State Route 32 Widening between Fir Street and Yosemite Drive
City of Chico, Butte County, California

Bridge Design Hydraulic Study Report

Prepared for:

Prepared by:

November 2011

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City of Chico, Butte County, California

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Submitted to:
City of Chico

This report has been prepared by or under the supervision of the following Registered Engineer. The Registered Civil Engineer attests to the technical information contained herein and has judged the qualifications of any technical specialists providing engineering data upon which recommendations, conclusions, and decisions are based.

Han-Bin Liang, Ph.D., P.E.
Registered Civil Engineer

11/22/2011
Date

REGISTERED PROFESSIONAL ENGINEER
HAN-BIN LIANG
No. C 048404
Exp. 6/30/12
CIVIL
STATE OF CALIFORNIA

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Table of Contents

Executive Summary iv
Acronyms vii
1 General Description 1
1.1 Project Description 1
1.2 Project Need 1
1.3 Project Location 1
1.4 Key Tasks 1
1.5 Design Criteria 2
1.6 Report Elevation Datum 2
2 Description of Watershed 6
2.1 Geographic Location 6
2.2 Watershed Size 6
2.3 Receiving Water Bodies 6
2.4 Precipitation 6
2.5 Land Use 6
3 Description of Stream and Site 8
3.1.1 Dead Horse Slough 8
3.1.2 South Fork Dead Horse Slough 8
3.2 Soil and Bed Material 9
3.3 Existing Facility 10
3.3.1 Dead Horse Slough 10
3.3.2 South Fork Dead Horse Slough 11
3.4 Proposed Action 13
4 Hydrology 15
4.1 Hydrologic Stability 15
4.2 Design Discharge 15
4.2.1 Dead Horse Slough 15
4.2.2 South Fork Dead Horse Slough 18
5 Hydraulic Analysis 21
5.1 Design Tools 21
5.2 Cross section Data 21
5.3 Manning's n 21
5.4 Expansion and Contraction Coefficients 21
5.5 Downstream Boundary Conditions 23
5.5.1 Dead Horse Slough 23
5.5.2 South Fork Dead Horse Slough 23
5.6 Water Surface Elevations 25
5.6.1 Dead Horse Slough 25
5.6.2 South Fork Dead Horse Slough 25
5.7 Flow Velocities 26
5.7.1 Dead Horse Slough 26
5.7.2 South Fork Dead Horse Slough 26
6 Scour Analysis 28
6.1 Design Criteria 28

6.2 Caltrans Bridge Inspection Report(s) ... 28
6.3 Existing Channel Bed ... 28
6.4 Long-Term Bed Elevation Change ... 28
6.5 Contraction Scour ... 29
6.6 Pier Scour ... 30
6.7 Abutment Scour ... 31
6.8 Total Scour ... 34
7 References ... 35

Figures

Figure 1. Project Location Map ... 3
Figure 2. Project Vicinity Map ... 4
Figure 3. Project Vicinity Map, Aerial ... 5
Figure 4. Watershed Map, Dead Horse Slough ... 7
Figure 5. As-Built, SR 32 Bridge over Dead Horse Slough. ... 12
Figure 6. Bridge General Plan, SR 32 Bridge over Dead Horse Slough. ... 14
Figure 7. Dead Horse Slough Extrapolated Flows ... 16
Figure 8. FEMA FIS Flooding Source and Locations ... 17
Figure 9. Little Chico Creek, Interpolated and Extrapolated Flows ... 18
Figure 10. Design Hydrographs at South Fork Dead Horse Slough ... 20
Figure 11. HEC-RAS Cross Section Locations, Dead Horse Slough and Little Chico Creek ... 22
Figure 12. HEC-RAS Cross Section Locations, South Fork Dead Horse Slough ... 22
Figure 13. 100-year WSE at Proposed SR 32 Bridge ... 32

Tables

Table 1. Hydraulic Summary, Dead Horse Slough at SR 32 – Proposed Condition ... v
Table 2. Hydraulic Summary, South Fork Dead Horse Slough at SR 32 ... v
Table 3. Scour Analyses Summary, SR 32 Bridge over Dead Horse Slough ... v
Table 4. Bridge General Specifications, Existing SR 32 Bridge over Dead Horse Slough ... 10
Table 5. Culvert General Specification, Existing RCB Cross Culvert for South Fork Dead Horse Slough ... 11
Table 6. Bridge General Specification, Proposed SR 32 Bridge over Dead Horse Slough ... 13
Table 7. Culvert General Specification, Proposed RCB Cross Culvert for South Fork Dead Horse Slough ... 13
Table 8. Dead Horse Slough Design Flows ... 16
Table 9. FEMA Flooding Source and Locations ... 18
Table 10. South Fork Dead Horse Slough Design Flows ... 19
Table 11. Downstream Boundary Conditions, Dead Horse Slough ... 23
Table 12. Downstream Boundary Condition, South Fork Dead Horse Slough ... 24
Table 13. Dead Horse Slough, Water Surface Elevations at River Station 10762 ... 25

Table 14. South Fork Dead Horse Slough, Water Surface Elevations 26
Table 15. Flow Velocities in Main Channel at River Station 10762 26
Table 16. Flow Velocities at Upstream and Downstream Ends of the RCB Cross Culvert 27
Table 17. Contraction Scour Summary..... 30
Table 18. Pier Scour Summary 31
Table 19. Abutment Scour Summary..... 33
Table 20. Total Scour Depths 34

Photos

Photo 1. SR 32 at Dead Horse Slough, looking downstream 8
Photo 2. SR 32 at South Fork Dead Horse Slough, looking upstream 9
Photo 3. Existing SR 32 Bridge, looking southwest (downstream)..... 10
Photo 4. Existing RCB cross culvert, looking north (downstream)..... 11
Photo 5. California Park Lake Outlet..... 15
Photo 6. Downstream Headwall of South Fork Dead Horse Slough RCB cross culvert.. 19

Appendices

Appendix A HEC-RAS Results: Existing Conditions
Appendix A.1 Dead Horse Slough
Appendix A.2 South Fork Dead Horse Slough
Appendix B HEC-RAS Results: Proposed Conditions
Appendix B.1 Dead Horse Slough
Appendix B.2 South Fork Dead Horse Slough
Appendix C Hydrologic Analyses
Appendix D FEMA FIRM and FIS
Appendix E Scour Analyses
Appendix F Scour Countermeasures

Executive Summary

This study presents the hydrologic and hydraulic assessment of the Dead Horse Slough and South Fork Dead Horse Slough crossings of State Route 32 (SR 32) in the existing and proposed conditions. The City of Chico is proposing to widen SR 32 from two lanes to four lanes from Fir Street to just east of Yosemite Drive in the City of Chico, California.

The proposed project is necessary to accommodate major development projects planned for the area and is in the City's General Plan. The proposed improvements include roadway widening in the stream crossings, which will affect the hydraulics of the Dead Horse Slough and South Fork Dead Horse Slough. The South Fork Dead Horse Slough flows north-northwest under SR 32 through a box culvert just east of Bruce Road (and just downstream of California Park Lake). Just north of SR 32, South Fork Dead Horse Slough joins the main Dead Horse Slough then flows west under Bruce Road and roughly parallels SR 32 on the north side for 450 feet (ft) until the slough turns south and passes under SR 32 beneath the Dead Horse Slough bridge (CT Bridge No. 12-0135). Dead Horse Slough flows into Little Chico Creek approximately 740 ft downstream of the SR 32 crossing.

The proposed improvement to the main Dead Horse Slough crossing is to widen the existing bridge by approximately 49 ft to the north to make the total bridge width 81.5 ft. The widening will include extension of the three pile bents and two abutments. The existing bridge will not be lengthened. The proposed improvement to the South Fork Dead Horse Slough crossing is to extend the existing 8 ft x 6 ft reinforced concrete box (RCB) cross culvert. This will be done by extending the culvert approximately 34 ft to the north with a new headwall and wingwalls.

The water surface elevations (WSEs) and flow velocities for the proposed condition shown in Table 1 are located at the modeled cross section just upstream of the proposed SR 32 bridge over Dead Horse Slough. The downstream controlling WSE is based on the Federal Emergency Management Agency's (FEMA) 100-year flood elevation. This information was obtained from the current FEMA Flood Insurance Study (FIS) for Butte County and Incorporated Areas (January 2011), and the 2005 FEMA-issued Letter of Map Revision (LOMR) for the area. The proposed bridge design has approximately 1.9 ft of freeboard above the 200-year flood. This does not meet the City of Chico's stringent freeboard design criteria of 3 ft above the 200-year flood, but does meet the Federal Highway Administration's (FHWA) and Caltrans' design criteria for bridges on State highways. Caltrans' design criteria are for bridges to pass the 100-year storm event without freeboard and the 50-year storm event plus 2 ft of freeboard.

Table 1. Hydraulic Summary, Dead Horse Slough at SR 32 – Proposed Condition

Design Flow Return Period (yr)	Design Flow (cfs)	Bridge Soffit Elevation(1) (ft, NAVD)	Water Surface Elevation(2) (ft, NAVD)	Freeboard (ft)	Velocity (ft/sec)
50	1,500	240.47	237.3	3.1	4.9
100	1,900	240.47	238.0	2.5	5.4
200	2,200	240.47	238.6	1.9	5.6

Notes:
(1) Lowest upstream soffit elevation (NW corner).
(2) At cross section immediately upstream of bridge.

The WSEs in are at the modeled cross section just upstream of the proposed RCB cross culvert under SR 32 along South Fork Dead Horse Slough. The culvert design meets Caltrans' design criteria that the culvert would not cause objectionable backwater during the 100-year event, and the 100-year WSE would not spread into the traveled way.

Table 2. Hydraulic Summary, South Fork Dead Horse Slough at SR 32

Return Period (yr)	Design Flow (cfs)	Edge of Traveled Way Elevation (ft, NAVD)	RCB Top Elevation (ft, NAVD)	Water Surface Elevation (ft, NAVD)	Upstream Velocity(2) (ft/s)	Downstream Velocity(3) (ft/s)
10	290	255.8	252.3	252.3(1)	0.7	17.1
25	360	255.8	252.3	253.3	0.6	17.9
50	430	255.8	252.3	254.1	0.6	18.7
100	470	255.8	252.3	254.6	0.5	19.0

Notes:
(1) The 10-year WSE as indicated is at the cross section upstream of the culvert opening. The 10-year WSE at the culvert opening is 249.73 ft as indicated in Appendix B.
(2) The upstream velocities as indicated are at the cross section upstream of the culvert opening
(3) The downstream velocities as indicated are at the downstream culvert opening (not the downstream cross section)

The scour analysis performed in this study follows the FHWA recommended methodology. Table 3 summarizes the estimated maximum potential total scour depths at the abutments and pile bents, and recommended design scour elevation for the SR 32 bridge over Dead Horse Slough.

Table 3. Scour Analyses Summary, SR 32 Bridge over Dead Horse Slough

Bridge component	Maximum Estimated Local Scour (ft)	Contraction Scour (ft)	Long Term Scour (ft)	Total Scour (ft)	Recommended Design Scour Elevation (ft, NAVD)
Abutment 5	2.9	0.3	0.0	**3.2**	**235.5**
Bent 4	7.1	0.3	0.0	**7.4**	**222.8**
Bent 3	7.1	0.3	0.0	**7.4**	**222.8**
Bent 2	7.1	0.3	0.0	**7.4**	**222.8**
Abutment 1	3.1	0.3	0.0	**3.4**	**235.3**

The foundation of the proposed bridge abutments and pile bents should be designed for loss of lateral support to the recommended design scour elevation to avoid structural damage and/or undermining. Protection measures such as rock slope protection (RSP) are also recommended for the abutments of the proposed bridge widening.

For the South Fork Dead Horse Slough culvert extension, WRECO recommends the installation of ¼ ton RSP at the downstream end of the culvert extension. This RSP will help dissipate the high flow velocities (as indicated in) at the outfall of the culvert and will protect the channel from scour.

Acronyms

Caltrans	California Department of Transportation
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIS	Flood Insurance Study
HEC-18	Hydraulic Engineering Circular No. 18, Evaluating Scour at Bridges
HEC-HMS	Hydrologic Engineering Centers Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Centers River Analysis System
LOMR	Letter of Map Revision
Mark Thomas	Mark Thomas and Company, Inc.
NAVD	North American Vertical Datum
NGVD	National Geodetic Vertical Datum
Project	State Route 32 Widening Project
RC	Reinforced Concrete
RCB	Reinforced Concrete Box
RSP	Rock Slope Protection
SR 32	State Route 32
SR 99	State Route 99
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WSE	Water Surface Elevation

1 GENERAL DESCRIPTION

1.1 Project Description

The proposed State Route 32 (SR 32) Widening Project (Project) would widen and improve approximately 2.6 miles of SR 32, beginning at the southbound State Route 99 (SR 99) ramps at the west end of the Project corridor and extending east past Yosemite Drive. SR 32 will be widened from two to three lanes in each direction from the east side of the SR 99 interchange to just east of Fir Street. The roadway will then be widened from two to four lanes (two in each direction) from Fir Street to 1,000 ft east of Yosemite Drive, where the roadway width will transition down from four lanes to the existing two lanes. The Project will also modify the ramp terminal intersections and the couplet at the SR 99/SR 32 interchange. The intersections of SR 32 with Forest Avenue, El Monte Avenue, and Bruce Road will be widened to include separated left- and right-turn pockets, and the existing signals will be modified. The intersections of SR 32 with Fir Street and Yosemite Drive will be widened to include left-turn pockets, and new traffic signals will be installed.

1.2 Project Need

The Project is needed because local growth in the area is anticipated to increase congestion due to inadequate capacity on SR 32. There are existing operational and safety concerns at the SR 99/SR 32 interchange, which can be expected to be impacted if the intersections of the two state highway facilities are not improved. The intersection improvements will also help maintain and improve connectivity between the neighborhoods on either side of SR 32. Without the proposed Project, congestion and safety concerns would increase and substantially degrade the operations of SR 32 and SR 99 in the Project area.

1.3 Project Location

The Project location is in the City of Chico, Butte County, California. The proposed bridge is located along SR 32 approximately 0.1 mile east of the SR 32/Forest Avenue intersection. The proposed reinforced concrete box (RCB) culvert extension is located just east of the SR 32/Bruce Road intersection. See Figures 1 through 3 for Project location, vicinity, and aerial maps.

1.4 Key Tasks

The key tasks performed for the project included: 1) investigation into previous hydrologic and hydraulic studies of Dead Horse Slough, 2) HEC-HMS hydrologic analysis of the South Fork Dead Horse Slough watershed to determine design flows, 3) hydraulic analyses to determine the water surface elevations (WSEs) and flow velocities at both the Dead Horse Slough and the South Fork Dead Horse Slough crossings, and 4) scour analysis to determine potential scour depths and countermeasures at the Dead Horse Slough crossing.

1.5 Design Criteria

Per Federal Highway Administration (FHWA) and California Department of Transportation (Caltrans) design criteria, the basic criterion for hydraulic design of bridges is that they should be designed to pass the two percent (2%) probability flood (50-year flood or Q_{50}) with 2 ft of freeboard and the one percent (1%) probability flood (100-year flood or Q_{100}) without causing objectionable backwater, excessive flow velocities, or encroaching onto traffic lanes. The design criteria for the RCB cross culvert is the water surface of the Q_{100} should not cause objectionable backwater or spread onto the traveled way.

1.6 Report Elevation Datum

All elevations used in this report are in North American Vertical Datum of 1988 (NAVD) unless otherwise noted. The conversion between NAVD 88 and National Geodetic Vertical Datum of 1929 (NGVD) is as follows: NAVD 88 = NGVD 29 + 2.3 ft. This datum conversion was obtained using the United States Army Corps of Engineers' (USACE's) Corpscon 6.0 software.

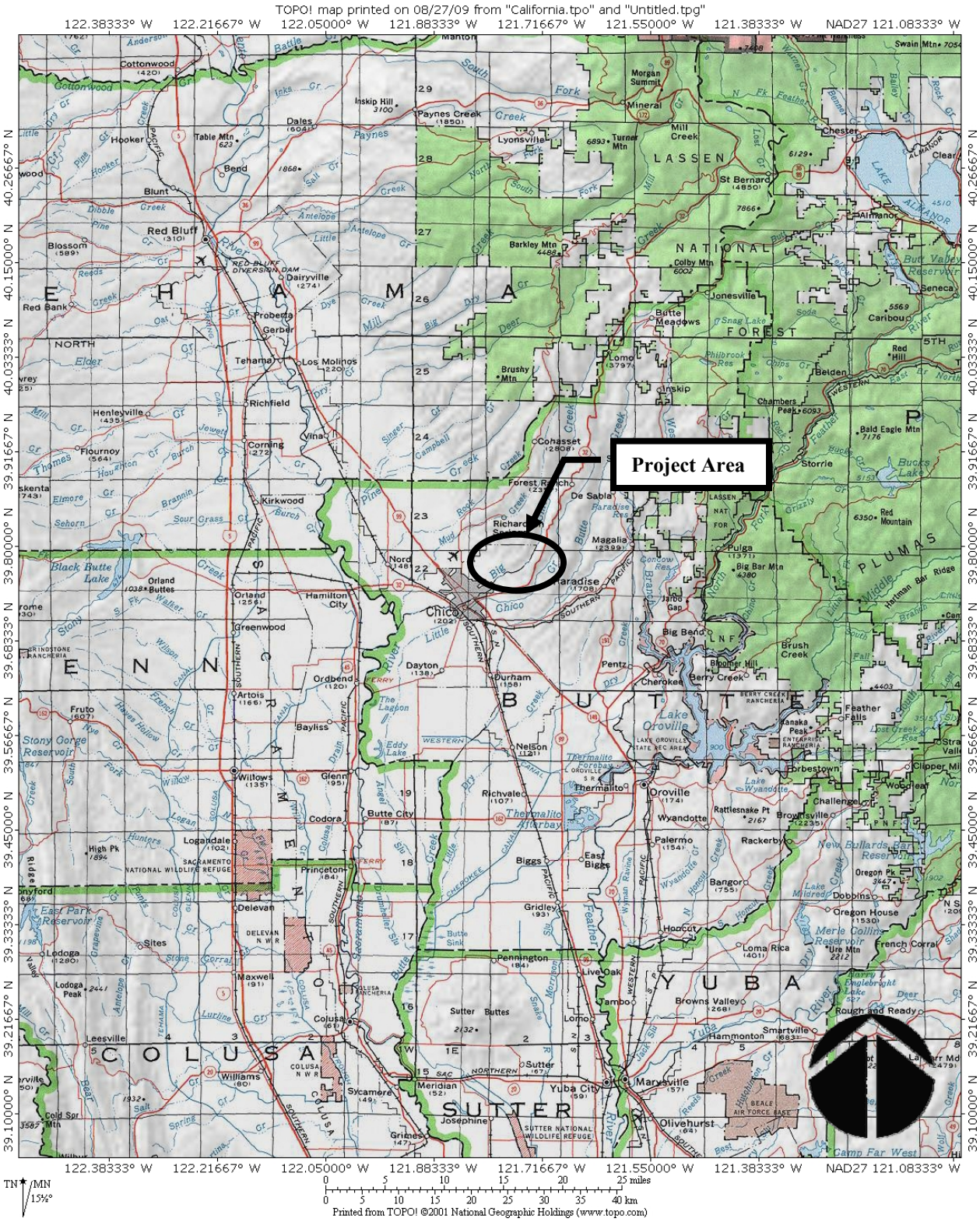

Figure 1. Project Location Map

Source: United States Geological Survey (USGS)

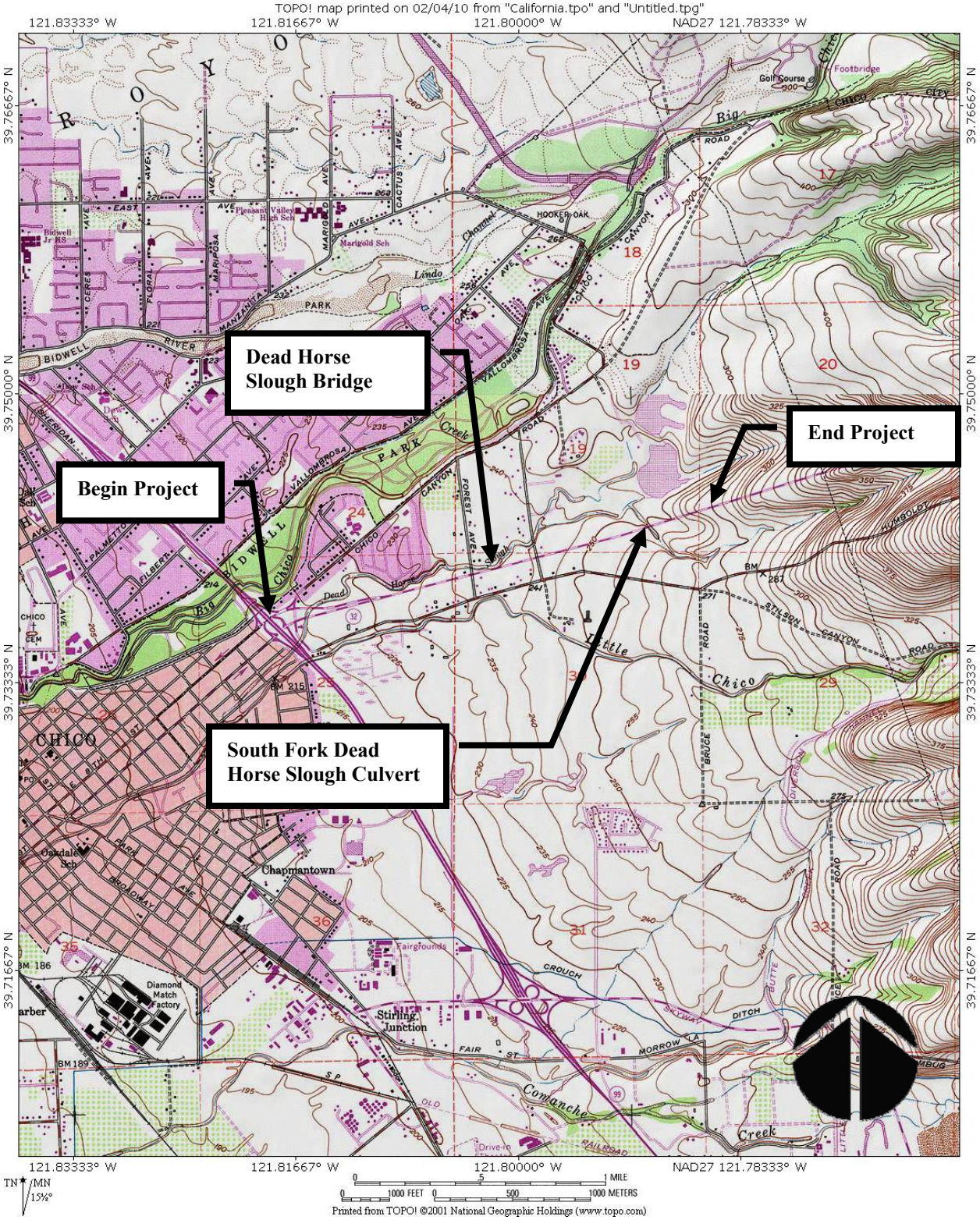

Figure 2. Project Vicinity Map

Source: USGS

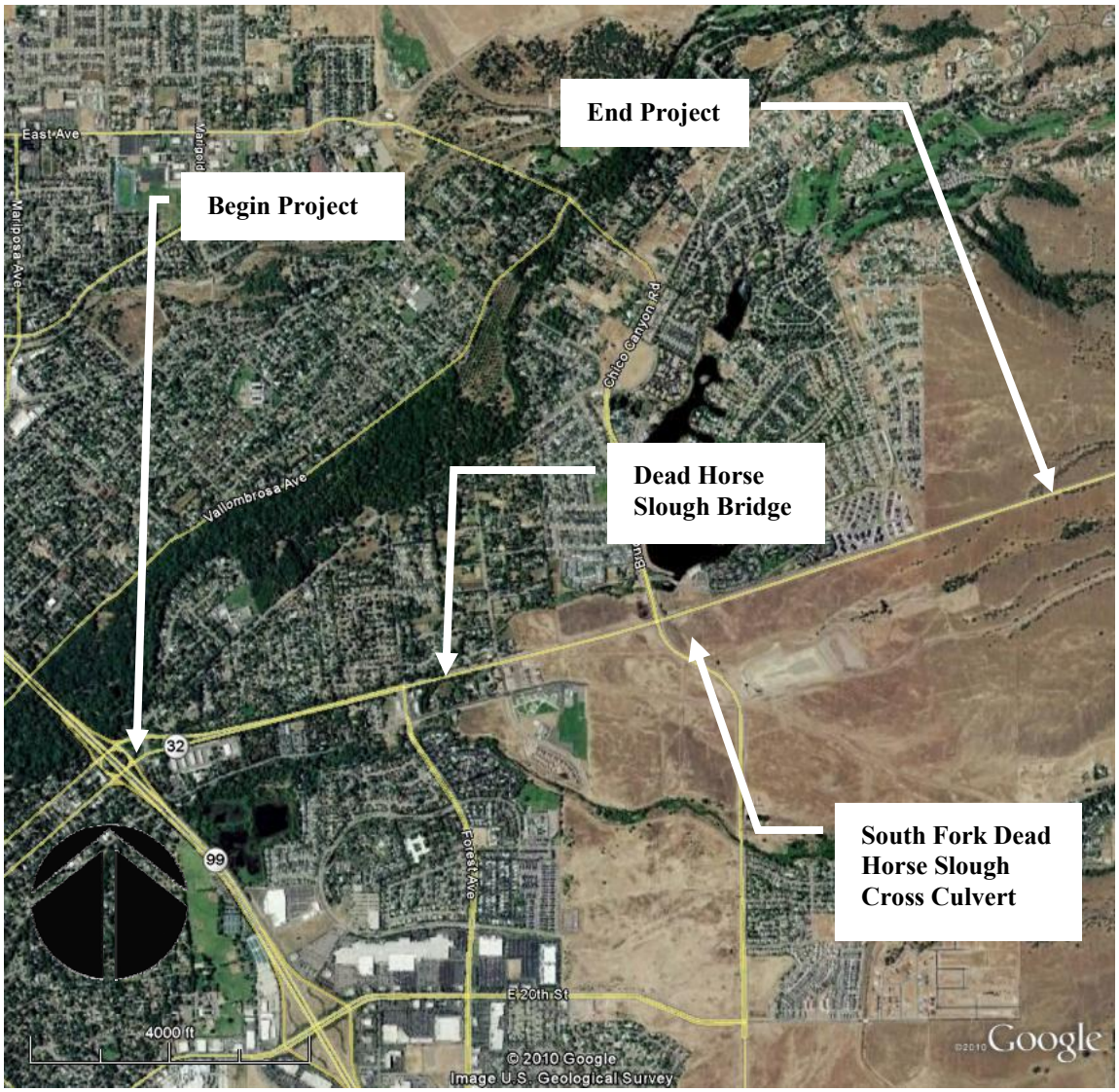

Figure 3. Project Vicinity Map, Aerial

Source: Google Earth

2 DESCRIPTION OF WATERSHED

2.1 Geographic Location

The Project site is located in the Dead Horse Slough watershed adjacent to the Little Chico Creek watershed (see Figure 4). Dead Horse Slough begins approximately 5.1 miles upstream of the Project site. South Fork Dead Horse Slough begins approximately 3.2 miles upstream of the Project site. Dead Horse Slough and its south fork drain a segment of the western slopes of the Sierra foothills between Musty Buck and Doe Mill ridges. The highest point in the watershed is at an elevation of 1,300 ft.

2.2 Watershed Size

The Dead Horse Slough watershed is about 5.2 square miles at the SR 32 bridge (see Figure 4). The South Fork Dead Horse watershed is about 0.9 square miles at the SR 32 RCB cross culvert.

2.3 Receiving Water Bodies

South Fork Dead Horse Slough is a tributary to Dead Horse Slough. Dead Horse Slough is a tributary to Little Chico Creek. Little Chico Creek flows southwest to join Angel Slough. Angel Slough in turn flows south to join Butte Creek just upstream of where Butte Creek joins the Sacramento River. The Sacramento River flows south to the city of Sacramento then west into San Francisco Bay and the Pacific Ocean.

2.4 Precipitation

Mean annual precipitation at the Project site is approximately 30 inches, which is based on the Spatial Climate Analysis Service (SCAS) Oregon State University (OSU) *1961-1990 Average Annual Precipitation, CA.*

2.5 Land Use

The lower watershed of Dead Horse Slough is currently zoned mostly residential at the California Park development, some community commercial at Bruce Road and SR 32, and mixed-use neighborhood core at the intersection of Bruce Road/8th Street and at California Park Drive/Chico Canyon Road. The upper watershed of Dead Horse Slough is rural residential, parks, open space for environmental conservation/safety, and open space for agriculture/resource management. The California Park development surrounds California Park Lake, except at the upstream end, which is a park. The uppermost part of the watershed is located in Bidwell Park.

Land uses along the Project corridor vary from offices and businesses near SR 99 to offices, residences and undeveloped land farther east. Land between SR 99 and El Monte Avenue is generally developed, primarily with residential uses in the north, and office, commercial, and residential uses in the south. Two park-and-ride lots are located between

the eastbound and westbound lanes on both sides of Fir Street. Dead Horse Slough crosses under SR 32 just east of Forest Avenue.

Land between El Monte Avenue and Yosemite Drive along the Project corridor is generally undeveloped, with the exception of an office and residential development located on the north side of SR 32 between Bruce Road and Yosemite Drive and recent building activity on the south side of SR 32 east of El Monte Avenue. The undeveloped land is characterized by mildly sloped to moderately sloped topography with nonnative annual grassland, isolated wetlands, and vernal pools. Hank Marsh Junior High School is located just south of SR 32 at the intersection of Humboldt Road and El Monte Avenue. The Humboldt Road Burn Dump is located east of Bruce Road and south of SR 32, and it is currently closed. The area within the Project limits is rural-residential, and there are no maintenance stations or rest areas.

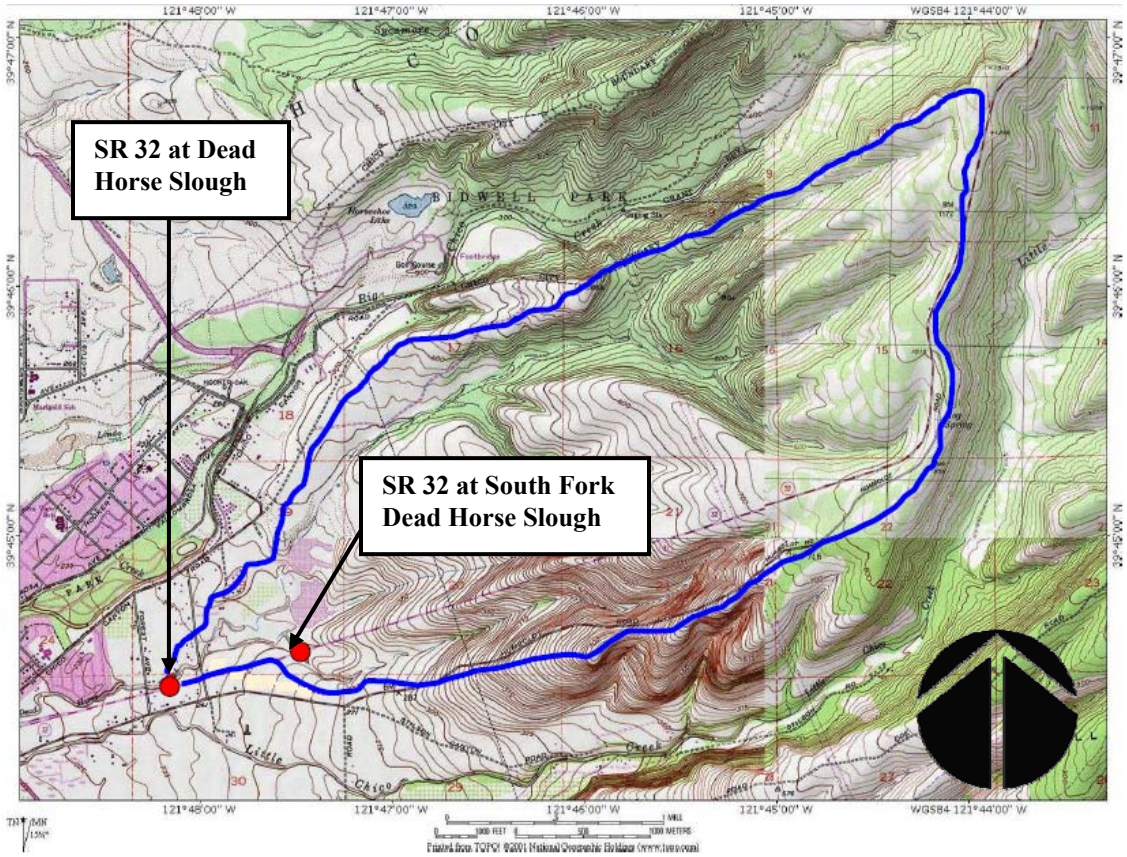

Figure 4. Watershed Map, Dead Horse Slough

Source: USGS

3 DESCRIPTION OF STREAM AND SITE

3.1.1 Dead Horse Slough

At the Project site, Dead Horse Slough occupies a well-defined, vegetated channel with medium thick riparian growth along the embankments (see Photo 1). The slough channel crosses SR 32 at an approximately 45° angle from perpendicular.

Photo 1. SR 32 at Dead Horse Slough, looking downstream

3.1.2 South Fork Dead Horse Slough

Upstream of the South Fork Dead Horse Slough crossing, the slough channel is located in a gravel and cobble laden swale with mild embankment slopes. The embankments are almost exclusively vegetated with grasses, with very few shrubs or trees (see Photo 2). Downstream of the crossing, the gravel and cobble channel is mostly clear of vegetation, with heavy foliage on the banks.

Photo 2. SR 32 at South Fork Dead Horse Slough, looking upstream

3.2 Soil and Bed Material

According to the Caltrans *Bridge Inspection Reports* (5/7/2004 and 10/4/2001), the bed material at the Dead Horse Slough crossing is described as silt and gravel. Based on field observation, the bed material at the South Fork Dead Horse Slough crossing is silty gravel with some cobbles.

3.3 Existing Facility

3.3.1 Dead Horse Slough

The existing SR 32 bridge over Dead Horse Slough is a four-span reinforced concrete (RC) slab bridge (123.5 ft by 32.5 ft wide) with RC pile bents and RC open diaphragm abutments on piles (see Photo 3; see Table 4 and Figure 5 for the bridge general specifications).

Table 4. Bridge General Specifications, Existing SR 32 Bridge over Dead Horse Slough

Bridge Type	RC slab with RC pile bents and RC open diaphragm abutments on piles.
Pier Bents	Three circular 15.5-in. concrete pile bents, four-span.
Bridge Span (ft)	123.5 (87.5 - in direction of flow)
Bridge Width (ft)	32.5 (46 - in direction of flow)
Deck Elevation (ft, NAVD)	241.67 to 242.65 (not including railing)
Soffit Elevation (ft, NAVD)	240.34-241.32
Thalweg Elevation (ft, u/s face/d/s face)	230.81/230.18

Photo 3. Existing SR 32 Bridge, looking southwest (downstream)

3.3.2 South Fork Dead Horse Slough

The South Fork Dead Horse Slough crosses SR 32 in a single 8 ft x 6 ft RCB cross culvert (see Photo 4). See Table 5 for the culvert general specifications.

Table 5. Culvert General Specification, Existing RCB Cross Culvert for South Fork Dead Horse Slough

Culvert Type	RCB Culvert
Size	8 ft x 6 ft
Length (ft)	88

Photo 4. Existing RCB cross culvert, looking north (downstream)

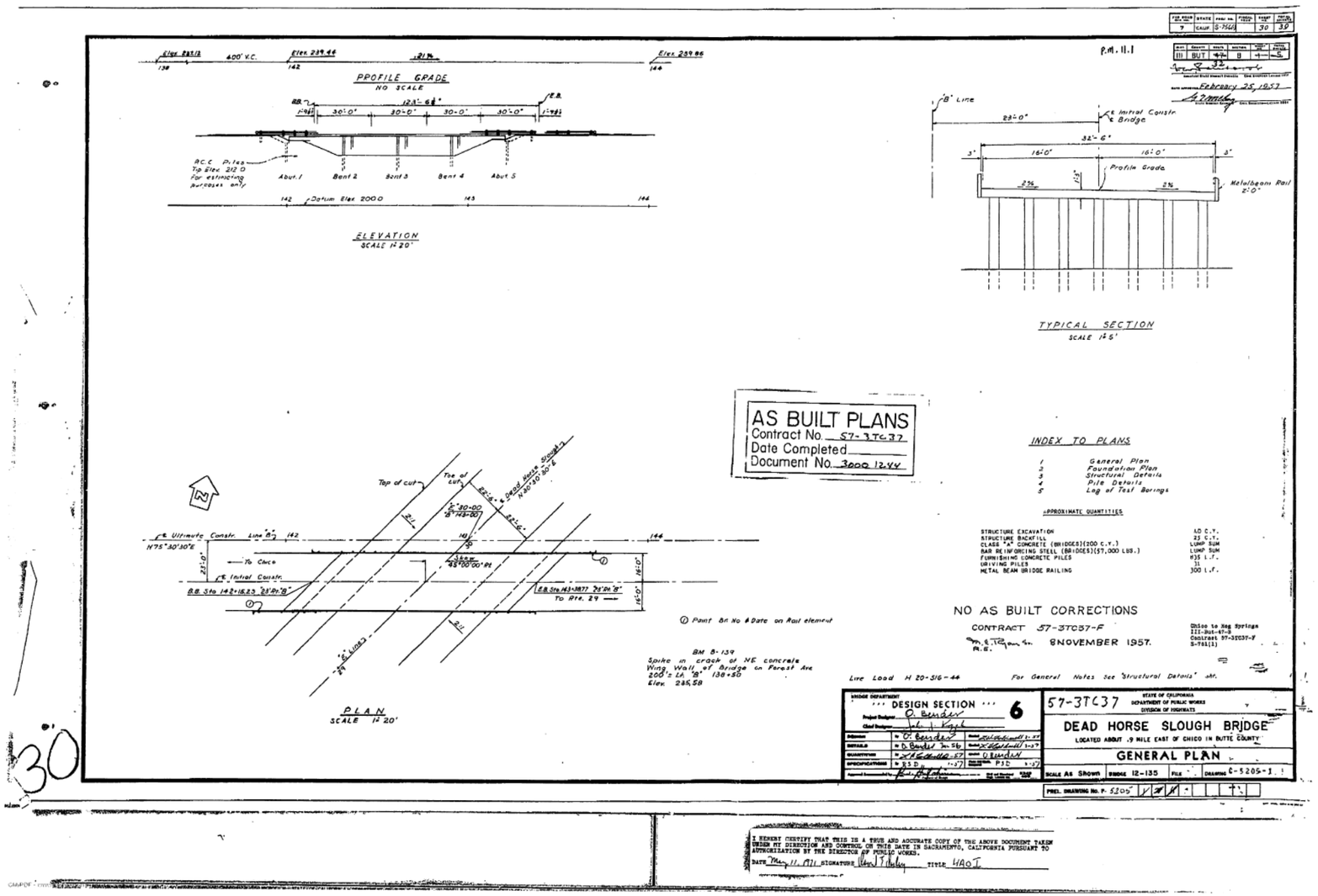

Figure 5. As-Built, SR 32 Bridge over Dead Horse Slough.

3.4 Proposed Action

The existing SR 32 bridge over Dead Horse Slough will be widened to the upstream side to accommodate the proposed widening of SR 32 from two lanes to four lanes. The general specifications of the proposed SR 32 bridge over Dead Horse are included in Table 6 and Figure 6.

Table 6. Bridge General Specification, Proposed SR 32 Bridge over Dead Horse Slough

Bridge Type	RC slab with RC pile bents and RC open diaphragm abutments on piles.
Pier Bents	Three circular 15-in. concrete pile bents, four-span.
Bridge Span (ft)	123.5 (87.5 - in direction of flow)
Bridge Width (ft)	81.5 (115.3 - in direction of flow)
Deck Elevation (ft, NAVD)	241.67 to 242.65 (not including railing)
Soffit Elevation (ft, NAVD)	240.47 to 240.73

The existing RCB cross culvert that carries South Fork Dead Horse Slough will be extended both upstream and downstream to accommodate the proposed widening of SR 32 from two lanes to four lanes. The general specifications of the proposed RCB cross culvert are included in Table 7.

Table 7. Culvert General Specification, Proposed RCB Cross Culvert for South Fork Dead Horse Slough

Culvert Type	RCB Culvert
Size	8 ft x 6 ft
Length (ft)	122

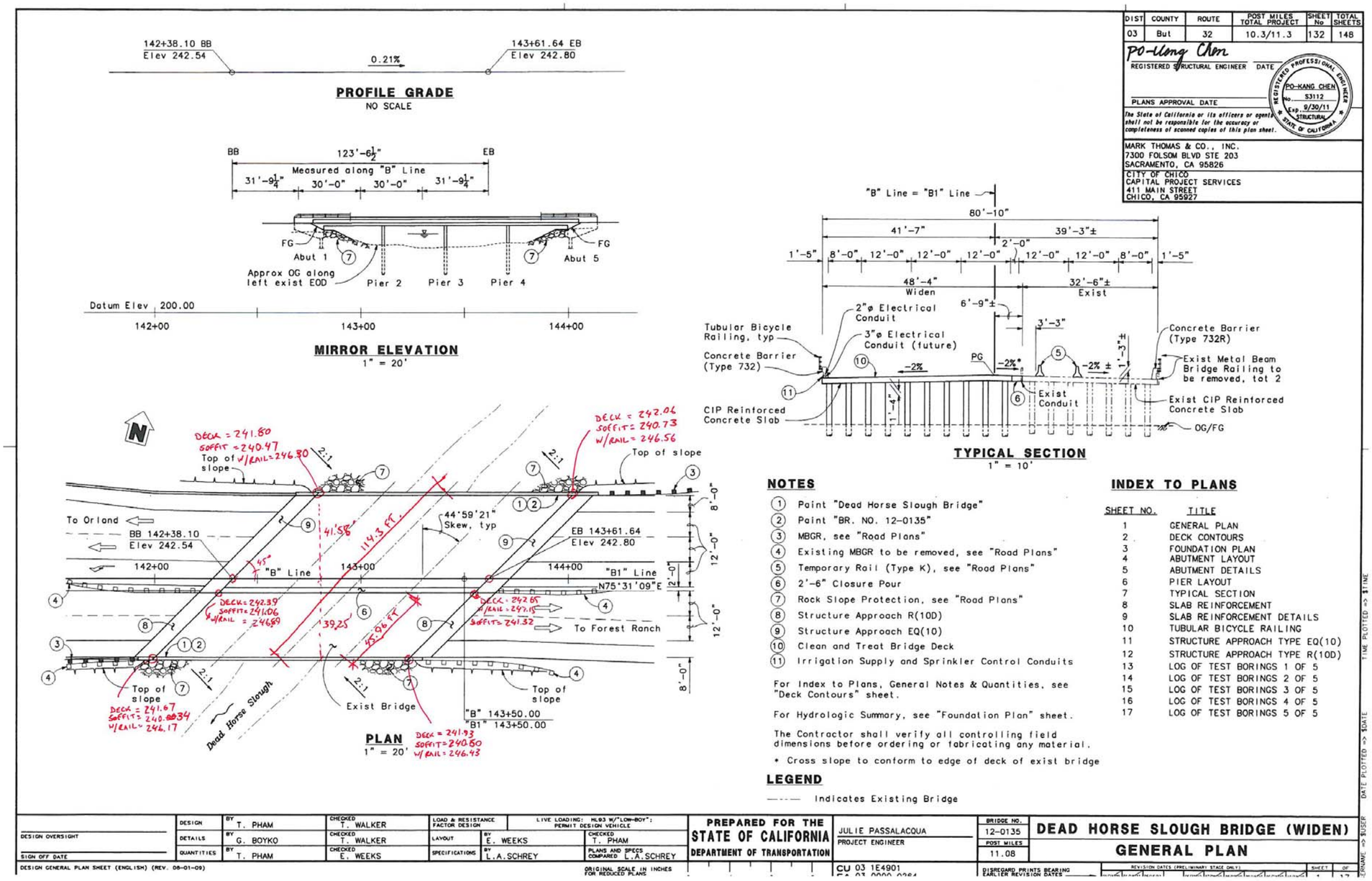

Figure 6. Bridge General Plan, SR 32 Bridge over Dead Horse Slough.

Source: Mark Thomas and Company, Inc. (Mark Thomas)

4 HYDROLOGY

4.1 Hydrologic Stability

California Park Lake is located approximately 0.7 miles upstream of the Dead Horse Slough crossing. The lake is unregulated and can only handle low flows (see Photo 5). There appear to be no significant changes in basin hydrology in recent years. Although there is some development around California Park Lake, most of the watershed is located in a rural setting with primarily open space.

Photo 5. California Park Lake Outlet

4.2 Design Discharge

4.2.1 Dead Horse Slough

4.2.1.1 FEMA LOMR

The Federal Emergency Management Agency's (FEMA) Flood Insurance Study (FIS) for the area (April 2000) and FEMA Letter of Map Revision (LOMR) (March 31, 2005) for Dead Horse Slough have been used to develop design flows for the Dead Horse Slough crossing. Furthermore, the *Proposed Husa Ranch Development Flood Mitigation Analysis* (2001) from Borcalli and Associates was reviewed for comparison. The LOMR flows for Dead Horse Slough at the confluence with Little Chico Creek were used to extrapolate a 200-year design flow for hydraulic analysis using the City's criteria. The 200-year flow of 2,200 cfs was extrapolated logarithmically as shown in Figure 7.

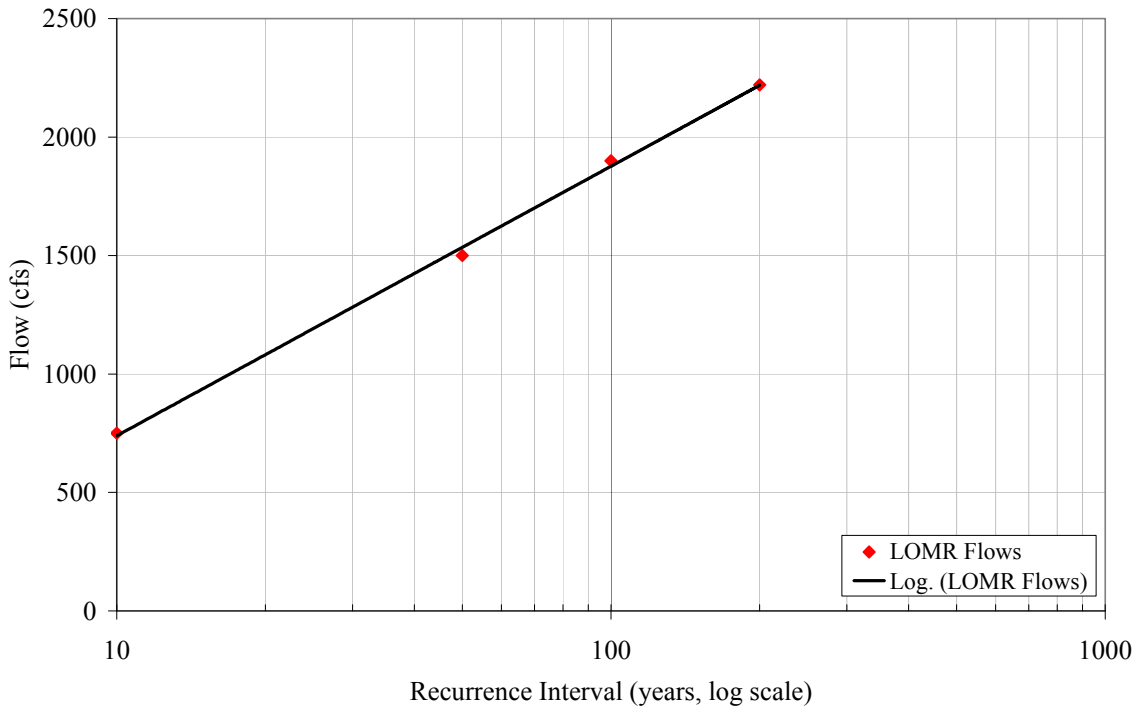

Figure 7. Dead Horse Slough Extrapolated Flows

Table 8 below summarizes the design flows for Dead Horse Slough based on the FEMA LOMR and the extrapolation of the 200-year flow. See Appendix C for detailed excerpts from the FEMA LOMR and calculations of Dead Horse Slough flows.

Table 8. Dead Horse Slough Design Flows

Design Storm Frequency (yr)	Design Flow (cfs)
10	750
50	1,500
100	1,900
200	2,200

4.2.1.2 FEMA FIS

The FEMA FIS for Butte County and Incorporated Areas (January 2011) provided the 100-year peak flow data of the Dead Horse Slough and Little Chico Creek. The FEMA peak flow locations are identified in Figure 8. The peak flow data from the FEMA FIS are summarized in Figure 9 and Table 9.

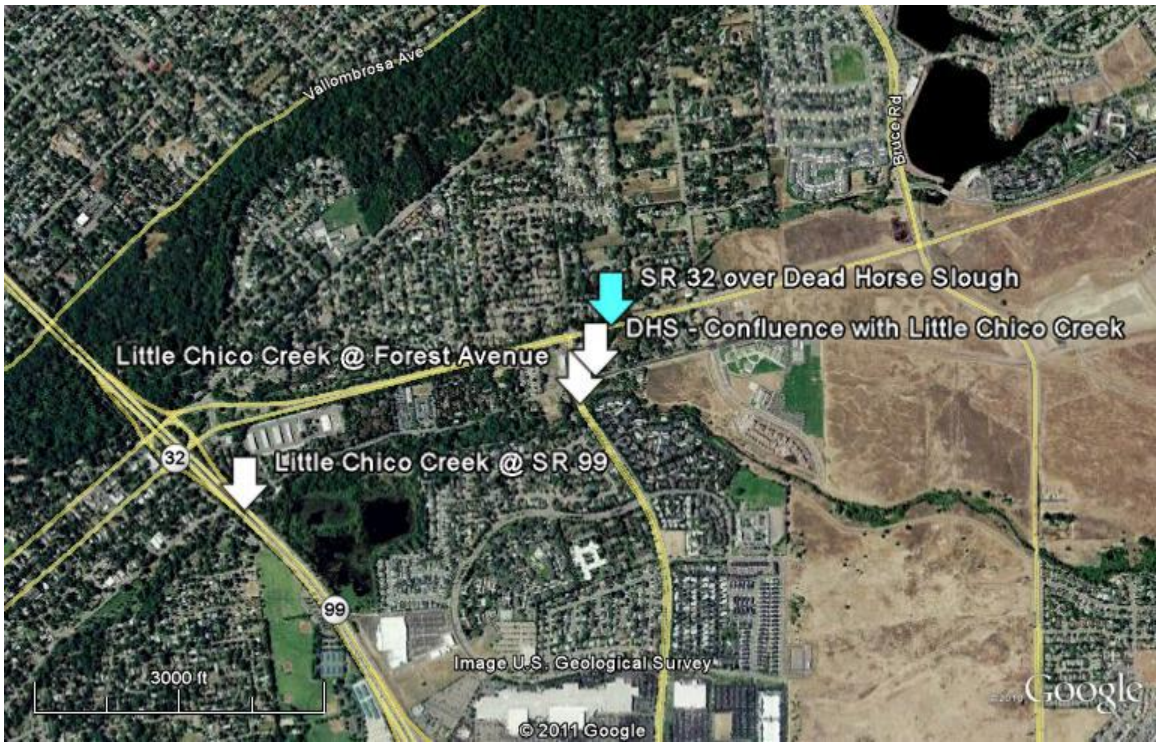

Figure 8. FEMA FIS Flooding Source and Locations

Source: FEMA, 2011 and Google Earth

The peak discharges for Dead Horse Slough in the 2011 FEMA FIS adopted the design flows from the 2005 LOMR. The peak discharges of Little Chico Creek at Forest Avenue and State Route 99 shows the peak discharges upstream and downstream of the confluence with Dead Horse Slough, respectively. The design 200-year flow rate of Little Chico Creek at the Project location were interpolated (at Forest Avenue) and extrapolated (at State Route 99) from the known peak discharges (see Figure 9 and Table 9).

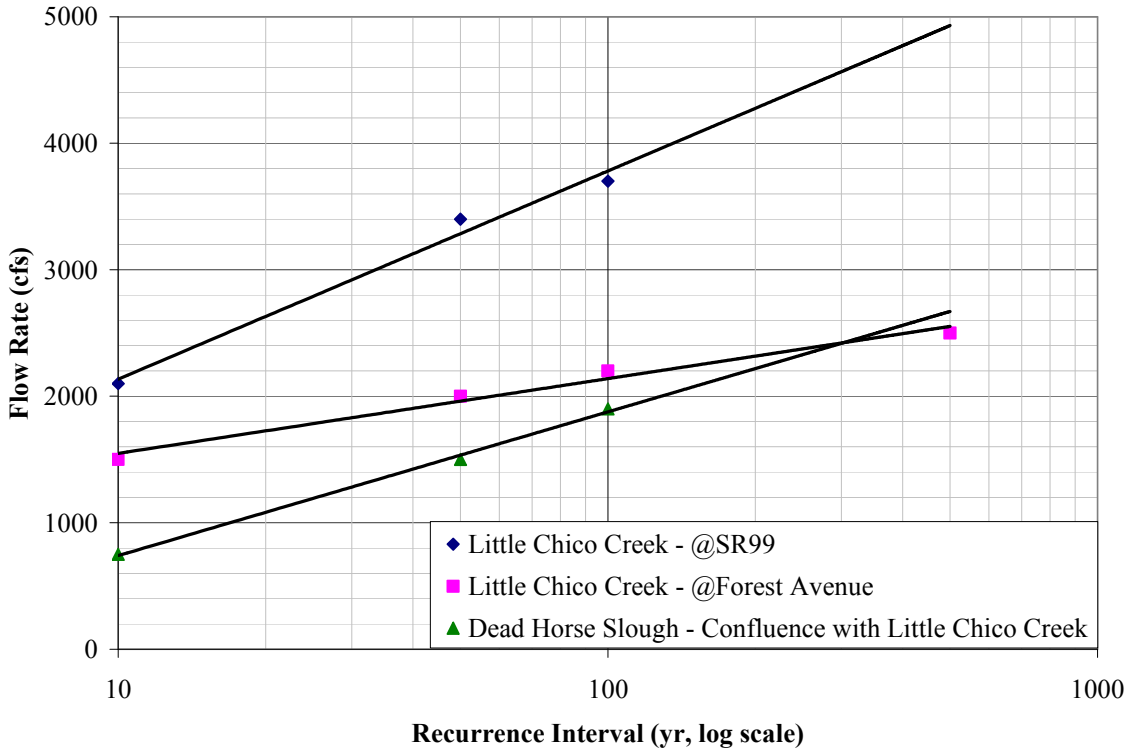

Figure 9. Little Chico Creek, Interpolated and Extrapolated Flows

Source: FEMA, 2011

Table 9. FEMA Flooding Source and Locations

Location	Peak Discharges (cfs)				
	10-Year	50-Year	100-Year	200-Year(1)	500-Year
Dead Horse Slough					
Confluence with Little Chico Creek	750	1,500	1,900	2,200	n/a
Little Chico Creek					
At Forest Avenue	1,500	2,000	2,200	2,350	2,500
At State Route 99	2,100	3,400	3,700	4,300	n/a

Note: (1) 200-year peak discharges are based on extrapolation and interpolation

Source: FEMA, 2011

4.2.2 South Fork Dead Horse Slough

A hydrograph transform method was applied using the U.S. Army Corps of Engineers' Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) computer program (version 2.2.2). The HEC-HMS hydrologic analysis of the South Fork Dead Horse Slough watershed at the RCB cross culvert crossing included the use of the SCS Transform method with SCS curve number loss calculations. The hydrologic model considers the limited future land use changes shown on the City of Chico General Plan Diagram provided for this Project.

The existing downstream headwall and wingwalls of the South Fork Dead Horse Slough RCB cross culvert are shown in Photo 6. This is located immediately north of SR 32 and just east of Bruce Road.

Photo 6. Downstream Headwall of South Fork Dead Horse Slough RCB cross culvert

4.2.2.1 Hydrologic Analyses

Twenty-four hour storm hydrographs for the various storm frequencies were developed by HEC-HMS based on the SCS Hypothetical Storm Type 1A. Return period rainfall depths were obtained from the National Oceanic and Atmospheric Administration's Isopluvial Maps. Table 10 shows the peak design flows for the South Fork Dead Horse Slough.

Table 10. South Fork Dead Horse Slough Design Flows

Design Storm Frequency (yr)	Design Flow (cfs)
10	290
25	360
50	430
100	470
200	530

Initial abstraction rates and constant rate infiltration were used to simulate abstractions. These values were estimated by an evaluation of the soil types present in the area. Lag time was estimated from the empirical relationship to the time of concentration. Time of

concentration was estimated based on shallow concentrated flow velocities and reach length. The design storm hydrographs are shown in Figure 10. See Appendix C for detailed HEC-HMS modeling data.

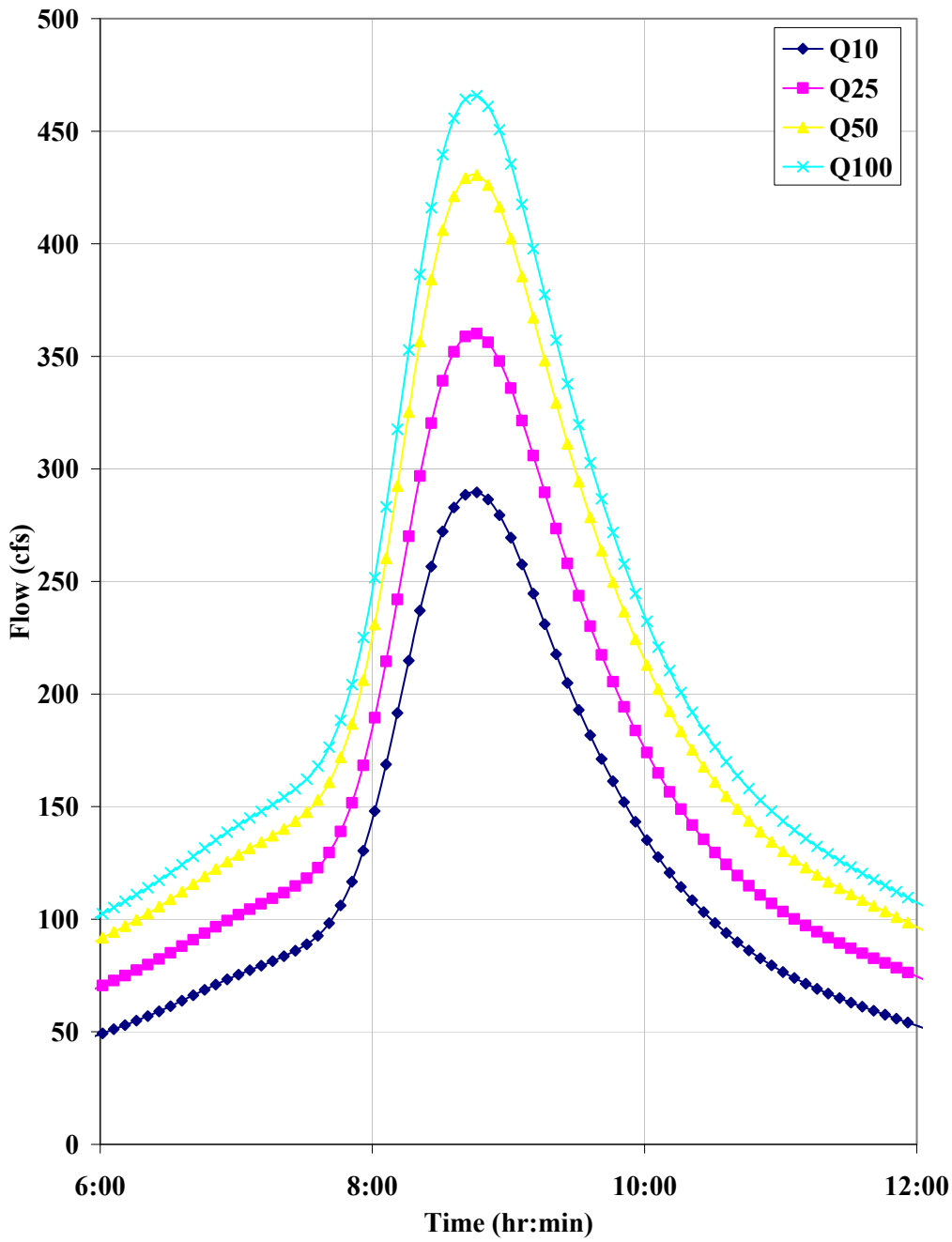

Figure 10. Design Hydrographs at South Fork Dead Horse Slough

5 HYDRAULIC ANALYSIS

5.1 Design Tools

The hydraulic analyses for Dead Horse Slough and South Fork Dead Horse Slough involved a standard step backwater calculation using the USACE's Hydrologic Engineering Centers River Analysis System (HEC-RAS), Version 4.1 computer program to provide flow characteristics. The analyses were performed for the existing and proposed conditions using the same hydrologic data and the same channel cross sections, where applicable.

5.2 Cross section Data

The channel cross sections of Dead Horse Slough and South Fork Dead Horse Slough were obtained from Mark Thomas. The survey data referenced NAVD as vertical datum.

A total of 12 cross sections were distributed over a 1,140 ft reach of Dead Horse Slough. The cross sections included six upstream and six downstream of the SR 32 crossing (see Figure 11). The surveyed reach includes two bridge crossings: the subject SR 32 bridge and Humboldt Road bridge. The additional survey from Mark Thomas included four cross sections over a 516-ft reach of Little Chico Creek and two cross sections upstream and two cross sections downstream of the confluence with Dead Horse Slough. The downstream limit of the hydraulic model is at the upstream face of Forest Avenue bridge over Little Chico Creek.

The hydraulic model for the South Fork Dead Horse Slough was developed from six surveyed cross sections along South Fork Dead Horse Slough (see Figure 12). Three cross sections were taken downstream and three were taken upstream. The downstream limit of the hydraulic model is at the confluence with Dead Horse Slough.

5.3 Manning's n

Manning's n values are used in the hydraulic model to estimate energy losses in the flow due to friction. Manning's n values were selected to best describe the existing and proposed channel characteristics of Dead Horse Slough and South Fork Dead Horse Slough. The Manning's n values for the main channel were 0.035 and 0.040. For the left and right banks, a Manning's n value of 0.05 to 0.045 was used. The n values for the South Fork were 0.030 in the main channel and 0.045 for the left and right overbanks.

5.4 Expansion and Contraction Coefficients

Expansion and contraction coefficients are used to describe the transition between cross sections. For both the Dead Horse Slough and South Fork models, the expansion and contraction coefficients used to represent the channel were 0.3 and 0.1, respectively. These values describe a creek or slough with gradual transitions between cross sections. The expansion and contraction coefficients used in the vicinity of the bridge and culvert

were 0.5 and 0.3, respectively. These values were used because the abutments of the bridge intrude slightly into the channel.

Figure 11. HEC-RAS Cross Section Locations, Dead Horse Slough and Little Chico Creek

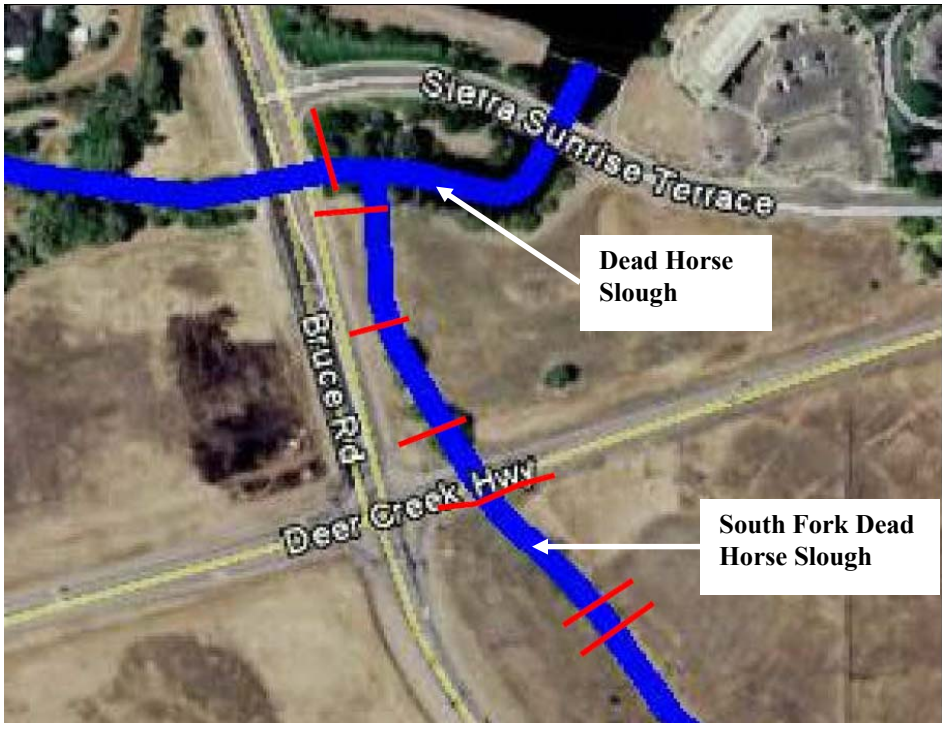

Figure 12. HEC-RAS Cross Section Locations, South Fork Dead Horse Slough

5.5 Downstream Boundary Conditions

5.5.1 Dead Horse Slough

As stated in Section 5.2, the downstream limit of the hydraulic model of Dead Horse Slough is the upstream face of Forest Avenue bridge over Little Chico Creek. According to the FEMA FIS for Butte County and Incorporated Areas, the 100-year WSE of Little Chico Creek at the upstream face of Forest Avenue bridge is approximately 234.5 ft, NAVD (see Appendix D).

The profile from FEMA FIRM only showed the 100-year WSEs of Little Chico Creek and Dead Horse Slough at the Project location. In addition, there were no available data for the 10-, 50-, and 200-year WSEs of Little Chico Creek and Dead Horse Slough at the Project location. The normal depth of the design 100-year flow at the downstream limit of the hydraulic model is 0.00364 ft/ft when the 100-year WSE at the downstream limit of the model matches the FEMA 100-year WSE (234.5 ft, NAVD). The surveyed channel slope of the Little Chico Creek at the Project location based on the thalweg elevation varied from 0.0018 ft/ft to 0.0075 ft/ft. Because normal depth of 0.00364 ft/ft is within the range of surveyed channel slope, the normal depth of 0.00364 ft/ft was selected as the downstream control for the design 10-, 50-, and 200-year storm events. The known WSE of 234.5 ft, NAVD from FEMA FIS was selected at the downstream control WSE for the design 100-year storm event. The normal depth slopes used as the downstream boundary condition for the design 10, 50-, and 200-year storm events are summarized in following table.

Table 11. Downstream Boundary Conditions, Dead Horse Slough

Design Storm Frequency (yr)	Normal Depth (ft/ft)	Corresponding WSE (ft, NAVD)
10	0.00364	232.6
50	0.00364	234.2
100	-	234.5
200	0.00364	235.0

Note: 100-year WSE is from FEMA FIS.

5.5.2 South Fork Dead Horse Slough

As stated in Section 5.2, the downstream limit of the hydraulic model of South Fork Dead Horse Slough is the confluence with Dead Horse Slough. According to the LOMR, the 100-year WSE at this location is approximately 245 ft NGVD (247.33 ft NAVD, see Appendix C).

The hydraulic model for South Fork Dead Horse Slough was calibrated to determine normal depth at the downstream boundary condition equivalent to the 100-year WSE from the FEMA FIRM (247.33 ft, NAVD). The calibrated normal depth slope was used as the downstream boundary condition for the design 10, 50-, 100-, and 200-year storm events (see Table 12).

Table 12. Downstream Boundary Condition, South Fork Dead Horse Slough

Design Storm Frequency (yr)	Normal Depth (ft/ft)	Corresponding WSE (ft, NAVD)
10	0.00397	245.2
25	0.00397	246.2
50	0.00397	246.7
100	-	247.3
200	0.00397	247.8

Note: 100-year WSE is from FEMA LOMR.

5.6 Water Surface Elevations

5.6.1 Dead Horse Slough

The design WSEs just upstream Dead Horse Slough bridge for the peak discharge of the design storm events for the existing and proposed conditions are summarized in Table 13.

Table 13. Dead Horse Slough, Water Surface Elevations at River Station 10762

Recurrence Interval (yr)	Existing Condition			Proposed Condition		
	Bridge Soffit Elevation(1) (ft, NAVD)	Water Surface Elevation(2) (ft, NAVD)	Freeboard (ft)	Bridge Soffit Elevation(1) (ft, NAVD)	Water Surface Elevation(2) (ft, NAVD)	Freeboard (ft)
50	240.5	237.1	3.4	240.5	237.3	3.2
100	240.5	237.8	2.8	240.5	238.0	2.5
200	240.5	238.3	2.2	240.5	238.6	1.9

Notes:
(1) Lowest upstream soffit elevation (NW corner).
(2) At cross section immediately upstream of bridge.

The hydraulic analysis indicated that, in both the existing and proposed conditions, the WSEs just upstream of the Project site are below the soffit elevation of the bridge during the 200-year, 100-year, and 50-year events. There is more than 3 ft of freeboard between the soffit and the design 50-year WSE.

The proposed bridge does not significantly impact the WSEs upstream of the bridge. Both the existing and proposed conditions meet the standard Caltrans/FHWA criteria of passing the 100-year flow and passing the 50-year flow with at least 2 ft of freeboard. Neither the existing condition nor the proposed condition meets the City's criteria of passing the 200-year flow with 3 ft of freeboard.

5.6.2 South Fork Dead Horse Slough

The design WSEs of South Fork Dead Horse Slough at the upstream face of the cross culvert during the design 10-, 25-, 50-, 100-, and 200-year storm events for the existing and proposed alternatives are listed in Table 14.

Table 14. South Fork Dead Horse Slough, Water Surface Elevations

Recurrence Interval (yr)	Existing Condition		Proposed Condition	
	Culvert Top Elevation (ft, NAVD)	Water Surface Elevation (ft, NAVD)	Culvert Top Elevation (ft, NAVD)	Water Surface Elevation (ft, NAVD)
10	252.0	252.0(1)	252.3	252.3(1)
25	252.0	253.0	252.3	253.3
50	252.0	253.8	252.3	254.1
100	252.0	254.3	252.3	254.6
200	252.0	255.2	252.3	255.3

Note: The 10-year WSE indicated is at the cross section upstream of the culvert opening. The 10-year WSE at the culvert opening for the existing and proposed conditions is 249.44 ft and 249.73 ft, respectively, as indicated in the Appendices A and B.

At the time of the analysis (circa 2006), WRECO assumed that the proposed condition will extend the RCB box culvert by the same amount that the roadway will be widened in the direction of the existing RCB cross culvert: 14 ft upstream and 39.5 ft downstream. The proposed condition hydraulic model assumed that the RCB cross culvert will be extended at the same slope as the existing culvert. WRECO's hydraulic analysis indicated that the proposed condition will slightly increase the upstream WSEs from the existing condition. This is due to head losses associated with the extended RCB, which result in slightly decreased flow velocities and slightly increased WSEs. After reviewing the 65% drainage design information, it was determined that the RCB cross culvert will not be lengthened on the south side and will be lengthened approximately 34 ft on the north side. Because the proposed design includes a smaller lengthening than what was analyzed, the increases in WSE will be smaller than those shown above.

5.7 Flow Velocities

5.7.1 Dead Horse Slough

The calculated Dead Horse Slough flow velocities in the main channel are shown in Table 15 for the existing and proposed conditions.

Table 15. Flow Velocities in Main Channel at River Station 10762

Recurrence Interval (yr)	Existing Condition (ft/sec)	Proposed Condition (ft/sec)
50	5.2	4.9
100	5.7	5.4
200	5.8	5.6

Per Table 15, the proposed Project acts as a negligible impact to the flow velocities.

5.7.2 South Fork Dead Horse Slough

The flow in the RCB cross culvert is entirely supercritical. This is due to the steep slope of the flowline inside of the existing and proposed RCB cross culvert. The calculated South Fork Dead Horse Slough flow velocities in the main channel are shown in Table 16 for the existing and proposed conditions:

Table 16. Flow Velocities at Upstream and Downstream Ends of the RCB Cross Culvert

Recurrence Interval (yr)	Culvert Upstream End		Culvert Downstream End	
	Existing (ft/sec)	Proposed (ft/sec)	Existing (ft/sec)	Proposed (ft/sec)
10	10.5	10.5	16.0	17.1
25	11.3	11.3	16.8	17.9
50	12.0	12.0	17.5	18.7
100	12.3	12.3	17.8	19.0

Per Table 16, the proposed Project slightly decreases the flow velocities of South Fork Dead Horse Slough upstream of the culvert, which is due to the head loss from the extended RCB cross culvert. The downstream flow velocities in the RCB cross culvert range 16.0 ft/sec to 17.8 ft/sec in the existing condition and 17.1 ft/sec to 19.0 ft/sec in the proposed condition. This represents a slight increase in downstream erosive forces. Although there is no evidence of significant erosion at the downstream end of the RCB cross culvert, WRECO recommends energy dissipating countermeasures such as rock slope protection (RSP) to protect against potential scour from the high flow velocities outfalling into the slough channel. The Caltrans Rock Slope Protection Design Guideline recommends ¼ Ton RSP for the mean stream velocity of 18 ft/sec.

6 SCOUR ANALYSIS

6.1 Design Criteria

WRECO evaluated bridge scour per the criteria described in the FHWA's *Hydraulic Engineering Circular No. 18, Evaluating Scour at Bridges, Fourth Edition* (HEC-18) (May 2001).

The footing of the piers and abutments should be adequately designed, and or protected to preclude bridge failure from scour. For new bridges, the long-term degradation of the channel bed is predicted over 75 years. Scour prevention methods should be used as necessary to protect the channel and bridge stability.

6.2 Caltrans Bridge Inspection Report(s)

The Caltrans Structure Maintenance & Investigations' Bridge Inspection Report (October 4, 2001) indicates the following:

> "Erosion of the slope protection at Abutment #1 is still occurring. According to a 1983 inspection report, the rock slope protection was put in place in either 1969 or 1970 to arrest erosion at the abutments. However, the report mentions that the rock slope protection at Abutment #1 had sloughed down the slope shortly after placement and bank erosion was still occurring and is still slowly occurring at this location to this date. Additional rock slope protection should be placed at Abutment #1 to prevent further erosion."

6.3 Existing Channel Bed

The bed material is predominantly silt and gravel (Caltrans, 2001). According to the *Civil Engineering Reference Manual*, AASHTO's (1970) classification of soil particle sizes defines gravel size as 2 mm –75 mm and defines silt size as 0.002 mm – 0.075 mm. WRECO assumed a D_{50} grain size of 0.05 mm.

6.4 Long-Term Bed Elevation Change

The channel bed elevation may fluctuate over time as a result of changes in local sediment transport capacity and availability. When more sediment is supplied by watershed erosion and upstream channel flow than can be transported locally, the channel bed aggrades. Channel degradation occurs when sediment transport capacity exceeds supply. Only channel degradation is considered for the purposes of analyzing scour.

The field observations did not indicate severe creek bed degradation. The long-term bed elevation change was assumed to be negligible. (See Table 20 for a summary of total estimated scour).

6.5 Contraction Scour

Contraction scour occurs when the flow area of a stream is reduced either by: 1) the natural contraction of the stream channel; 2) by a bridge structure; or 3) the overbank flow forced back to the channel.

The ratio of shear velocity and fall velocity of the median particle size in the channel (D_{50}) was determined for the hydraulic model with the proposed SR 32 bridge over Dead Horse Slough. If the critical velocity (V_c) is less than the mean channel velocity, live-bed contraction scour was assumed. If V_c is greater than the mean channel velocity, clear-water scour was assumed. The critical velocity was calculated using the following equation (HEC-18, equation 5.1)

$$V_c = K_u y^{1/6} D_{50}^{1/3}$$

Where:

V_c = critical velocity above which a bed material size of D and smaller will be transported (ft/sec)
D = particle size for V_c (ft)
y = average depth of flow upstream of the bridge (ft)
D_{50} = particle size in a mixture of which 50 percent are smaller (ft)
K_u = 6.19 for SI units and 11.17 for English units

The critical velocity for the median particle size in the Dead Horse Slough (0.05 mm, see section 6.3) is 0.8 ft/sec. The channel flow velocity of Dead Horse Slough during the design 100-year storm event varies from 5.4 to 7.7 ft/sec. Live-bed contraction scour was assumed for the scour analyses.

Live-Bed Contraction Scour (HEC-18, equation 5.2):

$$y_s = y_1 \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k1} - y_0$$

$$V^* = \left(g y_1 S_1\right)^{1/2}$$

Where:

y_s = average contraction scour depth (ft)
y_1 = average depth in the upstream main channel (ft)
y_0 = existing depth in the contracted section before scour (ft)
Q_1 = flow in the upstream channel transporting sediment (cfs)
Q_2 = flow in the contracted channel (cfs)
W_1 = bottom width of the upstream main channel that is transporting bed material (ft)
W_2 = bottom width of the main channel in the contracted section less pier widths (ft)

k_1 = exponent, function of V_*/ω
V^* = shear velocity in the upstream section (ft/s)
ω = fall velocity of bed material based on the D_{50} (ft/s)
g = gravitational acceleration (ft/s^2)
S_1 = slope of energy grade line of main channel (ft/ft)

V*/ω	k_1	Mode of Bed Material Transport
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge

See Table 17 for the calculated contraction scour with the design 100-year flow

Table 17. Contraction Scour Summary

Location	Scour Depth (ft)
Dead Horse Slough Proposed Bridge Crossing	0.3

(See Table 20 for a summary of total estimated scour)

6.6 Pier Scour

Pier scour is caused by the vortices forming at the base of the pier. The scour depth at the pier is influenced by pier design, flow characteristics (flow rate and local velocity at the pier), and sediment particle size distribution. The HEC-18 guideline recommended the Colorado State University (CSU) equation to determine pier scour. The pier scour was calculated using following equation (HEC-18, equation 6.1):

$$y_s = 2.0 y_1 K_1 K_2 K_3 K_4 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43}$$

$$Fr_1 = \frac{V_1}{\sqrt{g y_1}}$$

Where:

y_s = scour depth (ft)
y_1 = flow depth directly upstream of the pier (ft)
K_1 = correction factor for pier nose shape, 1.1 for square nose, 1.0 for round nose, circular cylinder, and group of cylinders, and 0.9 for sharp nose
K_2 = correction factor for angle of attack, 1.0 when angle is 0 degrees
K_3 = correction factor for bed condition, 1.1 for clear-water scour and small dunes
K_4 = correction factor for armoring by bed material size
If $D_{50} < 2$ mm, $K_4 = 1$
If $D_{50} \geq 2$mm and $D_{95} \geq 20$mm, then $K_4 = 0.4\ (V_r)^{0.15}$
a = pier width (ft)

Fr_1 = Froude Number directly upstream of the pier
V_1 = mean velocity of flow directly upstream of the pier (ft/s)
g = gravitational acceleration (ft/s^2)

The scour depths at the bridge piers were determined using the local flow depth velocity directly upstream of the pier. In addition, scour depth using the maximum flow depth and maximum flow velocity at the cross section upstream of the proposed bridge were determined to account for the future thalweg migration. The pier width in the equation above was tripled from 15 in. (1.25 ft) to 45 in. (3.75 ft) to accommodate the debris accumulation at the piers. See Table 18 for the calculated local scour at bents during the 100-year design flow.

Table 18. Pier Scour Summary

Bridge Component	Flow Depth (ft)	Flow Velocity (ft/sec)	Local Scour (ft)
Maximum Flow Depth and Velocity	6.7	6.4	7.1
Bent 4 (Pier 1 in HEC-RAS)	5.0	5.1	6.1
Bent 3 (Pier 2 in HEC-RAS)	6.6	6.1	6.9
Bent 2 (Pier 3 in HEC-RAS)	5.6	5.7	6.5

(See Table 20 for a summary of total estimated scour)

Although Bents 2 and 4 have shallower estimated local scour depths than Bent 2, there is potential for the thalweg to migrate from Bent 2 to Bent 3 and 4; thus, all pier foundations should be designed for the maximum estimated pier scour elevation.

6.7 Abutment Scour

High flow events would cause local scour at the abutments. A vortex is formed at the upstream end of the abutment and along the toe of the abutment due to the flow obstruction caused by the abutments. The highly turbulent flow caused by the abutments generates the erosive shear action and subsequently causes the scouring. Abutments 1 and 5 are outside of the 100-year floodplain, and would not obstruct the 100-year flood flow (see Figure 13). However, future shifts in thalweg location may shift the extent of the 100-year floodplain to include bridge abutments. Local scour at the bridge abutments was calculated based on the future shifts in thalweg location. The abutment scour at each abutment was evaluated using the Froehlich's Live-Bed Scour Equation or HIRE Live-Bed Abutment Scour Equation.

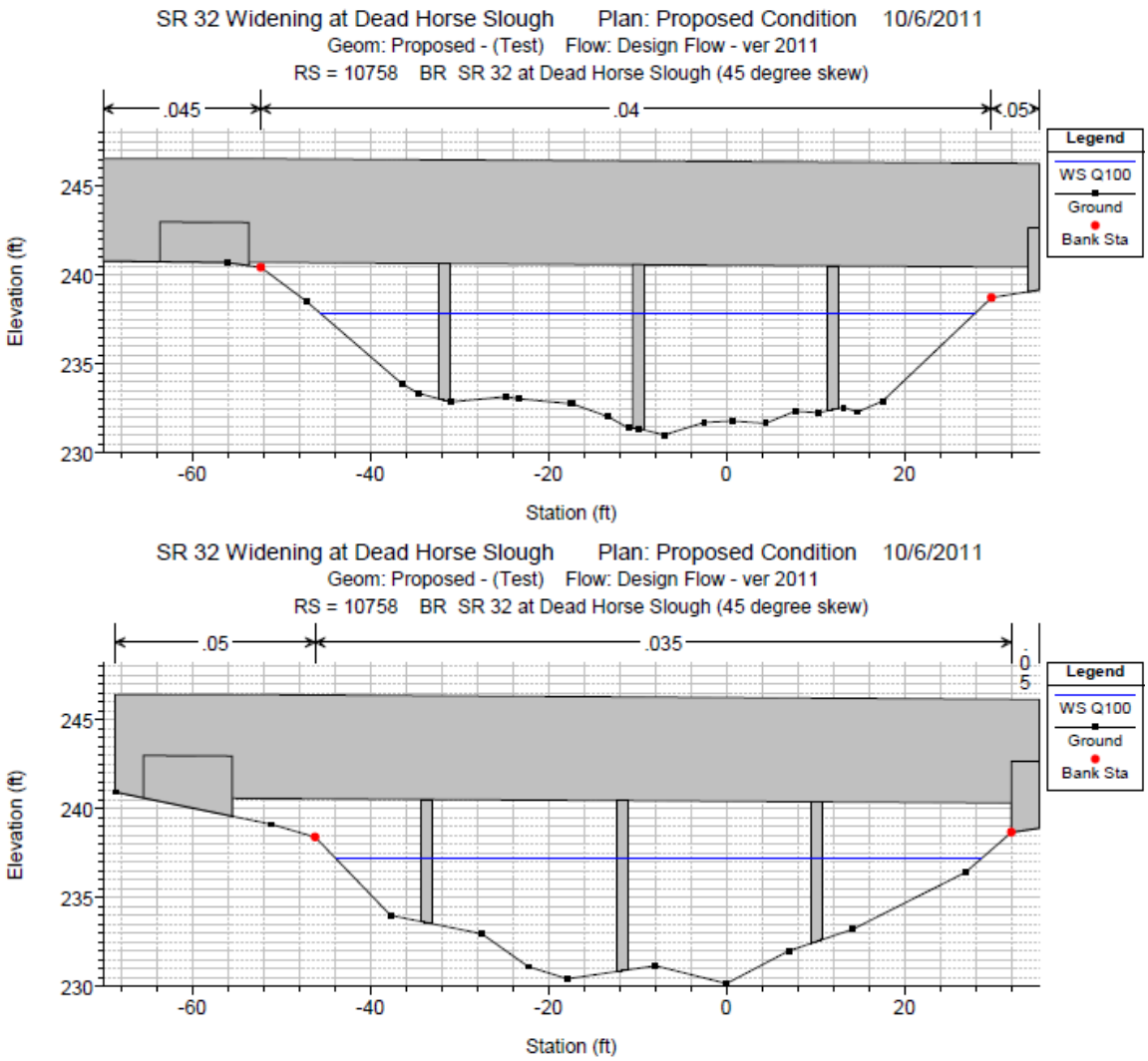

Figure 13. 100-year WSE at Proposed SR 32 Bridge

Froehlich's equation would be used for cases where the abutment length is small in comparison to the flow depth (L/y1 < 25). The HIRE equation would be applicable when the ratio of projected abutment length (L) to the flow depth (y1) is greater than 25. The abutment scour at each abutment for each of the alternatives was evaluated using the Froehlich equation (HEC-18, equation 7-1):

$$y_s = 2.27 y_a K_1 K_2 \left(\frac{L'}{y_a}\right)^{0.43} Fr_1^{0.61} + y_a$$

$$K_2 = (\theta/90°)$$

$$Fr_1 = \frac{V_e}{\sqrt{g y_a}}$$

$$y_a = A_e / L$$

Where:

K_1 = coefficient for abutment shape
K_2 = coefficient for angle of embankment to flow
L' = length of active flow obstructed by the embankment (ft)
A_e = Flow area of the approach cross section obstructed by the embankment (ft^2)
Fr_1 = Froude Number of approach flow upstream of the abutment
$V_e = Q_e/A_e$ (ft/s)
Q_e = flow obstructed by the abutment and approach embankment (cfs)
y_a = average depth of flow on the floodplain (ft)
L = length of embankment projected normal to the flow (ft)
y_s = scour depth (ft)
g = gravitational acceleration (ft/s^2)

According to the aerial image and the field visit, the left and right overbanks of Dead Horse Slough are within a residential zone. Based on the current land use adjacent to the left and right banks, a significant shift of the thalweg location upstream of the proposed SR 32 bridge is not anticipated to occur during the lifespan of the bridge.

The length of embankment projected normal to the flow was estimated to be 4 ft. The flow depths were determined using the existing side slope of the channel. The local 100-year flow velocity at the left and right banks at the cross section immediately upstream of the proposed bridge (STA 10762) was selected as the flow velocity at the obstructed area. The local scour depths at abutments are summarized in Table 19.

Table 19. Abutment Scour Summary

Lcoation	Bridge Component	Local Flow Velocity (ft/sec)	Flow Obstructed by Abutment (cfs)	Local Scour (ft)
Left Overbank	Abutment 5	2.1	6.6	2.9
Right Overbank	Abutment 1	1.9	7.5	3.1

6.8 Total Scour

The total estimated scour will be the sum of the long-term bed change, contraction scour, and local pier and abutment scour. The total scour depths at the proposed bridge are shown in Table 20.

Table 20. Total Scour Depths

Bridge component	Maximum Estimated Local Scour (ft)	Contraction Scour (ft)	Long Term Scour (ft)	Total Scour (ft)	Recommended Design Scour Elevation (ft, NAVD)
Abutment 5	2.9	0.3	0.0	**3.2**	**235.5**
Bent 4	7.1	0.3	0.0	**7.4**	**222.8**
Bent 3	7.1	0.3	0.0	**7.4**	**222.8**
Bent 2	7.1	0.3	0.0	**7.4**	**222.8**
Abutment 1	3.1	0.3	0.0	**3.4**	**235.3**

As the thalweg may migrate over time, WRECO recommends that the maximum estimated scour of 7.4 ft, regardless of bent or abutment, should be considered for foundation design. The foundations should be designed for loss of lateral support down to the estimated scour depth.

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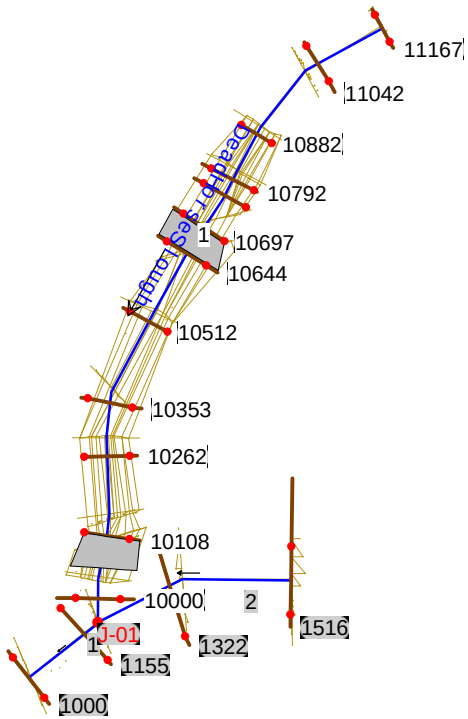
Appendix A HEC-RAS Results: Existing Conditions

Appendix A.1 Dead Horse Slough



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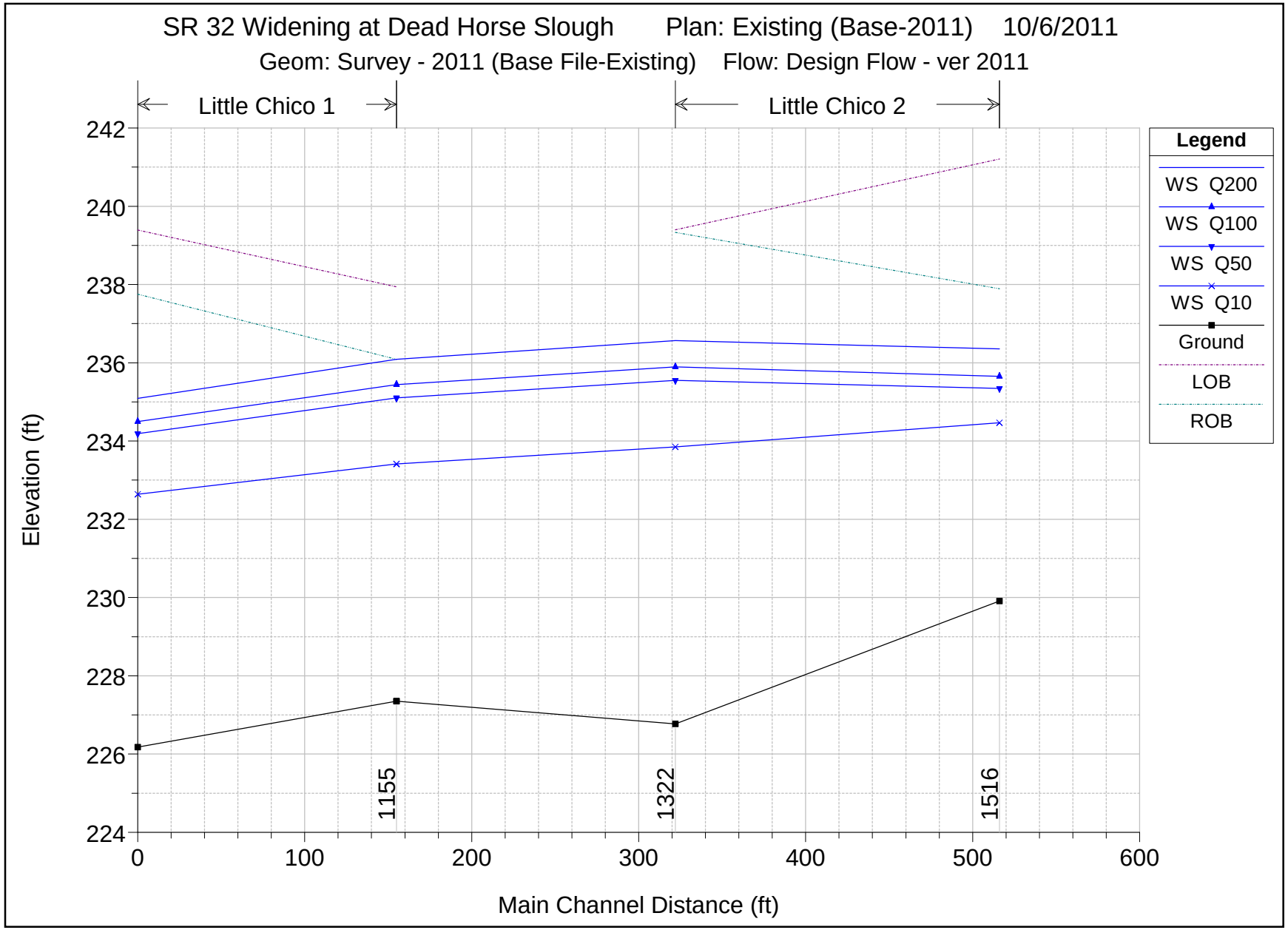
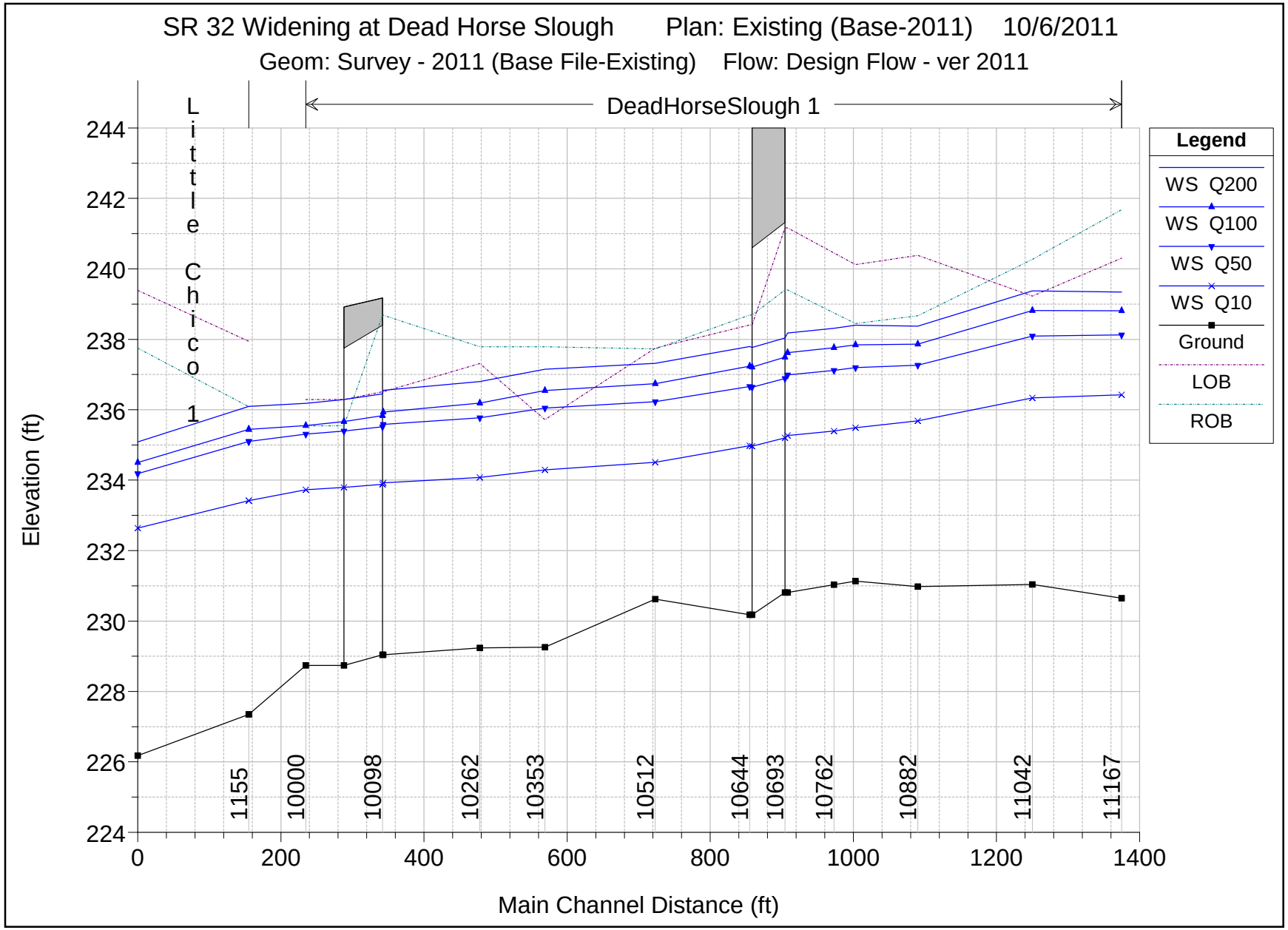

SR 32 Widening at Dead Horse Slough
Plan: Existing (Base-2011)
10/6/2011
Geom: Survey - 2011 (Base File-Existing)
Flow: Design Flow - ver 2011
Little Chico 1
Little Chico 2
Legend
WS Q200
WS Q100
WS Q50
WS Q10
Ground
LOB
ROB
Elevation (ft)
242
240
238
236
234
232
230
228
226
224
1155
1322
1516
0
100
200
300
400
500
600
Main Channel Distance (ft)


SR 32 Widening at Dead Horse Slough Plan: Existing (Base-2011) 10/6/2011
Geom: Survey - 2011 (Base File-Existing) Flow: Design Flow - ver 2011
DeadHorseSlough 1
Little Chico 1
Elevation (ft)
Main Channel Distance (ft)
244
242
240
238
236
234
232
230
228
226
224
0
200
400
600
800
1000
1200
1400
1155
10000
10098
10262
10353
10512
10644
10693
10762
10882
11042
11167
Legend
WS Q200
WS Q100
WS Q50
WS Q10
Ground
LOB
ROB

HEC-RAS Plan: Test-E-01

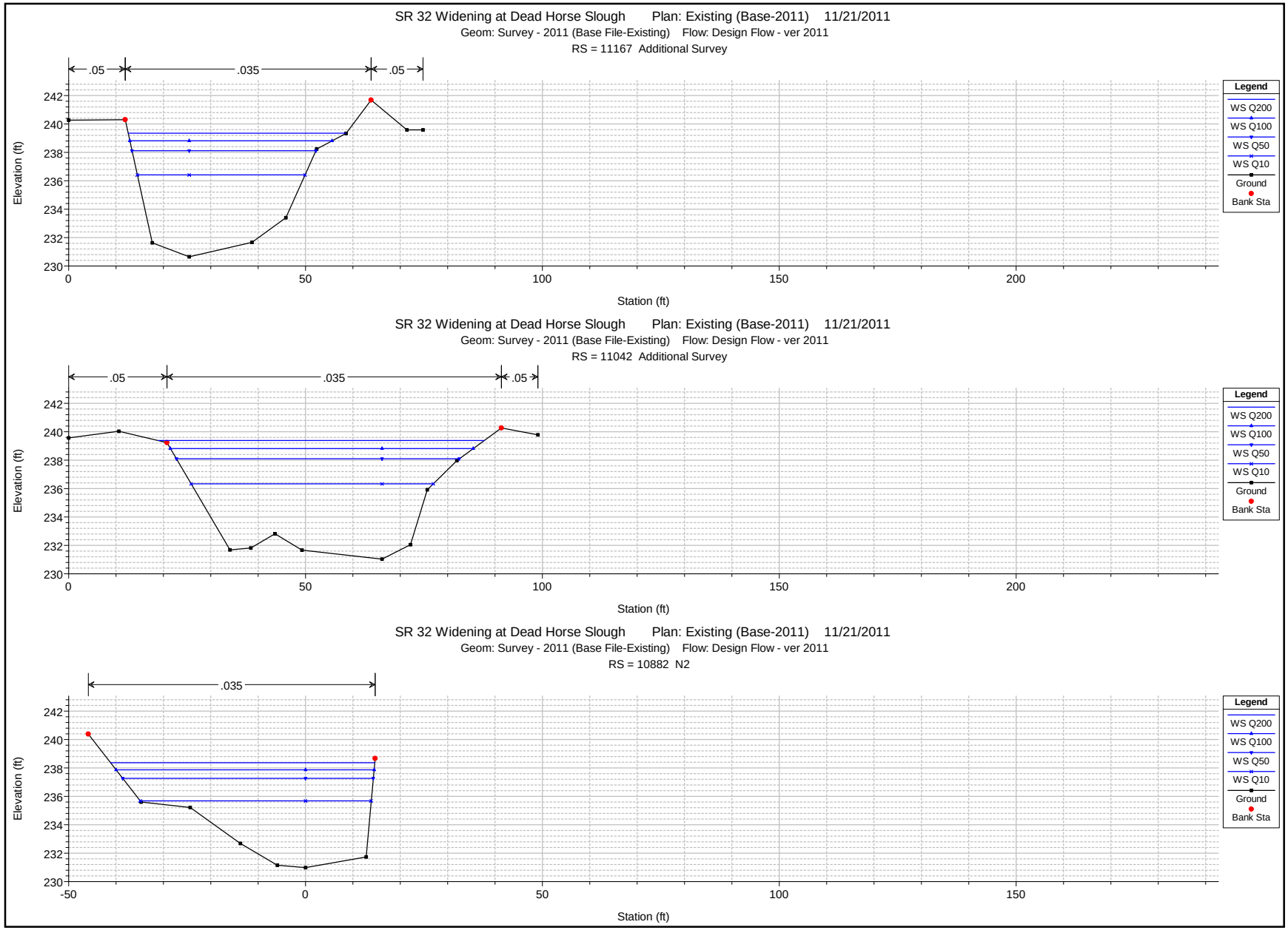
River	Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Little Chico	2	1516	2350.00	229.91	236.36		237.28	0.005831	7.69	305.68	81.18	0.70
Little Chico	2	1516	2200.00	229.91	235.65		236.85	0.009027	8.79	250.42	75.56	0.85
Little Chico	2	1516	2000.00	229.91	235.35	235.05	236.54	0.009816	8.79	227.61	73.11	0.88
Little Chico	2	1516	1500.00	229.91	234.47	234.47	235.73	0.013728	9.02	166.34	66.09	1.00
Little Chico	2	1322	2350.00	226.77	236.56		236.73	0.000768	3.26	721.85	152.57	0.26
Little Chico	2	1322	2200.00	226.77	235.89		236.09	0.001074	3.54	620.72	148.72	0.31
Little Chico	2	1322	2000.00	226.77	235.55		235.74	0.001155	3.51	570.46	146.76	0.31
Little Chico	2	1322	1500.00	226.77	233.85		234.17	0.003707	4.56	328.85	137.02	0.52
Little Chico	1	1155	4300.00	227.35	236.09		236.51	0.001549	5.17	831.11	149.91	0.39
Little Chico	1	1155	3700.00	227.35	235.44		235.84	0.001633	5.03	735.94	144.23	0.39
Little Chico	1	1155	3400.00	227.35	235.10		235.48	0.001686	4.95	686.94	141.21	0.40
Little Chico	1	1155	2100.00	227.35	233.42		233.74	0.002081	4.55	461.61	126.41	0.42
Little Chico	1	1000	4300.00	226.18	235.09	233.07	236.10	0.003640	8.06	533.74	92.28	0.59
Little Chico	1	1000	3700.00	226.18	234.50	232.59	235.42	0.003639	7.70	480.44	88.93	0.58
Little Chico	1	1000	3400.00	226.18	234.19	232.34	235.06	0.003641	7.51	452.84	87.15	0.58
Little Chico	1	1000	2100.00	226.18	232.64	231.10	233.29	0.003639	6.47	324.69	78.34	0.56
DeadHorseSlough	1	11167	2220.00	230.65	239.34		240.42	0.004336	8.31	267.16	45.98	0.61
DeadHorseSlough	1	11167	1900.00	230.65	238.81		239.76	0.003922	7.80	243.60	42.66	0.58
DeadHorseSlough	1	11167	1500.00	230.65	238.12		238.87	0.003245	6.96	215.62	38.84	0.52
DeadHorseSlough	1	11167	750.00	230.65	236.42		236.80	0.002203	4.92	152.47	35.43	0.42
DeadHorseSlough	1	11042	2220.00	231.04	239.38		239.90	0.001981	5.79	383.50	68.81	0.43
DeadHorseSlough	1	11042	1900.00	231.04	238.82		239.28	0.001912	5.48	346.54	63.93	0.42
DeadHorseSlough	1	11042	1500.00	231.04	238.09		238.48	0.001724	4.97	301.83	59.70	0.39
DeadHorseSlough	1	11042	750.00	231.04	236.33		236.54	0.001277	3.67	204.50	51.09	0.32
DeadHorseSlough	1	10882	2220.00	230.98	238.37		239.38	0.004878	8.04	276.18	55.79	0.64
DeadHorseSlough	1	10882	1900.00	230.98	237.86		238.77	0.004912	7.66	248.04	54.45	0.63
DeadHorseSlough	1	10882	1500.00	230.98	237.26		238.01	0.004632	6.95	215.92	52.89	0.61
DeadHorseSlough	1	10882	750.00	230.98	235.69		236.16	0.004741	5.52	135.78	48.78	0.58
DeadHorseSlough	1	10792	2220.00	231.13	238.40		238.94	0.002478	5.92	374.97	76.83	0.47
DeadHorseSlough	1	10792	1900.00	231.13	237.84		238.35	0.002569	5.70	333.06	74.25	0.47
DeadHorseSlough	1	10792	1500.00	231.13	237.20		237.63	0.002508	5.24	286.12	71.26	0.46
DeadHorseSlough	1	10792	750.00	231.13	235.49		235.79	0.002956	4.39	170.97	63.33	0.47

HEC-RAS Plan: Test-E-01 (Continued)

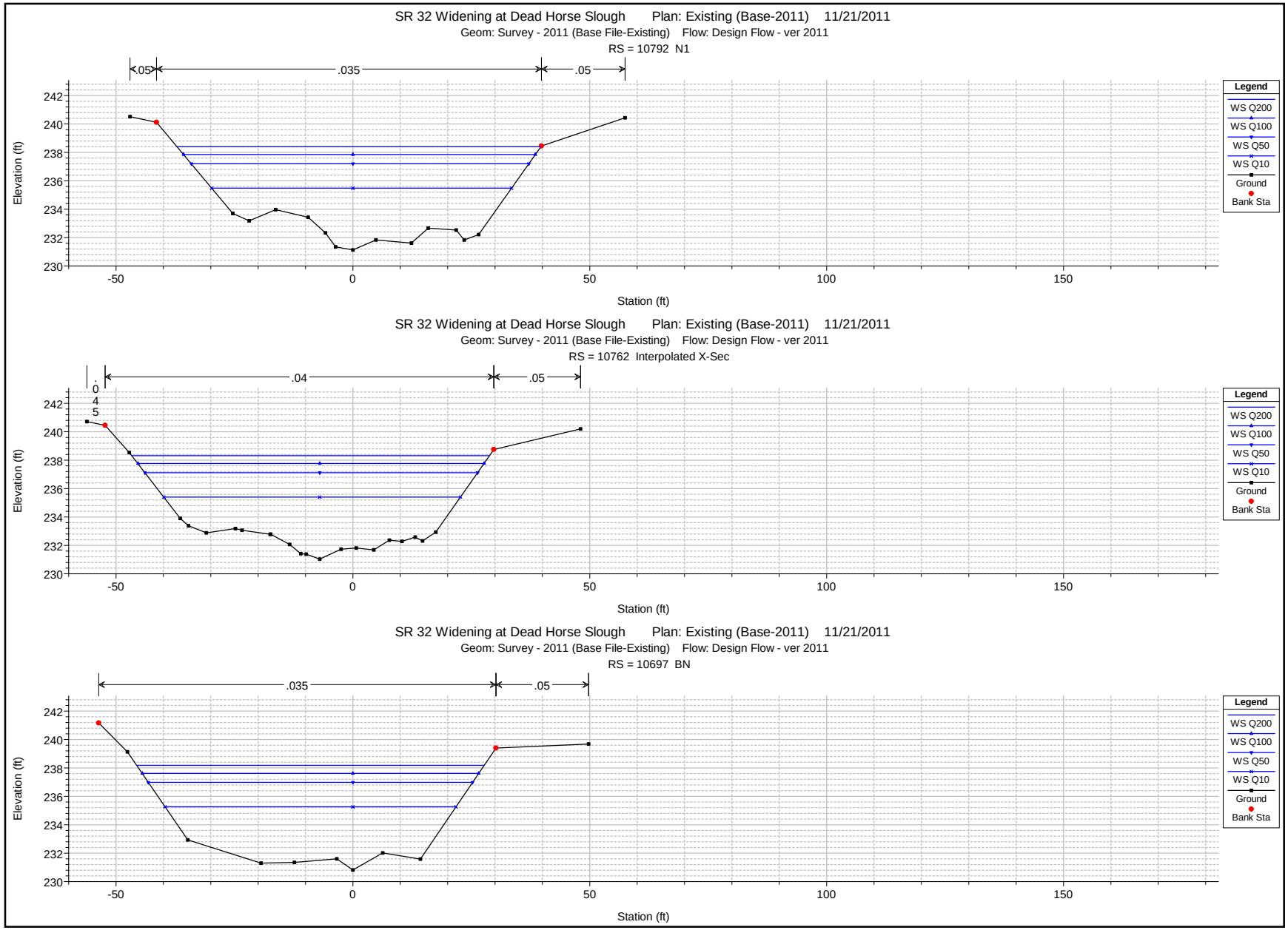
River	Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
DeadHorseSlough	1	10762	2220.00	231.03	238.31		238.86	0.003143	5.92	374.86	75.51	0.47
DeadHorseSlough	1	10762	1900.00	231.03	237.76		238.26	0.003241	5.70	333.58	73.06	0.47
DeadHorseSlough	1	10762	1500.00	231.03	237.12		237.54	0.003128	5.21	287.70	70.23	0.45
DeadHorseSlough	1	10762	750.00	231.03	235.40		235.69	0.003598	4.33	173.28	62.61	0.46
DeadHorseSlough	1	10697	2220.00	230.81	238.18	235.54	238.68	0.002021	5.67	391.27	73.29	0.43
DeadHorseSlough	1	10697	1900.00	230.81	237.62	235.17	238.07	0.002030	5.41	351.14	71.02	0.43
DeadHorseSlough	1	10697	1500.00	230.81	236.99	234.68	237.36	0.001873	4.88	307.26	68.44	0.41
DeadHorseSlough	1	10697	750.00	230.81	235.27	233.58	235.49	0.001812	3.84	195.34	61.39	0.38
DeadHorseSlough	1	10693	Bridge									
DeadHorseSlough	1	10644	2220.00	230.18	237.79		238.36	0.002537	6.04	367.50	74.95	0.48
DeadHorseSlough	1	10644	1900.00	230.18	237.24		237.76	0.002637	5.82	326.37	72.59	0.48
DeadHorseSlough	1	10644	1500.00	230.18	236.66		237.09	0.002459	5.26	284.99	70.15	0.46
DeadHorseSlough	1	10644	750.00	230.18	234.98		235.26	0.002559	4.29	174.84	60.63	0.45
DeadHorseSlough	1	10512	2220.00	230.62	237.32		237.98	0.003066	6.54	339.68	70.87	0.53
DeadHorseSlough	1	10512	1900.00	230.62	236.74		237.37	0.003251	6.35	299.42	68.40	0.53
DeadHorseSlough	1	10512	1500.00	230.62	236.23		236.73	0.002907	5.66	264.96	66.21	0.50
DeadHorseSlough	1	10512	750.00	230.62	234.51		234.86	0.003476	4.76	157.50	58.87	0.51
DeadHorseSlough	1	10353	2220.00	229.26	237.15		237.57	0.001632	5.25	438.60	91.55	0.39
DeadHorseSlough	1	10353	1900.00	229.26	236.54		236.94	0.001742	5.08	383.15	90.21	0.40
DeadHorseSlough	1	10353	1500.00	229.26	236.04		236.35	0.001520	4.48	338.51	89.12	0.37
DeadHorseSlough	1	10353	750.00	229.26	234.29		234.49	0.001449	3.52	212.95	64.86	0.34
DeadHorseSlough	1	10262	2220.00	229.24	236.80		237.38	0.002532	6.09	364.45	73.00	0.48
DeadHorseSlough	1	10262	1900.00	229.24	236.19		236.73	0.002652	5.92	320.85	69.50	0.49
DeadHorseSlough	1	10262	1500.00	229.24	235.77		236.18	0.002145	5.13	292.53	67.13	0.43
DeadHorseSlough	1	10262	750.00	229.24	234.08		234.33	0.001927	4.01	186.95	57.43	0.39
DeadHorseSlough	1	10108	2220.00	229.04	236.55	233.74	237.05	0.001979	5.66	391.98	72.54	0.43
DeadHorseSlough	1	10108	1900.00	229.04	235.93	233.33	236.40	0.002037	5.46	347.90	69.45	0.43
DeadHorseSlough	1	10108	1500.00	229.04	235.58	232.79	235.91	0.001558	4.63	323.78	67.71	0.37
DeadHorseSlough	1	10108	750.00	229.04	233.92	231.57	234.10	0.001211	3.44	218.22	59.45	0.32
DeadHorseSlough	1	10098	Bridge									

HEC-RAS Plan: Test-E-01 (Continued)

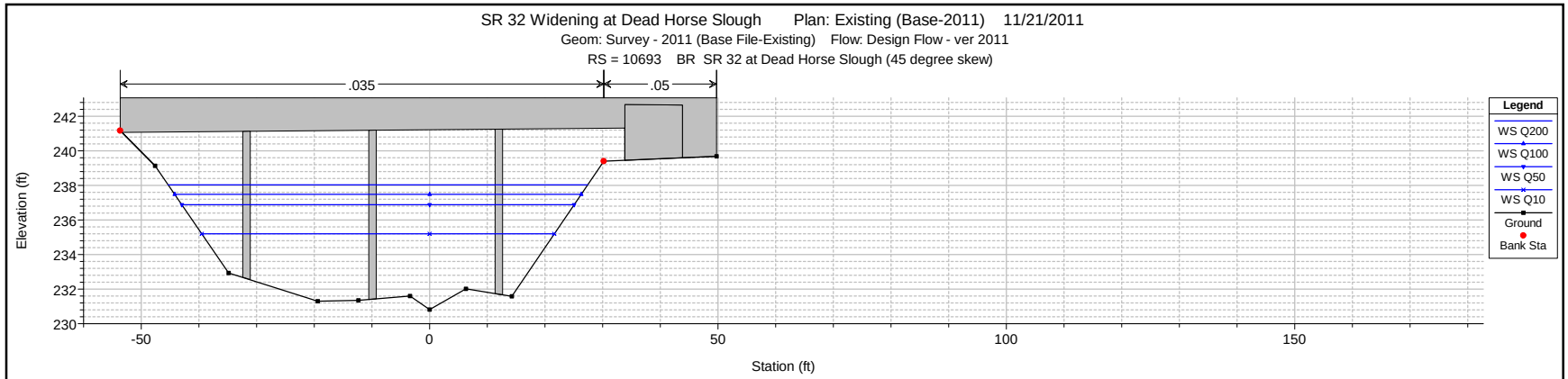
River	Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
DeadHorseSlough	1	10000	2220.00	228.74	236.18		236.66	0.001912	5.53	402.94	79.94	0.42
DeadHorseSlough	1	10000	1900.00	228.74	235.55		235.99	0.002057	5.37	353.97	73.94	0.43
DeadHorseSlough	1	10000	1500.00	228.74	235.31		235.62	0.001483	4.46	336.58	72.74	0.37
DeadHorseSlough	1	10000	750.00	228.74	233.73		233.89	0.001164	3.30	227.59	64.91	0.31

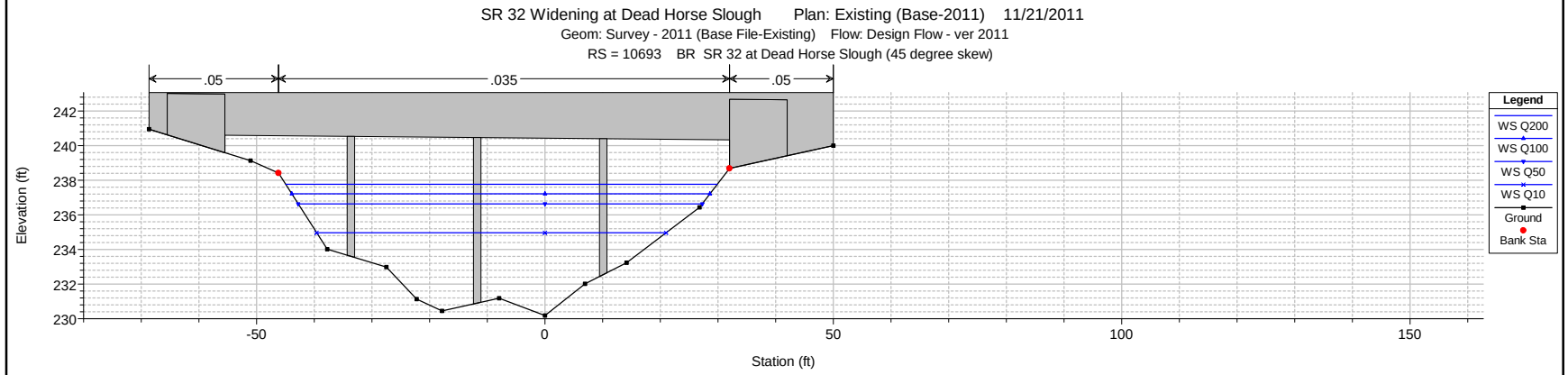


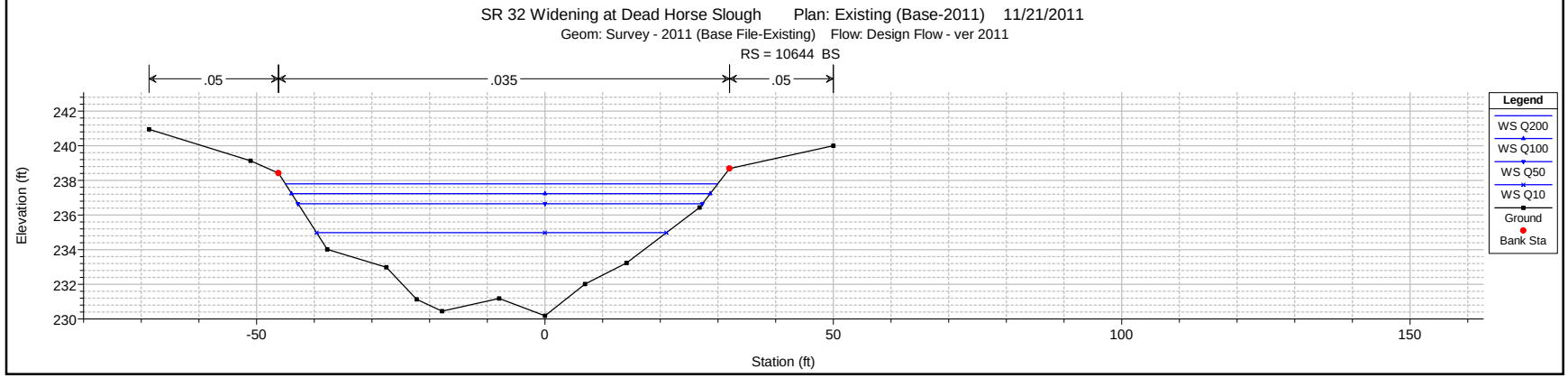
1 in Horiz. = 30 ft 1 in Vert. = 10 ft



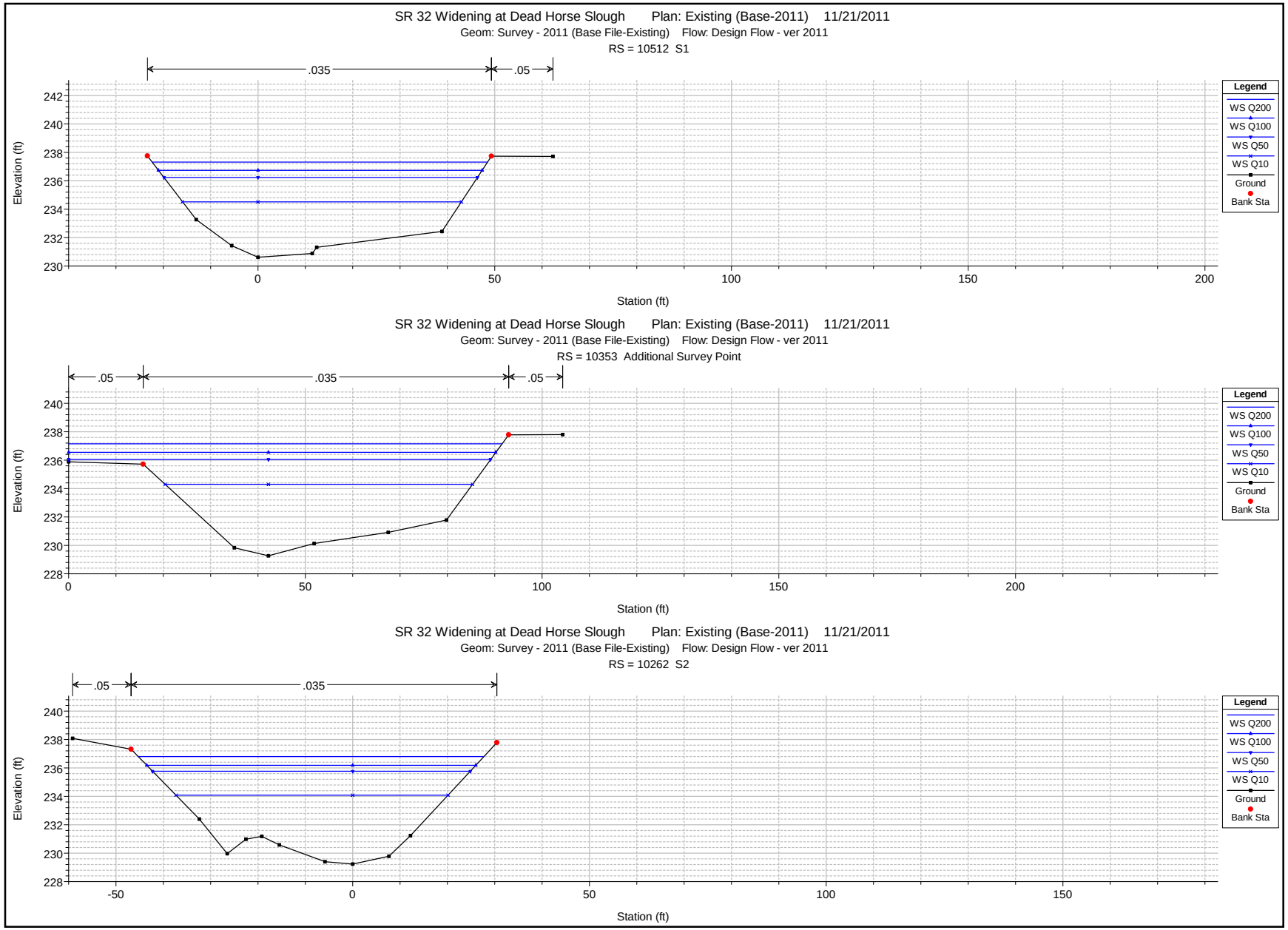
1 in Horiz. = 30 ft 1 in Vert. = 10 ft



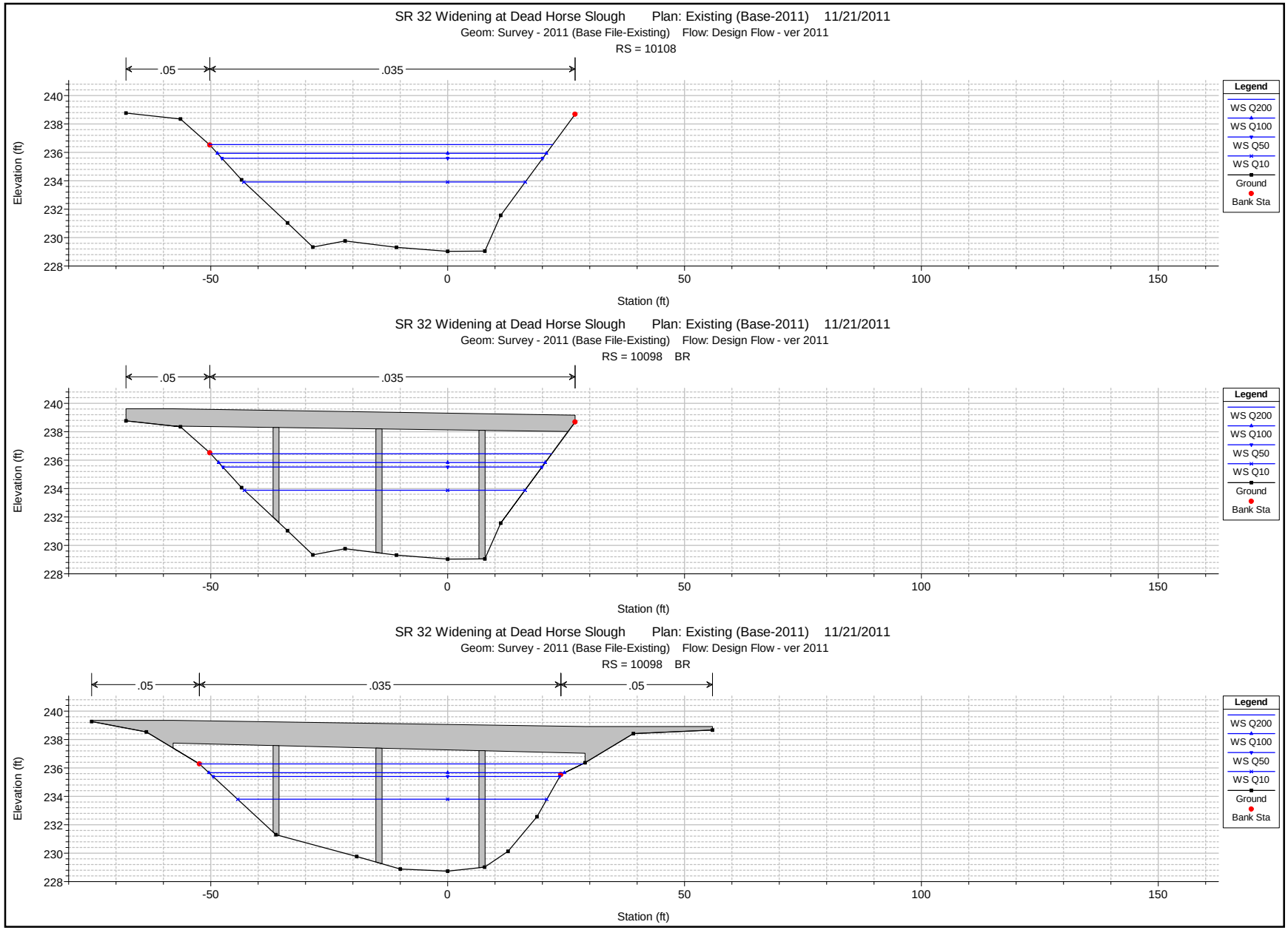




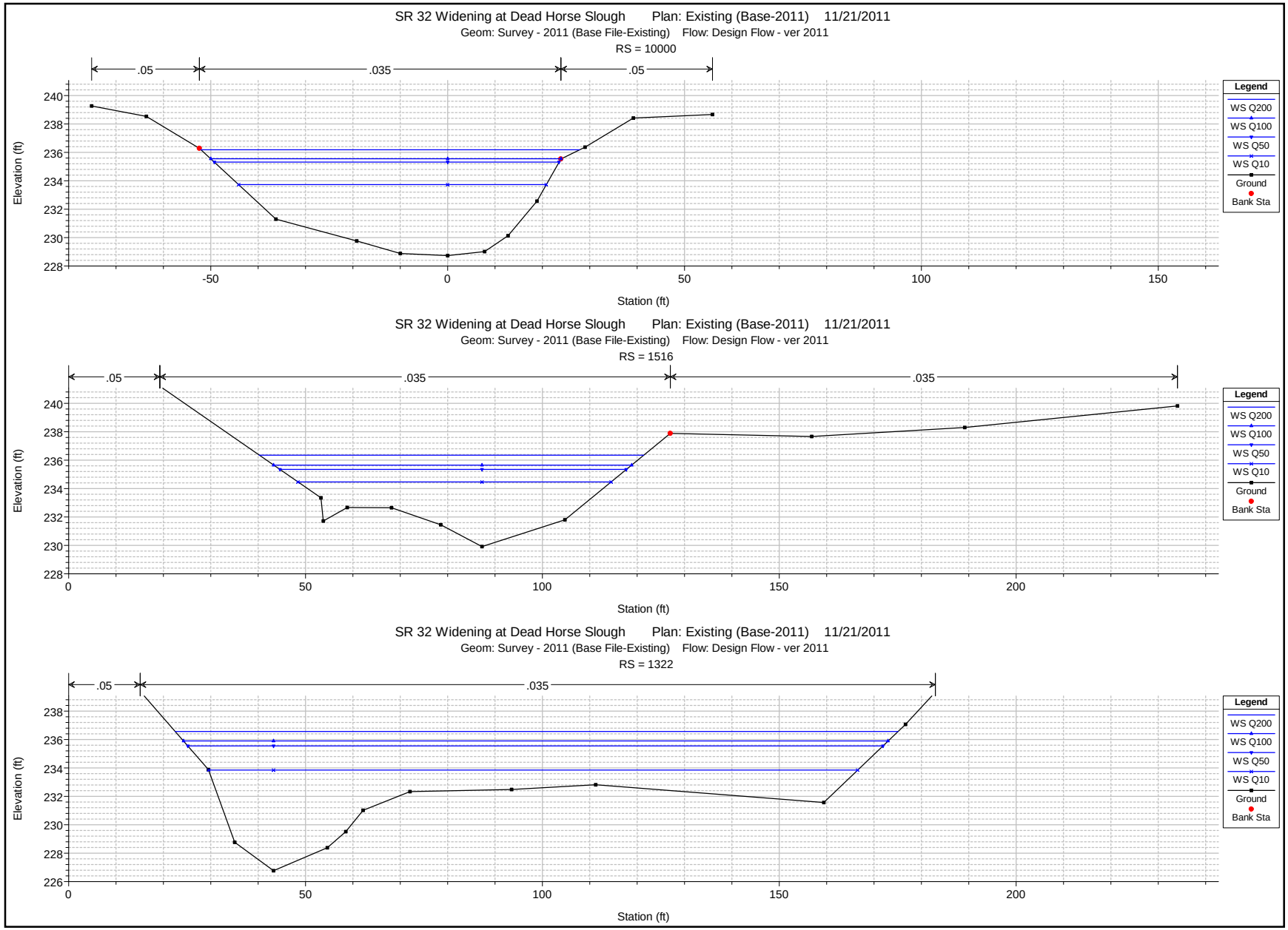
1 in Horiz. = 30 ft 1 in Vert. = 10 ft



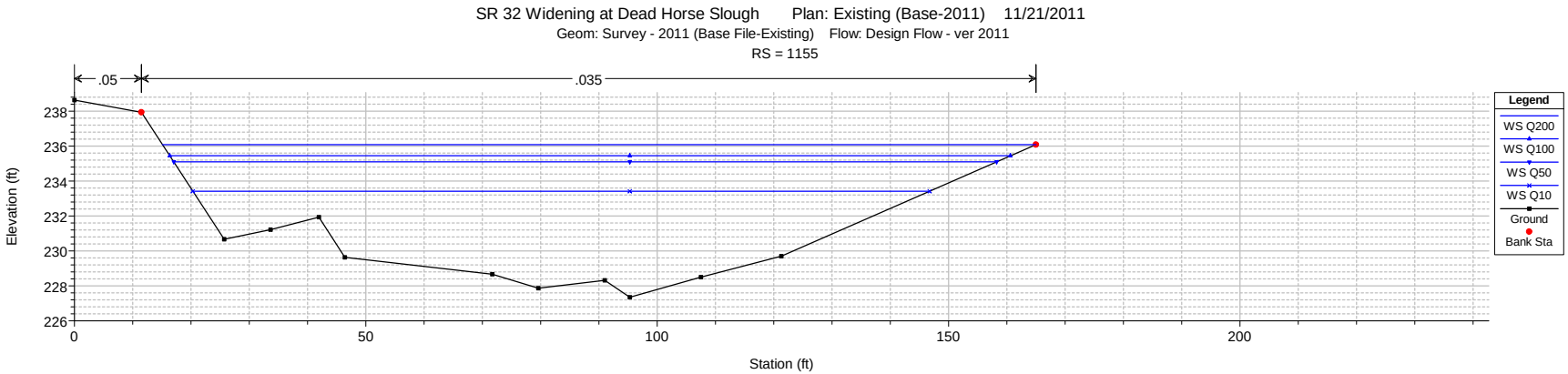
1 in Horiz. = 30 ft 1 in Vert. = 10 ft

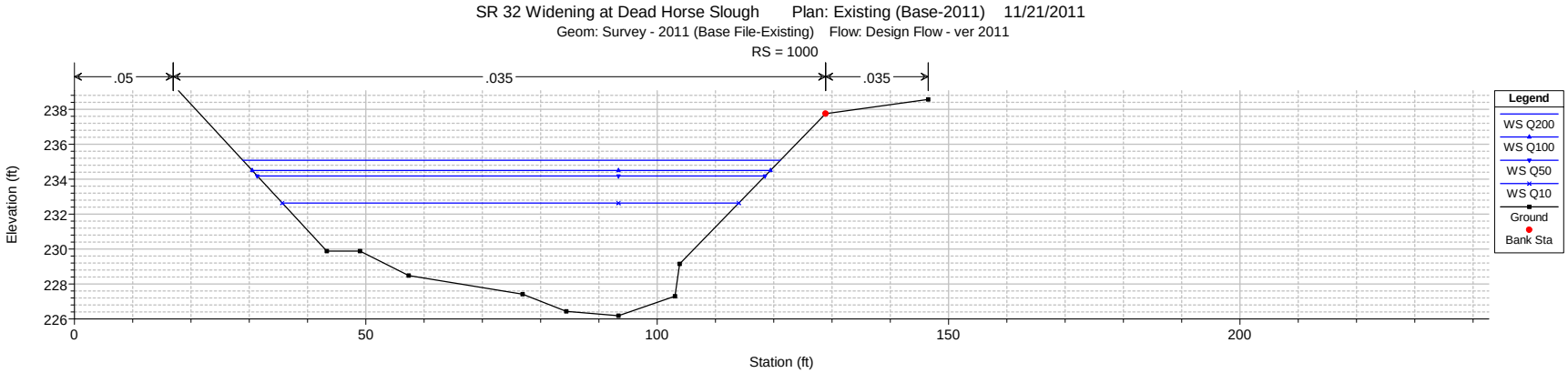


1 in Horiz. = 30 ft 1 in Vert. = 10 ft



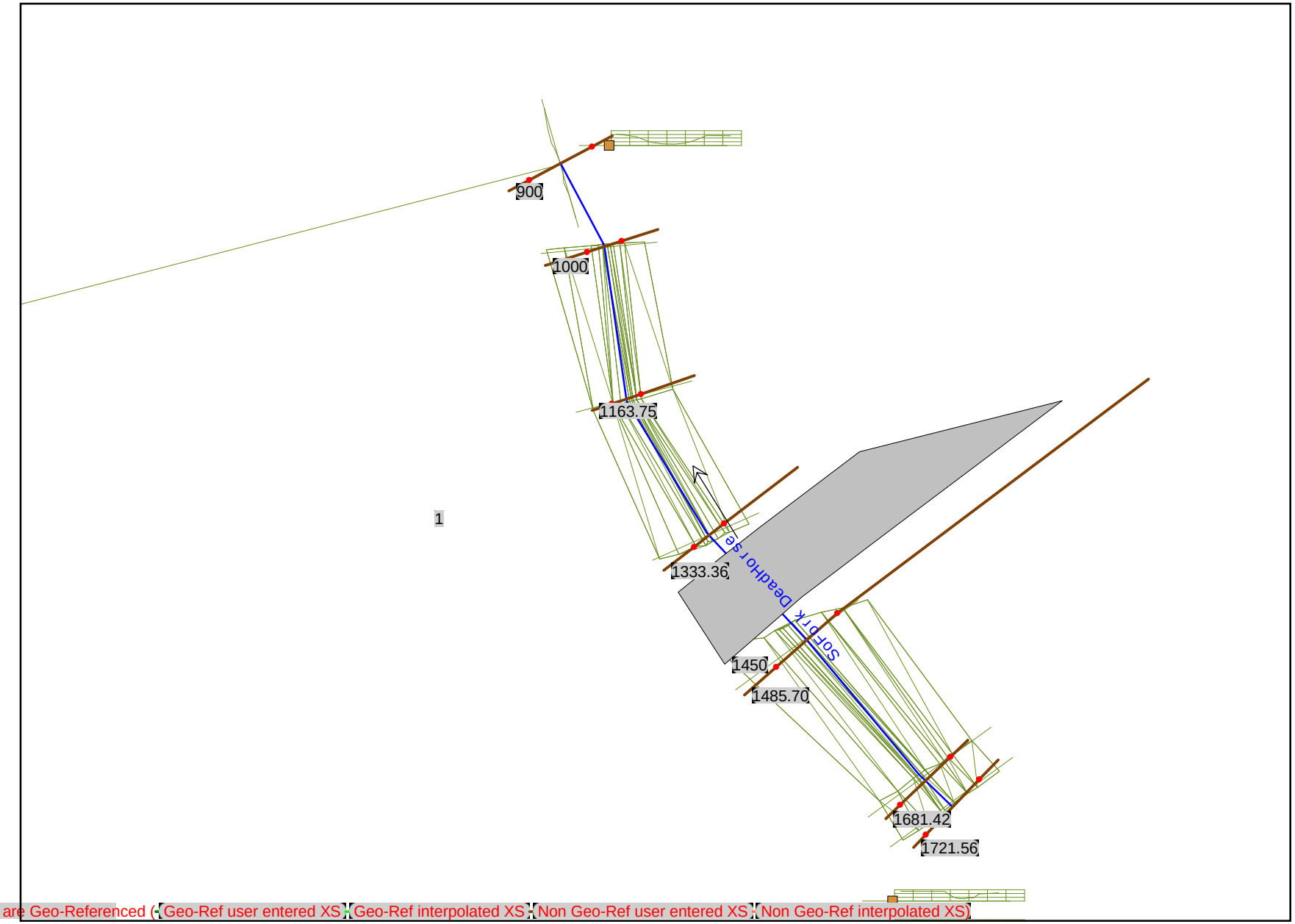
1 in Horiz. = 30 ft 1 in Vert. = 10 ft

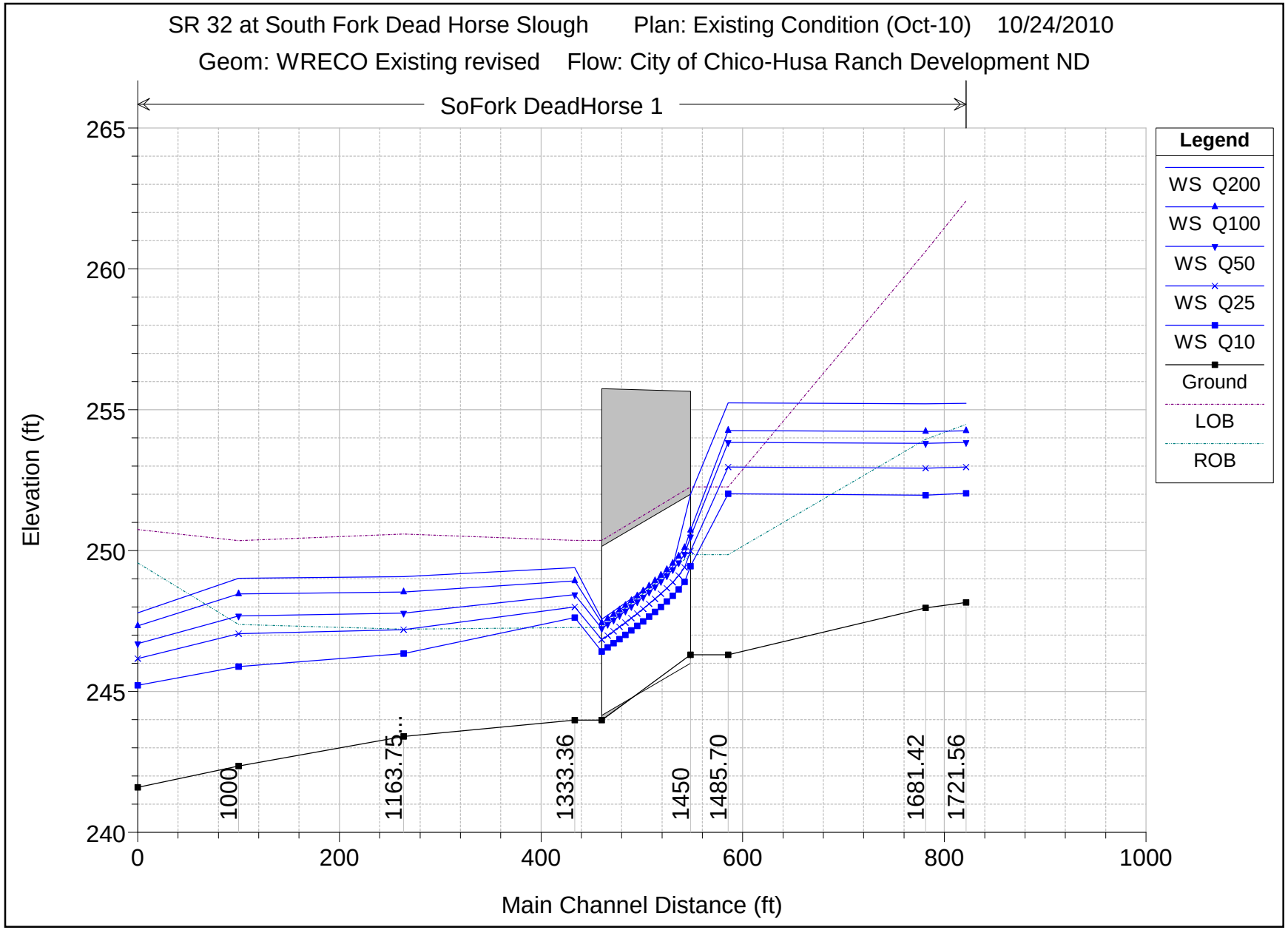




1 in Horiz. = 30 ft 1 in Vert. = 10 ft

Appendix A.2 South Fork Dead Horse Slough


900
1000
1163.75
1
1333.36
Deadhorse
SOFDTK
1450
1485.70
1681.42
1721.56
None of the XS's are Geo-Referenced (Geo-Ref user entered XS Geo-Ref interpolated XS Non Geo-Ref user entered XS Non Geo-Ref interpolated XS)


SR 32 at South Fork Dead Horse Slough
Plan: Existing Condition (Oct-10)
10/24/2010
Geom: WRECO Existing revised
Flow: City of Chico-Husa Ranch Development ND
SoFork DeadHorse 1
Elevation (ft)
265
260
255
250
245
240
0
200
400
600
800
1000
Main Channel Distance (ft)
1000
1163.75
1333.36
1450
1485.70
1681.42
1721.56
Legend
WS Q200
WS Q100
WS Q50
WS Q25
WS Q10
Ground
LOB
ROB

HEC-RAS Plan: Exist (Oct 10) River: SoFork DeadHorse Reach: 1

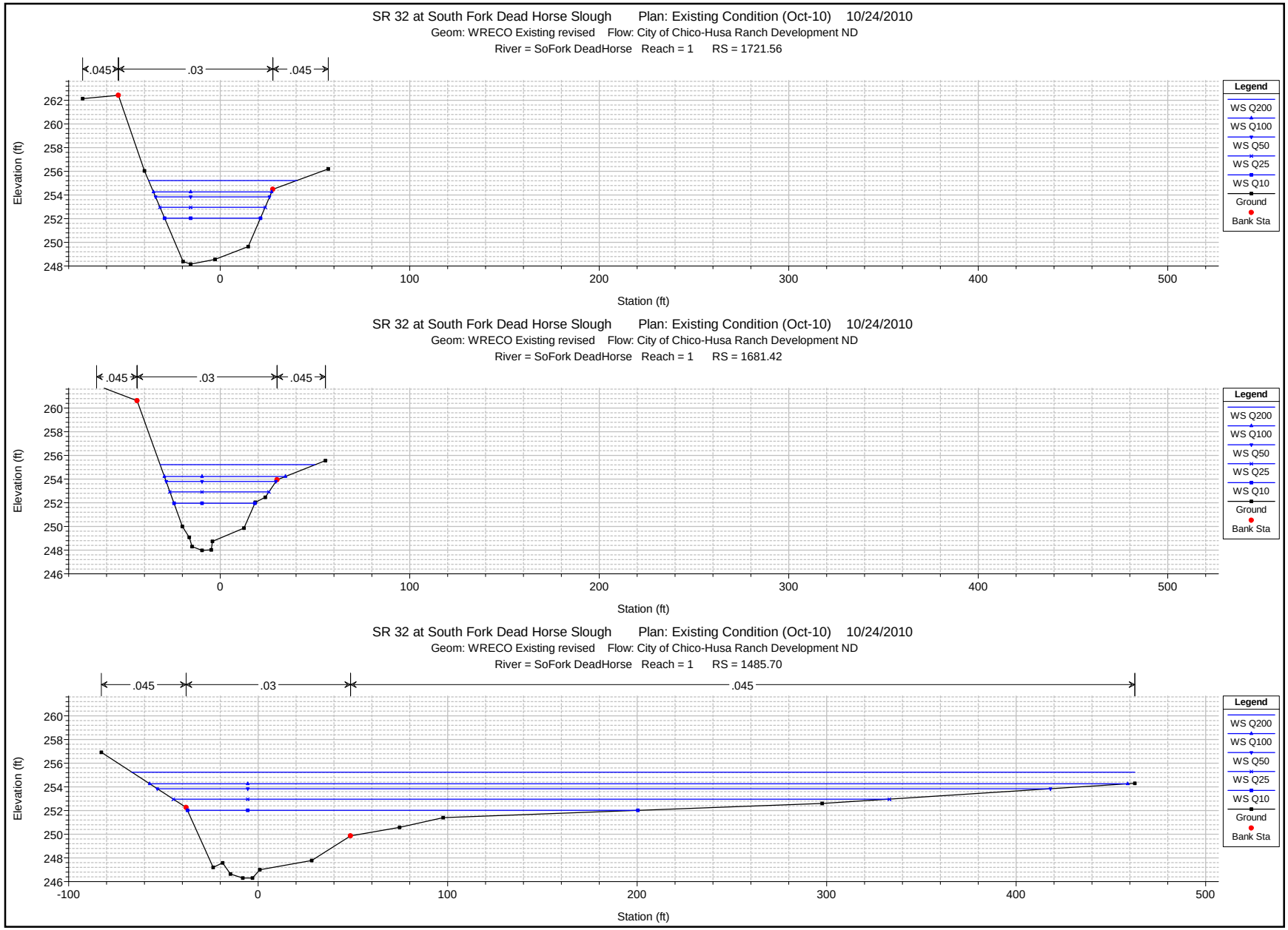
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	1721.56	Q200	528.00	248.16	255.23		255.27	0.000129	1.61	332.13	78.36	0.13
1	1721.56	Q100	466.00	248.16	254.25		254.30	0.000192	1.76	264.63	62.43	0.15
1	1721.56	Q50	431.00	248.16	253.84		253.89	0.000219	1.80	239.06	60.20	0.16
1	1721.56	Q25	361.00	248.16	252.97		253.03	0.000302	1.91	188.86	55.57	0.18
1	1721.56	Q10	290.00	248.16	252.04		252.10	0.000471	2.08	139.35	50.58	0.22
1	1681.42	Q200	528.00	247.97	255.21		255.26	0.000179	1.81	301.94	81.74	0.15
1	1681.42	Q100	466.00	247.97	254.23		254.29	0.000291	2.03	230.18	63.89	0.18
1	1681.42	Q50	431.00	247.97	253.81		253.87	0.000352	2.11	204.75	57.94	0.20
1	1681.42	Q25	361.00	247.97	252.92		253.01	0.000528	2.31	156.23	52.25	0.24
1	1681.42	Q10	290.00	247.97	251.97		252.07	0.000836	2.63	110.14	42.69	0.29
1	1485.70	Q200	528.00	246.30	255.24	248.55	255.24	0.000007	0.50	1848.68	529.36	0.03
1	1485.70	Q100	466.00	246.30	254.26	248.44	254.27	0.000013	0.60	1334.62	516.21	0.04
1	1485.70	Q50	431.00	246.30	253.84	248.37	253.85	0.000015	0.63	1127.26	471.41	0.05
1	1485.70	Q25	361.00	246.30	252.97	248.23	252.97	0.000024	0.70	755.13	377.93	0.06
1	1485.70	Q10	290.00	246.30	252.02	248.07	252.03	0.000038	0.77	456.08	237.66	0.07
1	1450		Culvert									
1	1333.36	Q200	528.00	243.98	249.39		249.52	0.000689	3.06	229.19	97.92	0.28
1	1333.36	Q100	466.00	243.98	248.92		249.06	0.000872	3.24	185.23	88.10	0.31
1	1333.36	Q50	431.00	243.98	248.44		248.63	0.001283	3.66	145.16	78.08	0.37
1	1333.36	Q25	361.00	243.98	248.00		248.21	0.001543	3.74	113.06	69.00	0.40
1	1333.36	Q10	290.00	243.98	247.63		247.82	0.001647	3.60	88.53	61.17	0.40
1	1163.75	Q200	528.00	243.40	249.08		249.34	0.001365	4.28	148.63	67.48	0.39
1	1163.75	Q100	466.00	243.40	248.53		248.84	0.001825	4.58	114.96	55.07	0.44
1	1163.75	Q50	431.00	243.40	247.78		248.26	0.003495	5.58	79.99	38.92	0.59
1	1163.75	Q25	361.00	243.40	247.19		247.74	0.005098	5.94	60.76	26.46	0.69
1	1163.75	Q10	290.00	243.40	246.35	246.31	247.17	0.011294	7.30	39.75	23.34	0.99
1	1000	Q200	528.00	242.35	249.02		249.15	0.000654	2.94	194.31	60.54	0.24
1	1000	Q100	466.00	242.35	248.47		248.60	0.000758	2.98	163.42	51.19	0.25
1	1000	Q50	431.00	242.35	247.68		247.86	0.001192	3.37	128.32	38.43	0.31
1	1000	Q25	361.00	242.35	247.05		247.23	0.001430	3.39	106.49	32.46	0.33
1	1000	Q10	290.00	242.35	245.88		246.14	0.003012	4.09	70.82	28.83	0.46

HEC-RAS Plan: Exist (Oct 10) River: SoFork DeadHorse Reach: 1 (Continued)

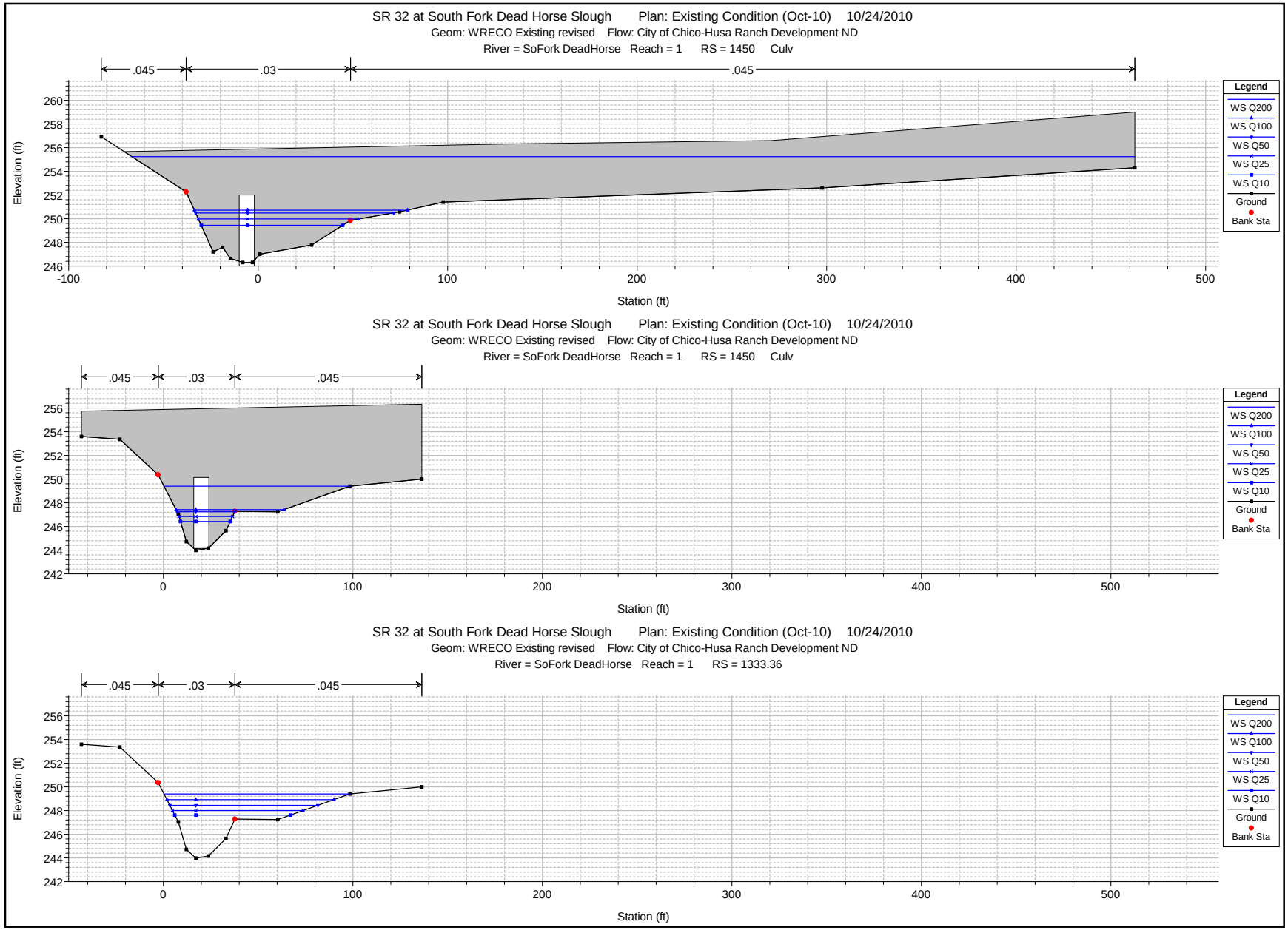
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	900	Q200	2220.00	241.60	247.79	246.66	248.82	0.003972	8.14	272.79	62.96	0.69
1	900	Q100	1900.00	241.60	247.33	246.27	248.27	0.003975	7.78	244.37	60.53	0.68
1	900	Q50	1500.00	241.60	246.70	245.72	247.51	0.003971	7.24	207.17	57.19	0.67
1	900	Q25	1200.00	241.60	246.16	245.25	246.88	0.003972	6.76	177.40	54.37	0.66
1	900	Q10	750.00	241.60	245.22	244.44	245.75	0.003973	5.84	128.53	49.40	0.64

HEC-RAS Plan: Exist (Oct 10) River: SoFork DeadHorse Reach: 1

Reach	River Sta		Profile	E.G. US.	W.S. US.	E.G. IC	E.G. OC	Min El Weir Flow	Q Culv Group	Q Weir	Delta WS	Culv Vel US	Culv Vel DS
				(ft)	(ft)	(ft)	(ft)	(ft)	(cfs)	(cfs)	(ft)	(ft/s)	(ft/s)
1	1450	Culvert #1	Q200	255.24	255.24	255.24	254.98	255.76	528.00		5.85	11.00	19.35
1	1450	Culvert #1	Q100	254.27	254.26	254.15	254.27	255.76	466.00		5.34	12.33	17.79
1	1450	Culvert #1	Q50	253.85	253.84	253.51	253.85	255.76	431.00		5.40	12.02	17.48
1	1450	Culvert #1	Q25	252.97	252.97	252.62	252.97	255.76	361.00		4.96	11.33	16.79
1	1450	Culvert #1	Q10	252.03	252.02	251.72	252.03	255.76	290.00		4.39	10.53	15.98

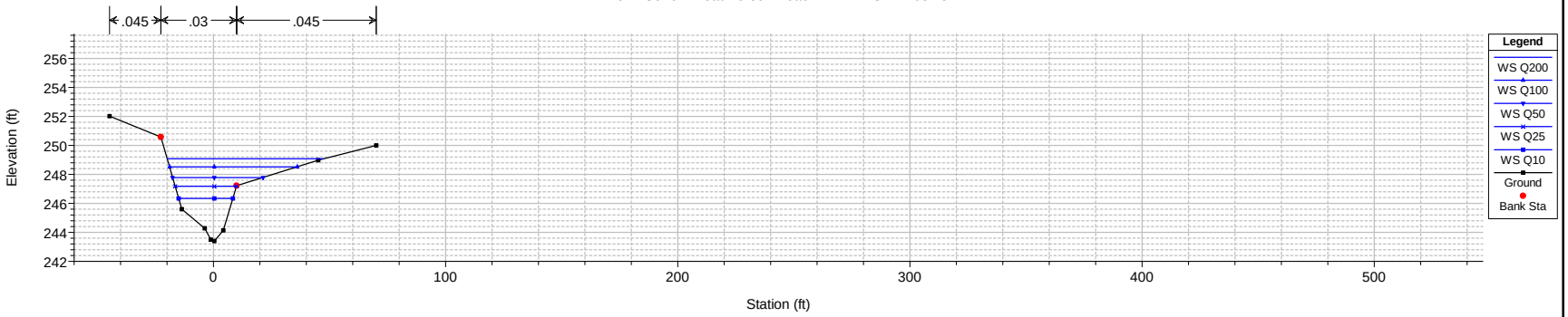


1 in Horiz. = 75 ft 1 in Vert. = 12 ft

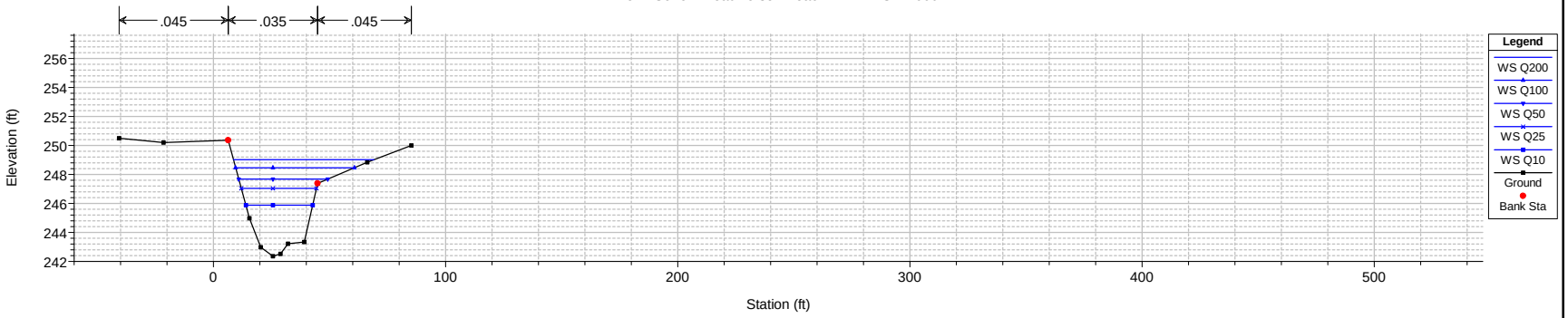


1 in Horiz. = 75 ft 1 in Vert. = 12 ft

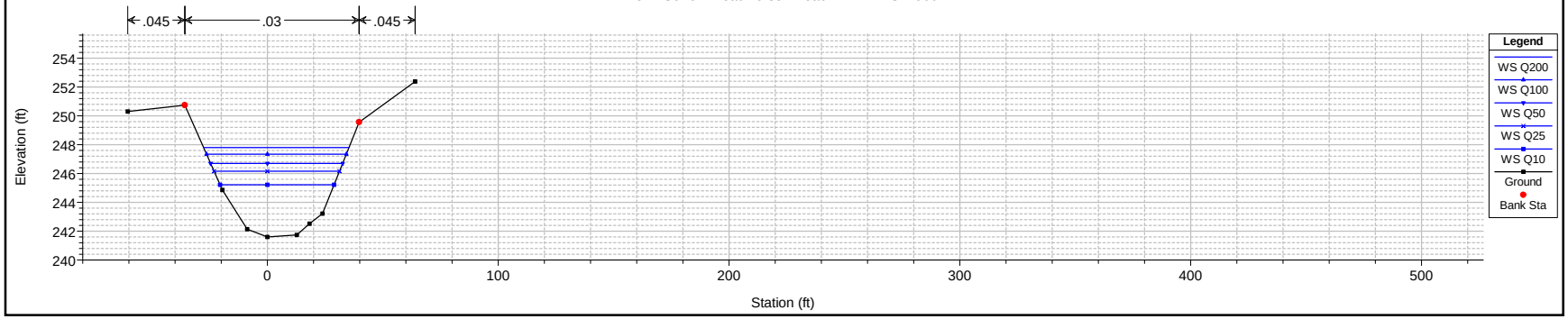
SR 32 at South Fork Dead Horse Slough Plan: Existing Condition (Oct-10) 10/24/2010
Geom: WRECO Existing revised Flow: City of Chico-Husa Ranch Development ND
River = SoFork DeadHorse Reach = 1 RS = 1163.75



SR 32 at South Fork Dead Horse Slough Plan: Existing Condition (Oct-10) 10/24/2010
Geom: WRECO Existing revised Flow: City of Chico-Husa Ranch Development ND
River = SoFork DeadHorse Reach = 1 RS = 1000



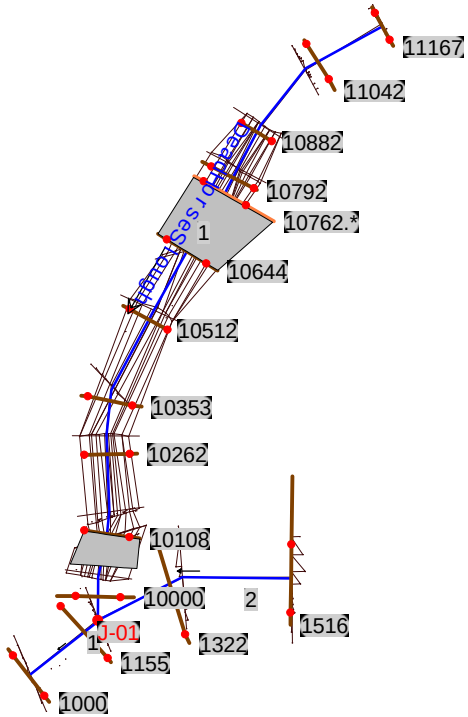
SR 32 at South Fork Dead Horse Slough Plan: Existing Condition (Oct-10) 10/24/2010
Geom: WRECO Existing revised Flow: City of Chico-Husa Ranch Development ND
River = SoFork DeadHorse Reach = 1 RS = 900



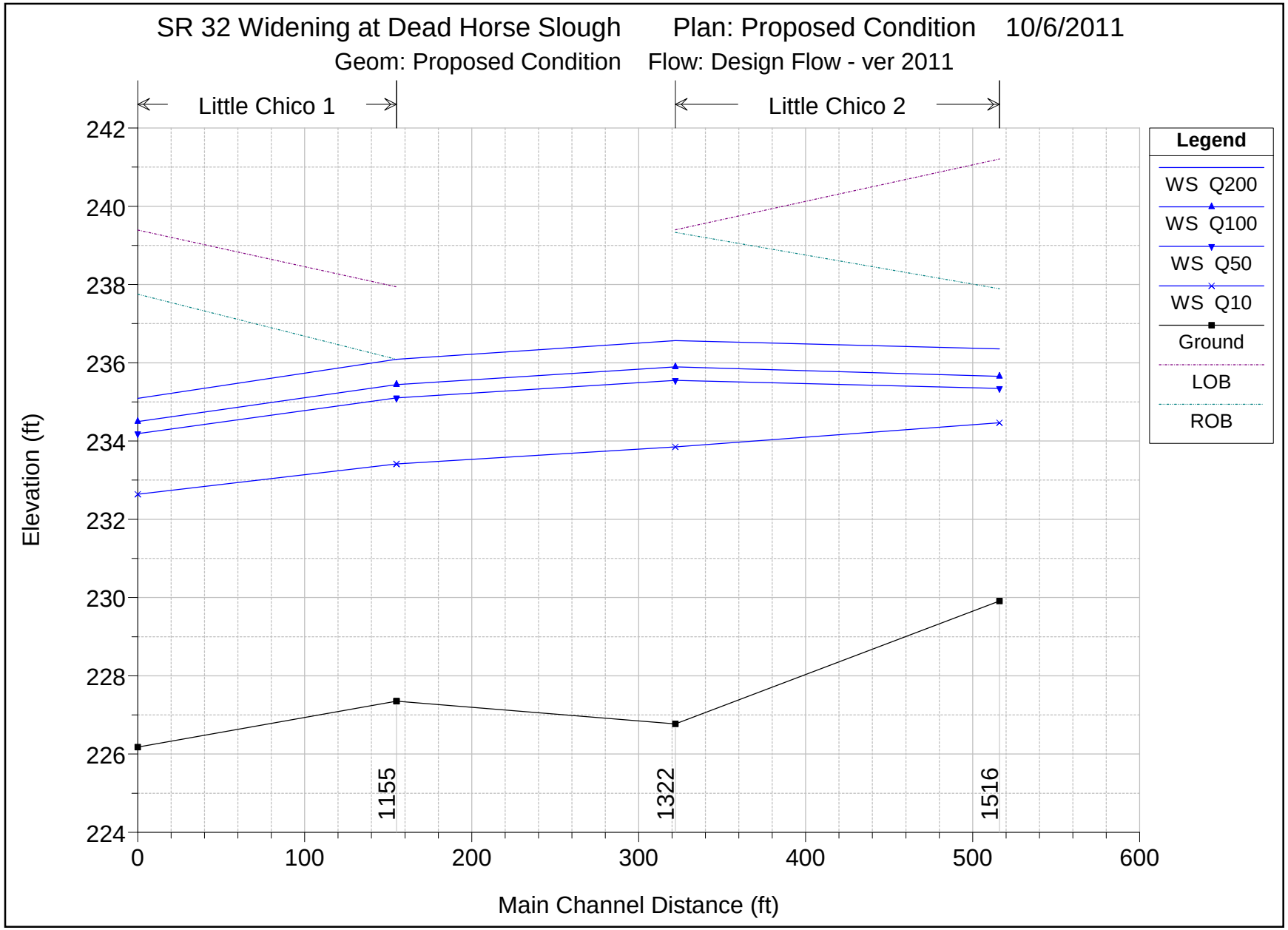
1 in Horiz. = 75 ft 1 in Vert. = 12 ft

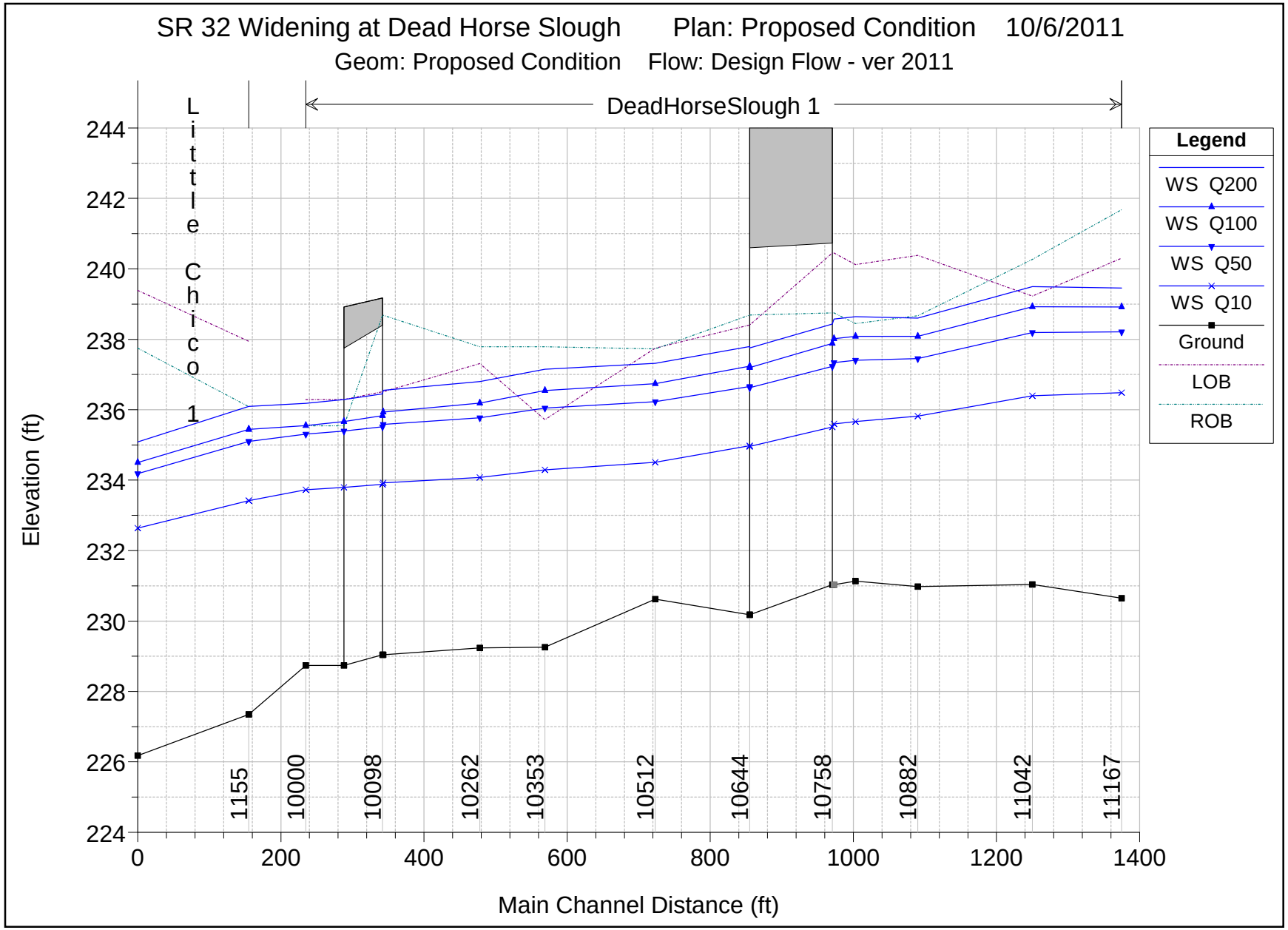
Appendix B HEC-RAS Results: Proposed Conditions

Appendix B.1 Dead Horse Slough



None of the XS's are Geo-Referenced ([Geo-Ref user entered XS][Geo-Ref interpolated XS][Non Geo-Ref user entered XS][Non Geo-Ref interpolated XS])


SR 32 Widening at Dead Horse Slough
Plan: Proposed Condition
10/6/2011
Geom: Proposed Condition
Flow: Design Flow - ver 2011
Little Chico 1
Little Chico 2
Legend
WS Q200
WS Q100
WS Q50
WS Q10
Ground
LOB
ROB
Elevation (ft)
242
240
238
236
234
232
230
228
226
224
1155
1322
1516
0
100
200
300
400
500
600
Main Channel Distance (ft)

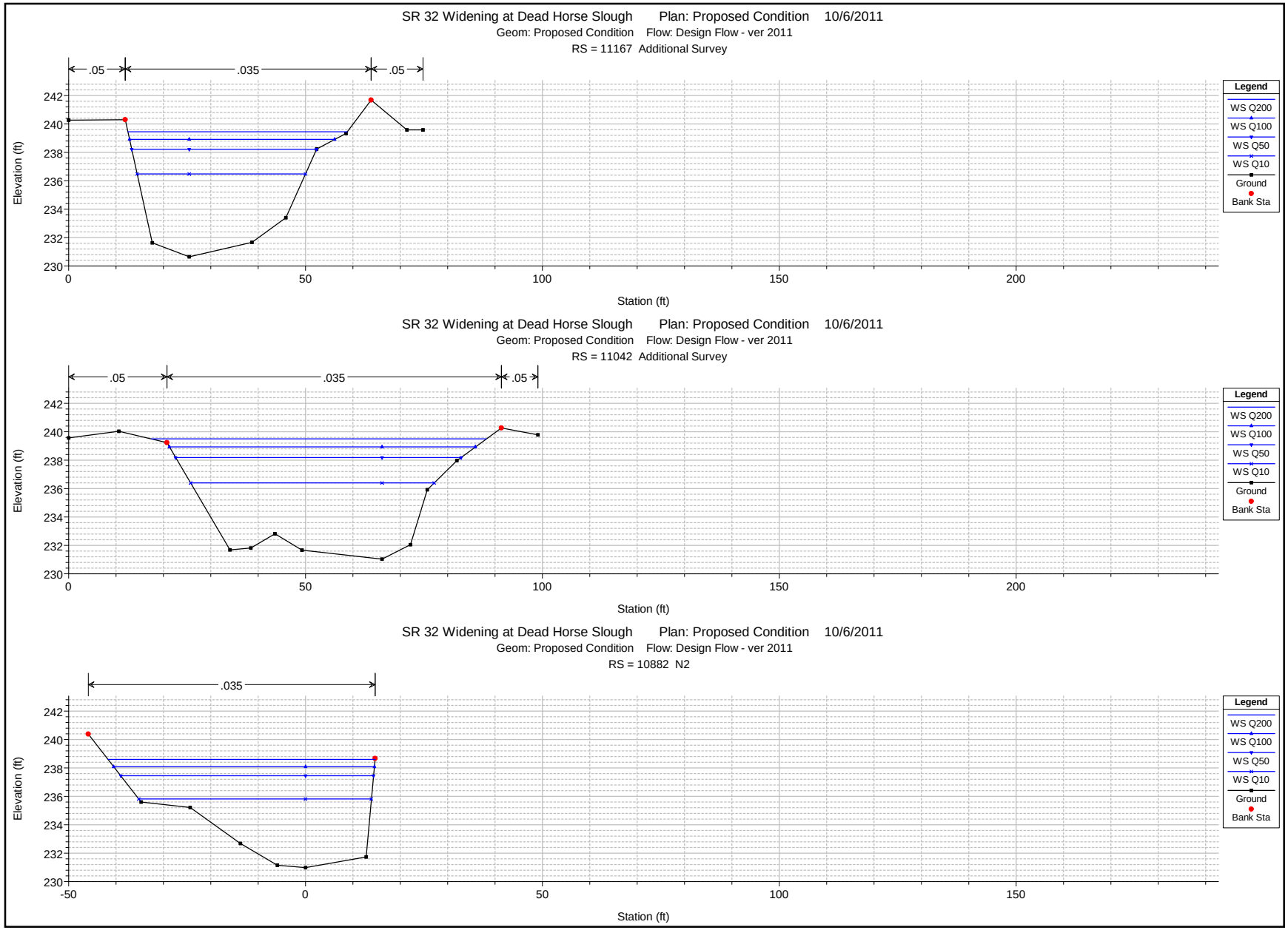

SR 32 Widening at Dead Horse Slough
Plan: Proposed Condition
10/6/2011
Geom: Proposed Condition
Flow: Design Flow - ver 2011
DeadHorseSlough 1
Little Chico 1
Elevation (ft)
Main Channel Distance (ft)
244
242
240
238
236
234
232
230
228
226
224
0
200
400
600
800
1000
1200
1400
1155
10000
10098
10262
10353
10512
10644
10758
10882
11042
11167
Legend
WS Q200
WS Q100
WS Q50
WS Q10
Ground
LOB
ROB

HEC-RAS Plan: Proposed

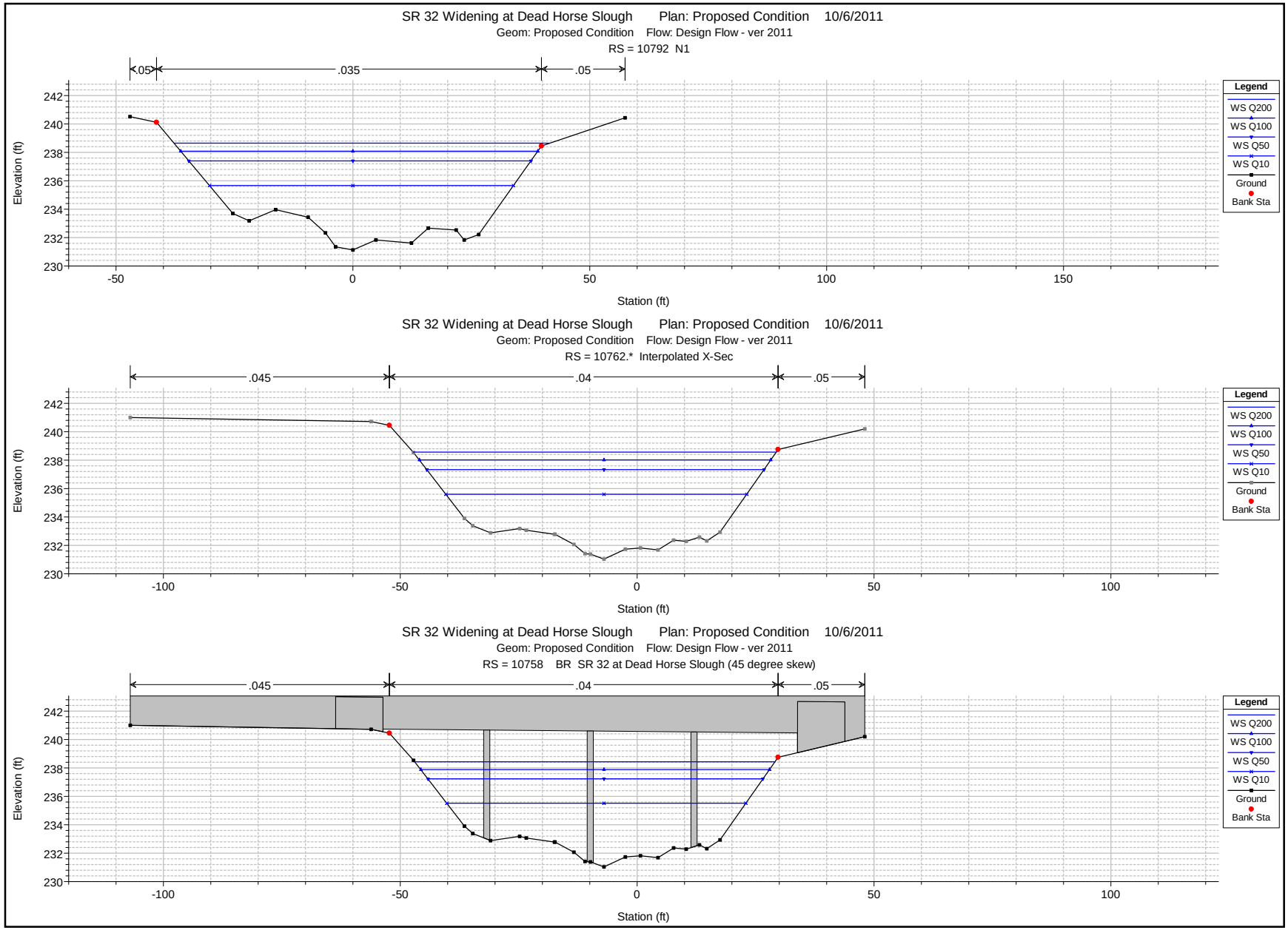
River	Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Little Chico	2	1516	2350.00	229.91	236.36		237.28	0.005831	7.69	305.68	81.18	0.70
Little Chico	2	1516	2200.00	229.91	235.65		236.85	0.009027	8.79	250.42	75.56	0.85
Little Chico	2	1516	2000.00	229.91	235.35	235.05	236.54	0.009816	8.79	227.61	73.11	0.88
Little Chico	2	1516	1500.00	229.91	234.47	234.47	235.73	0.013724	9.02	166.35	66.09	1.00
Little Chico	2	1322	2350.00	226.77	236.56		236.73	0.000768	3.26	721.85	152.57	0.26
Little Chico	2	1322	2200.00	226.77	235.89		236.09	0.001074	3.54	620.72	148.72	0.31
Little Chico	2	1322	2000.00	226.77	235.55		235.74	0.001155	3.51	570.46	146.76	0.31
Little Chico	2	1322	1500.00	226.77	233.85		234.17	0.003707	4.56	328.85	137.02	0.52
Little Chico	1	1155	4300.00	227.35	236.09		236.51	0.001549	5.17	831.11	149.91	0.39
Little Chico	1	1155	3700.00	227.35	235.44		235.84	0.001633	5.03	735.94	144.23	0.39
Little Chico	1	1155	3400.00	227.35	235.10		235.48	0.001686	4.95	686.94	141.21	0.40
Little Chico	1	1155	2100.00	227.35	233.42		233.74	0.002081	4.55	461.61	126.41	0.42
Little Chico	1	1000	4300.00	226.18	235.09	233.07	236.10	0.003640	8.06	533.74	92.28	0.59
Little Chico	1	1000	3700.00	226.18	234.50	232.57	235.42	0.003639	7.70	480.44	88.93	0.58
Little Chico	1	1000	3400.00	226.18	234.19	232.34	235.06	0.003641	7.51	452.84	87.15	0.58
Little Chico	1	1000	2100.00	226.18	232.64	231.09	233.29	0.003639	6.47	324.69	78.34	0.56
DeadHorseSlough	1	11167	2220.00	230.65	239.45		240.49	0.004114	8.15	272.26	46.30	0.59
DeadHorseSlough	1	11167	1900.00	230.65	238.92		239.83	0.003761	7.66	248.18	43.33	0.56
DeadHorseSlough	1	11167	1500.00	230.65	238.21		238.94	0.003100	6.85	219.13	39.02	0.51
DeadHorseSlough	1	11167	750.00	230.65	236.48		236.85	0.002117	4.85	154.58	35.55	0.41
DeadHorseSlough	1	11042	2220.00	231.04	239.49		239.99	0.001869	5.67	391.63	70.74	0.42
DeadHorseSlough	1	11042	1900.00	231.04	238.93		239.37	0.001810	5.37	353.71	64.59	0.40
DeadHorseSlough	1	11042	1500.00	231.04	238.19		238.56	0.001638	4.88	307.65	60.27	0.38
DeadHorseSlough	1	11042	750.00	231.04	236.40		236.60	0.001219	3.61	207.86	51.41	0.32
DeadHorseSlough	1	10882	2220.00	230.98	238.60		239.52	0.004264	7.68	289.09	56.39	0.60
DeadHorseSlough	1	10882	1900.00	230.98	238.08		238.91	0.004263	7.30	260.18	55.03	0.59
DeadHorseSlough	1	10882	1500.00	230.98	237.45		238.13	0.004052	6.64	225.78	53.38	0.57
DeadHorseSlough	1	10882	750.00	230.98	235.82		236.25	0.004112	5.27	142.21	49.12	0.55
DeadHorseSlough	1	10792	2220.00	231.13	238.64		239.14	0.002132	5.64	393.98	79.27	0.44
DeadHorseSlough	1	10792	1900.00	231.13	238.09		238.54	0.002201	5.41	351.08	75.37	0.44
DeadHorseSlough	1	10792	1500.00	231.13	237.41		237.79	0.002157	4.98	301.08	72.23	0.43
DeadHorseSlough	1	10792	750.00	231.13	235.67		235.93	0.002429	4.11	182.33	64.15	0.43

HEC-RAS Plan: Proposed (Continued)

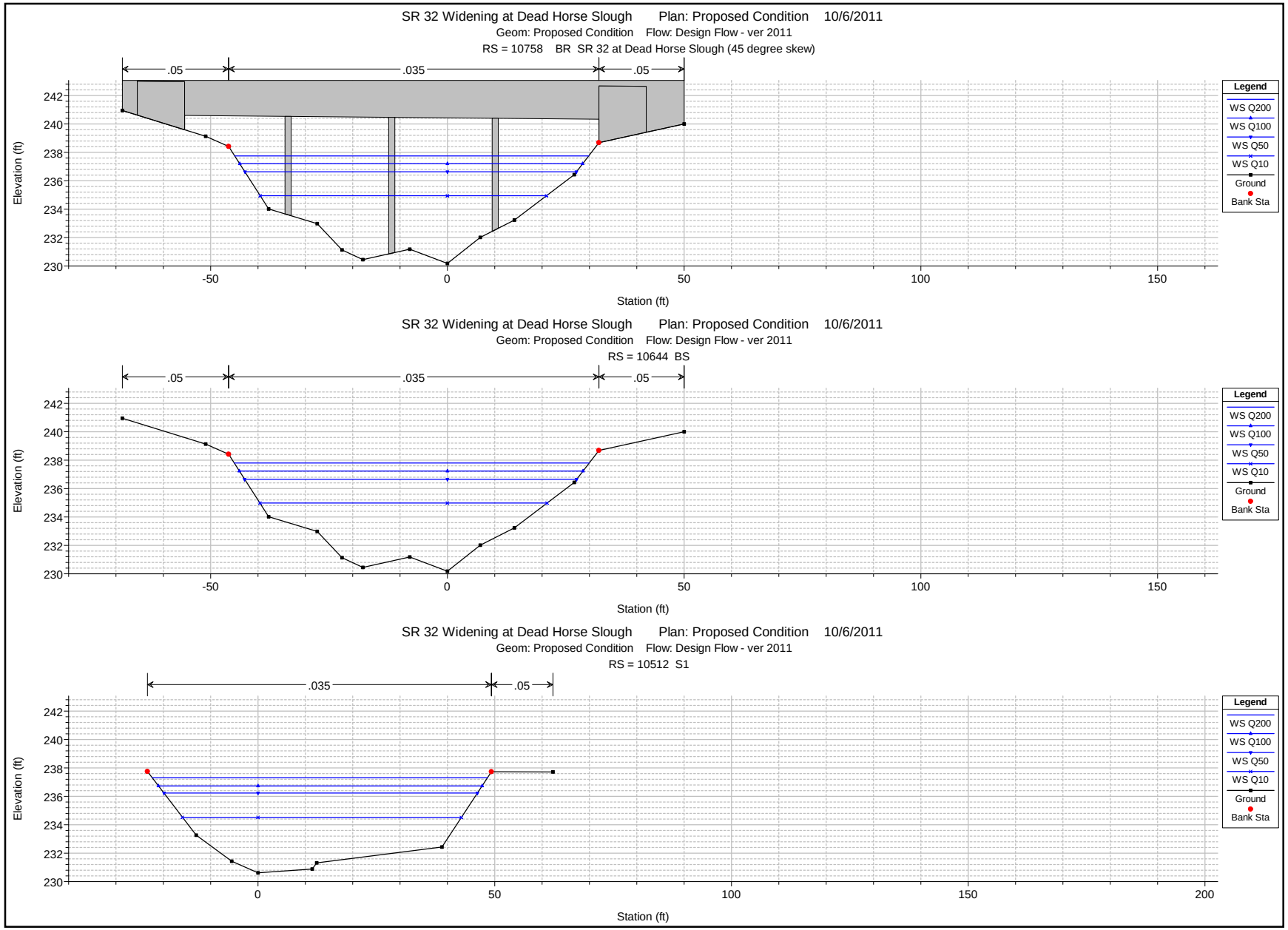
River	Reach	River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
DeadHorseSlough	1	10762.*	2220.00	231.03	238.57	236.04	239.06	0.002708	5.63	394.53	76.67	0.44
DeadHorseSlough	1	10762.*	1900.00	231.03	238.01	235.68	238.47	0.002759	5.39	352.40	74.19	0.44
DeadHorseSlough	1	10762.*	1500.00	231.03	237.34	235.23	237.72	0.002672	4.94	303.40	71.21	0.42
DeadHorseSlough	1	10762.*	750.00	231.03	235.59	234.16	235.85	0.002910	4.04	185.77	63.49	0.42
DeadHorseSlough	1	10758	Bridge									
DeadHorseSlough	1	10644	2220.00	230.18	237.79		238.36	0.002537	6.04	367.49	74.95	0.48
DeadHorseSlough	1	10644	1900.00	230.18	237.24		237.76	0.002637	5.82	326.37	72.59	0.48
DeadHorseSlough	1	10644	1500.00	230.18	236.66		237.09	0.002459	5.26	284.99	70.14	0.46
DeadHorseSlough	1	10644	750.00	230.18	234.98		235.26	0.002559	4.29	174.84	60.63	0.45
DeadHorseSlough	1	10512	2220.00	230.62	237.32		237.98	0.003066	6.54	339.68	70.87	0.53
DeadHorseSlough	1	10512	1900.00	230.62	236.74		237.37	0.003251	6.35	299.41	68.40	0.53
DeadHorseSlough	1	10512	1500.00	230.62	236.23		236.73	0.002907	5.66	264.96	66.21	0.50
DeadHorseSlough	1	10512	750.00	230.62	234.51		234.86	0.003476	4.76	157.50	58.87	0.51
DeadHorseSlough	1	10353	2220.00	229.26	237.15		237.57	0.001632	5.25	438.59	91.55	0.39
DeadHorseSlough	1	10353	1900.00	229.26	236.54		236.94	0.001743	5.08	383.14	90.21	0.40
DeadHorseSlough	1	10353	1500.00	229.26	236.04		236.35	0.001520	4.48	338.51	89.12	0.37
DeadHorseSlough	1	10353	750.00	229.26	234.29		234.49	0.001449	3.52	212.95	64.86	0.34
DeadHorseSlough	1	10262	2220.00	229.24	236.80		237.38	0.002532	6.09	364.44	73.00	0.48
DeadHorseSlough	1	10262	1900.00	229.24	236.19		236.73	0.002653	5.92	320.84	69.50	0.49
DeadHorseSlough	1	10262	1500.00	229.24	235.77		236.18	0.002146	5.13	292.52	67.13	0.43
DeadHorseSlough	1	10262	750.00	229.24	234.08		234.33	0.001927	4.01	186.95	57.43	0.39
DeadHorseSlough	1	10108	2220.00	229.04	236.55	233.74	237.05	0.001979	5.66	391.96	72.54	0.43
DeadHorseSlough	1	10108	1900.00	229.04	235.93	233.33	236.40	0.002037	5.46	347.89	69.45	0.43
DeadHorseSlough	1	10108	1500.00	229.04	235.58	232.79	235.91	0.001558	4.63	323.77	67.71	0.37
DeadHorseSlough	1	10108	750.00	229.04	233.92	231.57	234.10	0.001211	3.44	218.22	59.45	0.32
DeadHorseSlough	1	10098	Bridge									
DeadHorseSlough	1	10000	2220.00	228.74	236.18		236.66	0.001912	5.53	402.94	79.94	0.42
DeadHorseSlough	1	10000	1900.00	228.74	235.55		235.99	0.002057	5.37	353.97	73.94	0.43
DeadHorseSlough	1	10000	1500.00	228.74	235.31		235.62	0.001483	4.46	336.58	72.74	0.37
DeadHorseSlough	1	10000	750.00	228.74	233.73		233.89	0.001164	3.30	227.59	64.91	0.31



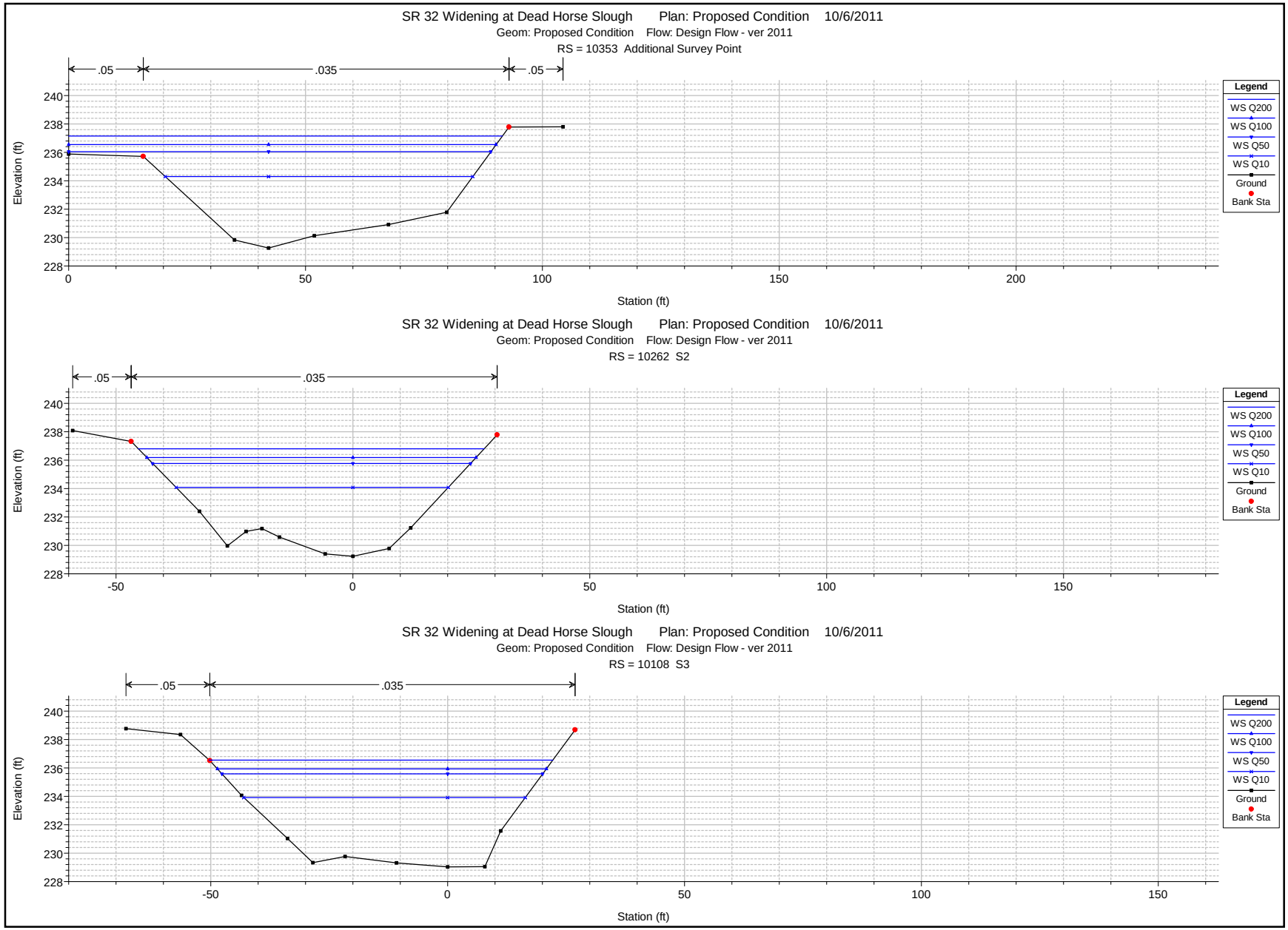
1 in Horiz. = 30 ft 1 in Vert. = 10 ft



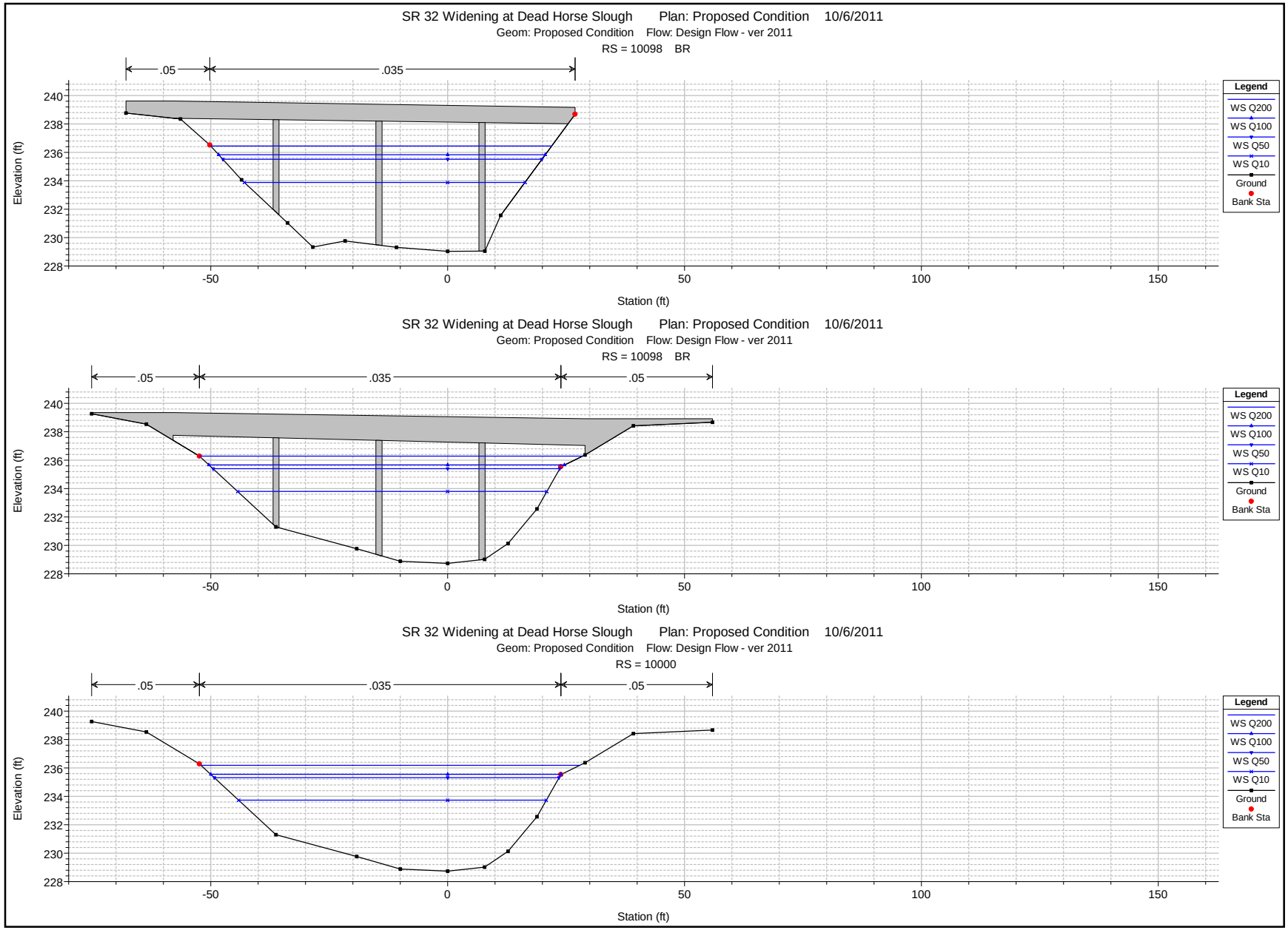
1 in Horiz. = 30 ft 1 in Vert. = 10 ft



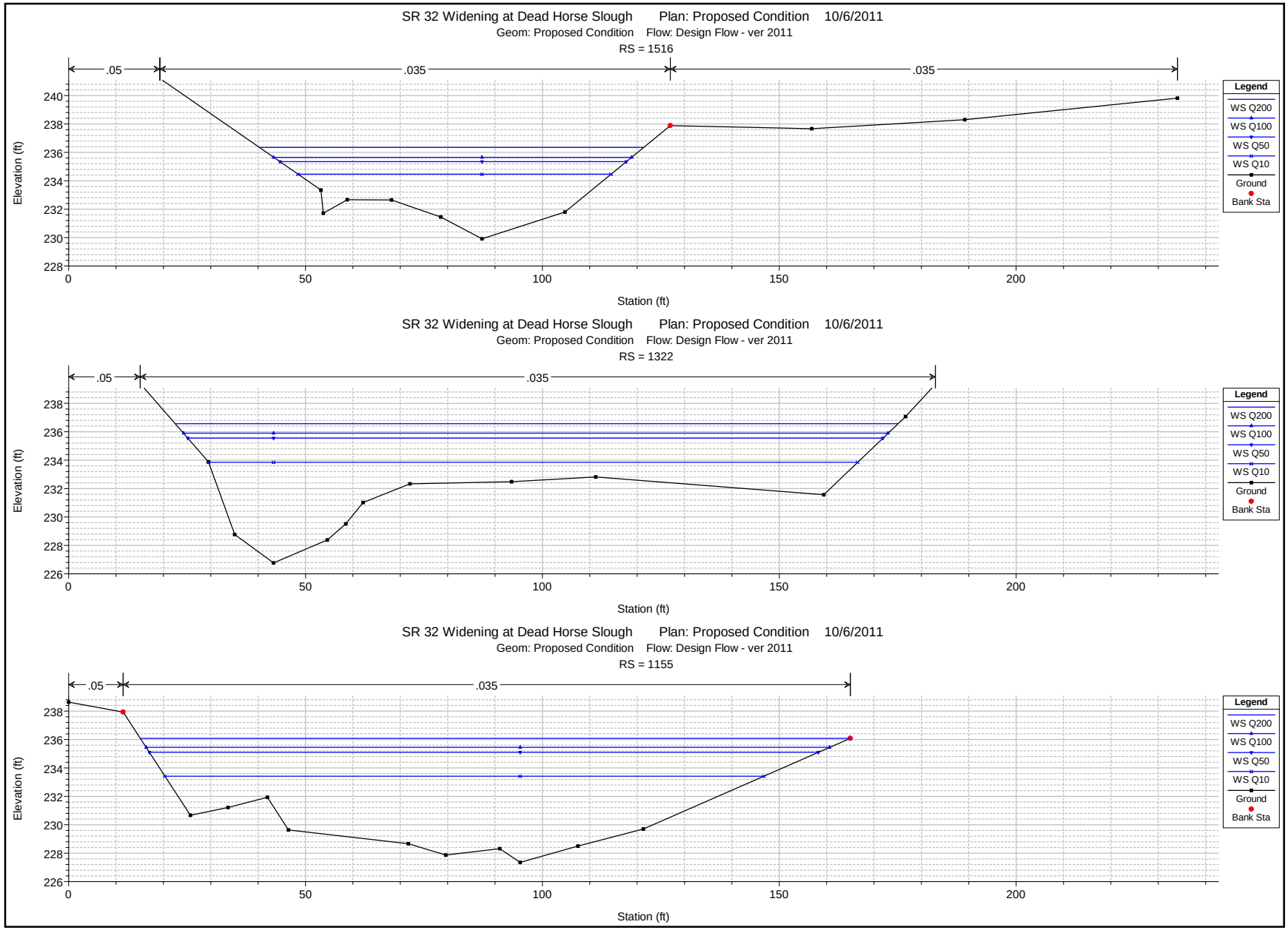
1 in Horiz. = 30 ft 1 in Vert. = 10 ft



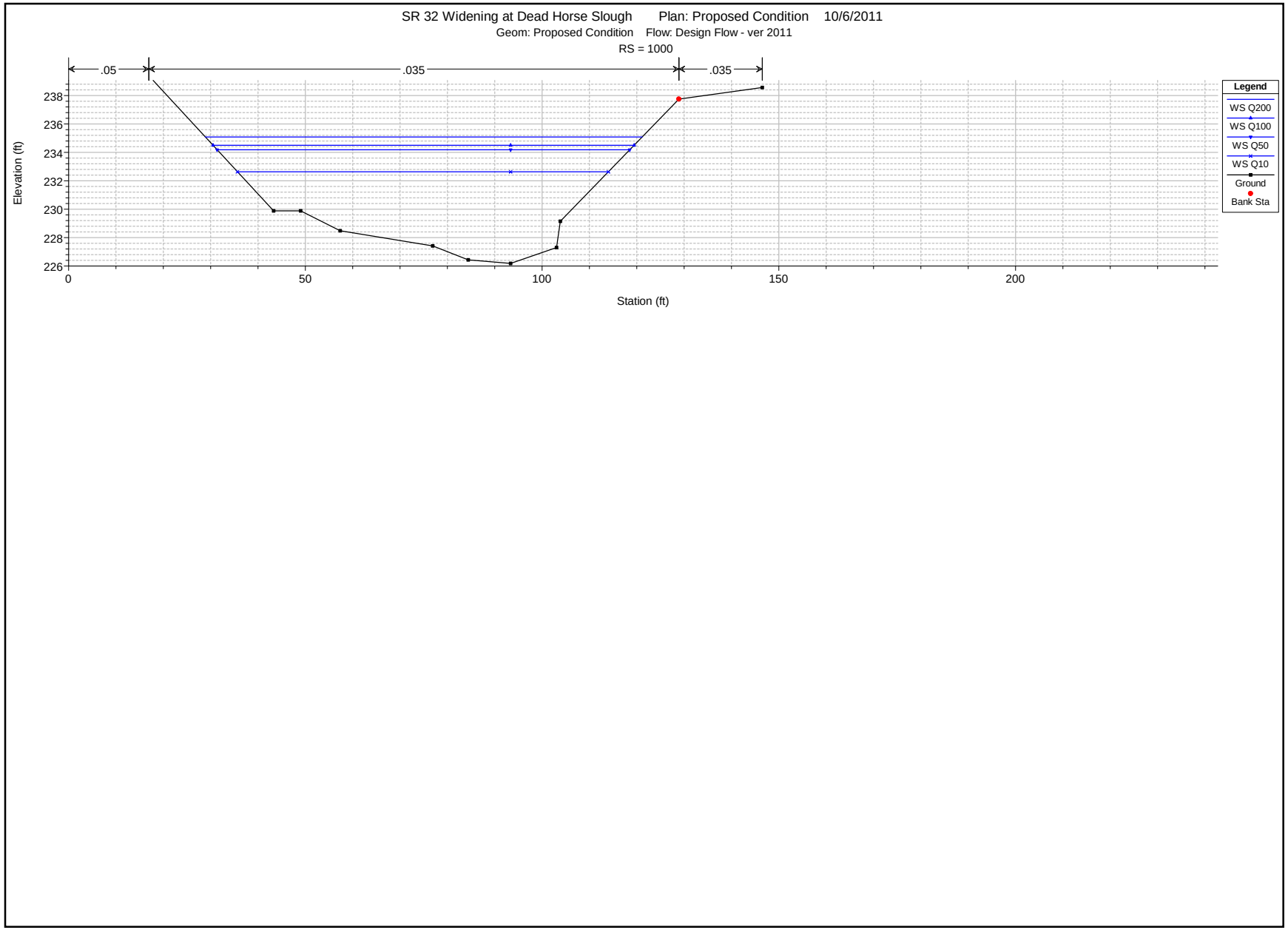
1 in Horiz. = 30 ft 1 in Vert. = 10 ft



1 in Horiz. = 30 ft 1 in Vert. = 10 ft

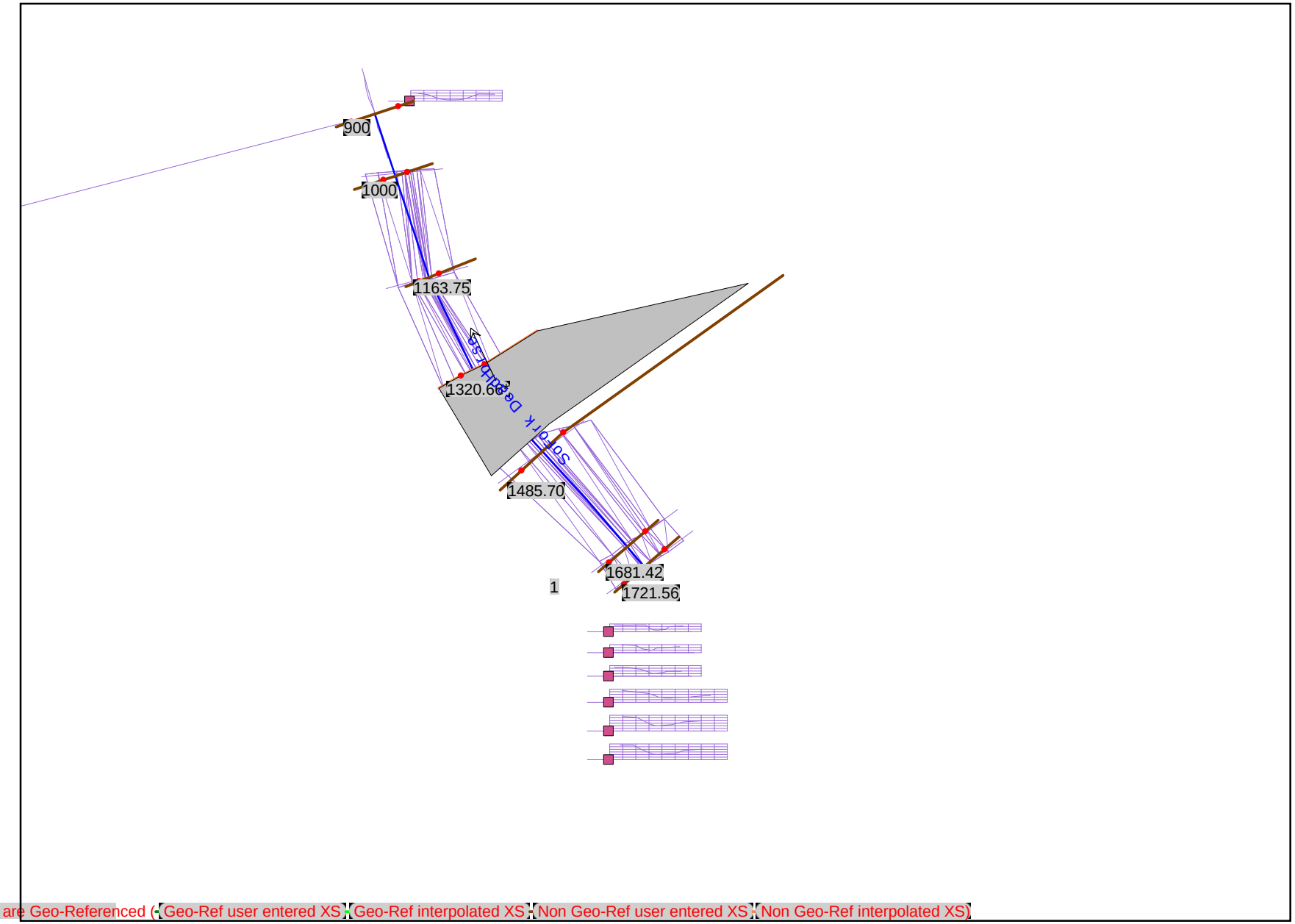


1 in Horiz. = 30 ft 1 in Vert. = 10 ft

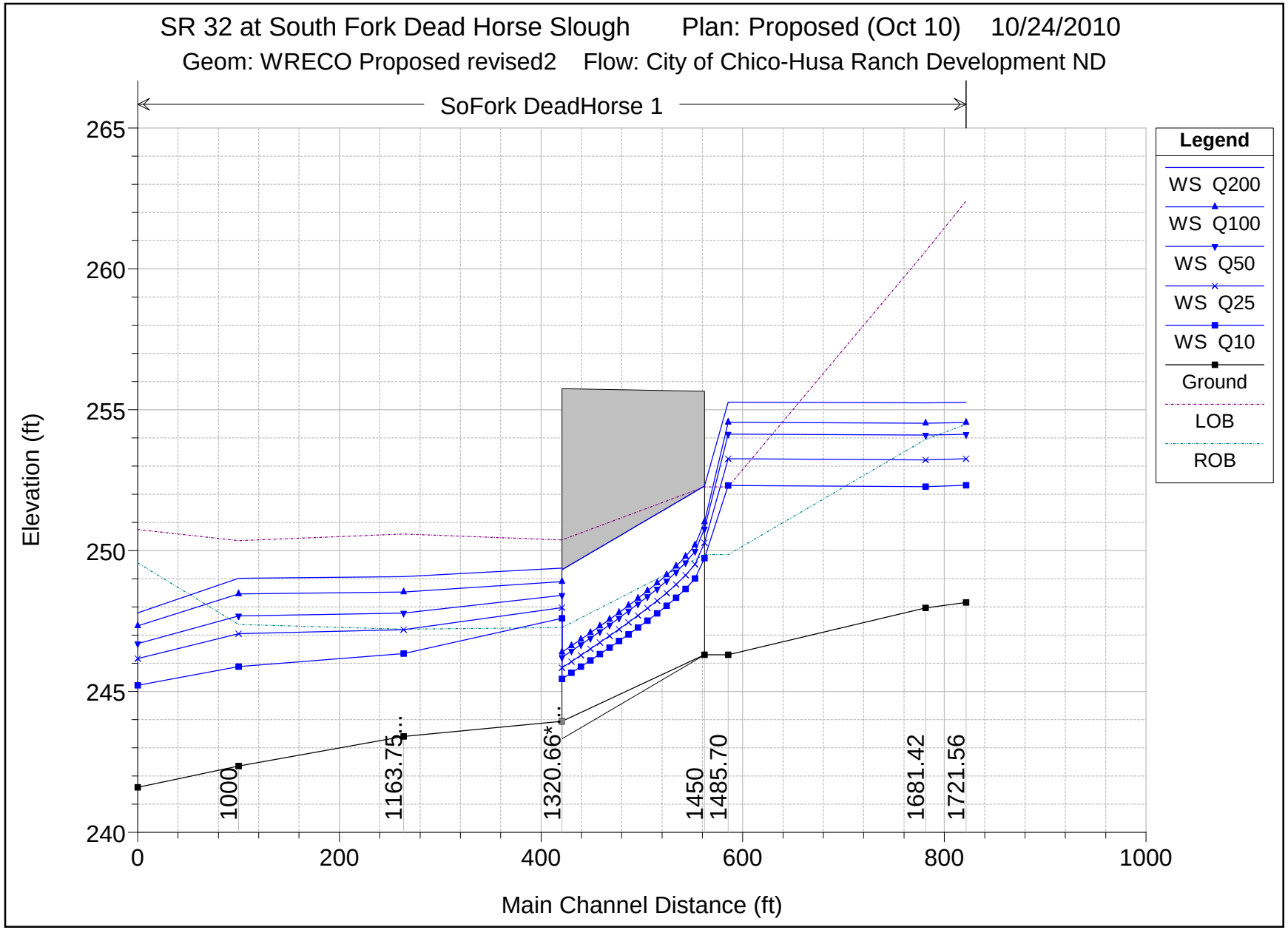


1 in Horiz. = 30 ft 1 in Vert. = 10 ft

Appendix B.2 South Fork Dead Horse Slough



None of the XS's are Geo-Referenced (Geo-Ref user entered XS Geo-Ref interpolated XS Non Geo-Ref user entered XS Non Geo-Ref interpolated XS)


SR 32 at South Fork Dead Horse Slough
Plan: Proposed (Oct 10)
10/24/2010
Geom: WRECO Proposed revised2
Flow: City of Chico-Husa Ranch Development ND
SoFork DeadHorse 1
Elevation (ft)
265
260
255
250
245
240
0
200
400
600
800
1000
Main Channel Distance (ft)
1000
1163.75
1320.66*
1450
1485.70
1681.42
1721.56
Legend
WS Q200
WS Q100
WS Q50
WS Q25
WS Q10
Ground
LOB
ROB

HEC-RAS Plan: Prop (Oct 10) River: SoFork DeadHorse Reach: 1

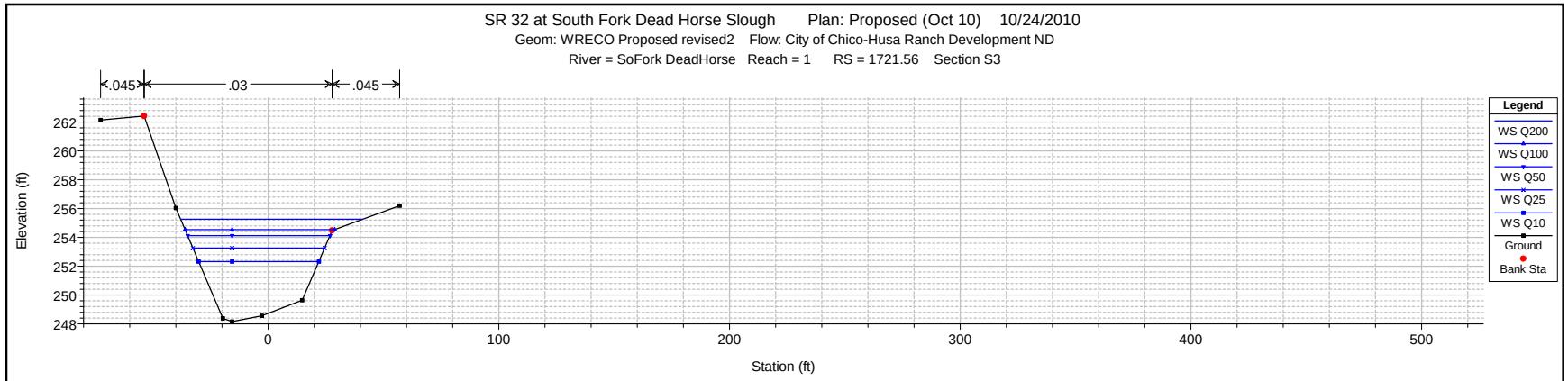
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	1721.56	Q200	528.00	248.16	255.26		255.30	0.000127	1.60	334.44	78.94	0.13
1	1721.56	Q100	466.00	248.16	254.54		254.59	0.000158	1.65	282.99	64.89	0.14
1	1721.56	Q50	431.00	248.16	254.13		254.17	0.000179	1.68	256.71	61.75	0.15
1	1721.56	Q25	361.00	248.16	253.26		253.31	0.000238	1.76	205.08	57.10	0.16
1	1721.56	Q10	290.00	248.16	252.32		252.38	0.000352	1.88	153.94	52.10	0.19
1	1681.42	Q200	528.00	247.97	255.24		255.29	0.000176	1.80	304.38	82.28	0.15
1	1681.42	Q100	466.00	247.97	254.52		254.58	0.000230	1.88	249.82	69.24	0.16
1	1681.42	Q50	431.00	247.97	254.10		254.16	0.000276	1.94	222.29	61.62	0.18
1	1681.42	Q25	361.00	247.97	253.22		253.29	0.000402	2.10	172.08	54.17	0.21
1	1681.42	Q10	290.00	247.97	252.27		252.35	0.000637	2.35	123.48	46.42	0.25
1	1485.70	Q200	528.00	246.30	255.27	248.55	255.27	0.000007	0.49	1864.25	529.65	0.03
1	1485.70	Q100	466.00	246.30	254.55	248.44	254.56	0.000010	0.54	1486.17	522.73	0.04
1	1485.70	Q50	431.00	246.30	254.13	248.37	254.14	0.000012	0.57	1268.91	502.45	0.04
1	1485.70	Q25	361.00	246.30	253.26	248.23	253.26	0.000018	0.64	869.78	409.01	0.05
1	1485.70	Q10	290.00	246.30	252.31	248.07	252.32	0.000029	0.70	532.63	287.43	0.06
1	1450		Culvert									
1	1320.66*	Q200	528.00	243.94	249.38		249.51	0.000725	3.14	222.68	96.25	0.29
1	1320.66*	Q100	466.00	243.94	248.90		249.05	0.000922	3.32	179.43	86.02	0.32
1	1320.66*	Q50	431.00	243.94	248.41		248.62	0.001373	3.77	139.80	75.88	0.38
1	1320.66*	Q25	361.00	243.94	247.97		248.19	0.001664	3.85	108.49	66.79	0.41
1	1320.66*	Q10	290.00	243.94	247.60		247.81	0.001781	3.71	84.79	58.93	0.42
1	1163.75	Q200	528.00	243.40	249.08		249.34	0.001365	4.28	148.63	67.48	0.39
1	1163.75	Q100	466.00	243.40	248.53		248.84	0.001825	4.58	114.96	55.07	0.44
1	1163.75	Q50	431.00	243.40	247.78		248.26	0.003495	5.58	79.99	38.92	0.59
1	1163.75	Q25	361.00	243.40	247.19		247.74	0.005098	5.94	60.76	26.46	0.69
1	1163.75	Q10	290.00	243.40	246.35	246.31	247.17	0.011294	7.30	39.75	23.34	0.99
1	1000	Q200	528.00	242.35	249.02		249.15	0.000654	2.94	194.31	60.54	0.24
1	1000	Q100	466.00	242.35	248.47		248.60	0.000758	2.98	163.42	51.19	0.25
1	1000	Q50	431.00	242.35	247.68		247.86	0.001192	3.37	128.32	38.43	0.31
1	1000	Q25	361.00	242.35	247.05		247.23	0.001430	3.39	106.49	32.46	0.33
1	1000	Q10	290.00	242.35	245.88		246.14	0.003012	4.09	70.82	28.83	0.46

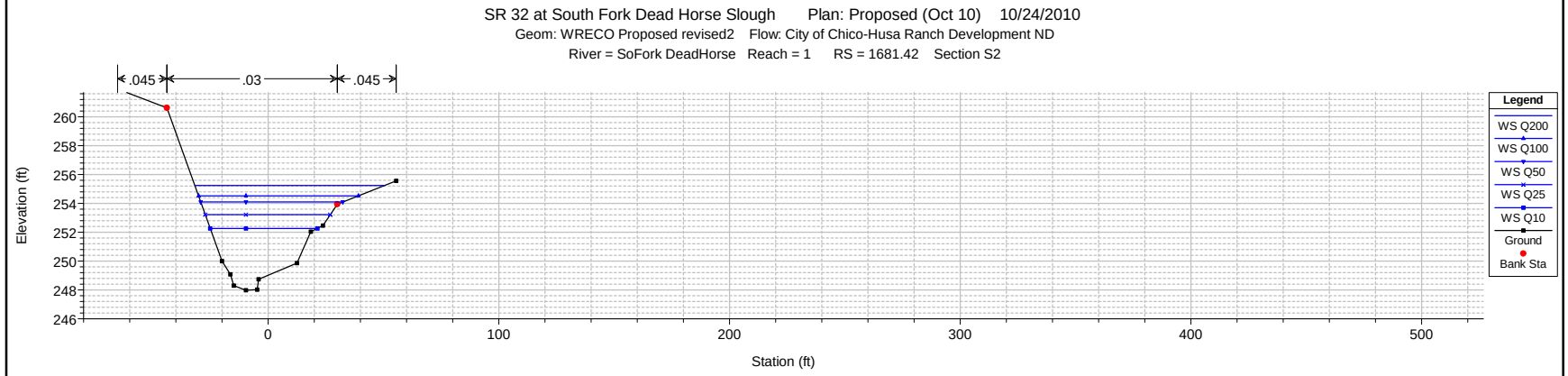
HEC-RAS Plan: Prop (Oct 10) River: SoFork DeadHorse Reach: 1 (Continued)

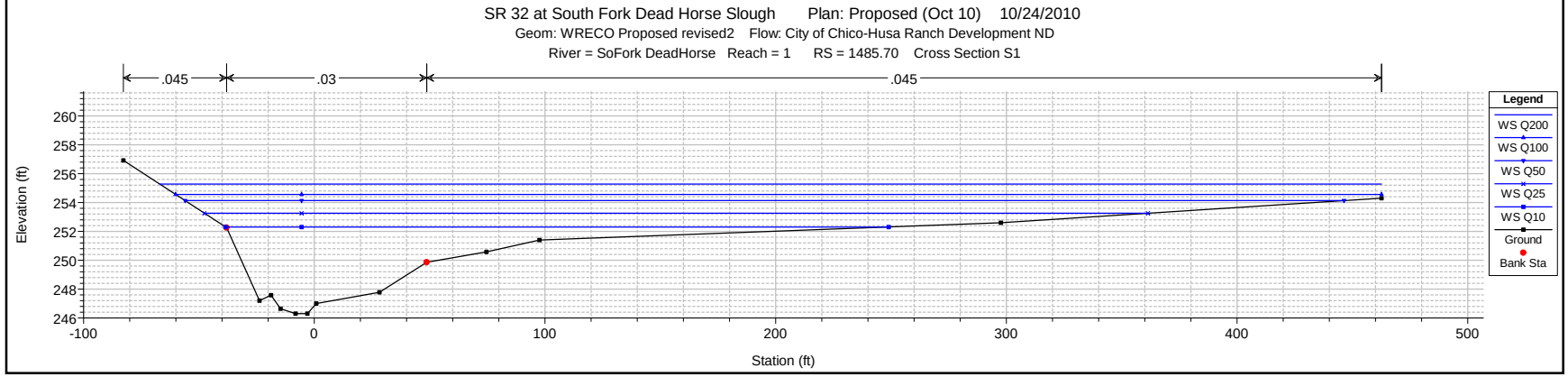
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1	900	Q200	2220.00	241.60	247.79	246.66	248.82	0.003972	8.14	272.79	62.96	0.69
1	900	Q100	1900.00	241.60	247.33	246.27	248.27	0.003975	7.78	244.37	60.53	0.68
1	900	Q50	1500.00	241.60	246.70	245.72	247.51	0.003971	7.24	207.17	57.19	0.67
1	900	Q25	1200.00	241.60	246.16	245.25	246.88	0.003972	6.76	177.40	54.37	0.66
1	900	Q10	750.00	241.60	245.22	244.44	245.75	0.003973	5.84	128.53	49.40	0.64

HEC-RAS Plan: Prop (Oct 10) River: SoFork DeadHorse Reach: 1

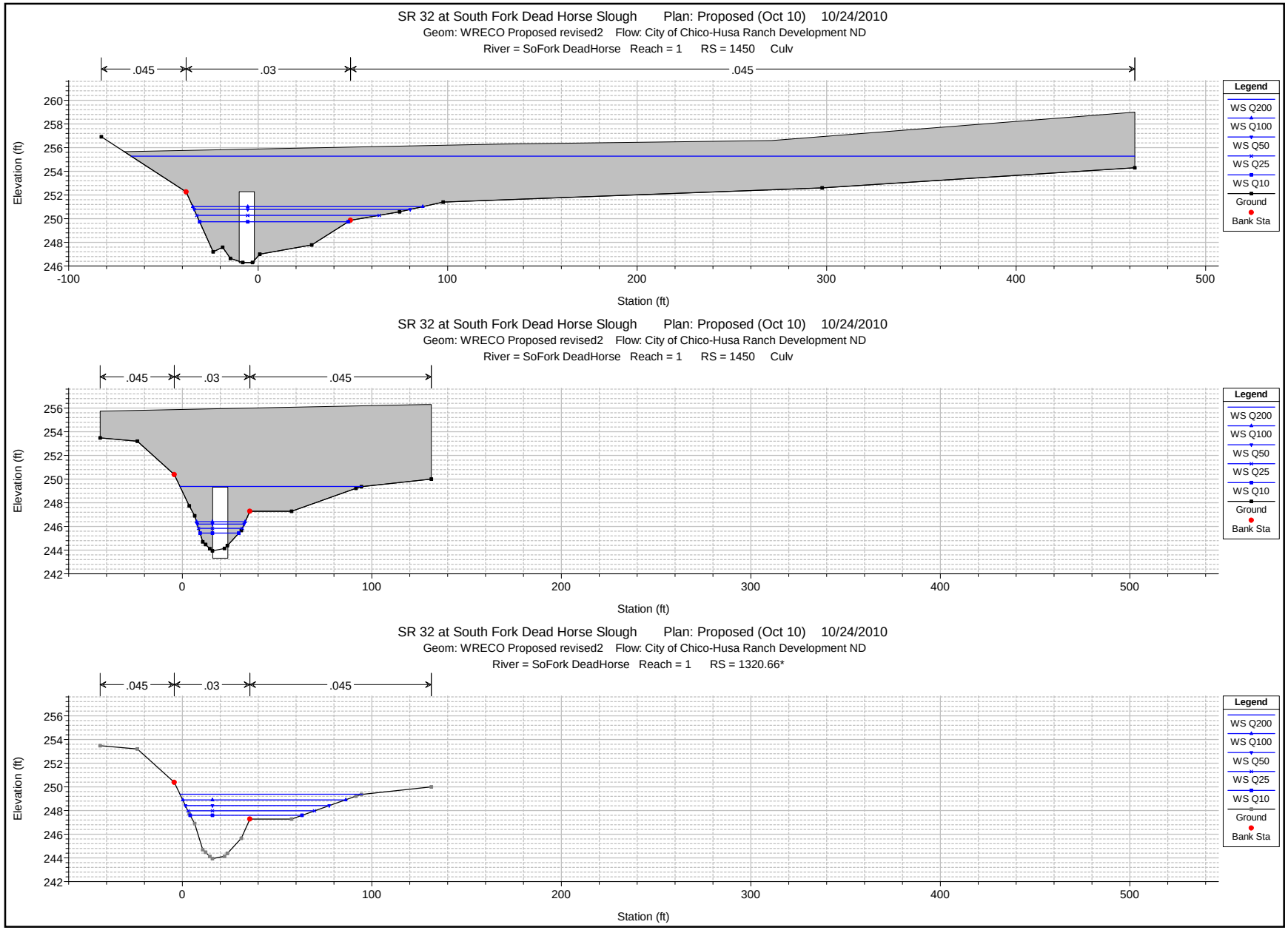
Reach	River Sta		Profile	E.G. US.	W.S. US.	E.G. IC	E.G. OC	Min El Weir Flow	Q Culv Group	Q Weir	Delta WS	Culv Vel US	Culv Vel DS
				(ft)	(ft)	(ft)	(ft)	(ft)	(cfs)	(cfs)	(ft)	(ft/s)	(ft/s)
1	1450	Culvert #1	Q200	255.27	255.27	255.53	255.27	255.76	528.00		5.89	11.00	11.00
1	1450	Culvert #1	Q100	254.56	254.55	254.44	254.56	255.76	466.00		5.65	12.33	18.97
1	1450	Culvert #1	Q50	254.14	254.13	253.80	254.14	255.76	431.00		5.72	12.02	18.65
1	1450	Culvert #1	Q25	253.26	253.26	252.91	253.26	255.76	361.00		5.28	11.33	17.93
1	1450	Culvert #1	Q10	252.32	252.31	252.01	252.32	255.76	290.00		4.71	10.53	17.07





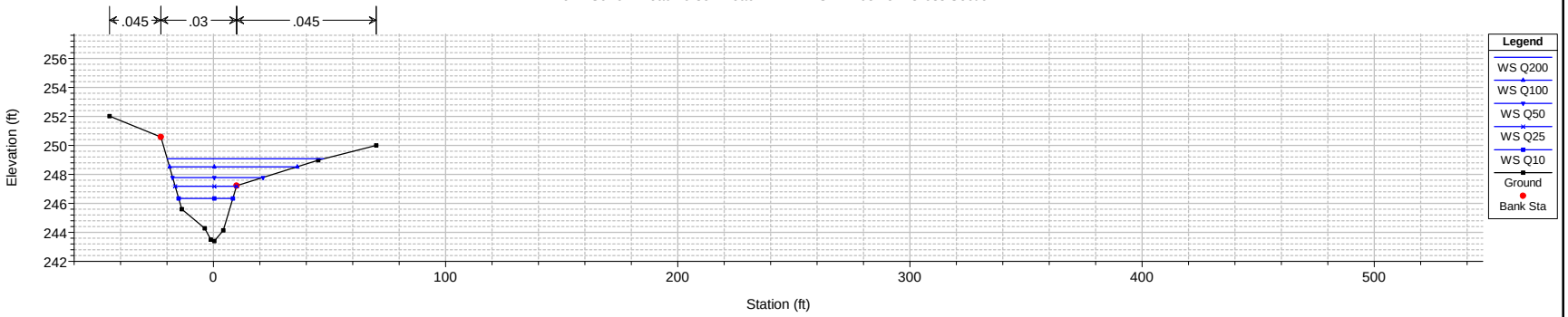


1 in Horiz. = 75 ft 1 in Vert. = 12 ft

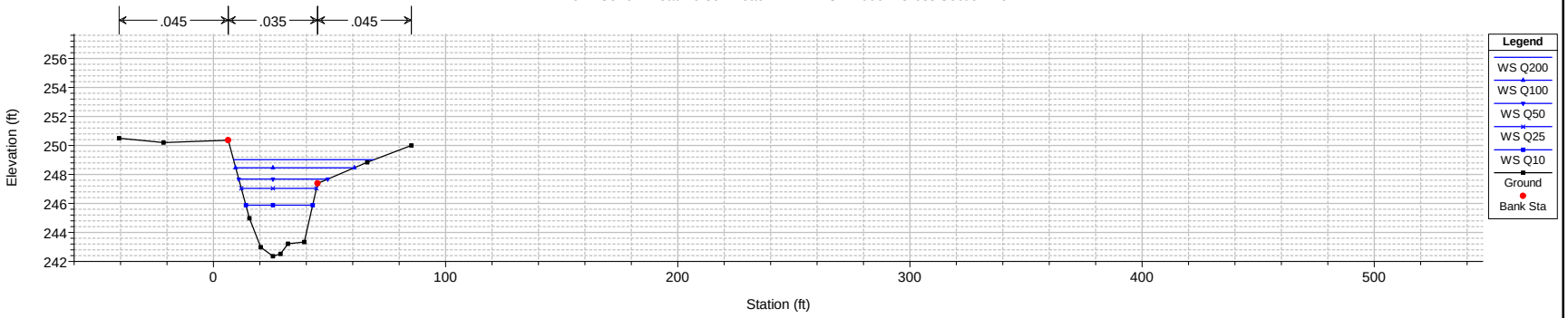


1 in Horiz. = 75 ft 1 in Vert. = 12 ft

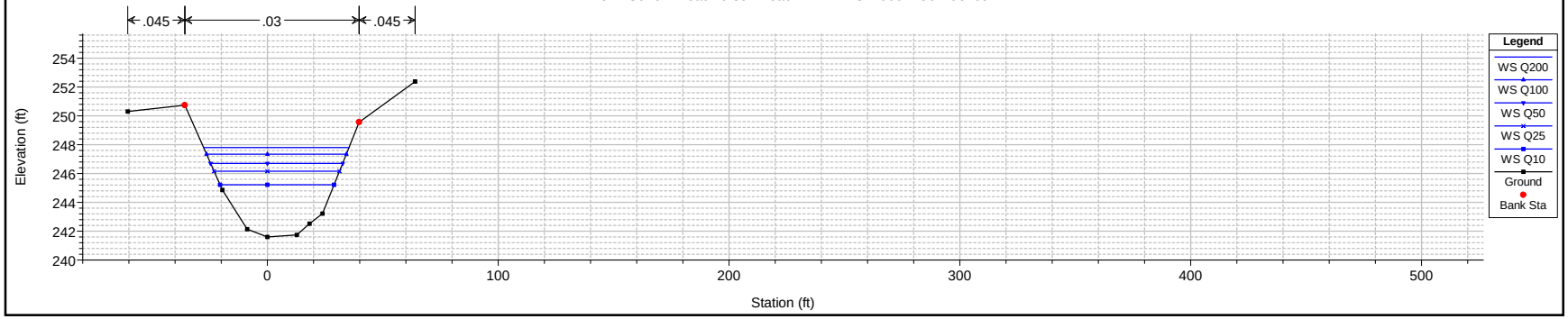
SR 32 at South Fork Dead Horse Slough Plan: Proposed (Oct 10) 10/24/2010
Geom: WRECO Proposed revised2 Flow: City of Chico-Husa Ranch Development ND
River = SoFork DeadHorse Reach = 1 RS = 1163.75 Cross Section N2



SR 32 at South Fork Dead Horse Slough Plan: Proposed (Oct 10) 10/24/2010
Geom: WRECO Proposed revised2 Flow: City of Chico-Husa Ranch Development ND
River = SoFork DeadHorse Reach = 1 RS = 1000 Cross Section N3



SR 32 at South Fork Dead Horse Slough Plan: Proposed (Oct 10) 10/24/2010
Geom: WRECO Proposed revised2 Flow: City of Chico-Husa Ranch Development ND
River = SoFork DeadHorse Reach = 1 RS = 900 Confluence



1 in Horiz. = 75 ft 1 in Vert. = 12 ft

Appendix C Hydrologic Analyses

Federal Emergency Management Agency

Washington, D.C. 20472

NOV 29 2004

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

The Honorable Robert J. Beeler
Chairman, Butte County
Board of Supervisors
Butte County Administration Center
25 County Center Drive
Oroville, CA 95965

IN REPLY REFER TO:

Case No.:	04-09-0415P
Follows Conditional Case No.:	02-09-0348X
Community Name:	Butte County, CA
Community No.:	060017
Effective Date of This Revision:	**MAR 31 2005**

Dear Mr. Beeler:

The Flood Insurance Study report and Flood Insurance Rate Map for your community have been revised by this Letter of Map Revision (LOMR). Please use the enclosed annotated map panel(s) revised by this LOMR for floodplain management purposes and for all flood insurance policies and renewals issued in your community.

Additional documents are enclosed which provide information regarding this LOMR. Please see the List of Enclosures below to determine which documents are included. Other attachments specific to this request may be included as referenced in the Determination Document. If you have any questions regarding floodplain management regulations for your community or the National Flood Insurance Program (NFIP) in general, please contact the Consultation Coordination Officer for your community. If you have any technical questions regarding this LOMR, please contact the Director, Federal Insurance and Mitigation Division of the Department of Homeland Security's Federal Emergency Management Agency (FEMA) in Oakland, California, at (510) 627-7103, or the FEMA Map Assistance Center toll free at 1-877-336-2627 (1-877-FEMA MAP). Additional information about the NFIP is available on our website at http://www.fema.gov/nfip.

Sincerely,

Max H. Yuan, P.E., Project Engineer
Hazard Identification Section
Mitigation Division
Emergency Preparedness
and Response Directorate

For: Doug Bellomo, P.E., CFM, Chief
Hazard Identification Section
Mitigation Division
Emergency Preparedness
and Response Directorate

List of Enclosures:
- Letter of Map Revision Determination Document
- Annotated Flood Insurance Rate Map
- Annotated Flood Insurance Study Report

cc: The Honorable Maureen Kirk
Mayor, City of Chico

[redacted] P.E.
Wood Rogers, Inc.

Ms. Yvonne Christopher
Floodplain Administrator
Department of Public Works
Butte County

 | Issue Date: NOV 29 2004 | Effective Date: MAR 31 2005 | Case No.: 04-09-0415P | LOMR-APP

Federal Emergency Management Agency
Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT

COMMUNITY AND REVISION INFORMATION		PROJECT DESCRIPTION	BASIS OF REQUEST
COMMUNITY	Butte County California (Unincorporated Areas) COMMUNITY NO.: 060017	FILL LEVEE DETENTION BASIN	BASE MAP CHANGES HYDROLOGIC ANALYSIS HYDRAULIC ANALYSIS NEW TOPOGRAPHIC DATA
IDENTIFIER	Husa Ranch Subdivision	APPROXIMATE LATITUDE & LONGITUDE: 39.744, -121.796 SOURCE: USGS QUADRANGLE DATUM: NAD 83	
FLOODING SOURCE(S) & REVISED REACH(ES)	Dead Horse Slough – from State Highway 32 to Bruce Road		

SUMMARY OF REVISIONS

Effective Flooding:	Zone A	Zone A	No BFEs*	Zone X (unshaded)
Revised Flooding:	Zone AE	Zone A	BFEs	Zone X (shaded)
Increases:	YES	YES	YES	YES
Decreases:	YES	YES	NONE	NONE

* BFEs – Base Flood Elevations

ANNOTATED MAPPING ENCLOSURES	ANNOTATED STUDY ENCLOSURES
TYPE: FIRM* NO.: 06007C0510 D Date: April 20, 2000	DATE OF EFFECTIVE FLOOD INSURANCE STUDY REPORT: April 20, 2000 SUMMARY OF DISCHARGES TABLE: 1 PROFILE: 61P

* FIRM – Flood Insurance Rate Map; ** FBFM – Flood Boundary and Floodway Map; *** FHBM – Flood Hazard Boundary Map

DETERMINATION

This document provides the determination from the Department of Homeland Security's Federal Emergency Management Agency (FEMA) regarding a request for a Letter of Map Revision (LOMR) for the area described above. Using the information submitted, we have determined that a revision to the flood hazards depicted in the Flood Insurance Study (FIS) report and/or National Flood Insurance Program (NFIP) map is warranted. This document revises the effective NFIP map, as indicated in the attached documentation. Please use the enclosed annotated map panels revised by this LOMR for floodplain management purposes and for all flood insurance policies and renewals in your community.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2677 (1-877-FEMA MAP) or by letter addressed to the LOMR Depot, 3601 Eisenhower Avenue, Alexandria, VA 22304. Additional information about the NFIP is available on our website at http://www.fema.gov/nfip.

Max H. Yuan, P.E., Project Engineer
Hazard Identification Section
Mitigation Division
Emergency Preparedness and Response Directorate

102426 D.A04090415E 102IAC

Federal Emergency Management Agency
Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT (CONTINUED)

OTHER COMMUNITIES AFFECTED BY THIS REVISION

CID Number: 060746 **Name:** City of Chico, California

AFFECTED MAP PANELS			AFFECTED PORTIONS OF THE FLOOD INSURANCE STUDY REPORT
TYPE: FIRM	NO.: 06007C0345 C	Date: June 8, 1998	DATE OF EFFECTIVE FLOOD INSURANCE STUDY REPORT: April 20, 2000
TYPE: FIRM	NO.: 06007C0510 D	Date: April 20, 2000	SUMMARY OF DISCHARGES TABLE: 1 PROFILE: 61P

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2677 (1-877-FEMA MAP) or by letter addressed to the LOMR Depot, 3601 Eisenhower Avenue, Alexandria, VA 22304. Additional information about the NFIP is available on our website at http://www.fema.gov/nfip.

Max H. Yuan, P.E., Project Engineer
Hazard Identification Section
Mitigation Division
Emergency Preparedness and Response Directorate

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Federal Emergency Management Agency
Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT (CONTINUED)

COMMUNITY INFORMATION

APPLICABLE NFIP REGULATIONS/COMMUNITY OBLIGATION

We have made this determination pursuant to Section 206 of the Flood Disaster Protection Act of 1973 (P.L. 93-234) and in accordance with the National Flood Insurance Act of 1968, as amended (Title XIII of the Housing and Urban Development Act of 1968, P.L. 90-448), 42 U.S.C. 4001-4128, and 44 CFR Part 65. Pursuant to Section 1361 of the National Flood Insurance Act of 1968, as amended, communities participating in the NFIP are required to adopt and enforce floodplain management regulations that meet or exceed NFIP criteria. These criteria, including adoption of the FIS report and FIRM, and the modifications made by this LOMR, are the minimum requirements for continued NFIP participation and do not supersede more stringent State/Commonwealth or local requirements to which the regulations apply.

COMMUNITY REMINDERS

We based this determination on the 1-percent-annual-chance discharges computed in the submitted hydrologic model. Future development of projects upstream could cause increased discharges, which could cause increased flood hazards. A comprehensive restudy of your community's flood hazards would consider the cumulative effects of development on discharges and could, therefore, indicate that greater flood hazards exist in this area.

Your community must regulate all proposed floodplain development and ensure that permits required by Federal and/or State/Commonwealth law have been obtained. State/Commonwealth or community officials, based on knowledge of local conditions and in the interest of safety, may set higher standards for construction or may limit development in floodplain areas. If your State/Commonwealth or community has adopted more restrictive or comprehensive floodplain management criteria, those criteria take precedence over the minimum NFIP requirements.

We will not print and distribute this LOMR to primary users, such as local insurance agents or mortgage lenders; instead, the community will serve as a repository for the new data. We encourage you to disseminate the information in this LOMR by preparing a news release for publication in your community's newspaper that describes the revision and explains how your community will provide the data and help interpret the NFIP maps. In that way, interested persons, such as property owners, insurance agents, and mortgage lenders, can benefit from the information.

This revision has met our criteria for removing an area from the 1-percent-annual-chance floodplain to reflect the placement of fill. However, we encourage you to require that the lowest adjacent grade and lowest floor (including basement) of any structure placed within the subject area be elevated to or above the Base (1-percent-annual-chance) Flood Elevation.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2677 (1-877-FEMA MAP) or by letter addressed to the LOMR Depot, 3601 Eisenhower Avenue, Alexandria, VA 22304. Additional information about the NFIP is available on our website at http://www.fema.gov/nfip.

Max H. Yuan, P.E., Project Engineer
Hazard Identification Section
Mitigation Division
Emergency Preparedness and Response Directorate

102426 D.A04090415E 102IAC

Federal Emergency Management Agency
Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT (CONTINUED)

COMMUNITY INFORMATION (CONTINUED)

We have designated a Consultation Coordination Officer (CCO) to assist your community. The CCO will be the primary liaison between your community and FEMA. For information regarding your CCO, please contact:

Ms. Sally M. Ziolkowski
Director, Federal Insurance and Mitigation Division
Federal Emergency Management Agency, Region IX
1111 Broadway Street, Suite 1200
Oakland, CA 94607-4052
(510) 627-7103

STATUS OF THE COMMUNITY NFIP MAPS

We will not physically revise and republish the FIRM and FIS report for your community to reflect the modifications made by this LOMR at this time. When changes to the previously cited FIRM panel and FIS report warrant physical revision and republication in the future, we will incorporate the modifications made by this LOMR at that time.

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2677 (1-877-FEMA MAP) or by letter addressed to the LOMR Depot, 3601 Eisenhower Avenue, Alexandria, VA 22304. Additional information about the NFIP is available on our website at http://www.fema.gov/nfip.

Max H. Yuan, P.E., Project Engineer
Hazard Identification Section
Mitigation Division
Emergency Preparedness and Response Directorate

102426D.A04090415E 102IAC

Federal Emergency Management Agency
Washington, D.C. 20472

LETTER OF MAP REVISION DETERMINATION DOCUMENT (CONTINUED)

PUBLIC NOTIFICATION OF REVISION

Within 90 days of the second publication in the local newspaper, a citizen may request that we reconsider this determination. Any request for reconsideration must be based on scientific or technical data. Therefore, this letter will be effective only after the 90-day appeal period has elapsed and we have resolved any appeals that we receive during this appeal period. Until this LOMR is effective, the revised BFEs presented in this LOMR may be changed.

A notice of changes will be published in the *Federal Register*. This information also will be published in your local newspaper on or about the dates listed below.

LOCAL NEWSPAPER Name: *Chico Enterprise-Record*
Dates: 12/23/2004 12/30/2004

PUBLIC NOTIFICATION

FLOODING SOURCE	LOCATION OF REFERENCED ELEVATION	BFE (FEET NGVD)		MAP PANEL NUMBER(S)
		EFFECTIVE	REVISED	
Dead Horse Slough	Just upstream of El Monte Avenue	None	240	06007C0510 D
	Just downstream of Bruce Road*	None	245	06007C0510 D

*City of Chico

This determination is based on the flood data presently available. The enclosed documents provide additional information regarding this determination. If you have any questions about this document, please contact the FEMA Map Assistance Center toll free at 1-877-336-2677 (1-877-FEMA MAP) or by letter addressed to the LOMR Depot, 3601 Eisenhower Avenue, Alexandria, VA 22304. Additional information about the NFIP is available on our website at http://www.fema.gov/nfip.

Max H. Yuan, P.E., Project Engineer
Hazard Identification Section
Mitigation Division
Emergency Preparedness and Response Directorate

102426D.A04090415E 102IAC

CHANGES ARE MADE IN DETERMINATIONS OF BASE FLOOD ELEVATIONS FOR THE CITY OF CHICO AND THE UNINCORPORATED AREAS OF BUTTE COUNTY, CALIFORNIA, UNDER THE NATIONAL FLOOD INSURANCE PROGRAM

On April 20, 2000, the Department of Homeland Security's Federal Emergency Management Agency identified Special Flood Hazard Areas (SFHAs) in the City of Chico and in the unincorporated areas of Butte County, California, through issuance of a Flood Insurance Rate Map (FIRM). The Mitigation Division has determined that modification of the elevations of the flood having a 1-percent chance of being equaled or exceeded in any given year (base flood) for certain locations in these communities is appropriate. The modified Base Flood Elevations (BFEs) revise the FIRM for the communities.

The changes are being made pursuant to Section 206 of the Flood Disaster Protection Act of 1973 (Public Law 93-234) and are in accordance with the National Flood Insurance Act of 1968, as amended (Title XIII of the Housing and Urban Development Act of 1968, Public Law 90-448), 42 U.S.C. 4001-4128, and 44 CFR Part 65.

A hydraulic analysis was performed to incorporate updated topographic information and the effects of construction of the Husa Ranch subdivision, which included detention basins, levees, and placement of fill along Dead Horse Slough from approximately 1,000 feet upstream to approximately 2,500 feet upstream of El Monte Avenue. This has resulted in increases and decreases in SFHA width and the establishment of BFEs for Dead Horse Slough from State Highway 32 to Bruce Road. The table below indicates existing and modified BFEs for selected locations along the affected lengths of the flooding source(s) cited above.

Location	Existing BFE (feet)*	Modified BFE (feet)*
[2]Just upstream of El Monte Avenue	None	240
[1]Just downstream of Bruce Road	None	245

*National Geodetic Vertical Datum, rounded to nearest whole foot
[1]City of Chico
[2]Unincorporated areas of Butte County

Under the above-mentioned Acts of 1968 and 1973, the Mitigation Division must develop criteria for floodplain management. To participate in the National Flood Insurance Program (NFIP), the community must use the modified BFEs to administer the floodplain management measures of the NFIP. These modified BFEs will also be used to calculate the appropriate flood insurance premium rates for new buildings and their contents and for the second layer of insurance on existing buildings and contents.

Upon the second publication of notice of these changes in this newspaper, any person has 90 days in which he or she can request, through the Chief Executive Officer of the community, that the Mitigation Division reconsider the determination. Any request for reconsideration must be based on knowledge of changed conditions or new scientific or technical data. All interested parties are on notice that until the 90-day period elapses, the Mitigation Division's determination to modify the BFEs may itself be changed.

Any person having knowledge or wishing to comment on these changes should immediately notify:

The Honorable Robert J. Beeler
Chairman, Butte County
Board of Supervisors
Butte County Administration Center
25 County Center Drive
Oroville, CA 95965

OR

The Honorable Maureen Kirk
Mayor, City of Chico
P.O. Box 3420
Chico, CA 95927

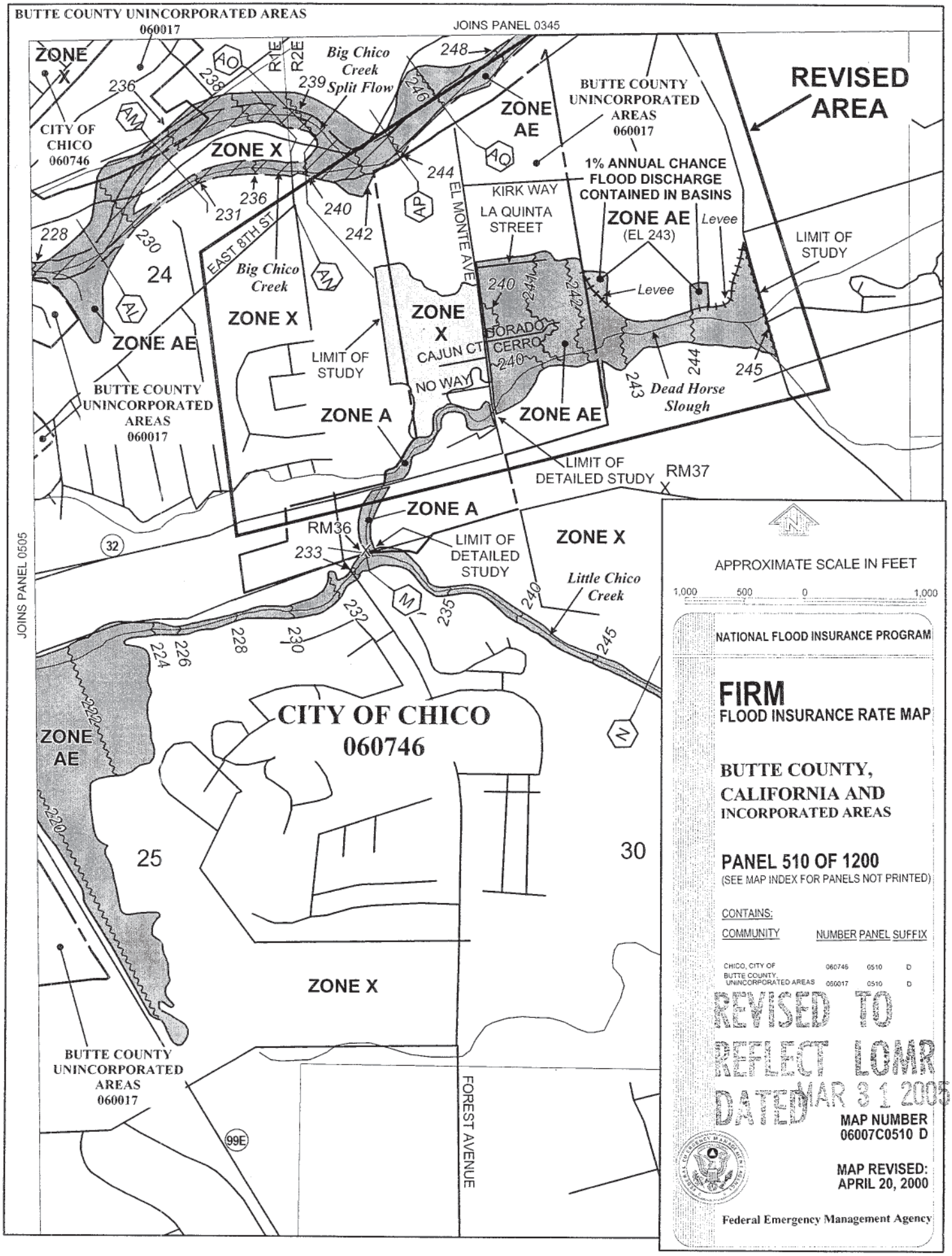
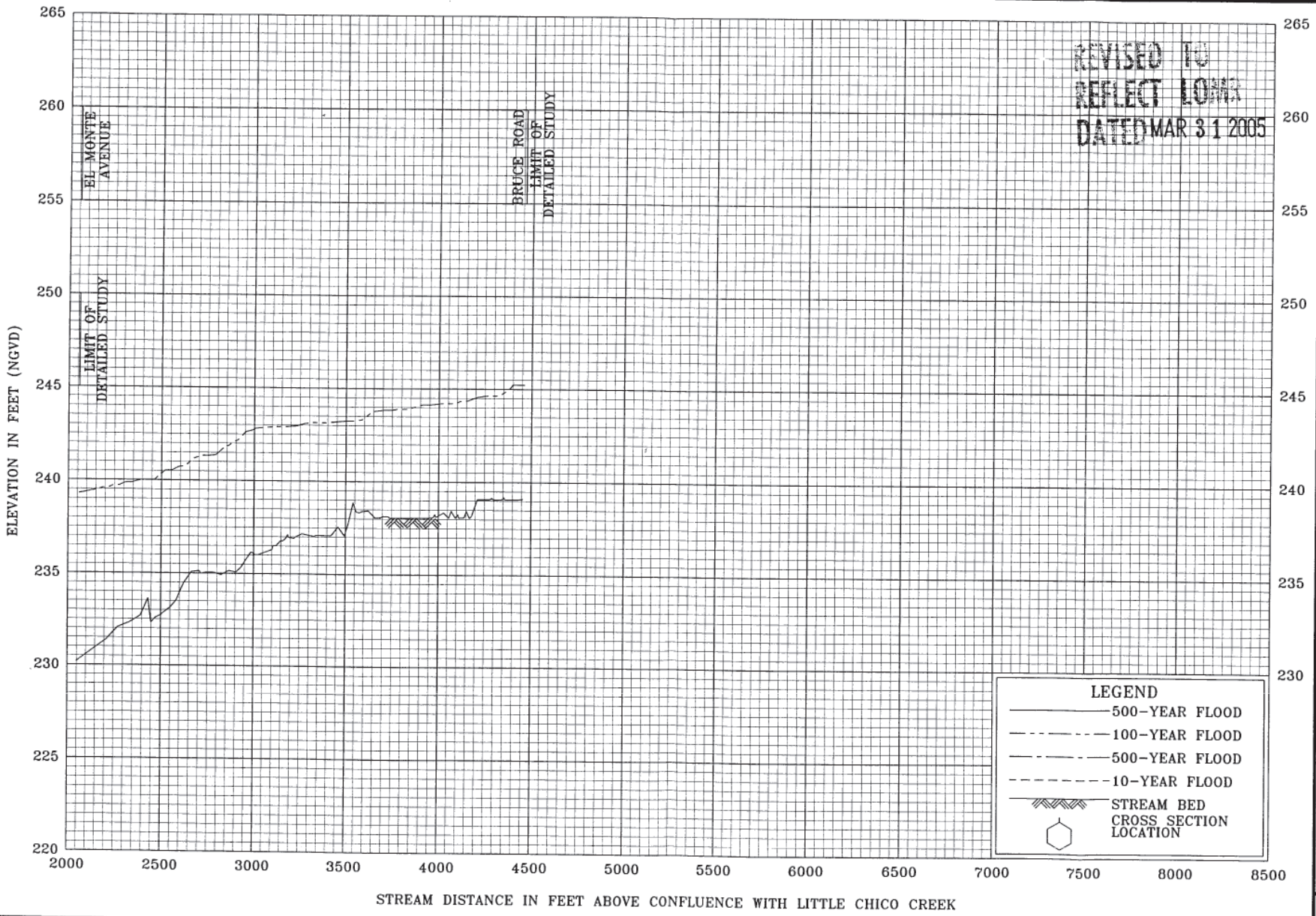

BUTTE COUNTY UNINCORPORATED AREAS
060017
JOINS PANEL 0345
ZONE X
CITY OF CHICO
060746
Big Chico Creek Split Flow
ZONE X
ZONE AE
BUTTE COUNTY UNINCORPORATED AREAS
060017
1% ANNUAL CHANCE FLOOD DISCHARGE CONTAINED IN BASINS
REVISED AREA
KIRK WAY
LA QUINTA STREET
EL MONTE AVE
EAST 8TH ST
Big Chico Creek
ZONE AE
(EL 243)
Levee
LIMIT OF STUDY
ZONE X
ZONE X
CAJUN CT
NO WAY
ZONE AE
ZONE A
ZONE AE
Dead Horse Slough
LIMIT OF DETAILED STUDY
RM37
ZONE A
RM36
LIMIT OF DETAILED STUDY
ZONE X
Little Chico Creek
JOINS PANEL 0505
CITY OF CHICO
060746
ZONE AE
ZONE X
BUTTE COUNTY UNINCORPORATED AREAS
060017
FOREST AVENUE
APPROXIMATE SCALE IN FEET
1,000 500 0 1,000
NATIONAL FLOOD INSURANCE PROGRAM
FIRM
FLOOD INSURANCE RATE MAP
BUTTE COUNTY, CALIFORNIA AND INCORPORATED AREAS
PANEL 510 OF 1200
(SEE MAP INDEX FOR PANELS NOT PRINTED)
CONTAINS:
COMMUNITY NUMBER PANEL SUFFIX
CHICO, CITY OF 060746 0510 D
BUTTE COUNTY, UNINCORPORATED AREAS 060017 0510 D
REVISED TO REFLECT LOMR DATED MAR 31 2005
MAP NUMBER
06007C0510 D
MAP REVISED:
APRIL 20, 2000
Federal Emergency Management Agency

Table 1. Summary of Discharges

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cubic feet per second) 10-YEAR	50-YEAR	100-YEAR	500-YEAR
Dead Horse Slough					
At confluence with Little Chico Creek	5.36	750	1,500	1,900	--[1]

[1]Data Not Available

REVISED TO
REFLECT LOMR
DATED MAR 3 1 2005



REVISED TO REFLECT LOMR DATED MAR 3 1 2005

FLOOD PROFILES

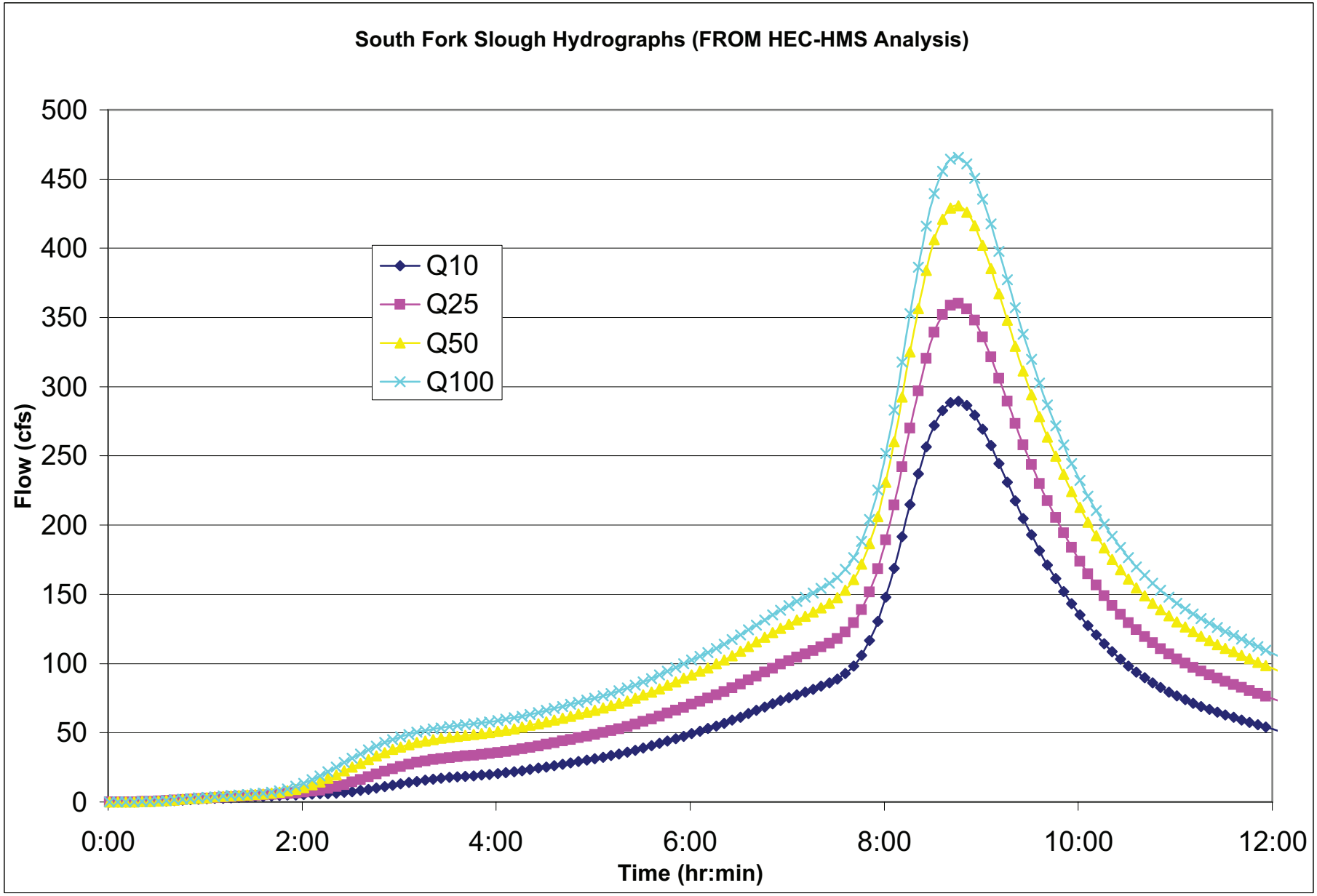
DEAD HORSE SLOUGH

FEDERAL EMERGENCY MANAGEMENT AGENCY

BUTTE COUNTY, CA

AND INCORPORATED AREAS

61P


South Fork Slough Hydrographs (FROM HEC-HMS Analysis)
Flow (cfs)
500
450
400
350
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
Time (hr:min)
Q10
Q25
Q50
Q100

Catchment Name: **South Fork Dead Horse Slough at SR32 RCB culvert**

Mean Annual Precipitation 28 in

Source: OSU Corvallis, PRISM Project California Mean Annual Precipitation Plot

Topographic Parameters

	sq ft	acres	sq mi	sq km
Size:	26,038,426	598	0.934	

Total flowline length		ft
10% flowline length:		ft
Elevation at 10% flowline length	316.1	ft
85% flowline length:		ft
Elevation at 85% flowline length	849.35	m

Source: "\Projects\Y2004\P0436 Cohasset\DWG\sheep hollow catchment.dwg"
Based on USGS 7.5' quadrangle excerpted using TOPO! Software application

Average of 10% and 85% elevatio	583	ft * 1000
Altitude Index	0.58	ft * 1000

Discharges by Return Period		**Sierra Region Coefficients**				
Q2	0.24	0.88	1.58	-0.80	67	cfs
Q5	1.20	0.82	1.37	-0.64	154	cfs
Q10	2.63	0.80	1.25	-0.58	219	cfs
Q25	6.55	0.79	1.12	-0.52	343	cfs
Q50	10.40	0.78	1.06	-0.48	437	cfs
Q100	15.70	0.77	1.02	-0.43	562	cfs

Source: Caltrans Highway Design Manual, Figure 819.2C from USGS, "Magnitude and Frequency of Floods in California", June 1977.

CALIFORNIIA

A N N U A L P R E C I P I T A T I O N S U M M A R Y (INCHES)

		PRECIPITATION							SNOWFALL			NUMBER OF DAYS			
	PERIOD OF RECORD	MEAN	MAX YEAR	YR	MIN YEAR	YR	MAX DAY	YEARMODY	MEAN	MAX YEAR	YR	>= .01	>= .10	>= .50	>= 1.0
CHICO EXPERIMENT STN	1906-2004	25.84	45.54	41	10.40	76	5.73	19160103	0.1	4.3	72	63	43	18	7

http://www.wrcc.dri.edu/htmlfiles/ca/ca.ppt.ext.html

Figure 28

ISOPLUVIALS OF 10-YR 24-HR PRECIPITATION FOR NORTHERN HALF OF CALIFORNIA IN TENTHS OF AN INCH

NOAA ATLAS 2, Volume XI

Prepared by U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service, Office of Hydrology

Prepared for U.S. Department of Agriculture,
Soil Conservation Service, Engineering Division

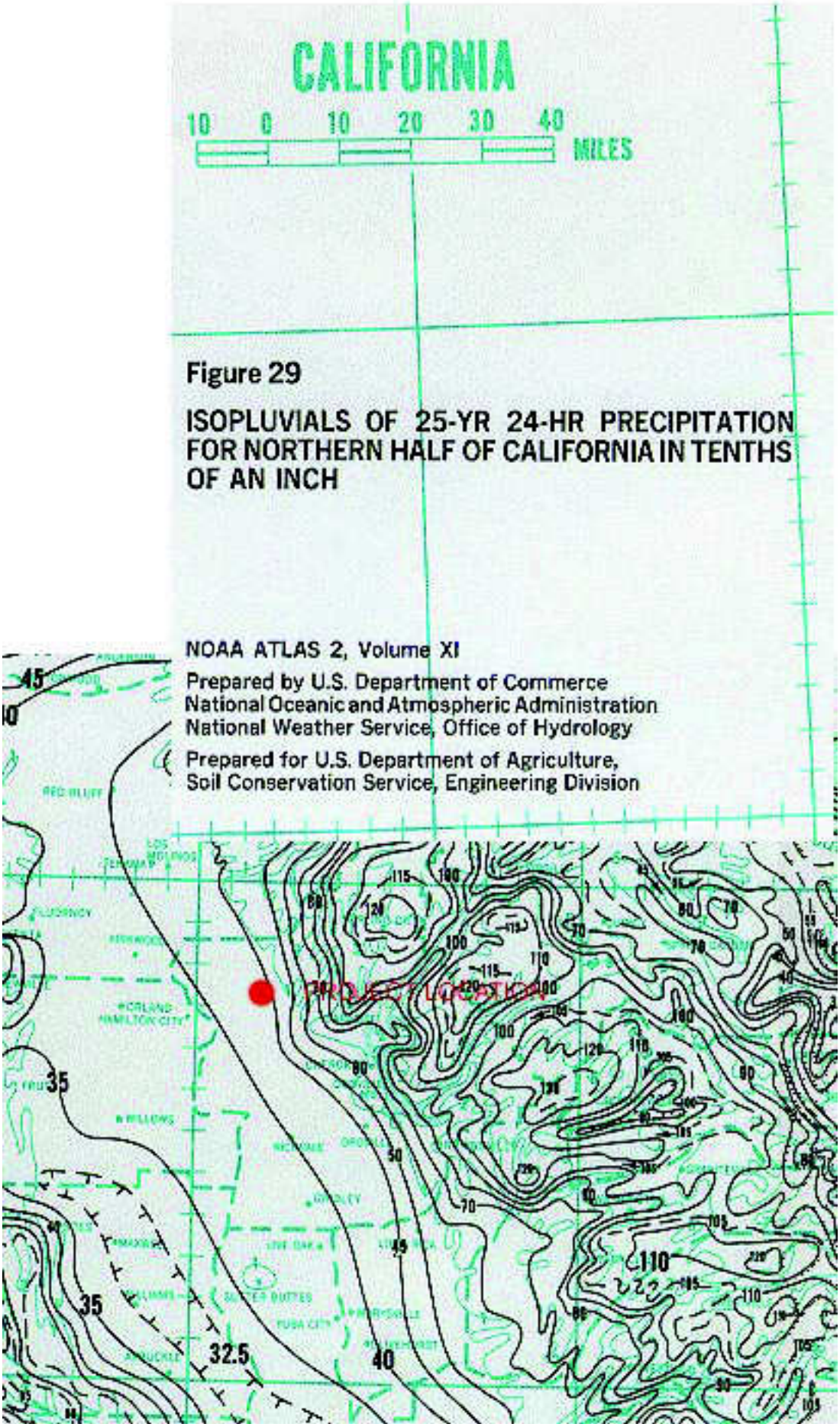


Figure 29

ISOPLUVIALS OF 25-YR 24-HR PRECIPITATION FOR NORTHERN HALF OF CALIFORNIA IN TENTHS OF AN INCH

NOAA ATLAS 2, Volume XI

Prepared by U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service, Office of Hydrology

Prepared for U.S. Department of Agriculture,
Soil Conservation Service, Engineering Division

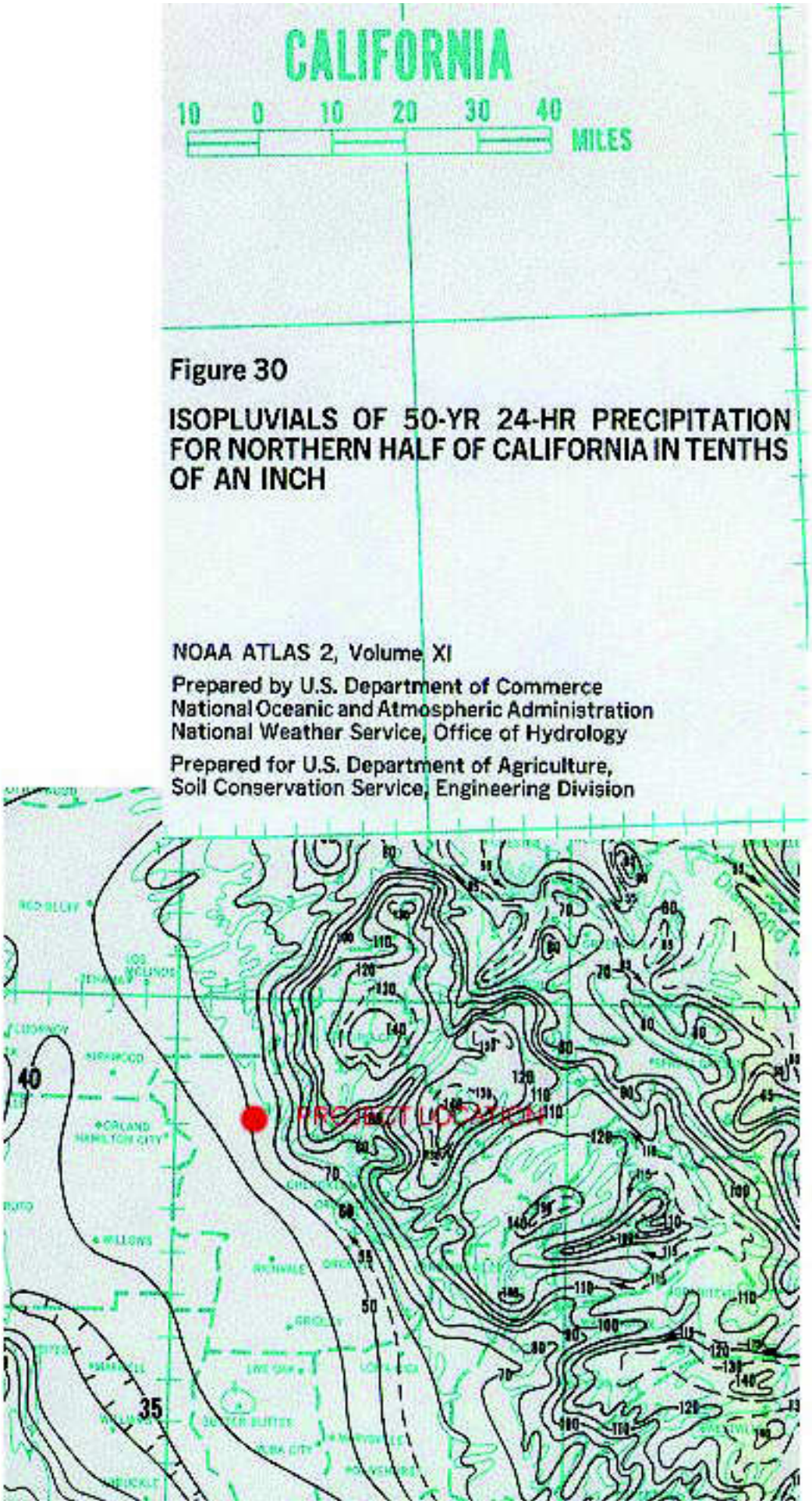


Figure 30

ISOPLUVIALS OF 50-YR 24-HR PRECIPITATION FOR NORTHERN HALF OF CALIFORNIA IN TENTHS OF AN INCH

NOAA ATLAS 2, Volume XI

Prepared by U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service, Office of Hydrology

Prepared for U.S. Department of Agriculture,
Soil Conservation Service, Engineering Division

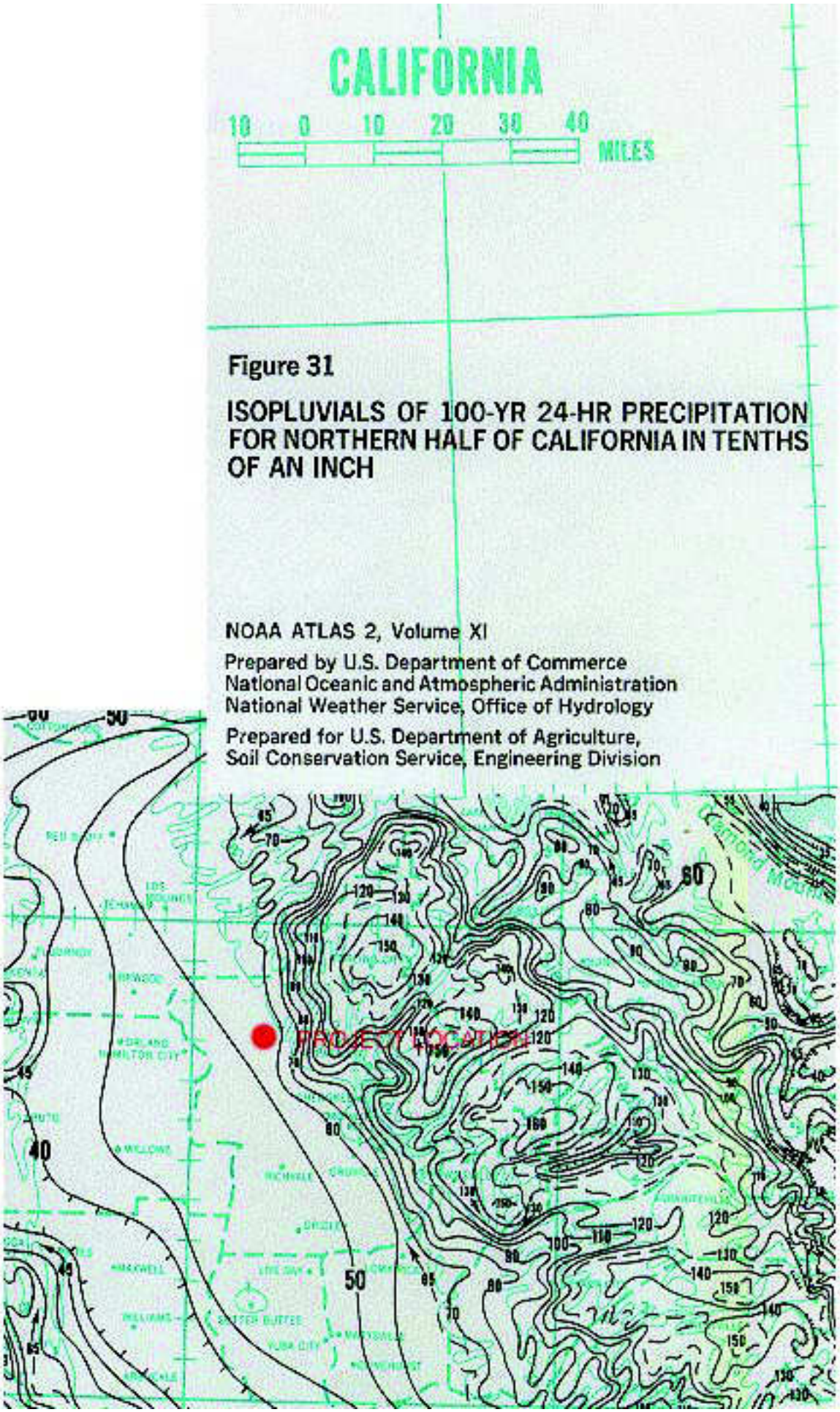


Figure 31

ISOPLUVIALS OF 100-YR 24-HR PRECIPITATION FOR NORTHERN HALF OF CALIFORNIA IN TENTHS OF AN INCH

NOAA ATLAS 2, Volume XI

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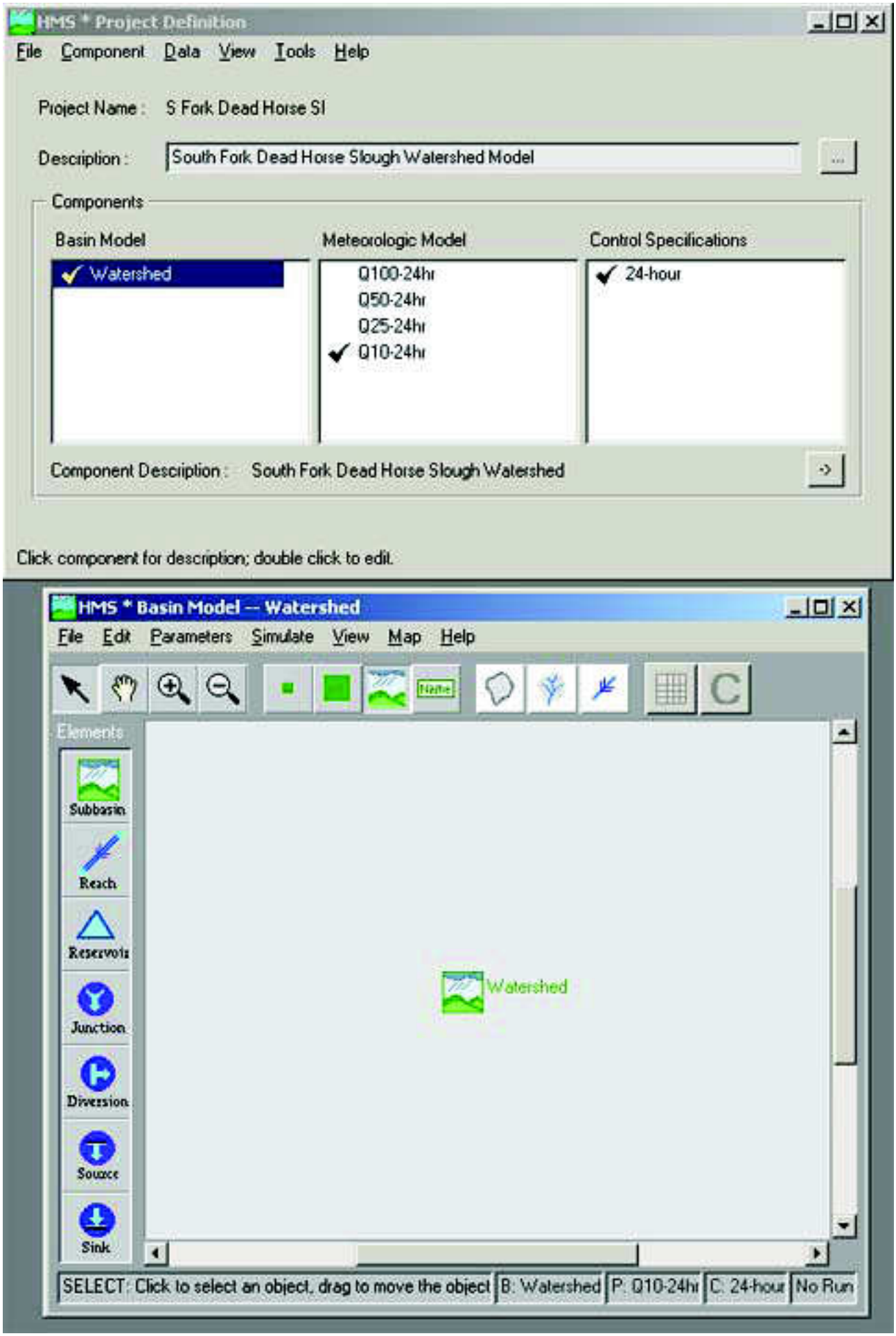
National Weather Service, Office of Hydrology

Prepared for U.S. Department of Agriculture,
Soil Conservation Service, Engineering Division


HMS * Project Definition
File Component Data View Tools Help
Project Name : S Fork Dead Horse Sl
Description : South Fork Dead Horse Slough Watershed Model
Components
Basin Model
Meteorologic Model
Control Specifications
Watershed
Q100-24hr
Q50-24hr
Q25-24hr
Q10-24hr
24-hour
Component Description : South Fork Dead Horse Slough Watershed
Click component for description; double click to edit.
HMS * Basin Model -- Watershed
File Edit Parameters Simulate View Map Help
Elements
Subbasin
Reach
Reservoir
Junction
Diversion
Source
Sink
Watershed
SELECT: Click to select an object, drag to move the object
B: Watershed
P: Q10-24hr
C: 24-hour
No Run

HMS * Basin Model * Subbasin Editor

Help

Subbasin Name : Watershed

Area (sq. mi.) 0.934

Description : South Fork Dead Horse Slough Watershed at SR32 Crossing

...

Loss Rate | Transform | Baseflow Method

Method: Initial/Constant

Initial Loss (in): 0.2

Imperviousness (%) : 10

Constant Rate (in/hr): 0.1

OK | Apply | Cancel

Subbasin name

HMS * Basin Model * Subbasin Editor

Help

Subbasin Name : Watershed

Area (sq. mi.) 0.934

Description : South Fork Dead Horse Slough Watershed at SR32 Crossing

...

Loss Rate | Transform | Baseflow Method

Method: SCS

SCS Lag : 52.200000 Minutes

OK | Apply | Cancel

Subbasin name

HMS * Basin Model * Subbasin Editor

Help

Subbasin Name : Watershed

Area (sq. mi.) 0.934

Description : South Fork Dead Horse Slough Watershed at SR32 Crossing

...

Loss Rate | Transform | Baseflow Method

Method: SCS

SCS Lag : 52.200000 Minutes

OK | Apply | Cancel

Subbasin name

HMS * Meteorologic Model

File Edit Help

Meteorologic Model: Q100-24hr

Subbasin List

Description: South Fork Dead Horse Slough Meterological Model

...

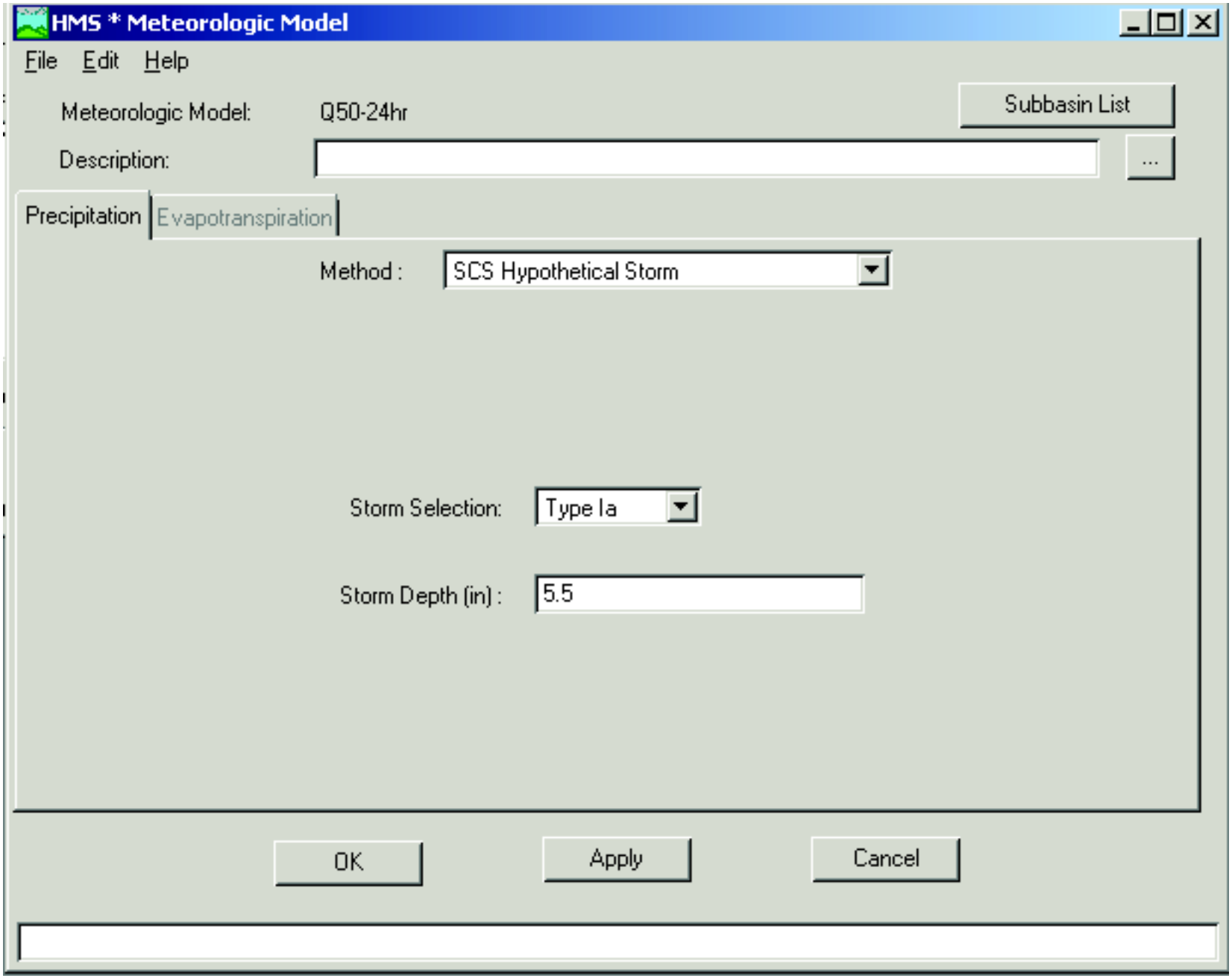
Precipitation | Evapotranspiration

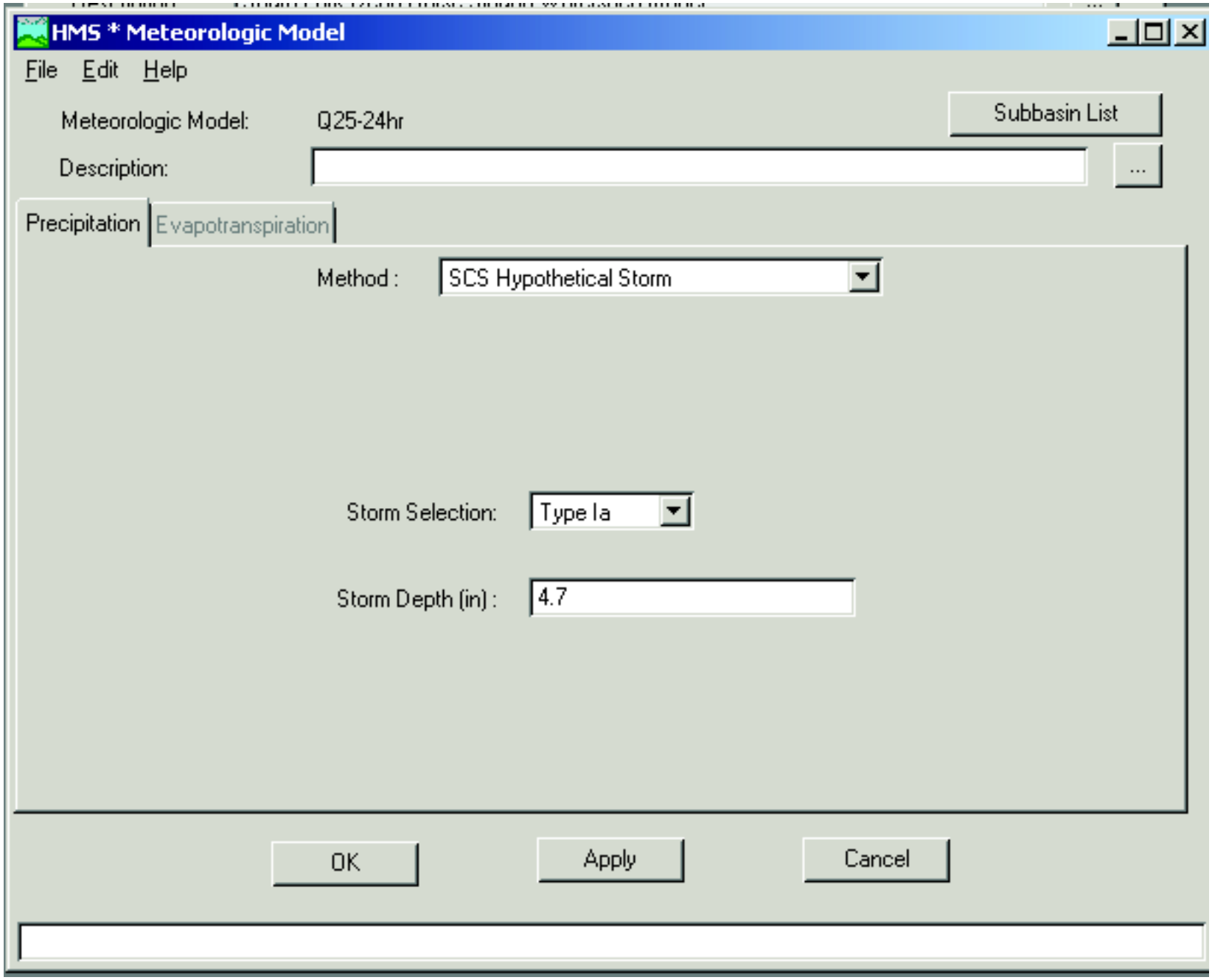
Method : SCS Hypothetical Storm

Storm Selection: Type Ia

Storm Depth (in) : 5.9

OK Apply Cancel


HMS * Meteorologic Model
File
Edit
Help
Meteorologic Model:
Q50-24hr
Subbasin List
Description:
...
Precipitation
Evapotranspiration
Method :
SCS Hypothetical Storm
Storm Selection:
Type Ia
Storm Depth (in) :
5.5
OK
Apply
Cancel


HMS * Meteorologic Model
File
Edit
Help
Meteorologic Model:
Q25-24hr
Subbasin List
Description:
...
Precipitation
Evapotranspiration
Method :
SCS Hypothetical Storm
Storm Selection:
Type Ia
Storm Depth (in) :
4.7
OK
Apply
Cancel

HMS * Meteorologic Model

File Edit Help

Meteorologic Model: Q10-24hr

Subbasin List

Description:

...

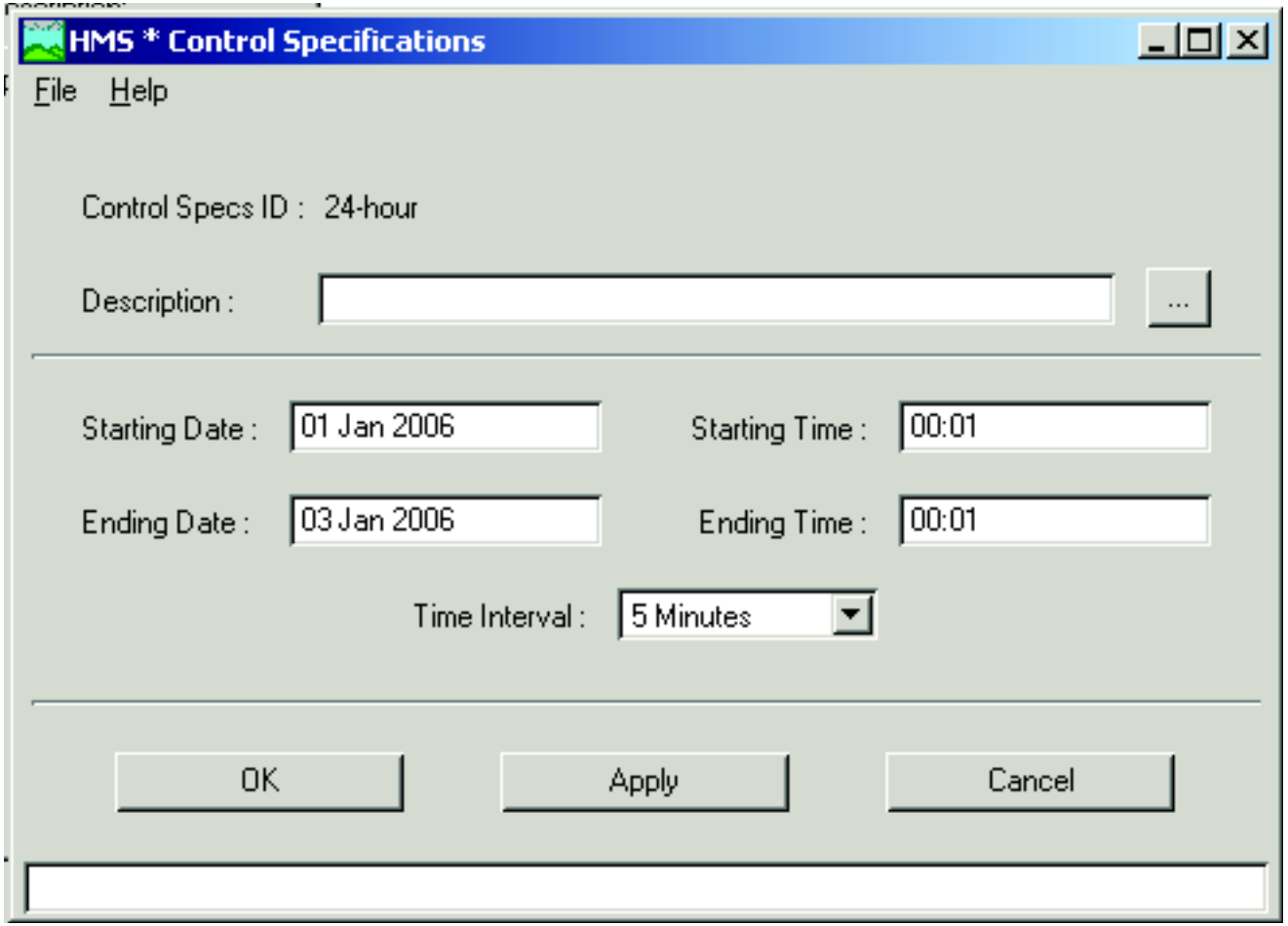
Precipitation | Evapotranspiration

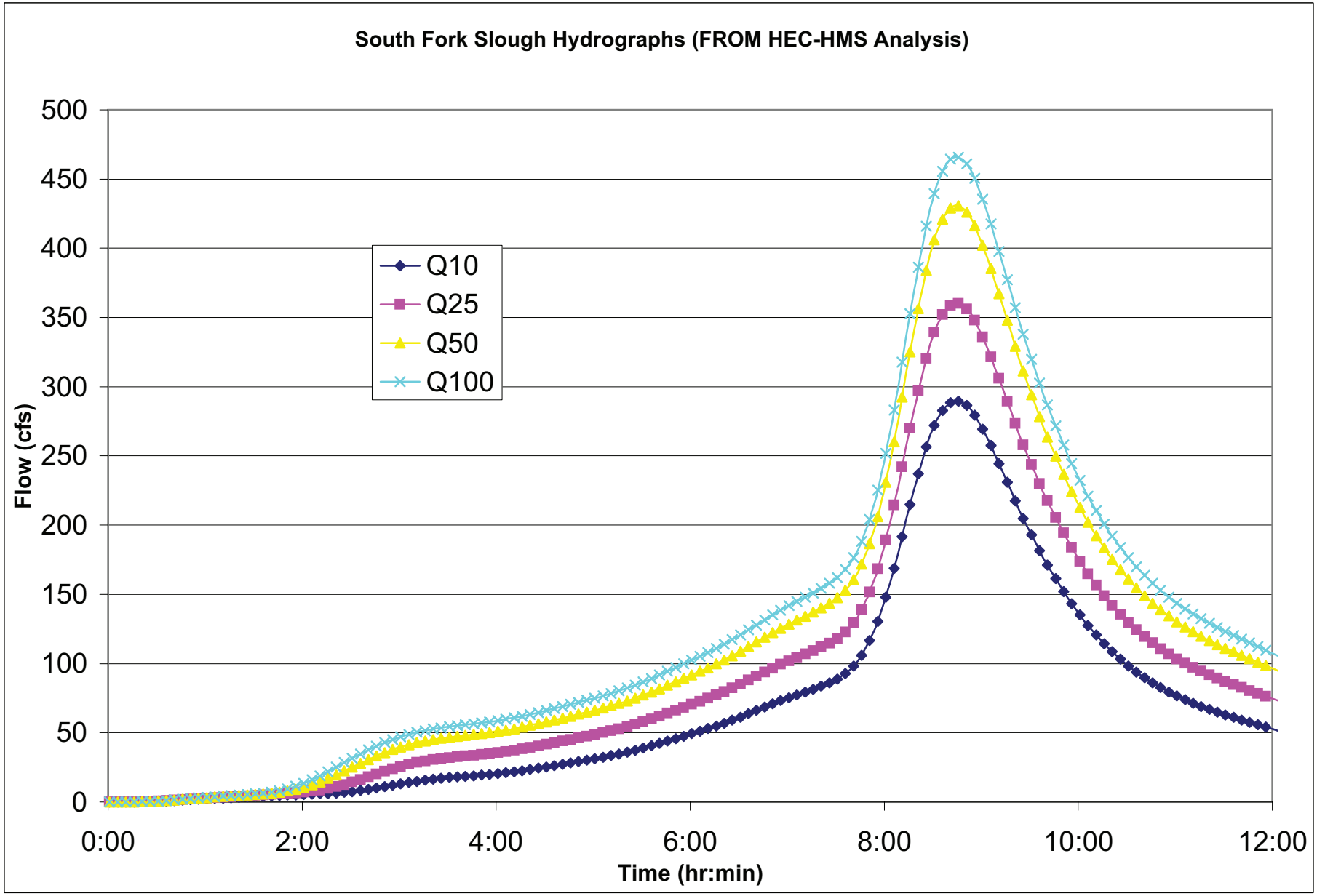
Method : SCS Hypothetical Storm

Storm Selection: Type Ia

Storm Depth (in) : 3.9

OK Apply Cancel


HMS * Control Specifications
File
Help
Control Specs ID : 24-hour
Description :
...
Starting Date :
01 Jan 2006
Starting Time :
00:01
Ending Date :
03 Jan 2006
Ending Time :
00:01
Time Interval :
5 Minutes
OK
Apply
Cancel

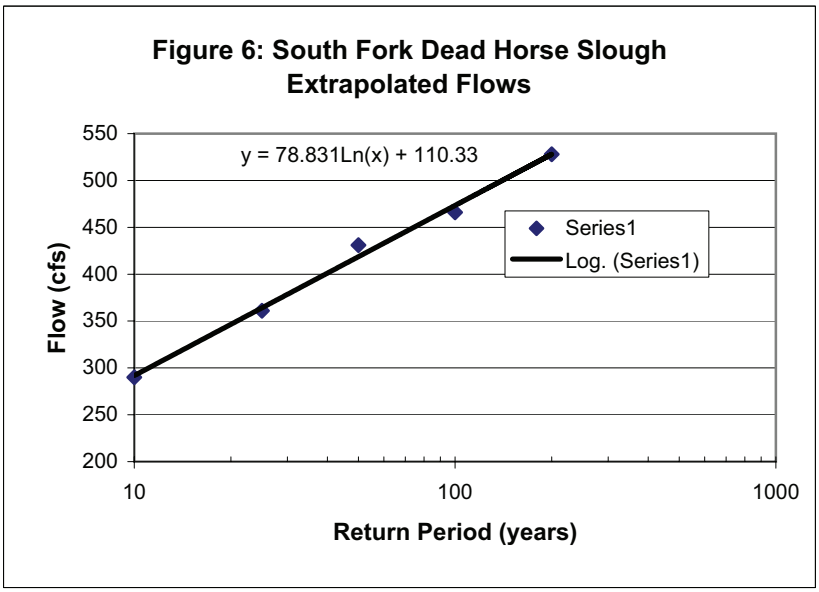

South Fork Slough Hydrographs (FROM HEC-HMS Analysis)
Flow (cfs)
500
450
400
350
300
250
200
150
100
50
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
Time (hr:min)
Q10
Q25
Q50
Q100

P0513: SR 32 Widening
South Fork Dead Horse Slough Flows

From HEC-HMS Analysis

Q200 =	200	528.0017	cfs	(FROM GRAPH)
Q100 =	100	466	cfs	(FROM HEC-HMS model)
Q50 =	50	431	cfs	(FROM HEC-HMS model)
Q25 =	25	361	cfs	(FROM HEC-HMS model)
Q10 =	10	290	cfs	(FROM HEC-HMS model)

Q200 =	200	528.0017	cfs	(FROM GRAPH)



Appendix D FEMA FIRM and FIS

FLOOD INSURANCE STUDY

BUTTE COUNTY, CALIFORNIA
AND INCORPORATED AREAS

COMMUNITY NAME	COMMUNITY NUMBER
BIGGS, CITY OF	060437
BUTTE COUNTY	
(UNINCORPORATED AREAS)	060017
CHICO, CITY OF	060746
GRIDLEY, CITY OF	060019
OROVILLE, CITY OF	060020
PARADISE, TOWN OF[1]	060748

[1]No Special Flood Hazard Areas

Revised:
January 6, 2011

Federal Emergency Management Agency

FLOOD INSURANCE STUDY NUMBER
06007CV000A

Table 3 – Summary of Discharges, continued

Flooding Source and Location	Drainage Area (sq mi)	Peak Discharges (cfs) 10-Percent-Annual-Chance	2-Percent-Annual-Chance	1-Percent-Annual-Chance	0.2-Percent-Annual-Chance
COMANCHE CREEK, continued					
At Union Pacific Railroad	*	400	800	2,100	2,100
Approximately 1,300 feet below Union Pacific Railroad	*	500	900	2,300	2,300
Approximately 1,500 feet above Dayton Road	*	500	900	1,600	1,600
At Lone Pine Road	*	500	900	900	900
Sacramento River Floodplain	*	500	900	1,200	1,200
DEAD HORSE SLOUGH					
At confluence with Little Chico Creek	5.36	750	1,500	1,900	*
HAMLIN SLOUGH					
North Branch at confluence	9.3	523	1,380	1,820	2,640
South Branch at confluence	10.16	741	1,710	2,300	3,290
Hamlin Canyon	33.85	2,300	4,700	6,200	8,650
Hayes Canyon	37.75	2,570	5,210	6,720	9,330
At confluence with Butte Creek	40.12	2,670	5,330	6,830	9,430
KEEFER SLOUGH[1]					
Approximately 1,125 feet downstream of Hicks Lane	0.3	130	400	560	750
Approximately 500 feet upstream of Garner Lane	2.9	275	500	680	850
At State Highway 99[2]	4.4	415	525	525	525
LINDO CHANNEL					
Upstream of confluence with Channel Slough/Sandy Gulch (0.6 miles Downstream of Highway 32)	5.25	*	*	4,600	*
Downstream of Big Chico Creek Diversion Structure	*	*	*	4,000	*
LITTLE CHICO-BUTTE CREEK DIVERSION CHANNEL					
At Diversion Structure	*	700	2,200	3,100	4,900
Approximately 1,500 feet below Warfield	*	800	2,400	3,300	5,200
Approximately 2,000 feet below Skyway	*	1,100	3,000	3,900	6,000

[1]*Drainage area only refers to Keefer Slough local drainage; diversions from Rock Creek are a major source of the listed discharges.*

[2]*See Section 3.1 for an explanation of the reduction in flow.*

**Data not available*

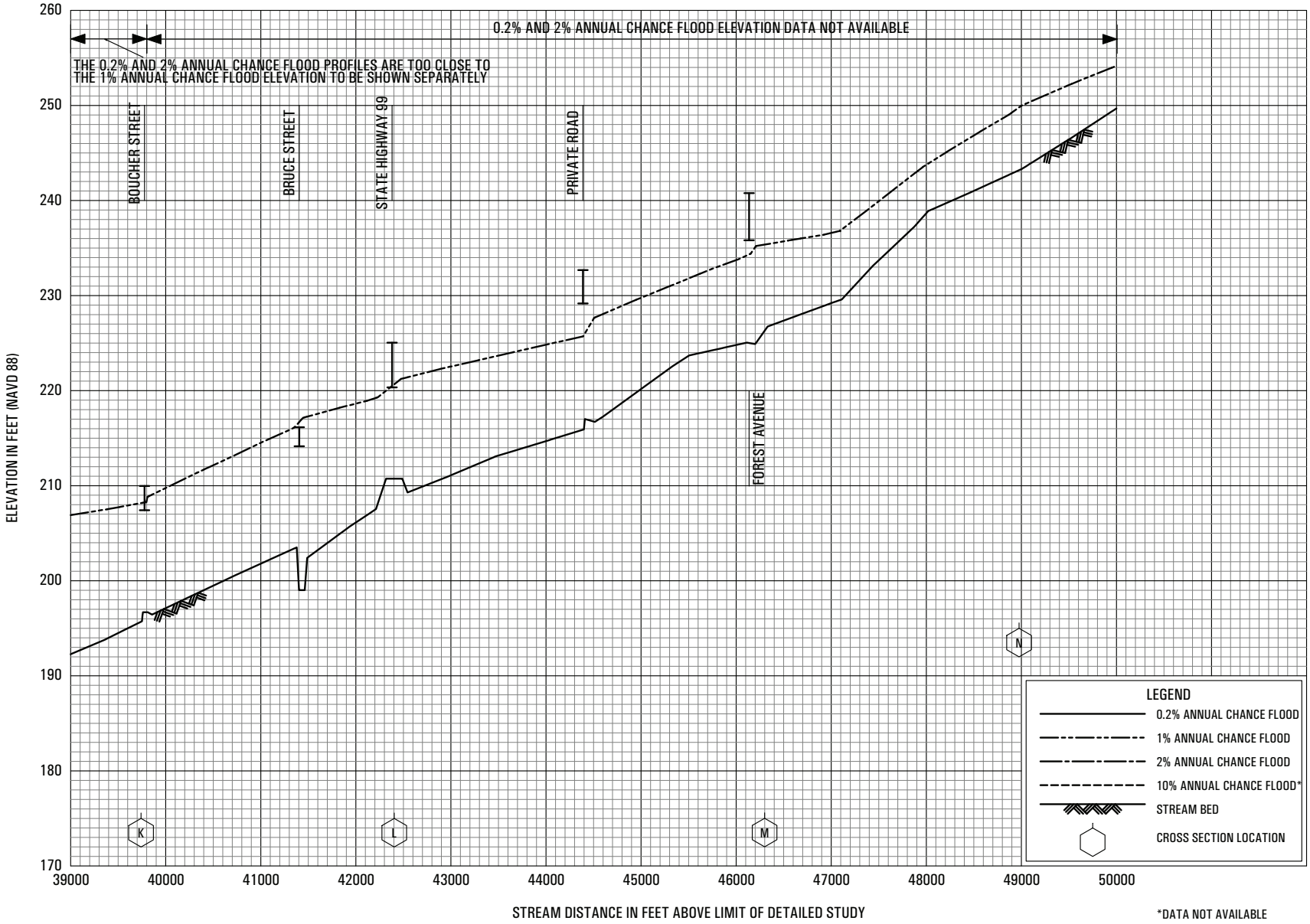
Table 3 – Summary of Discharges, continued

Flooding Source and Location	Drainage Area (sq mi)	Peak Discharges (cfs) 10-Percent-Annual-Chance	2-Percent-Annual-Chance	1-Percent-Annual-Chance	0.2-Percent-Annual-Chance
LITTLE CHICO CREEK					
Below Diversion Structure	*	2,300	4,400	5,600	7,800
At Forest Avenue	*	1,500	2,000	2,200	2,500
At State Highway 99	*	2,100	3,400	3,700	*
Approximately 100 feet above Bruce Street	*	2,100	3,400	3,500	3,700
At Bruce Street	*	2,200	3,100	3,100	3,100
At Mills Street	*	2,200	2,800	2,800	2,800
At Crouch Road	*	2,200	2,500	2,500	2,500
Approximately 3,000 feet below Alberton	*	2,300	2,600	2,600	2,600
Sacramento River Floodplain	*	2,300	2,700	2,700	2,700
MUD CREEK					
Downstream of Confluence with Sycamore Circle	44.89[2]	*	*	10,410	*
At Nord Highway	45.44[2]	*	*	10,700	*
PALERMO TRIBUTARY					
At Baldwin Avenue	1.0	255	355	390	470
Approximately 100 feet downstream of Palermo Road	1.7	500	690	760	920
Approximately 550 feet downstream of South Villa Avenue[1]	1.7	126	126	126	126
At confluence with Wyman Ravine Tributary 1	2.1	500	690	760	920
RUDDY CREEK					
Just upstream of confluence with Ruddy Creek Tributary	0.7	255	350	380	460
Approximately 350 feet upstream of Feather River	1.9	580	790	870	1,050
Entire Reach	0.5	165	220	250	300

[1]*See Section 3.2 for an explanation of the reduction in flow.*

[2]*Includes Big Chico Creek Diversion Channel and Sycamore Creek drainage area.*

**Data not available*



*DATA NOT AVAILABLE

FLOOD PROFILES

LITTLE CHICO CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

BUTTE COUNTY, CA

AND INCORPORATED AREAS

Appendix E Scour Analyses

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Walnut Creek, CA 94596
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SR 32 Widening

Scour Summary - SR 32 Bridge over Dead Horse Slough

Date:	March 16, 2011
Calculations performed by:	Kazuya Tsurushita-WRECO
Calculations checked by:	Chris Sewell -WRECO

	Bridge component	Local Scour	Contraction Scour	Long Term Scour	Total Scour
Left Overbank	Abutment 5	0.00	0.25	0.00	**0.25**
Channel	Bent 4	5.23	0.25	0.00	**5.48**
	Bent 3	6.71	0.25	0.00	**6.96**
	Bent 2	7.09	0.25	0.00	**7.34**
Right Overbank	Abutment 1	2.75	0.25	0.00	**2.99**

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SR 32 Widening

Contraction Scour - Proposed SR 32 Bridge over Dead Horse Slough

Calculation guideline from Hec-18 4th edition
Input from: Outputs from HEC-RAS, version 4.1
As-built plans for bridge

Units = (SI or English)	English	
Ku = constant = 6.19 (SI) or 11.17 (English)	11.17	
g = acceleration due to gravity =	32.174	ft/s^2

Channel

Vchannel = Mean velocity of flow in main channel just upstream of bridge =	5.47	ft/s
D50channel = grain size in channel for which 50% of bed material is finer =	0.000164	ft
Y_o channel = existing depth in the contracted channel section before scour =	4.68	ft
Y_1 channel = depth of flow just upstream of bridge in channel =	4.62	ft
VcD50channel = Ku*(Ychannel^(1/6))*(D50channel^(1/3))	0.7891	ft/s
Contraction scour equation for channel =	**Live Bed Equation**	

Live Bed Equation

Q1 channel = Flow in the upstream channel transporting sediment =	1900	ft^3/s
Q2 channel = Flow in the contracted channel = transporting sediment =	1900	ft^3/s
W1 channel = bottom width of the upstream channel that is transporting bed material =	75.12	ft
W2 channel = bottom width of the contracted channel section less pier widths =	68.42	ft
ω channel = fall velocity of bed material based on D50 =	0.0094	ft/s
S channel = slope of energy grade line in main channel =	0.002277	ft/ft
V* channel = shear velocity in the upstream channel section = (Ychannel*g*S channel)^.5 =	0.5818	ft/s
V* channel/ω channel =	61.8910	
k1 channel = (if V*/ω <0.5, 0.59, if(0.5<=V*/ω<=2,0.64,0.69)) =	0.69	
Y2channel = average depth in contracted section after scour = Ychannel*((Q2 channel/Q1 channel)^(6/7))*((W1 channel/W2 channel)^k1 channel) =	4.9276	ft
Ys channel = Y2 channel - Yo channel =	**0.25**	**ft**

Clear Water Equation

Ku = constant = 0.0077 (English) or 0.025 (SI) =	0.0077	
Q = Discharge through bridge associated with the width W =		ft^3/s
Dm = Diameter of the smallest non transportable particle in the bed material in contracted section = 1.25*d50 =	0.000205	ft
W = Bottom width of contracted section less pier widths =		ft
Y2channel = average depth in contracted section after scour = ((Ku*(Q^2))/((Dm^(2/3))*(W^2)))^(3/7) =	n/a	ft
Ys channel = Y2 channel - Yo channel =	**n/a**	**ft**

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SR32 Widening

Local Scour - Proposed SR32 Bridge over Dead Hourse Slough, Bent

Calculation guideline from Hec-18 4th edition
Input from: Outputs from HEC-RAS, version 4.1
As-built plans for bridge

Units = (SI or English) =	English	

Pier Scour component

f = distance between front edge of cap/footing and pier = (enter	n/a	ft
ho = height of pile cap above bed at beginning of computation (negative indicates partially or entirely submerged pile cap) (enter	n/a	ft
a = pier width =	4	ft
S = spacing between columns of piles, center to center =	0	ft
T = thickness of pile cap or footing (enter n/a for no pile cap) =	n/a	ft
h1 = ho+T=height of the pier stem above the bed before scour =	n/a	ft
y1 = Approach flow depth at the beginning of computations =	3.05	ft
V1 = Approach velocity used at the beginning of computations =	3.69	ft/s
Khpier = coefficient to account for the height of the pier stem above the bed and the shielding effect by the pile cap overhang distance "f" in front of the pier stem = (0.4075 - 0.0669*(f/apier)) - (0.4271 - 0.0778*(f/apier))*h1/apier + (0.1615 - 0.0455*(f/apier))*((h1/apier)^2) - (0.0269-0.012*(f/apier))*((h1/apier)^3) = (if >1 then Khpier = 1) =	1.0000	
K1 = correction factor for pier nose shape =	1	
Θ = angle of attack of flow =	0	degrees
L = length of pier =	111	ft
K2 = correction factor for angle of attack = (cosΘ+(L/a)*sinΘ)^0.65	1	
K3 = correction factor for bed condition =	1.1	
D50 = grain size for which 50% of bed material is finer =	0.000164	ft
D90 = grain size for which 90% of bed material is finer =	0.006562	ft
Ku = constant = 6.19 (SI) or 11.17 (English)	11.17	
VcD50 = Ku*(y1^(1/6))*(D50^(1/3))	0.7364	ft/s
VcD90 = Ku*(y1^(1/6))*(D90^(1/3))	2.5183	ft/s
VicD50 = the approach velocity required to initiate scour at the pier for grain size D50 = 0.645*((D50/a)^0.053)*VcD50	0.2781	ft/s
VicD90 = the approach velocity required to initiate scour at the pier for grain size D90 = 0.645*((D90/a)^0.053)*VcD90	1.1563	ft/s
VR = (V1-VicD50)/(VcD50-VicD90)>0 =	-8.1253	ft
K4 = correction factor for armoring by bed material = 0.4*((VR)^.15 > 0.4 =	1.0000	
g = acceleration due to gravity =	32.174	ft/s^2
Yspier = scour component for the pier stem in the flow = y1*(Khpier*(2*K1*K2*K3*K4*((a/y1)^0.65)*((V1/((g*y1)^0.5))^0.43)) =	**5.23**	**ft**

Total Scour

Ys = Yspier + Yspc + Yspg = total scour from superposition of components =	**5.23**	**ft**

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Fax: 925.941.0018
www.wreco.com

SR32 Widening

Local Scour - Proposed SR32 Bridge over Dead Hourse Slough, Bent

Calculation guideline from Hec-18 4th edition
Input from: Outputs from HEC-RAS, version 4.1
As-built plans for bridge

Units = (SI or English) =	English	

Pier Scour component

f = distance between front edge of cap/footing and pier = (enter	n/a	ft
ho = height of pile cap above bed at beginning of computation (negative indicates partially or entirely submerged pile cap) (enter	n/a	ft
a = pier width =	4	ft
S = spacing between columns of piles, center to center =	0	ft
T = thickness of pile cap or footing (enter n/a for no pile cap) =	n/a	ft
h1 = ho+T=height of the pier stem above the bed before scour =	n/a	ft
y1 = Approach flow depth at the beginning of computations =	5.26	ft
V1 = Approach velocity used at the beginning of computations =	5.54	ft/s
Khpier = coefficient to account for the height of the pier stem above the bed and the shielding effect by the pile cap overhang distance "f" in front of the pier stem = (0.4075 - 0.0669*(f/apier)) - (0.4271 - 0.0778*(f/apier))*h1/apier + (0.1615 - 0.0455*	1.0000	
K1 = correction factor for pier nose shape =	1	
Θ = angle of attack of flow =	0	degrees
L = length of pier =	111	ft
K2 = correction factor for angle of attack = (cosΘ+(L/a)*sinΘ)^0.65	1	
K3 = correction factor for bed condition =	1.1	
D50 = grain size for which 50% of bed material is finer =	0.000164	ft
D95 = grain size for which 95% of bed material is finer =	0.006562	ft
Ku = constant = 6.19 (SI) or 11.17 (English)	11.17	
VcD50 = Ku*(y1^(1/6))*(D50^(1/3))	0.8064	ft/s
VcD95 = Ku*(y1^(1/6))*(D95^(1/3))	2.7578	ft/s
VicD50 = the approach velocity required to initiate scour at the pier for grain size D50 = 0.645*((D50/a)^0.053)*VcD50	0.3045	ft/s
VicD95 = the approach velocity required to initiate scour at the pier for grain size D95 = 0.645*((D95/a)^0.053)*VcD95	1.2662	ft/s
VR = (V1-VicD50)/(VcD50-VicD95)>0 =	-11.3854	ft
K4 = correction factor for armoring by bed material = 0.4*((VR)^.15 > 0.4 =	1.0000	
g = acceleration due to gravity =	32.174	ft/s^2
Yspier = scour component for the pier stem in the flow = y1*(Khpier*(2*K1*K2*K3*K4*((a/y1)^0.65)*((V1/((g*y1)^0.5))^0.43)) =	**6.71**	**ft**

Total Scour

Ys = Yspier + Yspc + Yspg = total scour from superposition of components =	**6.71**	**ft**

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SR32 Widening

Local Scour - Proposed SR32 Bridge over Dead Hourse Slough, Bent

Calculation guideline from Hec-18 4th edition
Input from: Outputs from HEC-RAS, version 4.1
As-built plans for bridge

Units = (SI or English) =	English	

Pier Scour component

f = distance between front edge of cap/footing and pier = (enter	n/a	ft
ho = height of pile cap above bed at beginning of computation (negative indicates partially or entirely submerged pile cap) (enter	n/a	ft
a = pier width =	4	ft
S = spacing between columns of piles, center to center =	0	ft
T = thickness of pile cap or footing (enter n/a for no pile cap) =	n/a	ft
h1 = ho+T=height of the pier stem above the bed before scour =	n/a	ft
y1 = Approach flow depth at the beginning of computations =	6.15	ft
V1 = Approach velocity used at the beginning of computations =	6	ft/s
Khpier = coefficient to account for the height of the pier stem above the bed and the shielding effect by the pile cap overhang distance "f" in front of the pier stem = (0.4075 - 0.0669*(f/apier)) - (0.4271 - 0.0778*(f/apier))*h1/apier + (0.1615 - 0.0455*	1.0000	
K1 = correction factor for pier nose shape =	1	
Θ = angle of attack of flow =	0	degrees
L = length of pier =	111	ft
K2 = correction factor for angle of attack = (cosΘ+(L/a)*sinΘ)^0.65	1	
K3 = correction factor for bed condition =	1.1	
D50 = grain size for which 50% of bed material is finer =	0.000164	ft
D95 = grain size for which 95% of bed material is finer =	0.006562	ft
Ku = constant = 6.19 (SI) or 11.17 (English)	11.17	
VcD50 = Ku*(y1^(1/6))*(D50^(1/3))	0.8277	ft/s
VcD95 = Ku*(y1^(1/6))*(D95^(1/3))	2.8305	ft/s
VicD50 = the approach velocity required to initiate scour at the pier for grain size D50 = 0.645*((D50/a)^0.053)*VcD50	0.3125	ft/s
VicD95 = the approach velocity required to initiate scour at the pier for grain size D95 = 0.645*((D95/a)^0.053)*VcD95	1.2996	ft/s
VR = (V1-VicD50)/(VcD50-VicD95)>0 =	-12.0502	ft
K4 = correction factor for armoring by bed material = 0.4*((VR)^.15 > 0.4 =	1.0000	
g = acceleration due to gravity =	32.174	ft/s^2
Yspier = scour component for the pier stem in the flow = y1*(Khpier*(2*K1*K2*K3*K4*((a/y1)^0.65)*((V1/((g*y1)^0.5))^0.43)) =	**7.09**	**ft**

Total Scour

Ys = Yspier + Yspc + Yspg = total scour from superposition of components =	**7.09**	**ft**

1243 Alpine Road, Suite 108
Walnut Creek, CA 94596
Phone: 925.941.0017
Fax: 925.941.0018
www.wreco.com

P0746 - SR32 Widening at Dead Horse Slough

Local Scour - Proposed SR32 Bridge over Dead Hourse Slough - Abutments

Calculation guideline from HEC-18 4th edition
Input from: Outputs from HEC-RAS, version 4.1
As-built plans for bridge

Units = (SI or English)	English	
g = acceleration due to gravity =	32.174	ft/s^2

Left Overbank - Abutment 5

y1 = depth of flow at abutment on the overbank or in the main channel =	0	ft
L = length of embankment projected normal to flow =	0	ft
Ratio of projected embankment length to flow depth = L/y1 =	N/A	
Abutment scour equation to be used =	N/A	

Froehlich's Live Bed Abutment Scour Equation

L' = length of active flow obstructed by the embankment =	0	ft
Ae = flow area of the approach cross section obstructed by the embankment =	0	ft^2
ya = average depth of flow on the flood plain = ae/L	N/A	ft
Qe = flow obstructed by the abutment and approach embankment =	0	ft^3/s
Ve = flow velocity = Qe/Ae =	N/A	ft/s
Fr = Froude Number of approach flow upstream of the	N/A	
Θ = abutment skew =	90	degrees
K1 = coefficient for abutment shape =	1	
K2 = coefficient for angle of embankment shape = (Θ/90)^0.13 =	N/A	
Ys = abutment scour = ya*(2.27*k1*k2*((L'/ya)^0.43)*(Fr^0.61)+1) =	**N/A**	**ft**

HIRE Live Bed Abutment Scour Equation

V = velocity of flow at upstream face of abutment =	0.71	ft/s
Fr = Froude Number = V/((g*y1)^.5) =	N/A	
Θ = abutment skew =	90	degrees
K1 = coefficient for abutment shape =	1	
K2 = coefficient for angle of embankment shape = (Θ/90)^0.13 =	N/A	
Ys = abutment scour = y1*(4*(Fr^0.33)*(K1/0.55)*K2) =	**N/A**	**ft**

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Calculation guideline from HEC-18 4th edition
Input from: Outputs from HEC-RAS, version 4.1
As-built plans for bridge

Units = (SI or English)	English	
g = acceleration due to gravity =	32.174	ft/s^2

Right Overbank - Abutment 1

y1 = depth of flow at abutment on the overbank or in the main channel =	0.59	ft
L = length of embankment projected normal to flow =	2.43	ft
Ratio of projected embankment length to flow depth =	4.119	
Abutment scour equation to be used =	Froehlich	

Froehlich's Live Bed Abutment Scour Equation

L' = length of active flow obstructed by the embankment =	2.43	ft
Ae = flow area of the approach cross section obstructed by the embankment =	2.58	ft^2
ya = average depth of flow on the flood plain = ae/L	1.06	ft
Qe = flow obstructed by the abutment and approach embankment =	4.68	ft^3/s
Ve = flow velocity = Qe/Ae =	1.813953	ft/s
Fr = Froude Number of approach flow upstream of the	0.310361	
Θ = abutment skew =	90	degrees
K1 = coefficient for abutment shape =	1	
K2 = coefficient for angle of embankment shape = (Θ/90)^0.13 =	1	
Ys = abutment scour = ya*(2.27*k1*k2*((L'/ya)^0.43)*(Fr^0.61)+1) =	**2.75**	**ft**

HIRE Live Bed Abutment Scour Equation

V = velocity of flow at upstream face of abutment =	1.01	ft/s
Fr = Froude Number = V/((g*y1)^.5) =	n/a	
Θ = abutment skew =	90	degrees
K1 = coefficient for abutment shape =	1	
K2 = coefficient for angle of embankment shape = (Θ/90)^0.13 =	n/a	
Ys = abutment scour = y1*(4*(Fr^0.33)*(K1/0.55)*K2) =	**n/a**	**ft**

Appendix F Scour Countermeasures

Table 873.3B
Rock Slope Protection Design Guide

Mean Stream Velocity V_M	PARALLEL FLOW ALONG TANGENT BANK					IMPINGEMENT FLOW AGAINST CURVED BANK				
	Bank Velocity V_A	Minimum Stone W	Protection Class W_C	Placement Method	Section Thickness T	Bank Velocity VB	Minimum Stone W	Protection Class W_C	Placement Method	Section Thickness T
fps	fps	lb		A or B	ft	fps	lb or T		A or B	ft
4.5	3		None			6	3 lb	None		
6	4		None			8	15	Facing	B	1.8
7.5	5	1	None			10	57	1/4 ton	B	3.3
9	6	3	None			12	170	1/4 ton	B	3.3
10.5	7	7	Facing	B	1.8	14	430	1/2 ton	A	3.3
									B	4.2
12	8	15	Facing	B	1.8	16	950	1 ton	A	4.2
									B	5.3
13.5	9	30	Light	B	2.5	18	1.0 T	2 ton	A	5.3
15	10	57	1/4 ton	B	3.3	20	1.8	4 ton	A	6.7
18	12	170	1/4 ton	B	3.3	24	5.5	8 ton	A	8.3
21	14	430	1/2 ton	A	3.3	28	13.7	Special		
				B	4.2					
24	16	950	1 ton	A	4.2	32	30.4	Special		
				B	5.3					

NOTES:

1. **All Values in Figure 873.3A and Table 873.3B are in U.S. Customary Units. Conversions to the S.I. System are; 1 ft. = 0.305 m**
   1 lb. = 0.454 kg
   1 ton = 0.907 tonne
2. See Section 72 of the Standard Specifications for Gradations of the Protection Classes (W_C) indicated.

Index 873.3(2)(a)(2)(b) "Design Height." For depth of toe, the estimated scour was given as 5.5 feet. This is the minimum toe depth to be considered. Again, based on site conditions and discussions with maintenance staff and others, determine if any long-term conditions need to be addressed. These could include streambed degradation due to local aggregate mining or headcutting. Regardless of the condition, the toe must be founded below the lowest anticipated elevation that could become exposed over the service life of the embankment or roadway facility. As for the upstream and downstream ends, the given length of revetment is 500 feet. Again, this will typically be a minimum, as the designer should seek natural rock outcroppings, areas of quiescent stream flow, or other inherently stable bank segments to end the RSP, see Figure 873.3D for example at ocean shore location.

Table 873.3B
California Layered RSP

Outsider Layer RSP-Class *	Inner Layers RSP-Class *	Backing Class No. *	RSP-Fabric Type **
8 T	2 T over ½ T	1	B
8 T	1 T over ¼ T	1 or 2	B
4 T	½ T	1	B
4 T	1 T over ¼ T	1 or 2	B
2 T	½ T	1	B
2 T	¼ T	1 or 2	B
1 T	Light	None	B
1 T	¼ T	1 or 2	B
½ T	None	1	B
¼ T	None	1 or 2	A
Light	None	None	A
Backing No.1 ***	None	None	A

* Rock grading and quality requirements per Section 72-2.02 Materials of the Caltrans Standard Specifications.

** RSP-fabric Type of geotextile and quality requirements per Section 88-1.04 Rock Slope Protection Fabric of the Caltrans Standard Specifications. Type A RSP-fabric has lower weight per unit area and it also has lower toughness (tensile x elongation, both at break) than Type B RSP-fabric.

*** "Facing" RSP-Class has same gradation as Backing No. 1.

Table 873.3A
Guide for Determining RSP-Class of Outside Layer

Standard Rock MASS	GRADING OF ROCK SLOPE PROTECTION PERCENTAGE LARGER THAN												
	RSP-Classes [A]												
	Method A Placement						Method B Placement						
	RSP-Classes other than Backing									Backing No.			
SI Unit	8 T	4 T	2 T	1 T	1/2 T	1 T	1/2 T	1/4 T	Light	1	2	3
16 ton	0-5											
8 ton	50-100	0-5										
4 ton	95-100	50-100	0-5									
2 ton		95-100	50-100	0-5		0-5						
1 ton			95-100	50-100	0-5	50-100	0-5					
1/2 ton				95-100	50-100	-----	50-100	0-5				
1/4 ton					95-100	95-100	-----	50-100	0-5			
200 lb							95-100	-----	50-100	0-5		
75 lb								95-100	-----	50-100	0-5	
25 lb									95-100	90-100	25-75	0-5
5 lb											90-100	25-75
1 lb												90-100

[A] “Facing” has same gradation as “Backing No. 1”. To conserve space “Facing” is not shown.