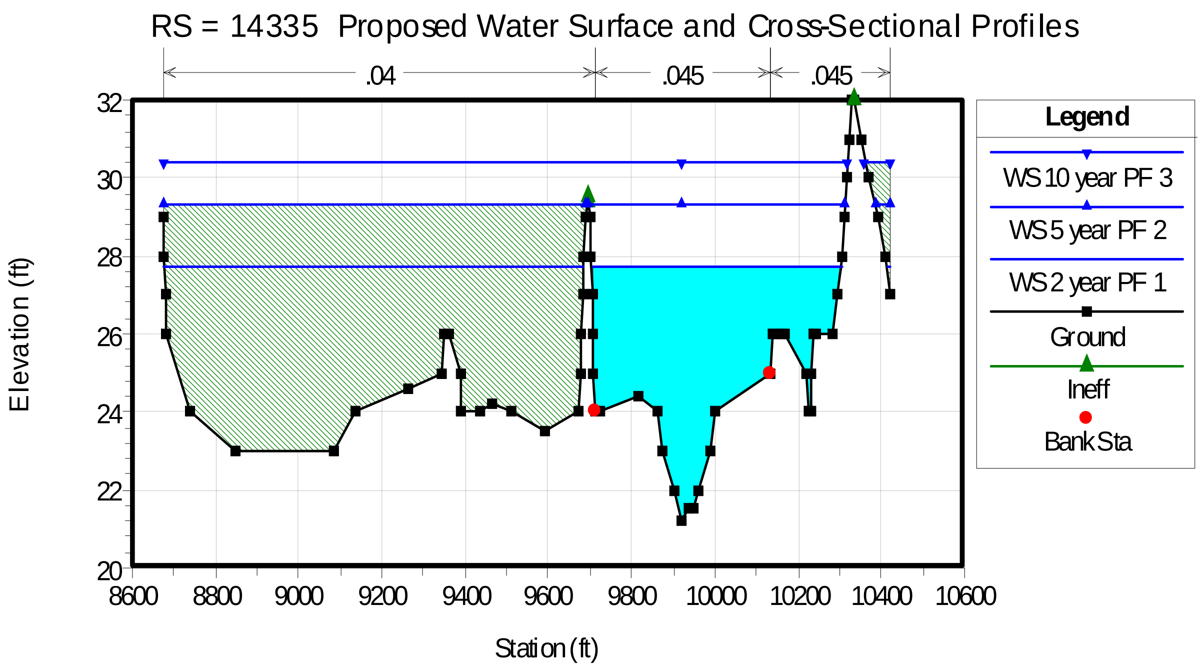
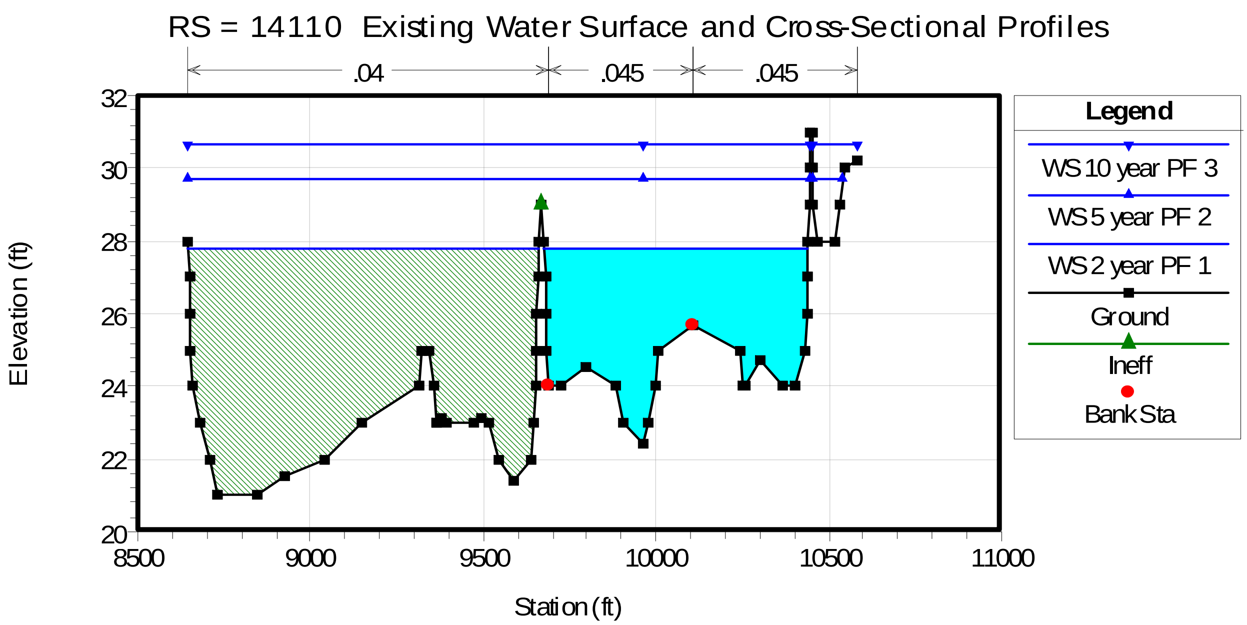
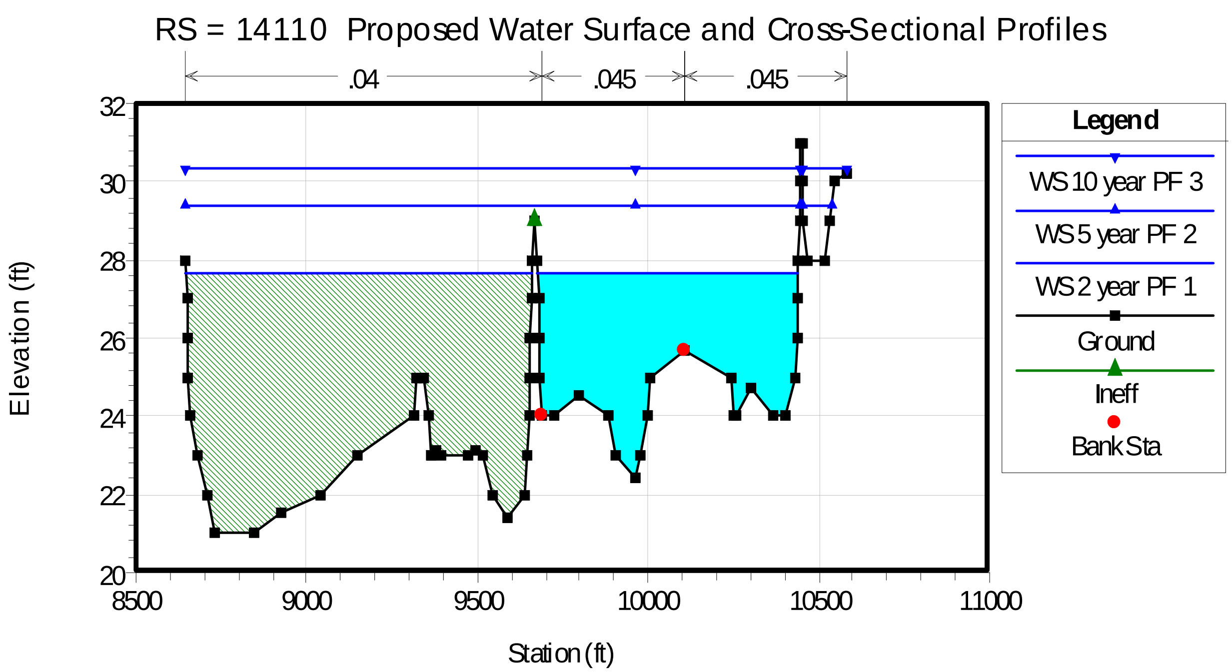


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site





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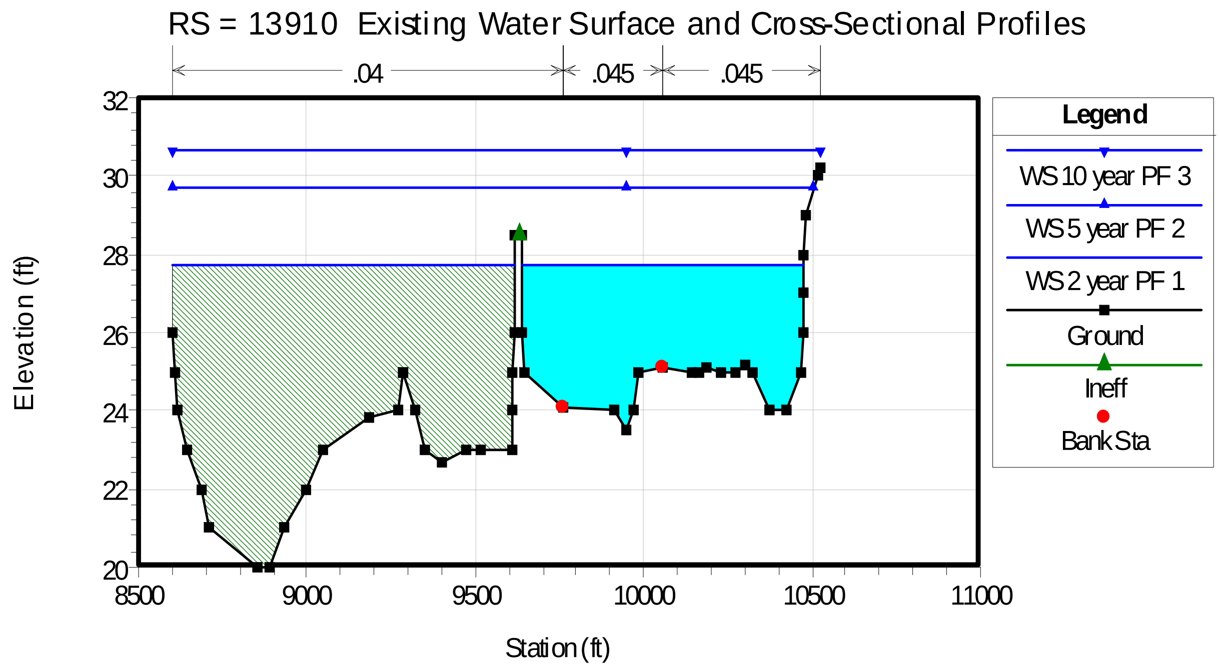


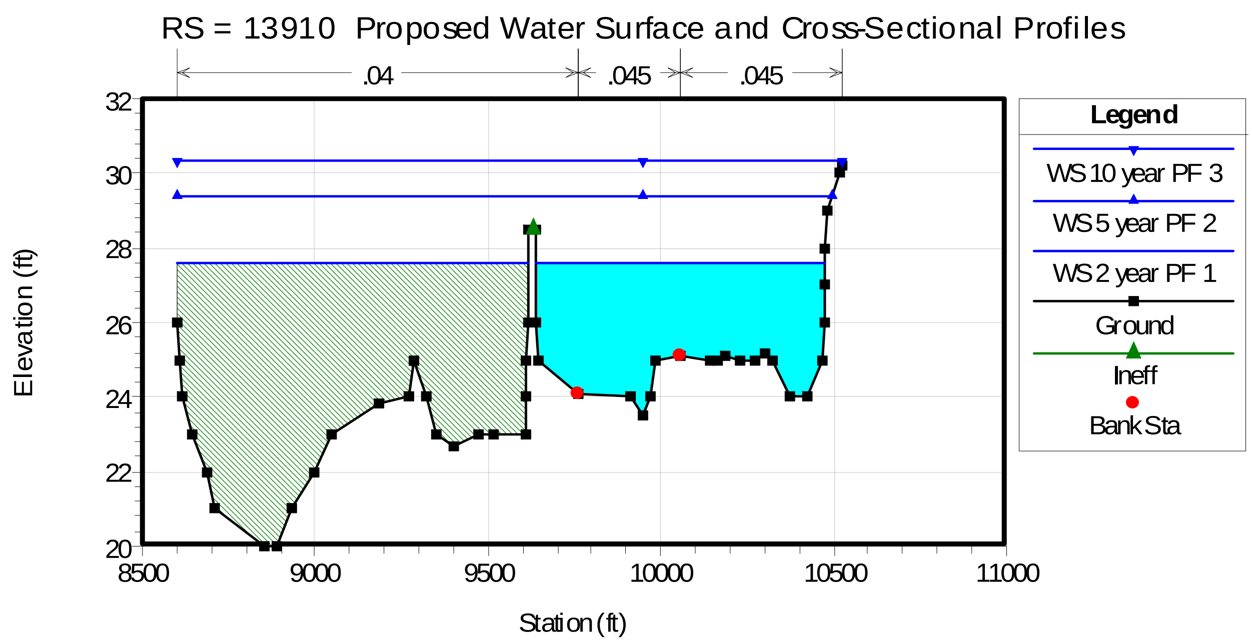
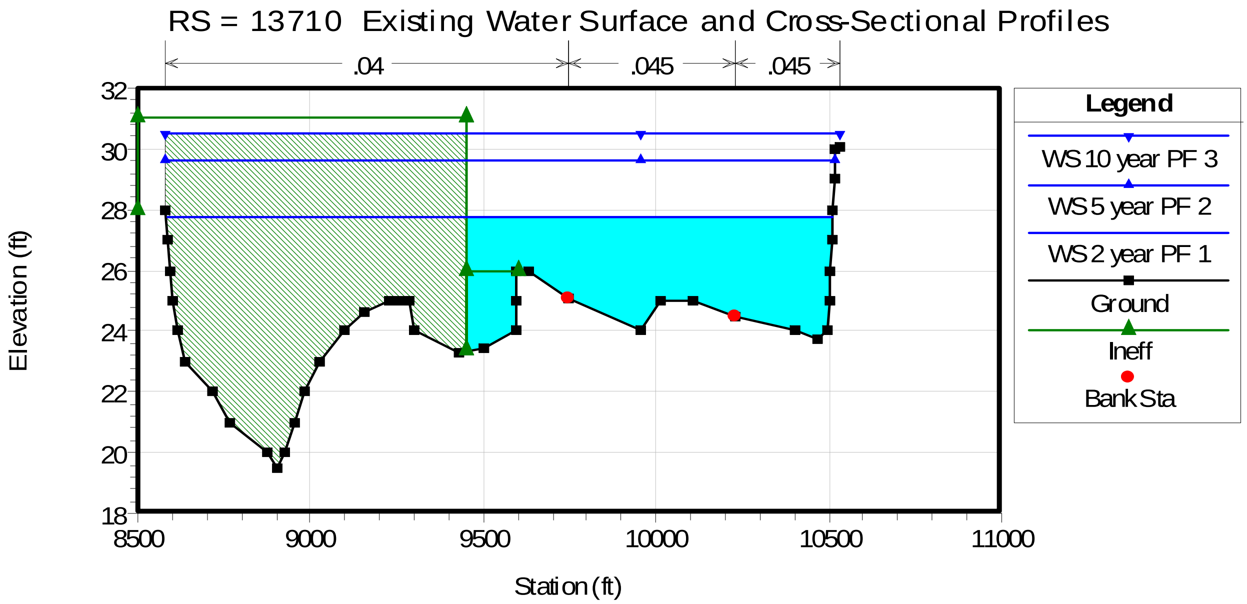


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site



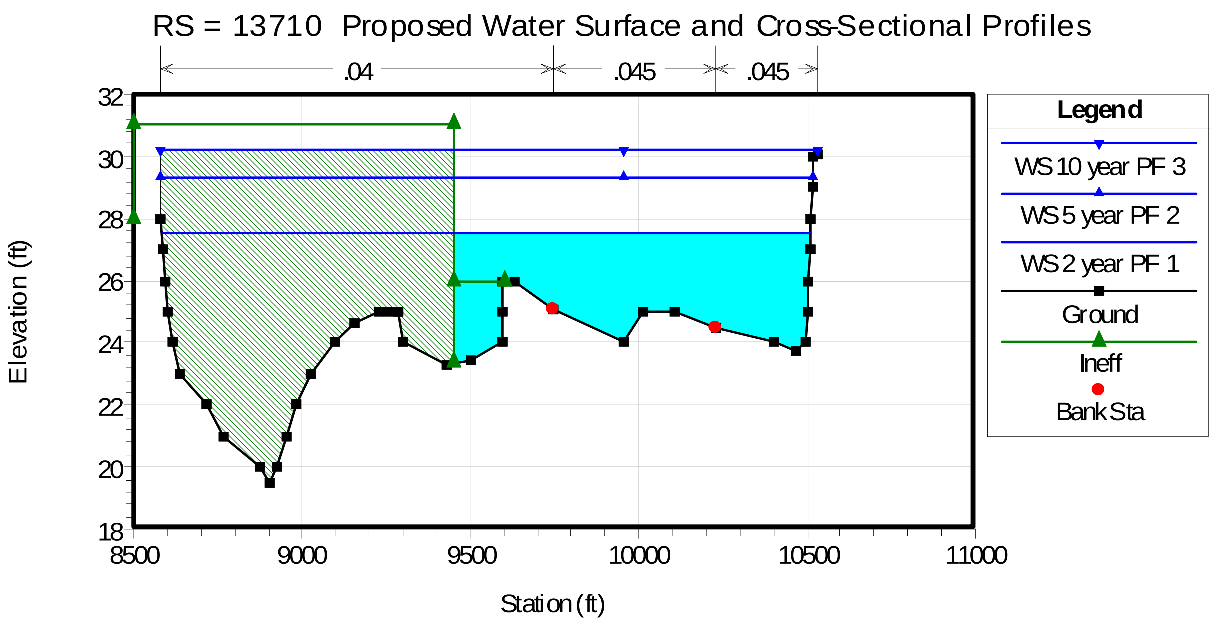
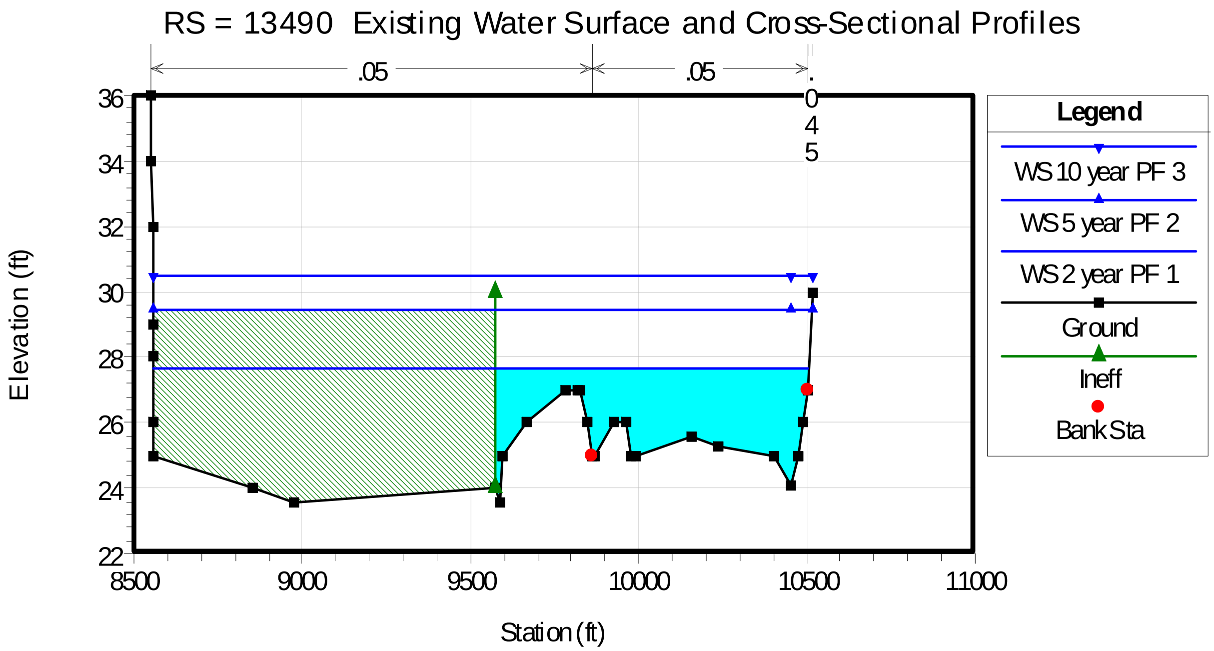


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site



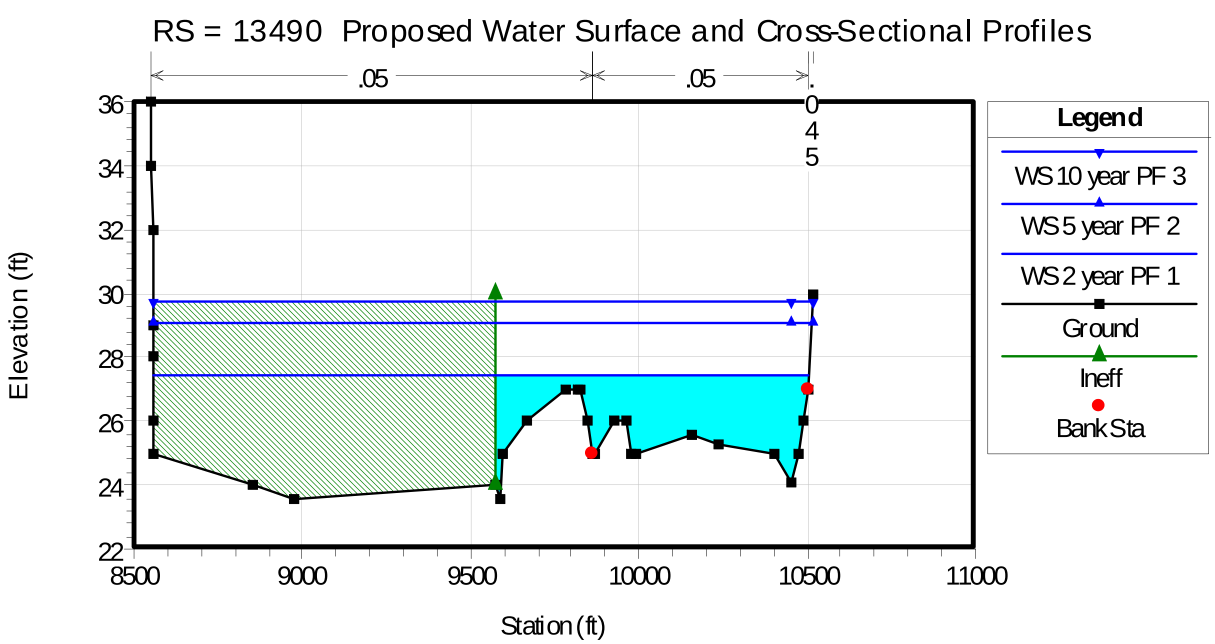


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site

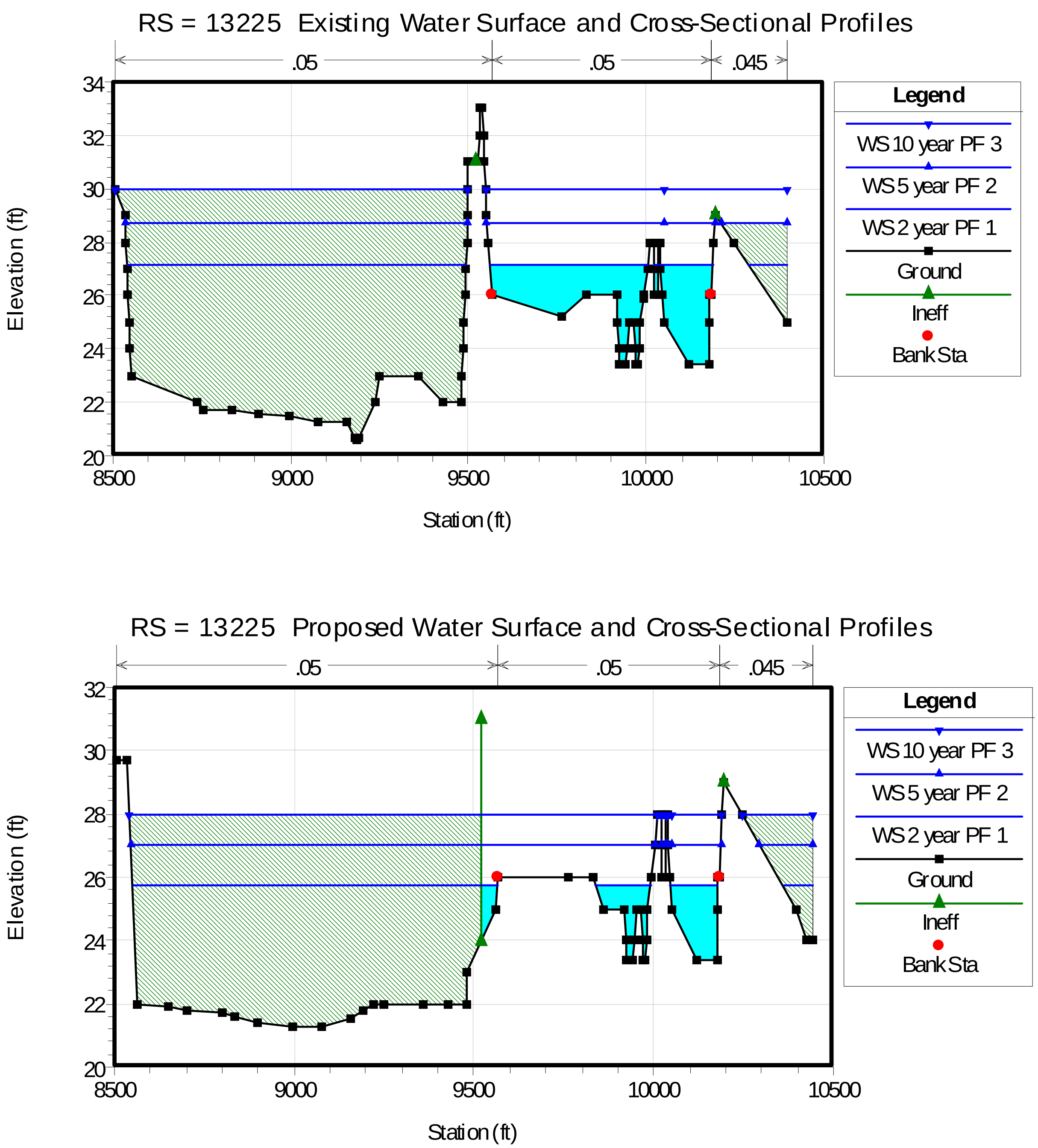
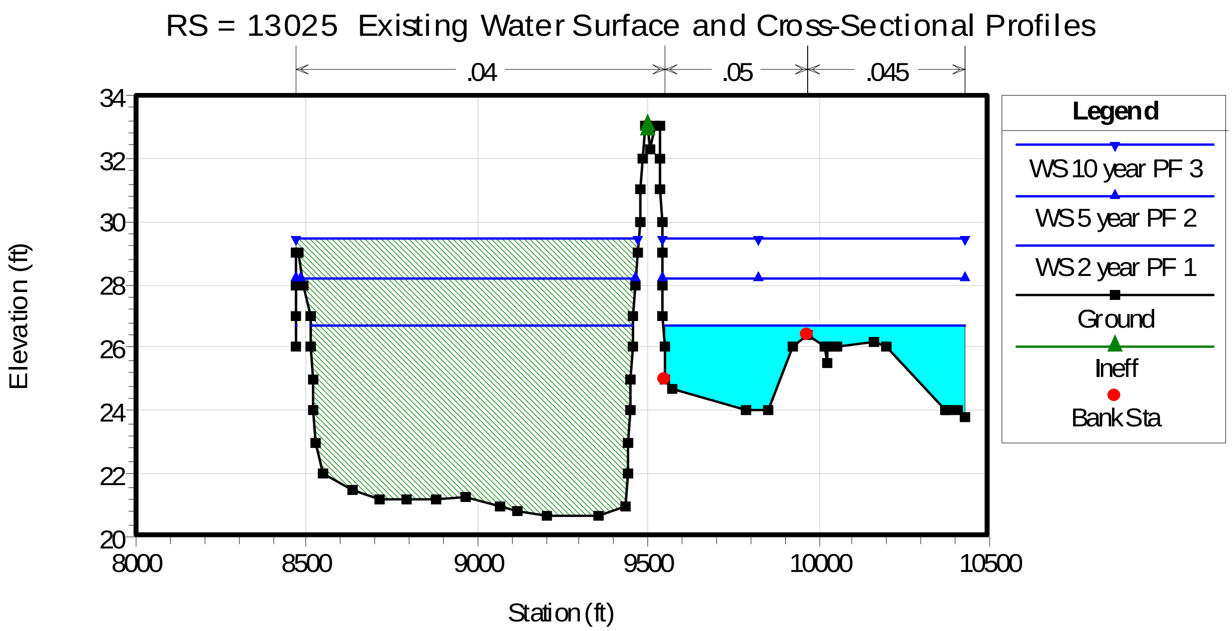


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 9,300.



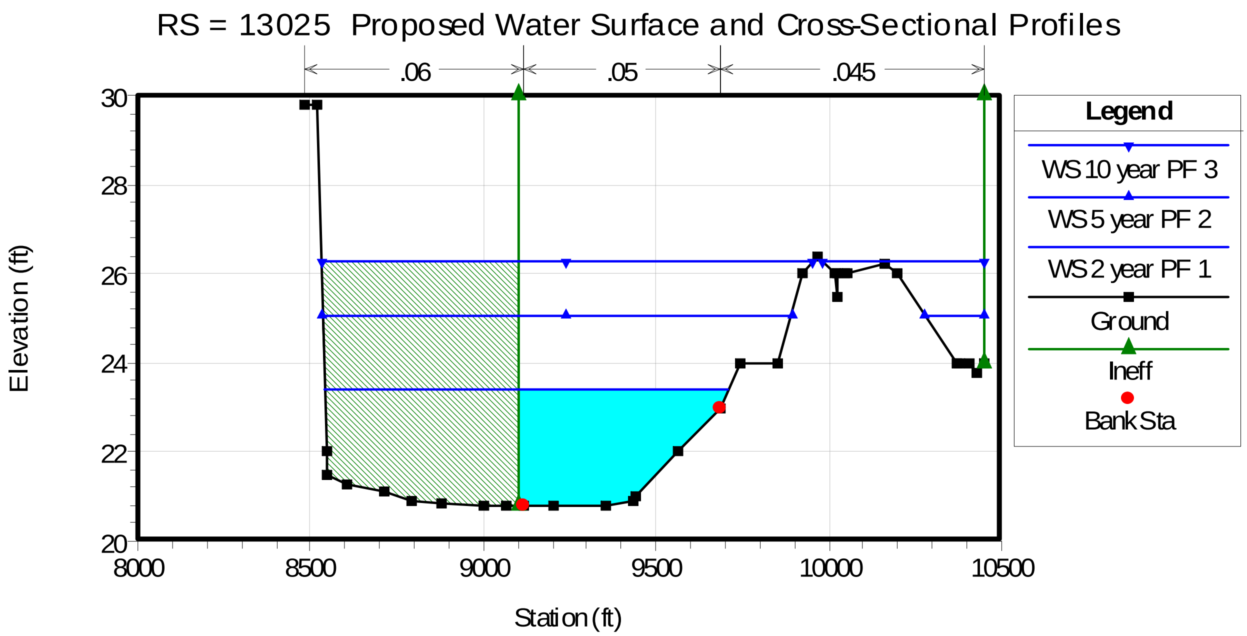
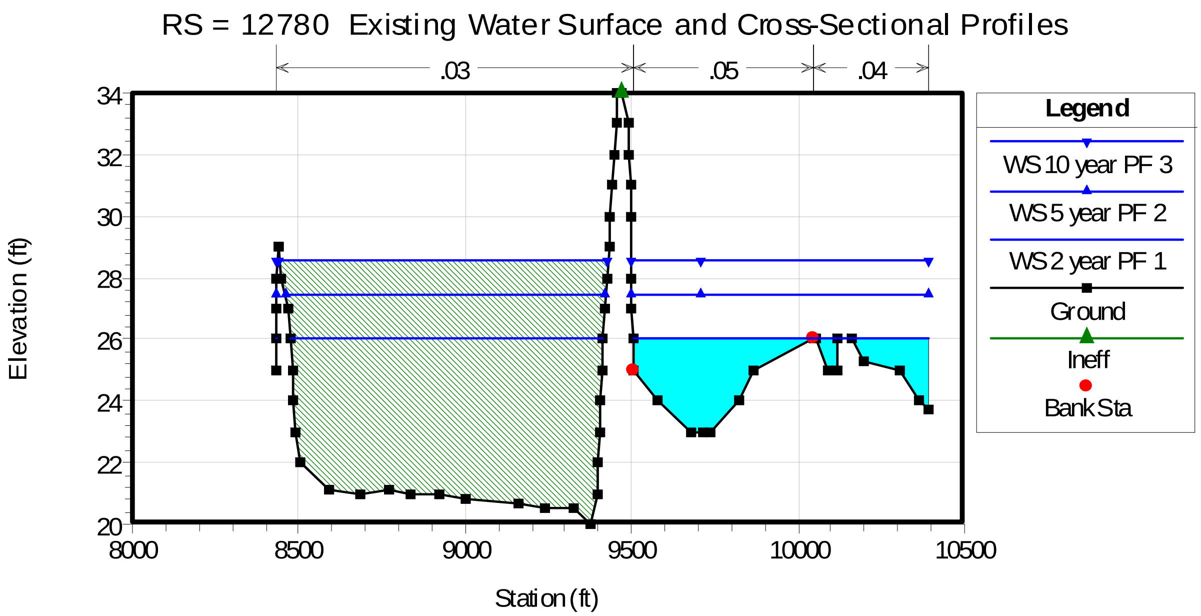


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 9,450.



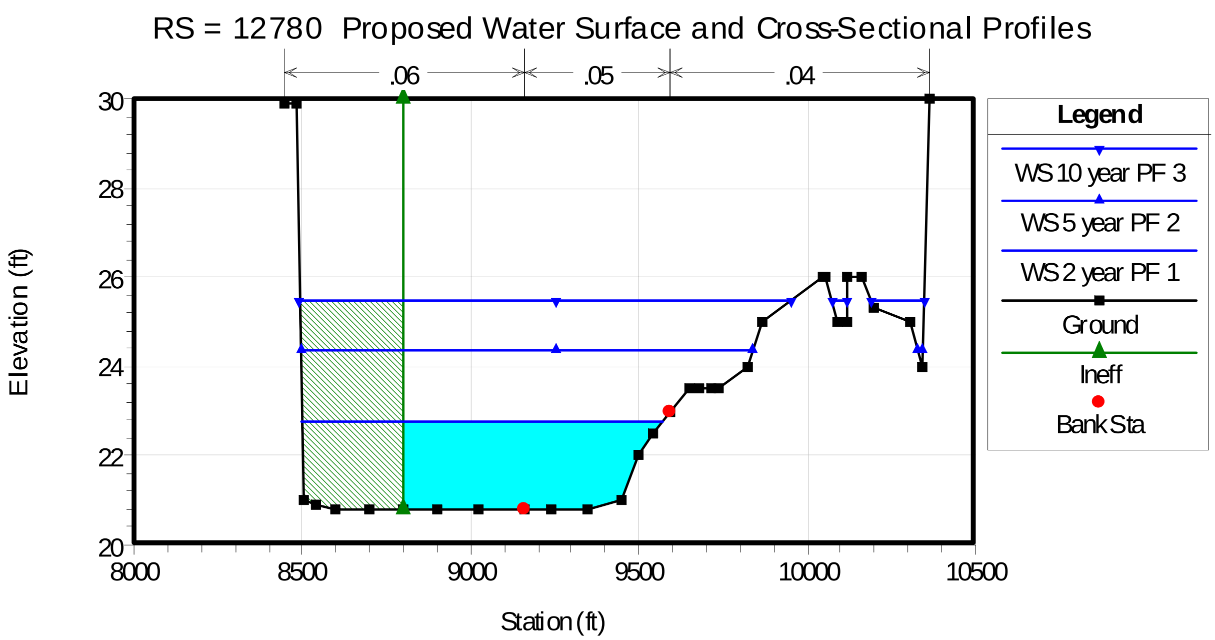
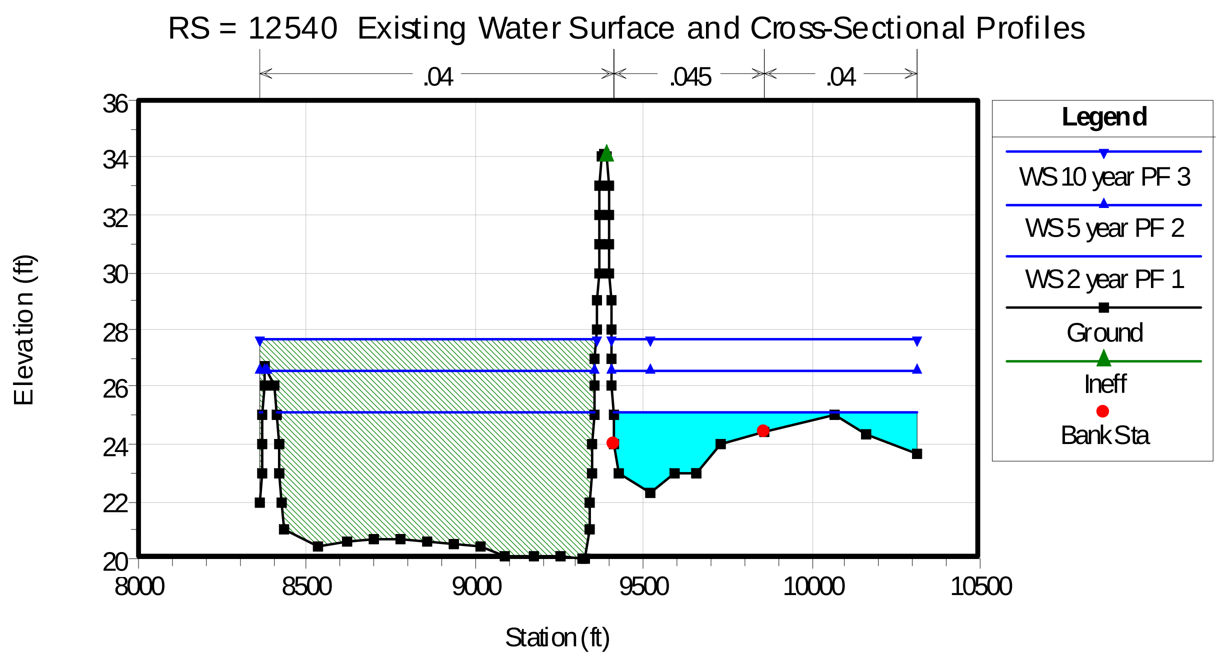


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 9,450.



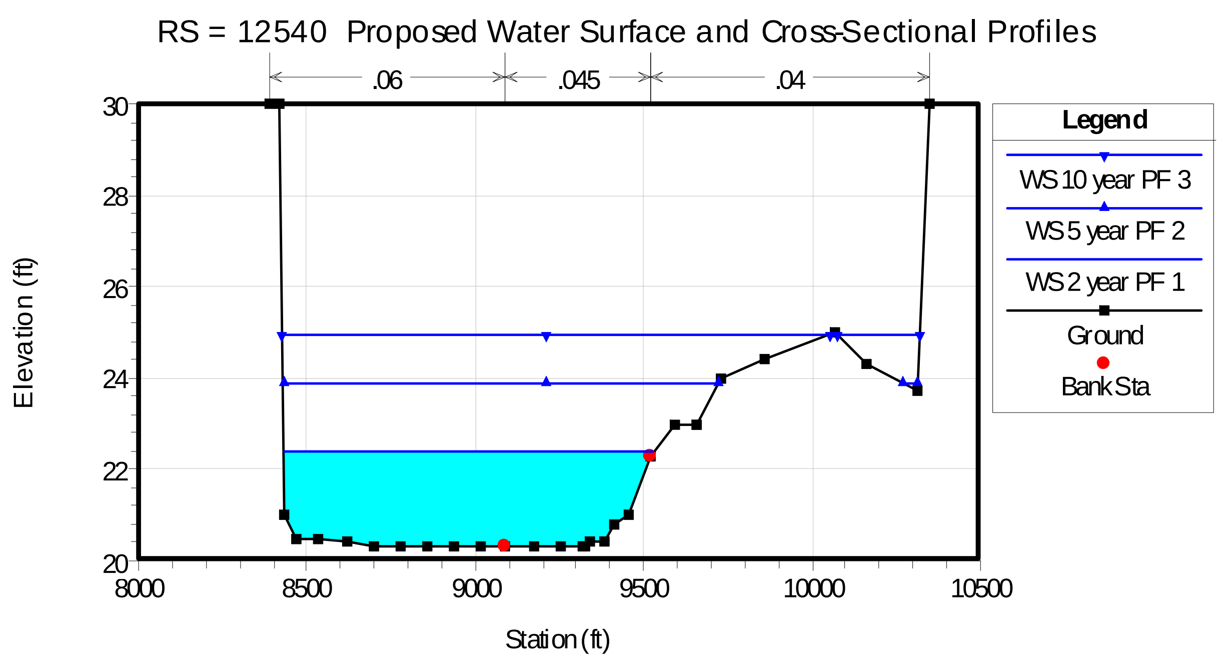
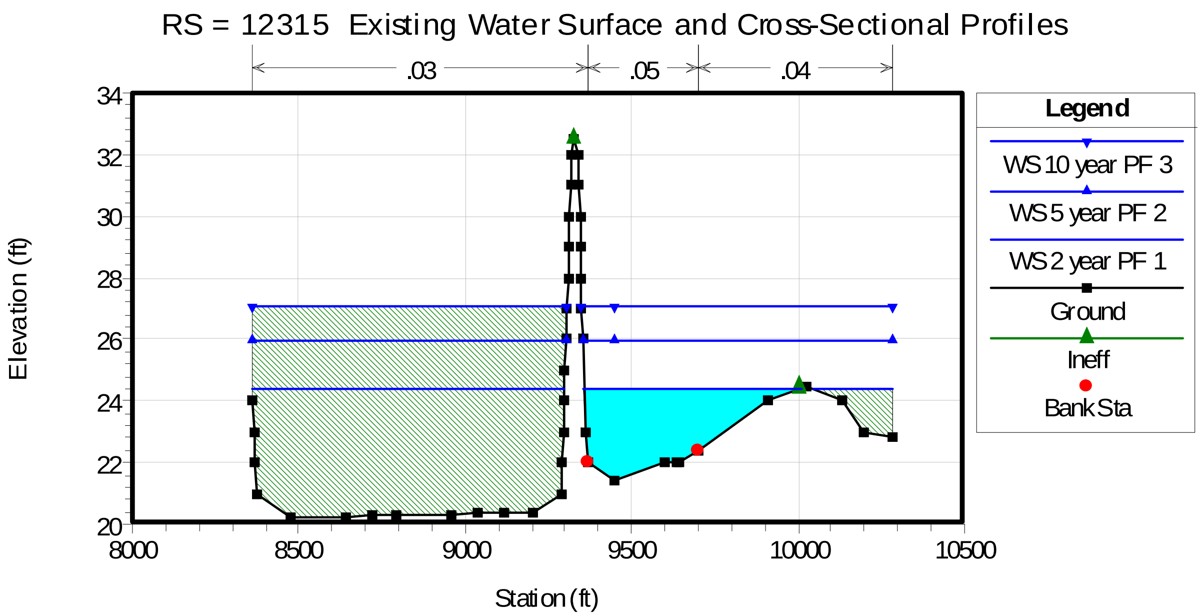


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 9,400.



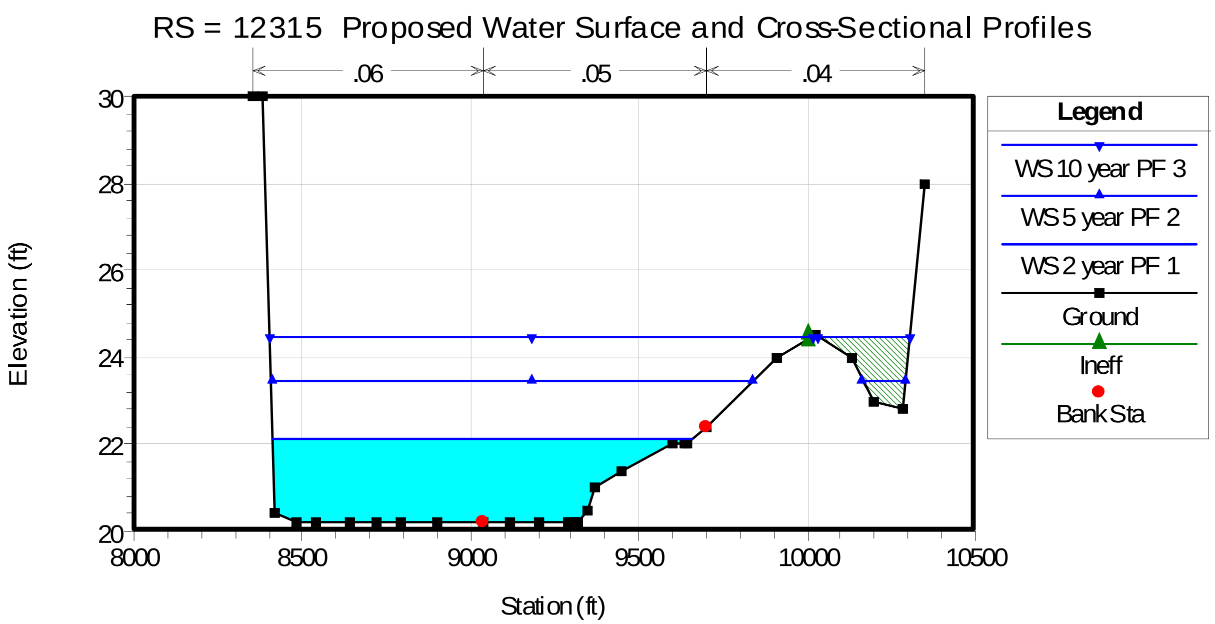
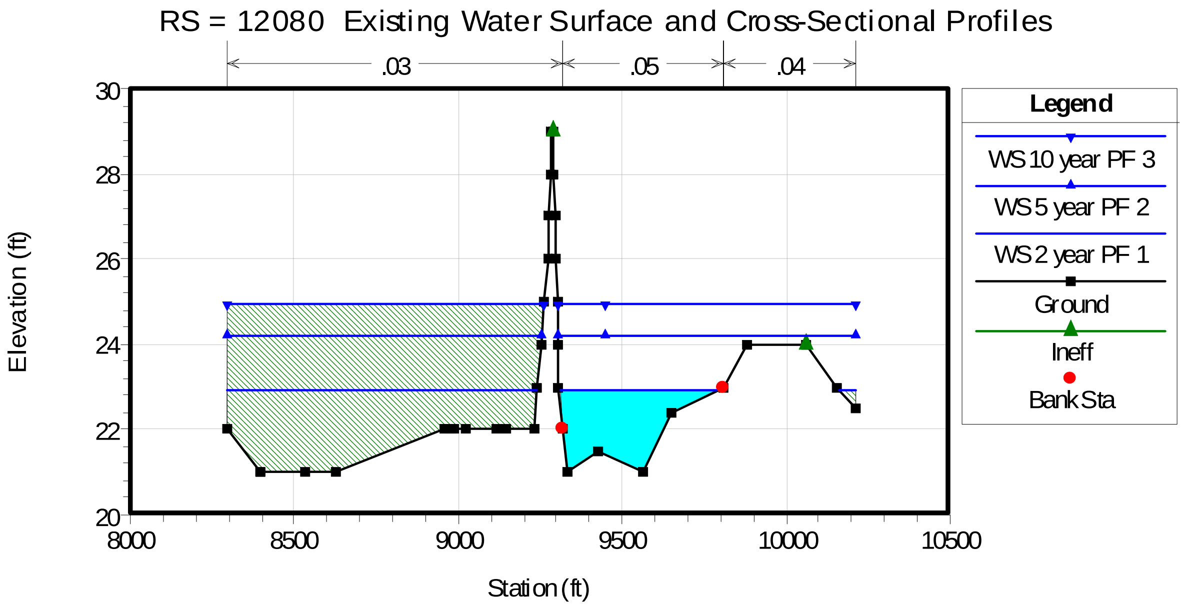


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 9,300.



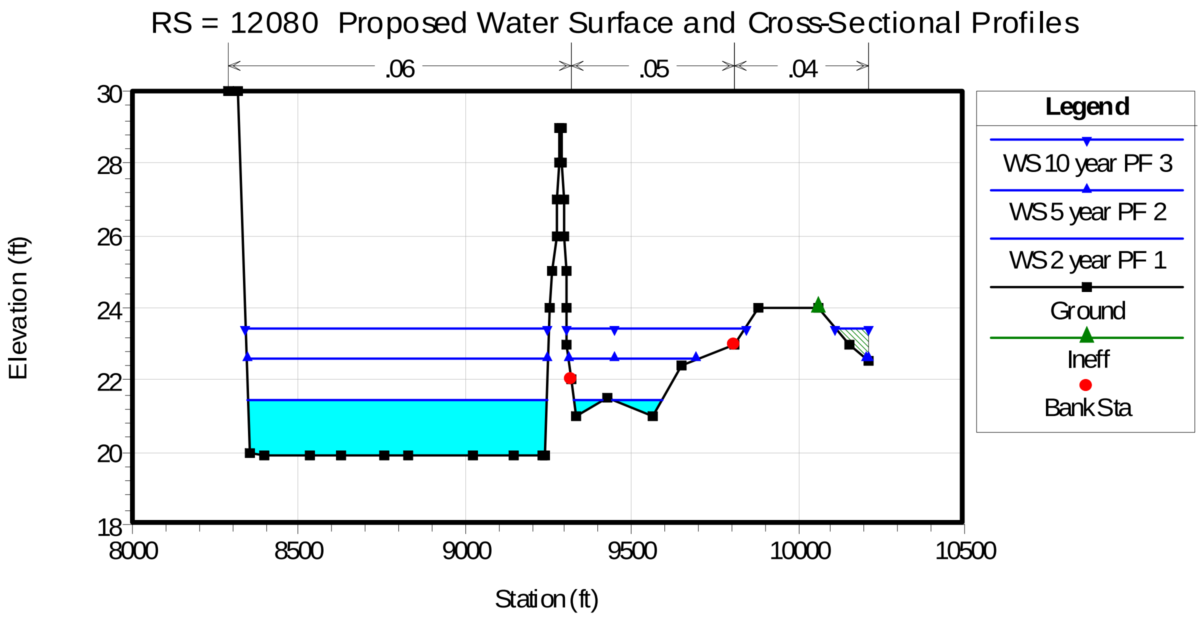
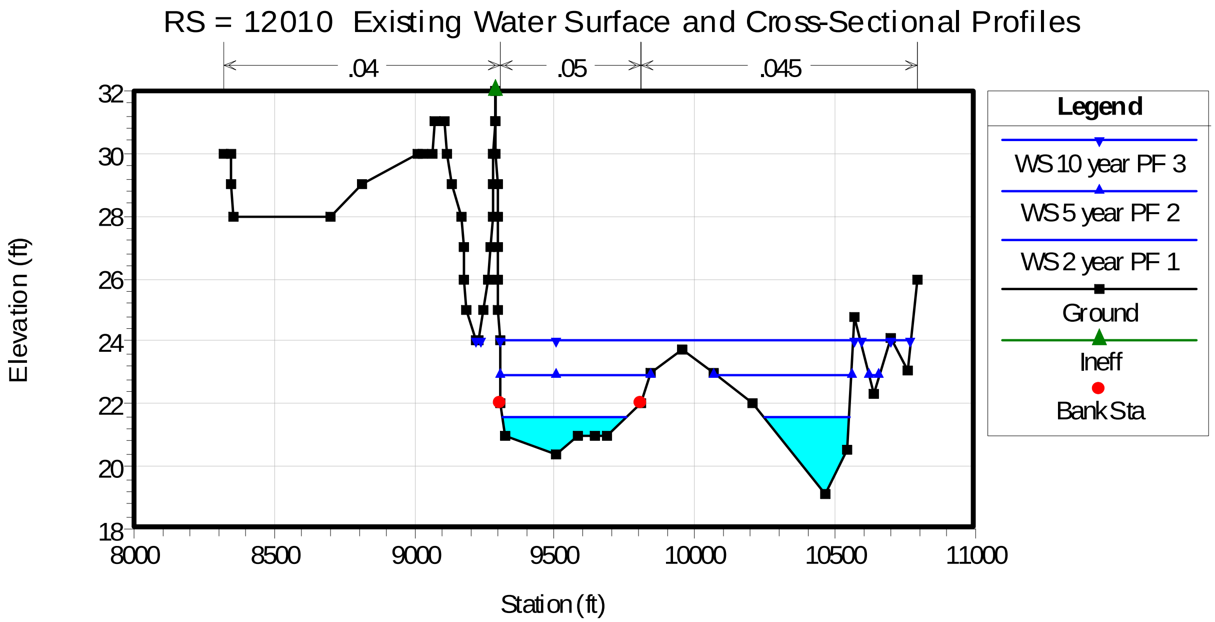


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 9,250.



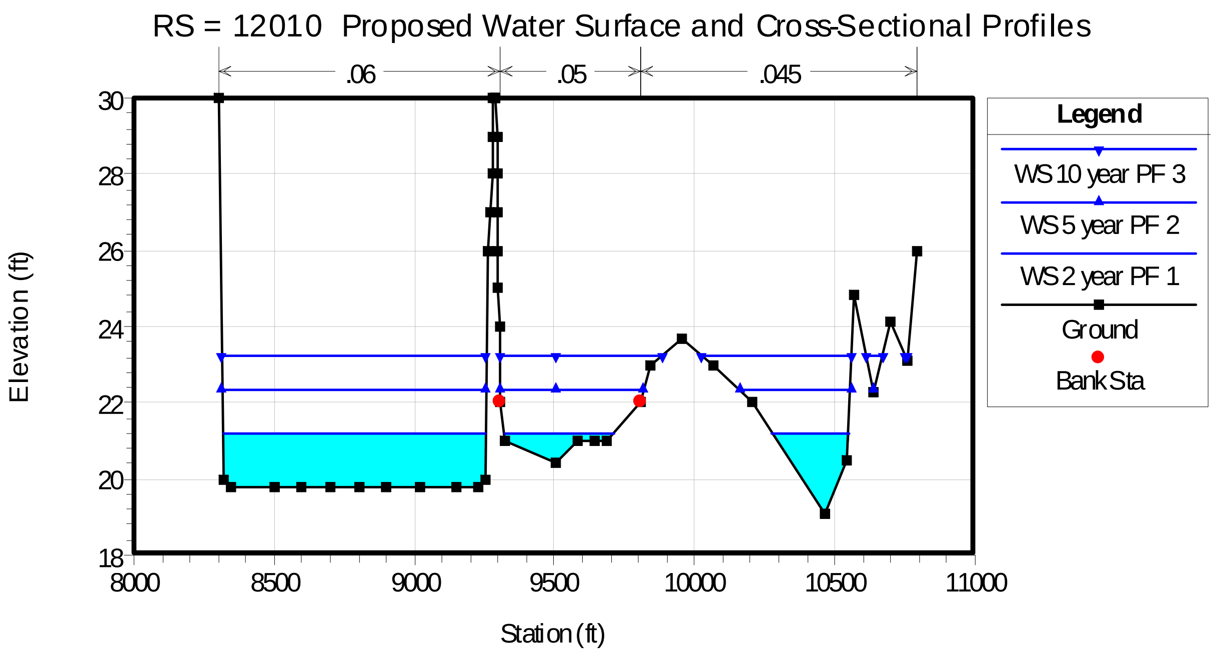
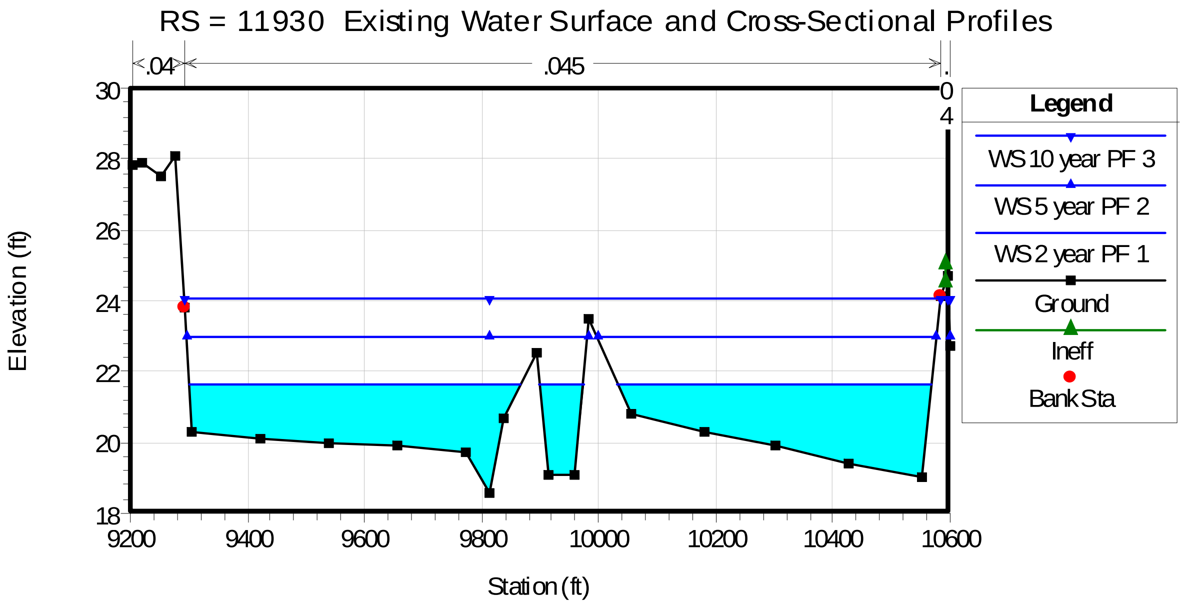


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 9,250.



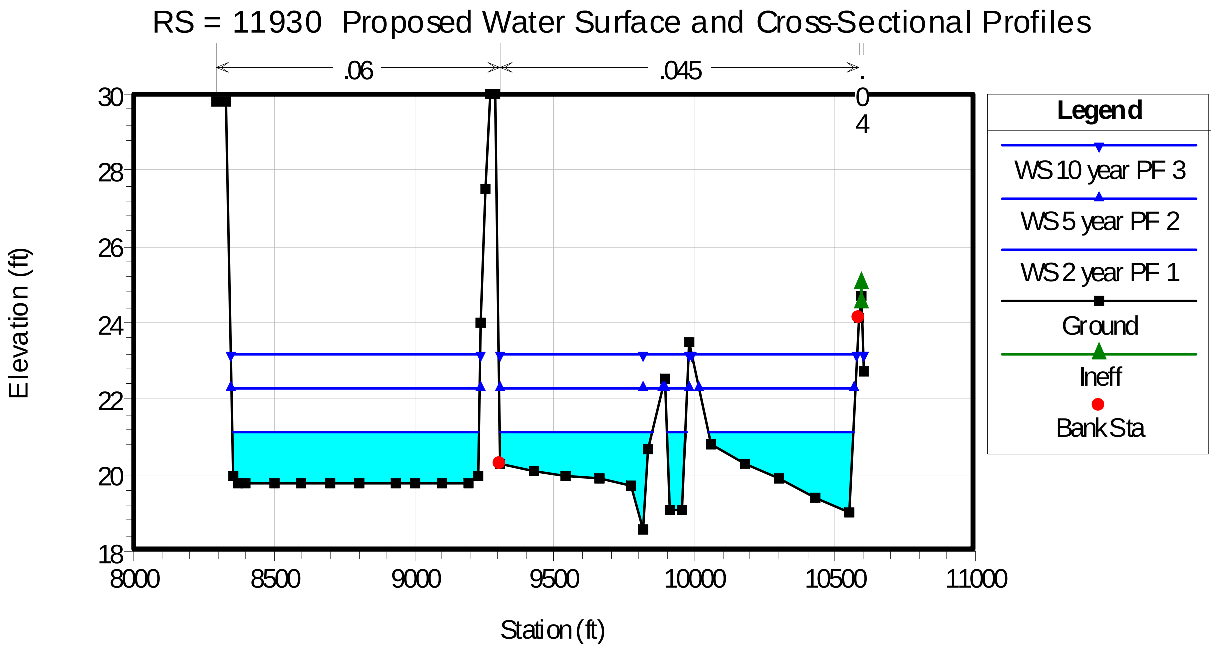
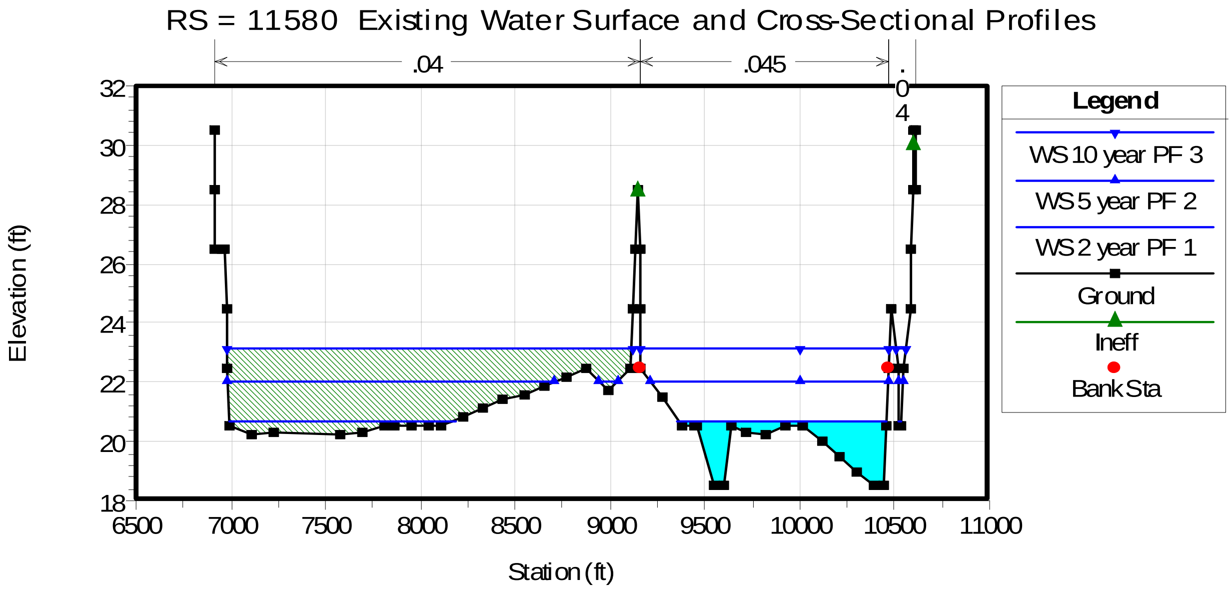


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 9,250.



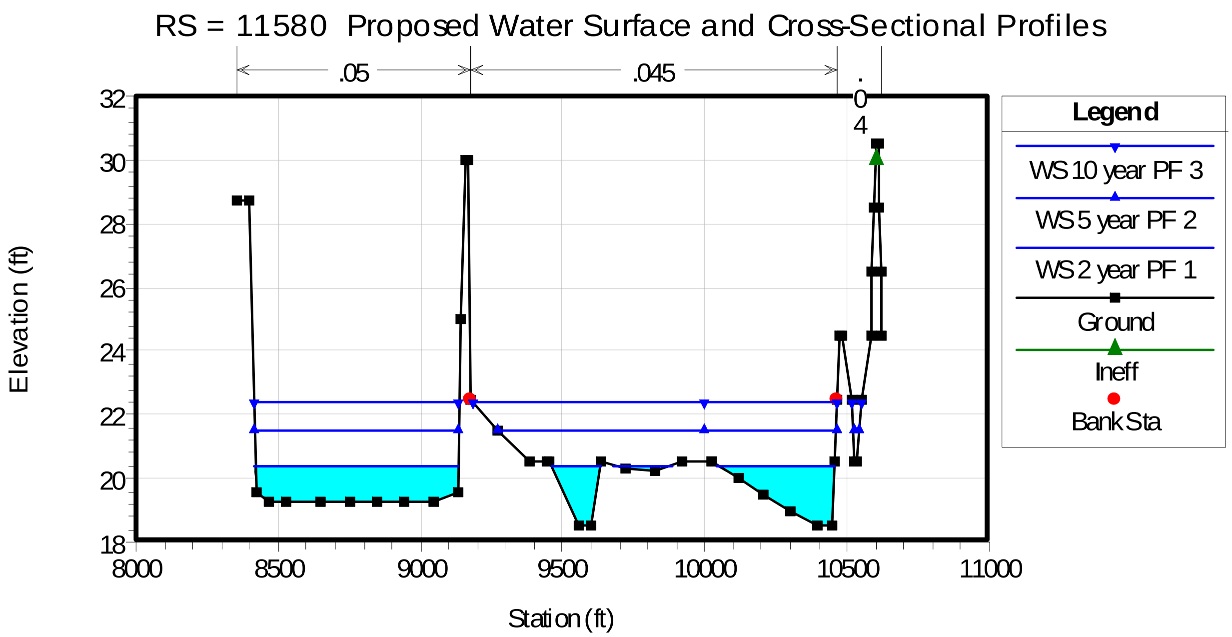
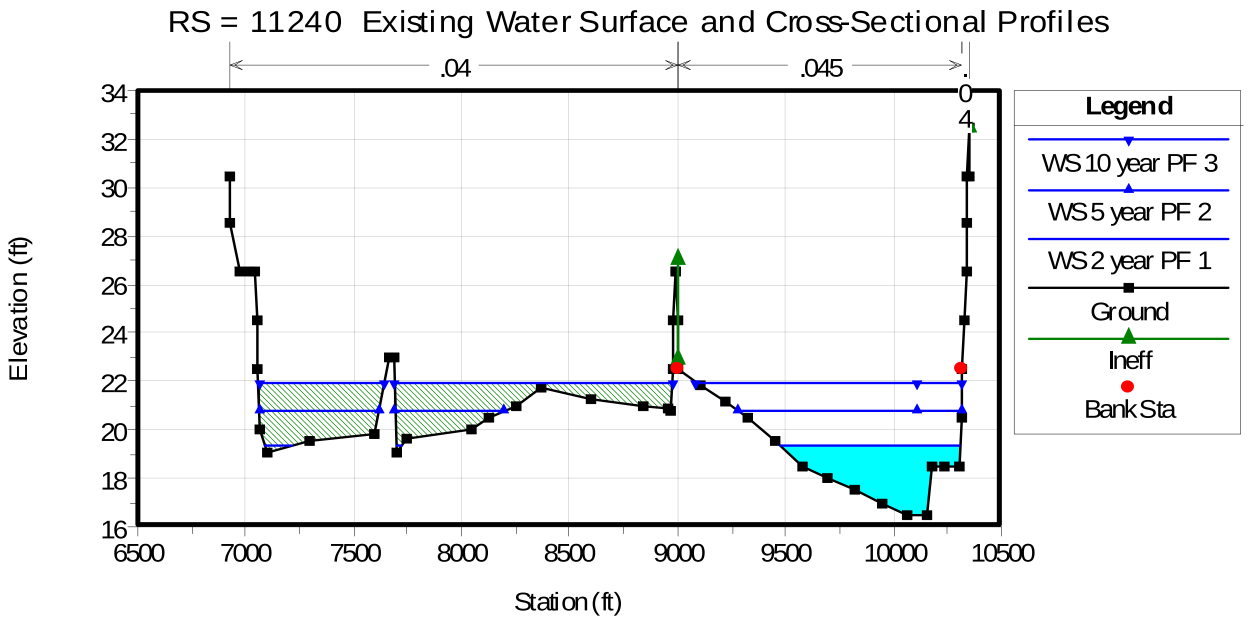


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 9,150.



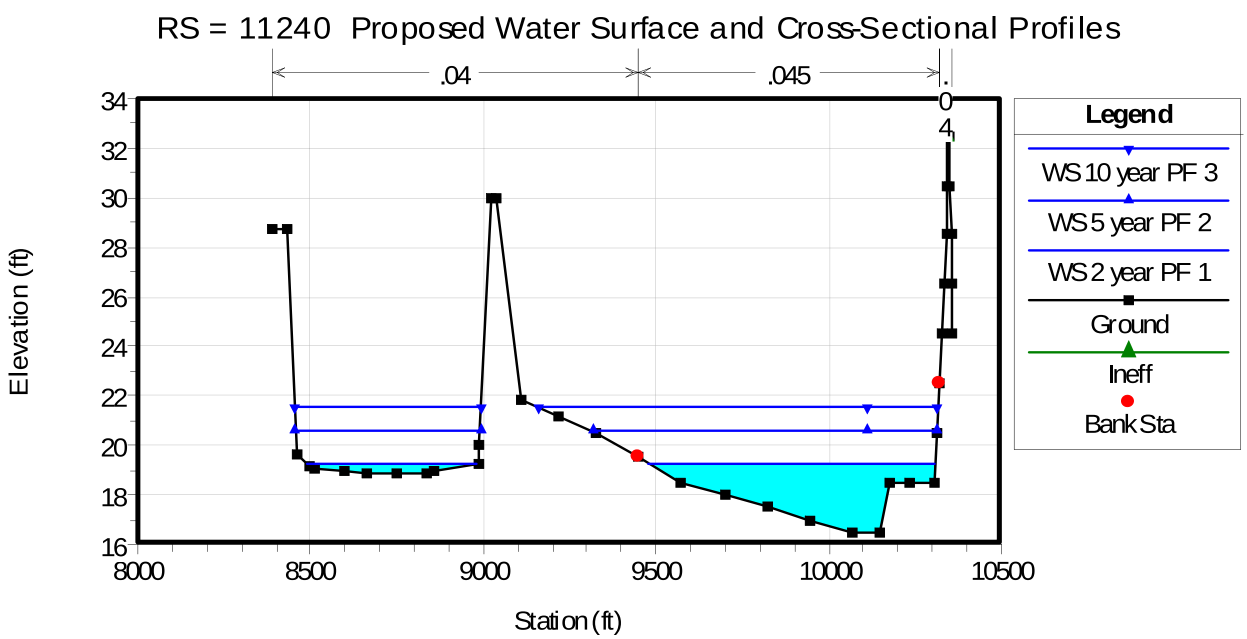
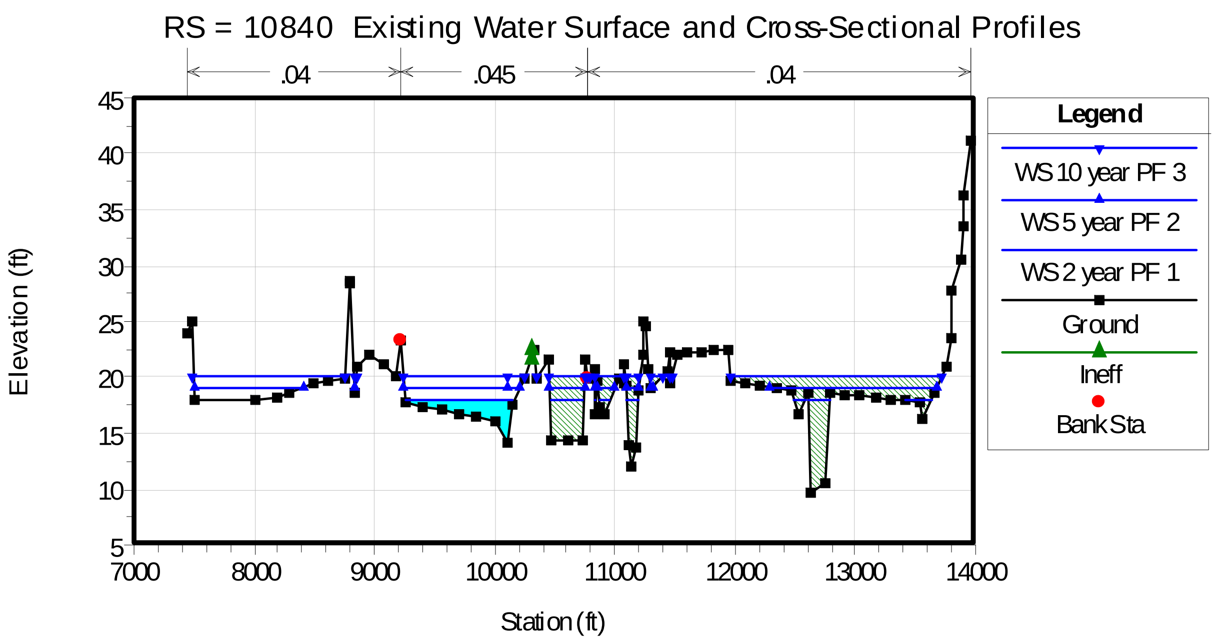


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 9,000.



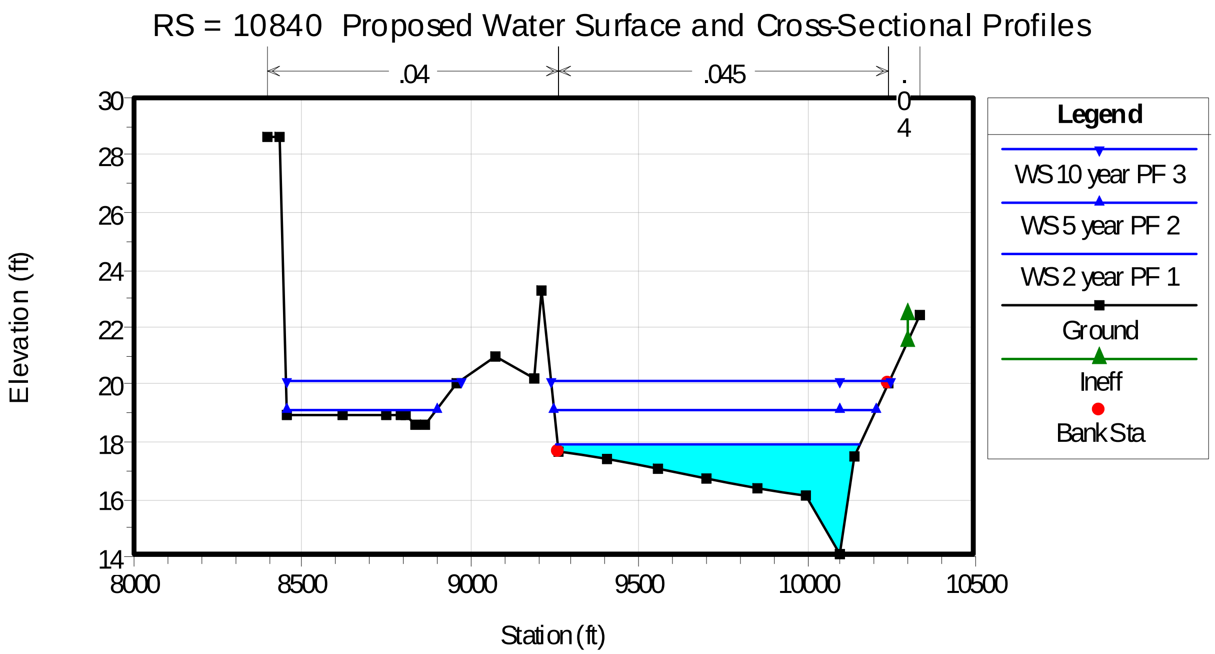
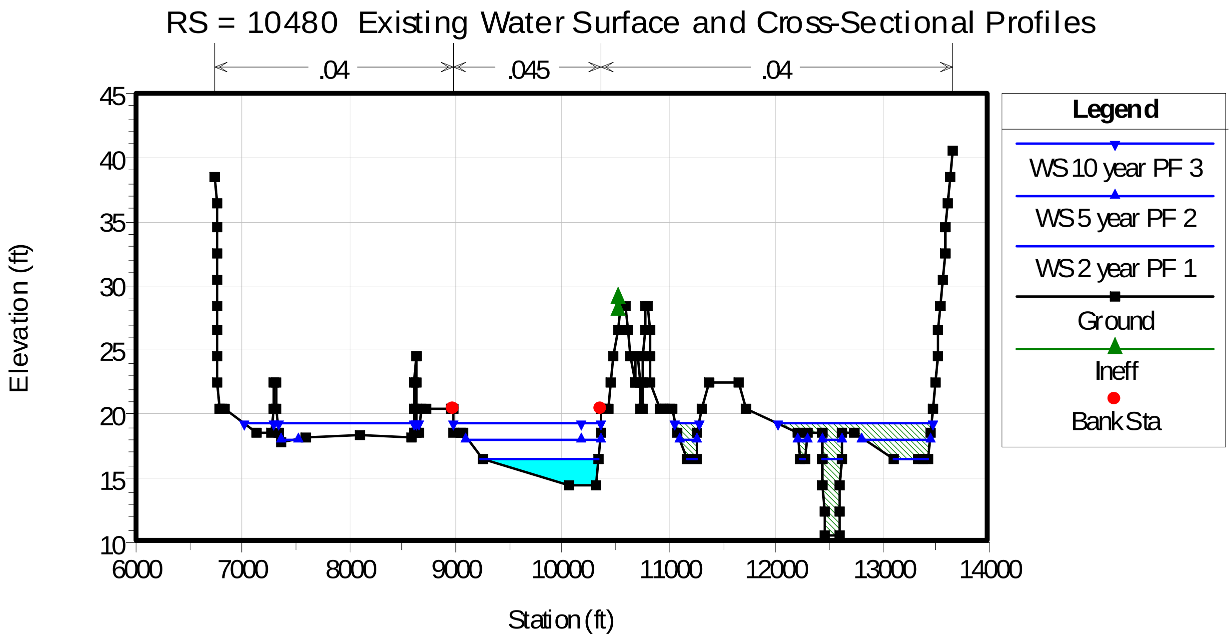


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 8,900.



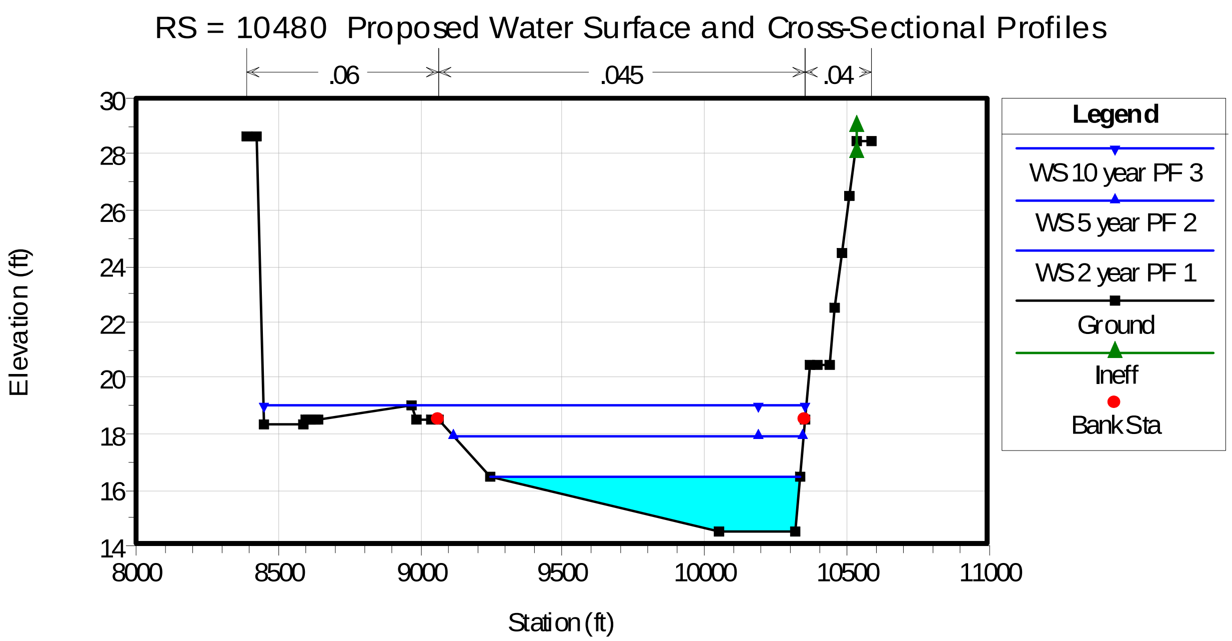
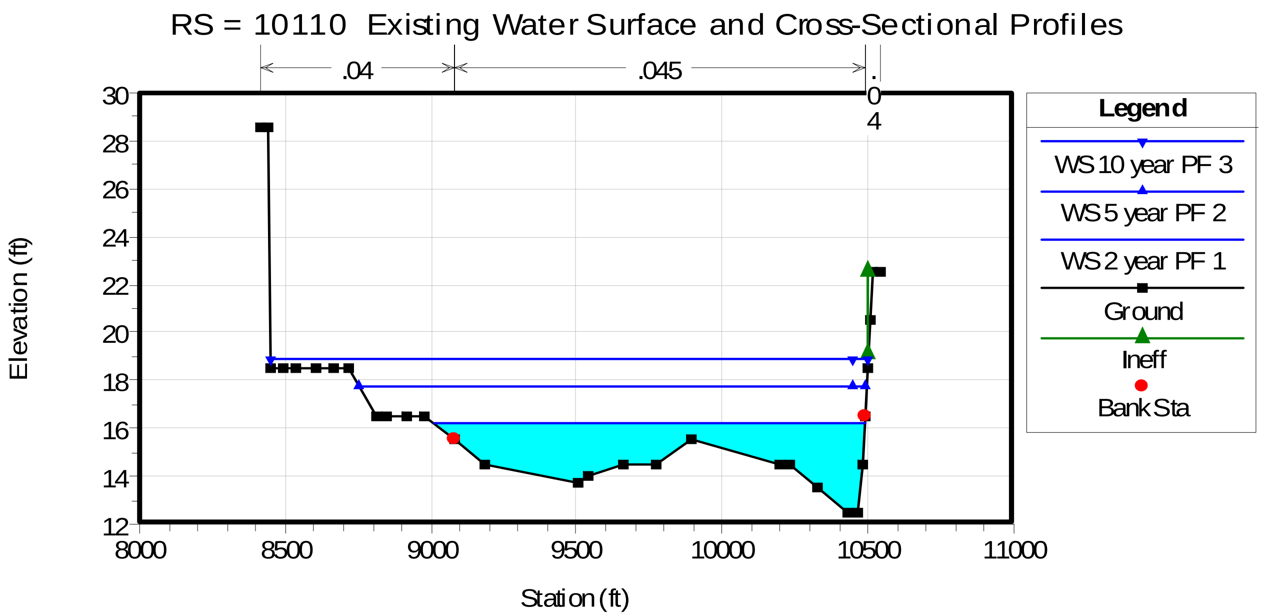


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 8,600.



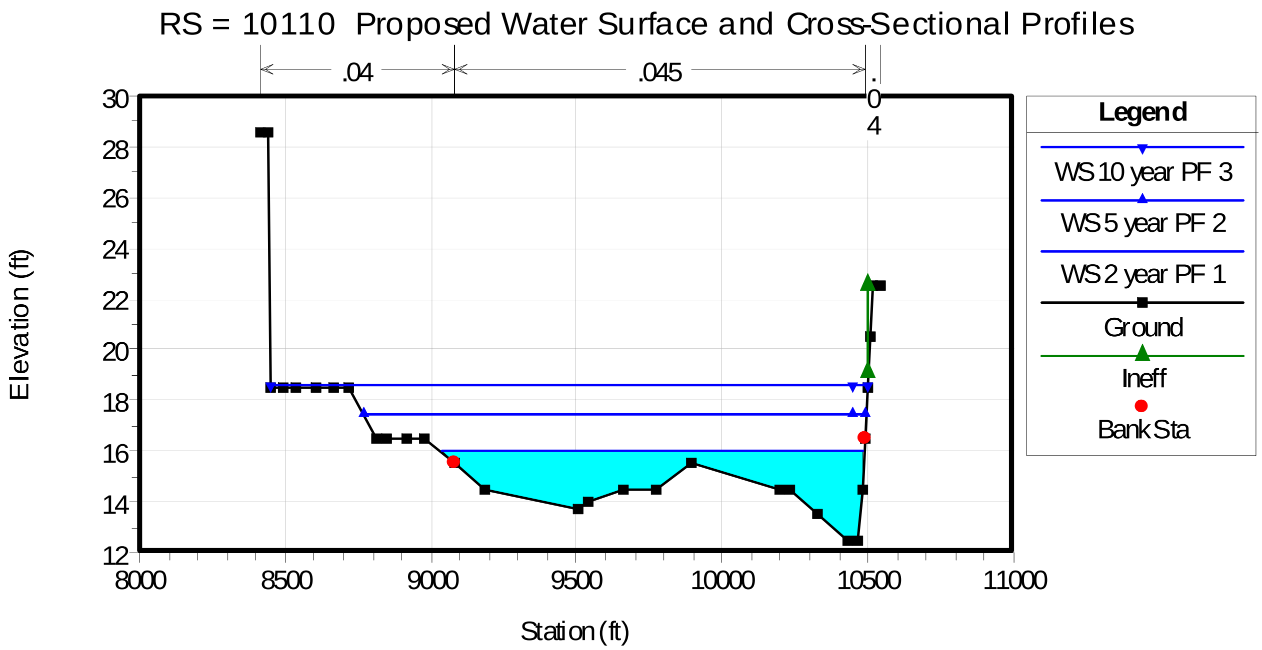
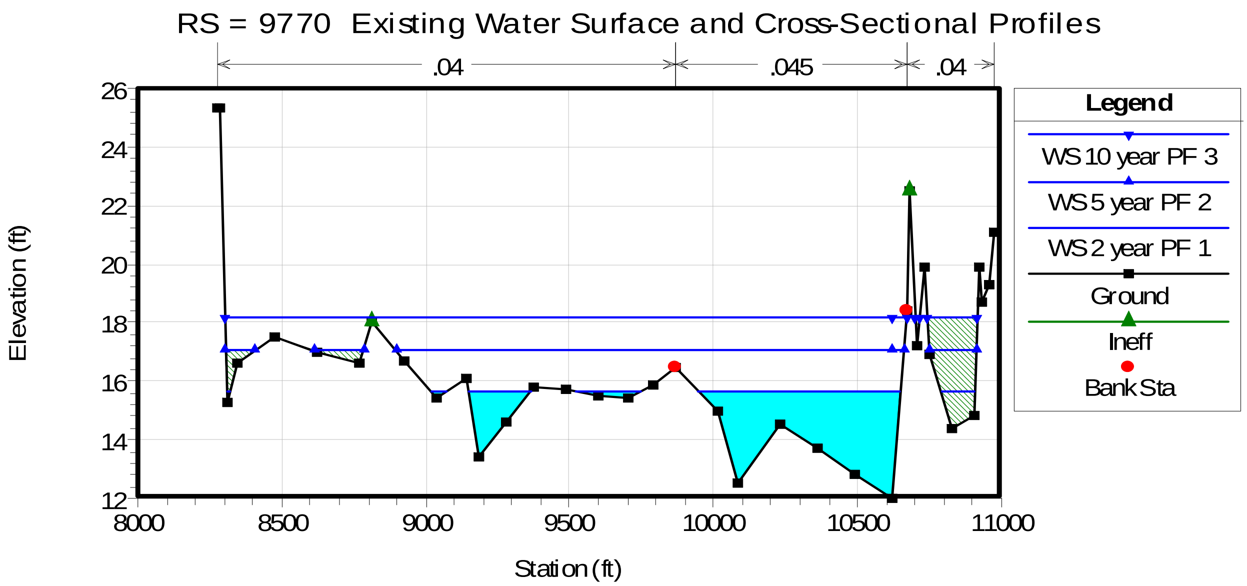


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site. The proposed wetland is to the left of station 8,500.



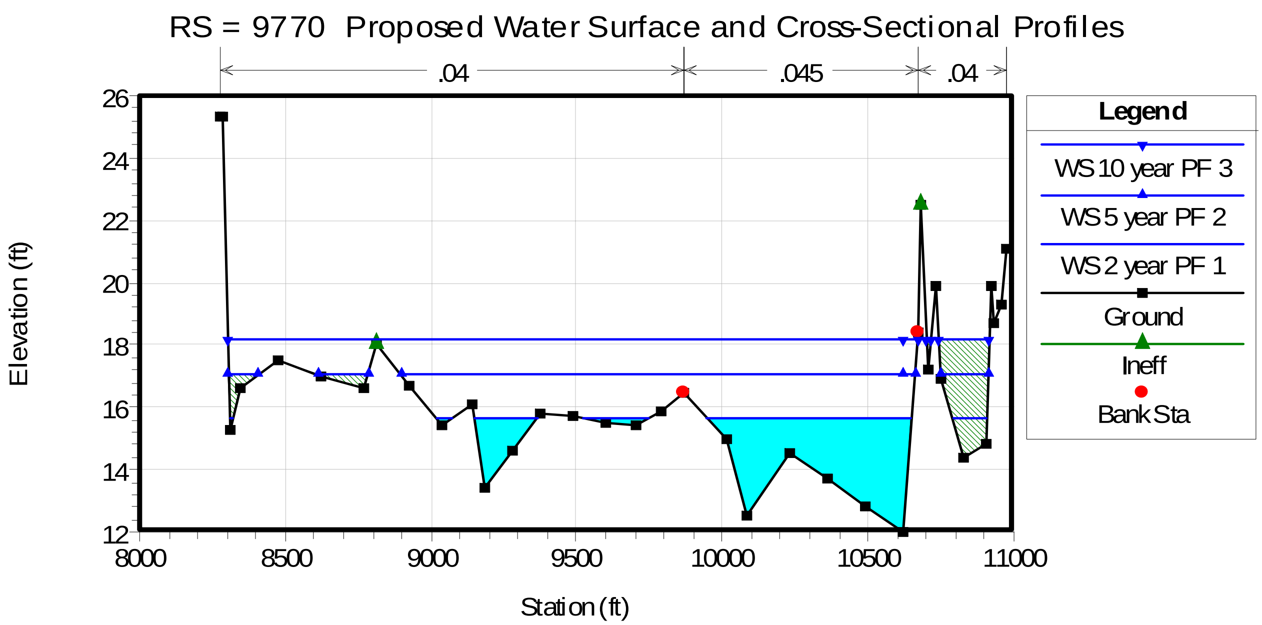
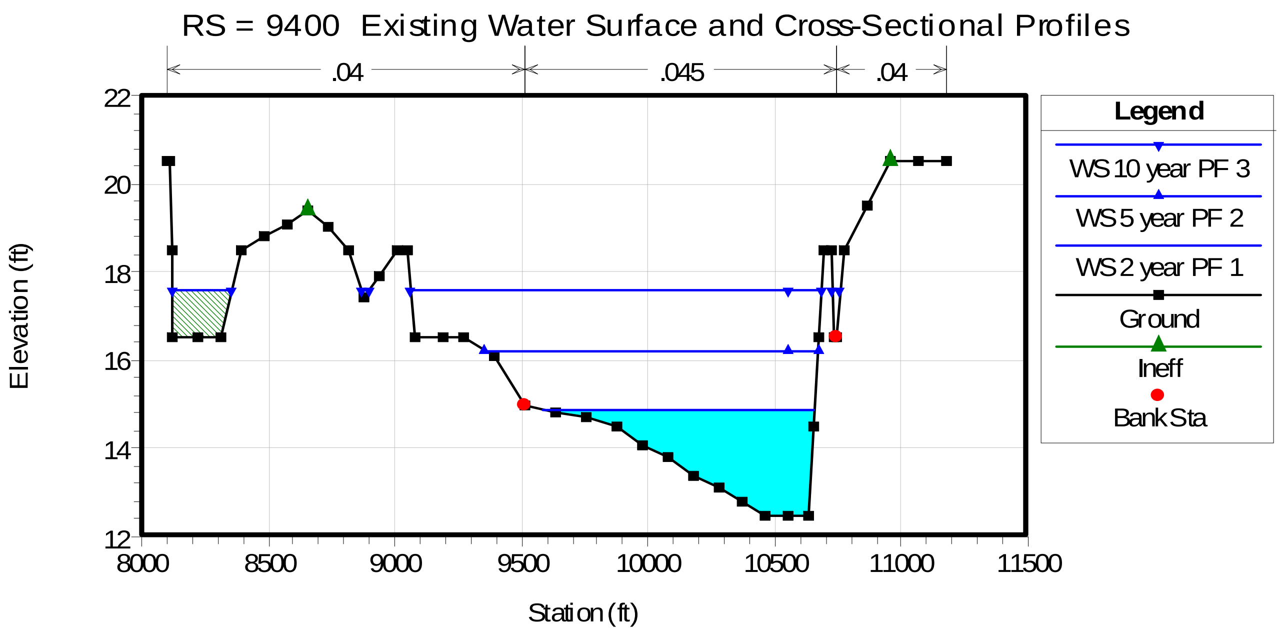


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site



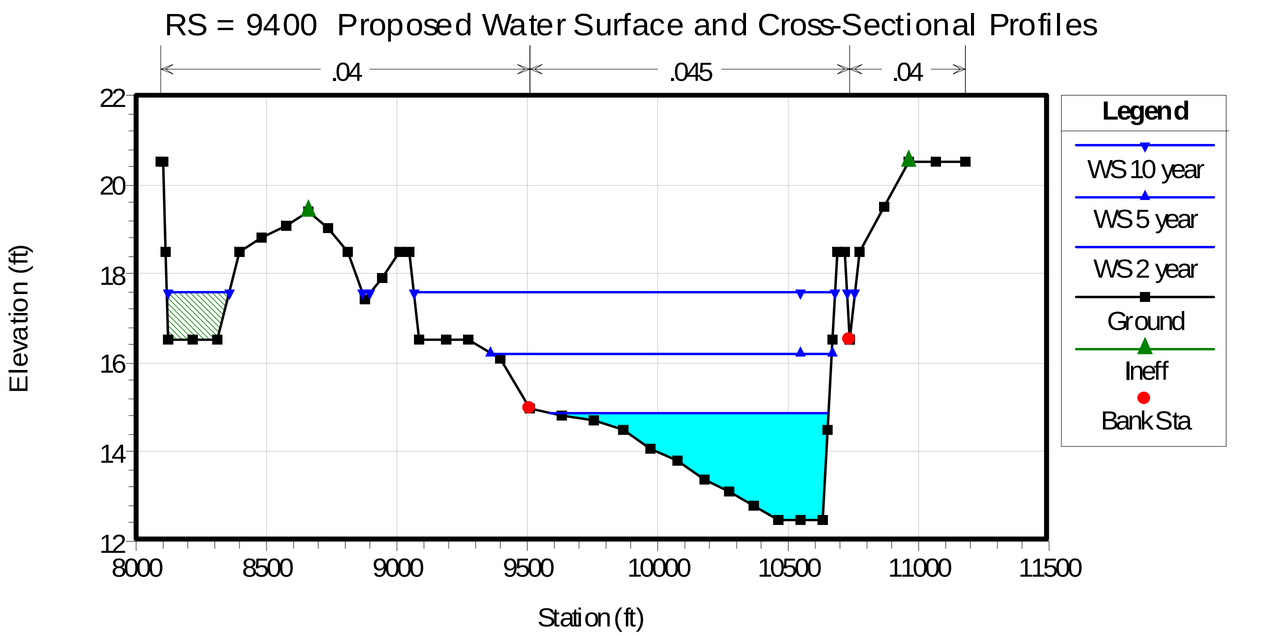
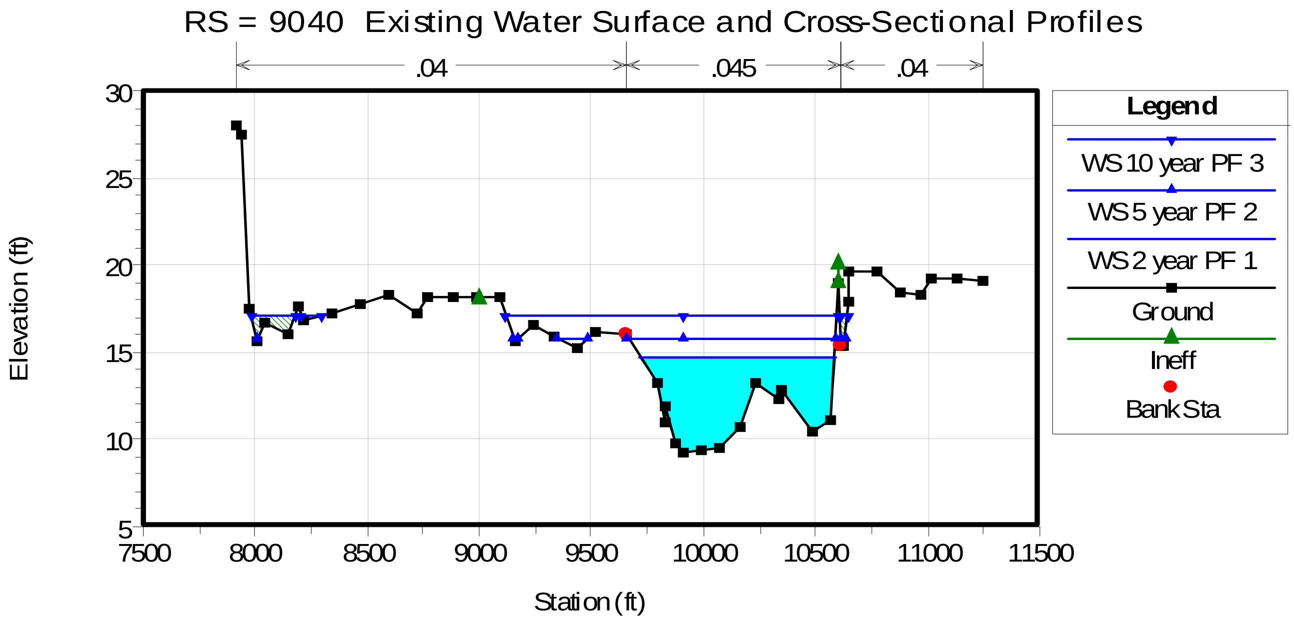


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site



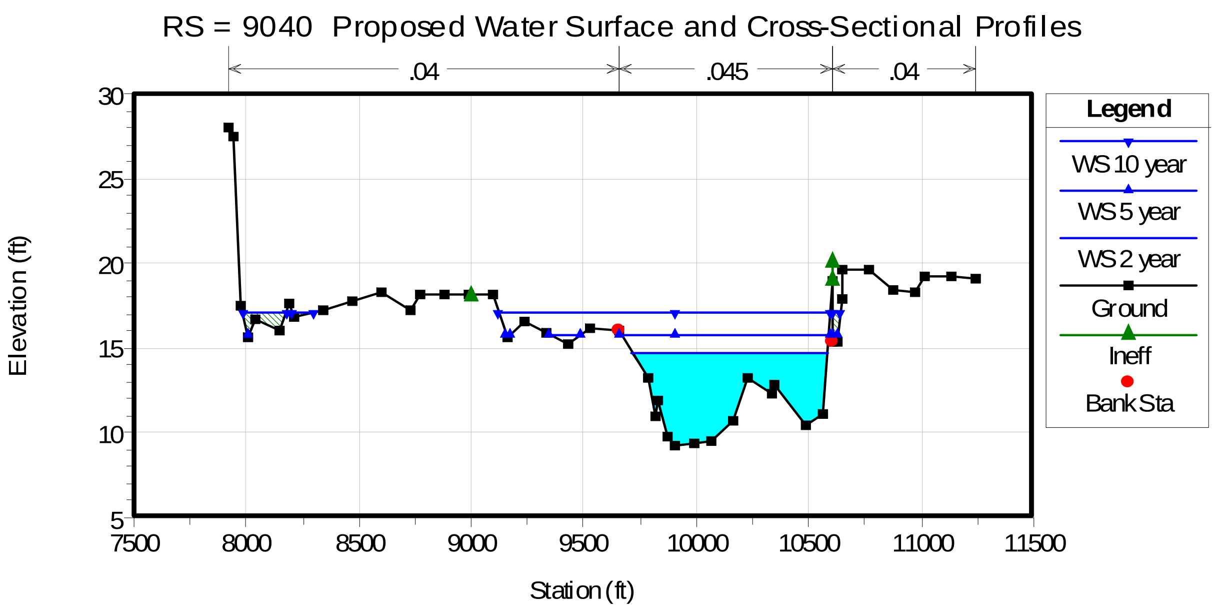
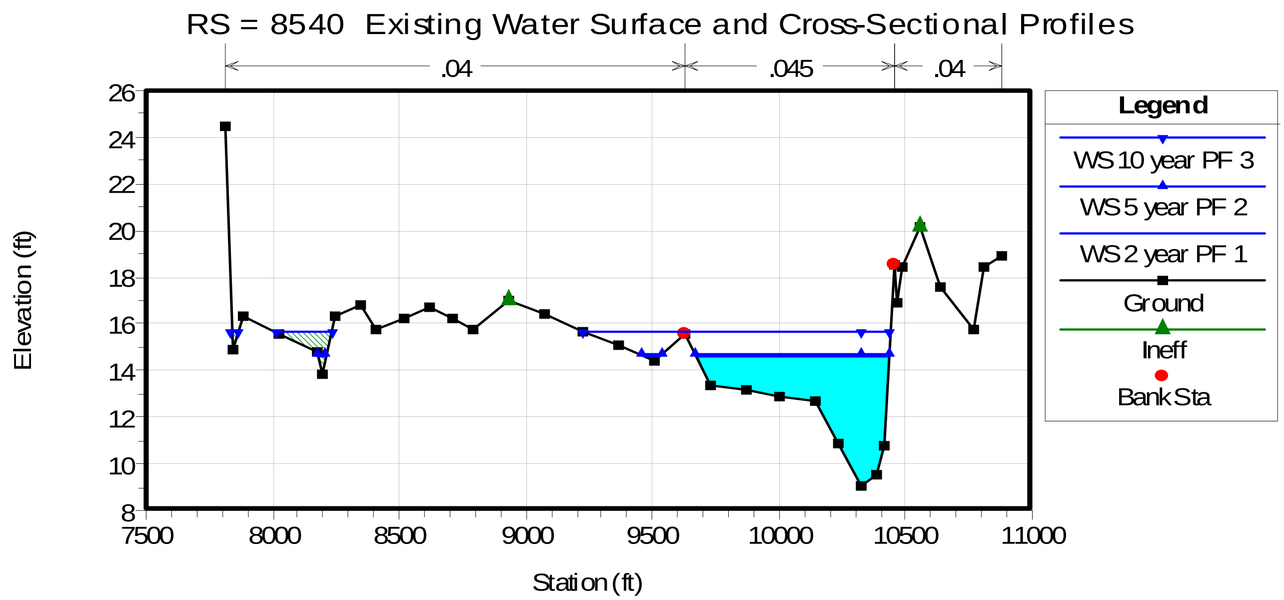


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site



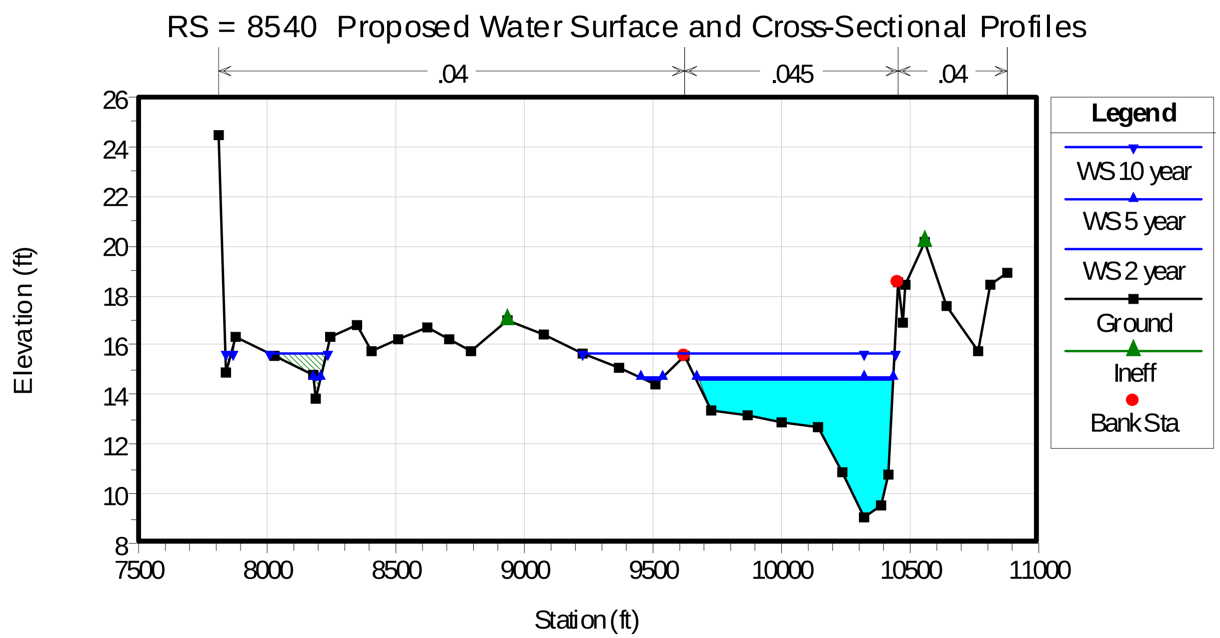


Fig. 11(continued). Water-surface and cross-sectional profiles for existing and proposed conditions near wetland site

The input parameters and computed results from the HEC-RAS hydraulic modeling for the existing and proposed conditions are summarized and listed in Table 3. The cross-sectional profiles shown in Fig. 11 are for the south branch channel. Under the proposed conditions, the 2-, 5-, and 10-yr floods can be contained in the south branch channel since their water-surface profiles are generally lower than the divider between the south and north channel branches. For the existing conditions, however, higher flows may overtop the divider and some higher discharges may overflow the divider to the north channel branch. Under this situation, the actual water-surface elevation in the south branch will be lower than the water surface shown in the figures.

Locations of the proposed wetland are shown in the cross-sectional profiles for Sections 101.10 to 132.25. These figures show that the proposed wetland from Section 112.40 to 132.25 are subject to flood inundation during the 2-yr event. The depth of inundation varies from 4 feet at Section 132.25 to almost zero at Section 112.40. The computed 2-yr water surface as shown is below the proposed wetland ground in the west portion of the wetland from Section 101.10 to 108.40. This small west portion of the proposed wetland will actually be flooded during a 2-yr flood as explained below.

Under the proposed plan, the existing berm along the north boundary of the wetland area from Section 110.00 to 123.15 will not be removed. With this berm in place, floodwater in the eastern part of the wetland will flow through the wetland area toward the west and it tends to establish a more or level water surface equal to that at Section 123.15 for the wetland all the way to the west end at Section 101.10. By separating the flow in the wetland from the river flow, the berm will keep the water in the wetland south of the berm. Since the 2-yr water surface at Section 123.15 of 22 feet is higher than western wetland ground elevation by about 2 feet, it should cause flooding of the western wetland area.

Table 3. Summary of input and computed results from hydraulic modeling study

River Sta	Profile	Plan	Q (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Froude #
14710	PF 1	Proposed	3000.00	21.10	27.84	1.64	0.12
14710	PF 1	Existing	3000.00	21.10	27.99	1.58	0.12
14710	PF 2	Proposed	9400.00	21.10	29.49	3.70	0.24
14710	PF 2	Existing	9400.00	21.10	29.69	3.57	0.23
14710	PF 3	Proposed	17000.00	21.10	30.44	4.01	0.25
14710	PF 3	Existing	17000.00	21.10	30.76	3.71	0.23
14535	PF 1	Proposed	3000.00	21.20	27.76	1.86	0.16
14535	PF 1	Existing	3000.00	21.20	27.92	1.79	0.15
14535	PF 2	Proposed	9400.00	21.20	29.54	1.53	0.11
14535	PF 2	Existing	9400.00	21.20	29.74	1.46	0.11
14535	PF 3	Proposed	17000.00	21.20	30.42	2.27	0.15
14535	PF 3	Existing	17000.00	21.20	30.73	2.13	0.14
14335	PF 1	Proposed	3000.00	21.20	27.69	1.58	0.14
14335	PF 1	Existing	3000.00	21.20	27.86	1.51	0.13
14335	PF 2	Proposed	9400.00	21.20	29.32	3.33	0.25
14335	PF 2	Existing	9400.00	21.20	29.72	1.00	0.07
14335	PF 3	Proposed	17000.00	21.20	30.38	1.62	0.11
14335	PF 3	Existing	17000.00	21.20	30.71	1.53	0.10
14110	PF 1	Proposed	3000.00	22.40	27.63	1.30	0.12
14110	PF 1	Existing	3000.00	22.40	27.80	1.23	0.11
14110	PF 2	Proposed	9400.00	22.40	29.39	0.72	0.06
14110	PF 2	Existing	9400.00	22.40	29.71	0.69	0.05
14110	PF 3	Proposed	17000.00	22.40	30.36	1.15	0.08
14110	PF 3	Existing	17000.00	22.40	30.69	1.10	0.08

River Sta	Profile	Plan	Q (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Froude #
13910	PF 1	Proposed	3000.00	23.50	27.57	1.27	0.12
13910	PF 1	Existing	3000.00	23.50	27.75	1.19	0.11
13910	PF 2	Proposed	9400.00	23.50	29.38	0.71	0.06
13910	PF 2	Existing	9400.00	23.50	29.71	0.68	0.05
13910	PF 3	Proposed	17000.00	23.50	30.34	1.13	0.08
13910	PF 3	Existing	17000.00	23.50	30.67	1.08	0.08
13710	PF 1	Proposed	3000.00	24.00	27.53	0.88	0.09
13710	PF 1	Existing	3000.00	24.00	27.72	0.83	0.08
13710	PF 2	Proposed	9400.00	24.00	29.31	1.76	0.14
13710	PF 2	Existing	9400.00	24.00	29.65	1.65	0.13
13710	PF 3	Proposed	17000.00	24.00	30.19	2.72	0.20
13710	PF 3	Existing	17000.00	24.00	30.54	2.56	0.19
13490	PF 1	Proposed	3000.00	24.10	27.41	1.82	0.22
13490	PF 1	Existing	3000.00	24.10	27.63	1.62	0.19
13490	PF 2	Proposed	9400.00	24.10	29.08	2.95	0.27
13490	PF 2	Existing	9400.00	24.10	29.47	2.65	0.23
13490	PF 3	Proposed	17000.00	24.10	29.72	4.49	0.38
13490	PF 3	Existing	17000.00	24.10	30.51	1.41	0.11
13225	PF 1	Proposed	3000.00	23.40	25.71	6.70	1.00
13225	PF 1	Existing	3000.00	23.40	27.17	2.49	0.31
13225	PF 2	Proposed	9400.00	23.40	27.04	7.62	0.99
13225	PF 2	Existing	9400.00	23.40	28.75	4.31	0.41
13225	PF 3	Proposed	17000.00	23.40	27.96	9.27	0.99
13225	PF 3	Existing	17000.00	23.40	30.00	4.90	0.40
13025	PF 1	Proposed	3000.00	20.80	23.42	2.44	0.30
13025	PF 1	Existing	3000.00	24.00	26.73	2.21	0.27
13025	PF 2	Proposed	9400.00	20.80	25.06	4.00	0.36

River Sta	Profile	Plan	Q (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Froude #
13025	PF 2	Existing	9400.00	24.00	28.21	3.49	0.32
13025	PF 3	Proposed	17000.00	20.80	26.26	5.09	0.40
13025	PF 3	Existing	17000.00	24.00	29.44	4.46	0.36
12780	PF 1	Proposed	3000.00	20.80	22.79	2.23	0.31
12780	PF 1	Existing	3000.00	23.00	26.05	2.52	0.34
12780	PF 2	Proposed	9400.00	20.80	24.34	3.64	0.37
12780	PF 2	Existing	9400.00	23.00	27.41	3.82	0.38
12780	PF 3	Proposed	17000.00	20.80	25.47	4.65	0.40
12780	PF 3	Existing	17000.00	23.00	28.56	4.78	0.41
12540	PF 1	Proposed	3000.00	20.30	22.42	1.60	0.21
12540	PF 1	Existing	3000.00	22.30	25.13	3.03	0.40
12540	PF 2	Proposed	9400.00	20.30	23.87	2.87	0.28
12540	PF 2	Existing	9400.00	22.30	26.53	4.21	0.41
12540	PF 3	Proposed	17000.00	20.30	24.96	3.78	0.32
12540	PF 3	Existing	17000.00	22.30	27.68	5.15	0.43
12315	PF 1	Proposed	3000.00	20.20	22.11	1.44	0.23
12315	PF 1	Existing	3000.00	21.40	24.46	2.79	0.30
12315	PF 2	Proposed	9400.00	20.20	23.46	2.55	0.28
12315	PF 2	Existing	9400.00	21.40	25.96	3.60	0.31
12315	PF 3	Proposed	17000.00	20.20	24.48	3.40	0.32
12315	PF 3	Existing	17000.00	21.40	27.07	4.55	0.35
12080	PF 1	Proposed	3000.00	21.00	21.47	0.72	0.26
12080	PF 1	Existing	3000.00	21.00	22.82	5.97	0.99
12080	PF 2	Proposed	9400.00	21.00	22.62	2.25	0.38
12080	PF 2	Existing	9400.00	21.00	24.19	7.17	0.82
12080	PF 3	Proposed	17000.00	21.00	23.52	3.23	0.43
12080	PF 3	Existing	17000.00	21.00	24.92	8.75	0.87

River Sta	Profile	Plan	Q (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Froude #
12010	PF 1	Proposed	3000.00	20.40	21.27	0.89	0.23
12010	PF 1	Existing	3000.00	20.40	21.69	2.67	0.53
12010	PF 2	Proposed	9400.00	20.40	22.41	2.03	0.30
12010	PF 2	Existing	9400.00	20.40	23.09	4.31	0.52
12010	PF 3	Proposed	17000.00	20.40	23.34	2.84	0.33
12010	PF 3	Existing	17000.00	20.40	24.20	5.06	0.50
11930	PF 1	Proposed	3000.00	18.60	21.15	1.28	0.20
11930	PF 1	Existing	3000.00	18.60	21.64	1.51	0.20
11930	PF 2	Proposed	9400.00	18.60	22.28	2.10	0.25
11930	PF 2	Existing	9400.00	18.60	23.01	2.57	0.27
11930	PF 3	Proposed	17000.00	18.60	23.20	2.71	0.27
11930	PF 3	Existing	17000.00	18.60	24.10	3.36	0.30
11580	PF 1	Proposed	3000.00	18.50	20.41	1.99	0.38
11580	PF 1	Existing	3000.00	18.50	20.74	2.93	0.54
11580	PF 2	Proposed	9400.00	18.50	21.51	2.59	0.36
11580	PF 2	Existing	9400.00	18.50	22.05	3.62	0.44
11580	PF 3	Proposed	17000.00	18.50	22.43	3.12	0.36
11580	PF 3	Existing	17000.00	18.50	23.16	4.19	0.42
11240	PF 1	Proposed	3000.00	16.50	19.30	2.21	0.31
11240	PF 1	Existing	3000.00	16.50	19.32	2.27	0.32
11240	PF 2	Proposed	9400.00	16.50	20.56	3.12	0.33
11240	PF 2	Existing	9400.00	16.50	20.78	3.50	0.38
11240	PF 3	Proposed	17000.00	16.50	21.51	3.82	0.35
11240	PF 3	Existing	17000.00	16.50	21.96	4.24	0.41
10840	PF 1	Proposed	3000.00	14.10	17.91	2.67	0.42
10840	PF 1	Existing	3000.00	14.10	17.91	2.67	0.42
10840	PF 2	Proposed	9400.00	14.10	19.13	4.12	0.47

River Sta	Profile	Plan	Q (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Froude #
10840	PF 2	Existing	9400.00	14.10	19.13	4.17	0.48
10840	PF 3	Proposed	17000.00	14.10	20.13	4.77	0.46
10840	PF 3	Existing	17000.00	14.10	20.20	5.16	0.50
10480	PF 1	Proposed	3000.00	14.50	16.49	2.22	0.35
10480	PF 1	Existing	3000.00	14.50	16.50	2.21	0.35
10480	PF 2	Proposed	9400.00	14.50	17.91	3.13	0.35
10480	PF 2	Existing	9400.00	14.50	17.92	3.13	0.35
10480	PF 3	Proposed	17000.00	14.50	19.05	3.78	0.36
10480	PF 3	Existing	17000.00	14.50	19.06	3.77	0.37
10110	PF 1	Proposed	3000.00	12.50	15.99	1.31	0.18
10110	PF 1	Existing	3000.00	12.50	15.99	1.31	0.18
10110	PF 2	Proposed	9400.00	12.50	17.44	2.09	0.21
10110	PF 2	Existing	9400.00	12.50	17.44	2.09	0.21
10110	PF 3	Proposed	17000.00	12.50	18.57	2.72	0.23
10110	PF 3	Existing	17000.00	12.50	18.57	2.72	0.23
9770	PF 1	Proposed	3000.00	12.00	15.64	1.83	0.22
9770	PF 1	Existing	3000.00	12.00	15.64	1.83	0.22
9770	PF 2	Proposed	9400.00	12.00	17.04	2.67	0.26
9770	PF 2	Existing	9400.00	12.00	17.04	2.67	0.26
9770	PF 3	Proposed	17000.00	12.00	18.21	2.96	0.25
9770	PF 3	Existing	17000.00	12.00	18.21	2.96	0.25
9400	PF 1	Proposed	3000.00	12.50	14.88	2.29	0.36
9400	PF 1	Existing	3000.00	12.50	14.88	2.29	0.36
9400	PF 2	Proposed	9400.00	12.50	16.23	3.26	0.37
9400	PF 2	Existing	9400.00	12.50	16.23	3.26	0.37
9400	PF 3	Proposed	17000.00	12.50	17.56	3.57	0.33
9400	PF 3	Existing	17000.00	12.50	17.56	3.57	0.33

River Sta	Profile	Plan	Q (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Vel Chnl (ft/s)	Froude #
9040	PF 1	Proposed	3000.00	9.30	14.77	0.99	0.09
9040	PF 1	Existing	3000.00	9.30	14.77	0.99	0.09
9040	PF 2	Proposed	9400.00	9.30	15.82	2.36	0.20
9040	PF 2	Existing	9400.00	9.30	15.82	2.36	0.20
9040	PF 3	Proposed	17000.00	9.30	17.12	3.12	0.23
9040	PF 3	Existing	17000.00	9.30	17.12	3.12	0.23
8540	PF 1	Proposed	3000.00	9.10	14.58	1.64	0.19
8540	PF 1	Existing	3000.00	9.10	14.58	1.64	0.19
8540	PF 2	Proposed	9400.00	9.10	14.67	4.96	0.56
8540	PF 2	Existing	9400.00	9.10	14.67	4.96	0.56
8540	PF 3	Proposed	17000.00	9.10	15.67	6.12	0.59
8540	PF 3	Existing	17000.00	9.10	15.67	6.12	0.59

Summary of Computed Results - The input parameters and computed results from the HEC-RAS hydraulic modeling for the existing and proposed conditions are summarized and listed in Table 3. The analysis shows that proposed wetland site is subject to flooding during the 2-yr and higher events. Since the 2-ye flood is a frequent event, it may therefore be concluded that the project site will receive river water frequently and it may therefore be suitable for wetland development.

The comparison of the computed water-surface elevations for the existing and proposed conditions shows that the proposed wetland project will not cause any rise of the water-surface elevation. The proposed project will cause slight lowering of the water-surface profile, primarily because parts of the existing berm south of the main channel will be removed and the cross-sectional area of flow will thus be enlarged. Of course, it is still necessary to control the river flow by blocking flows to the north channel branch for frequent events. The berm blocking the north channel entrance needs to maintain the top elevation of 28 feet (NAVD88 datum) or higher.

IV. FLUVIAL ANALYSIS OF POTENTIAL RIVER CHANNEL CHANGES DUE TO EROSION AND SEDIMENTATION

The purpose of the fluvial analysis is to model potential river channel changes due to the erosion and sedimentation processes. At the same time, the impacts of the proposed wetland project on river channel erosion and sedimentation will be assessed.

Stream channel scour consists of general scour and local scour. General scour is related to the sediment supplied to and transported out of a channel reach. Local scour is due to a local obstruction to flow by a bridge pier/bent or abutment. To determine general scour, it is necessary to consider the sediment supply by flow to the channel reach and sediment removal out of the reach. Sediment delivery in the stream channel and supply to the subject area is related to the flood hydrograph, channel geometry, and sediment characteristics, etc. To account for these factors, it requires mathematical simulation of the hydraulics of stream flow, sediment transport and stream channel changes.

Mathematical Model for General Scour - The FLUVIAL-12 model (Chang, 1988) is employed for this project. For a given flood hydrograph, the FLUVIAL model simulates spatial and temporal variations in water-surface elevation, sediment transport and channel geometry. Scour and fill of the streambed are coupled with width variation in the prediction of river 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. 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 river channel may not have a uniform power expenditure or linear water-surface profile, but it is constantly adjusting itself toward that direction. The model was calibrated using 12 sets of field data. Such calibration studies are as listed in the Users Manual for FLUVIAL-12. Most of the calibration studies were peer-reviewed.

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. 12); 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.

(3) In a calibration study of the FLVUAIL-12 model, the results generated by the Engelund-Hansen formula can be correlated with the measured channel changes in the San Dieguito River during the 1993 flood.

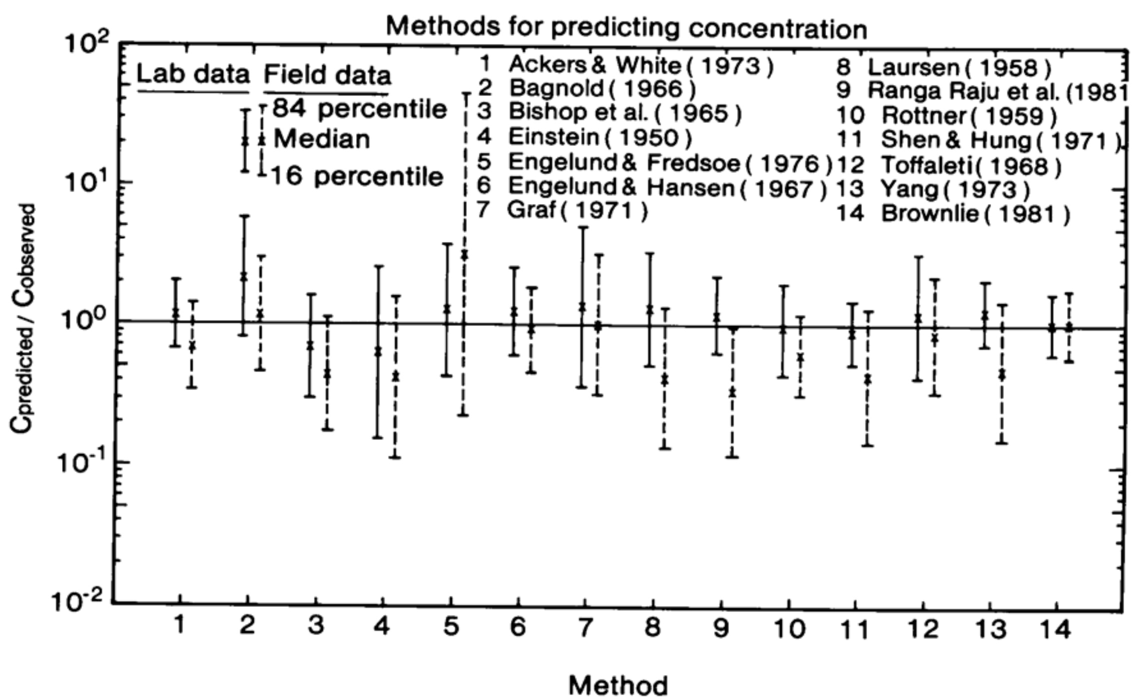


Fig. 12. Evaluation of sediment transport formulas by Brownlie

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

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

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

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

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

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

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.

V. MODELING FOR EXISTING CONDITIONS AND PROPOSED CONDITIONS

The FLUVIAL-12 model was used to simulate the hydraulics of river flow, sediment transport, together with potential changes in river channel geometry during the 100-yr flood. Modeling runs were made for the river channel under existing conditions and with the proposed wetland project. The results for these two cases are compared in order to assess the project impacts. The modeled results pertaining to water-surface profiles, flow velocities, and river channel scour are presented and described below. It should be noted that the modeling study is for the purpose of identifying potential scour impacts of the project on the river channel. The fluvial modeling study does not simulate lateral migration (or meandering development) of the channel course. The Tijuana River is subject to major changes in channel course during major flood events. Fig. 13 shows the 1980 image of the river channel with the main channel directly over the wetland site. The eroded channel was later refilled and a berm was also built to block the mitigation site from the river flow.

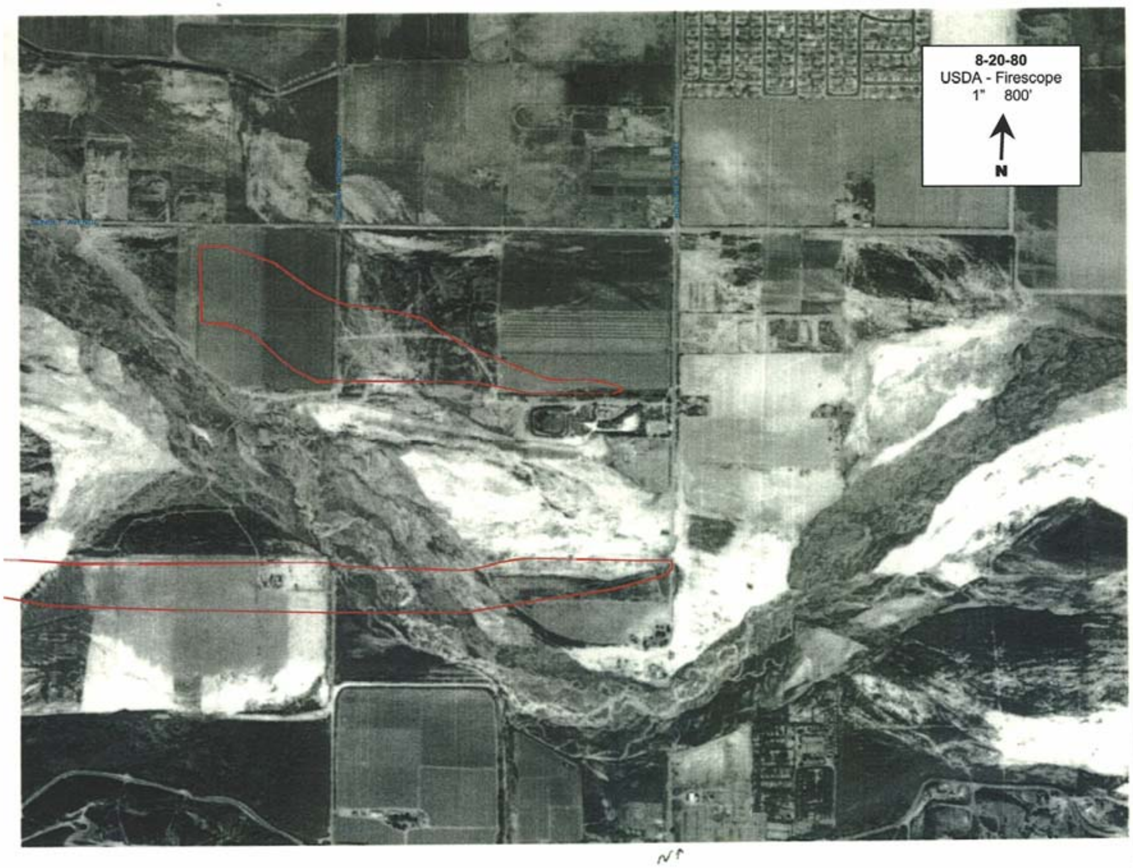


Fig. 13. The 1980 image showing river channel directly over the mitigation site

Channel-Bed and Water-Surface Profiles Based on the FLUVIAL-12 Model - The channel reach within 3,000 to 4,000 feet of the river mouth is subject to significant scour during major floods; therefore, the water-surface profile is affected by scour development. Channel-bed scour has the direct effect of lowering the flood level. For this reason, a water-surface profile computed using the FLUVIAL-12 model with scour consideration should be lower than the corresponding profile obtained based on the HEC-2 model (or HEC-RAS model) that assumes rigid channel boundary.

Figures 14 and 15 show the simulated water-surface profiles and channel-bed profile changes during the 100-yr flood for the existing and proposed conditions, respectively. It can be seen that the channel bed is susceptible to major scour near the river mouth. Such scour development is primarily because the flow removes the sand deposition brought in by the littoral drift during the dry season. After scour and sediment flushing by a flood, the inlet channel also undergoes refill by beach sand related to the littoral process.

The computed water-surface elevations are based on the peak 100-yr flood discharge. Numerical comparison of the water-surface elevations for the existing and proposed conditions as listed in Table 4 shows that these two water-surface profiles are closely similar with only minor differences. With a portion of the flow through the wetland area, the proposed project will not cause any rise of the flood level. In other words, the project will have no flooding impacts.

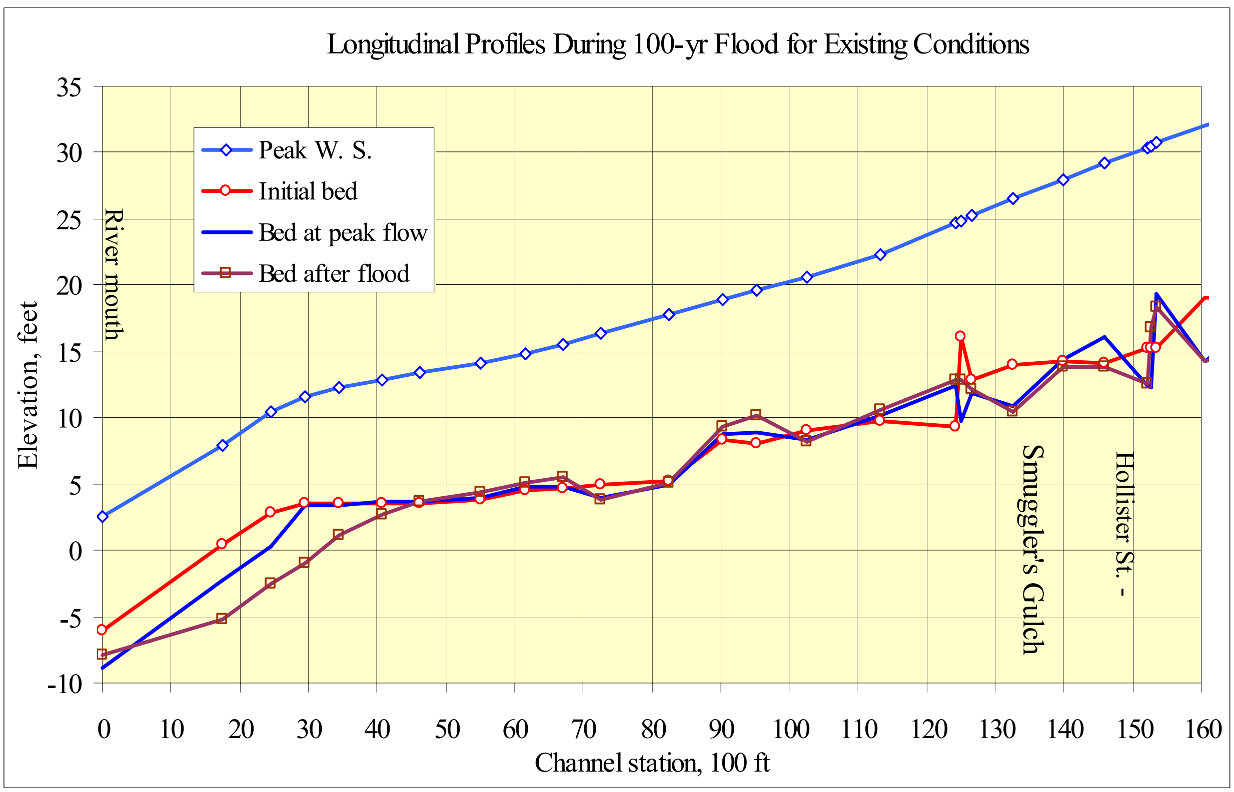


Fig. 14. Water-surface and channel-bed profile changes during 100-yr flood for existing conditions

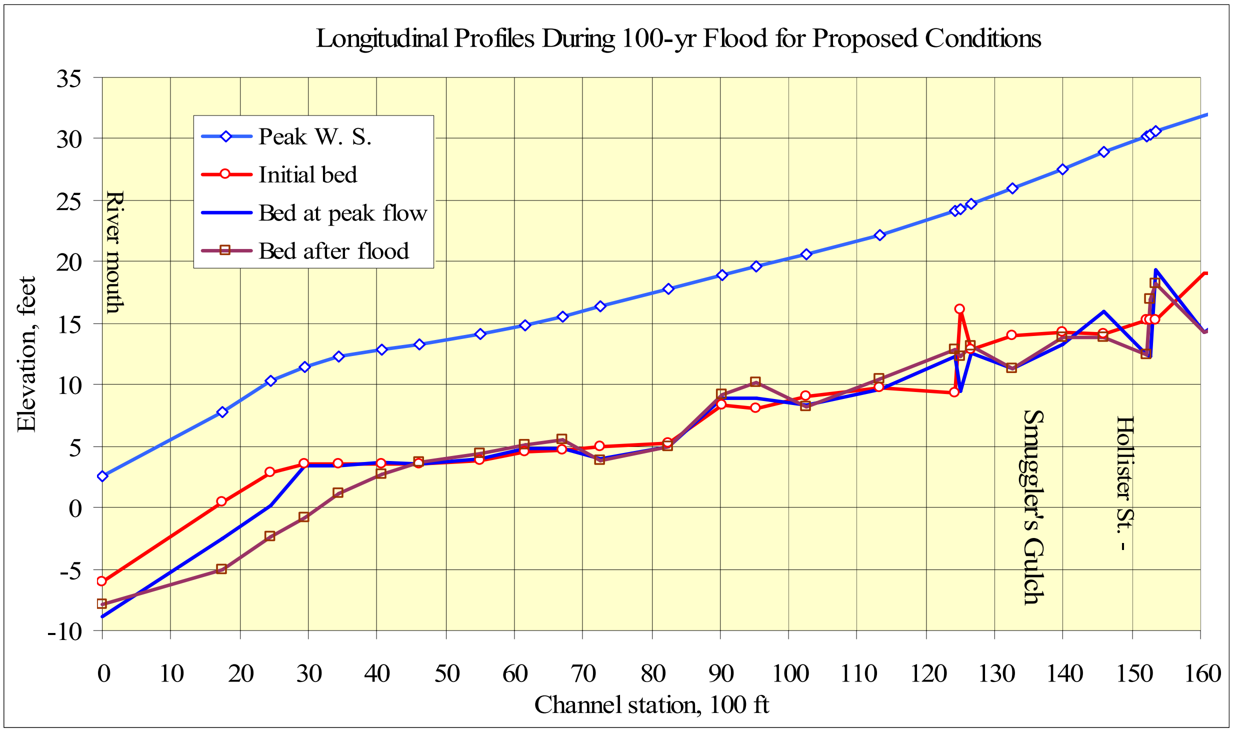


Fig. 15. Water-surface and channel-bed profile changes during 100-yr flood for proposed conditions

Table 4. Comparison of computed for 100-yr flood elevations based on FLUVIAL-12

Section 100 feet	Location	Computed water-surface elevation feet, NAVD	
		Existing conditions	Proposed plan
0.00		2.5	2.5
1.00	River mouth	3.1	3.1
12.5		7.9	7.8
19.6		10.4	10.4
24.5		11.6	11.5
29.5		12.3	12.3
35.8		12.9	12.9
41.3		13.4	13.3
50.2		14.1	14.1
56.8		14.9	14.9

62.2		15.6	15.6
67.7		16.4	16.4
77.5		17.8	17.8
85.4		18.9	18.9
90.4		19.6	19.6
97.7	Downstream project limit	20.6	20.6
108.4		22.3	22.2
119.3		24.7	24.2
120.1		24.8	24.4
121.7		25.2	24.8
127.8		26.6	26.2
134.9	Upstream project limit	28.0	27.7
141.1		29.2	29.0
147.1		30.4	30.3
147.8	Hollister Street	30.5	30.4
148.6		30.8	30.7
155.7		32.1	32.0
163.1		33.2	33.2
174.3		34.0	34.0
179.2		34.3	34.2

Spatial Variations in Velocity Along the River Channel - The flow velocity is often used as a criterion to assess the potential for river channel scour. The cross-sectionally averaged velocities are included in the output of the FLUVIAL-12 model. The simulated velocities at the peak 100-yr flood and their spatial variations along the river channel are shown in Fig. 16 for the existing and proposed conditions. The spatial variations in velocity are useful to characterize the flow along the river channel. The figure shows that the river channel has very high velocities near the river mouth.   The high velocities are also responsible for the severe scour development. The computed velocities are much lower along the remaining channel reach. When the velocities for the existing and proposed conditions are compared, it can be seen that the velocities for the proposed plan are closely similar to those for the existing conditions. The proposed project will cause a small decrease of the flow velocity near the project site.   Since the proposed project will not cause significant increases of the flow velocity, it will have insignificant effects on river channel scour.

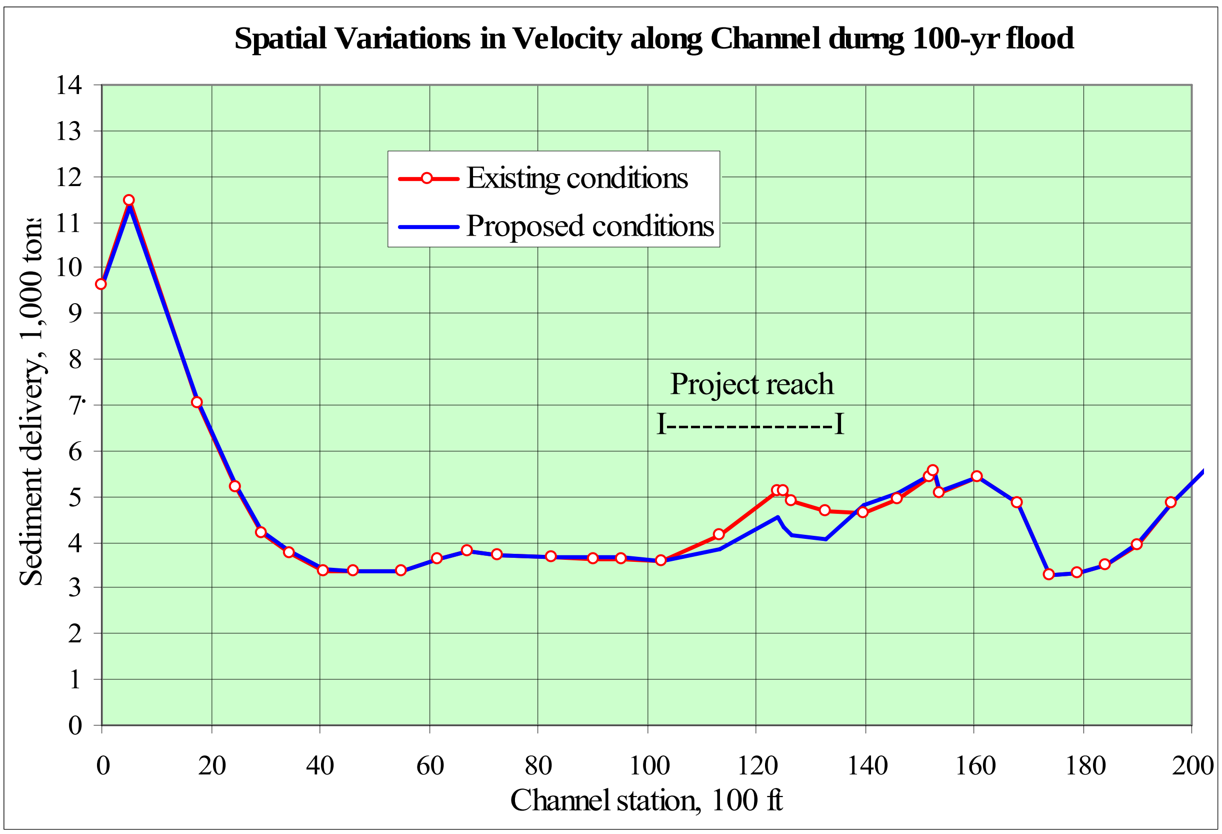


Fig. 16. Spatial variations in flow velocity along the channel for existing and proposed conditions

The velocity is also used as a criterion to assess the need for bank protection for the berms. For berms that are made of cohesive materials, planted with vegetation, and parallel to flow, the permissible velocity of 6 feet per second is normally used as the criterion for bank stability. In other words, a berm that meets these conditions does not require additional protection. The proposed berm will be constructed with cohesive materials and planted with vegetation. For this reason, additional bank protection is not needed for the berms.

Bridge Hydraulics – The lower Tijuana River has two bridge crossings at the Hollister Street Bridge and the Dairy Mart Road Bridge, respectively. The proposed project is at large distances away from these bridges; it does not affect the hydraulics of river flow nor sediment transport at these bridge crossings. Therefore, the proposed project has no impacts at these bridges.

Simulated Results on Scour - The lower Tijuana River is a sand bed river. Grain size distributions of sediment samples are shown in Fig. 2. The 100-yr flood was used to simulate sediment transport and stream channel changes for the lower Tijuana River under the existing conditions as well as under the proposed plan. Simulated results are presented in graphical forms, in Figs. 14, 15, 17, 18, 19, 20 and 21. In each figure, the graphical results include those before the flood, at the peak flow, and at the end of flood. These results are described below.

Simulated results pertaining to potential channel-bed scour during the 100-yr flood for the existing conditions are shown in Fig. 14; those for the proposed plan are shown in Fig. 15. It can be seen from the channel-bed changes that the river channel near the river mouth is subject to severe scour during the 100-yr flood. The cross-sectional area of flow will be greatly enlarged and the flood level will thus be lowered. The changes are the most pronounced at the river mouth and such changes gradually decrease toward upstream. While bed sediment is flushed from the channel bed during a flood, the channel bed is also recharged by littoral sand during the dry season. By comparing the simulated river channel changes for the existing and proposed conditions, it is easy to see that the proposed project will have insignificant effects on river channel scour.

Sample cross-sectional changes near the wetland site as simulated are shown in Figs.17 through 21. These figures show that the wetland site is not subject to severe erosion or deposition changes. Of course, any meandering development of the mean channel course that may cause severe scour is not a part of the study.

By comparing the simulated cross-sectional changes for the existing and proposed conditions, it can be seen that the proposed wetland project will have insignificant scour impacts on other parts of the river channel. The proposed wetland project will have no significant scour impacts at the Hollister Street crossing as shown in Fig. 21.

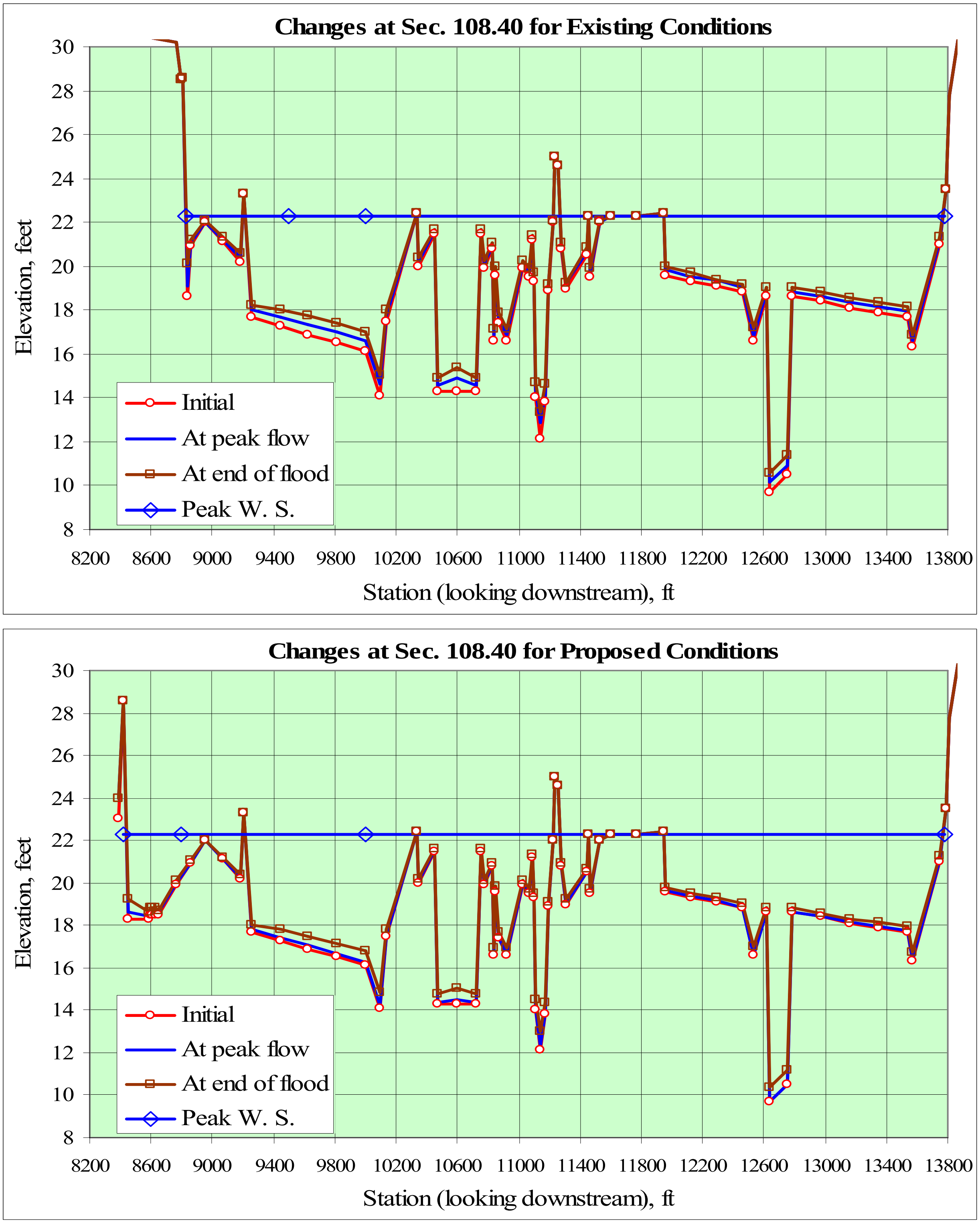
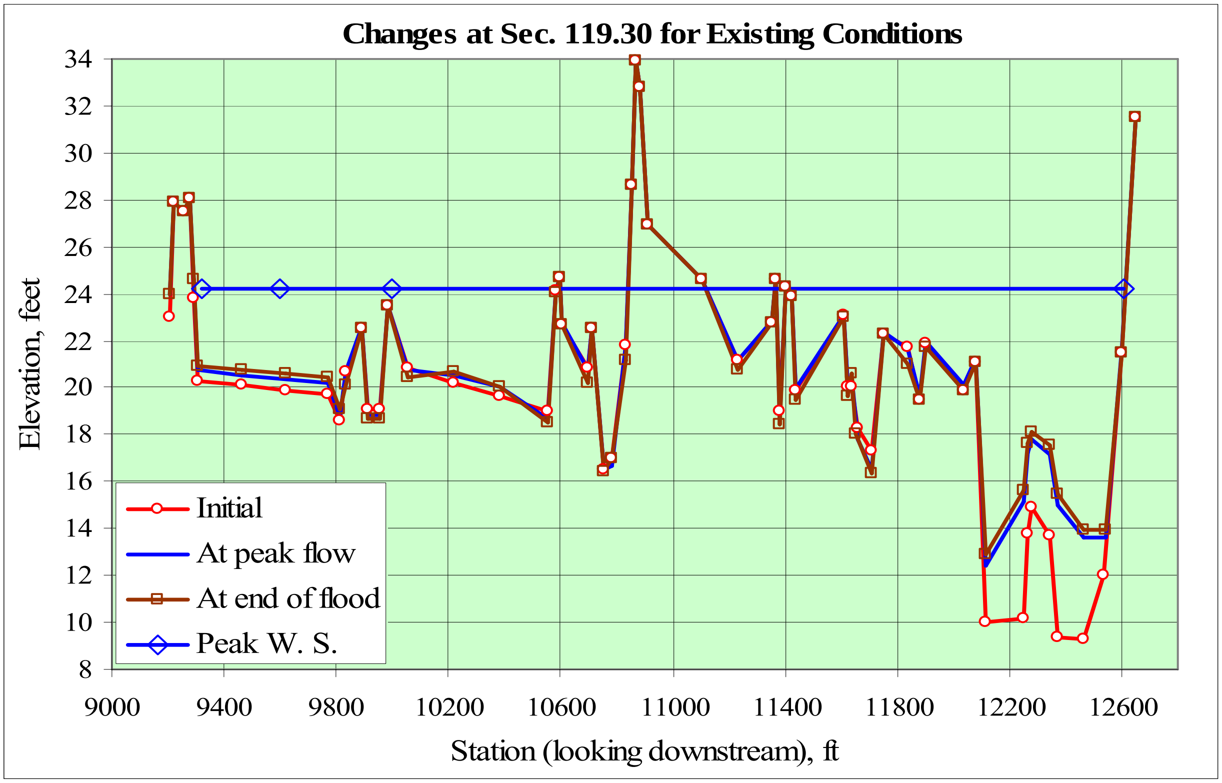


Fig. 17. Simulated channel changes during 100-yr flood at Section 108.40 for existing and proposed conditions. The proposed wetland is located to the left of station 8600.



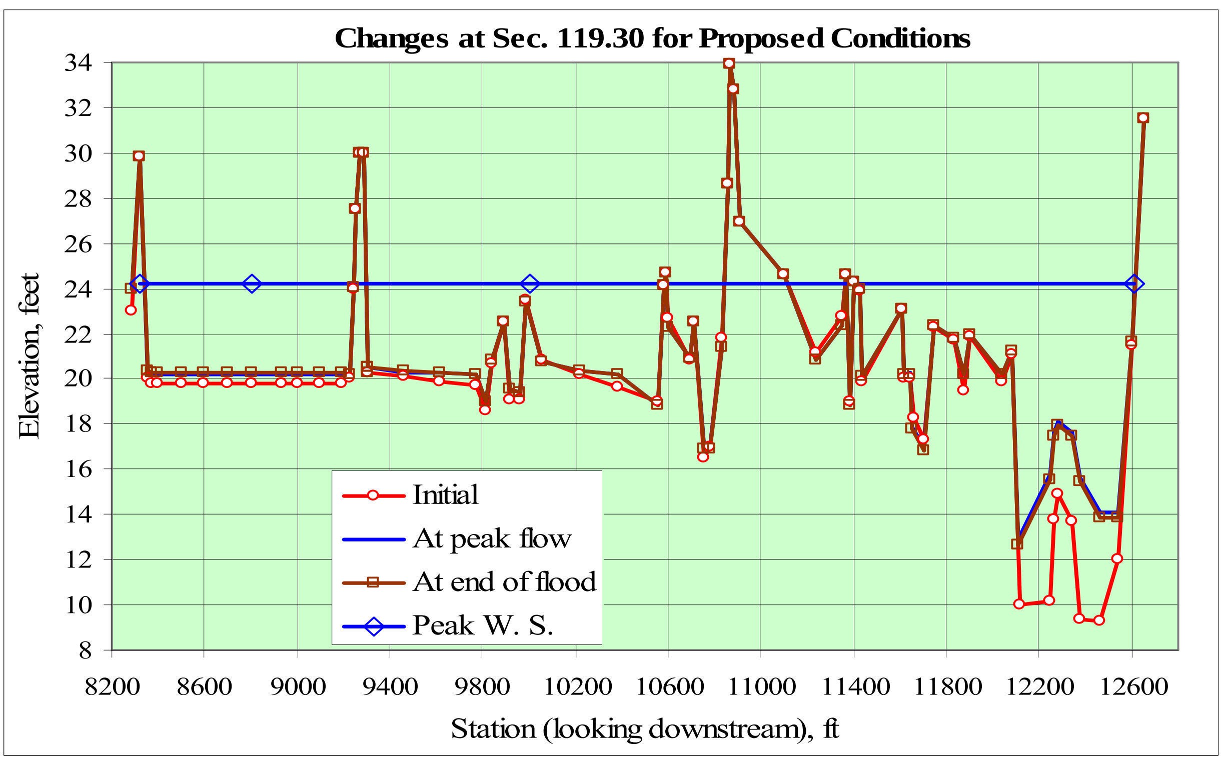
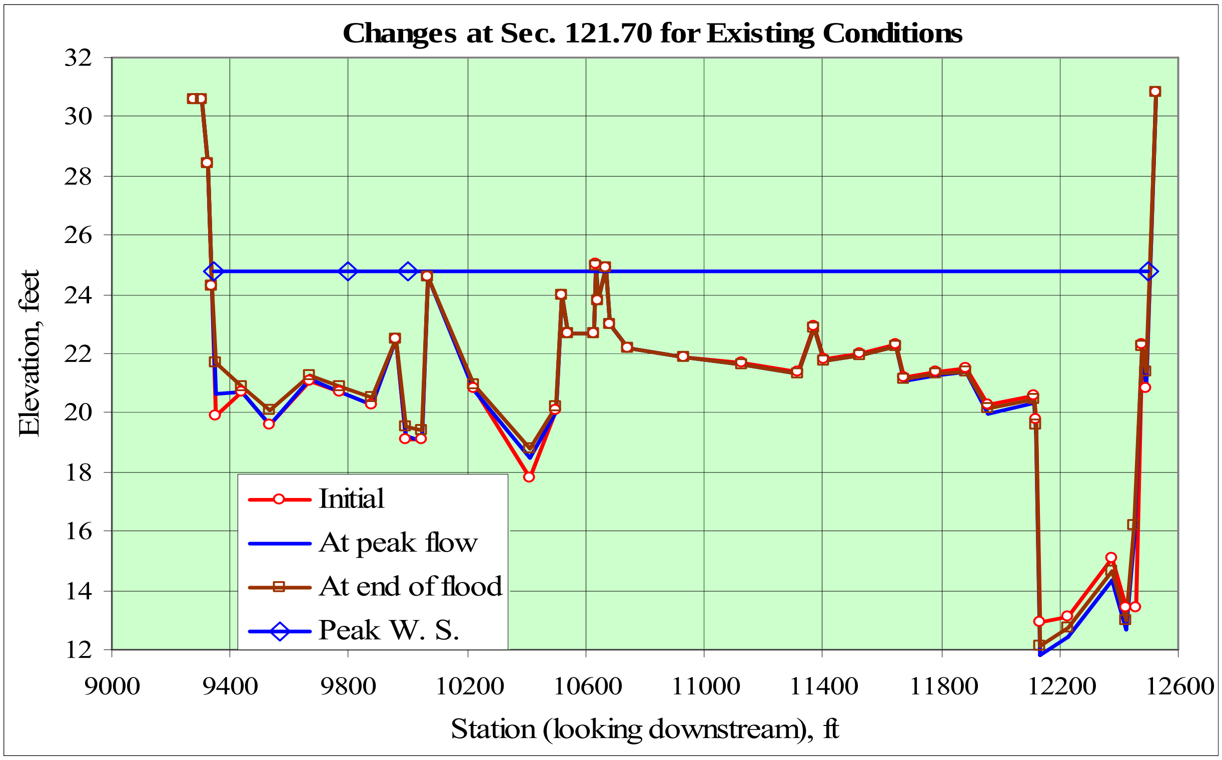


Fig. 18. Simulated channel changes during 100-yr flood at Section 119.30 for existing and proposed conditions. The proposed wetland is located to the left of station 9300.



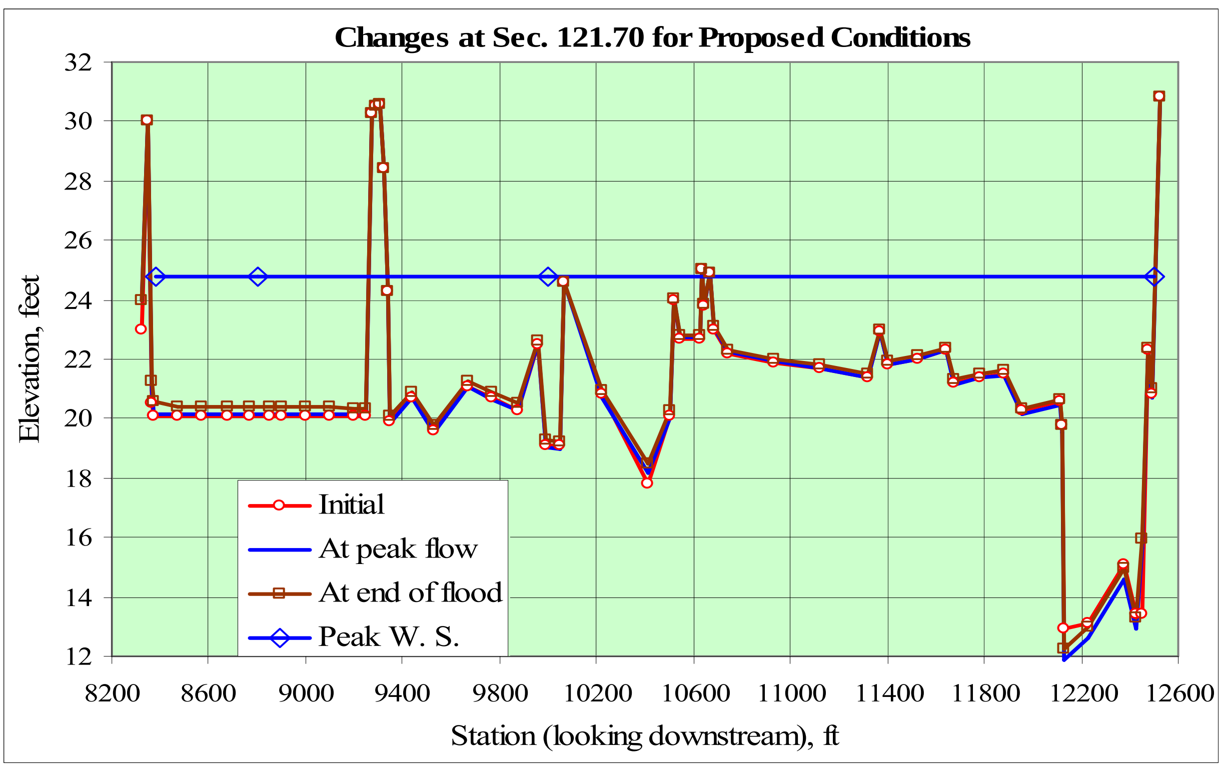
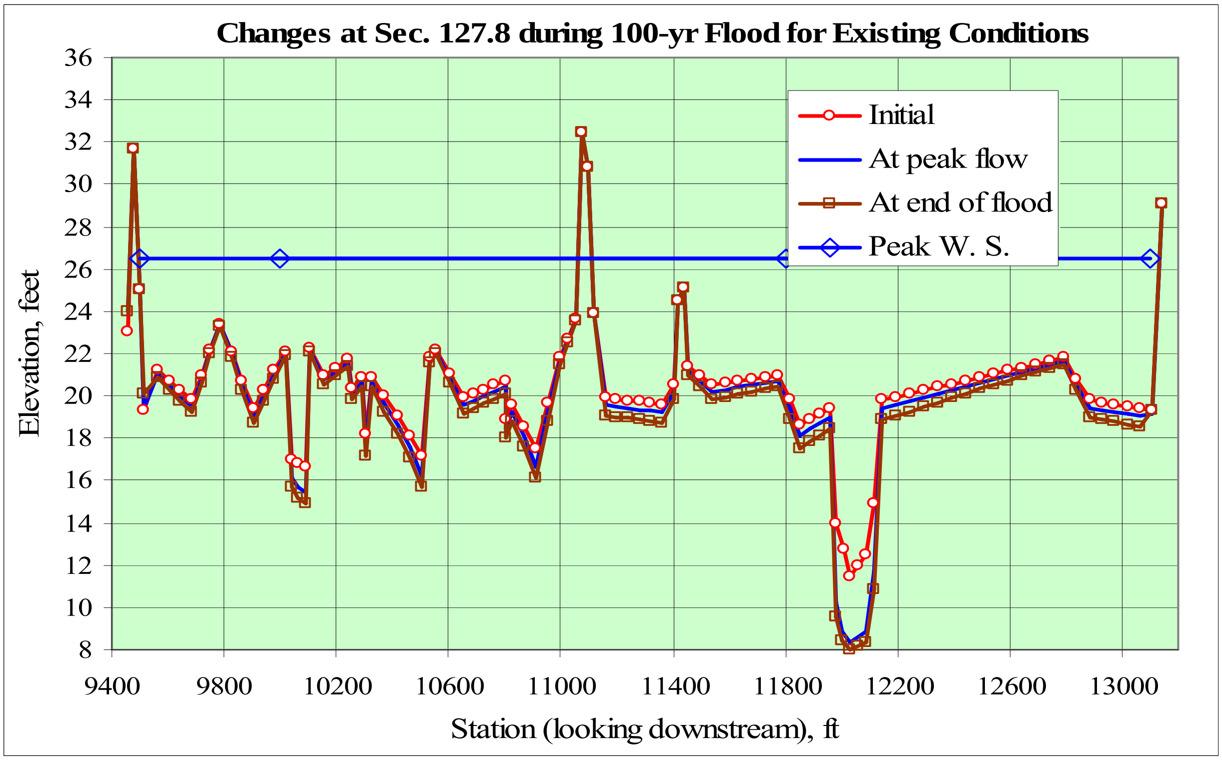


Fig. 19. Simulated channel changes during 100-yr flood at Section 121.70 for existing and proposed conditions. The proposed wetland is located to the left of station 9300.



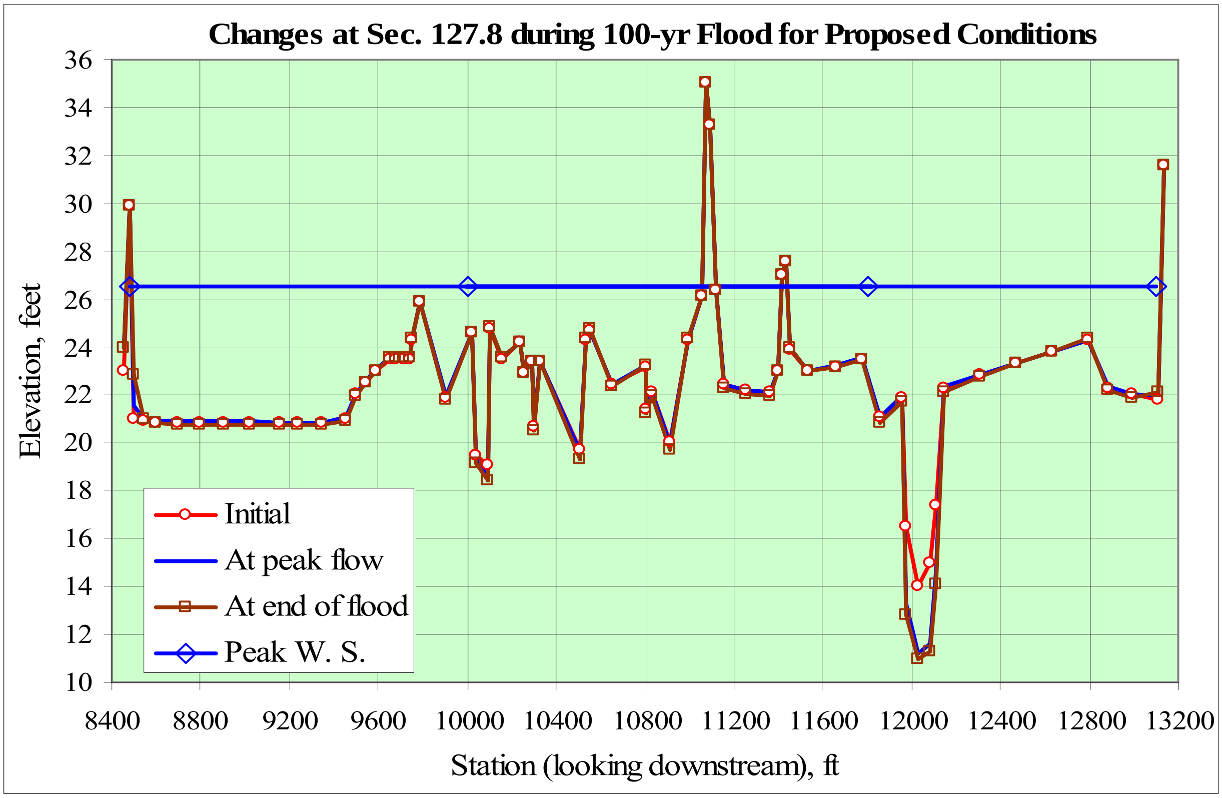
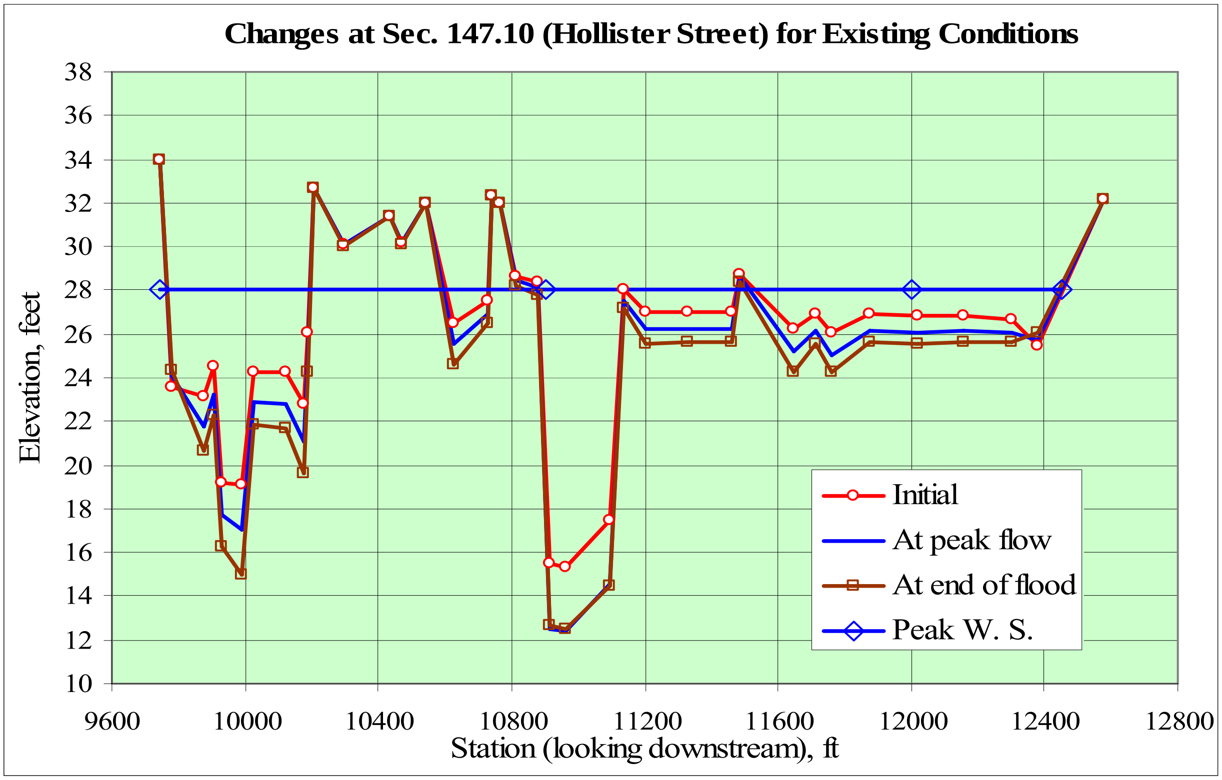


Fig. 20. Simulated channel changes during 100-yr flood at Section 127.80 for existing and proposed conditions. The proposed wetland is located to the left of station 9450.



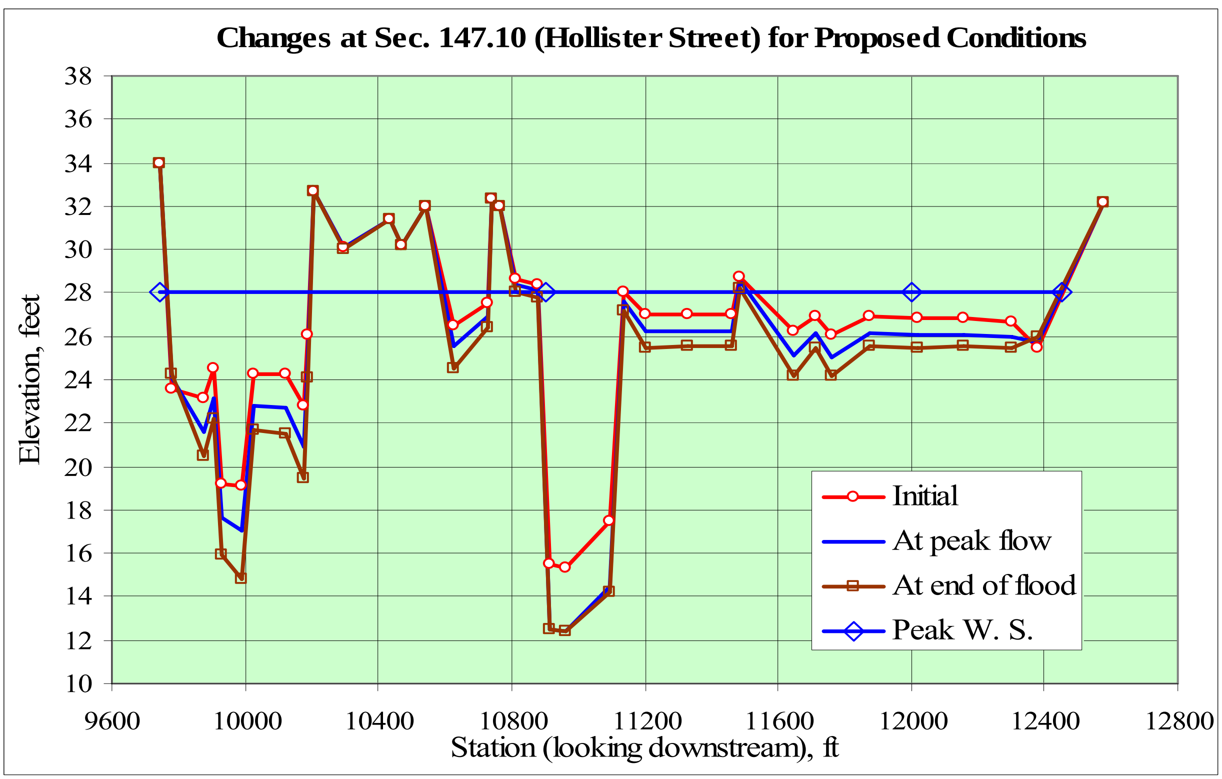


Fig. 21. Simulated channel changes during 100-yr flood at Section 147.10 for existing and proposed conditions.

VI. BEACH SAND SUPPLY

Simulation of 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,

$$Y = \int_T Q_s \, dt \tag{5}$$

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 sediments of clay and silt constituting the wash load may not be computed by a sediment transport formula. Sediment delivery is widely employed by hydrologists for watershed management; it is used herein to keep track of sediment supply and removal along the channel reach.

Spatial variations in sediment delivery are manifested as channel storage or depletion of sediment associated stream channel changes since the sediment supply from upstream may be different from the removal. The spatial variation of sediment delivery depicts the erosion and deposition along a stream reach. A decreasing delivery in the downstream direction, i.e. negative gradient for the delivery-distance curve, signifies that sediment load is partially stored in the channel to result in a net deposition. On the other hand, an increasing delivery in the downstream direction (positive gradient for the delivery-distance curve) indicates sediment removal from the channel boundary or net scour. A uniform sediment delivery along the channel (horizontal curve) indicates sediment balance, i.e., zero storage or depletion. Channel reaches with net sediment storage or depletion may be designated in each figure 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.

Simulated Results on Sediment Delivery by the 100-yr Flood - Sediment deliveries were simulated based on the 100-yr flood. Spatial variations in sediment delivery during the 100-yr flood along the river channel are shown in Fig. 22 for the existing and proposed conditions, respectively. The spatial patterns are similar; they both show a general increasing trend of delivery toward the downstream direction along the reach from channel station 40+00 to the river mouth. Such a trend depicts a general pattern of sediment removal, or scour, from the channel boundary. Sediment removal from the river channel contributes to beach sand supply. Spatial variations of sediment delivery from the Smuggler's Gulch confluence at channel station 134+90 to channel station 40+00 have a mild decreasing trend toward downstream. Such a mild decreasing trend for sediment delivery indicates sediment deposition in the river channel.

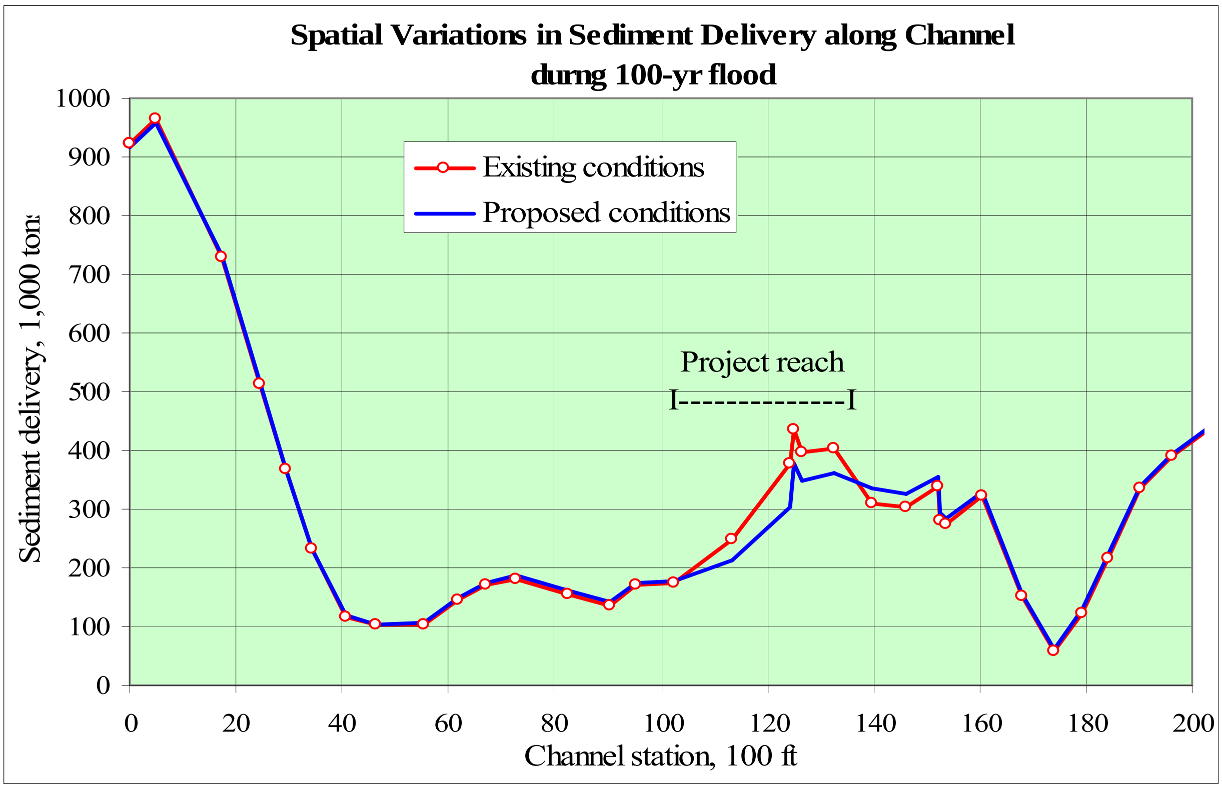


Fig. 22. Spatial variations of sediment delivery during the 100-yr flood
for existing and proposed conditions

The results on sediment delivery may be used to assess the impacts of the proposed project on beach sand supply. As shown in Fig. 22, sediment delivery patterns for the existing and proposed conditions are closely similar. Section 0.00 is located at the river mouth; the amount of sediment delivery passing this station is also the amount of beach sand supply during the flood event. It can be seen that there is no significant difference in beach sediment supply between the existing and proposed conditions.

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APPENDIX A. INPUT/OUTPUT DESCRIPTIONS FOR FLUVIAL-12

I. INPUT DESCRIPTION

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

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

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

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

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

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

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

Field	Variable	Value	Description
0	IA	G1	Record identification characters
1	TYME	+	Starting time of computation on the hydrograph, in hours
2	ETIME	+	Ending time of computation on the hydrograph, in hours
3	DTMAX	+	Maximum time increment Δt allowed, in seconds
4	ISED	1	Select Graf's sediment transport equation.
		2	Select Yang's unit stream power equation. The sediment size is between 0.063 and 10 mm.
		3	Select Engelund-Hansen sediment equation.
		4	Select Parker gravel equation.
		5	Select Ackers-White sediment equation.
		6	Select Meyer-Peter Muller equation for bed load.
5	BEF	+	Bank erodibility factor for the study reach. This value is used for each section unless otherwise specified in Field 9 of the XF and 1 may be used.
6	IUC	0	English units are used in input and output.
		1	Metric units are used in input and output.
7 sec-	CNN	+	Manning's *n* value for the study reach. This value is used for a tion 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^{o}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^{o}.
		+	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.

Field	Variable	Value	Description
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

Field	Variable	Value	Description
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.
		±	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	$\pm$	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