

# Preliminary Existing Condition Stability, Seepage and Settlement Evaluation

## Sacramento River and Georgiana Slough East Levees

Community of East Walnut Grove, California

California Department of Water Resources Small  
Community Flood Risk Reduction Program

August 2020

Prepared for:



2868 Prospect Park Drive, Suite 400  
Rancho Cordova, CA 95670



Prepared by:



2491 Boatman Avenue  
West Sacramento, CA 95722  
(916) 375-8706

West Sacramento Office:  
2491 Boatman Ave  
West Sacramento, CA 95691  
(916) 375-8706



Auburn (530) 887-1494  
Fresno (559) 438-8411

Blackburn File No. 3139.x  
August 3, 2020

Mr. Jeff Twitchell, P.E.  
Senior Consultant  
GEI Consultants, Inc.  
2868 Prospect Park Drive, Suite 400  
Rancho Cordova, CA 95670

**Subject: PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION**  
**SACRAMENTO RIVER AND GEORGINA SLOUGH EAST LEVEES**  
**Community of East Walnut Grove, California**  
California Department of Water Resources Small Community Flood Risk Reduction Program

Dear Mr. Twitchell,

At your request, Blackburn Consulting (Blackburn) prepared this Preliminary Existing Condition Stability, Seepage and Settlement Evaluation (Evaluation) for the Sacramento River and Georgiana Slough East Levees adjacent to the Community of East Walnut Grove (East Walnut Grove). This Evaluation supports GEI Consultants' overall evaluation of East Walnut Grove's flood control protection as part of the California Department of Water Resources (DWR) Small Community Flood Risk Reduction Program. Blackburn prepared this Evaluation in accordance with our Subconsultant Agreement with GEI Consultant (GEI) and approval of additional budget on March 17, 2020 by GEI.

Please call if you have questions or require additional information.

Sincerely,

**BLACKBURN CONSULTING**

Prepared by:

Daniel Contreras, P.E.  
Project Engineer

Reviewed by:



Robert B. Lokteff, P.E., G.E.  
Principal Geotechnical Engineer

Copies: 1 to Addressee (PDF)

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



## **TABLE OF CONTENTS**

<b>1</b>	<b>INTRODUCTION .....</b>	<b>1</b>
1.1	Purpose of This Evaluation .....	1
1.2	East Walnut Grove Levee System, Segment 128, and Stationing .....	1
<b>2</b>	<b>SEGMENT 128 CONSTRUCTION HISTORY AND IMPROVEMENTS .....</b>	<b>2</b>
<b>3</b>	<b>SEGMENT 128 PAST PERFORMANCE .....</b>	<b>3</b>
<b>4</b>	<b>REACH DETERMINATION .....</b>	<b>3</b>
<b>5</b>	<b>CURRENT SEGMENT 128 CONDITIONS .....</b>	<b>3</b>
5.1	Geometry.....	3
5.2	Roads and Storefronts.....	4
5.3	Vegetation .....	4
5.4	Erosion, Penetrations and Encroachments .....	7
<b>6</b>	<b>SUBSURFACE SOIL AND GROUNDWATER CONDITIONS.....</b>	<b>7</b>
6.1	Geology.....	7
6.1.1	Regional Geology .....	7
6.1.2	Local Geology and Geomorphology.....	8
6.2	Existing Subsurface Explorations .....	8
6.3	Existing Laboratory Test Results.....	9
6.4	Ground Water.....	9
6.5	Geophysical Evaluations .....	9
<b>7</b>	<b>CROSS-SECTION DEVELOPMENT .....</b>	<b>10</b>
<b>8</b>	<b>DESIGN PARAMETER SELECTION.....</b>	<b>12</b>
8.1	Unit Weight .....	12
8.2	Strength and Hydraulic Conductivity Parameter.....	12
<b>9</b>	<b>EVALUATION WATER SURFACE ELEVATION.....</b>	<b>13</b>
<b>10</b>	<b>GEOTECHNICAL ANALYSIS GUIDANCE DOCUMENTS and CRITERIA .....</b>	<b>13</b>
10.1	Seepage and Slope Stability Criteria Guidance Documents .....	13
10.2	Steady-State Seepage Criteria.....	13
10.2.1	Underseepage .....	13
10.2.2	Through Seepage.....	14
10.3	Slope Stability Criteria .....	14
<b>11</b>	<b>UNDERSEEPAGE EVALUATION .....</b>	<b>14</b>
11.1	Analysis Procedure .....	14

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



11.2	Analysis Results .....	15
11.3	Underseepage Conclusions .....	15
<b>12</b>	<b>THROUGH-SEEPAGE EVALUATION .....</b>	<b>15</b>
12.1	Analysis Procedure .....	15
12.2	Analysis Results and Conclusions .....	16
<b>13</b>	<b>SLOPE STABILITY EVALUATION .....</b>	<b>18</b>
13.1	Steady-State Condition Analysis .....	18
13.1.1	Analysis Procedure .....	18
13.1.2	Analysis Results .....	18
13.1.3	Steady-State Slope Stability Conclusions.....	19
13.2	Rapid Drawdown Condition Analysis .....	19
13.2.1	Analysis Procedure .....	19
13.2.2	Analysis Results .....	20
13.2.3	Rapid Drawdown Slope Stability Conclusions .....	20
13.3	Non-Rapid Drawdown Water-Side Slope Stability .....	20
13.3.1	Analysis Procedure .....	20
13.3.2	Analysis Results .....	21
13.3.3	Waterside Slope Stability Conclusions .....	21
13.4	Seismic Slope Stability Analysis.....	21
13.4.1	Site Seismicity .....	22
13.4.2	Liquefaction .....	23
13.4.3	Seismic Slope Stability Conclusions .....	24
<b>14</b>	<b>SETTLEMENT EVALUATION .....</b>	<b>24</b>
<b>15</b>	<b>SUMMARY.....</b>	<b>24</b>
<b>16</b>	<b>RECOMMENDATIONS FOR ADDITIONAL EVALUATIONS .....</b>	<b>25</b>
16.1	Subsurface investigations.....	25
16.2	Laboratory Testing .....	26
16.3	Updated Hydrology .....	26
16.4	Updated Bathymetry.....	26
16.5	Geophysical Survey .....	27
<b>17</b>	<b>LIMITATIONS .....</b>	<b>27</b>
<b>18</b>	<b>REFERENCES .....</b>	<b>27</b>

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



## **TABLE OF CONTENTS (cont.)**

### **TABLES**

Table 1: Hydraulic Conductivity Values Used in This Evaluation

Table 2: Strength Values Used in This Evaluation

### **FIGURES**

Figure 1: Project Vicinity Map

Figure 2: Site Map

Figure 3: Existing Explorations

Figure 4: Levee History and Improvements

Figure 5: Past Performance Issues

Figure 6: Proposed Explorations for Further Analysis

### **APPENDIX A**

Raney Plan and Profile

Historic Boring Logs, Cone Penetrometer Tests, and LOTBs

### **APPENDIX B**

Historic Laboratory

### **APPENDIX C**

NULE GAR Segment 128

NULE Geomorphology Technical Memorandum

### **APPENDIX D**

RD 554 5-Year Plan with Appendices

### **APPENDIX E**

Seepage and Slope Stability Evaluations by Blackburn

### **APPENDIX F**

Seismic Evaluation by Blackburn

## **1 INTRODUCTION**

### **1.1 Purpose of This Evaluation**

This Preliminary Existing Condition Stability, Seepage and Settlement Evaluation (Evaluation) presents a summary of Blackburn Consulting's (Blackburn's) preliminary evaluation of the Sacramento River and Georgiana Slough East Levees adjacent to the Community of East Walnut Grove (East Walnut Grove). The purpose of this Evaluation is to advance the knowledge of the current condition of these State Plan of Flood Control (SPFC) or Project levees relative to under and through seepage, slope stability, and settlement potential so that the potential for Federal Emergency Management Agency (FEMA) certification can be assessed by GEI Consultants (GEI) and Sacramento County. This evaluation is limited to the Sacramento River and Georgiana Slough East (SPFC) Levees adjacent to the west side of East Walnut Grove, south of the Delta Cross Channel. It does not address potential deficiencies of other non-SPFC levees surrounding the community or impacts potential deficiencies in those levees may have on the levees covered in this evaluation. We understand that the other levees will be evaluated by Raney Geotechnical.

This Evaluation is preliminary because it is based on limited geotechnical data. Additional subsurface exploration, laboratory tests and engineering analysis are needed to provide final conclusions regarding potential levee deficiencies and mitigation alternatives analysis. These additional services are described later in this Evaluation.

### **1.2 East Walnut Grove Levee System, Segment 128, and Stationing**

The community of East Walnut Grove is in the Sacramento Delta within Reclamation District 554 (RD 554). The community is surrounded by levees. The California Department of Water Resources (DWR), Non-Urban Levee Evaluation (NULE) numbered the levee segments surrounding East Walnut Grove as follows:

- NULE Segment 128 is an SPFC levee along the left banks of the Sacramento River and Georgiana Slough (west boundary of East Walnut Grove).
- NULE Segment 1052 is a non-SPFC levee along the right bank of the Delta Cross Channel (North boundary of East Walnut Grove).
- NULE Segment 1051 is a non-SPFC levee along the right bank of Snodgrass Slough (East boundary of East Walnut Grove), and
- The “dry cross levee” is a non SPFC levee that follows the Old Walnut Grove–Thornton Road alignment and connects Segment 128 to Segment 1051 along the south boundary of East Walnut Grove. The NULE project did not evaluate the dry cross levee, therefore it does not have a segment number.

This Evaluation is for Segment 128 that extends along the Sacramento River and Georgiana Slough left/east banks. A Project Vicinity Map showing the location of RD 554 is included as Figure 1. The location of the levee segments listed above are shown on Figure 2.

The Segment 128 levees extend along the left (east) bank of the Sacramento River from the confluence of the Sacramento River and the Delta Cross Channel southward, downstream to the divergence of the Sacramento River and Georgiana Slough. The levee segment continues south and downstream along the left (east) bank of Georgiana Slough for approximately 1500'. Segment 128 is approximately 0.9 miles long (0.6 miles along the Sacramento River and 0.3 miles along Georgiana Slough).

Stationing used in this Evaluation is based on stationing used in the Reclamation District 554 Five-Year Plan, September 2012. The stationing begins at the intersection of NULE Segment 128 and the dry cross levee and runs clockwise around RD 554. Segment 128 begins downstream at Station 0+00 and ends upstream at approximate Station 46+58. Existing levee condition and geotechnical information used in this Evaluation are primarily from the DWR NULE, which assessed the existing conditions of State Plan of Flood Control (SPFC) levees protecting populations of fewer than 10,000 people and non-SPFC levees that were considered appurtenant and may impact the performance of SPFC levees. The April 2011 DWR NULE Geotechnical Assessment Report (GAR) is contained in Appendix C.

We also used the following in this Evaluation:

- Boring logs and Cone Penetrometer Test (CPT) sounding results for subsurface explorations performed by Raney Geotechnical, Inc. along the Segment 128 levees in 2013 and 2016 (Appendix A).
- Boring logs prepared by others for subsurface explorations within the Segment 128 levees for the design or retrofit of vehicular bridges that extend into East Walnut Grove in 1959 and 1997 (Appendix A).
- The September 25, 2012 RD 554 5-Year-Plan developed by DCC Engineering Co, Inc. to provide a workplan outlining anticipated repairs/improvements (Appendix D).

## **2 SEGMENT 128 CONSTRUCTION HISTORY AND IMPROVEMENTS**

Per the DWR NULE documents, local interests constructed the Segment 128 levees prior to 1906. Documentation of construction methods or materials are not available. Between 1954 and 1955, the United States Army Corps of Engineers (USACE) improved portions of the segment to meet SPFC standards. The improvements included levee construction and bank protection at undocumented locations. In 1972 and 1984 rock revetments were placed and the levee prism re-sloped between approximate Stations 13+85 and 17+40 and between approximate Stations 00+00 and 4+00. Riprap was placed along approximately 750 feet near 31+15 in 1976 and along approximately 745 feet near Station 38+75 in 2006. Additional rock revetments have been placed from approximate Station 11+15 to 13+85 and 24+00 to 46+37.

According to the RD 554 Five-Year Plan of 2012, DWR constructed a 1,210-foot-long erosion repair and mitigation berm along the waterside toe of the levee to address erosion concerns in 2006. The RD 554 Five-Year Plan of 2012 did not state the location of the improvements.

No additional improvements or repairs were planned at the time DWR published the NULE GAR.

Figure 4 shows the levee improvements listed above based on available information.

### **3 SEGMENT 128 PAST PERFORMANCE**

Table 3.1 summarizes Segment 128 past performance events from the April 2011 NULE GAR, which was based on information obtained from reviewed historical documents and interviews with maintenance personnel.

**Table 3.1 Levee Past Performance**

<b>Flood Season</b>	<b>Reported Event</b>	<b>Approximate Location (RD 554 Stationing)</b>	<b>Mitigation</b>
1957	Waterside erosion, slope caved	2+70 – 20+45	Not documented
1997	Erosion – Scouring, embankment slope failure	39+25	Not documented
1998	Toe failure of rock revetment	33+15 – 33+65	Repair recommended, not documented
2003	Erosion site	30+10	Upstream end (140') repaired

The locations of the above events are shown on Figure 5.

To the best of our knowledge, landside slope instability, under seepage and through seepage have not been documented along the Segment 128 levees.

### **4 REACH DETERMINATION**

We considered topography, levee geometry, available subsurface explorations, and surface features to divide the Segment 128 levees into three reaches for this Evaluation:

- Reach A – South of Depot Lane (Station 0+00 to 18+50)
- Reach B – Between Depot Lane and Winnie Street (Station 18+50 to 37+50)
- Reach C – North of Winnie Street (Station 37+50 to 46+58)

Figure 3 shows the extents of the Reaches.

### **5 CURRENT SEGMENT 128 CONDITIONS**

#### **5.1 Geometry**

The RD 554 2008-2009 survey indicates an existing minimum freeboard of at least 3 feet above the 100-year Water Surface Elevations (WSE, as defined in Section 7) from Station 0+00 to approximate Station 20+10 and from approximate Station 22+00 to Station 46+58. Between approximate Stations 20+10 and 22+00, the freeboard drops below 3 feet but does not drop below 2 feet.

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



Table 5.1 presents existing levee geometry per the NULE GAR.

**Table 5.1 Levee Geometry**

<b>Height above Landside toe (ft.)</b>	<b>Landside Slope (Horizontal: Vertical)</b>	<b>Crest Width (ft.)</b>	<b>Waterside Slope (Horizontal: Vertical)</b>
10 to 15	1.7:1 to 2.8:1	30 to 60	2.2:1 to 3:1

## **5.2 Roads and Storefronts**

River Road and Sacramento County Road E13 run along the crown of the Segment 128 levees. These roads serve as the main thoroughfare for East Walnut Grove. The levee crown has storefronts and residences on the landside and widened portions for street parking and sidewalks.

## **5.3 Vegetation**

Blackburn's Project Engineer Daniel Contreras performed a site visit on March 30, 2020 to observe Segment 128 surface conditions. At the time of his site visit, the waterside slope of the levees in Segment 128 were heavily vegetated with wild grasses, shrubs, and trees. In Reach A, the landside slope is generally covered with wild grasses, trees, and shrubs, with some residential lawns and gardens. In Reach B, the portions of the landside slope that are not paved or encroached upon by structures are generally covered with wild grasses and occasional shrubs and trees. The landside slope in Reach C is typically either vegetated with wild grasses or covered in compacted gravel.

Photographs 1a-2c show existing site conditions along the waterside and landside slopes of Segment 128 on March 30, 2020.

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



**Photo 1a: Waterside Slope**



Looking north along the waterside slope of Segment 128. The bridge over Georgiana Slough can be seen in the background.

**Photo 1b: Waterside Slope**



Looking south along the waterside slope of Segment 128. The bridge over the Sacramento River can be seen in the background.

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



**Photo 2a: Landside Slope**



Looking north at residential lawns along the landside slope of Segment 128.

**Photo 2b: Landside Slope**



Looking south along the landside slope of Segment 128. The building in the background is typical of buildings encroaching upon the levee prism.

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



**Photo 2c: Landside Slope**



Looking south from Mealer Lane along the landside slope of Segment 128.

## **5.4 Erosion, Penetrations and Encroachments**

Multiple waterside erosion mitigation projects have been performed along Segment 128. The 2011 NULE GAR indicates that 26 pipes penetrate the levee at depths from 1 to 13.3 feet below the levee crown, and that the pipe diameters range from 1 to 8 inches. At the time of our recent site visit, we observed numerous structures built into the landside and waterside slopes of the levee.

Erosion, Penetrations and Encroachments evaluations are being performed by others. These evaluations were not complete as of the date of this Evaluation. The findings of these evaluations must be included within the overall assessment of Segment 128 in connection with ultimately securing FEMA accreditation.

## **6 SUBSURFACE SOIL AND GROUNDWATER CONDITIONS**

### **6.1 Geology**

#### **6.1.1 Regional Geology**

East Walnut Grove is located along the eastern edge of the Sacramento-San Joaquin River Delta (the Delta). The *Geologic Map of the Sacramento Quadrangle, California*, D.L. Wagner et al., 1981 (Geologic Map), shows that East Walnut Grove is near the gradual transition from riverbank and fluvial deposits to a deltaic depositional environment. The Geologic Map indicates that the Segment 128 levees generally overlie Quaternary basin deposits (Qb) in the northern portion of Tyler Island and intertidal deposits (Qi)

in the south. These materials likely consist of silts and clays deposited in low energy environments. The intertidal deposits potentially contain peat.

In this transitional zone, the fluvial and deltaic environments cyclically encroached upon each other and retreated. As sea levels rose, fine grain materials (predominantly silt and clay), were deposited in wetlands, tidal marshes and supratidal flood plains. As sea levels receded, deposits in these wetlands, marshes and flood plains erode. Simultaneously, rivers carried coarser grained sediment eroded from the Sierra Nevadas to this zone, building alluvial fans and eolian sand dunes. As these two environments formed this transition zone, other lesser actors also contributed to modify the geology.

#### **6.1.2 Local Geology and Geomorphology**

Geomorphology mapping developed for the DWR NULE project (see Appendix C) indicates that the Segment 128 levees are underlain by Recent Overbank Deposits, which likely consist predominantly of interbedded silt, sand, and clay layers, which vary laterally in extent and character.

The Natural Resources Conservation Service (NRCS) Web Soil Survey identifies the soil underlying the Segment 128 levees as clay loam to a depth of approximately 4 feet overlying sandy clay loam to the maximum studied depth of 5 feet.

### **6.2 Existing Subsurface Explorations**

Raney Geotechnical, Inc (Raney) drilled 3 borings and pushed 3 Cone Penetrometer Tests (CPTs) along the Segment 128 levees in 2013 through 2016. According to the Raney boring logs and CPT plots, the Segment 128 levees are constructed mainly of soft to medium stiff sandy silt and very loose to loose silty sand with some gravel. The logs indicate that the foundation soil generally consists of a 20- to 30-foot-thick layer of soft to stiff silty clay/clayey silt with varying sand content, which is underlain by interbedded layers of sand, silt, and clay to a depth of 60 feet below the levee.

Borings logs for explorations drilled for design of the bridge over Georgiana Slough (in 1959) and for the seismic retrofit of the bridge over the Sacramento River (in 1997) indicate a similar subsurface profile to the profile indicated by the Raney boring logs.

In 1997, USBR drilled 1 boring in the levee prism for the seismic retrofit of the Delta Cross Channel bridge near the Sacramento River. This boring showed the levee consists of very stiff silty, sandy clay and loose sand with silt and the foundation soil consists of a 4- to 5-foot-thick layer of clayey silt with sand to sandy clayey silt above 2 to 12 feet of clay, which is underlain by interbedded layers of sand, silt, and clay to a depth of approximately 60 feet below the levee.

Appendix A presents the boring logs and CPT plots for the explorations described above. The approximate locations of the explorations are shown on Figure 3.

### **6.3 Existing Laboratory Test Results**

Raney performed laboratory tests associated with their 2013 borings, and Taber performed laboratory tests associated with borings drilled for design or retrofit of the bridges over the Sacramento River and over the Delta Cross Channel.

Tests included:

- 72 Moisture Content, Dry Density
- 9 Atterberg Limits
- 19 Grain Size Analysis
- 49 Unconfined Compressive Strength (unknown test method but probably pocket penetrometer)

The few strength tests that were performed do not have laboratory test reports, which contain important information that pertains to the type of test, properties of the soil tested, and confirmation with regard to sample depth and location. Therefore, the confidence of the applicability of the results is low. The evaluations Blackburn reviewed did not include Hydraulic Conductivity, Triaxial Strength, Consolidation tests, or Organic Matter tests.

Appendix B contains the laboratory classification test results (Atterberg limits and Grain size analysis). The other test results are included on the boring logs in Appendix A.

### **6.4 Ground Water**

Minimal groundwater elevation data is available within RD 554. An observation well by the landside levee toe near Segment 1051, Station 134+50 (along Snodgrass Slough) provides the most recent data and indicates that, since 2014, the groundwater elevation has ranged from 2 to 8 feet (NAVD88).

Raney measured groundwater in four of the borings drilled throughout RD 554 in 2013. The borings drilled at the toe of the levee measured groundwater at a range of 5.5 to 15 feet below the ground surface, and the boring drilled in the crown measured groundwater 24 feet below the ground surface.

The Taber LOTBs indicate that groundwater was encountered 19.0 to 23.2 feet below the levee crown.

### **6.5 Geophysical Evaluations**

In the fall of 2008, Conductance Subsurface Instrumentation, LLC (CSI) completed a subsurface conductance study of the RD 554 levee system south of the Delta Cross Channel. Subsurface conductance studies use electromagnetic induction to measure subsurface electrical conductivity, which reveals changes in subsurface conditions.

CSI performed 3 traverses along the length of the Segment 128 levees and analyzed the data obtained to determine locations of pipes, soil type changes, anomalies, and variations in signal for unknown reasons. Due to the number of cars parked on River Road at the time of the study, CSI could not obtain quality

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



data for Segment 128. CSI reported 1 anomaly near approximate RD 554 Station 16+75 (at the confluence of the Sacramento River and Georgiana Slough), which we understand may be within a cultural site of potential significance currently under investigation by others. After reviewing and analyzing the data, CSI reported that one potential problem area exists near Station 46+30 in Levee Segment 128, which CSI “felt” justified further attention. See Appendix D for the complete Levee Subsurface Conductance Study Report.

Due to the age of the levee, absence of construction records and CSI survey results, we recommend a follow-up geophysical survey along the Segment 128 levees to help identify potential significant anomalies that could impact the future performance of the levee. The type of survey should consider the presence of parked cars and transmission lines present near and/or along the alignment.

## **7 CROSS-SECTION DEVELOPMENT**

Blackburn selected a representative cross-section for each Reach to evaluate stability, seepage, and settlement. Table 7.1 summarizes the reaches and their respective cross-sections.

**Table 7.1 Analysis Cross-Sections**

Reach	Begin Station	End Station	Analysis Cross-Section Station
A	0+00	18+50	5+75
B	18+50	37+50	25+00
C	37+50	46+58	42+25

Figure 3 shows the cross-section locations.

Future explorations performed for the East Walnut Grove Evaluation may provide additional information that could warrant adjustment of these reaches and cross-sections.

Blackburn used the following information to create each cross-section model:

- Surface topography, bathymetry and Lidar provided by the design team. Blackburn prepared models for each cross-section to extend landward a minimum of 2,000 feet, and waterside a minimum of 200 feet from the levee centerline.
- Water surface elevation (WSE) information provided by GEI in the spreadsheet and accompanying table “Delta Legacy Small Communities, East Walnut Grove – RD 554 South of Delta Cross Channel.” This table presents the 100-year WSE values at specific stations along the Project alignment. Blackburn understands that the table presents 100-year flow accounting for upstream improvements, climate change, and Sea Level Rise. Blackburn determined the water surface elevations presented in Table 7.2 at each cross-section based on linear interpolation of values presented in the table and spreadsheet.

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



**Table 7.2 Geotechnical Analysis Water Surface Elevations (NAVD D88 ft)**

Station	100-yr WSE
5+75	18.14
25+00	18.37
42+25	18.41

### **Station 5+75 Cross-Section**

Explorations near Station 5+75 indicate that the levee is constructed of loose poorly graded sand. These explorations indicate the subsurface conditions below the levee at the following approximate elevations (NAVD 88):

- Silty sands and sandy silts transitioning to clean sand and silty sand landward from the ground surface to elevation 2 to -3 feet.
- Lean clay and silty lean clay from elevation 2 to -3 feet to elevation -5.5 and dropping to elevation -15 feet landward.
- Silty sand from elevation -5.5 to -15 feet (landward) to elevation -16 feet and dropping to -23 feet landward.
- Poorly-graded sand with silt from elevation -16 to -23 feet (landward) to elevation -39 feet.
- Fat clay below elevation -39 feet.

### **Station 25+00 Cross-Section**

Explorations near Station 25+00 indicate that the levee is constructed of loose to medium dense poorly graded sand and silty sand. These explorations indicate the subsurface conditions below the levee at the following approximate elevations (NAVD 88):

- Poorly-graded sand from the ground surface to elevation 7 feet.
- Sandy silt and silty sand from elevation 7 feet to elevation -6 feet.
- Layers of silty clay and lean clay from elevation -6 feet to elevation -27 feet.
- Layers of silty sand, sandy silt, and silty clay from elevation -27 feet to elevation -53 feet.
- Silty clay below elevation -53 feet.

### **Station 42+25 Cross-Section**

Explorations near Station 42+25 indicate that the levee is constructed of approximately 7 feet of very stiff silty clay over loose poorly graded sand with silt. These explorations indicate the subsurface conditions below the levee at the following approximate elevations (NAVD 88):

- Silty clay from the ground surface to elevation 0 feet.
- Clayey sand and sandy clay from elevation 0 feet to elevation -18 feet.

- Silty clay from elevation -18 feet to elevation -30 feet.
- Silty sand below elevation -30 feet.

The subsurface soil profiles in Appendix E are based on the soil conditions outlined above and present the soil profiles used in this Evaluation at each cross-section.

## **8 DESIGN PARAMETER SELECTION**

Steady state underseepage evaluation requires hydraulic conductivity parameter input, and each individual slope stability evaluation requires unit weight and strength parameter input. Selection of these parameters considers both the soil properties encountered within the East Walnut Grove area as well as the specific subsurface soil layering within each cross-section. Blackburn assigned the soil layers based on the existing exploration data near each specified cross-section.

### **8.1 Unit Weight**

Blackburn estimated saturated unit weights for each stability analysis cross-section based on sampler blow counts and laboratory test results in near-by explorations by Raney and Taber. Where laboratory tests were insufficient, we also considered our knowledge of similar soils.

### **8.2 Strength and Hydraulic Conductivity Parameter**

Due to the absence of strength tests on soils obtained within or near the RD 554 levee system, Blackburn relied heavily on the strength parameters proposed in the April 2015 Guidance Document for Geotechnical Analyses, Urban Levee Evaluations Project, Contract 4600008101, URS (URS Guidance Document). Blackburn considered these published values to assign strength parameters based on soil classification and blow count correlations. The available boring logs often classified soils imprecisely, and occasionally, classifications contradicted the few available lab tests. In addition to these difficulties in assigning parameters, Blackburn simplified the subsurface profiles by combining similarly classified soils into layers of combined soil types. Because the URS Guidance Document proposes parameters for most individual USCS soil types, Blackburn used engineering judgment to develop reasonably conservative strength parameters based on the published values. Table 2 contains the strength parameters used by Blackburn in this evaluation. Future explorations and lab tests may indicate that these parameters need to be modified.

Hydraulic conductivity tests were not performed on individual samples obtained during the previous field exploration programs. Blackburn therefore considered the hydraulic conductivity values published in the URS Guidance Document to assign hydraulic conductivity values based on soil classification and fines content. Table 1 contains the hydraulic conductivity values used by Blackburn for this evaluation. Future explorations and lab tests may indicate that these parameters need to be modified.

## **9 EVALUATION WATER SURFACE ELEVATION**

We used the 100-year water surface elevation in this Evaluation as provided by provided by GEI. The 100-year water surface elevation ranges from approximately 18.4 feet at the upstream end near the Delta Cross Channel to approximately 18.1 feet at the southern, downstream end of Segment 128 (NAVD 88).

## **10 GEOTECHNICAL ANALYSIS GUIDANCE DOCUMENTS AND CRITERIA**

### **10.1 Seepage and Slope Stability Criteria Guidance Documents**

Blackburn considered the following guideline documents to develop the geotechnical design criteria for steady-state underseepage, steady-state through seepage, steady-state slope stability, and rapid drawdown slope stability:

- USACE, Engineer Manual, EM 1110-2-1913, Design and Construction of Levees, 30 April 2000.
- USACE, Engineer Manual, EM 1110-2-1902, Engineering and Design, Slope Stability, 31 October 2003.
- USACE, Engineer Technical Letter ETL 1110-2-569, Design Guidance for Levee Underseepage, May 1, 2005.
- USACE, Geotechnical Levee Practice Standard Operating Procedure, Revision 2, 11 April 2008.
- USACE, Engineer Circular, EC 1110-2-6067, USACE Process for the National Flood Insurance Program (NFIP) Levee System Evaluation, 31 April 2010.
- FEMA, 44 CFR 65.10, 4 June 2001
- California Department of Water Resources, Urban Levee Design Criteria (ULDC), May 2012.

### **10.2 Steady-State Seepage Criteria**

#### **10.2.1 Underseepage**

The average exit gradient is defined as the average head loss per foot traveling upward through the landside blanket (relatively low permeability silt and clay). Elevated average exit gradients may result in sand boils and piping near the landside levee toe and potentially lead to levee failure.

Blackburn evaluated the average exit gradients under steady state conditions at the 100-year WSE for the cross-sections at Station 5+75 and Station 42+25. Blackburn did not evaluate an average exit gradient at Station 25+00 because our current understanding of subsurface conditions indicates that there is no blanket present to create a gradient.

For water levels at the 100-year WSE, the criteria for steady-state underseepage state that the average exit gradient must be  $\leq 0.5$  at the landside levee toe.

The average exit gradient criteria above is based on the assumption that the saturated unit weights of the in-situ landside blanket soils must be at or above 112 pounds per cubic foot, which is applicable to the Segment 128 analyses as discussed above.

### 10.2.2 Through Seepage

Phreatic surface breakout on the landside levee slope can reduce the strength of embankment soils leading to slope failures and can initiate piping and landside surface erosion. If the phreatic surface emerges on the landside slope of an embankment constructed with erodible materials (i.e., sand and silt), it typically constitutes a through seepage deficiency.

Limited quantities of seepage may not necessarily be a concern with respect to levee performance, especially for relatively wide levees. However, seepage exiting through relatively permeable granular soil layers near the landside toe of the levee can create piping (also referred to as backward erosion) concerns. The susceptibility to piping is generally a factor of soil permeability, quantity of water exiting the ground near the toe of the levee, levee width, and height of water behind the levee relative to the ground surface at the toe of the levee. We used "The Evaluation of Potential Erosion in Levees and Levee Foundations, Virginia Polytechnic Institute and State University, The Charles E. Via, Jr. Department of Civil Engineering, Center for Geotechnical Practice and Research, Evaluation of Potential Erosion in Levees and Levee Foundations by J. Michael Duncan, Brendan O'Neil, Thomas Brandon and Daniel R. VandenBerge, February 2011" (EPELLF) to evaluate the severity of seepage at each cross-section.

### 10.3 Slope Stability Criteria

Blackburn evaluated steady-state slope stability at the 100-year WSE and rapid drawdown slope stability assuming a drawdown WSE equal to the landside levee toe for each cross-section. Based on the guidance documents listed above, the required minimum acceptable slope stability factors of safety are:

<u>Condition</u>	<u>Minimum Factor of Safety</u>
Steady-State 100-year WSE:	1.4
Rapid Drawdown:	1.0 to 1.2

The Factor of Safety range for rapid drawdown accounts for the extent to which the levee embankment saturates under flood WSE prior to drawdown. For this preliminary evaluation, Blackburn used an averaged factor of safety of 1.1 to determine satisfaction of criteria.

## 11 UNDERSEEPAGE EVALUATION

### 11.1 Analysis Procedure

Blackburn evaluated steady-state underseepage at the 100-year WSE for each cross-section. To perform the analysis, Blackburn used the program SEEP/W, Version 2020, 10.2.1.19666, with the hydraulic conductivity values presented in Table 1 as input parameters. Blackburn then applied the following boundary conditions to each model:

- Fixed-head set to the channel stage along the boundary nodes of the waterside levee slope and channel bottom.
- Potential seepage surface for nodes on the landside levee slope and landside ground surface.
- No-flow condition along the bottom of the model, and along the waterside vertical edge of the model.
- Total head boundary along the landside vertical edge set to the lower elevation of the landside ground surface elevation at the landside edge or the landside levee toe elevation.

The above boundary conditions are similar to those applied in previous projects by both Blackburn and USACE and are recommended in the 2015 URS Guidance Document.

## **11.2 Analysis Results**

Our Steady State Underseepage analysis indicates that the average exit gradients with existing conditions meet the criteria under the 100-year WSE. Table 11.1 summarizes underseepage results for each reach.

**Table 11.1 Underseepage Analysis Results**

Reach	Station	Criteria	Average Exit Gradient	Pass/Fail
A	5+75	<0.5	<0.05	Pass
B	25+00	<0.5	NA	NA
C	42+25	<0.5	0.30	Pass

Appendix E presents the SEEP/W output result figures.

## **11.3 Underseepage Conclusions**

Based on Blackburn's current understanding of the existing conditions and analysis summarized above, Segment 128 levees meet underseepage criteria using the 100-year WSE. However, the analysis is based on limited subsurface information and laboratory test results. We therefore recommend additional exploratory borings (along the levee crown, toe and in far-field) and laboratory classification and hydraulic tests to confirm or refine the models, parameters and analysis.

# **12 THROUGH-SEEPAGE EVALUATION**

## **12.1 Analysis Procedure**

Blackburn evaluated steady-state through seepage at the 100-year WSE for each cross-section. To perform the analysis, Blackburn used the program SEEP/W, Version 2020, 10.2.1.19666, with the hydraulic conductivity values presented in Table 1 as input parameters. Blackburn then applied the following boundary conditions to each model:

- Fixed-head set to the channel stage along the boundary nodes of the waterside levee slope and channel bottom.
- Potential seepage surface for nodes on the landside levee slope and landside ground surface.
- No-flow condition along the bottom of the model, and along the waterside vertical edge of the model.
- Total head boundary along the landside vertical edge set to the lower elevation of the landside ground surface elevation at the landside edge or the landside levee toe elevation.

The above boundary conditions are similar to those applied in previous projects by both Blackburn and USACE and are recommended in the 2015 URS Guidance Document.

## 12.2 Analysis Results and Conclusions

Our through seepage analyses indicate that the phreatic surface exits the landside levee embankment approximately 2 to 3 feet above the levee toe at each analyzed cross-section. Table 12.1 summarizes through seepage results for each reach. Appendix E presents our SEEP/W output result figures.

Table 12.1 Through Seepage Analysis Results

Reach	Station	Landside Toe Elevation* (feet)	Phreatic Surface Breakout Elevation* (feet)
A	5+75	12.0	15.0
B	25+00	9.9	11.9
C	42+25	9.0	11.0

\*NAVD 88

The above results, along with the granular soil within and below the levee, warrants evaluation of backwards erosion piping (BEP) and its potential impacts on levee stability. To perform this evaluation, Blackburn considered the information contained in EPELLF. This document provides the Section titled *Rational Methods of Evaluating Safety Against Erosion and Piping*, with a Subsection titled *Seepage Severity*. This section was included as the authors of the document believed it would be useful to have a lower bound threshold, assumed as 1 gallon per minute per 100 feet of levee, below which seepage is considered to be negligible and seepage remediation not needed. The document includes Table 4, *Proposed categories of seepage severity*, shown below.

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



**Table 4 - Rational Methods of Evaluating Safety Against Erosion and Piping,  
Proposed categories of seepage severity<sup>(1)</sup>**

<b>Q<sub>s</sub>/H</b>		<b>Severity of Seepage</b>	<b>Seepage Remediation Needed</b>
<b>(gpm per foot of head per 100 feet of levee)</b>	<b>(cfs per foot of head per foot of levee)<sup>(2)</sup></b>		
>10	>2.2x10 <sup>-4</sup>	Heavy	Yes
5 to 10	1.1x10 <sup>-4</sup> to 2.2x10 <sup>-4</sup>	Medium	Possible
1 to 5	2.2x10 <sup>-5</sup> to 1.1x10 <sup>-4</sup>	Light	Marginal
<1	<2.2x10 <sup>-5</sup>	Negligible	Not Needed

<sup>(1)</sup> Modified after Section 140 of TM3-424 (1956)

<sup>(2)</sup> 1 cfs/ft of head/ft of levee = 44883 gpm/ft of head/100 ft of levee

Q<sub>s</sub>, in the above table, is defined as the seepage rate and H is defined as the change in head across the levee.

Table 12.2 presents Blackburn's BEP analysis results. Our seepage severity evaluation figures are included in the Appendix E figures.

**Table 12.2 Seepage  
Severity Analysis Results**

<b>Reach</b>	<b>Station</b>	<b>Q<sub>s</sub>/H (cfs)</b>	<b>Severity of Seepage</b>
A	5+75	3.7x10 <sup>-5</sup>	Light
B	25+00	7.7x10 <sup>-6</sup>	Negligible
C	42+25	4.8x10 <sup>-6</sup>	Negligible

The above indicates that the need for BEP seepage remediation at the cross-sections evaluated is marginal or not needed. Blackburn understands that observations of the levee by RD personnel and others familiar with Segment 128 indicate that seepage has not been observed. These observations combined with the analysis results indicate that through seepage remediation is likely not necessary. As stated in Section 11.3, we recommend additional subsurface exploration along the levee and laboratory tests be performed to confirm this expected conclusion.

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



## 13 SLOPE STABILITY EVALUATION

### 13.1 Steady-State Condition Analysis

#### 13.1.1 Analysis Procedure

Blackburn performed steady-state slope stability analysis at each cross-section. Blackburn used the program SLOPE/W, Version 2020, 10.2.1.19666, and the strength parameters presented in Table 2. Blackburn's slope stability analyses used the following:

- Spencer's Method, a limit-equilibrium method of analysis.
- Effective shear strengths shown in Table 2 and pore water pressures imported from the SEEP/W model for the steady-state slope stability models at the 100-year WSE.

Blackburn modeled slope failure through the crown of the existing, wide levee prism and through the crown of a theoretical standard riverine levee prism geometry (as defined in ULDC) fit within the existing levee prism. Table 13.1 presents ULDC geometry and freeboard requirements.

**Table 13.1 Levee Geometry Requirements**

Landside Slope (Horizontal: Vertical)	Crest Width (feet)	Waterside Slope (Horizontal: Vertical)	Freeboard*
2:1	20	3:1	100-yr WSE + 3 feet

\*ULDC defines freeboard as 200-year WSE + 3 feet; however, we used 100-year WSE for consistency with Evaluation WSE.

The representative cross-section for Reach C does not meet the standard riverine levee prism geometry as defined in the ULDC. The existing waterside slope is steeper than 2:1 (H:V) and a theoretical standard levee prism with a 3:1 waterside slope does not fit within the existing prism.

#### 13.1.2 Analysis Results

Table 13.2 summarizes steady-state landside slope stability results for each reach. Appendix E presents our SLOPE/W stability result figures.

**Table 13.2 Steady State Slope Stability Analysis Results**

Reach	Station	Criteria	FoS (through levee crown)	Pass/Fail	FoS (through standard riverine levee prism crown)	Pass/Fail
A	5+75	$\geq 1.4$	1.1	Fail	1.1	Fail
B	25+00	$\geq 1.4$	1.1	Fail	1.4	Pass
C	42+25	$\geq 1.4$	1.0	Fail	1.0	Fail

The above results indicate that the existing-condition landside slope stability does not meet criteria under the 100-year WSE at all 3 analyzed cross-sections for the steady-state seepage condition. When the failure slope is forced through the crest of the theoretical standard riverine levee prism, the Factor of Safety against slope failure for the cross-section at Station 25+00 meets criteria, however the slopes at Stations 5+75 and 42+25 still fail to meet criteria.

### **13.1.3 Steady-State Slope Stability Conclusions**

Based on the above and current understanding of the existing conditions, Segment 128 levees may not meet steady-state slope landside stability criteria under the 100-year WSE at Stations 5+75 and 42+25. Our analysis at Station 25+00 indicates that the landside slope meets criteria for an imbedded minimum levee prism, but surficial stability may be relatively low. Surficial failure may be a concern because it could damage the roadways and lead to progressive slope failure further into the levee.

Additional subsurface explorations and laboratory strength testing is needed to confirm or revise the above models, parameters and analysis, and determine appropriate mitigation methods if necessary.

## **13.2 Rapid Drawdown Condition Analysis**

### **13.2.1 Analysis Procedure**

Blackburn evaluated the potential for rapid drawdown slope stability to occur along the Segment 128 levee waterside slope. Stage hydrographs were not available for this evaluation. Therefore, based on experience with other levee evaluation and discussion with GEI, Blackburn used a drawdown that would bring the water from the 100-year WSE down to the same elevation as the landside toe. We believe this is a realistic drawdown amount associated with a potential breach near the Segment 128 levees. However, breach scenario hydraulic evaluation is needed to confirm this drawdown value and analysis.

In general, clay soil requires a slow drawdown rate to create drained conditions, in the order of less than one-foot-per-day. Blackburn assumed the clay layers should be modeled as undrained.

Blackburn used the program SLOPE/W, Version 2020, 10.2.1.19666, and the effective and total strength parameters presented in Table 2. Blackburn's rapid drawdown slope stability analyses used the following:

- Spencer's Method, a limit-equilibrium method of analysis, for each stability analysis.
- The rapid drawdown slope stability analysis method in SLOPE/W, which uses the three-stage method developed by Duncan, Wright, and Wong<sup>1</sup>. Blackburn input the pre-drawdown WSE equal to the 100-year WSE and a drawdown elevation equal to the landside levee toe. The analysis used both effective and total shear strengths shown in Table 2 as inputs into the program. For free-draining material, the analyses use only effective strengths. Blackburn evaluated waterside stability analysis for each cross-section.

---

<sup>1</sup> Duncan, J.M., Wright, S.G, and Wong, K.S. (1990), "Slope Stability during Rapid Drawdown". H. Bolton Seed Memorial Symposium, Vol. 2, University of California at Berkeley.

### 13.2.2 Analysis Results

Table 13.3 summarizes our waterside rapid drawdown slope stability results for each reach. Appendix E presents the SLOPE/W result figures.

Table 13.3 Underseepage Analysis Results				
Reach	Station	Criteria	FoS (through levee crown)	Pass/Fail
A	5+75	$\geq 1.1$	1.2	Pass
B	25+00	$\geq 1.1$	1.3	Pass
C	42+25	$\geq 1.1$	0.9	Fail

The above indicates that the cross-sections at Stations 5+75 and 25+00 meet criteria but the cross-section at Station 42+25 does not meet criteria for rapid drawdown slope stability under the 100-year WSE.

### 13.2.3 Rapid Drawdown Slope Stability Conclusions

Based on Blackburn's current understanding of the existing conditions, some portions of Segment 128 levees may not meet rapid drawdown criteria under the 100-year WSE.

Additional subsurface explorations and laboratory strength testing is needed to confirm or revise the above models, parameters, and analysis, and determine appropriate mitigation methods if necessary.

## 13.3 Non-Rapid Drawdown Water-Side Slope Stability

### 13.3.1 Analysis Procedure

Section 13.2 provides our evaluation of waterside rapid drawdown slope stability. However, waterside slopes should also have an appropriate factor of safety under typical non-rapid drawdown conditions. We therefore performed an analysis using typical, non-rapid drawdown conditions. To model this condition, we analyzed slope stability at a low WSE of 3 feet (NAVD 88) with saturated/non-buoyant soils up to an elevation equal to the 10-yr WSE as defined by the table provided by GEI.

We performed slope stability at each cross-section. Blackburn used the program SLOPE/W, Version 2020, 10.2.1.19666, and strength parameter values presented in Table 2. Blackburn's slope stability analyses used the following:

- Spencer's Method, a limit-equilibrium method of analysis.
- Effective shear strengths shown in Table 2 and pore water pressures imported from the SEEP/W model for the steady-state slope stability models at the estimated annual low WSE.

### 13.3.2 Analysis Results

Table 13.4 summarizes the waterside slope stability results for each reach. Appendix E presents the SEEP/W result figures. We used a factor of safety of 1.2 based on our experience that this is a minimum acceptable slope stability factor of safety for typical conditions.

**Table 13.4 Waterside Stability Analysis Results**

Reach	Station	Criteria	Factor of Safety	Pass/Fail
A	5+75	$\geq 1.2$	1.2	Pass
B	25+00	$\geq 1.2$	1.4	Pass
C	42+25	$\geq 1.2$	1.0	Fail

The above indicates a factor of safety less than 1.2 in Reach C but greater than, or equal to, 1.2 in Reaches A and B under typical WSE conditions.

### 13.3.3 Waterside Slope Stability Conclusions

Based on Blackburn's current understanding of the existing conditions, Segment 128 waterside levee slopes may have relatively low factors of safety for typical conditions. We recommend that this condition be analyzed in subsequent evaluations using updated topography, stratigraphy, and strength parameters from the additional subsurface exploration and lab testing recommended in Sections 11.3, 12.2, 13.1.3, and 13.2.3.

## 13.4 Seismic Slope Stability Analysis

Blackburn completed an evaluation of seismic vulnerability of Segment 128 levees. Blackburn generally followed the methodology presented in ETL 1110-2-580, *Guidelines for Seismic Evaluation of Levees*, Expires 1 March 2018, USACE. In January 2020, Blackburn verified with the USACE that these Guidelines are still valid and have not been updated.

The USACE Guidelines for Seismic Stability Evaluation of USACE Levees, states that the typical water surface elevation considered for liquefaction triggering analysis should be the highest of the following:

- The median annual river level,
- The median annual groundwater level,
- The typical seasonal water level, and
- The mean high tide elevation for levees affected by the tide.

Blackburn did not have access to these data at the time of this evaluation. Therefore, to determine a reasonably conservative WSE for liquefaction analysis, Blackburn considered a 2-year high channel water surface elevation provided by GEI, historic groundwater levels in an observation well on the east side of RD 554, and groundwater levels recorded on historic boring logs. Based on the available

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



data, Blackburn ran sensitivity analyses and conservatively chose a typical water surface elevation for liquefaction triggering of 8.4 feet for Georgiana Slough and 10.4 feet for the Sacramento River (NAVD 88).

To evaluate levee seismic vulnerability, Blackburn:

- Used an approximate return period of 100 years.
- Determined site specific Peak Ground Acceleration (PGA) and earthquake Magnitude (M) for an earthquake with a 100-year return period. Blackburn obtained the PGA from the United States Geological Survey (USGS) website.

Completed liquefaction triggering at select subsurface data locations. Blackburn used Youd et al., 2001, Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 127, No. 10., pp 817-833. Blackburn based fine-grained soil susceptibility on Seed et al, 2003.

ETL 1110-2-580 defines liquefaction potential through a factor of Safety against liquefaction, calculated in accordance with Youd et al., 2001. Potential for liquefaction is:

- Likely if the Factor of Safety is  $\leq 1.0$  and
- Marginal if the Factor of Safety is  $> 1.0$  and  $\leq 1.4$

If the Factor of Safety against liquefaction is  $> 1.0$  within all investigated depths and the levee is not a high-hazard levee, no further seismic evaluation is needed.

#### **13.4.1 Site Seismicity**

An estimate of ground motion parameters such as peak horizontal ground acceleration (PGA) and earthquake moment magnitude (M) are necessary for liquefaction analysis. Blackburn used the USGS Unified Hazards Tool website (<https://earthquake.usgs.gov/hazards/interactive/>) to complete a probabilistic analysis and develop the peak horizontal ground acceleration (PGA) for an earthquake with a 100-year return period. The USGS 2008 Interactive Deaggregations program is based on source and attenuation models as presented in Petersen, M. and others, 2008, *“Documentation for the 2008 Update of the National Seismic Hazard Maps, USGS OFR 08-1128,”* available on the web at <http://pubs.usgs.gov/of/2008/1128/>.

To estimate the ground motion parameters for Segment 128, Blackburn checked the PGA near the center of the Segment 128 alignment. Blackburn used  $V_{S,30}$  equal to 259 meters per second (mps, approximately 850 feet per second). This velocity is based on the general soil conditions logged in historical explorations completed along Segment 128. The 259 mps velocity is the value for Site Class D (Stiff Soil site).

To determine the PGA for an earthquake with a 100-year return period, Blackburn used the USGS Unified Hazards Tool which determined the PGA for several return periods and plotted the results

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



as a hazard curve. From the hazard curve, the tool calculated a PGA equal to 0.135 for a 100-year return period.

A “most likely” earthquake moment magnitude (M) and distance to rupture (R) for the event that will cause the PGA of interest is necessary for liquefaction analysis. Deaggregation within the USGS Unified Hazards Tool website allows for determination of the magnitude and distance with the most significant contribution to the ground motion.

For the 100-year return period, the mean M is 6.6 and the mean R is 35 miles. Listed below are the faults that contribute most significantly to the PGA hazard with percent contribution and magnitude shown (from deaggregation at the 100-year return period level).

Fault Name	Contribution (%)	Magnitude	Distance (miles)
San Andreas (Peninsula)	2.85%	7.94	66.3
Hayward (So)	2.59%	7.29	46.8
Great Valley 5 Pittsburg – Kirby Hills alt1	2.51%	6.35	19.4
Great Valley 04b Gordon Valley	1.75%	6.71	25.1
Mount Diablo Thrust North CFM	1.69%	7.19	29.6
Concord	1.47%	6.56	34.0
Calaveras (no)	1.35%	7.11	40.2

A weighted average of the four largest percent contributing faults results in M equal to 7.1. However, the website calculated a mean M of 6.6 considering the entire system. Blackburn therefore selected an applicable M equal to 6.6 for use in the current Segment 128 analysis.

#### 13.4.2 Liquefaction

Blackburn completed liquefaction analyses in general accordance with Youd et al, (2001); Cetin et al, (2004); and Idriss and Boulanger, (2008). In determining the soils Factor of Safety against liquefaction, all three methods use a similar approach where they compare the cyclic stress ratio (CSR), which is the seismic demand on a soil layer, versus the cyclic resistance ratio (CRR), which is the capacity of the soil to resist liquefaction. Blackburn’s analysis considered fine grained soils with Plasticity Index (PI)<10 and Liquid Limit (LL) <35 as potentially liquefiable, consistent with USACE guidelines.

For this evaluation, Blackburn completed liquefaction triggering analysis at borings B-4 located in Reach A, B-1 located in Reach B, and B-3 located in Reach C.

Blackburn used the following parameters for liquefaction triggering analysis:

- Earthquake magnitude of M=6.6
- PGA of 0.135g
- Evaluation ground water elevation equal to an assumed nominal annual high water surface elevation (WSE) of Elevation 8.4 feet (NAVD88) for Georgiana Slough and Elevation 10.4 feet (NAVD 88) for the Sacramento River as the typical critical condition.

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



Blackburn's analyses indicated factors of safety against liquefaction  $\geq 1.0$  for all liquefiable soil layers. Appendix F presents the liquefaction analysis spreadsheets.

### 13.4.3 Seismic Slope Stability Conclusions

Based on the above, Segment 128 levees are not likely vulnerable to seismic-induced slope instability, settlement or lateral spreading.

## 14 SETTLEMENT EVALUATION

There is no available documentation of significant settlement issues over the history of the Segment 128 levees. Based on this history and subsurface conditions, we do not anticipate that settlement is a concern for the Segment 128 levees in their existing condition.

## 15 SUMMARY

We completed a preliminary existing condition evaluation of the Sacramento River and Georgiana Slough East Levees using existing subsurface information and reasonably conservative geotechnical parameters. Table 15.1 summarizes our evaluation.

**Table 15.1 Summary of Analysis Results**

Analysis	Criteria	Analysis Result			Pass/Fail		
		Reach A	Reach B	Reach C	Reach A	Reach B	Reach C
Steady-state Underseepage	Exit Gradient $< 0.5$	<0.05	NA	0.30	Pass	NA	Pass
Steady-state Through Seepage Seepage Severity	$Q_s/H < 2.2 \times 10^{-5}$	$3.7 \times 10^{-5}$	$7.7 \times 10^{-6}$	$4.8 \times 10^{-6}$	Light	Negligible	Negligible
Landside Slope Stability through existing crown	$FoS \geq 1.4$	1.1	1.1	1.0	Fail	Fail	Fail
Landside Slope Stability through Minimum Embedded Levee Prism	$FoS \geq 1.4$	1.1	1.4	1.0	Fail	Pass	Fail
Rapid Drawdown Waterside Slope Stability	$FoS \geq 1.1$	1.2	1.3	0.9	Pass	Pass	Fail
Non-Rapid Drawdown Waterside Slope Stability	$FoS \geq 1.2$	1.2	1.4	1.0	Pass	Pass	Fail
Liquefaction	$FoS \geq 1.0$ ( $1.0 < FoS < 1.4$ – marginal potential)	$\geq 1.0$	$\geq 1.0$	$\geq 1.0$	Pass	Pass	Pass

The above results indicate the following for existing conditions:

- All three reaches likely meet underseepage and through seepage criteria.
- All three reaches fail criteria for landside slope stability; however, Reach B may pass if relatively shallow landside failures that do not pass through a minimum levee prism are allowed.

- Reaches A and B likely meet waterside rapid drawdown criteria but Reach C likely will not meet rapid drawdown or non-rapid drawdown criteria.
- All three reaches likely meet criteria for factor of safety against liquefaction.
- Settlement is not a likely concern.

Based on Blackburn's current understanding and the above summary, Reach B is the most likely to meet FEMA accreditation requirements, while Reach C is the least likely.

The cross-sections representing Reach A and Reach B meet all criteria for accreditation except landside slope stability through the existing crown. The factor of safety against this mode of failure will likely increase with information gained by additional subsurface exploration and laboratory testing. Improved understanding of levee material properties may decrease the seepage severity in Reach A from light to negligible.

The representative cross-section in Reach C fails to meet criteria for landside and waterside slope stability. Additional subsurface explorations and associated laboratory testing may result in increased strength parameters that would increase the factors of safety. However, given the steep waterside slope and relatively narrow levee embankment, it is unlikely that more accurate strength properties will increase the factor of safety enough to meet accreditation criteria. Levees in Reach C will likely require mitigation of slope instability. An improved understanding of existing conditions will refine the extent of slope instability along the alignment and help determine potential mitigation alternatives.

## **16 RECOMMENDATIONS FOR ADDITIONAL EVALUATIONS**

These analyses are based on limited subsurface information and laboratory test results, minimal and relatively old bathymetry, and certain assumptions with regard to levee geometry consistency. To confirm or refine the reaches, models, parameters and analyses we recommend:

- Additional exploratory borings and CPTs and laboratory tests. Figure 6 shows Blackburn's recommended exploration locations, types, and depths.
- Updated hydrology information concerning minimum annual water surface elevations and drawdown water surface elevations.
- Updated bathymetry.
- A follow-up geophysical survey.

### **16.1 Subsurface investigations**

Blackburn recommends advancing 6 auger/mud rotary borings and 4 CPTs along the crown and landside toe of the Segment 128 levees and 5 auger/mud rotary borings in the far field to achieve the 1,000-foot spacing required by USACE and to close current data gaps. Figure 6 shows recommended exploration locations and depths.

Prior to drilling in Project Levees, the design team must submit a drilling Program Plan (DPP) to the USACE. In Blackburn's experience, it may take 6 months to a year for the USACE to approve a DPP.

All drilling should be done under the supervision of a registered Professional Engineer, and an engineer/geologist should visually classify and log soil samples during drilling operations. The drilling subcontractor should obtain soil samples using drive (Standard Penetration Test and Modified California) and push (Shelby Tube) samplers at depths determined by the supervising Engineer. Blackburn recommends continuous sampling in the levee prism and to sufficient depth to determine presence and thickness of a blanket layer. The engineer/geologist should collect samples, secure them in labelled containers, and transport them to a USACE approved laboratory in accordance with ASTM standards.

Blow count N values are sensitive to the energy efficiency of each drill rig hammer. To account for this in blow count calculations, the drilling contractor should measure hammer energy delivered to the sampler in the field during drilling operations. The drilling contractor should use the data collected in the field to calculate hammer efficiency and report this efficiency to the geotechnical engineer. The Engineer should use the hammer efficiency to calculate N values from blow counts recorded in the field.

## **16.2 Laboratory Testing**

USACE approved laboratory(ies) should test samples selected by the Engineer to assist in soil classification and determine soil parameters necessary for geotechnical analyses. We recommend the following soil tests on samples obtained during the investigation described in Section 16.1:

- Moisture Content (ASTM D2216)
- Dry Density (ASTM D7263)
- Atterberg Limits (ASTM D4318)
- Grain Size Analysis (ASTM D1140)
- Triaxial Shear (ASTM D2166, D2850, D4767)
- Hydraulic Conductivity (ASTM D5084)
- Direct Shear (ASTM D3080)

All tests should be performed in accordance with ASTM standards.

## **16.3 Updated Hydrology**

Blackburn recommends a further hydrologic study to determine minimum annual WSEs and drawdown WSEs. These WSEs are critical to performing waterside slope stability but were unavailable for this Preliminary Evaluation. Accurate WSEs may substantially change the results of Blackburn's waterside slope stability analyses.

## **16.4 Updated Bathymetry**

Blackburn recommends a new bathymetry study be conducted to update the bathymetry used in this Preliminary Evaluation. Bathymetry available for this Preliminary Evaluation was, at best, 7 years old, though much of the Segment 128 alignment relied on bathymetry that was over 20 years old. The older bathymetry also used NGVD29 for the vertical datum. Converting data from one datum to another can introduce error.

Considering the age of the available bathymetry along with the verbal reports of erosion along the segment, Blackburn recommends updated bathymetry to confirm the channel profile.

## **16.5 Geophysical Survey**

Blackburn recommends that a geophysical survey be performed along the Segment 128 alignment. Due to the age of the levee, absence of construction records, and the CSI survey results and recommendations, we recommend performing a follow-up geophysical survey along the Segment 128 levees to help identify potential significant anomalies that could impact the future performance of the levee. The type of survey should consider the presence of parked cars and transmission lines present near and/or along the alignment.

Upon completion of the above recommendations, Blackburn can use the additional information to update our analyses and prepare an updated Existing Conditions Evaluation.

## **17 LIMITATIONS**

Blackburn prepared this Evaluation for GEI for GEI's overall evaluation of East Walnut Grove's flood control protection as part of the California Department of Water Resources (DWR) Small Community Flood Risk Reduction Program. This Evaluation should not be used by others or for other projects without Blackburn's written permission.

Blackburn prepared this report in accordance with the generally accepted geotechnical standard of practice currently being used in this area.

Blackburn based this Evaluation on available historical documentation, the current site, and Segment 128 conditions. For this Evaluation, Blackburn assumed soil and ground water conditions documented on the available boring logs and CPT plots are representative of the subsurface conditions across the site. Actual conditions between explorations could be different. Ground water may be higher in other locations and at other times than measured and presented on the exploration logs.

## **18 REFERENCES**

DCC Engineering Co., Inc. 2012. *Reclamation District 554 Five-Year Plan*. Prepared by DCC for Department of Water Resources (DWR) Division of Flood Management. September.

Raney Geotechnical, Inc. 2016. *Boring logs and CPT Logs*.

URS Corporation and Fugro William Lettis & Associates. 2011. *Final Geomorphology Technical Memoranda and Maps. North NULE Area, Geomorphic Assessments*. Non-Urban Levee Evaluations Project. Prepared by URS and Fugro for Department of Water Resources (DWR) Division of Flood Management. January.

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



URS Corporation. 2011. *Geotechnical Assessment Report, North NULE Project Study Area. Non-Urban Levee Evaluations Project*. Prepared by URS for Department of Water Resources (DWR) Division of Flood Management. April.

URS Corporation. 2015. *Guidance Document for Geotechnical Analyses*. Urban Levee Evaluations Project. Prepared by URS for whom? April.

Moore and Taber. 1961. *Log of Test Borings, Bridge Across Georgiana Slough*. Prepared by Moore and Taber for Caltrans. February.

Taber Consultants. 1998. *Log of Test Borings, Walnut Grove Bridge Over Sacramento River*. Earthquake Retrofit. Prepared by Taber Consultants for Dokken Engineering and Caltrans. July.

Taber Consultants. 1998. *Log of Test Borings, Delta Cross Channel Bridge*. Earthquake Retrofit. Prepared by Taber Consultants for Dokken Engineering and Caltrans. June.

United States Bureau of Reclamation. 2017. *Mid-Pacific Region, Delta Cross Channel*. MP Region Public Affairs. May.

Blackburn Consulting. 2020. *Updated Existing Geotechnical Data Technical Memorandum, Community of East Walnut Grove, California*. Prepared by Blackburn Consulting for GEI. March

# **Preliminary Existing Condition Stability, Seepage and Settlement Evaluation**

## **Sacramento River and Georgiana Slough East Levees**

**Community of East Walnut Grove, California**

**California Department of Water Resources Small  
Community Flood Risk Reduction Program**

### **TABLES**

**Table 1: Hydraulic Conductivity Values Used in This  
Evaluation**

**Table 2: Strength Values Used in This Evaluation**

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



**TABLE 1**

**Hydraulic Conductivity Values Used in This Evaluation**

Material Type	USCS Designation	Soil Description	YBEL			
			Kh (ft/day)	Kh (cm/s)	Kv/Kh	Kv (cm/s)
Non-Engineered Levee	CL-ML	Non-Engineered Levee SILTY CLAY	0.1134	$4.0 \times 10^{-5}$	0.25	$1.0 \times 10^{-5}$
	SP, SM	Non-Engineered Levee Layers of Poorly-graded SAND and SILTY SAND	11.339	$4.0 \times 10^{-3}$	0.25	$1.0 \times 10^{-3}$
	SP-SM	Non-Engineered Levee Poorly-graded SAND with SILT	11.339	$4.0 \times 10^{-3}$	0.25	$1.0 \times 10^{-3}$
	SP	Non-Engineered Levee Poorly-graded SAND	56.693	$2.0 \times 10^{-2}$	0.25	$5.0 \times 10^{-3}$
Foundation	CH	Stiff to Very Stiff Fat CLAY	0.0006	$2.0 \times 10^{-7}$	0.25	$5.0 \times 10^{-8}$
	CL, CL-ML	Layers of Medium Stiff Lean CLAY and SILTY CLAY	0.0567	$2.0 \times 10^{-5}$	0.25	$5.0 \times 10^{-6}$
	CL-ML	Medium Stiff to Stiff SILTY CLAY	0.1134	$4.0 \times 10^{-5}$	0.25	$1.0 \times 10^{-5}$
	SC, CL	Medium Stiff Lean CLAY, Medium Dense CLAYEY SAND	0.3402	$1.2 \times 10^{-4}$	0.25	$3.0 \times 10^{-5}$
	SM, ML	Medium Dense to Dense SILTY SAND and Medium Stiff to Stiff SANDY SILT	0.5669	$2.0 \times 10^{-4}$	0.25	$5.0 \times 10^{-5}$
	SM (shallow)	Loose to Medium Dense SILTY SAND, shallow	1.1339	$4.0 \times 10^{-4}$	0.25	$1.0 \times 10^{-4}$
	SM (deep)	Medium Dense SILTY SAND, deep	1.1339	$4.0 \times 10^{-4}$	0.25	$1.0 \times 10^{-4}$
	SP-SM	Medium Dense to Dense Poorly-graded SAND with SILT	11.339	$4.0 \times 10^{-3}$	0.25	$1.0 \times 10^{-3}$
	SP	Loose Poorly-graded SAND	56.693	$2.0 \times 10^{-2}$	0.25	$5.0 \times 10^{-3}$

**PRELIMINARY EXISTING CONDITION STABILITY, SEEPAGE AND SETTLEMENT EVALUATION  
SACRAMENTO RIVER AND GEORGIANA SLOUGH EAST LEVEES**

**Community of East Walnut Grove, California**

California Department of Water Resources Small Community Flood Risk Reduction Program

August 3, 2020



**TABLE 2**

**Strength Values Used in This Evaluation**

<b>Material Type</b>	<b>USCS Designation</b>	<b>Soil Description</b>	<b>YBEL</b>			
			<b><math>\phi'</math></b>	<b>C'</b>	<b><math>\phi^{\text{total}}</math></b>	<b><math>C^{\text{total}}</math></b>
<b>Non-Engineered Levee</b>	CL-ML	Non-Engineered Levee SILTY CLAY	26	50	13	50
	SP, SM	Non-Engineered Levee Layers of Poorly-graded SAND and SILTY SAND	30	0	30	0
	SP-SM	Non-Engineered Levee Poorly-graded SAND with SILT	28	0	28	0
	SP	Non-Engineered Levee Poorly-graded SAND	28	0	28	0
<b>Foundation</b>	CH	Stiff to Very Stiff Fat CLAY	28	100	14	100
	CL, CL-ML	Layers of Medium Stiff Lean CLAY and SILTY CLAY	28	50	14	50
	CL-ML	Medium Stiff to Stiff SILTY CLAY	28	50	14	50
	SC, CL	Medium Stiff Lean CLAY, Medium Dense CLAYEY SAND	28	50	14	50
	SM, ML	Medium Dense to Dense SILTY SAND and Medium Stiff to Stiff SANDY SILT	32	0	32	0
	SM (shallow)	Loose to Medium Dense SILTY SAND, shallow	30	0	30	0
	SM (deep)	Medium Dense SILTY SAND, deep	32	0	32	0
	SP-SM	Medium Dense to Dense Poorly-graded SAND with SILT	34	0	34	0
	SP	Loose Poorly-graded SAND	32	0	32	0

# Preliminary Existing Condition Stability, Seepage and Settlement Evaluation

## Sacramento River and Georgiana Slough East Levees

Community of East Walnut Grove, California

California Department of Water Resources Small  
Community Flood Risk Reduction Program

### FIGURES

Figure 1: Project Vicinity Map

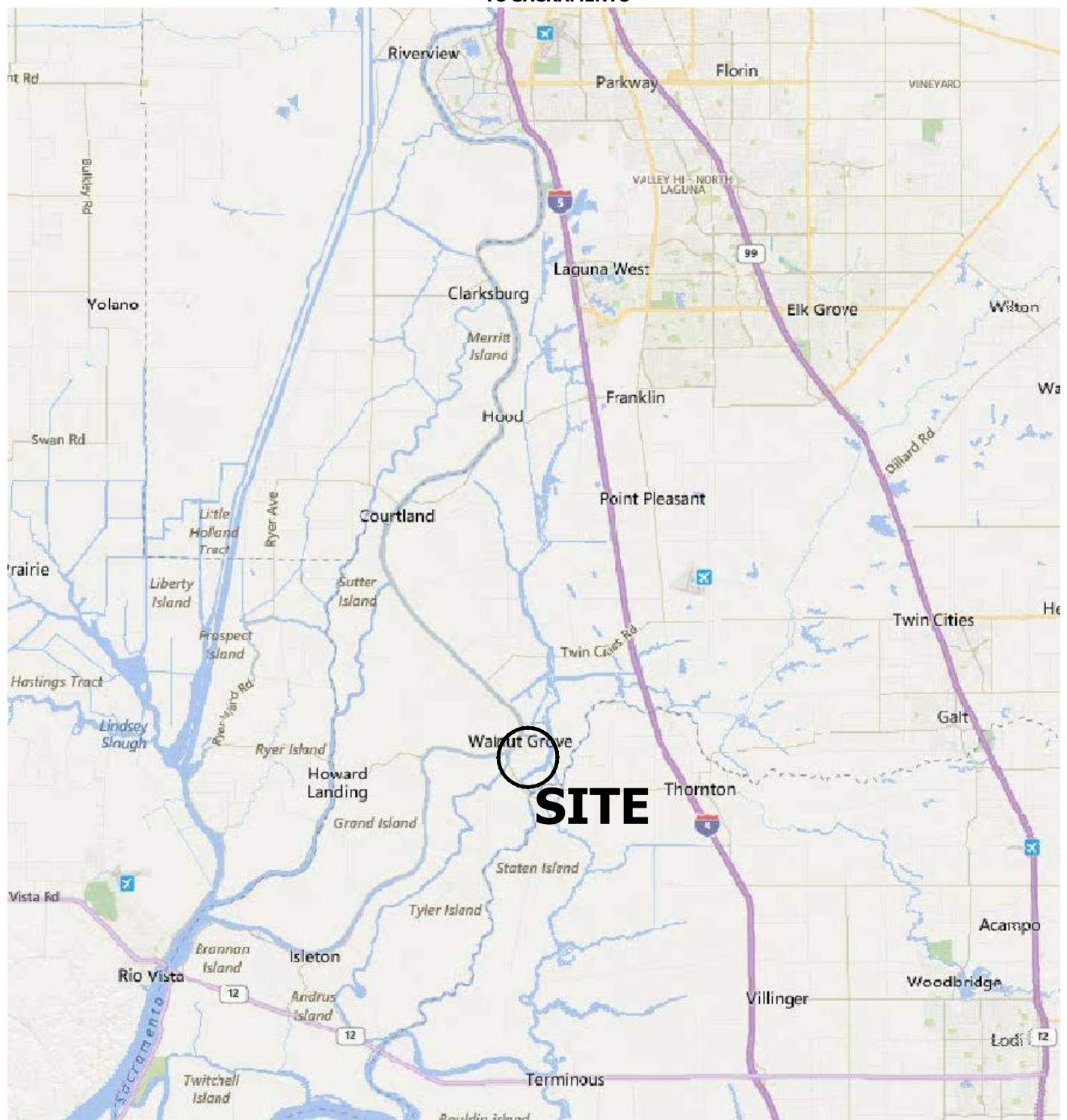
Figure 2: Site Map

Figure 3: Existing Explorations

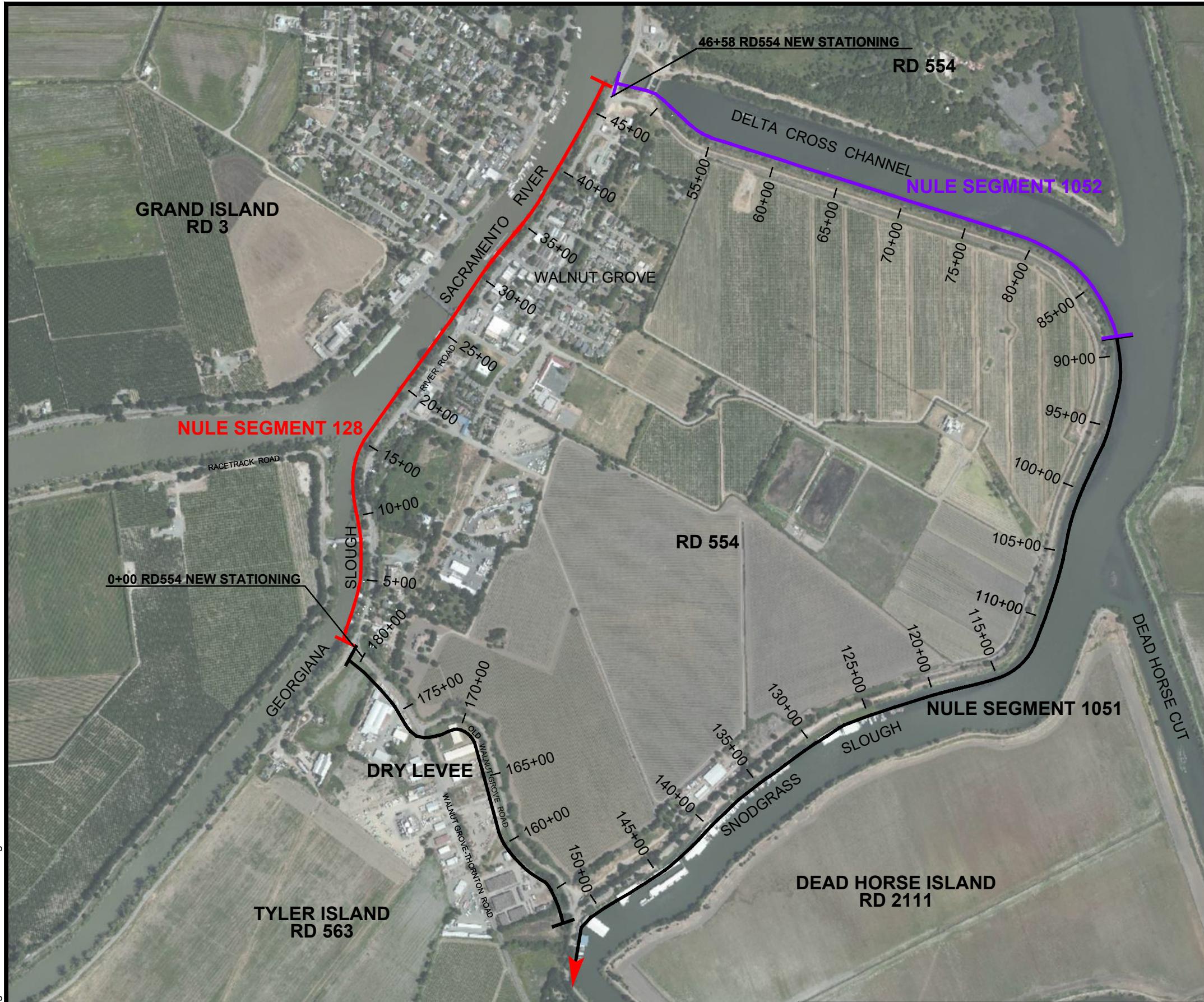
Figure 4: Levee History and Improvements

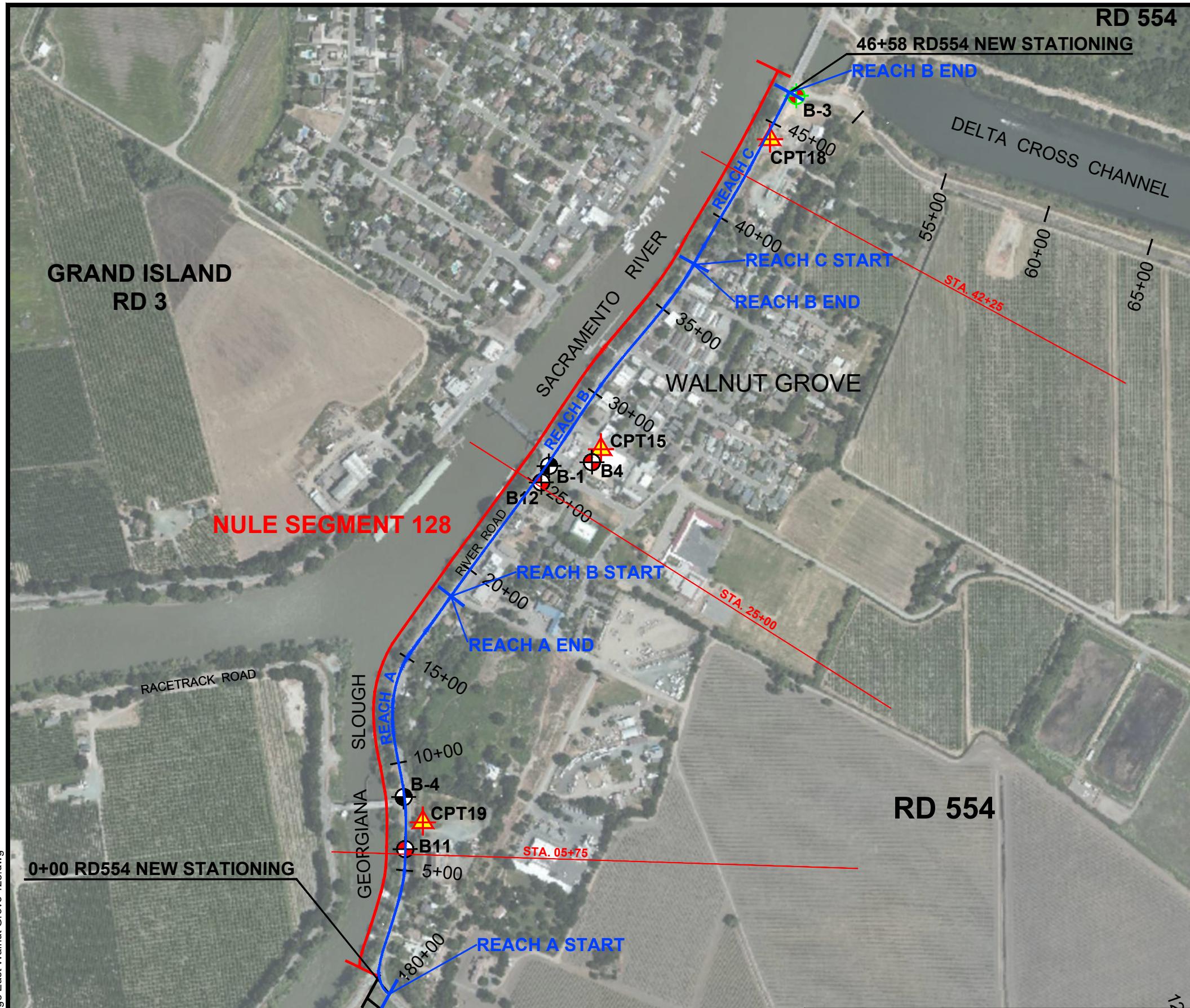
Figure 5: Past Performance Issues

Figure 6: Proposed Explorations for Further Analysis



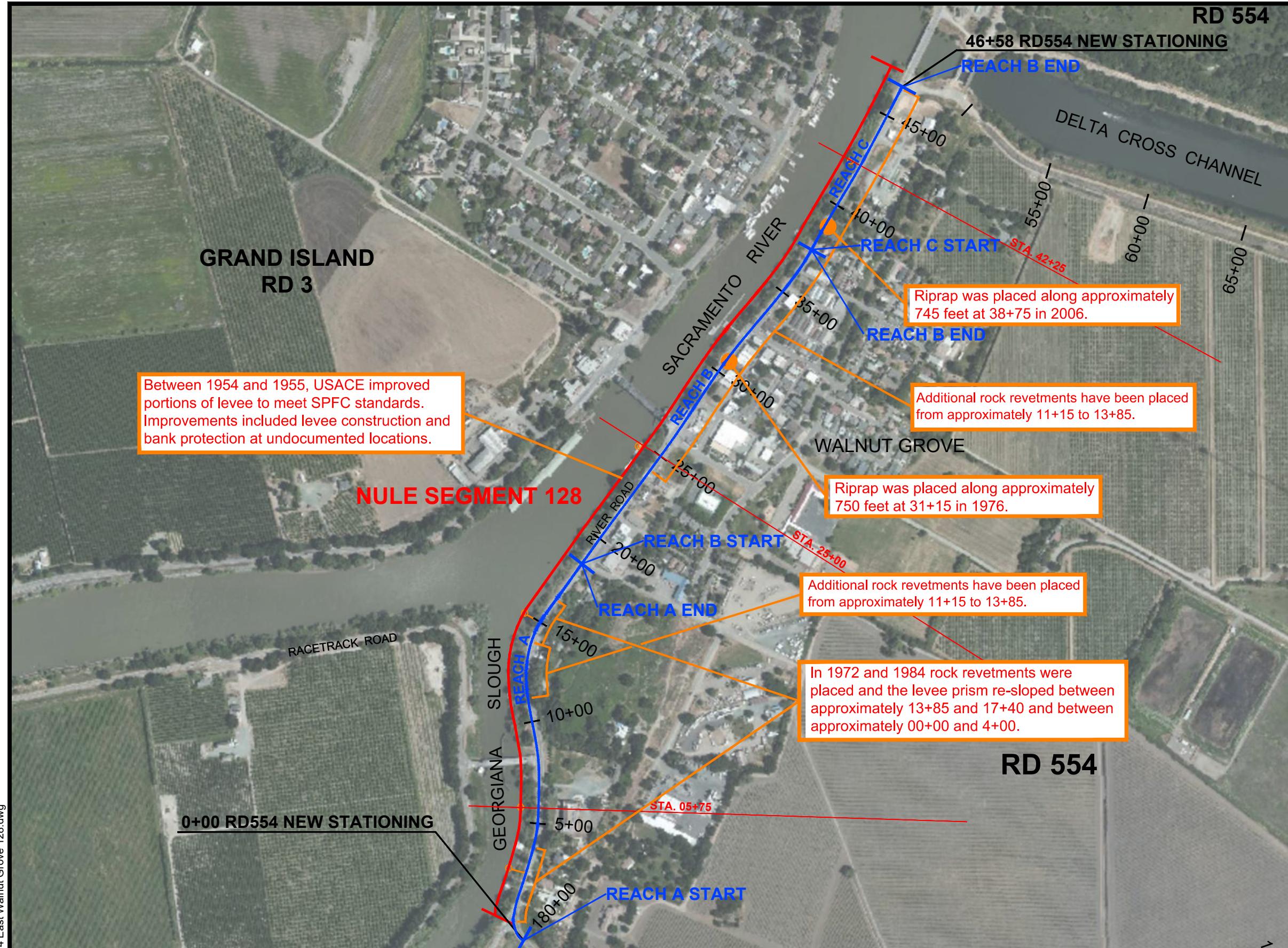
SCALE 1"=20,000'

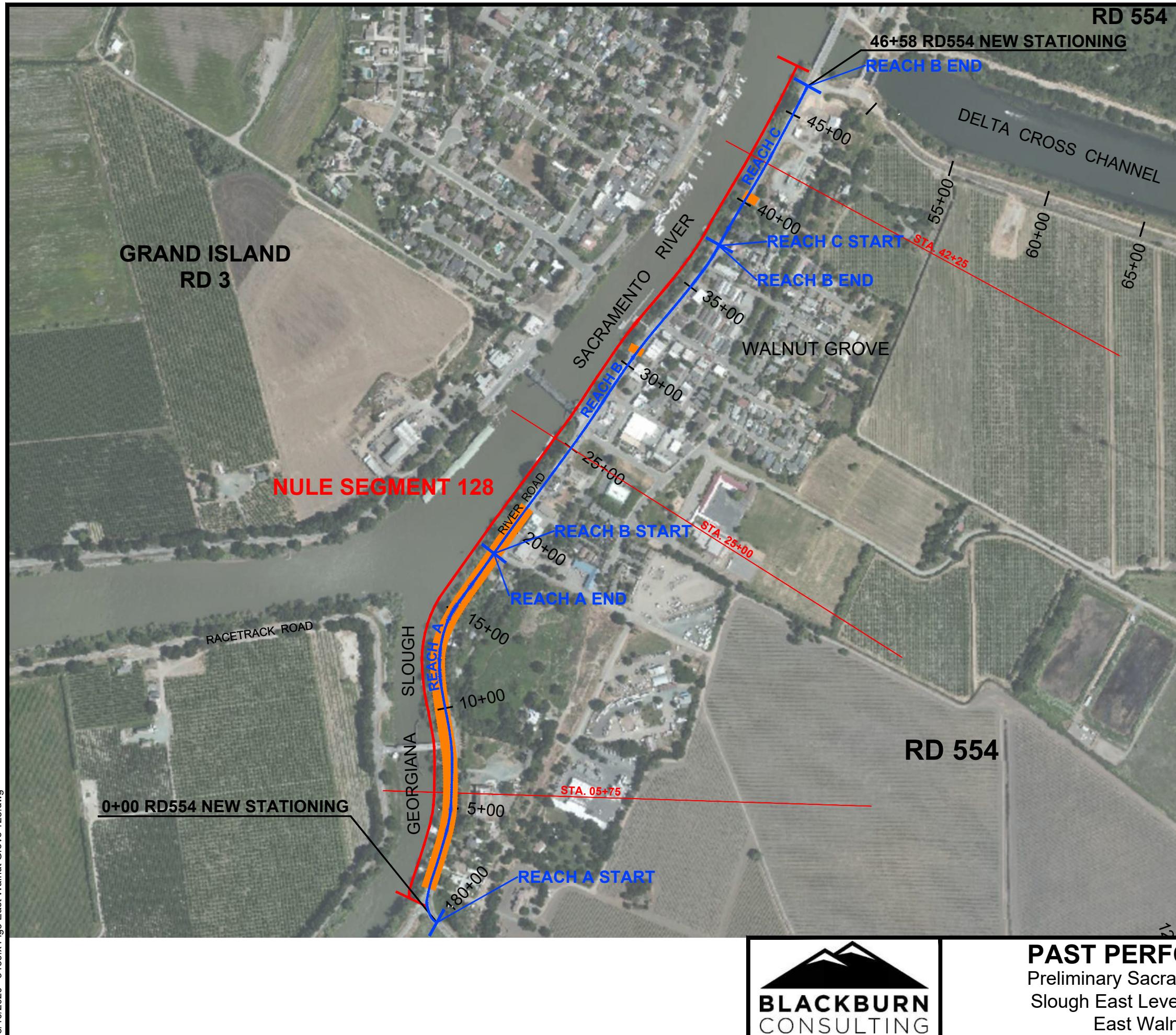




### LEGEND

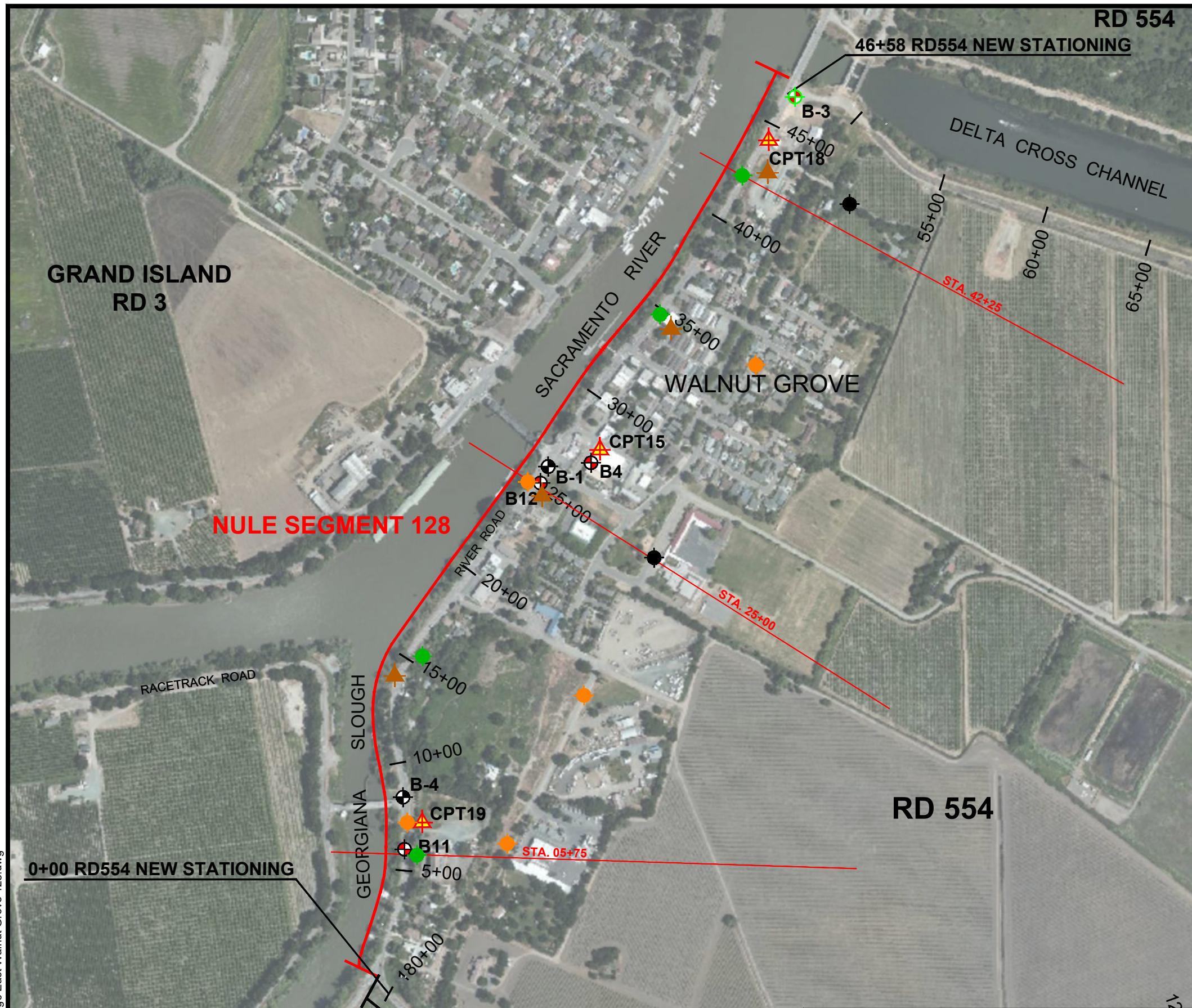
- B1 ● Approximate Boring Location (Raney, 2013)
- CPT2 ▲ Approximate CPT Location (Raney, 2016)
- B-4 ● Approximate Georgiana Slough Bridge Boring Location (1959)
- B-1 ● Approximate Sacramento River Bridge Boring Location (1997)
- B-3 ● Approximate Delta Cross Channel Bridge Boring Location (1997)
- 60+00 - RD 554 Stationing (Typical)
- Sta. 5+75 Analysis Cross Section Locations 2020
- REACH A-C Nule Segment 128, Reaches A-C





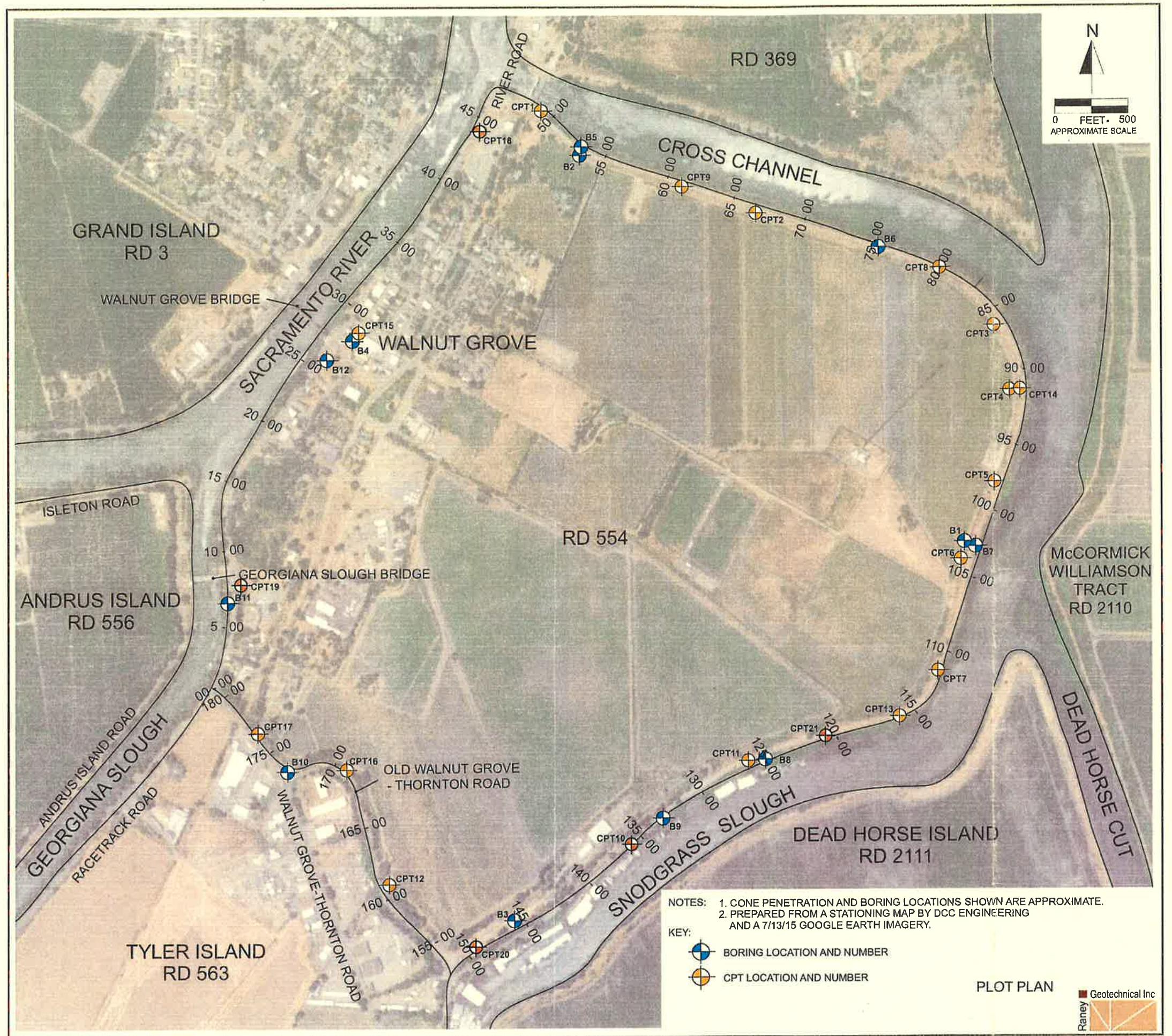
**PAST PERFORMANCE ISSUES**  
Preliminary Sacramento River and Georgiana  
Slough East Levee Evaluation, Segment 128  
East Walnut Grove, California

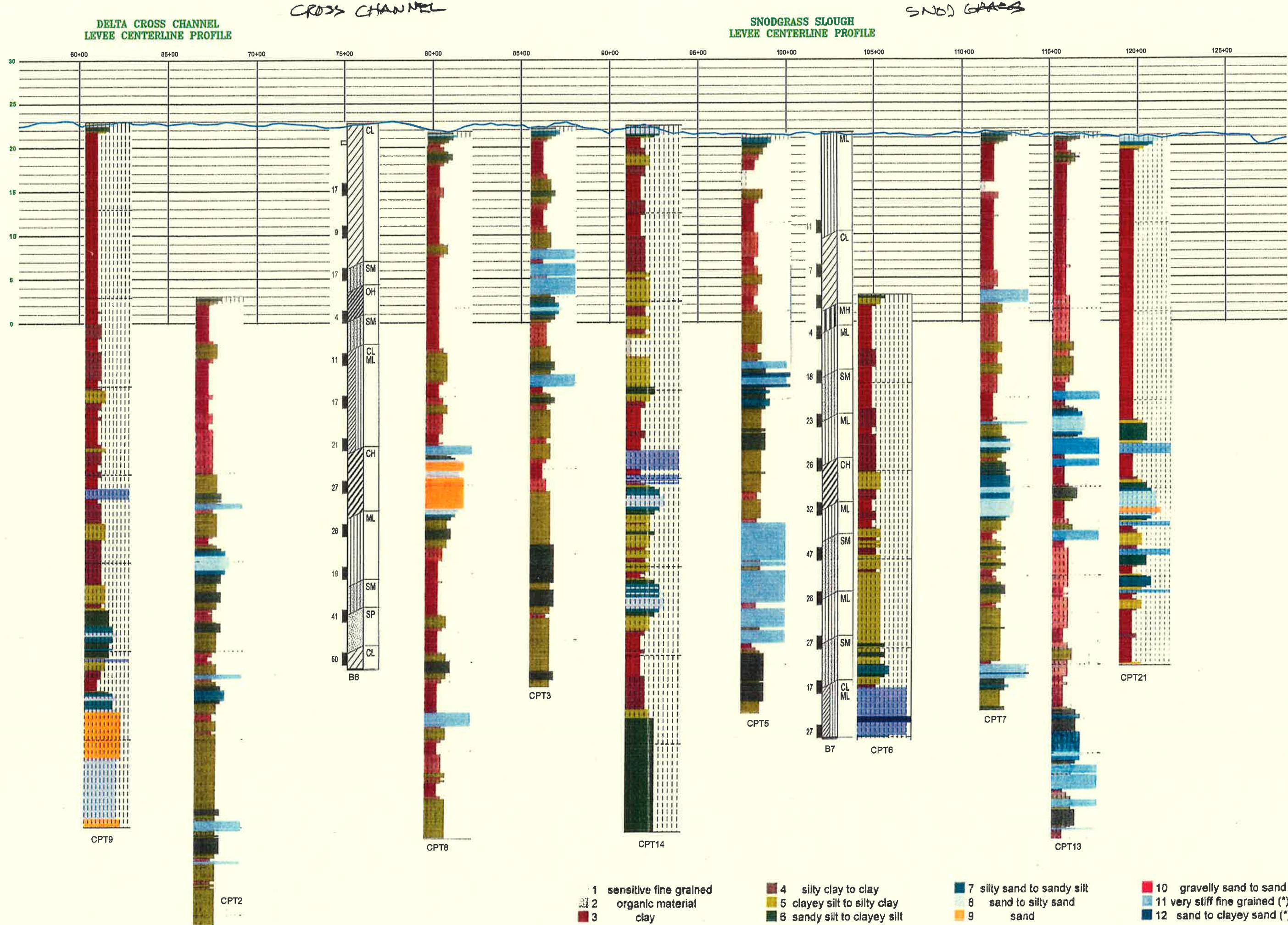
File No. 3139.x  
August 2020  
Figure 5





PROJECT NUMBER: 1135-021

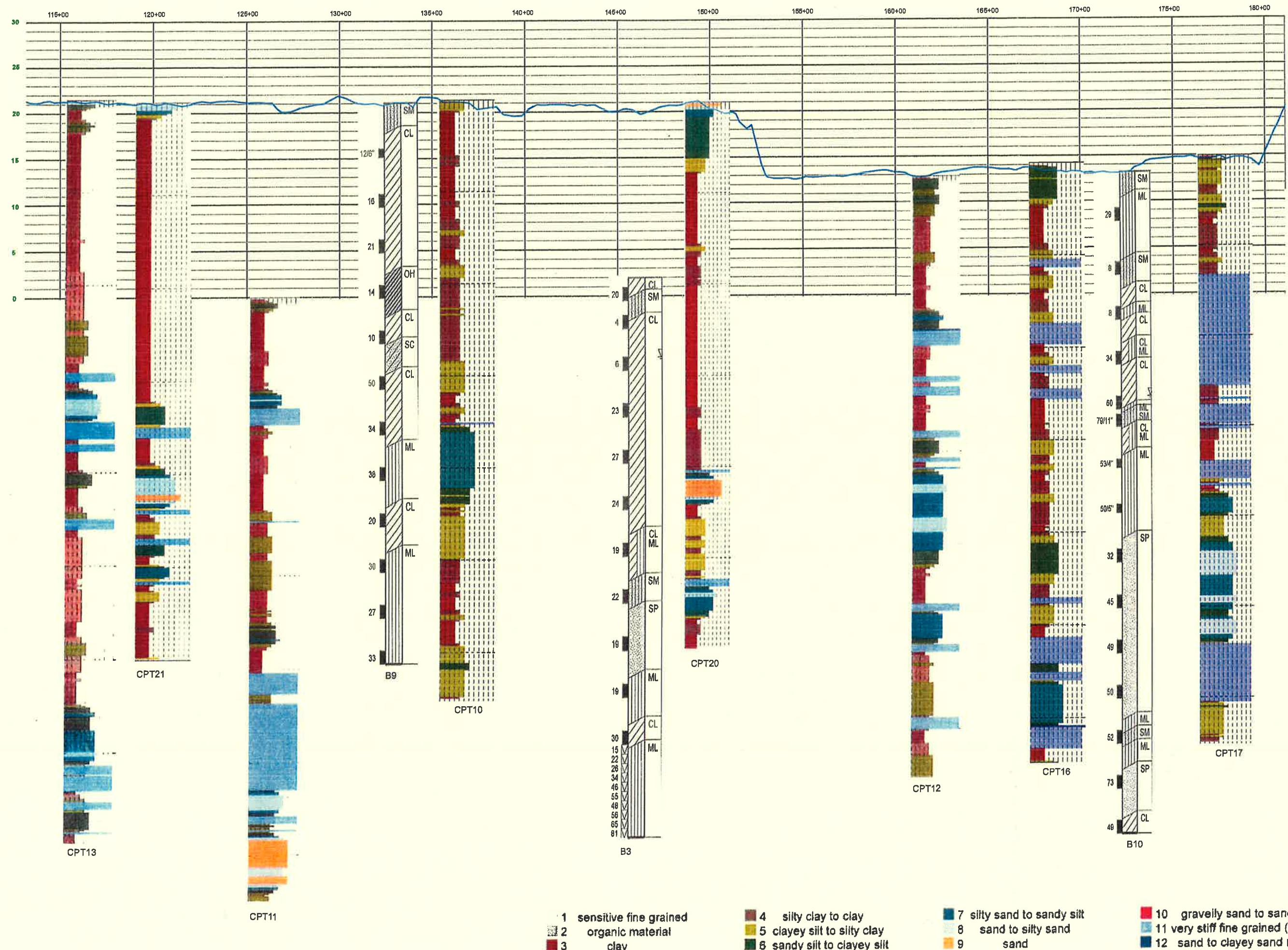




SNODGRASS

TYLER CROSS LEVEE  
LEVEE CENTERLINE PROFILE

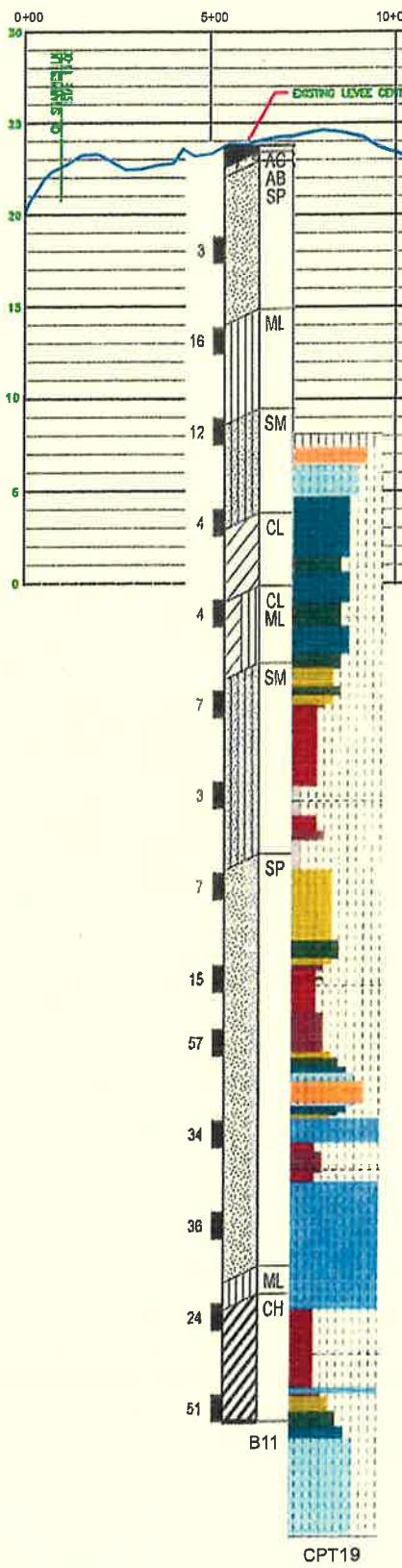
TYLER



NOTES:

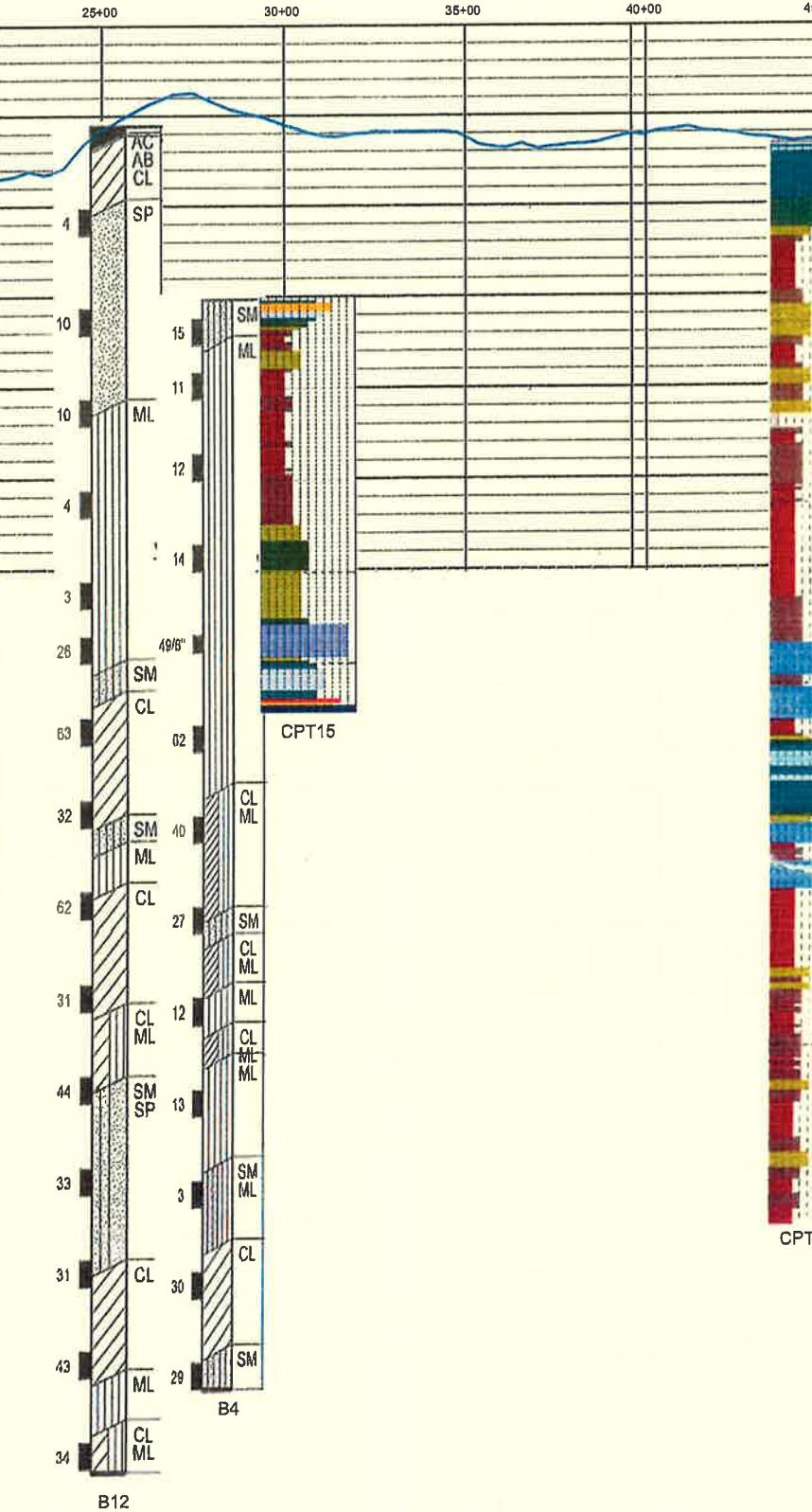
- 1) THE 100-YEAR AND 300-YEAR FLOOD LINE IS BASED ON THE CORPS OF ENGINEERS DATA, CHART 71A DATED FEBRUARY 1992.
- 2) THE LEVEE CENTERLINE ELEVATIONS ARE BASED ON A FIELD SURVEY PERFORMED BY DCC ENGINEERING CO., INC. ON OCTOBER 20, 21 2002.
- 3) THE ELEVATIONS SHOWN HEREIN ARE BASED ON NOV 20.

## GEORGIANA SLOUGH LEVEE CENTERLINE PROFILE



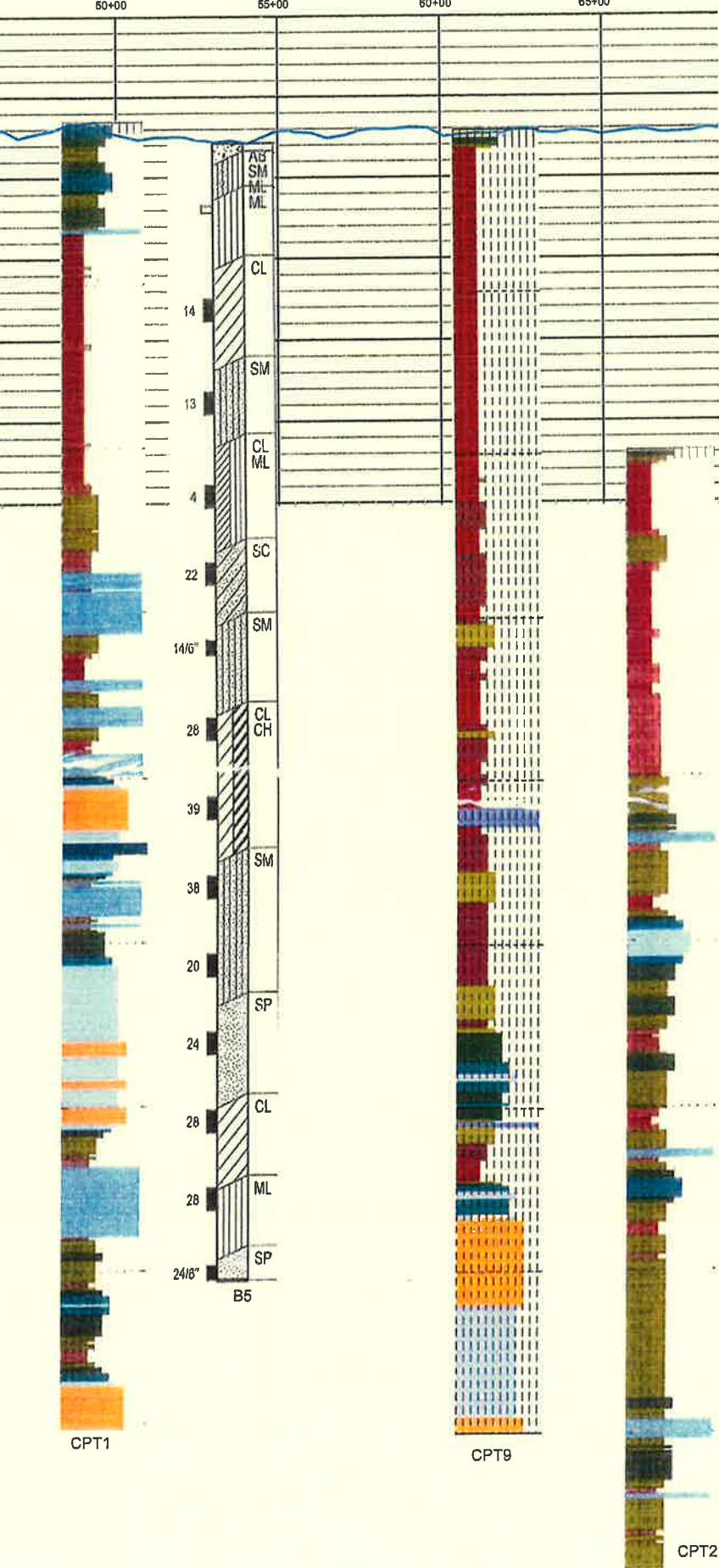
## SACRAMENTS

SACRAMENTO RIVER  
LEVEE CENTERLINE PROF.



## CROSS CHANNEL

## DELTA CROSS CHANNEL LEVEE CENTERLINE PROFILE



- 1 sensitive fine grained
- 2 organic material
- 3 clay

- 4 silty clay to clay
- 5 clayey silt to silty clay
- 6 sandy silt to clayey silt

- 7 silty sand to sandy
- 8 sand to silty sand
- 9 sand

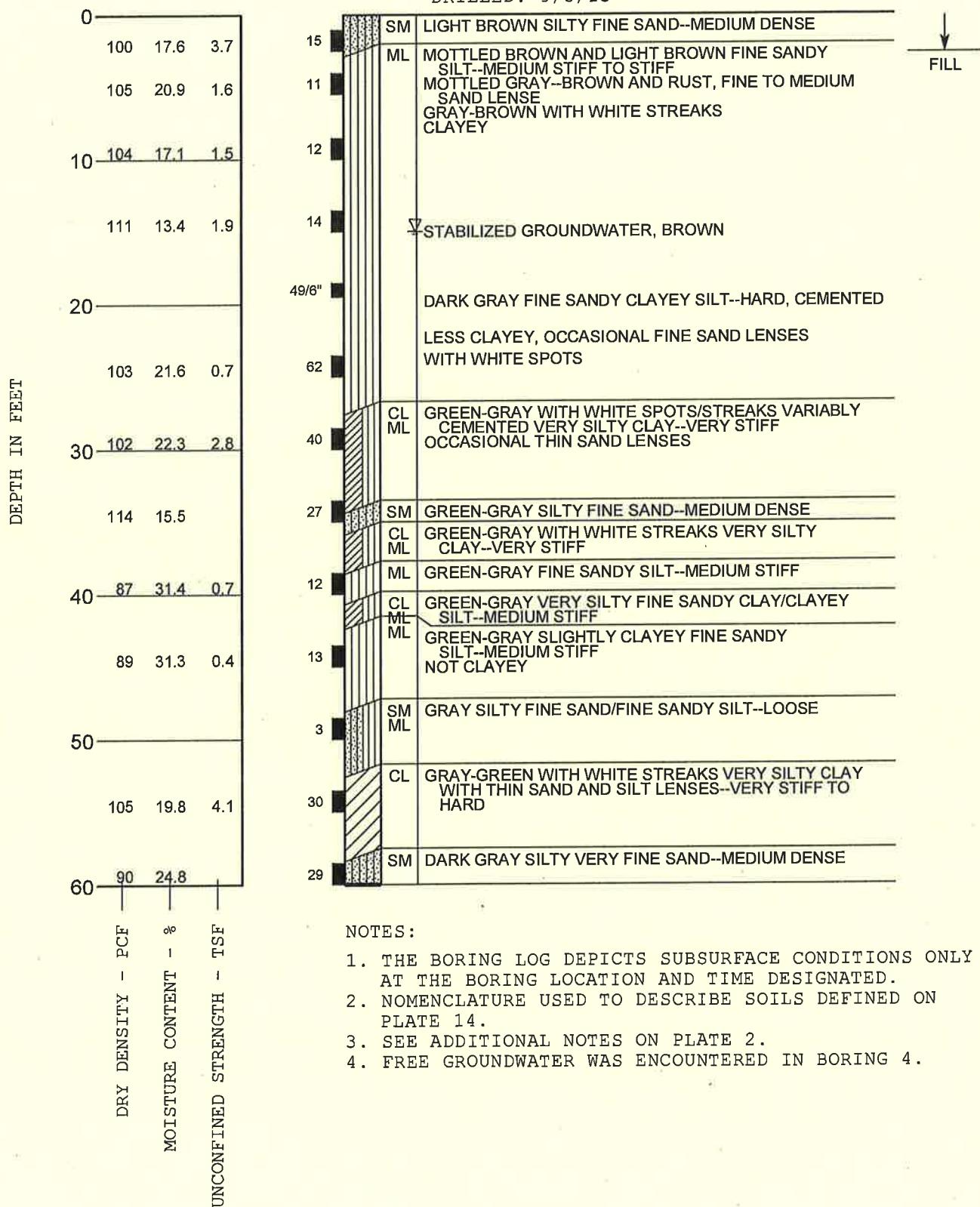
- 10 gravelly sand to sand
- 11 very stiff fine grained (\*)
- 12 sand to clayey sand (\*)

## BORING 4

DRILLED: 9/5/13

DRAWN BY: EM  
DATE: 5/19/15

PROJECT NUMBER: 1135-021  
PLATE NUMBER: 5



LOG OF BORING

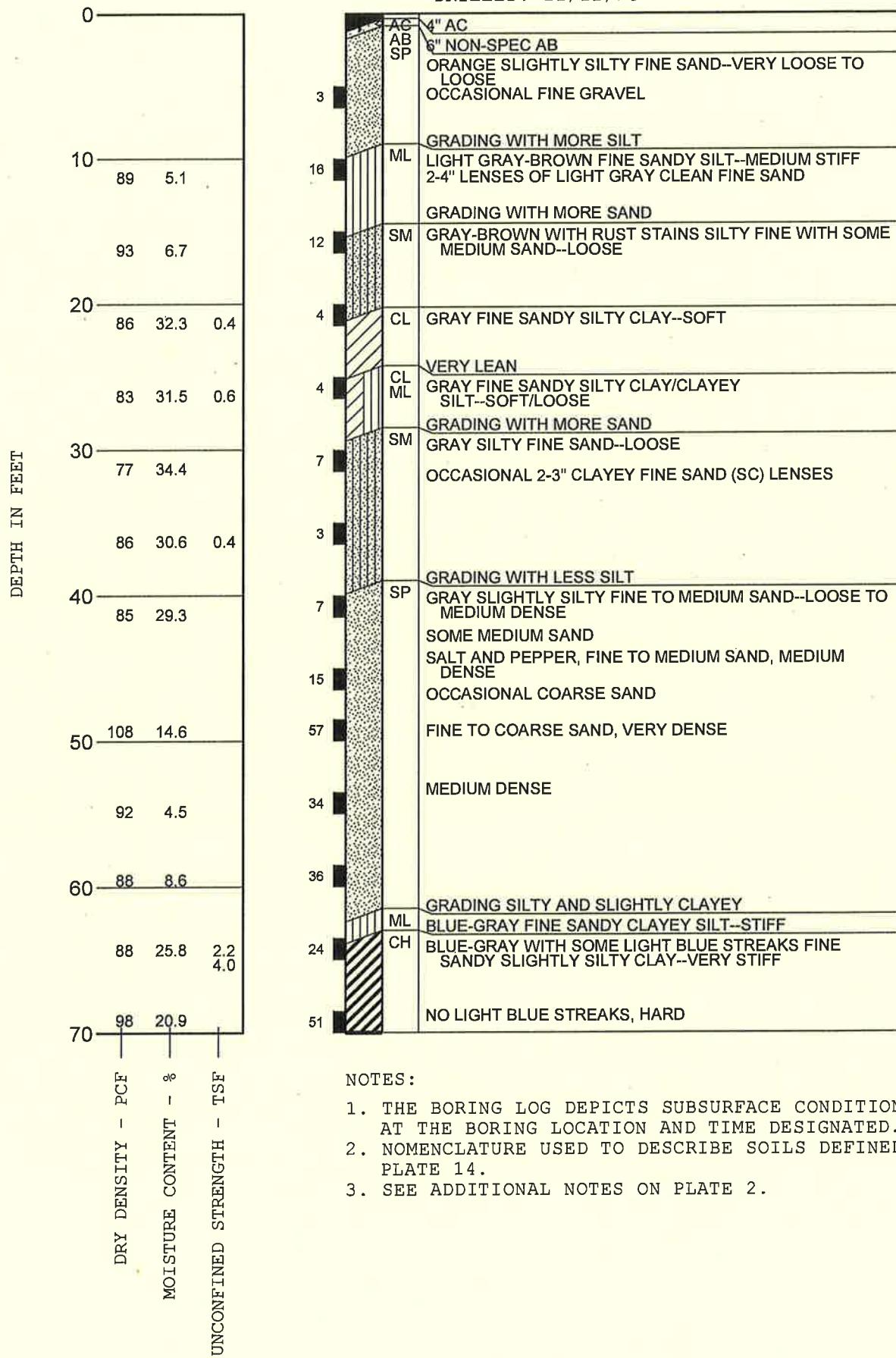
PLATE 5

# BORING 11

DRILLED: 11/12/13

DRAWN BY: TL  
DATE: 3/10/16

PROJECT NUMBER: 1135-021  
PLATE NUMBER: 12



## NOTES:

1. THE BORING LOG DEPICTS SUBSURFACE CONDITIONS ONLY AT THE BORING LOCATION AND TIME DESIGNATED.
2. NOMENCLATURE USED TO DESCRIBE SOILS DEFINED ON PLATE 14.
3. SEE ADDITIONAL NOTES ON PLATE 2.

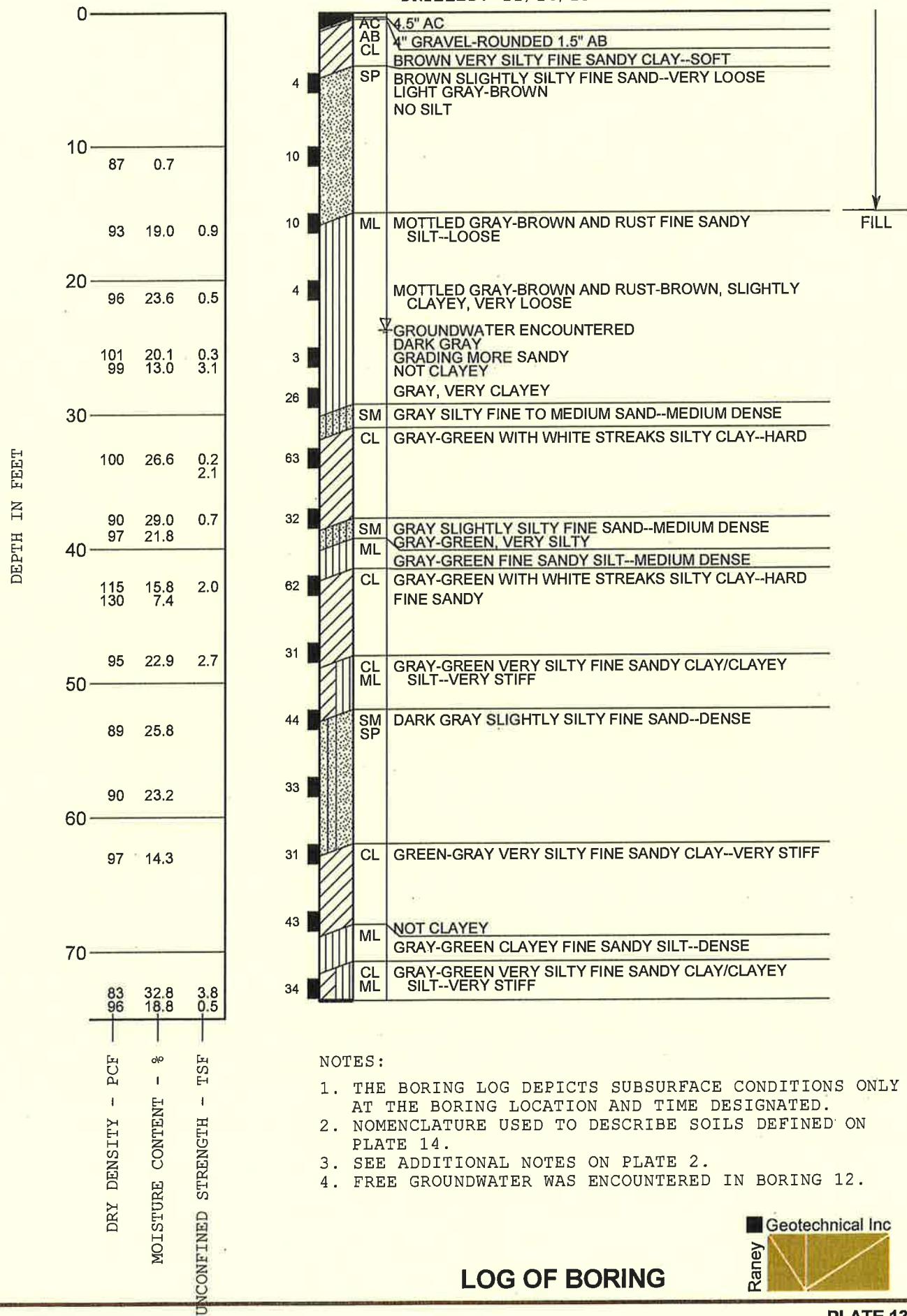
## LOG OF BORING

PROJECT NUMBER: 1135-021  
PLATE NUMBER: 13

DRAWN BY: T.L.  
DATE: 3/10/16

## BORING 12

DRILLED: 11/14/13



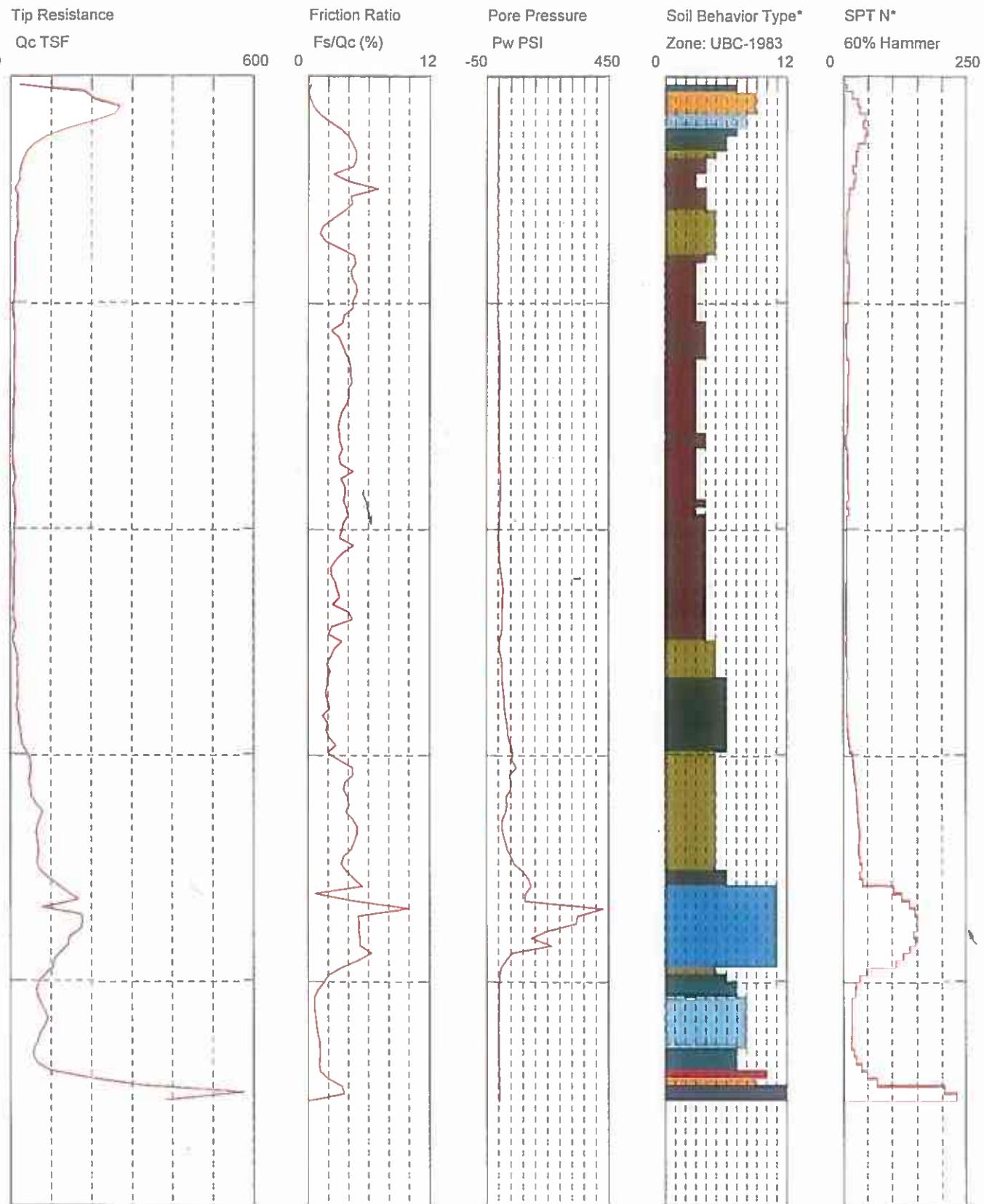
GRAPH	SYMBOL	DESCRIPTION	MAJOR DIVISIONS	
Dotted	GW	WELL GRADED GRAVELS, GRAVEL-SAND MIXTURES	CLEAN GRAVELS WITH LESS THAN 5% FINES	GRAVEL AND GRAVELLY SOILS
	GP	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES		
	GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES	GRAVELS WITH MORE THAN 12% FINES	MORE THAN 50% OF COARSE FRACTION <u>RETAINED</u> ON NO. 4 SIEVE
	GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES		
	SW	WELL GRADED SANDS, GRAVELLY SANDS	CLEAN SANDS WITH LESS THAN 5% FINES	SANDS AND SANDY SOILS
	SP	POORLY GRADED SANDS, GRAVELLY SANDS		
	SM	SILTY SANDS, SAND-SILT MIXTURES	SANDS WITH MORE THAN 12% FINES	MORE THAN 50% OF COARSE FRACTION <u>PASSING</u> NO. 4 SIEVE
	SC	CLAYEY SANDS, SAND-CLAY MIXTURES		
	ML	INORGANIC SILTS, ROCK FLOUR, OR CLAYEY SILTS WITH SLIGHT PLASTICITY	LIQUID LIMIT <u>LESS THAN 50</u>	SILTS AND CLAYS
	CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS		
	OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY		
Dashed	MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS SILTS, ELASTIC SILTS	LIQUID LIMIT <u>GREATER THAN 50</u>	SILTS AND CLAYS
	CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS		
	OH	ORGANIC CLAYS AND ORGANIC SILTS OF MEDIUM TO HIGH PLASTICITY		
Dotted	PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENT	HIGHLY ORGANIC SOILS	

## UNIFIED SOIL CLASSIFICATION SYSTEM

# Raney Geotechnical

Operator: Rocco  
 Sounding: CPT-15Sta.27+70  
 Cone Used: DSG1111

CPT Date/Time: 1/31/2014 12:29:29 PM  
 Location: Walnut Grove  
 Job Number: RNY-464-1135-021



Maximum Depth = 22.64 feet

Depth Increment = 0.164 feet

1 sensitive fine grained  
 2 organic material  
 3 clay

4 silty clay to clay  
 5 clayey silt to silty clay  
 6 sandy silt to clayey silt

7 silty sand to sandy silt  
 8 sand to silty sand  
 9 sand

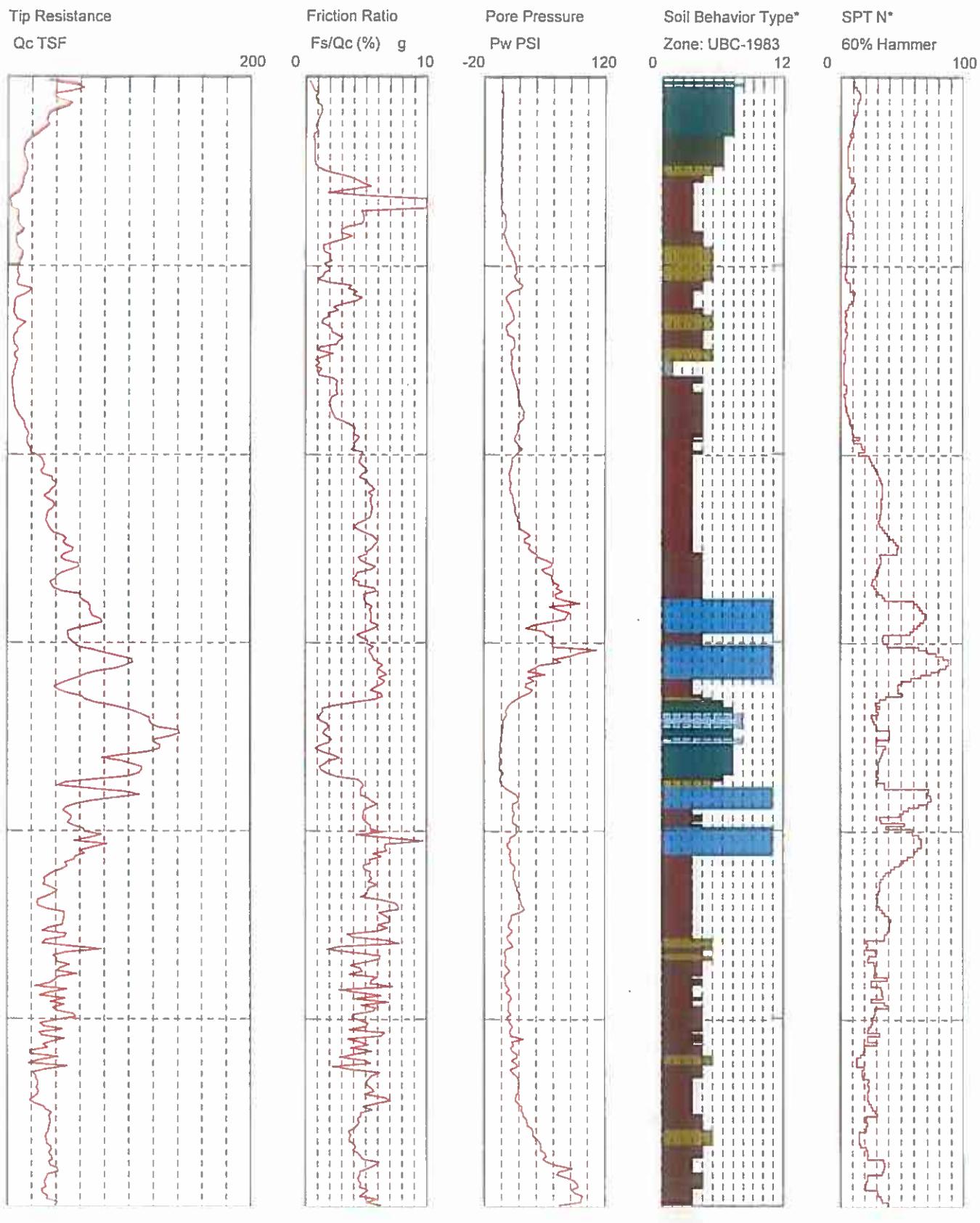
10 gravelly sand to sand  
 11 very stiff fine grained (\*)  
 12 sand to clayey sand (\*)

# Raney Geotechnical

Operator: Rocco  
 Sounding: CPT-1  
 Cone Used: DDG1316

**CPT 18**

CPT Date/Time: 8/2/2016 3:21:12 PM  
 Location: Walnut Grove  
 Job Number: RNY-569



1 sensitive fine grained  
 2 organic material  
 3 clay  
 Auto Enhance On

4 silty clay to clay  
 5 clayey silt to silty clay  
 6 sandy silt to clayey silt

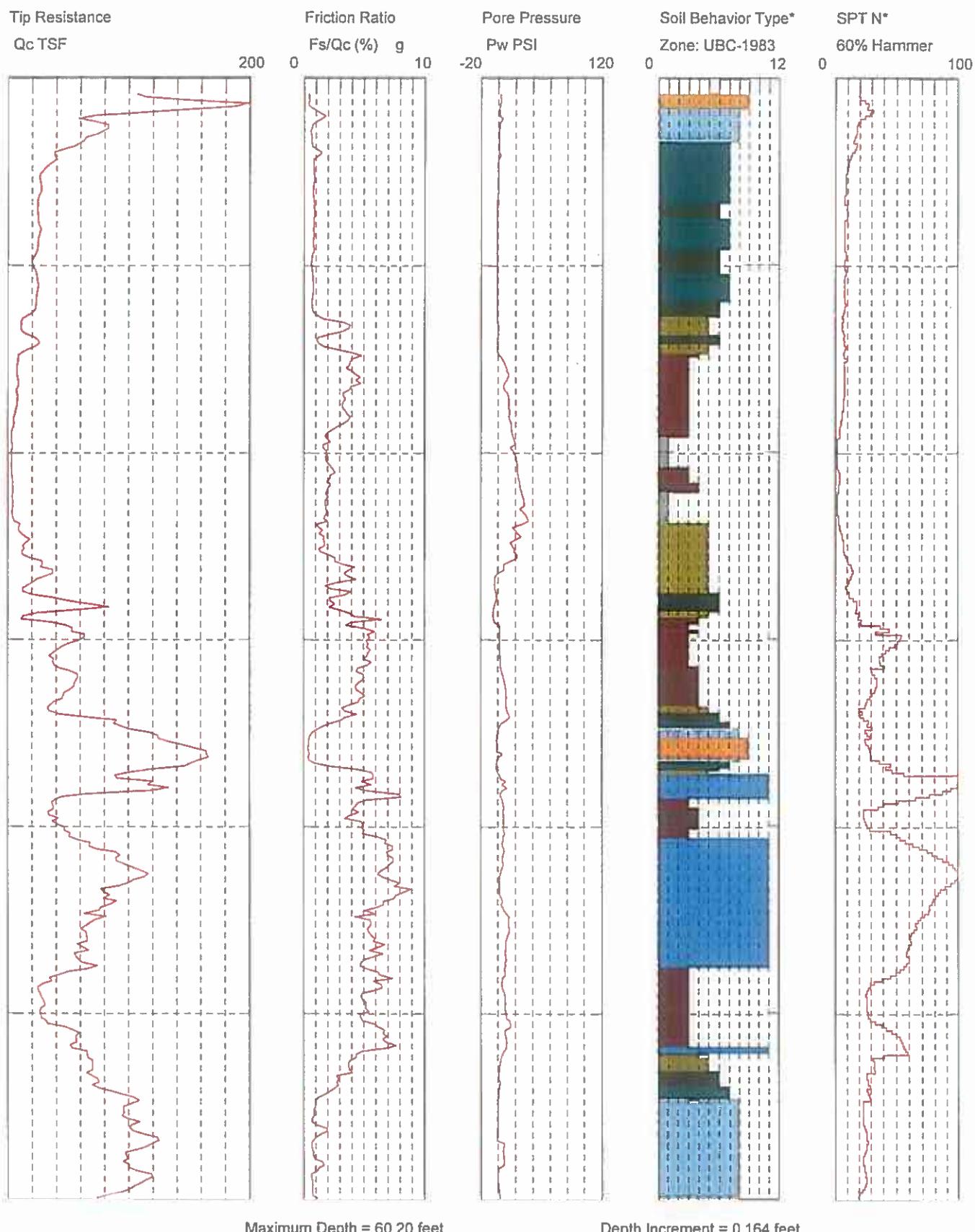
7 silty sand to sandy silt  
 8 sand to silty sand  
 9 sand  
 Filter On  
 10 gravelly sand to sand  
 11 very stiff fine grained (\*)  
 12 sand to clayey sand (\*)

# Raney Geotechnical

Operator: Rocco  
 Sounding: CPT-2  
 Cone Used: DDG1316

**CPT 19**

CPT Date/Time: 8/2/2016 11:07:40 AM  
 Location: Walnut Grove  
 Job Number: RNY-569



1 sensitive fine grained  
 2 organic material  
 3 clay  
 Auto Enhance On

4 silty clay to clay  
 5 clayey silt to silty clay  
 6 sandy silt to clayey silt

7 silty sand to sandy silt  
 8 sand to silty sand  
 9 sand

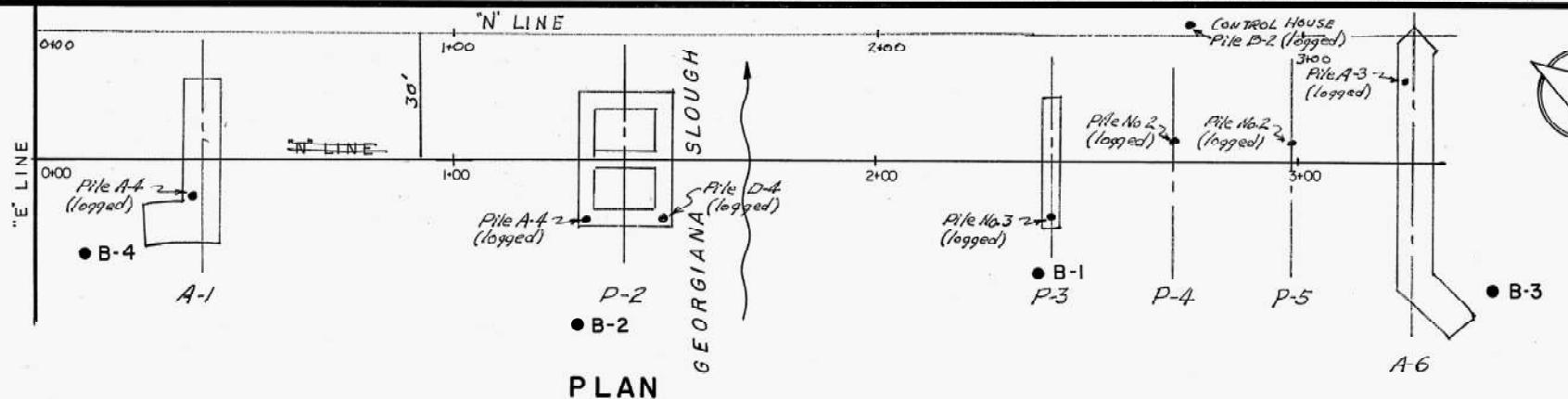
10 gravelly sand to sand  
 11 very stiff fine grained (\*)  
 12 sand to clayey sand (\*)

DIST	COUNTY	ROUTE	SECTION	SHRIFT NO	TOTAL SHEETS
111	SAC	1260		13	34

*W.J. Pend*

Approved February 2, 1961

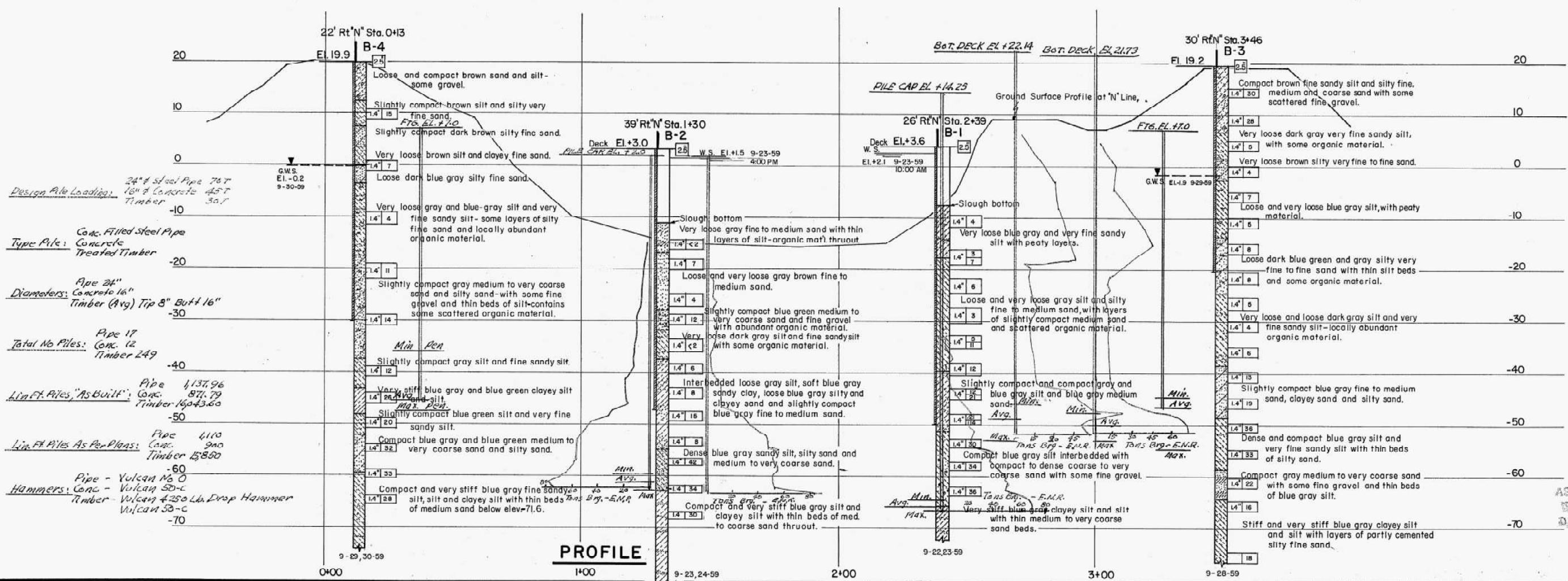
Received February 2, 1961



## PLAN

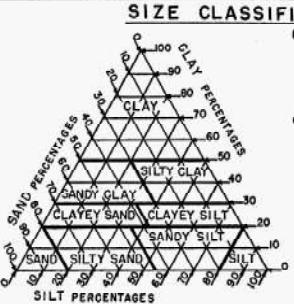
## **NOTE**

TBM — Bolt in pavement at "N" Sta. 0+00  
Elevation 20.18 U.S.G.S. datum.



## PROFIL

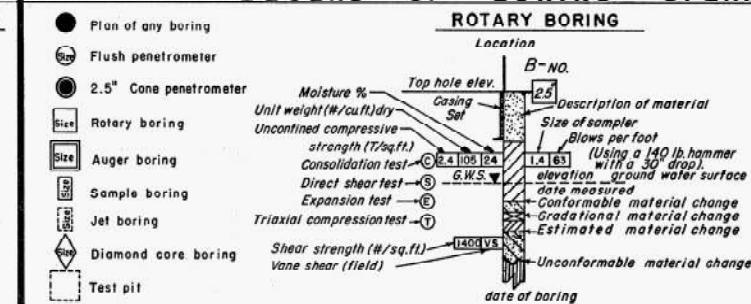
## LEGEND OF EARTH MATERIAL



MATERIAL SYMBOLS	
	Gravel
	Sand
	Silt
	Clay
	Sandy clay or clayey sand
	Sandy silt or silty sand
	Silty clay or clayey silt
	Peat or organic m.
	Fill mate
	Shale
	Sandstone
	Limestone
	Metamorph
	Igneous ro

CONSISTENCY CLASSIFICATION		
According to the Standard Penetration Test.		
No. of blows	Granular	Cohesive
0-5	very loose	very soft
6-10	loose	soft
11-20	slightly compact	stiff
21-35	compact	very stiff
36-70	dense	hard
70+	very dense	very hard

**LEGEND OF BORING OPERATIONS**



**PENETRATION TEST**

---

Location \_\_\_\_\_

**Top hole elev.** B-NO.

Pushed-in P elevation ground water surface

No count recorded date measured

**Blows per foot**

(Using a 140-lb.  
hammer with a  
30" drop)

Graphic representation  
of driving rate.

Date of boring	Blows per foot
0	10
1	11
2	12
3	13
4	14
5	15
6	16
7	17
8	18
9	19
10	20
11	21
12	22
13	23
14	24
15	25
16	26
17	27
18	28
19	29
20	30
21	31
22	32
23	33
24	34
25	35
26	36
27	37
28	38
29	39
30	40

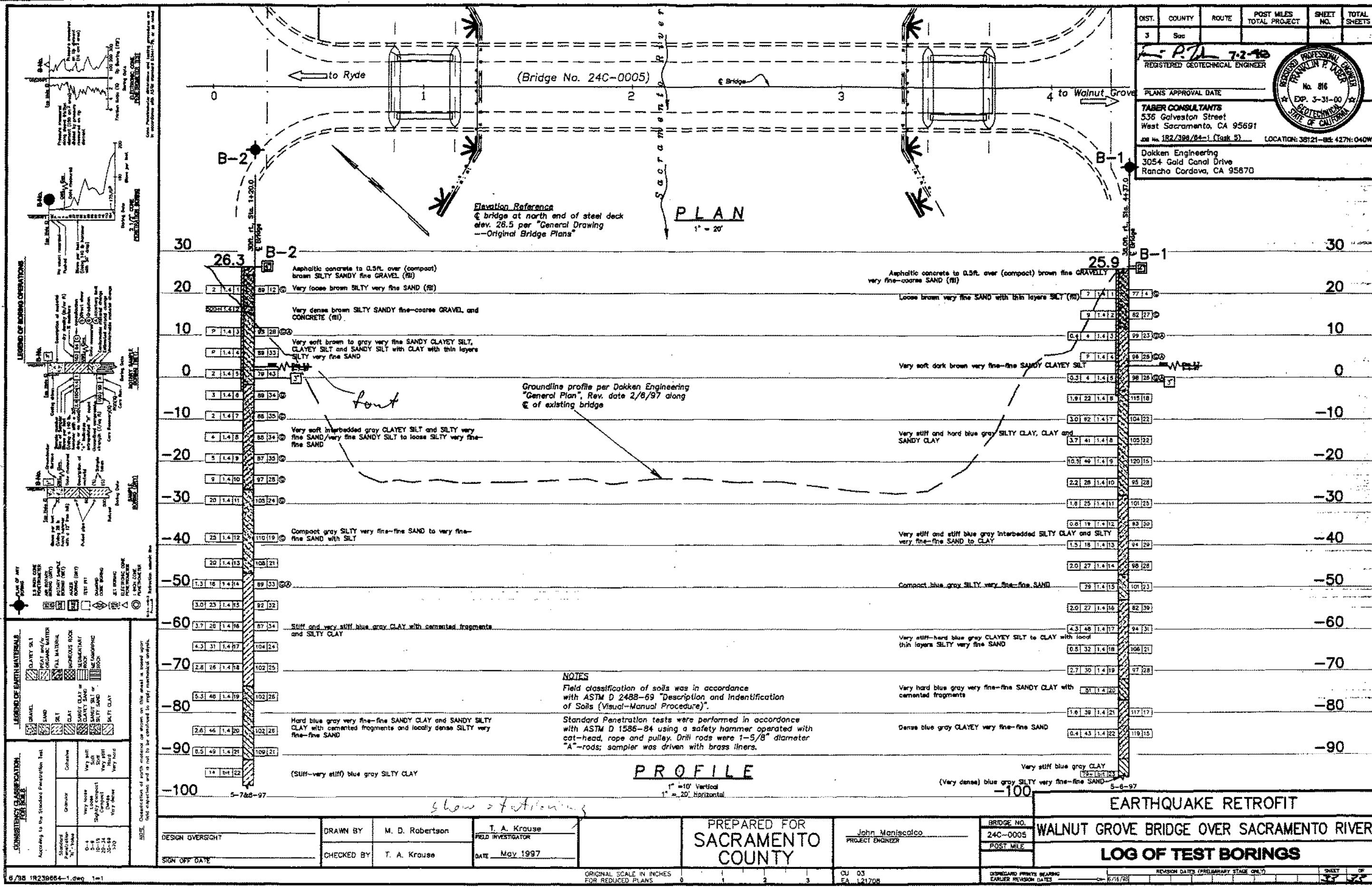
MOORE and TABER

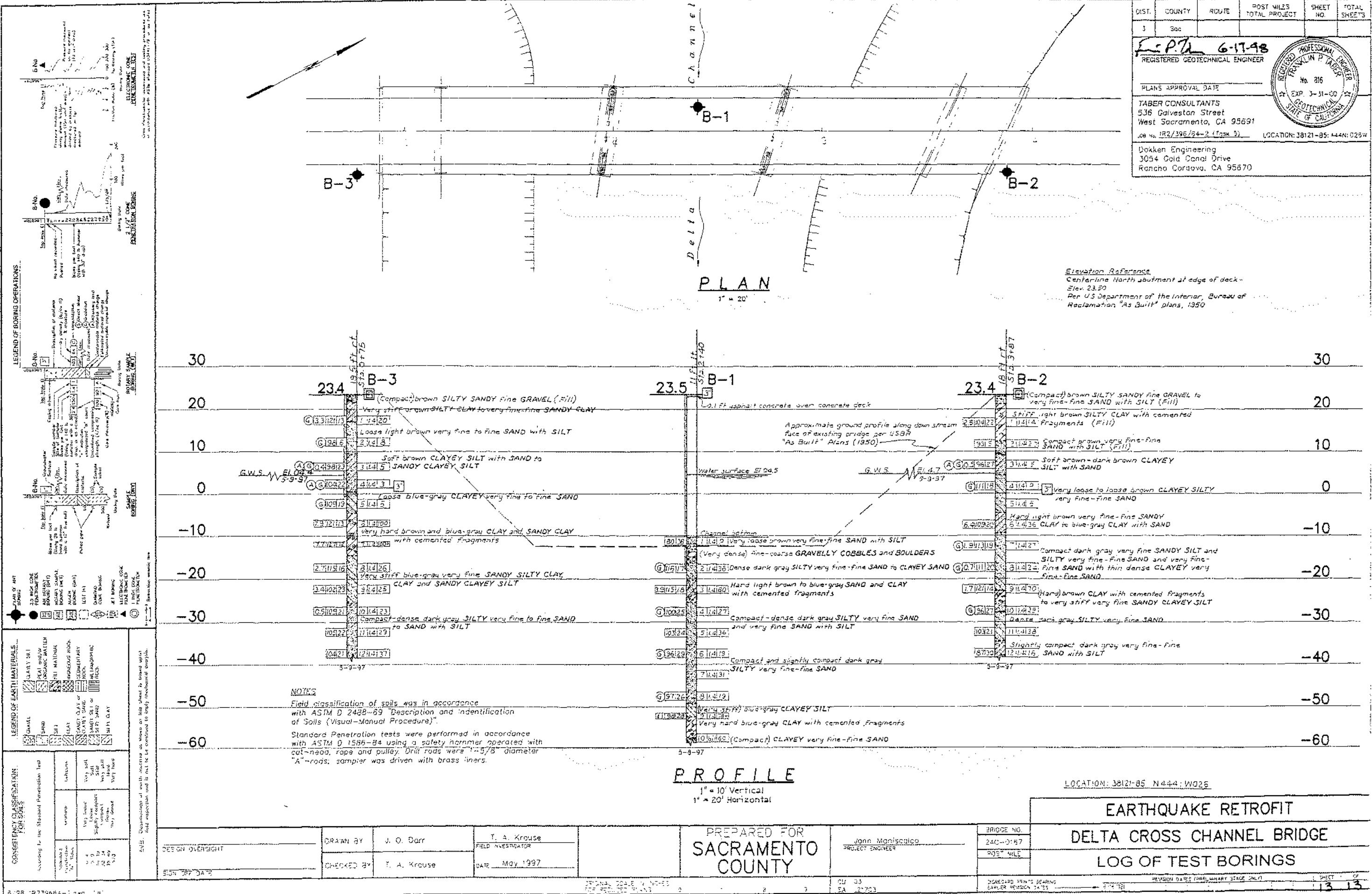
Engineers — Geologists

SACRAMENTO COUNTY

## BRIDGE ACROSS SEASIDE AND COUNTRY

## LOG OF TEST BORINGS





# **Preliminary Existing Condition Stability, Seepage and Settlement Evaluation**

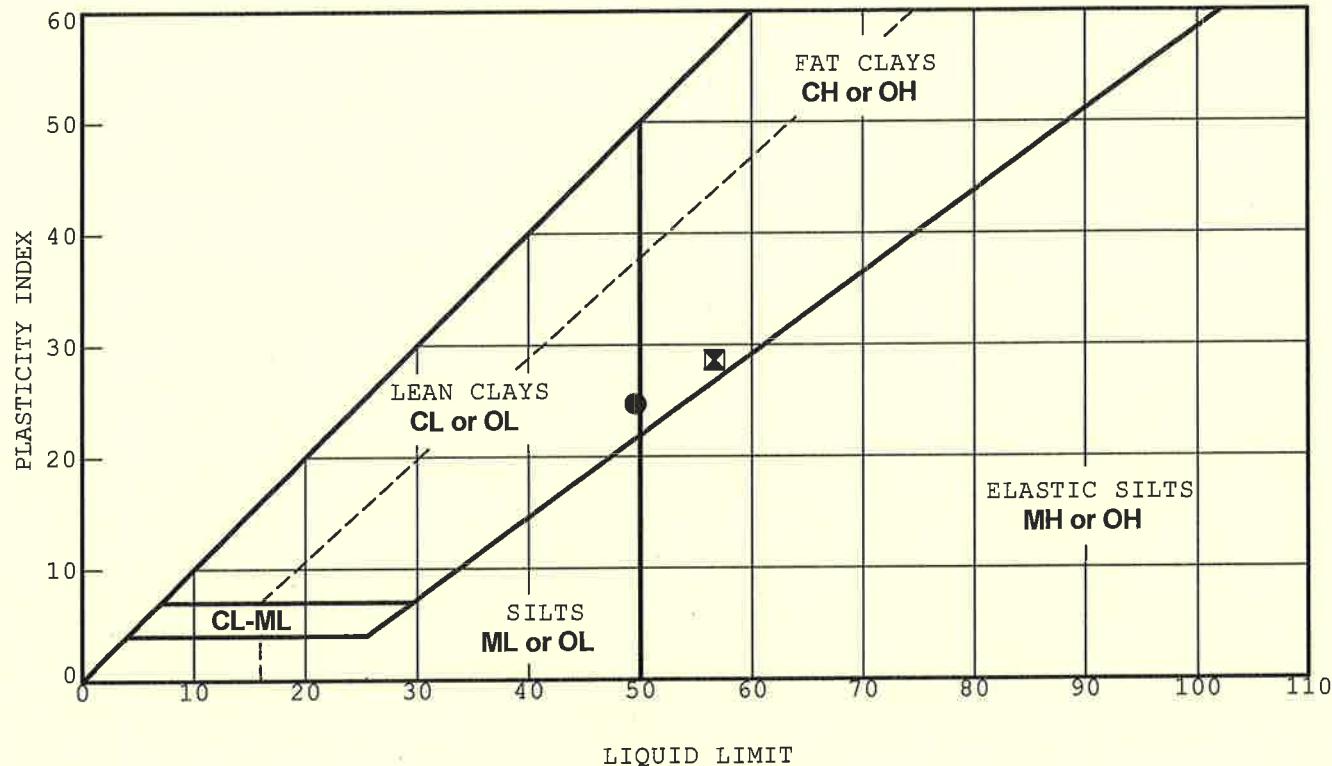
## **Sacramento River and Georgiana Slough East Levees**

**Community of East Walnut Grove, California**

**California Department of Water Resources Small  
Community Flood Risk Reduction Program**

### **APPENDIX B**

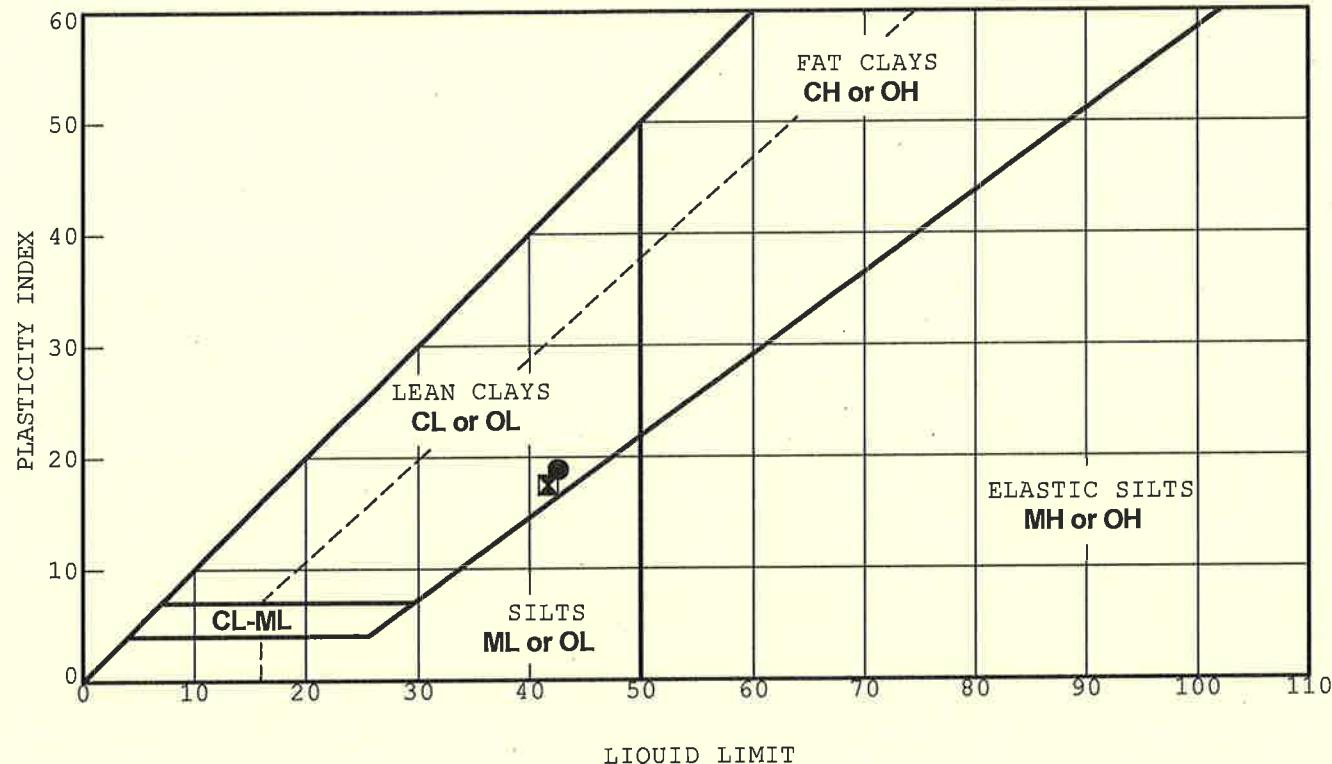
#### **Historic Laboratory**



CLASSIFICATION TEST RESULTS						
SYMBOL	SAMPLE LOCATION	DEPTH FEET	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL CLASSIFICATION
●	BORING 11	64.5	50	25	25	CH
■	BORING 11	69.0	57	28	29	CH

## ATTERBERG LIMIT DATA

PROJECT NUMBER: 1135-021  
 PLATE NUMBER: 24H

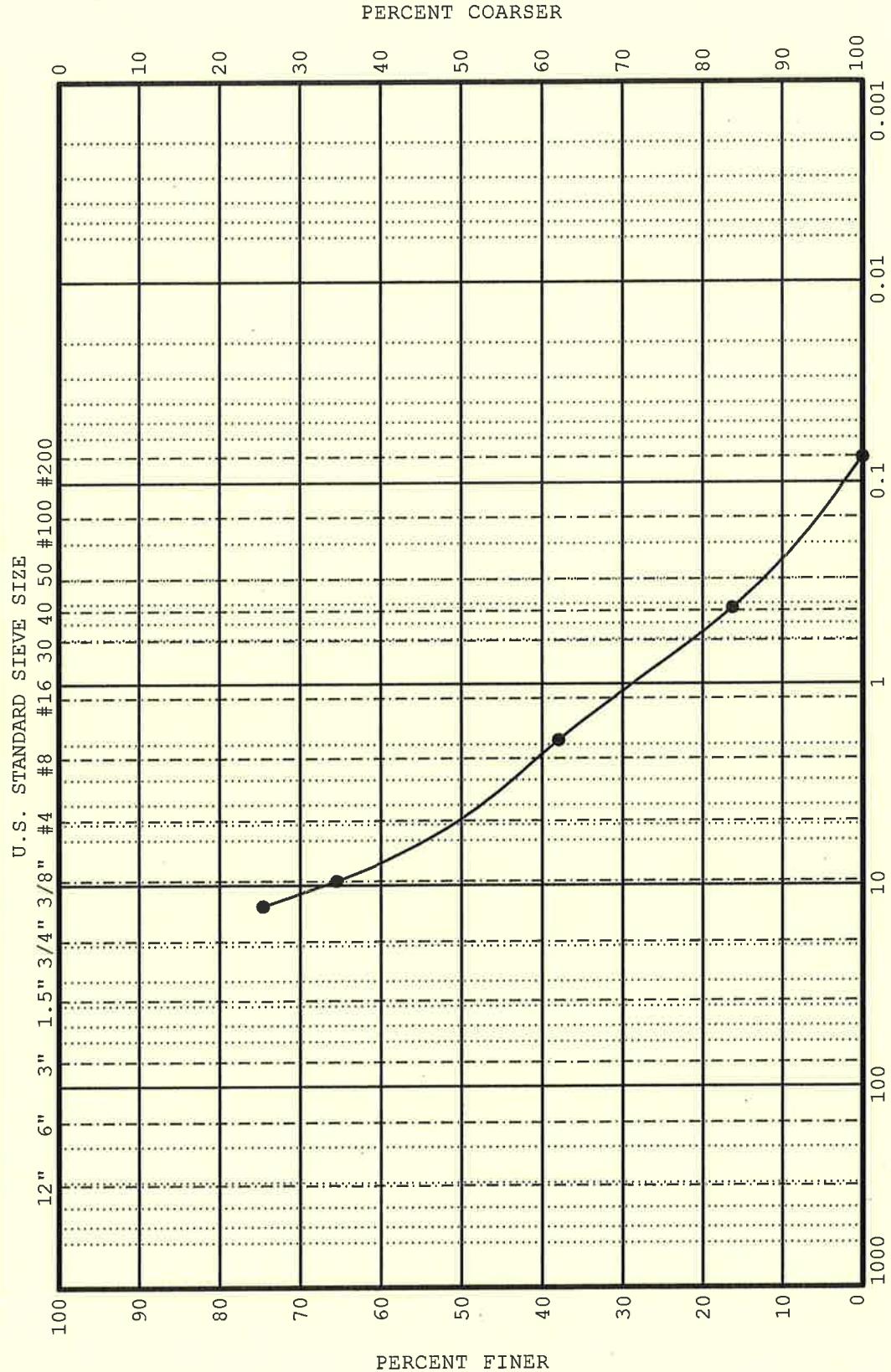


CLASSIFICATION TEST RESULTS						
SYMBOL	SAMPLE LOCATION	DEPTH FEET	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL CLASSIFICATION
●	BORING 12	34.5	43	24	19	CL
■	BORING 12	47.5	42	24	18	CL

## ATTERBERG LIMIT DATA

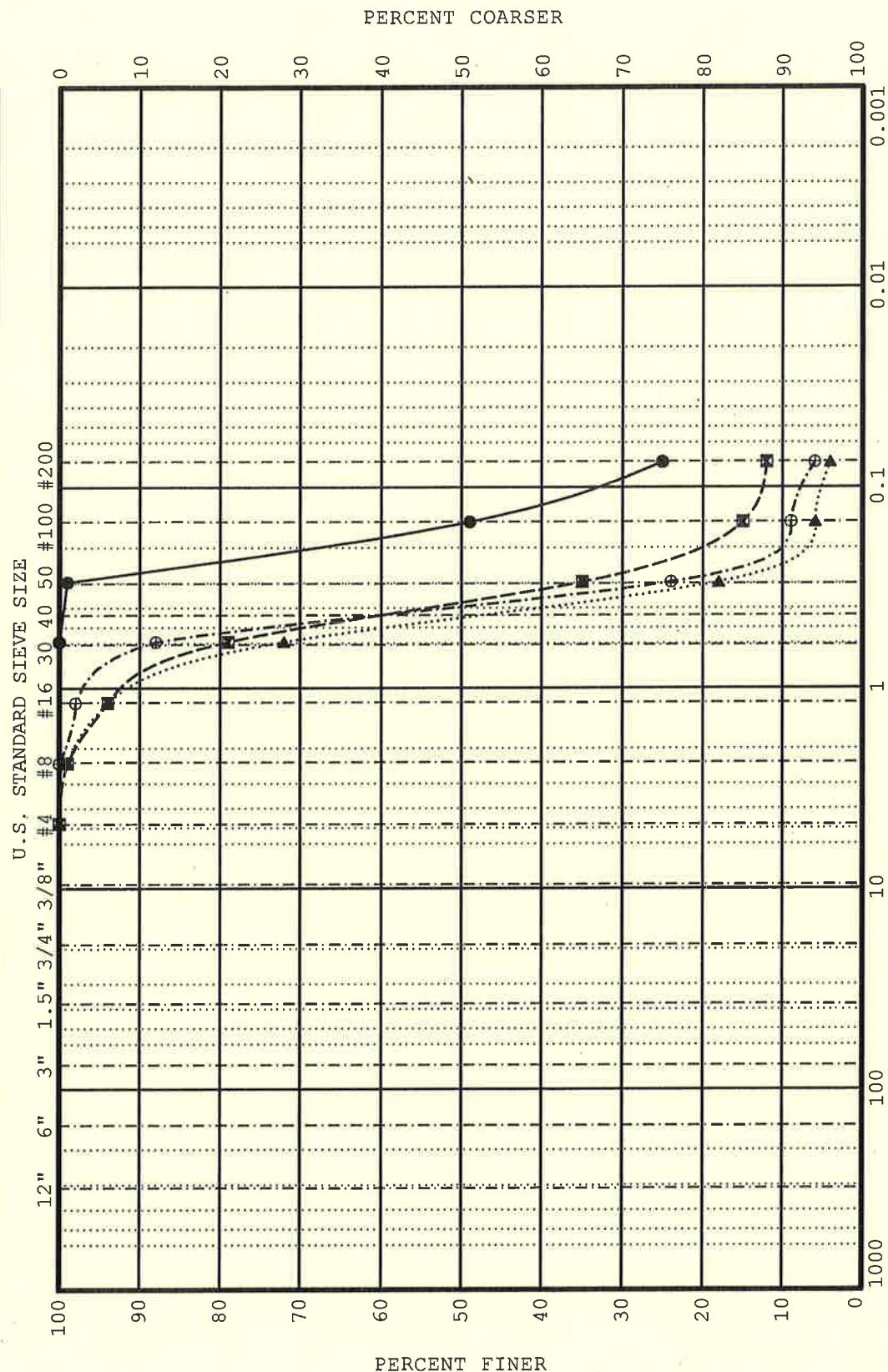
PROJECT NUMBER: 1135-021  
 PLATE NUMBER: 25D

SYMBOL	LOCATION	DEPTH	UNIFIED CLASSIFICATION	DESCRIPTION
●	BORING 4	2.0'	SP	GRAY-BROWN FINE TO MEDIUM SAND



PROJECT NUMBER: 1135-021  
PLATE NUMBER: 251

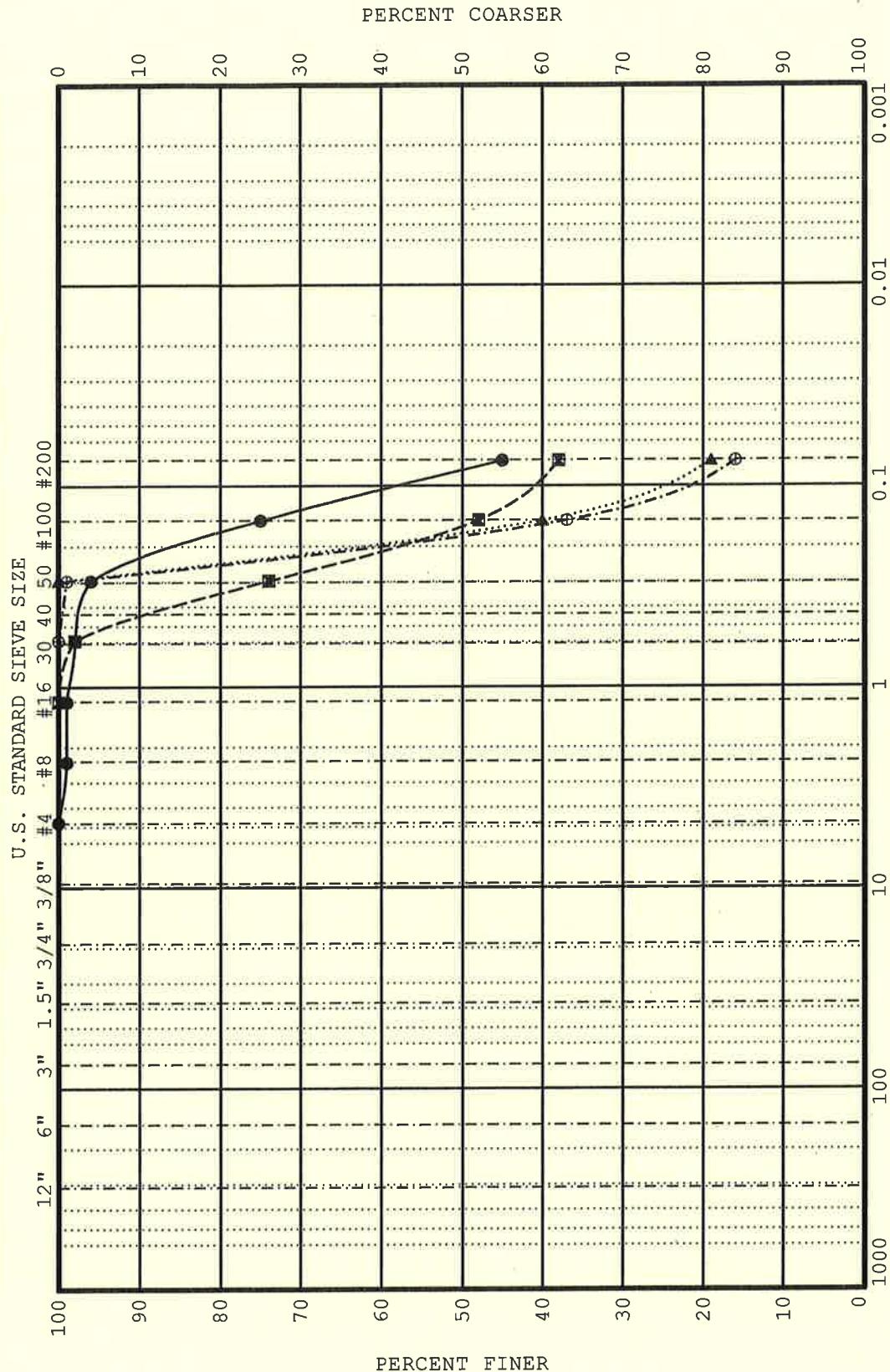
SYMBOL	LOCATION	DEPTH	UNIFIED CLASSIFICATION	DESCRIPTION
●	BORING 11	41.0'	SM	GRAY SILTY FINE SAND
■	BORING 11	49.5'	SP-SP	GRAY SILTY FINE TO MEDIUM SAND
▲	BORING 11	54.5'	SP	GRAY SLIGHTLY SILTY FINE TO COARSE SAND
⊕	BORING 11	59.5'	SP-SP	GRAY SILTY FINE TO COARSE SAND



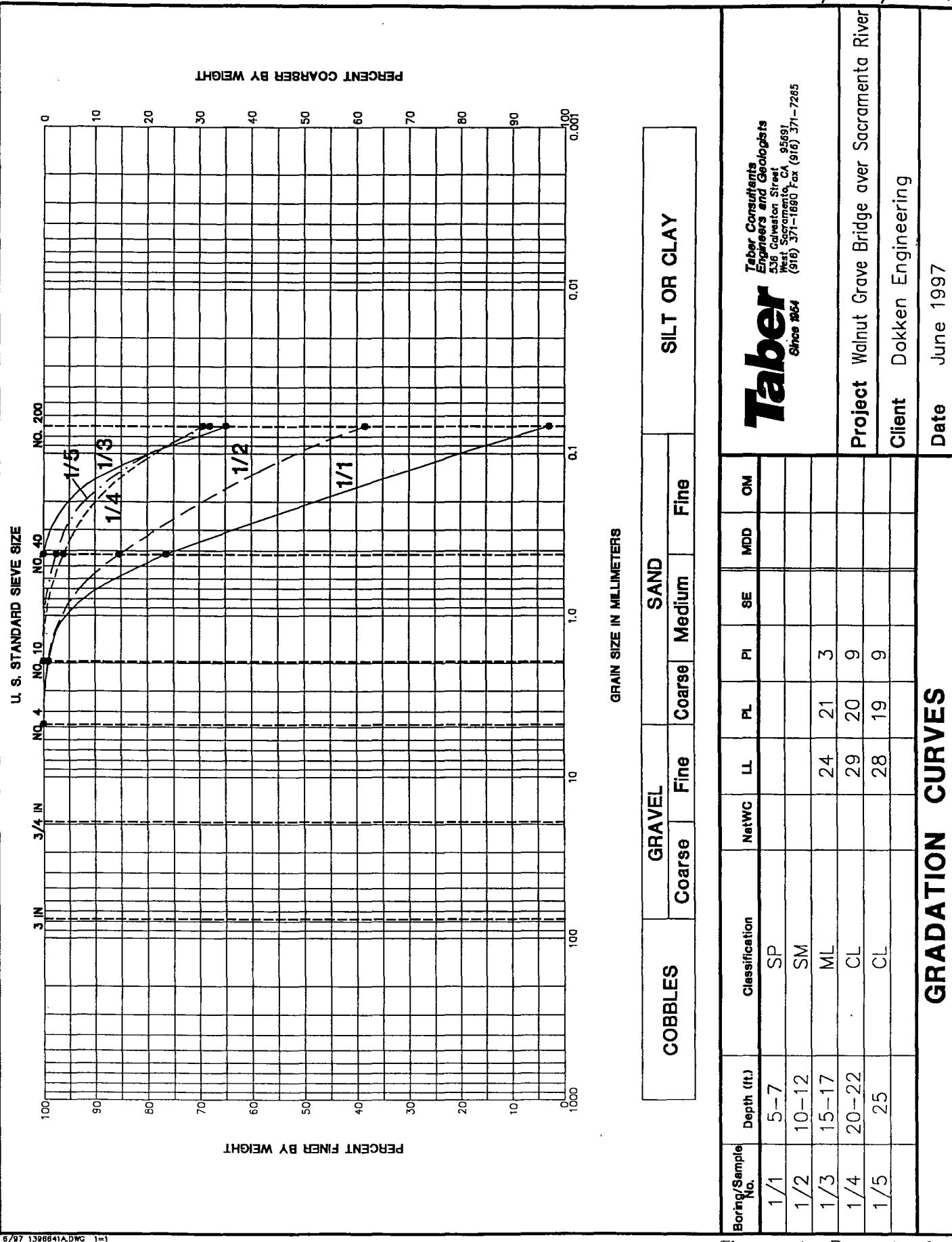
## GRAIN SIZE DISTRIBUTION

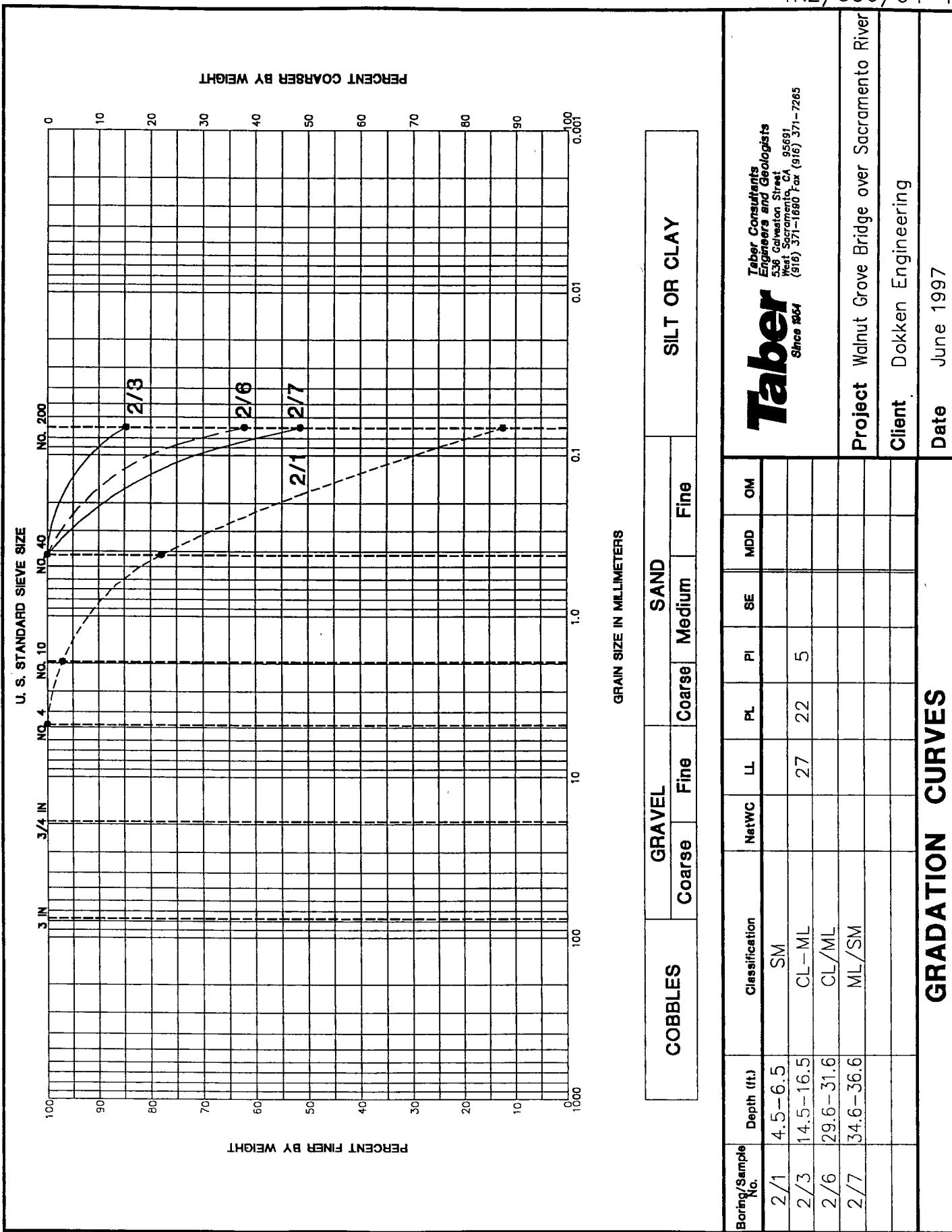
PROJECT NUMBER: 1135-021  
 PLATE NUMBER: 25J

SYMBOL	LOCATION	DEPTH	UNIFIED CLASSIFICATION	DESCRIPTION
●	BORING 12	38.0'	SM	GRAY SLIGHTLY SILTY FINE SAND
■	BORING 12	43.5'	SM	GRAY FINE SANDY SILTY CLAY
▲	BORING 12	53.5'	SM	DARK GRAY SLIGHTLY SILTY FINE SAND
⊕	BORING 12	58.5'	SM	DARK GRAY SLIGHTLY SILTY FINE SAND



## GRAIN SIZE DISTRIBUTION





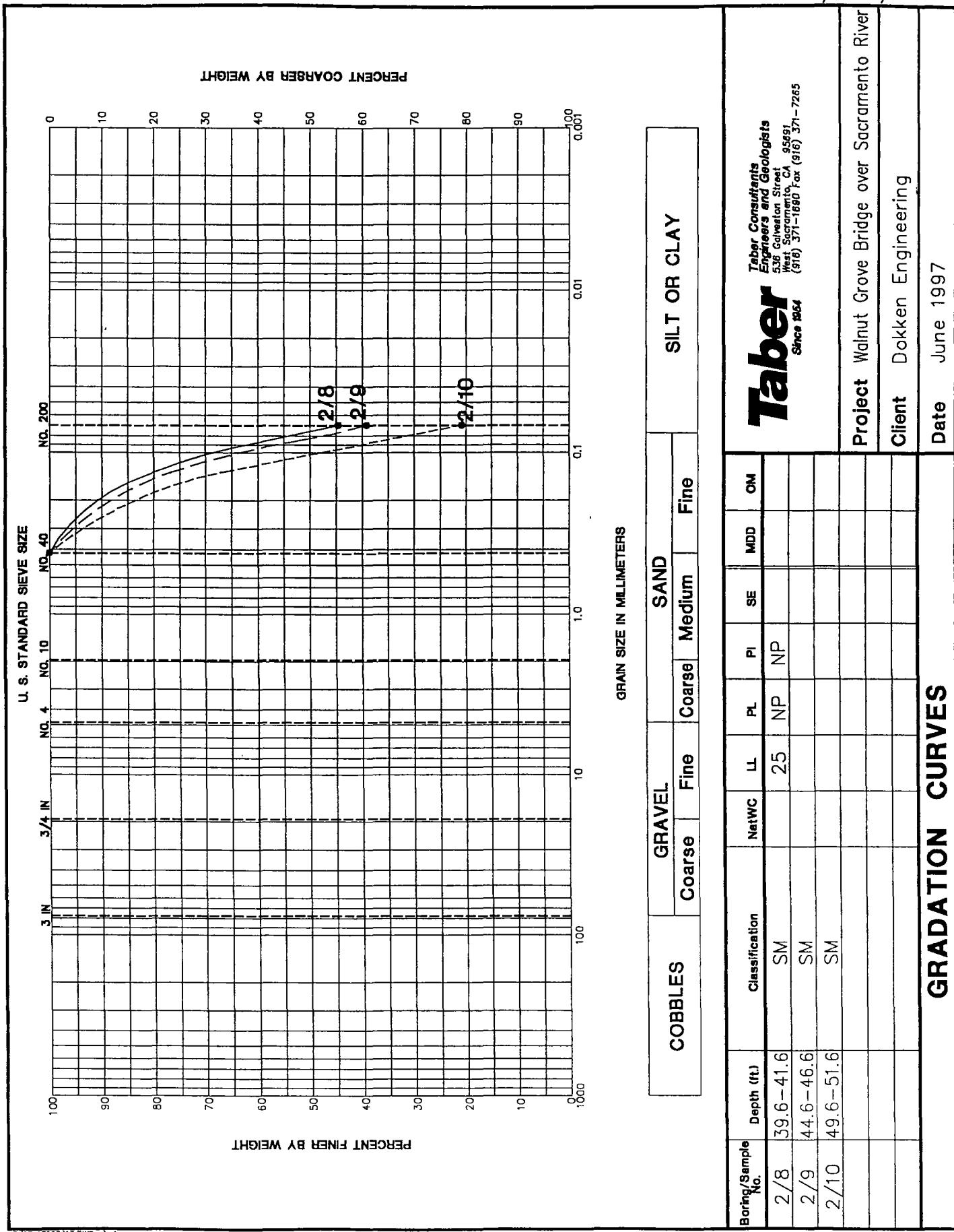
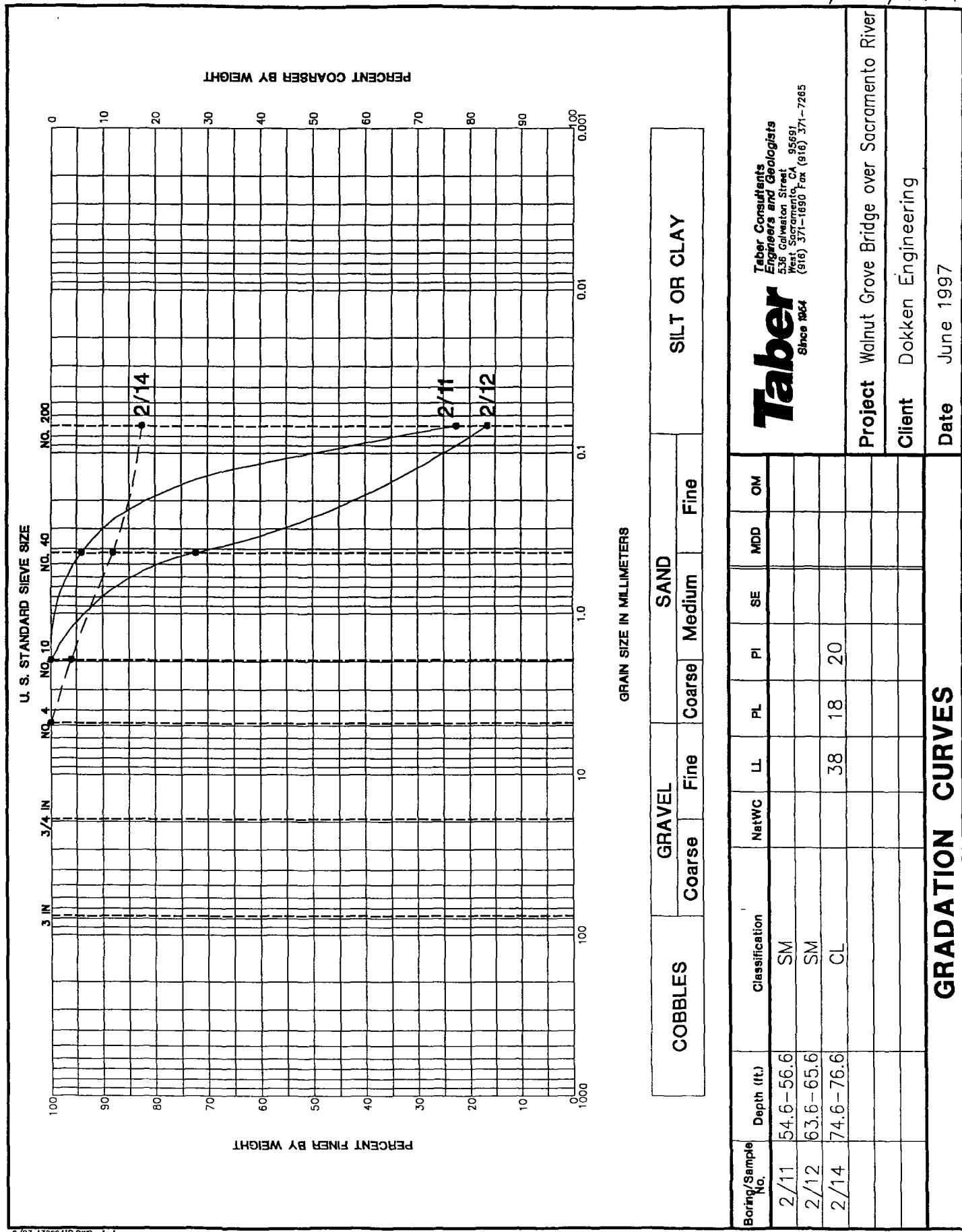
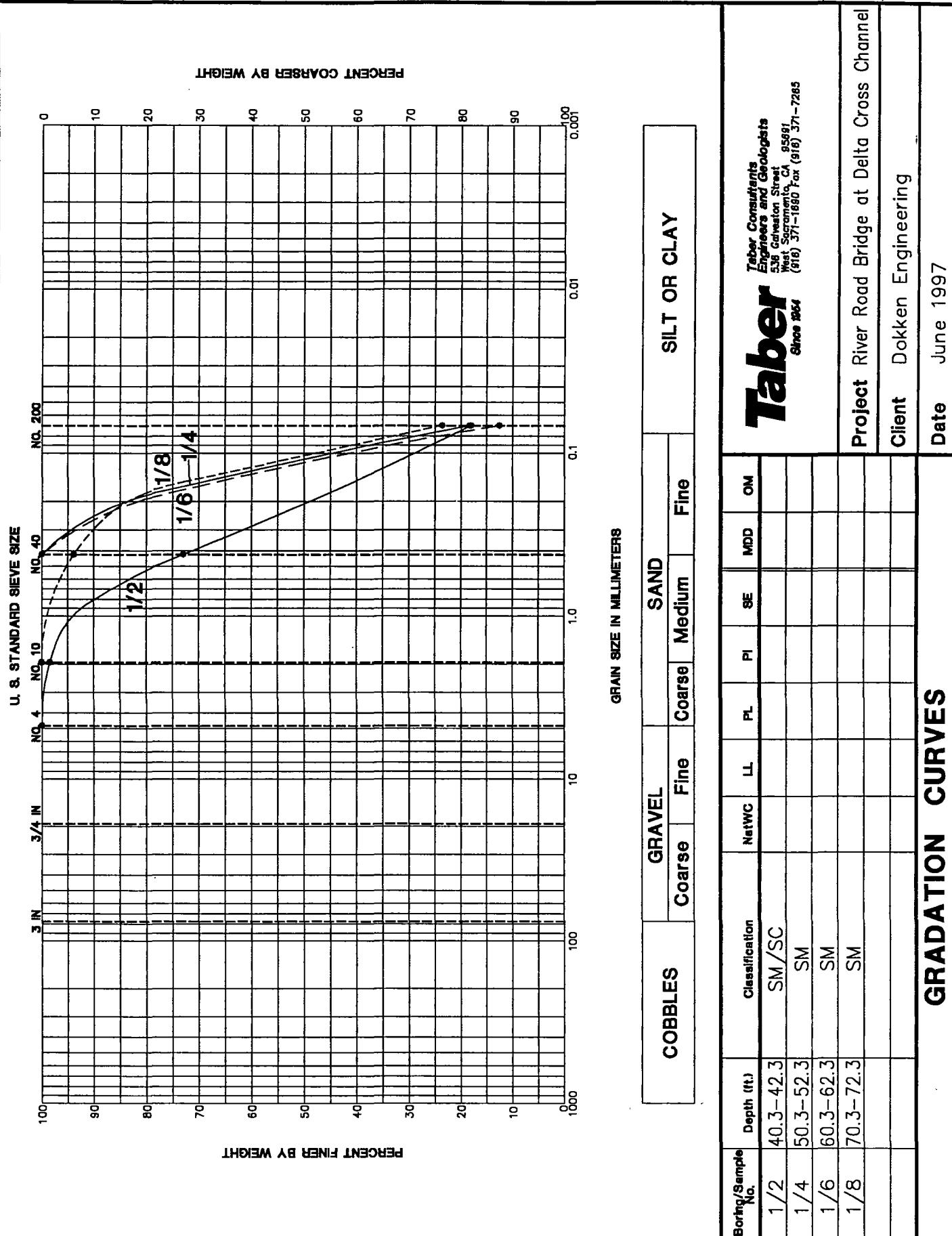


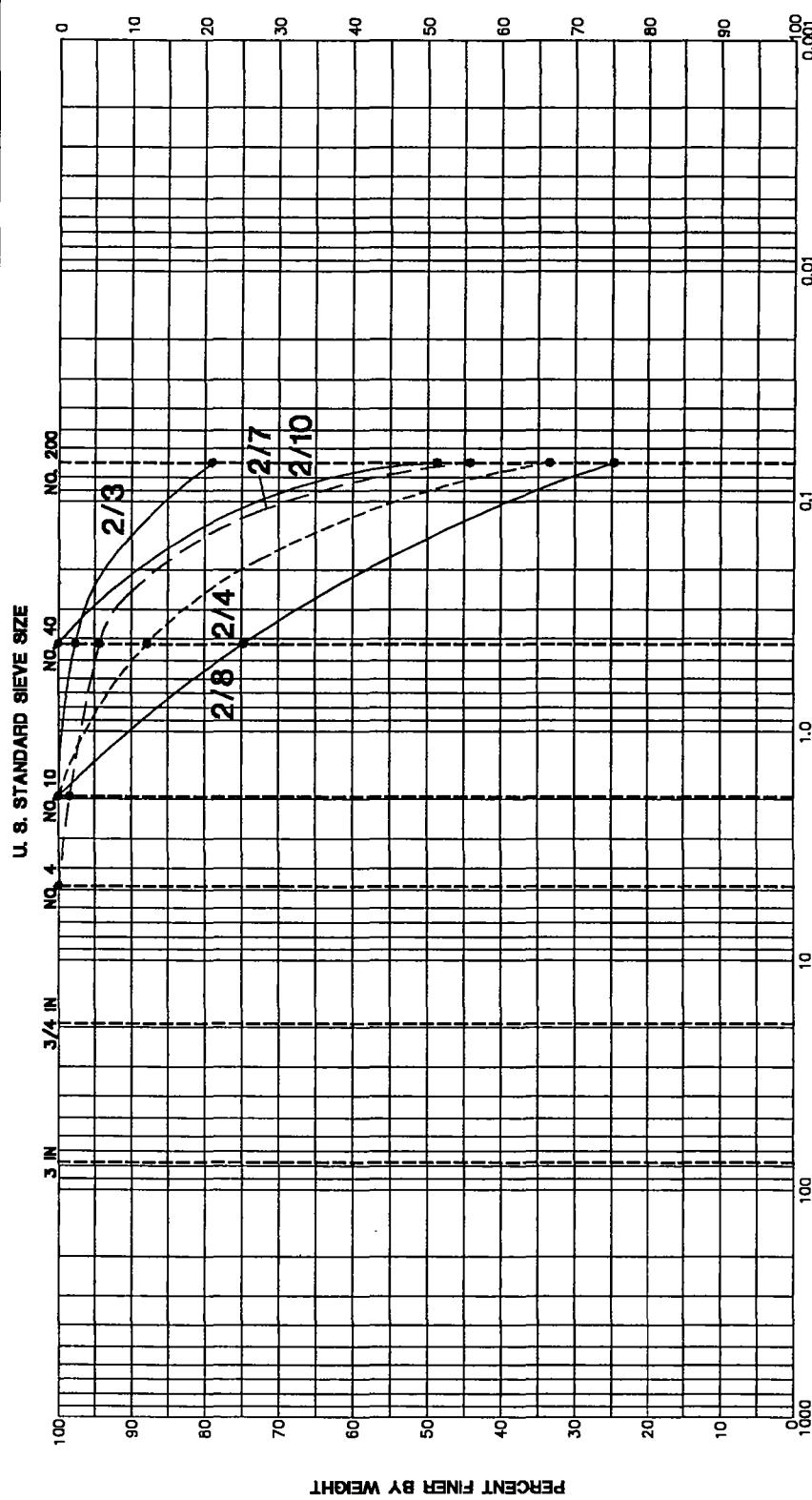
Figure-1 Page 3 of 4

Boring/Sample No.	Depth (ft.)	Classification	NaIWC	LL	PL	PI	SE	MDD	OM	<b>Taber</b>
2/8	39.6-41.6	SM		2.5	NP					Taber Consultants Engineers and Geologists 538 Colton Street West Sacramento, CA (916) 371-1590 Fax (916) 371-7265 Since 1964
2/9	44.6-46.6	SM								Project Walnut Grove Bridge over Sacramento River
2/10	49.6-51.6	SM								Client Dokken Engineering



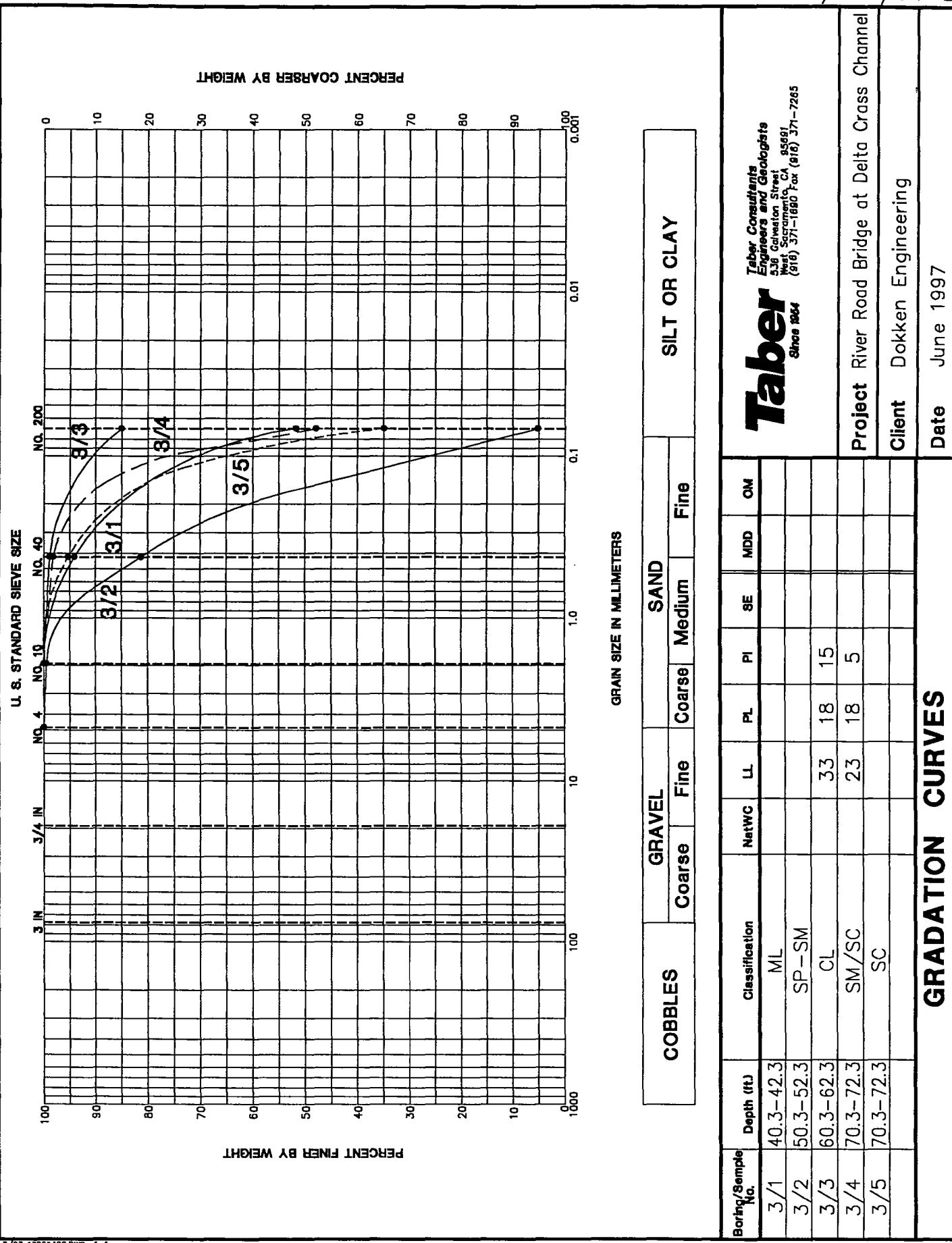


PERCENT COARSE BY WEIGHT



COBBLES	GRAVEL	FINE	COARSE	MEEDIUM	FINE	
2/3	2/4	2/7	2/8	2/10		

<b>Taber</b> Consultants Engineers and Geologists 538 Callejon Street West Sacramento, CA 95691 (916) 371-1880 Fax (916) 371-7285 Since 1964	<b>Project</b> River Road Bridge at Delta Cross Channel	<b>Client</b> Dakken Engineering
<b>GRADATION CURVES</b>	<b>Date</b> June 1997	



**Taber** Taber Consultants  
Engineers and Geologists  
538 Calivation Street  
West Sacramento, CA 95691  
(916) 371-1800 Fax (916) 371-7265  
Since 1904

Project River Road Bridge at Delta Cross Channel

Client Dokken Engineering

Date June 1997

# **Preliminary Existing Condition Stability, Seepage and Settlement Evaluation**

## **Sacramento River and Georgiana Slough East Levees**

**Community of East Walnut Grove, California**

**California Department of Water Resources Small  
Community Flood Risk Reduction Program**

## **APPENDIX C**

**NULE GAR Segment 128  
NULE Geomorphology Technical Memorandum**

## RD 0554, UNIT 1, SEGMENT 128 SUMMARY

This segment summary presents collected information and the assessment results for Segment 128. The summary is based on data that were readily available data at the time the segment was assessed. The amount of detail that was available varied. Known pertinent details are included. For details on the data collection and assessment procedures, see Volume 1, Section 2 of this report.

This summary is organized into the following seven sections:

- Segment Description and Assessment Summary
- Levee Segment History
- General Levee Conditions
- Levee Composition and Foundation Conditions
- Geotechnical Assessment Results
- Other Levee Assessments
- Hazard Mitigation

### Segment 128: Segment Description and Assessment Summary

Segment 128 is a non-urban Project levee located near Walnut Grove on the left (east) bank of the Sacramento River in Sacramento County, California (see attached map). The segment extends from the confluence of the Delta Cross Canal and the Sacramento River southward to the confluence of Georgiana Slough and the Sacramento River. The following table summarizes information for Segment 128.

---

#### *Segment 128 Information*

---

Maintenance Authority	Unit	Levee Miles*	NULE Stationing*
RD 0554	1	0.2 to 1.15	Sacramento River Left Bank 2470+93 to 2502+38 and Georgiana Slough Left Bank 1641+12 to 1656+04

\* The levee mile and stationing alignments differ.

As directed by DWR, the segment was assessed for each potential failure mode at the 1955/1957 design water surface elevation provided by DWR. The following table presents the Segment 128 categorizations for each potential failure mode.

---

#### *Segment 128 Potential Failure Mode Assessment Summary*

---

Potential Failure Mode	Categorization
Underseepage	Hazard Level A
Stability	Hazard Level A
Through Seepage	Hazard Level A
Erosion	Hazard Level A

Based on these NULE Phase 1 levee assessments, the overall categorization for Segment 128 is Hazard Level A.

## **Segment 128: Levee Segment History**

The levee segment history described in the following sections is based on reviews of documents that are available in the NULE document database, and on interviews with personnel familiar with the levee and its history. The descriptions include construction history, performance, improvements, and planned improvements. The amount and quality of information varies from segment to segment. This segment summary contains pertinent information gathered during data collection. Some details may not be known.

### ***Construction History***

Based on historical topographic maps (Isleton, 1:31,680), the Segment 128 levees were initially constructed prior to 1906 by local interests. Specific documentation of the construction methods for the levee were not available. Portions of the levee that did not meet Project standards were improved by the USACE to Project standards between 1954 and 1955 (Doc-2116). The improvements included levee construction and bank protection. The locations of the improvements were not available. The following table presents the 1953 MOU geometric criteria for Segment 128.

---

### ***Segment 128 Geometric Criteria***

Levee Type	Crown Width (feet)	Waterside Slope	Landside Slope
Project Levee	20	3H:1V	2H:1V

### ***Performance***

Levee performance information was obtained from reviewed documents and interviews with maintenance personnel. Based on the available information, performance events in Segment 128 include erosion that was reported in 1957, 1997, 1998, and 2003. There are no documented reports of underseepage, through seepage, or slope instability. The following table summarizes reported performance events.

---

### ***Segment 128 Reported Levee Performance Events***

Flood Season	Reported Performance Event	Approximate Location (Levee Mile)	Mitigation
1957	Waterside erosion, slope caved (Doc-5039).	LM 0.71 – LM 1.09	Mitigation not documented.
1997	Erosion - Scouring, embankment slope failure (Doc-256)	0.10, 0.34	Mitigation not documented.
1998	Toe failure of rock revetment (Doc-1540).	0.45 – 0.46	Repair recommended, Not documented.
2003	Erosion site (Doc-797).	0.52 (RM 26.9)	Upstream end (140') repaired (Doc-797).

### ***Improvements***

Re-sloping and placement of rock revetment in Segment 128 occurred between LM 0.77 and LM 0.84 in 1972 (Doc-4261) and between LM 1.06 and LM 1.15 in 1984 (Doc-4261).

Improvements also include riverbank protection work performed under the Sacramento River Bank Protection Project (SRBPP). The completed riverbank protection work included rip-rap placement along approximately 750 feet of the segment at LM 0.5 in 1976, and along approximately 745 feet at LM 0.35 in 2006 (Doc-8587). The levee inspection log (Doc-4261) also indicates that rock revetments have been placed from LM 0.0 to LM 0.64, LM 0.77 to LM 0.90, and LM 1.06 to LM 1.15.

### ***Planned Improvements***

Based on reviewed documents, no improvements to Segment 128 are currently planned.

## **Segment 128: General Levee Conditions**

This section describes levee conditions based on document reviews, interviews, site reconnaissance, the LiDAR survey, and other collected data. These conditions include the levee geometry, penetrations, and animal activity.

### ***Levee Geometry***

Segment 128 levee heights range from approximately 10 to 15 feet above the landside toe. Including the rounded shoulders, crest widths range from approximately 30 to 60 feet. According to LiDAR survey data, the landside slopes are approximately 1.7H:1V to 2.8H:1V. The waterside slopes are approximately 2.2H:1V to 3H:1V.

### ***Penetrations***

According to the DWR Pipe Inventory, 26 pipes penetrate the levee segment. Pipe diameters range from 1 to 8 inches. The pipes are approximately 1 to 13.3 feet below the levee crown.

### ***Animal Activity***

Animal activity was not reported in the reviewed documents. Animal persistence based on data from DWR is "None Documented."

### ***Maintenance***

The DWR assessments performed in the fall of 2008 indicate that DWR rates the levee maintenance as "Unacceptable (U)" for this segment.

### ***Other Features***

Segment 128 contains three bridges: the Delta Cross Canal bridge at the north end of the segment, the east end of the Walnut Grove Bridge across the Sacramento River at LM 0.6, and the north end of the Georgiana Slough Bridge at LM 0.96. The town of Walnut Grove has many buildings on the levee crown and landside slope of the levee.

## **Segment 128: Levee Composition and Foundation Conditions**

The NULE team established an understanding of levee and levee foundation geotechnical conditions based on work performed by the geomorphology team, reviews of other available geologic and soil maps, data contained in reports that were reviewed, and general knowledge of levee conditions in the area. This section summarizes the team's understanding of geotechnical conditions in Segment 128.

In Segment 128, the levee foundations consist of silt and clay with interbedded layers of sand, and the levee consists of sand and some silt.

### ***Geomorphic Setting***

Segment 128 is in the Sacramento Valley flood basin. Geomorphology Level 2-II mapping indicates the Segment 128 levee overlies recent overbank deposits (Rob) consisting of interbedded silt, sand and clay that likely interfingers with adjacent flood plain silt and clay sediments and are likely to vary laterally in extent and character.

### ***Geotechnical Investigations***

Geotechnical investigations for Segment 128 performed by others were not found. Seven borings along adjacent levee segments within the same geomorphic setting may be indicative of the levee and foundation conditions for Segment 128. These investigations include two borings in the DWR Salinity Control Barrier Study (1958) and five borings from the Sacramento River Flood Control System Evaluation (USACE, 1993) (Doc-1044). Two of these borings were drilled through the crest of the levee. The other five were drilled near the landside levee toe. The borings range in depth from 14 to 80 feet. According to the stick logs for the seven borings, the soil in the levee prism is mostly sand and some silt, and the soil in the foundation is silt and clay overlying sand.

### ***Other Subsurface Information***

According to the USCS soil map, the existing levee overlies fine-grained surface soils (CL). The USCS map does not indicate the variation of soil types shown in the Level 2-II mapping or that was found in the borings.

### ***Levee Composition***

The available boring data from adjacent segments indicate that the levee material is mostly loose sand and some silt.

## **Segment 128: Geotechnical Assessment Results**

The overall Segment 128 categorization is Hazard Level A. As discussed in Volume 1, Section 2 of this report, the overall assessment is based on the individual potential failure mode categorizations. Since the potential failure mode categorizations for underseepage, stability, through seepage and erosion are Hazard Level A, the overall categorization is Hazard Level A.

A Weighted Hazard Indicator Score was calculated for each potential failure mode at the assessment water surface elevation, the 1955/1957 water surface elevation provided by DWR. The assessment was based on identified geologic, geometric, and other hazards. A rating for past performance based on documented performance events was assigned. The categorizations for each potential failure mode are discussed in the sections that follow.

### ***Underseepage***

#### ***Segment 128 Underseepage Assessment Results***

WHIS			Performance Summary			Categorization
Best Estimate	Minimum Credible	Maximum Credible	Best Estimate	Minimum Credible	Maximum Credible	
44	44	44	None documented	None documented	None documented	Hazard Level A

Although the levee foundation materials (overbank deposits of silt, clay and sand) with high to very high underseepage susceptibility suggest that underseepage could occur the levee section is very wide for the differential head between the assessment water surface elevation and the levee toe making underseepage less likely to occur. Segment 128 is categorized as Hazard Level A due to the consistency between the hazard indicators that suggest that underseepage is less likely to occur and the absence of underseepage past performance data in the segment.

### ***Stability***

#### ***Segment 128 Stability Assessment Results\****

WHIS			Performance Summary			Categorization
Best Estimate	Minimum Credible	Maximum Credible	Best Estimate	Minimum Credible	Maximum Credible	
35	25	35	None documented	None documented	None documented	Hazard Level A*

\* Stability is assessed independently of through seepage and underseepage. Seepage might cause instability not accounted for in the stability assessment.

Hazard indicators that suggest that levee instability is less likely to occur include moderate levee height of 10 to 15 feet, wide levee crest, low differential head between the assessment water surface elevation and the levee toe and the absence of soft soil in the foundation. Segment 128 is categorized as Hazard Level A due to the consistency between the hazard indicators that suggest that levee instability is less likely to occur, and the absence of instability past performance data in the segment.

### **Through Seepage**

#### ***Segment 128 Through Seepage Assessment Results***

WHIS			Performance Summary			Categorization
Best Estimate	Minimum Credible	Maximum Credible	Best Estimate	Minimum Credible	Maximum Credible	
43	23	43	None documented	None documented	None documented	Hazard Level A

Although the levee composition of loose sand would suggest that through seepage could occur, other hazard indicators that suggest that through seepage is less likely to occur include a levee section that is wide for the differential head between the assessment water surface elevation and the levee toe, the absence of animal activity, and the moderate number of levee penetrations. Segment 128 is categorized as Hazard Level A due to the consistency between the hazard indicators that suggest that through seepage is less likely to occur, and the absence of through seepage past performance data in the segment.

### ***Erosion***

Segment 128 is categorized as Hazard Level A for erosion because erosion events in the segment during the 1997 and 1998 flood seasons were minor and did not impact the levee crown. In addition, the levee section is very wide.

### **Segment 128: Other Levee Assessments**

#### ***Freeboard***

Data from the LiDAR survey indicate that the levee crest for this segment is above the 1955/57 WSE. A minimum freeboard of 3 feet is present throughout the segment.

#### ***Overtopping***

Overtopping was considered based only on past performance. Evaluation of flood flows, flood elevations, channel capacities, and other factors influencing overtopping risk is beyond the scope of the NULE project. These factors should be studied by others to evaluate the overtopping risk to the NULE levees. Documents do not indicate that this levee segment has been overtopped.

#### ***Geometry***

Using the LiDAR data, the levee geometry was compared with a standard levee prism defined by the Segment 128 1953 MOU geometric criteria. This check was performed by assessing whether the levee indicated by topography developed from the LiDAR data was larger than or equal to the standard levee prism at any given cross section. Wide levees could meet this requirement even where levee slopes are steeper than those described in the 1953 MOU. For Segment 128, 100 percent of the levee meets the standard levee prism.

### **Segment 128: Hazard Mitigation**

No hazards were identified for this segment.

### **Segment 128: Anomalous Hazards**

The town of Walnut Grove has many buildings on the levee crown and landside slope of the levee.

**RD 0554, UNIT 1, SEGMENT 128 SUMMARY**

---

## LEGEND

- Non-Urban Non-Project Levee
- Non-Urban Project Levee

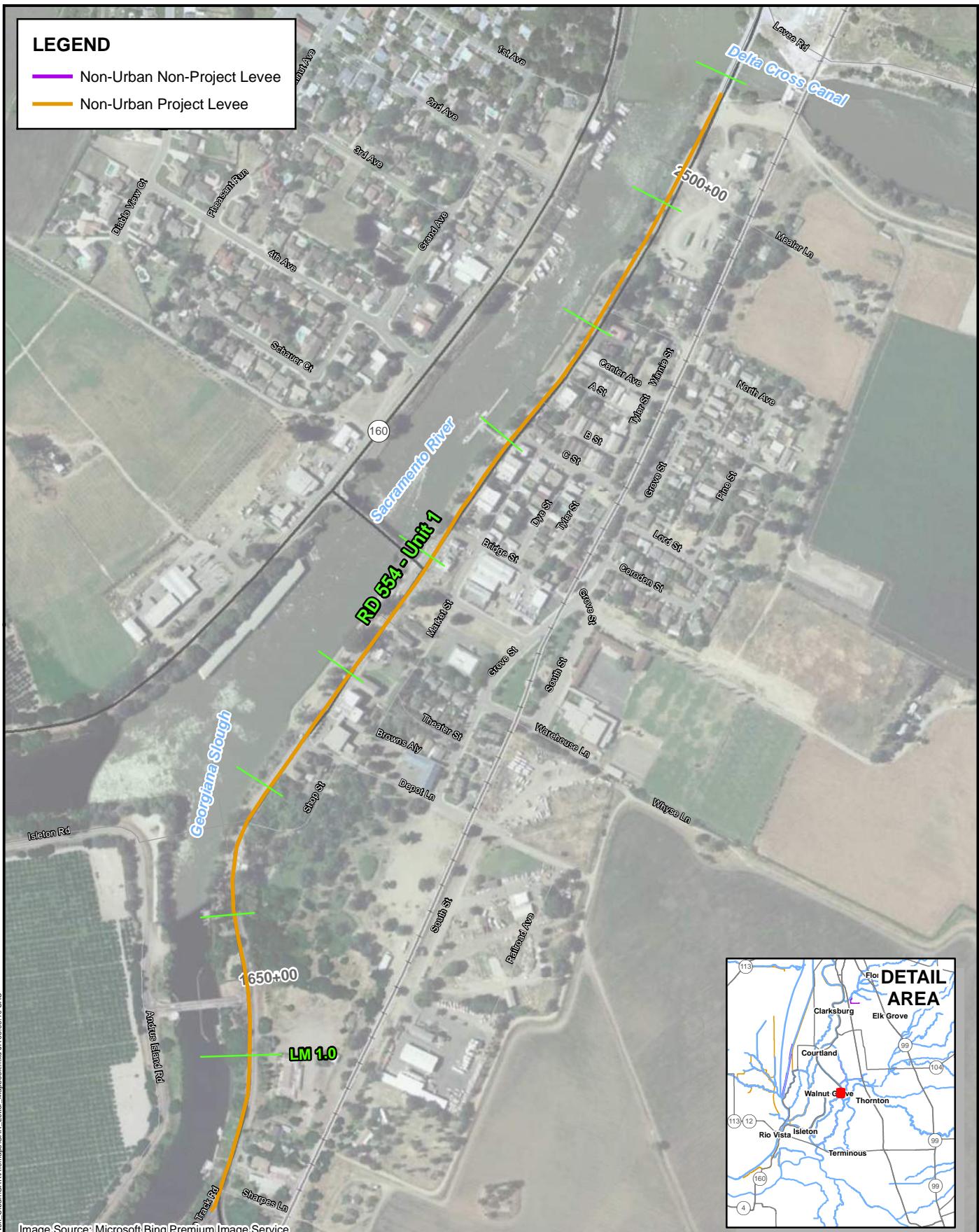


Image Source: Microsoft Bing Premium Image Service

H:\Projects\DW\GEOTECHNICAL\Non Urban\GAR\rcmaps\GAR Letter Mapbook.mxd JA 03.08.10 SAC

A horizontal scale bar with tick marks at 0, 250, and 500. The word "Feet" is written below the bar.



Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch

URS

## Segment 128

RD 0554 - South Portion  
Geotechnical Assessment Report

NORTH NON-URBAN LEVEE EVALUATIONS

## Non Urban Levee Evaluation Program (NULE) Levee Assessment Tool, Version 1.2 (revised: 1/7/2010)

Levee Segment Name:	RD 0554 - south portion		NULE Station (ft):	Begin	End
Levee Segment Number:	128		Levee Mile:	0	0.9
Brief Description of Segment/Reach:	RD 0554 - Walnut Grove - south of Delta Cross Channel		Segment/Reach Length:	0.6 (miles)	3145 (feet)
Local Maintenance Authority:	RD 0554		Crest Width Design Criterion (ft):	20	
Freeboard Evaluation Criterion (ft):	3		Design Guidance Document:	1953 MOU	
Water Side Slope Design Criterion:	3H : 1V	Enter Other Criterion	Project or Non-Project Levee?	Project	
Land Side Slope Design Criterion:	2H : 1V	Enter Other Criterion			
North or South NULE?	North				

### LEVEE CONSTRUCTION

Describe what is known about construction of this levee segment:

Based on historical topographic maps (Isleton, 1:31,680), the Segment 128 levees were initially constructed prior to 1906 by local interests. Specific documentation of the construction methods for the levee were not available. Portions of the levee that did not meet Project standards were improved by the USACE to Project standards between 1954 and 1955 (Doc-2116). The improvements included levee construction and bank protection. The location of the improvements was not available.

Analysts should populate all yellow cells, and not populate grey cells; green cells store calculated values. Use the suite of available data in making ratings. See User Guide and tables for further information.

### PAST PERFORMANCE

	Value (where applicable)	Best Estimate Rating	Minimum Credible Rating	Maximum Credible Rating	Explanation & Comments (include event date and flood elevation, if available)
Underseepage		None documented	None documented	None documented	N/A
Landside slope stability		None documented	None documented	None documented	N/A
Through seepage		None documented	None documented	None documented	N/A
In addition to Ayres 2008/DWR 2009 studies, are there erosion occurrences identified in this study?	Yes	If yes, please describe:	The segment has had erosion occurrences reported in 1957, 1997, 1998 and 2003.		
North NULE	Erosion sites from the Ayres 2008 study	Ayres Methodology 2		Ayres Methodology 4	
Are there erosion occurrences compiled in the Ayres study?		Rating (1 to 72)	Ranking (out of 117)	Rating (1 to 47)	Ranking (out of 117)
	No	N/A	N/A	N/A	N/A
	Comments:	N/A		Comments:	N/A
South NULE	Erosion sites from the DWR 2008 study	DWR Prioritization 2008			
Are there erosion occurrences compiled in the DWR study?		Rating (1 to 100)	Ranking (out of 67)		
	Comments:				
Past overtopping or near overtopping?:	Never overtopped	Comments:	N/A		
Past breach in area?	None Identified	Comments:	N/A		

### HAZARD INDICATORS

	Value (where applicable)	Best Estimate Rating	Minimum Credible Rating	Maximum Credible Rating	Explanation & Comments
<b>I- LEVEE COMPOSITION - at selected cross section</b> - Interpreted from Borings, Test Pits, field reconnaissance, NRCS maps, and analyst's interpretation of this assemblage of information					
Composition of levee material <i>for through seepage assessment</i>		5 - Loose: SP, SP-SM, SM, NP ML; documented loose high permeability fill; loose sand, sand with silt, silty sand, non-plastic silt	3 - SM, ML, Moderately dispersive soils; soils are silty sands or sandy silts with higher permeability than category 1 soil; soils are suspected of being moderately dispersive based on SAR or other factors	5 - Loose: SP, SP-SM, SM, NP ML; documented loose high permeability fill; loose sand, sand with silt, silty sand, non-plastic silt	Based on NULE Level 2-II mapping and borings on adjacent segments.
Composition of levee material <i>for stability assessment</i>		4 - CH, MH; moderately dispersive soils; loose sand, sand with silt, or non-plastic silt	2 - SM, ML, clean gravels; soils are silty sands or sandy silts	4 - CH, MH; moderately dispersive soils; loose sand, sand with silt, or non-plastic silt	Based on NULE Level 2-II mapping and borings on adjacent segments.

### II- GEOLOGY - at selected cross section (Scale of mapping)

Underseepage susceptibility <i>for underseepage assessment</i>	1:24,000	5 - Very high	5 - Very high	5 - Very high	Mapped as very high in Underseepage Susceptibility Map (NULE Level 2-II).
Dispersive soils <i>for stability assessment</i>	1:24,000	1 - Not dispersive	1 - Not dispersive	1 - Not dispersive	SAR map shows soils are likely not dispersive
Piping potential <i>for underseepage assessment</i>	1:24,000	4 - High	4 - High	4 - High	Piping potential map shows high piping potential, borings on adjacent levees indicate silt is present in foundation.
Piping potential <i>for through-seepage assessment</i>	1:24,000	4 - High	2 - Low	4 - High	Borings on levee on adjacent segments show sand and silt.
Soft soils <i>for stability assessment</i>	1:24,000	1 - Not present	1 - Not present	1 - Not present	Based on NULE Level 2-II mapping.

### III- OTHER INDICATORS - at selected cross section

Animal persistence/burrows? <i>for through-seepage assessment</i>		1 - None documented	1 - None documented	1 - None documented	Based on DWR data - none documented .
Is a landside ditch or borrow pit present within 200 ft of toe? <i>for underseepage assessment</i>	No ditch	1		0	
Is a landside ditch or borrow pit present within 200 ft of toe? <i>for stability assessment</i>	No ditch	1		0	
Is waterside blanket present? <i>for underseepage assessment</i>	No			0	
Are there locations where penetrations and historical underseepage are coincident?	No	If yes, please describe:	N/A		
Are there locations where penetrations and historical through seepage are coincident?	No	If yes, please describe:	N/A		
Have encroachments that may potentially affect levee integrity been identified?	No	If yes, please describe:	N/A		
Provide the number of levee penetrations below the evaluation water surface elevation:	3 - >5 to 10	Notes:	26 pipes ranging in size from 1 to 8 inches in diameter and between 1 and 13.3 feet below the levee crest. 9 of the pipes are below the evaluation water surface elevation (about 5 feet below the levee crown).		
DWR's LMA maintenance rating from Maintenance Deficiency Summary Report:	Unacceptable	Notes:	Fall 2008; Unacceptable rating for vegetation and trees.		



Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



Segment 128 LAT Results  
Geotechnical Assessment Report

NORTH NON-URBAN LEVEE EVALUATIONS

## IV- TOPOGRAPHIC &amp; ELEVATION INFORMATION - at selected cross section(s)

Report elevations in NAVD 88	Default cross section (used for Underseepage assessment)		Would you like to evaluate a different cross-section for Stability?	No	Would you like to evaluate a different cross-section for Through Seepage?	No
	Cross-section Station	2485+00	Cross-section Station		Cross-section Station	
	Underseepage		Stability		Through Seepage	
Levee crest elevation (ft)	25					
Levee toe elevation (landside) (ft)	12					
Levee crest width (ft)	39	1				
Evaluation water elevation (ft)	16.9					
Levee slope - landside (xH : 1V); Enter x	2.23	3				
Levee slope - waterside (xH : 1V); Enter x	2.06					
Freeboard above evaluation flood elevation (ft) (= levee crest elevation - evaluation water elevation)	8.1					
Levee height (ft) (= levee crest elevation - landside toe elevation )	13.0	3				
Levee prism base width (ft)	94.8					
Head (ft) (= evaluation water level - landside toe elevation )	4.9	1				
Head-to-base-width ratio (= head / base width )	0.052	1				
Base-width to head ratio (= base width / head )	19					

## V- ANOMALIES

	Anomalies?	Description	Effect on Performance
Underseepage	No	N/A	N/A
Stability	No	N/A	N/A
Through Seepage	No	N/A	N/A
Erosion	No	N/A	N/A

## MITIGATION AND PAST BREACHES

Existing constructed mitigation (List all)	Resloping and placement of rock revetment of Segment 128 occurred between LM 0.77 and LM 0.84 in 1972 (Doc-4261) and between LM 1.06 and LM 1.15 in 1984 (Doc-4261). Improvements also include riverbank protection work performed under the Sacramento River Bank Protection Project (SRBPP). The completed riverbank protection work included riprap placement along approximately 750 feet of the segment at LM 0.5 in 1976, and along approximately 745 feet at LM 0.35 (RM 26.9) 2006. The levee inspection log (Doc-4261) also indicates that rock revetments have been placed between LM 0.0 to LM 0.64, LM 0.77 to LM 0.90, and from LM 1.06 to LM 1.15.					
Has there been a past breach? If yes, describe nature of the breach and how it has been mitigated?	None Identified					

## SUMMARY

Failure Mode	Weighted Hazard Indicator Score (Best)	Weighted Hazard Indicator Score (Minimum Credible)	Weighted Hazard Indicator Score (Maximum Credible)	Past performance issues?	Are past performance and Weighted Hazard Indicator Score consistent?	Levee categorization
Underseepage	44	44	44	None documented	Yes	Hazard Level A
Justification:	Segment 128 is categorized as Hazard Level A due to the consistency between the hazard indicators that suggest that underseepage is less likely to occur and the absence of underseepage past performance data in the segment.					
Suggested additional data:	N/A					
Stability	35	25	35	None documented	Yes	Hazard Level A
Justification:	Segment 128 is categorized as Hazard Level A due to the consistency between the hazard indicators that suggest that levee stability is less likely to occur, and the absence of instability past performance data in the segment.					
Suggested additional data:	N/A					
Through Seepage	43	23	43	None documented	Yes	Hazard Level A
Justification:	Segment 128 is categorized as Hazard Level A due to the consistency between the hazard indicators that suggest that through seepage is less likely to occur, and the absence of through seepage past performance data in the segment.					
Suggested additional data:	N/A					
Erosion				Yes		Hazard Level A
Justification:	Segment 128 is categorized as Hazard Level A for erosion because erosion events in the segment during the 1997 and 1998 flood seasons were minor and did not impact the levee crown. In addition, the levee section is very wide and can therefore withstand erosion while maintaining the design levee prism.					
Suggested additional data:	N/A					
Freeboard Check	Does levee pass freeboard check?	Yes				
Provide details about where along segment (and by how much) levee does not pass freeboard check:	N/A					
Are there anomalies along the segment with respect to freeboard?	No	Describe anomalies:	0			
Levee Geometry Check	Does levee pass geometry check?	Yes				
Provide details about where along segment (and by how much) levee does not pass geometry check:	N/A					
Are there anomalies along the segment with respect to geometry?	No	Describe anomalies:	0			
Summary Characterization of Levee Segment	Hazard Level A	Comment / Justification:	Since the potential failure mode categorizations for underseepage, stability, through seepage and erosion are Hazard Level A, the overall categorization is Hazard Level A.			

Evaluator: JWR  
Checked By: TK  
Senior Reviewer: Review Team

Evaluation Date: 2/9/2010  
Check Date: 2/9/2010  
Review Date: 2/10/2010

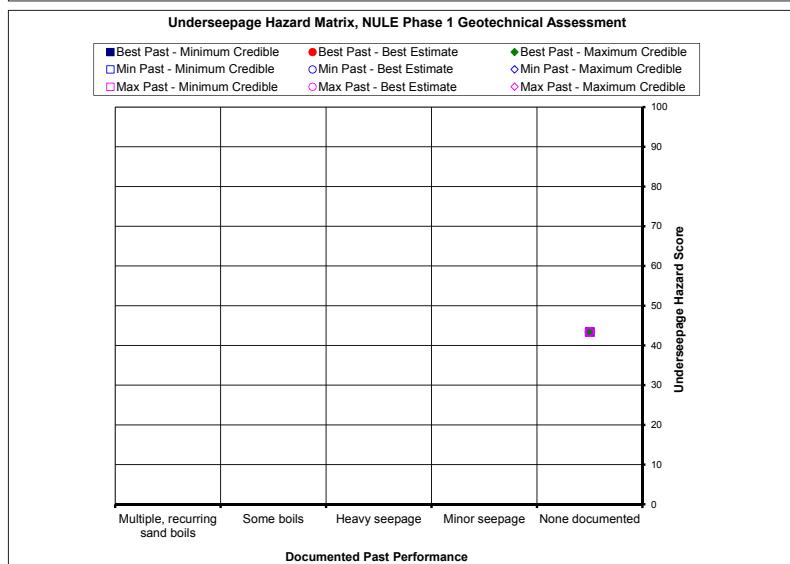
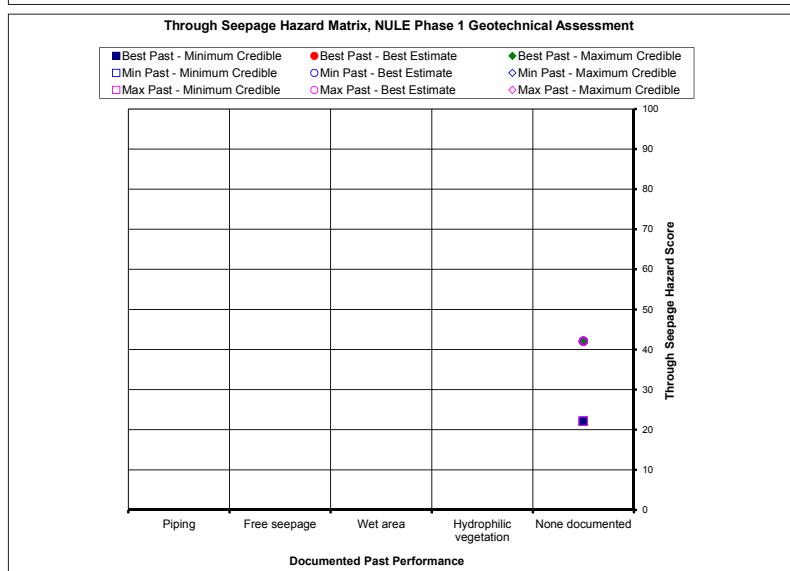


Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



Segment 128 LAT Results  
Geotechnical Assessment Report

NORTH NON-URBAN LEVEE EVALUATIONS



# TECHNICAL MEMORANDUM

## Level 2-I Geomorphic Assessment North NULE Area

Non-Urban Levee Evaluations Project  
Contract 4600008101

April 2010



*Prepared for:*

DEPARTMENT OF WATER RESOURCES  
Division of Flood Management  
2825 Watt Avenue, Suite 100  
Sacramento, CA 95821

*Prepared by:*



2870 Gateway Oaks Drive, Suite 150  
Sacramento, CA 95833

*In Association with:*



William Lettis & Associates, Inc.  
1777 Botelho Drive, Suite 262  
Walnut Creek, CA 94596

<b>1.0</b>	<b>EXECUTIVE SUMMARY .....</b>	<b>1-1</b>
<b>2.0</b>	<b>INTRODUCTION.....</b>	<b>2-1</b>
2.1	DWR Levee Evaluations Program Overview .....	2-1
2.2	NULE Project Scope and Phasing.....	2-1
2.3	Geomorphic Assessment Purpose .....	2-2
2.4	Geomorphic Assessment Scope of Work .....	2-2
2.5	North NULE Project Study Area .....	2-3
2.6	General Geologic and Geomorphic Setting .....	2-3
<b>3.0</b>	<b>APPROACH AND METHODOLOGY .....</b>	<b>3-1</b>
3.1	General Approach and Methods.....	3-1
3.2	Data Sources.....	3-2
3.2.1	Available Geologic Mapping.....	3-2
3.2.2	NRCS Soil Survey Maps and Data.....	3-3
3.2.3	Historical Topographic Maps.....	3-4
3.2.4	Historical Documents .....	3-4
3.2.5	Aerial Photography and Imagery .....	3-4
3.2.6	Levee Performance Database.....	3-4
3.3	Data Gaps .....	3-6
3.4	Limitations of Analytical Procedures and Maps .....	3-7
<b>4.0</b>	<b>GEOLOGIC AND GEOMORPHIC DOMAINS .....</b>	<b>4-1</b>
4.1	Sacramento River Meander Belt (SRm) .....	4-3
4.2	Sacramento River Floodplain and Natural Levees (SR) .....	4-3
4.3	Feather River Floodplain and Natural Levees (FR) .....	4-4
4.4	Sierran Tributaries (ST) .....	4-4
4.5	Flood Basins (FB).....	4-5
4.6	Sierra Nevada Fans (SNF) .....	4-5
4.7	Sierra Nevada Fan – Flood Basin (SNF-FB) .....	4-6
4.8	Coast Range Fans (CRF).....	4-6
4.9	Sutter Buttes Fans (SBF).....	4-7
4.10	Cascade Range Fan (CF).....	4-7
4.11	Delta (D) .....	4-8
<b>5.0</b>	<b>GEOMORPHIC ASSESSMENT AND ANALYSIS.....</b>	<b>5-1</b>
5.1	Geomorphic and Surficial Geologic Analysis .....	5-1
5.1.1	Geology and Geomorphology .....	5-1
5.1.2	Underseepage Susceptibility of Mapped Geologic Units.....	5-3
5.2	Hazard Susceptibility Analysis.....	5-5
5.2.1	Assessment of Levee Underseepage Susceptibility Hazard .....	5-5

5.2.2	Assessment of Levee Foundation Soft Soils .....	5-13
5.2.3	Assessment of Regional and Local Ground Subsidence.....	5-14
<b>6.0</b>	<b>IMPLICATIONS FOR NON-URBAN LEVEES.....</b>	<b>6-1</b>
6.1	Associations with Historical Levee Performance .....	6-1
6.2	Sources and Degrees of Uncertainty .....	6-3
6.2.1	Relative Underseepage Susceptibility Classes .....	6-4
6.2.2	Resolution and Quality of Existing 1:62,500-Scale Geologic Map Data .....	6-4
6.2.3	Inferences on Subsurface Conditions.....	6-5
6.2.4	Gradational Deposits and Mapped Contacts.....	6-5
6.2.5	Map Border Effects.....	6-5
6.2.6	Stratigraphic Variability.....	6-5
<b>7.0</b>	<b>SUMMARY AND RECOMMENDATIONS .....</b>	<b>7-1</b>
7.1	Summary .....	7-1
7.2	Recommendations.....	7-2
<b>8.0</b>	<b>CREDITS AND LIMITATIONS.....</b>	<b>8-1</b>
8.1	Credits .....	8-1
8.2	Limitations .....	8-1
<b>9.0</b>	<b>REFERENCES.....</b>	<b>9-1</b>

## Tables

Table 3-1	List of Topographic Maps
Table 3-2	Correlation of Geologic Units
Table 3-3	Sources of Digital Soil Data
Table 4-1	Characteristics of Geomorphic Domains
Table 5-1	Underseepage Susceptibility Criteria Matrix
Table 5-2	Underseepage Susceptibility Assignment Table for ULE Geologic Map Units
Table 6-1	Underseepage Performance and Underseepage Susceptibility Mapping, North NULE Levees

## Figures

Figure 1	North NULE Levees
Figure 2	North NULE Geomorphic Domains
Figure 3	Index of Geologic Source Data

## **Figures**

Figure 4      Conceptual Block Diagram  
Figure 5      Generalized Workflow Diagram  
Figure 6      NULE Performance and Susceptibility Map  
Figure 7      Plot Of Seepage and Boil Frequency By Susceptibility Class  
Figure 8      Plot of Failure Frequency By Susceptibility Class  
Figure 9      Index of Levee Underseepage Susceptibility Maps  
Figures 10      Maps of Levee Underseepage Susceptibility (1:62,500)  
through 36  
Figure 37a      Map of Peat Deposits, Organic Soils, Historical Marshes and Wetlands  
and b  
Figure 38      Map of Regional Subsidence

## **Appendices**

Appendix A      Hydrologic Soil Groups

## **Acronyms and Abbreviations**

<b>Term</b>	<b>Description</b>
CBDC	Colusa Basin Drainage Canal
CLD	California Levee Database
CVFPP	Central Valley Flood Protection Plan
DWR	Department of Water Resources (California)
GER	Geotechnical Evaluation Report
GIS	geographic information system
HSG	hydrologic soil groups
KLRC	Knights Landing Ridge Cut
NRCS	National Resource Conservation Service
NULE	Non-Urban Levee Evaluations Project
POI	point of interest
RCE	Resource Consultants & Engineers, Inc.
RMS	root mean square
SPT	standard penetration test
SSURGO	Soil Survey Geographic

**Acronyms and Abbreviations**

<b>Term</b>	<b>Description</b>
UC	University of California
ULE	Urban Levee Geotechnical Evaluations Program
URS	URS Corporation
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WET	Water Engineering and Technology
WLA	William Lettis & Associates

## 1.0 EXECUTIVE SUMMARY

The California Department of Water Resources' (DWR) Non-Urban Levee Evaluations (NULE) Project evaluates over 1,300 miles of non-urban state/federal Project levees and over 400 miles of appurtenant non-urban non-Project levees. URS Corporation (URS), under the North NULE Project contract with DWR, is in the process of evaluating over 810 miles of state/federal Project levees and 90 miles of non-Project levees in the north portion of the study area covering the Sacramento Flood Control System. Kleinfelder, Inc., under the South NULE Project contract with DWR, is in the process of evaluating the remaining non-urban levees in the southern portion of the study area covering the San Joaquin River Flood Control System.

Geomorphic analyses for the NULE project consist of two main levels (Level 1 and Level 2) and are part of Phase 1 geotechnical evaluation for the NULE project. Level 1 geomorphic analysis was completed in October, 2008, and provided a reconnaissance-level assessment of geomorphic domains and characteristics in the Northern NULE study area with respect to underseepage hazard. Level 2 analyses consist of two tiers (Level 2-I and Level 2-II). Level 2-I provides additional technical detail to improve and supersede Level 1 analysis results and provides a technical basis for recommending additional, more detailed geomorphic analysis and assessment. Level 2-I mapping is based primarily on the compilation and analysis of existing regional geologic and geomorphic information (e.g., soil survey maps, geologic maps). The North NULE Level 2-1 Geomorphic Assessment was completed December 23, 2009. Level 2-II studies yield detailed geologic and geomorphic information for use during future levee assessments.

Level 2-I analyses provide geologic and geomorphic maps at a regional scale, provide preliminary assessments of the hazard of levee underseepage and also provide information on soft soil areas and subsidence. The technical approach for geomorphic analysis in the North and South NULE areas is coordinated to develop consistent analytical results over the entire NULE region. Level 2-I analyses assess regional levee underseepage susceptibility via a criteria matrix based on existing geologic and soil data using a consistent framework applied to both North and South NULE areas.

Maps of underseepage susceptibility generated by Level 2-I analysis are being used during the selection of areas for additional, more detailed geomorphic or geotechnical analyses. Selection is based on several factors as outlined in the NULE work flow process chart. Regional underseepage susceptibility maps developed as part of Level 2-I analysis also will be used as screening tools to develop preliminary geotechnical analysis or exploration plans.

The Level 2-I approach is based on the principle that analysis and interpretation of existing geologic and geomorphic mapping can provide a regional assessment of underseepage susceptibility for NULE levees throughout the Central Valley. The map scale of 1:62,500 is chosen because it is between the reconnaissance-style Level 1 1:100,000 map scale and the Urban Levee Evaluation (ULE) project mapping or NULE Level 2-II studies map scale of 1:24,000.

Underseepage hazard for the NULE levees is assessed via an underseepage susceptibility map in which levee segments are assigned a susceptibility class. Susceptibility classes are

assigned using a matrix involving several geologic and geomorphic criteria. The criteria matrix combines information about Quaternary geologic deposits, channel features mapped from historical topographic maps, and National Resource Conservation Service (NRCS) hydrologic soil groups (HSG). Input data are imported into a GIS and spatially analyzed with North NULE levee lines; susceptibility categories (very high, high, moderate, and low) are assigned to levee lengths according to the criteria matrix. In areas previously mapped for the ULE project, or in future North NULE Level 2-II mapping, susceptibility classes are assigned using a one-to-one correlation between an underseepage susceptibility class and the detailed geologic map unit.

Because the Sacramento Valley is large and contains many miles of levees, it is subdivided into geomorphic domains having relatively consistent characteristics. Primary geomorphic domains include: older and younger alluvial fans, river floodplains and their natural levees, alluvial flood basins, and the Sacramento-San Joaquin Delta. Within each domain are individual geologic deposits that possess certain lithologic or soil characteristics. Much of the North NULE levees overlie geologic deposits belonging to natural levee or flood basin domains.

Level 2-I geomorphic analyses result in a series of maps delineating interpreted foundation susceptibility to underseepage. The Level 2-I study confirms the conceptual model of geomorphic domains generated for the Level 1 study, but improves the model's level of detail and available information. Within the North NULE area, 14 percent of the non-urban levee lengths are assessed to have very high underseepage susceptibility (128 miles); 50 percent are assessed to have high underseepage susceptibility (459 miles); 10 percent are assessed to have moderate underseepage susceptibility (89 miles); and 26 percent are assessed to have low underseepage susceptibility (237 miles).

Preliminary levee performance information developed in the North NULE area is analyzed to compare documented occurrences of underseepage to the mapped distribution of geologic deposits and susceptibility classes. The frequency of documented underseepage events (i.e., points per mile exposed) provide input for the assignment and testing of susceptibility classes to specific deposit types. In general, historical levee performance and interpreted underseepage susceptibility correlate.

This technical memorandum presents mapping and analyses for North NULE Project as well as non-Project levees, and supersedes the September, 2009 submittal that included only maps and analyses of non-urban Project levees in the North NULE area.

## **2.0 INTRODUCTION**

### **2.1 DWR Levee Evaluations Program Overview**

As an essential first step in providing improved flood protection for communities in California's Central Valley, DWR is conducting geotechnical evaluation of state/federal (Project) levees in the Sacramento and San Joaquin Flood Control Systems under the Levee Evaluations Program. This program supports the Central Valley Flood Protection Plan (CVFPP) and other flood management-related programs in evaluating state/federal Project levees and appurtenant non-Project levees. The Levee Evaluations Program also evaluates whether levees meet defined geotechnical criteria and, if appropriate, identifies remedial measures for meeting those criteria. Depending on the population protected by a particular levee, program evaluations are conducted under either the ULE Project or the NULE Project.

### **2.2 NULE Project Scope and Phasing**

DWR's NULE Project is evaluating over 1,300 miles of non-urban state/federal Project levees and over 400 miles of appurtenant non-urban Non-project levees to assess whether they meet defined geotechnical criteria. The NULE Project will also, where needed, identify remedial measure(s) and develop corresponding cost estimates that may help identified levees to meet those criteria. URS, under the North NULE Project contract, is in the process of evaluating over 810 miles of state/federal Project levees and 90 miles of non-Project levees in the north portion of the study area covering the Sacramento Flood Control System. Kleinfelder, Inc., under the South NULE Project contract with DWR, is evaluating the non-urban levees in the southern portion of the study area covering the San Joaquin River Control System. URS also is contracted to provide technical oversight for the entire NULE project. Levees included in the North NULE project area are shown on Figure 1.

The NULE Project is being implemented in two major phases. The first phase consists of collecting levee historical and performance data, geomorphic studies, preliminary assessment of geotechnical performance of levees, and developing conceptual remediation alternatives and associated cost estimates. The second phase involves field explorations, additional geomorphic and geotechnical evaluations, refining remediation alternatives, refining cost estimates and preparing a Geotechnical Evaluation Report (GER).

Geomorphic analyses for the NULE Project consist of two main levels (Level 1 and Level 2). Level 1 geomorphic analysis was completed on October 21, 2008, and provided a reconnaissance-level assessment of geomorphic characteristics in the Northern NULE study area with respect to underseepage hazard. Level 2 analyses consist of two tiers: Level 2-I and Level 2-II. Level 2 analyses provide additional technical detail to improve and supersede Level 1 analyses and provide a technical basis to recommend locations for additional, more detailed geomorphic analysis and assessment that will occur as part of Level 2-II analysis. Level 2-I analysis is primarily based on the compilation and analysis of existing regional information (e.g., soil survey maps, geologic maps). The North NULE Level 2-1 Geomorphic Assessment was completed December 23, 2009. North NULE Level 2-II studies are developing original, detailed information and analysis based on interpretations of early aerial photography, early historical topographic maps and other available data.

An understanding of alluvial processes and recognizing deposits and depositional environments in the geologic record is important for identifying locations along levees where underseepage is most likely to occur (Llopis et al., 2007). This Level 2-I geomorphic assessment focuses on an analysis of surficial geologic deposits, including soils developed on those deposits, and their relationship with documented past levee performance history to assess levee foundation susceptibility to underseepage.

Geomorphology and surficial geology are intimately related to this understanding because sediments in the NULE Project study area are deposited (and landforms are constructed or modified) by rivers and streams during flow events over hundreds to thousands of years. The dominant geologic processes of the last several tens of thousands of years (e.g., climate fluctuations, base-level rise and fall, changes in sediment supply) drive fluvial geomorphic responses (e.g., aggradation, incision, changes in stream gradient) that in total result in the present-day suite of geologic deposits and geomorphic landforms (Shlemon, 1967).

## **2.3 Geomorphic Assessment Purpose**

The primary purpose of Level 2-I analysis is to assess, on a regional scale, the hazard of levee underseepage. Level 2-I analyses also delineate areas of potential soft soils and ground subsidence. The Level 2-I study relies on the compilation and interpretation of existing data. The technical approach for geomorphic analysis in the North and South NULE Project areas was coordinated to develop consistent analysis results over the entire NULE region. Level 2-I analyses assess regional levee underseepage susceptibility via a criteria matrix based on existing geologic and soil data using a consistent framework applied to the North and South NULE areas.

This technical memorandum presents map figures at 1:62,500-scale. However, the primary product from this Level 2-I analysis is a geographic information system (GIS) database that can be analyzed or queried by other members of the NULE Project team beyond this geomorphic assessment.

Level 2-I maps of underseepage susceptibility can be used during selection of critical levee areas for additional, more detailed geomorphic or geotechnical analyses. The development of regional underseepage susceptibility maps satisfies the geomorphic assessment objectives noted above, and these maps also can be used as screening tools to develop geotechnical analysis, exploration plans, remedial alternatives, or cost estimates.

## **2.4 Geomorphic Assessment Scope of Work**

The scope of work for this Level 2-I analysis was developed to complete a regional geomorphic assessment of the North NULE study area. This study established a foundation for future, more-focused geomorphic analyses for the Northern NULE area.

The scope of work for Level 2-I study is:

1. Compiling existing geologic and soils mapping
2. Developing a criteria matrix
3. Mapping levee underseepage susceptibility

#### 4. Preparing a technical report and GIS database

The Level 2-I assessment is based primarily on compiling and analyzing geologic data collected during the Level 1 data collection task. To add detail relevant to underseepage hazard where only regional geologic mapping was available, channel features and water bodies adjacent to existing non-urban levees are mapped from historical topographic maps and digitized as part of the Level 2-I geologic compilation. The analysis includes development of a criteria matrix that assigns relative susceptibility categories (very high, high, moderate, low) to levees based on combinations of geologic unit and soil type present beneath the levees.

#### 2.5 North NULE Project Study Area

The North NULE Project study area lies in the broad Sacramento Valley comprising the northern third of California's 350-mile-long Central Valley. The study area includes non-urban Project and non-Project levees that extend as far north as Red Bluff, and as far south as the Sacramento-San Joaquin Delta (Figure 1).

#### 2.6 General Geologic and Geomorphic Setting

The Sacramento Valley is bordered on the west by the Coast Range, on the north by the Cascade Range, and on the east by the Sierra Nevada (Figure 1). The valley is low in elevation and has little relief with the exception of Sutter Buttes, a volcanic plug that rises 2,000 feet above the valley floor. Alluvial fans flank the margin of the valley and consist of topographically higher, geologically older and erosionally dissected surfaces, and topographically lower, younger and less dissected alluvial plains. Two major rivers traverse the Sacramento Valley floor flowing from north to south: the Sacramento River and the Feather River (Figure 1). These rivers and their tributaries drain the entire Sacramento Valley and, prior to construction of modern flood control features (dams, levees), provided floodwater and sediment into adjacent, topographically-lower flood basins during times of large runoff. The rivers are separated from the flood basins by natural levees adjacent to the river. Natural levees are low ridges built of sandy and silty sediment deposited during flood-stage conditions. They are highest adjacent to the river and slope gently away from the river toward the flood basins.

Riverine deposits in the Central Valley are highly variable, although relatively homogeneous flood basin deposits underlie large areas. The western margin of the valley is bordered by east-sloping alluvial fans derived from watersheds in the Coast Range; west-sloping alluvial fans derived from the Sierra Nevada and the southernmost part of the Cascade Range border the eastern valley margin. These alluvial fans are highly variable and stratigraphically complex. At the southern end of the valley is the Sacramento-San Joaquin Delta, where salty water from the San Francisco Bay extends landward and mixes with fresh water and sediment carried by the Sacramento and San Joaquin Rivers. The Delta area is at about sea level, and consists of low elevation marsh islands separated by channels or sloughs. Because of their geomorphic position, Delta islands consist mostly of fine-grained sediment (silt and clay) intermixed and interbedded with organic-rich material (peat), and commonly overlie older granular deposits (USACE, 1987). The entire North NULE Project study area is highly variable, both as a region and locally within several smaller areas. This technical

memorandum divides North NULE Project study areas into geomorphic domains in which overall stratigraphic characteristics may be relatively consistent (Figure 2).

## **3.0 APPROACH AND METHODOLOGY**

Because North NULE levees are constructed on a wide variety of geologic deposits within a large region, the project team developed a regionally consistent approach for assessing underseepage susceptibility that relies on geology and geomorphology to characterize the materials likely underlying the levees. This geomorphic assessment considers landforms, related geologic deposits, characteristics of soils developed on those deposits, and the surficial landscape features that may influence the phenomena of underseepage or settlement.

### **3.1 General Approach and Methods**

The Level 2-I assessment is based on the principle that analysis and interpretation of existing geologic and geomorphic mapping can provide a regional assessment of underseepage susceptibility for NULE levees. The 1:62,500 scale selected is between the reconnaissance-level Level 1 study's 1:100,000 scale, and the ULE project mapping or NULE Level 2-II studies' scale of 1:24,000. Most of the geologic data for the Level 2-I study were collected during the Level 1 data collection task and then compiled for Level 2-I study. In areas where 2007 and 2008 ULE project mapping areas overlapped NULE levees, the ULE 1:24,000-scale mapping is included in the compilation.

To add detail relevant to underseepage where existing mapping do not provide it, channel features and water bodies adjacent to existing non-urban levees are mapped from historical topographic maps and digitized as part of the Level 2-I geologic compilation. Channel features (and inferred coarse-grained deposits) are interpreted from early U.S. Geological Survey (USGS) 1:31,680 maps on the basis of topographic expression and morphology, or in the case of very small channels, the presence of a stream channel line on the map. Also included from the early topographic maps are abandoned meanders that typically lie landside of, or intersect present-day levees, as well as smaller (narrower) distributary or secondary channels. The smaller distributary channels likely also contain some unconsolidated granular material (Saucier, 1994), but this is an inference that requires confirmatory testing. Water features (e.g., marshes) also were mapped. Channels that are present within a 3,000-foot-wide band on either side of the present-day levee were mapped. Channel initiation points are located as precisely as possible given the scale and quality of the maps. For GIS analysis, widths of secondary channels are measured from original map data and single lines are buffered to develop a polygon of the appropriate width.

Underseepage hazard for the NULE levees is assessed via an underseepage susceptibility matrix in which levee segments are assigned a susceptibility class. Susceptibility classes are assigned using either this criteria matrix, or for areas covered by ULE mapping, an assignment table. The criteria matrix combines information about Quaternary geologic deposits, channel features mapped from historical topographic maps, and NRCS HSG (Appendix A). Data are imported into a GIS and spatially intersected with NULE levee lines; susceptibility categories were assigned to levee segments according to the cells in the matrix. Underseepage susceptibility category assignments were based on geologic age and depositional environment, as well as relative hydraulic conductivity. The assessment approach and categories are developed in coordination with the South NULE team to maintain consistent analytical results. For areas in the North NULE study area where HSG

data do not exist, susceptibility is assigned based on the underlying geologic unit and comparison with adjacent soil types. Where detailed ULE mapping is available, susceptibility is assigned based on the underlying geologic unit using an assignment table.

The Level 2-I analysis also include a regional assessment of soil settlement and ground subsidence. Subsidence is a lowering of land surface elevation with respect to a fixed datum, and may be caused by natural or human-induced processes. Subsidence may occur as a result of sediment pore fluid extraction (e.g., subsurface fluid or water mining) or from deformation related to deep-seated tectonic processes (Harwood and Helley, 1987). Many of the floodways, levees and canals of the Sacramento Valley traverse long distances with very gentle gradients, and may be strongly affected by small subsidence-related elevation changes. Subsidence poses a hazard to a levee system by decreasing levee crest elevations, by differential settlement of the soil beneath the levee, or by changing local channel gradients, causing local aggradation (increasing flood stage) or degradation (erosion and undermining of levee foundations).

### **3.2 Data Sources**

Basic relevant geomorphic data collected for the North NULE geomorphic assessment include:

- Early and modern USGS topographic maps, scales ranging from 1:24,000 to 1:100,000
- Early and modern soil survey maps of the Sacramento Valley published by the USDA, scales ranging from 1:24,000 to 1:250,000
- Early topographic maps of the Sacramento and Feather Rivers published by the California Debris Commission, variable scales, published 1909-1910
- 1937 black and white stereo-paired aerial photographs, approximately 1:20,000-scale
- Geologic and geomorphic maps and data published from 1981 to 2008, scales ranging from 1:20,000 to 1:62,500

A complete list of topographic map data sources is provided in Table 3-1. Geologic and soil data are listed and described in Subsections 3.2.1 through 3.2.6 below.

#### **3.2.1 Available Geologic Mapping**

Available geologic mapping is incorporated from the following sources:

- Helley and Harwood (1985)
- Atwater (1982)
- DWR Northern District (Buer, 1994)
- William Lettis & Associates (WLA) (2007, 2008)

The sources and extents of geologic map data are shown on Figure 3. Helley and Harwood (1985) map data were published at 1:62,500-scale, and later digitized by Jonathan Mulder (DWR Northern District) in GIS format. For the most part, Helley and Harwood mapping is incorporated without modification, with one important exception. Quaternary stream channel deposits (map unit Qsc) is merged with undifferentiated Quaternary alluvium (map unit Qa)

south of the town of Colusa. There are substantial misalignments of the contact between these deposits, probably due to a combination of imprecision in the original maps and errors associated with converting paper maps to a digital format. These inaccuracies cause erroneous results in the susceptibility assessment and, for this reason, the two map units are merged.

Mapping by Atwater (1982) is compiled in the southern portion of the map area (Figure 3). These maps were developed at 1:24,000-scale, a more detailed scale than the Helley and Harwood (1985) maps. Map units by Atwater were correlated to Helley and Harwood mapping based on interpreted age, topographic position, and environment of deposition (Table 3-2). Where Atwater's map overlapped with Helley and Harwood's, Atwater's (1982) mapping is used.

Surficial geologic mapping by DWR's Northern District is incorporated along the Sacramento River north of Colusa (Buer, 1994). This mapping delineated surficial geologic deposits as well as historical margins of the Sacramento River meanders from 1896 through 1997. These channel maps were updated by DWR staff through 2006 primarily from topographic maps supplemented with aerial photography. The individually mapped channel margins are enveloped, and a new map unit, Sacramento River meanders topographic channels (SRtc), is added to the geologic layer in the GIS database.

Detailed surficial geologic mapping recently developed at 1:20,000 scale is included where available. This surficial geologic mapping was developed for the Urban Levee Geotechnical Evaluations (ULE) Program (WLA, 2007; 2008) based on analysis of early aerial photographs, topographic and soil maps. This ULE mapping is used wherever it overlapped with NULE levee studies (Figure 3) in lieu of Helley and Harwood (1985) or Atwater (1981). A correlation of the surficial geologic map units to Helley and Harwood (1985), Atwater (1981), and Buer (1994) is presented in Table 3-2.

### **3.2.2 NRCS Soil Survey Maps and Data**

Both historical and modern soil survey data are evaluated. Early soil map data for the entire Sacramento Valley were compiled by Holmes et al. (1913), which provides a regional distribution of soil types. Modern soil data at a detailed 1:24,000 scale were obtained for the North NULE Project study area from the NRCS soil survey maps and data. These data are provided as GIS files and databases, are mapped by county, and are distributed as a Soil Survey Geographic (SSURGO) Database (Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture [USDA]). These digital files were downloaded from <http://soildatamart.nrcs.usda.gov> in October 2008. Counties and publication dates included with the soil data for North NULE Project study area are listed in Table 3-3.

The soil map units are grouped by HSG using a GIS tool for underseepage susceptibility analysis. The soil data layers from SSURGO are GIS shape files are based on soil mapping units. Each soil mapping unit is assigned to a particular HSG: A, B, C, or D. For example, soils in group A (gravels and sands) are characterized by rapid infiltration (i.e.,  $> 0.001$  cm/sec), and those in group D (clays) by very slow infiltration (e.g.,  $< 0.00004$  cm/sec). Detailed documentation about NRCS HSG assignments is provided in Appendix A.

### **3.2.3 Historical Topographic Maps**

Early topographic maps (1895 to 1923) were obtained as full-size digital scans from Chico State University's Merriam Library and the UC Berkeley Library. Fifty-four topographic maps have been compiled and spatially geo-referenced into GIS. Table 3-1 lists the individual maps collected, map scales, original and modern quadrangle names, survey date, publication date, year reprinted (if any), and root mean square (RMS) error in meters associated with the georeferencing process. RMS error is a measure of the accuracy of a map's spatial registration in GIS. An RMS value represents the average registration error (1-sigma) of the ground control points associated with each historical image as calculated in GIS during the georeferencing process. The magnitude of uncertainty via the RMS and the delineated channel positions reflect inherent inaccuracy in the original unreferenced dataset. Large RMS error values indicate poor spatial registration; small RMS values indicate more accurate spatial registration.

Historical topographic maps provide information about the features at or near the ground surface prior to present-day agricultural modification of the land. These data also depict the presence of channels or smaller water courses that may have been obliterated or obscured by land reclamation or development.

### **3.2.4 Historical Documents**

Historical documents collected and reviewed for this study include geomorphic reports completed for the U.S. Army Corps of Engineers (USACE) Sacramento District (RCE, 1992; WET, 1990, 1991), geomorphic reports completed by the USGS (Brice, 1977), and regional hydrogeologic reports (Bryan, 1923; Olmstead and Davis, 1961).

### **3.2.5 Aerial Photography and Imagery**

Black and white stereo-paired aerial photographs taken in 1937 were obtained from the National Archives in Washington, D.C. via private vendor services. These photos cover the extent of the non-urban Levees in the North NULE Project study area. These aerial photographs were visually inspected when necessary to assist with analysis but interpretive mapping was not developed from these data for the Level 2-I study. These 1937 photographs were however relied upon in developing ULE Program maps (WLA 2007, 2008) that were incorporated into Level 2-I geologic compilation.

### **3.2.6 Levee Performance Database**

Preliminary levee performance information developed for the North NULE Project study area is analyzed to compare documented occurrences of underseepage to the mapped distribution of geologic deposits. The frequency of documented underseepage occurrences provides verification of the assignment of susceptibility classes to specific deposit types.

Two historical levee performance databases in GIS format are used in this geomorphic assessment:

- California Levee Database (CLD) created by DWR, 2008. Period of observation is 1955 to 2007.

- Point of Interest data (POI) collected by North NULE team, January, 2009. Period of observation is 1926 to 2008.

The maximum period of record in the databases extends at least 52 years. However, not all levees necessarily have received the same level of performance documentation over time and not all years in the record may have performance recordings (e.g., drought years). Many of the database's entries are from observations made in the 1980s and 1990s.

For this geomorphic assessment, performance data are combined and edited to create a single performance database containing documented occurrences of seepage, boils, and probable seepage-related failures. These performance data are considered preliminary and are subject to change based on additional quality checks or new information. Analysis based on these performance data for this geomorphic assessment are thus preliminary in nature. However, the North NULE Project team considers the data sufficiently complete to analyze.

Levee performance data consist of on-the-ground observations typically made by Reclamation District staff and Maintenance Area personnel. Some observations were made during routine inspections and others were made as a response to prolonged high flow conditions. Some performance records were documented via levee repair applications. Because the databases contain a variety of levee distress classes and events (e.g., erosion, overtopping, sand boils), the POI database and the CLD were filtered to reflect data that are attributable or likely related to underseepage alone. The specific types of information used from each database are described below.

### ***3.2.6.1 California Levee Database (CLD)***

Only data points describing boils, seepage, and levee breaches likely attributable to the underseepage process were selected from the CLD. While boils are directly related to underseepage, the term "seepage" as used in the CLD is interpreted for the purposes of this assessment as representing levee underseepage.

In the CLD, many occurrences of levee failure are ascribed to erosion or overtopping processes and these are filtered out of analysis. Failures attributed to levee slumping mechanisms also are removed. Where levee failure observations lacked a description of the failure mechanism, it is assumed they are related to underseepage processes. This assumption is conservative as it may over-represent underseepage related failures; however additional justification from the data may not be forthcoming.

### ***3.2.6.2 Point of Interest (POI) Database***

The POI database includes both point and line-based observations. This analysis uses performance data from the POI database that was described as "seepage," "boil," or "breach, levee failure" only. As with the CLD data, where levee failure observations lacked a description of the failure mechanism, it is assumed they are related to underseepage processes.

### ***3.2.6.3 Data Tabulation***

The CLD database contains a variety of well- and poorly-attributed data in a point file. Analyses of these variable and diverse data required a combination of manual analysis and automated analysis in ArcGIS. Specifically, the CLD and POI point data were viewed onscreen along with the NULE underseepage susceptibility classes in ArcGIS; analysis was conducted onscreen. The spatial distribution and association of the levee performance data is analyzed with respect to underseepage susceptibility classes, HSG, and geologic map units. Results were reduced manually.

Performance data are tabulated by susceptibility class (very high, high, moderate, low). Next, the total number of performance points (occurrences) for each susceptibility class is divided by the number of levee miles in each susceptibility class (i.e., normalized by exposure). Line data are similarly normalized by dividing the number of miles affected by the levee miles of the susceptibility class, resulting in a percent of levee affected.

## **3.3 Data Gaps**

Data gaps are conditions of missing or unavailable data, partial/incomplete data, or inadequate data. Data are considered missing if they were likely collected or produced at some time in the past, but could not be located at time of analysis. Data are considered unavailable if they were never collected or compiled in the first place, or if they were not collected. Incomplete or inadequate data are those data that exist and are available, but require improvement, refinement, or replacement with better information.

Specific data gaps identified through Level 2-I analysis include:

- Unavailable early 1:31,680 topographic maps
- Small-scale (1:62,500) geologic map data
- Preliminary status of levee performance case history data
- Absence of direct subsurface information on shallow stratigraphic conditions
- Lack of field verification of the sedimentologic characteristics within small channels identified through Level 2-I mapping

### ***3.3.1.1 Unavailable Early Topographic Maps***

A search for topographic map data was performed at the California State Archives, as well as at the UC Davis, UC Berkeley, and Chico State University libraries. Early 1:31,680-scale topographic maps were unavailable for the following 7.5-minute quadrangles:

- Vina (east side Sacramento River, near Red Bluff)
- Glenn (upper Sacramento River, west side)
- Colusa (near town of Colusa); Dunnigan (covers Colusa Drain)
- Vernon (covers Pleasant Grove Cross Canal and parts of Sacramento River, west side)
- Taylor Monument (parts of Sacramento River, west side)
- Courtland (lower Sacramento River and sloughs)

Based on discussion with librarians and archive staff, it is likely these areas were never topographically mapped at 1:31,680 scale.

### ***3.3.1.2 Small-Scale Geologic Map Data***

Geologic map data covering a majority of the North NULE Project study area was published at 1:62,500 scale (Holley and Harwood, 1985), and are only of limited adequacy for the assessment of surficial and near-surface geologic deposits. Typical geologic hazard assessments (e.g., liquefaction hazard) rely on larger-scale map data that are commonly published at 1:24,000-scale. The 1:62,500-scale geologic data used in this study are a gap in the analytical data because the small scale limits precision, accuracy, and level of detail in mapping. These data exist and are available, but require improvement, refinement, or replacement with better (1:24,000 scale) map data and information.

### ***3.3.1.3 No Direct Subsurface Information on Shallow Stratigraphic Conditions***

Absence of direct subsurface information on shallow stratigraphic conditions (e.g., via geotechnical explorations) also is considered a data gap under Level 2-I geomorphic assessment. Once compiled, these data will help constrain and verify interpretations of foundation conditions beneath present-day levees, and would extend the ability to anticipate locations likely prone to underseepage processes. These data also are necessary to establish correlations across similar geologic deposits. Past subsurface exploration data may exist but may not have been collected or compiled by the NULE Project team.

### ***3.3.1.4 Lack of Field Verification of Sedimentologic Characteristics***

Field verification of the sedimentologic characteristics within small channels identified through Level 2-I mapping would improve and enhance understanding of the geologic and geotechnical characteristics of these features and deposits, and would refine assessment of their likely controls on underseepage processes. Field verification techniques could consist of hand auguring or sediment coring, shallow test pits, or shallow trenching.

## **3.4 Limitations of Analytical Procedures and Maps**

Appropriate application of the information presented in this geomorphic assessment requires an understanding of the limitations of the analytical procedures used and resultant maps. The primary limitations fall into the following categories:

- Spatial inconsistency in the nature of available geologic, topographic, and soils data
- Limited precision of mapping due to the use of a regional scale (1:62,500)
- Inherent variability and complexity of geologic deposits
- Failure to account for factors – in addition to geologic materials – that may affect levee underseepage susceptibility

These limitations are discussed below.

Level 2-I mapping is a compilation and interpretation of geologic, topographic, and soils data developed by different workers at different times using different scales and covering different

parts of the NULE Project study area. Geologic mapping schemes and styles differ among workers. This Level 2-I map compilation attempts to integrate all the various data into a unified mapping scheme, but the nature of the diverse source data is reflected in the final product. There are limitations with respect to the accuracy of the geomorphic data and to interpretations of hazard susceptibility.

The regional scale of the susceptibility mapping (1:62,500) limits data precision and the ability to show detail. This scale is selected to provide a reasonable balance between levels of detail and scope of analysis. At this scale, map unit boundaries are considered about 300 feet on either side of the line shown, or about two pencil widths at the 1:62,500 scale. It is important that Level 2-I maps and GIS files are not displayed or used at scales larger than 1:62,500, as this may introduce apparent inaccuracies or imply a greater level of detail or map precision than intended.

Because analysis is executed in a GIS environment, the effects of scale and the precision of input data merits further elaboration. Within the GIS, polygon lines (soil units or geologic contacts) are infinitely narrow; small discrepancies (over- and underlaps) between input data layers may produce local artifacts in susceptibility that are locally inaccurate. This effect is most pronounced when lines or contacts are sub-parallel or oblique to the levee. This effect is less obvious when contacts are oriented orthogonally to the levee. Underseepage susceptibility maps are presented at a scale of 1:62,500 (1 inch to about 1 mile), and the thickness of the levee line shown is equivalent to about 210-feet-width in real space. It is difficult to visually detect levee susceptibility segments that are shorter than about 0.5 mm on the figures (about 100 feet in real space).

Geologic deposits in the NULE Project study area have been deposited by rivers and streams during high flow events over hundreds to thousands of years. Each mapping unit is a composite of numerous smaller deposits, each of which may originate from a different flow event and each of which will be slightly different in characteristics from its neighbor. The underseepage susceptibility at specific locations within a given deposit is expected to vary spatially in unpredictable ways. Also, because this is a regional-level assessment, there may be unique or unusual site-specific conditions that are not captured by this analysis. The maps described in this Level 2-I assessment serve as guidance-level information for future, more detailed geomorphic and geotechnical analyses.

This geomorphic assessment focuses on geologic conditions that may affect levee underseepage. However, other factors affect levee underseepage, including water surface elevation and stage duration or biologic factors such as burrowing animals. The stability of levee materials, slope stability, levee erosion, and seismic performance factors are addressed by in-parallel geotechnical studies for the NULE Project. In addition, this study does not consider existing underseepage mitigation measures that may be planned along NULE levee systems or may already exist.

Interpretations of levee susceptibility do not necessarily reflect expectations of levee performance, and are not an evaluation of levee design suitability or future adequacy.

## 4.0 GEOLOGIC AND GEOMORPHIC DOMAINS

The previous Level 1 study provided a reconnaissance-level overview of the Sacramento Valley's geology and geomorphology. The technical approach for that study was based on the delineation of geomorphic domains, or areas within which surface and shallow subsurface features and deposits likely have similar characteristics due to similar geologic history and depositional processes. Development of these domains began with the collection and analysis of:

- Early and modern USGS topographic maps
- Early and modern USDA soil maps
- Early and modern geologic maps
- Other available scientific or engineering reports

Synthesis of these data provides a broad understanding of primary geomorphic processes active in the study area during recent geologic and historical time. Identification and characterization of these regional geomorphic domains is a first logical step toward assessing underseepage susceptibility in non-urban levees in the Sacramento Valley.

Because the Sacramento Valley is large and contains many miles of levees, the area is subdivided into geomorphic domains having relatively consistent characteristics (Figure 2). This section presents the criteria used for identifying geomorphic domains having similar foundation material characteristics.

This Level 2-I study employs three primary criteria for delineating geomorphic domains:

- Dominant geomorphic processes based on large-scale landforms and landscape relationships
- General texture (grain size) of the surficial materials (a proxy for permeability)
- General age of geologic deposits (a proxy for consolidation and permeability)

Geomorphic landforms and landscape relationships provide an indication of the dominant geomorphic processes and near-surface deposits. Primary geomorphic domains include older and younger alluvial fans, river floodplains and their natural levees, alluvial flood basins, and the Sacramento-San Joaquin Delta. These domains are further divided based on landscape position; for instance, alluvial fans and plains on the eastern side of the Central Valley differ from those on the western side, primarily as a result of the differences in source lithology, deposit texture, watershed size and relief, and glacial history.

Early regional soil maps (Mann et al., 1911; Strahorn et al., 1911; Holmes et al., 1913) provide basic data on the dominant texture of surficial materials, which is important because of the influence of grain size on soil permeability. These early soil maps help synthesize numerous county-specific soil surveys into a regionally consistent framework. Early maps do not depict some of the intricate soil relationships shown on modern maps. Soil textures in the North NULE Project study area generally include: gravelly loam, fine sand, sandy loam, silt loam, and clay. Other textures also are encountered in the area, and may locally be primary constituents.

The general age of a surficial geologic deposit provides a reasonable basis for assessing the density or consolidation of the deposit. Density generally describes geologic consolidation; older deposits tend to be more compacted, consolidated, or cemented than younger deposits, and so are commonly less permeable than younger deposits. In some instances, older geologic deposits may possess unique characteristics that could influence underseepage processes (e.g., laterally extensive, low-permeability duripan horizons). This Level 2-I analysis considers three primary geologic ages:

- Pliocene (between 5.3 million years to 1.6 million years old)
- Pleistocene (between less than 1.6 million years and 11,000 years)
- Holocene (less than 11,000 years)

Associated deposits are considered consolidated (Pliocene), semi-consolidated (Pleistocene), and unconsolidated (Holocene), respectively. At this very coarse scale of approximation, differences in lateral vs. vertical conductivity are ignored, but should be considered in future, more detailed analyses. Because of the large areal extent of the North NULE project and the approach using regional geomorphic domains as a screening tool, it is not appropriate to develop quantitative estimates of hydraulic conductivity for the domains at this scale.

The Sacramento Valley is subdivided into 11 geomorphic domains based on the characteristics of:

- Geologic age
- Environment of deposition
- Topographic position
- Geomorphic process
- Deposit grain size

Foundation materials most likely to be encountered beneath present-day levees are characterized within each domain on Table 4-1, and the anticipated variability in subsurface stratigraphy is also described. Foundation materials are characterized based on a synthesis of geologic and soils information; subsurface variability is inferred based on the dominant geomorphic processes within the domain that were likely in effect at, or immediately prior to, the time of levee construction. Subsurface stratigraphic variability is the homogeneity or heterogeneity of sedimentary beds or layers in the vertical direction, and the continuity or discontinuity of sedimentary beds or layers in the lateral direction. Subsurface stratigraphic variability is assessed based on the environment of deposition and geomorphic processes responsible for the deposit. Figure 4 conceptually illustrates some depositional environments (e.g., a flood basin). Figure 4 also conceptually illustrates lateral interfingering of discontinuous relationships in the subsurface (e.g., zig-zag contacts, isolated channel lenses) that likely contribute to stratigraphic variability.

The North NULE project area's geomorphic domains are described below. The domains are described in general order from north to south, and then in order of increasing distance away from the valley floor (i.e., from domains near the North NULE Project levees to older alluvial fans and foothill areas farther from the levees). A summary map of the domains is provided

as Figure 2, and a schematic block diagram of general stratigraphic relationships is shown on Figure 4. Domain characteristics are summarized in Table 4-1.

#### **4.1 Sacramento River Meander Belt (SRm)**

The Sacramento River meander belt domain extends from the northern boundary of the study area near the town of Los Molinos downstream to the town of Colusa (Figure 2). The meander belt is a corridor within which the river channel is free to move laterally and longitudinally; it includes the present-day extent of the river meanders, meander scrolls, and point-bar deposits. The belt also includes abandoned meander scroll features and oxbow lakes that mark former positions of the Sacramento River (DWR, 1994). This geomorphic domain reflects the relatively steep channel gradient of the river between Hamilton City and Colusa. Geologic deposits within this domain are generally coarse-grained, consisting of cobbles, gravel, and sand, with lesser amounts of silt and clay (Schumm and Harvey, 1986). Because of the spatially variable position of the river through time, subsurface stratigraphy in this domain is highly variable (Table 4-1; WET, 1990) and is characterized by laterally discontinuous strata and abrupt vertical changes in grain size (e.g., coarse-grained buried channels, fine-grained oxbow lakes). Strata are unconsolidated, although cobble-rich strata may result in anomalously high standard penetration test blow counts. Bulk permeability is probably variable because of the variability in subsurface textures and distributions (DWR, 2006a), but overall, deposits within this domain are considered highly permeable. This domain ends at the marked change in the Sacramento River plan form at the town of Colusa, south of which the river channel becomes much narrower, and the meander belt pattern disappears (Figure 2). Historically, the river in this domain was fed by groundwater (i.e., it is a gaining stream; Bryan, 1923), and was characterized by an absence of a laterally extensive shallow low-permeability materials that would impede groundwater contributions to the river channel (e.g., a confining bed).

Presently, there are three flood relief structures in this domain, two of which are engineered weirs (DWR, 2003). The first structure occurs at the upstream end of the North NULE Project levee along the east (left) bank of the Sacramento River near the latitude of Glenn, California. Flood waters are allowed to escape over the east bank of the river and overflow into the Butte Basin. The other two structures are engineered weirs that serve a similar flood relief purpose: Moulton Weir and Colusa Weir. As such, the flood relief structures could have an influence on downstream water surface elevation and thus be a limiting hydraulic control on underseepage.

#### **4.2 Sacramento River Floodplain and Natural Levees (SR)**

Flanking the Sacramento River meander belt (SRm) north of Colusa and the river itself south of Colusa is the Sacramento River floodplain and natural levees domain (SR; Figure 2). This domain chiefly consists of overbank sediments laid down by flood flows and distributary channels of the Sacramento River. This domain extends along the length of the river, and as noted above, directly abuts the river from Colusa southward into the Delta. Broadly, the sediments comprising the floodplain and natural levee deposits consist of mixtures of sand, silt, and clay (Table 4-1, Holmes et al., 1913). Prominent distributary channels also possess natural levees, and include levees of Butte Slough and Sycamore Slough that are present near Colusa. The surficial deposits are late Holocene, unconsolidated, and sandy fluvially-

laid sediment that are likely to be highly permeable (Olmstead and Davis, 1961; Helle and Harwood, 1985; WET, 1991). Anticipated subsurface variability in the natural levee deposits is moderate, meaning that there are probably grossly similar overall textures and compaction along the flank of the river in the upper 15 to 20 feet of soil within this domain. However, layers are probably laterally discontinuous. Sediments are bedded and may have layers from 2 to 5 feet thick. While there is site-specific lateral variability, the shallow subsurface stratigraphic relationships should be relatively basic. Historically, the river in this domain between Colusa and the latitude of Robbins (Figure 2) recharged the groundwater aquifer, meaning that the river bottom was slightly above the water table (i.e., it is a losing stream; Bryan, 1923).

#### **4.3 Feather River Floodplain and Natural Levees (FR)**

Similar to the Sacramento River, the Feather River floodplain and natural levees encompass and flank the channel of the Feather River. Within this domain (FR; Figure 2), the Feather River meanders in a wide valley entrenched into Pleistocene deposits. The river itself flows through Holocene deposits. The Feather River has less prominent natural levees and distributary channels compared to the Sacramento River. The Feather River and its tributaries were substantially impacted by gold mining activities in the late 1800s and early 1900s (Table 4-1). These activities, including hydraulic mining, introduced large quantities of sediment to the river in a short period of time, resulting in aggradation of the river bed and deposition of sediment derived from mining debris along the course of the river and the adjacent floodplain. The rapid deposition of coarse-grained sediment in a relatively high-energy environment over existing Holocene and older deposits resulted in substantial subsurface stratigraphic variability. The historical sediments are probably massive (not bedded), and may show an inverted stratigraphy where finer-grained silts (or slickens) are overlain by coarser-grained sediment. Surficial deposits are late Holocene, unconsolidated, and granular fluvially-laid sediments that likely are highly permeable (Olmstead and Davis, 1961).

#### **4.4 Sierran Tributaries (ST)**

Sierran tributaries are the principal west-flowing creeks that join either the Feather River or the Sacramento River south of its confluence with the Feather River (Figure 2). These tributaries include, from north to south, Honcut Creek, Yuba River, Bear River, and American River. Prior to 19th century human influence, these tributaries were narrow and incised into the adjacent, older alluvial deposits (Ellis, 1939). The tributaries were then substantially impacted by sediment derived from gold mining debris, resulting in aggradation of the channel beds. Historical flood events deposited this mining-derived sediment on the adjacent floodplain prior to the construction of the present-day levees (Ellis, 1939). The sediment in this domain is Holocene to historical, unconsolidated and coarse-grained (Helle and Harwood, 1985; Busacca et al., 1989), ranging from cobbles to sand and silt with high permeability (DWR, 2006b). Subsurface stratigraphic variability is probably high because of significant and rapid channel deposition, erosion and re-working of sediment derived from hydraulic mining activities. Based on the geologic history of Sierran tributaries (Shlemon, 1967), buried west-trending channels may be present in the subsurface. The present-day levee structures in this domain are oriented approximately parallel to the geomorphic fabric.

## 4.5 Flood Basins (FB)

The flood basin domain occupies the low lands on either side of the Sacramento River in broad and topographically low-relief areas between the river's natural levees and adjacent alluvial fans (Figure 2). During times of flood, these flood basins filled with water delivered by distributary creeks or channels from the river, or by shallow sheet flow passing over the river's natural levees creating slow moving inland seas. Five flood basins are recognized in the Sacramento Valley (Olmstead and Davis, 1961):

- Butte Basin
- Colusa Basin
- Sutter Basin
- Natomas (or American) Basin
- Yolo Basin

Because of the similarity in geomorphic process and geologic deposits, these basins are characterized as one generalized domain, but delineated as individual basins on Figure 2.

Deposition in the flood basins was from slow moving or standing water as opposed to channelized flow, so sediments are primarily silt and clay (Table 4-1). These deposits have low permeability (DWR, 2006a, c). However, these deposits also may be locally interbedded with higher-permeability stream deposits adjacent to the Sacramento River and lenses of sediment from alluvial fan lobes coming from west- or east-flowing streams in the Sierra Nevada and Coast Ranges (Figure 4). Flood basin deposits are unconsolidated and late Holocene in age (Helle and Harwood, 1985). Because of the relatively low-energy environment of deposition, the subsurface stratigraphy should at most places have low variability and relatively laterally-extensive deposits.

Two prominent natural levees extend into and over the Colusa flood basin deposits. The first is the natural levee of Sycamore Slough, a distributary channel of the Sacramento River (Figure 2). This channel ridge (natural levee) of silty and sandy sediment extends out across the clay soils of the basin. The present-day Colusa Drain and its associated levee traverse parts of the Sycamore Slough deposits. Sycamore Slough rejoins the Sacramento River directly north of Knight's Landing. It was funneled into the Sacramento River at this location because of the second natural levee, a channel ridge of Cache Creek Slough (Bryan, 1923; Olmstead and Davis, 1961). Cache Creek Slough is an abandoned arm of Cache Creek, and its channel ridges extend to the town of Colusa. This topographic feature separates Colusa Basin from the Yolo Basin to the south.

## 4.6 Sierra Nevada Fans (SNF)

Sierra Nevada fans consist of alluvial fans and terraces on the west side of the Sierra Nevada Range, and are divided into older and younger alluvial fans. The older fans (SNFo, generally Pliocene age) are topographically higher and exhibit erosional modification and dissection. Although coarse in grain size, older fan deposits (SNFo) are fairly consolidated and cemented (Marchand and Allwardt, 1981), with low to moderate permeability. Geologic units present in the SNFo domain include the Tertiary Laguna Formation, Mehrten

Formation, and Lovejoy basalt (Holley and Harwood, 1985). While older fans do not directly underlie the North NULE Project study area levees, their deposits probably are present in the subsurface beneath the younger alluvial deposits.

The younger alluvial fans and terraces (SNF<sub>y</sub>, generally late Pleistocene in age), are topographically lower and exhibit only moderate dissection. The younger alluvial fans are composed of Riverbank Formation and Modesto Formation deposits (Holley and Harwood, 1985), and each deposit contains one or more hardpan or duripan horizons at the top of the formation. Duripan horizons are silica-iron cemented zones, not more than 5 feet thick, which are laterally extensive and are of low permeability (Table 4-1). The Pleistocene deposits are semi-consolidated and possess a wide range of grain sizes from gravel to clay. They generally decrease in grain size with increasing distance from the foothills. Deposition in an alluvial fan environment is characterized by multiple erosional fan channels separated by depositional surfaces, as well as changing location of fan channels through time. It is likely there is wide lateral and vertical variability in the subsurface stratigraphy (e.g., buried paleochannels). With the exception of duripan or hardpan horizons, the Modesto Formation is likely moderate to highly permeable; the Riverbank Formation is likely low to moderately permeable (DWR, 2006b). Overall, the deposits within SNF<sub>y</sub> are considered highly variable in texture (grain size) and permeability.

#### **4.7 Sierra Nevada Fan – Flood Basin (SNF-FB)**

This domain is a transitional domain between the SNF and FB domains (Figure 2). It encompasses the gently southwest-sloping distal alluvial plain west of the Feather River and east of the Butte and Sutter Flood Basins. This domain contains Pleistocene and Holocene alluvium consisting of silt, sand, gravel and clay (Holley and Harwood, 1985). These southwest-dipping permeable alluvial deposits (Modesto Formation) are overlain by fine-grained flood basin deposits that may have extended as far upslope as 60 feet in elevation (Bryan, 1923). A veneer of fine-grained basin deposits overlies consolidated, sandier, older alluvial deposits and thickens toward the Butte and Sutter Basins but is overall thinner than flood basins to the south (e.g., Yolo Basin). Early soil maps depict this area as Stockton clay loam and clay adobe (black soils over heavy yellow subsoils) and Madera clay loam (dark grey soils with a somewhat thin duripan horizon (Holmes et al., 1913). Deposit permeability within this domain is layered, based on general surficial soil texture and underlying strata. Finer-grained basin deposits overlie coarser-grained strata of older alluvial fans, and the surficial deposits are substantially less permeable than the underlying fan deposits (perhaps constituting a geotechnical blanket layer). Subsurface stratigraphic variability may be moderate (Table 4-1) because the basin deposits overlie eroded fan deposits. The present-day levee structures in this domain are oriented approximately perpendicular to the geomorphic fabric.

#### **4.8 Coast Range Fans (CRF)**

The Coast Range fan domain consists of alluvial fans and low alluvial plains on the western side of the Sacramento Valley, between the uplands of the Coast Range and the flood basins of the Sacramento River (Figure 2). Along the range front, the fans coalesce and interfan boundaries are not discrete. The alluvial fan sediments are composed of relatively fine-grained, weathered clastic materials eroded from weak shales, sandstones, and low-

grade metamorphic rocks of the eastern Coast Ranges. Much of the soil textures at the surface of the Coast Range fans are loams, clay loams, and clay (Table 4-1; Holmes et al., 1913). Coast Range fan deposits are proximal to the Sacramento River floodplain in two areas: at the north end of the study area near Stony Creek, and near the middle of the study area near Knight's Landing (Cache Creek alluvial fan). While the Stony Creek alluvial fan surface is chiefly fine grained, the creek proper transports sand and gravel-sized sediment and conveys it to the Sacramento River (Schumm and Harvey, 1986). Moreover, alluvial deposits underlying the Stony Creek fan are substantially coarse-grained (Page, 1986).

Coast Range fan deposits include a complex arrangement of Pleistocene and Holocene alluvial deposits. Surficial deposits are abundantly silt and silty clay, and were probably transported as mudflows before deposition on the alluvial fan surface. Coast Range fans are coarser-grained upslope (i.e., gravels and sands) and finer-grained downslope (i.e., silts and clays). Natural levee deposits (channel ridges) are present on the larger alluvial fans like Cache Creek, Putah Creek, Petroleum Creek, and Cortina Creek. The deposits adjacent to these creeks are Holocene and unconsolidated alluvium (map unit Qa of Helley and Harwood, 1985). Based on previous studies in the Woodland and Davis areas (WLA, 2008a, b), subsurface stratigraphy is moderately variable with lenses or lobes of coarser-grained deposits in the subsurface from past positions of the fan distributary channels. The lobes typically are localized in extent, typically elongate in the down-fan direction (west to east), and lenticular in the cross-fan direction (north to south, Figure 4). The geomorphic fabric generally trends eastward, and the North NULE Project study area levees lie parallel to this fabric (e.g., a levee along Cache Creek north bank), as well as perpendicular to this fabric (e.g., a western levee of the Yolo Bypass). Overall, the permeability of the deposits in this domain varies and range from low to high.

#### **4.9 Sutter Buttes Fans (SBF)**

Sutter Buttes fans emanate from the Sutter Buttes uplands, and form an apron of sediment that surrounds the roughly circular remnant volcanic dome (Figure 2). The fans are dominantly Pleistocene (Helley and Harwood, 1985), and may be semi-consolidated. The Sutter Buttes' alluvial deposits consist of fine gravel, sand, silt and clay (DWR, 2006c) derived from erosion, reworking, and transport of the volcanic rocks that form the Buttes. Although the North NULE Project levees do not directly overlie these fans, fan deposits probably extend laterally away from the Buttes in the subsurface, and may interfinger or underlie parts of the adjacent flood basin. Stratigraphic variability of the Sutter Buttes fans is probably moderate to high based on their proximity to the source area and dynamic nature of alluvial fan deposition processes. Deposit permeability in SBF likely ranges from low to high, and is extremely variable from place to place (Olmstead and Davis, 1961).

#### **4.10 Cascade Range Fan (CF)**

Cascade Range fans consist of alluvial surfaces located on the west side of the Cascades (Figure 2). These are divided into older and younger surfaces. Pleistocene alluvial fan surfaces (CFo) are restricted to the foothills region, are consolidated and are relatively coarse grained (Helley and Harwood, 1985). Holocene alluvial fans (CFy) are present generally west and south of the town of Chico, and were deposited by Little Chico Creek, Chico Creek, and Butte Creek. The creek channels are relatively deep and narrow, generally

less than 50 feet wide and less than 25 feet deep (Bryan, 1923). The channels transport coarse-grained material although the fan surface itself consists chiefly of fine sand and sandy silt deposited during the overflow of the creeks (Holmes et al., 1913). Deposit permeability in this domain likely ranges from low to high (Olmstead and Davis, 1961). The variability of the subsurface stratigraphy is moderate based on the environment and deposition process.

#### **4.11 Delta (D)**

The Delta geomorphic domain is at the southern end of the study area (Figure 2). This domain consists of islands separated by fluvial channels and tidal sloughs that, prior to construction of artificial levees and dredge cuts, were intimately connected with fluvial and estuarine hydrology and sediment fluxes. The islands are saucer-shaped in cross section, and possess elevated flanks consisting of silt and loam from overflow of the directly-adjacent channels and sloughs. At a few feet above and below sea level prior to reclamation, the central part of the islands was covered by peat originally formed from decaying vegetation. Delta island deposits are late Holocene, unconsolidated and fine-grained muck (organic-rich silt and clay with high water content) and peat (Atwater, 1982). Because of the relatively uniform processes of delta island construction, and the relatively low-energy environment of deposition, the anticipated subsurface stratigraphic variability within this domain is probably low (Table 4-1). Directly adjacent to the watercourses, Sacramento River supratidal alluvium and sloughs overlie Delta islands peat and mud (Atwater, 1982). The alluvium forms natural levee ridges paralleling the river and distributary sloughs that extend into the Delta domain (Figure 2). Because the present-day artificial levees are constructed on the banks of the river and distributary sloughs, most of them rest on the natural levee deposits, and only locally do they rest on peat and mud deposits. Natural levee deposits and peat and mud deposits interfinger in the subsurface, creating vertical interbeds of silt and sand with organic-rich material. The deposits in the Delta domain are moderately permeable, with peat conservatively considered more abundant and more permeable than clay. The percentage of organic material (peat) is highest near the center of the Delta, and decreases in the direction of higher elevations of the delta rim (Atwater, 1982).

## **5.0 GEOMORPHIC ASSESSMENT AND ANALYSIS**

This section summarizes NULE Project Level 2-I geomorphic assessment and analysis results. It describes the geologic mapping and characteristics of the major map units and the analysis of underseepage, settlement, and subsidence hazards for the north NULE Project study area.

Intermediate in detail compared to the previous Level 1 study and the anticipated Level 2-II studies, this Level 2-I geomorphic assessment relies on the compilation and interpretation of existing data to produce a map of the entire NULE study area. Future, more focused Level 2-II studies will be undertaken at selected areas to develop a more detailed analysis of levee foundation materials in the North NULE Project study area (Figure 5).

### **5.1 Geomorphic and Surficial Geologic Analysis**

This section provides a description of the existing mapping used for analysis and a brief characterization of major map units. This is the basis of the framework applied to develop the underseepage susceptibility matrix and assignments.

Level 2-I analysis results are shown on susceptibility maps as described in Section 3.0. These maps are a compilation and interpretation of existing published and unpublished data. Most geologic units are compiled from previous mapping of Quaternary geology. The Level 2-I study generally confirms the conceptual model of geomorphic domains generated during the Level 1 study. Via Level 2-I assessment, geologic detail is added that enables an analysis of underseepage hazard for specific NULE levees.

#### **5.1.1 Geology and Geomorphology**

Existing geologic maps used in this study (Atwater, 1982; Helley and Harwood, 1985; DWR, 1994) recognize individual map units within five main depositional environments: flood plain, flood basin, alluvial fan, Delta, and channel. Much of the North NULE levees overlie flood plain or flood basin deposits (Table 4-1). Existing published mapping depicts these deposits as Qa or Qb; however, these can be further subdivided with closer inspection (i.e., crevasse splays or distributary deposits). Generally, river natural levee deposits are mapped as Qa, and slackwater deposits in topographic lows are mapped as Qb.

Natural levees are formed as floodwaters overtop channel banks, depositing fine sand and silt-rich alluvium along the flanks of the river bank, then carrying finer-grained clay and silt in suspension onto the distal floodplain. This depositional sorting process creates a “natural levee” landform with a topographic gradient sloping away from the river.

Natural levees (map unit Qa of Helley and Harwood, 1985; QI of Atwater, 1982) are a composite of many individual deposits accumulated over thousands of years. As currently depicted in published maps, map units Qa and QI are a generalization of the complex deposits that make up natural levee landforms. Detailed mapping subdivides these units as historical or Holocene overbank or crevasse splay deposits (Saucier, 1994; WLA 2007). Also, detailed mapping identifies smaller distributary channels on the floodplain that commonly are not recognized by the general Qa (Table 3-2). Natural levee deposits are

extensive over the north NULE Project study area (SR, FR; Figure 2) and commonly are associated with HSG soil group C (low permeability silt; Figures 10 through 36). Conceptually, the present-day silty natural levee deposits overlie older, buried, coarser-grained deposits of latest Pleistocene river channel alluvium (Shlemon, 1967).

Flood basins were frequently inundated swamplands prior to reclamation. River flood overflow and tributary fan contributions drained into thousands of acres of sloughs, swamps, and dense marshes of bulrushes creating a region then known generally as the Tule. During high flows, this environment was akin to an inland sea of slow-moving, broad bodies of water. Flood basin deposits created by these bodies (map unit Qb) consist of very fine sand, silt, and clay laid in a relatively low-energy depositional environment. Basin and marsh deposits are present in the topographically low areas west of the present-day Sacramento and Feather Rivers (Figure 2). Soils associated with these deposits are the Sacramento silt loam, heavy clay, and clay adobe. Heavy clay is prone to shrink-swell; clay adobe is prone to desiccation cracking. Prior to cultural draining of the land, basin deposits were generally saturated and often thick with tule or bulrush vegetation in the latest Holocene environment, and organic-rich clay may be present. Existing mapping (Holley and Harwood, 1985) identifies basin deposits in topographic lows as well as on gently dipping slopes. Mapping of Qb gently dipping slopes is probably inappropriate; these areas would more appropriately be mapped as distal alluvial fan facies that consist of silt and clay. The application of the unit Qb is more appropriately used in actual topographic depressions directly adjacent to the major rivers (Yolo Basin, Natomas Basin).

Along the flanks of the study area and buried beneath parts of the valley are mid- to late-Pleistocene Riverbank and Modesto Formation deposits (map units Qrl, Qru, Qml, Qmu). Alluvial fan map units derived from the Sierra Nevada to the east of the study area have a distinct geologic watershed, history and geomorphic relationship as compared to those derived from the west side of the NULE Project study area (Shlemon, 1967; Atwater, 1982).

Deposits from the Sacramento-San Joaquin Delta directly underlie the non-urban levees in the southern part of the study area. The delta deposits (map unit Qp of Holley and Harwood, 1985; Qpm of Atwater, 1982) are chiefly peat and peaty mud of tidal wetlands and waterways. The deposits of the former wetlands commonly contain organic matter from plant detritus, and generally the organic content is highest in the central and south-central Delta. The formerly high groundwater table kept peat wet and inhibited organic material decay. Historical draining of soils and water table decline promoted oxidation and organic material decay. The maximum thickness of peat in the Delta is about 50 feet near Sherman Island (Atwater, 1982), where the peat overlies unmapped sand and silt deposits of latest Pleistocene age. Where peat is thicker, it could have been deposited in depressions carved by Pleistocene channels. Granular soils underlie much of the Delta peat, and are likely highly permeable (USACE, 1987).

Channel deposits are mapped by Holley and Harwood (1985) as map unit Qsc, which is an encompassing unit including point and in-channel bars, meander scrolls, oxbows, bed material, and other sediments from the active river channel. Geomorphic mapping by DWR (1994) identifies these deposits in some detail north of Colusa, and shows channel meander migration of the Sacramento River over the past hundred or so years. Individual map units from DWR (1994) were grouped to delineate historical Sacramento River channel positions

(map unit SRtc), and to delineate older river deposits from former meander positions of the river (late Pleistocene – early Holocene, map unit SRm). The sediments in these deposits, both SRm and SRtc, primarily consist of cobbles, gravel and sand from the relatively steep gradient channel sediment transport interbedded with sand, silt, and clay from overbank sedimentation. By definition, deposits of SRtc are younger than SRm.

The preceding discussion of geomorphic domains briefly summarizes the major map units comprising levee foundations in the North NULE Project study area. These summary characterizations provide a context for interpretation of general sediment grain sizes that are encountered in the shallow subsurface. Sediment type, permeability and shallow stratigraphic relationships exert controls on underseepage processes and are incorporated into the underseepage susceptibility analysis and assessment.

### **5.1.2 Underseepage Susceptibility of Mapped Geologic Units**

This underseepage susceptibility assessment considers geologic deposits underlying present-day levees, the characteristics of soils developed on those deposits, and the surficial landscape features that may influence or control underseepage. To assess underseepage hazard, underseepage susceptibility maps are constructed using a criteria matrix (Table 5-1). The criteria matrix combines information about late Quaternary geologic deposits from published map sources, channel features mapped from historical topographic maps, and NRCS HSG. Where detailed surficial geologic mapping was available (1:20,000-scale or better), underseepage susceptibility classes were assigned based on geologic age, depositional environment, stratigraphic relationships and inferred relative soil permeability. This univariate assignment (Table 5-2) is used because detailed surficial geologic mapping interprets and incorporates soil survey data as part of the map development, and using HSG would be redundant. The underseepage susceptibility of mapped geologic deposits is described below by susceptibility class. In some instances, underseepage susceptibility is interpreted to decrease slightly as surface soil permeability decreases (Table 5-1). Examination of the interpreted underseepage susceptibility classes based on associations with levee performance case histories is presented in Section 6.1.

#### **5.1.2.1 *Very High Susceptibility***

Geologic deposits interpreted to have very high underseepage susceptibility are:

- Historical and active stream channel deposits (map units SRtc and ac)
- Hydraulic dredge spoils (map unit Qds)
- Quaternary channel meander zone (map unit SRm)
- Peat and mud deposits (map unit Qp, Qpm)

Stream deposits, both SRtc and SRm, consist chiefly of coarse-grained sediment and have relatively high permeability. They also have very high susceptibility to underseepage. Stream deposits in the shallow subsurface are considered to have promoted failure of the Linda levee near Marysville, and have a documented influence on underseepage (subsurface flow pathways).

Hydraulic dredge spoils are known to consist of silty and fine sand material that typically were sucked from the river channel and hydraulically emplaced on the ground surface immediately prior to levee construction. These deposits are known to be permeable, and have generally poor engineering characteristics due to their method of emplacement (Bryan, 1923).

Peat and mud deposits are interpreted to have very high underseepage susceptibility based on the fact that much of the peat and mud are underlain by older and more-permeable strata (Atwater, 1982, USACE, 1987). The stratigraphic relationship of relatively fine-grained sediment overlying relatively coarser-grained sediment presents a geotechnical blanket condition, reducing head loss in the soil column and promoting relatively high exit gradients.

Detailed mapping (WLA 2007, 2008a, 2008b) interprets historical deposits as having very high underseepage susceptibility (map unit Rob; Table 5-2). The basis for this assignment is the likelihood that these sediments consist of granular material derived from the transport and deposition of debris from hydraulic mining higher in the watershed; the sediments likely are relatively permeable.

#### ***5.1.2.2 High Susceptibility***

Mapped geologic units interpreted to have high susceptibility include: tailings from hydraulic mining (map unit "t"), natural levee deposits (map units Qa, Ql; Table 5-1), latest Pleistocene alluvial fans (map units Qmu; Tables 5-1 and 5-2) and Holocene age floodplain and channel deposits (map unit Hob; Table 5-2).

Tailings from hydraulic mining are restricted to areas near the margin of the valley floor. These deposits are derived from re-working and re-mining gold flecks in river alluvium, and were emplaced in long "mole track"-type mounds by mechanized equipment. Typically these are coarse-grained deposits, but their exact sedimentologic consistency is not known at this time. As a result, this unit is conservatively assigned a high underseepage susceptibility. Tailing deposits are different from hydraulic dredge spoils in that hydraulic dredge spoil sediment (unit Qds) were commonly sucked out of the river channel and hydraulically emplaced on the adjacent ground to widen, deepen, or straighten the Sacramento River. (Atwater, 1982). The majority of hydraulic dredge spoils deposits are mapped between Collinsville and Cache Slough.

As described previously, natural levees consist chiefly of interbedded silt, clay, and fine sand. In some instances, these natural levee deposits overlie thick granular sands of much older river deposits, and may represent a relatively finer-grained layer over coarser strata. These units, Qa and Ql, are interpreted to have high susceptibility to underseepage (Table 5-1). Again, as currently depicted in published maps, map units Qa and Ql are a generalization of complex deposits making up natural levee landforms. Detailed mapping subdivides and delineates additional deposits not recognized in the broad Qa or Ql unit by Helle and Harwood (1985) or Atwater (1982). Detailed mapping interprets much of the surficial geology of the natural levees as either historical and therefore of very high susceptibility, or of Holocene age, and so of moderate susceptibility (Table 3-2; Table 5-2). While map units Qa and Ql are interpreted as having high susceptibility, they actually encompass a range of underseepage susceptibility states from very high to moderate.

### **5.1.2.3    *Moderate Susceptibility***

Map units interpreted as having moderate susceptibility to underseepage include flood basin deposits (map unit Qb with HSG A or B; Table 5-1), Holocene alluvial fan deposits from the Coast Ranges (map unit Hf; Table 5-2), and mid- to late-Pleistocene alluvial fan deposits (map units Qml, Qop with HSG A or B; Table 5-1). Flood basin deposits with HSG A and B are interpreted as having moderate susceptibility because of their generally fine-grained texture, but apparent permeability is based on NRCS HSG mapping. Map unit Qa with HSG A or B comprises less than 2 percent of the total North NULE Project levee miles. Holocene alluvial fan deposits are interpreted as having moderate susceptibility because of their silty and sandy consistency, which is derived from erosion, transport, and weathering of sedimentary Great Valley rocks in the Coast Ranges (WLA, 2008a; 2008b). Mid- to late-Pleistocene alluvial fan deposits (map unit Qml, Qop with HSG A or B) are similarly assigned moderate susceptibility to underseepage.

### **5.1.2.4    *Low Susceptibility***

Deposits mapped as having low susceptibility include flood basin deposits with HSG C or D (Table 5-1), and early Pleistocene to Pliocene deposits (map units Qru, Qrl, Qrb, Qtl; Tables 5-1 and 5-2). Flood basin deposits commonly consist of lean or fat clay, with thickness greater than about 10 feet. These deposits have low permeability strata with low permeability soils, and are interpreted to have low susceptibility to underseepage. Similarly, early Pleistocene to Pliocene deposits are interpreted as having low susceptibility based on their age and consolidation, which usually correlates with low permeability strata.

## **5.2      Hazard Susceptibility Analysis**

The susceptibility of NULE Project study area levees is assessed in this section with respect to three types of hazards: underseepage, settlement, and subsidence. The larger part of the effort in this Level 2-I study was applied to the analysis of underseepage; discussion of this hazard is presented in detail by geographic area in subsection 5.2.1. Level 2-I analysis also included a regional assessment of soil settlement and subsidence based on available data, and is presented below in subsections 5.2.2 and 5.2.3.

### **5.2.1    Assessment of Levee Underseepage Susceptibility Hazard**

The underseepage hazard is in large part a function of the presence beneath the levee of permeable geologic materials. The underseepage susceptibility map is based on the assessment of the relative permeability of the mapped geologic units, as detailed in the criteria matrix (Table 5-1) and assignment table (Table 5-2), and described in subsection 5.1.2.

This discussion of levee underseepage susceptibility hazard is organized by NULE Project study area region and then by sub-areas within each region. The North NULE Project study area is subdivided first into Regions 1 and 2 (Figure 3). Beginning in the north with Region 1, sub-areas within each region are discussed in order from north to south. For each sub-area, a summary of geomorphic and geographic setting, geologic conditions beneath the NULE levees, and an assessment of underseepage hazards based on these conditions is

presented. Seven sub-areas are described in Region 1 and eight sub-areas are described in Region 2.

### ***5.2.1.1 Region 1***

#### **Red Bluff to Vina (Figures 10 and 11)**

NULE levees and underseepage susceptibility in the area of Red Bluff and southward to Vina are shown on Figures 10 and 11. Locations and extents of non-urban non-Project levees are shown on Figure 9, and are present on Figure 10. The Sacramento River flows southerly along this stretch, meandering laterally, creating oxbows and depositing sediment as sandy to gravelly point bars and mid-channel bars. The non-urban Project and non-Project levees near Blackberry Island, Sacramento Bar, and Copeland Bar overlie alluvium and meander-laid Sacramento River deposits. The Sacramento River is dynamic in this area and the channel changes location on timescales of tens of years, based on map data (map unit SRtc). As a result, deposits in these areas (SRm, SRtc) are young and coarse and of variable consolidation resulting in very high underseepage susceptibility (Figures 10 and 11). The Project levees along east-flowing Elder Creek (Figure 10) overlie Modesto-age alluvial fan material along the west, and Quaternary alluvium (Qa) of the Sacramento River upon traversing the floodplain. The underseepage susceptibility in this area is moderate along the alluvial fan deposits, and high along the floodplain. Levee failures have been documented along Elder Creek (Figure 10). Southwest-flowing Deer Creek NULE Project levees overlie alluvial fan material of Riverbank and Modesto ages. The mapped extent of these moderately to well-consolidated deposits, in conjunction with mapped historical fan channels, results in a range from low to very high underseepage susceptibilities along this creek (Figure 11).

#### **Chico Area (Figures 12 and 28)**

NULE levees in the Chico area include those along Mud Creek, Sycamore Creek, and a length of canal and associated levee that diverts water from Big Chico Creek into Sycamore Creek (Figure 12). Non-urban non-Project levees lie southwest of Chico, along southwesterly-flowing Little Chico Creek and Comanche Creek (Figure 12), and overlie foundations that range from high to low susceptibility. Mud Creek flows across a low relief, slope angle alluvial fan surface that emanates from the mountains and slopes gently to the valley floor adjacent to the Sacramento River. In the past, the creek was part of a complex anastomosing fan-channel network that meandered, forked, and re-joined repeatedly down the alluvial fan, as indicated by the channels mapped from historical topographic maps (Figure 12). Mud Creek is currently confined between two levees spaced approximately 250 to 400 feet apart. The bulk of foundation materials along Mud Creek levees are semi-consolidated Riverbank and Modesto-age alluvial fan deposits that are surficially cross cut by the now-abandoned channel network (Figure 12). Farther upstream on the alluvial fan (Figure 28), the flood diversion levee diverting water from Big Chico Creek into Sycamore Creek mostly overlies Pliocene-aged Tuscan Formation, and has low susceptibility to underseepage based on interpreted low permeability and overall consolidation of the Tuscan Formation. These spatially variable foundation conditions in the Chico area (Figures 12 and 28) result in a range of underseepage susceptibilities from low to moderate to high and very high.

### **Butte Creek and Cherokee Canal (Figures 28 to 31)**

Butte Creek (Figures 28 and 29) and Cherokee Canal (Figures 30 and 31) are similar fluvial systems; they both collect water from drainages emerging from the Cascade foothills and direct water across a low relief, low slope alluvial fan surface into a flood basin east of the Sacramento River (Figures 29 and 31). The alluvial fan surface grades into the flood basin east of the Sacramento River very gradually and, prior to levee construction, the middle to lower reaches of these watercourses exhibited anastomosing channel networks. Based on soil and geologic data, the upstream third to half of the levees along Butte Creek rest on upper Modesto Formation, and are assessed as having high susceptibility (Figure 28). Tailings from hydraulic mining are mapped along upper Cherokee Canal and are assessed as having moderate underseepage susceptibility (Figure 30). The lower sections of both systems have mostly low underseepage susceptibilities (Figure 29 and 31) based on the presence of fine-grained flood basin deposits. Few to no performance problems are documented along low susceptibility foundations. However, where present-day levees cross over channel deposits from anastomosing lower stream sections, underseepage susceptibility is interpreted to be very high.

### **Sacramento River—Ordbend to Colusa (Figures 13 and 14)**

From Ordbend (Figure 13) to directly north of Colusa (Figure 14), the Sacramento River dynamically meanders within a meander zone generally confined by erosion-resistant lower Modesto Formation (DWR, 1994). Evidence of persistent river overtopping is observed in the soil HSG map pattern in distributary fingers of coarser-grained material flanking the east and west sides of the river (Figure 13 and 14). Narrow distributary channels mapped from historical topographic maps also attest to this pre-levee fluvial process. In this sub-area, NULE Project levees overlie channel deposits (SRm), undifferentiated Quaternary alluvium (map unit Qa, overbank sediments), and lower Modesto Formation (map unit Qml). Based on the distribution of geologic units and the soil HSG, NULE Project levee foundation susceptibility along this sub-area correspondingly is very high, high, moderate, and low (Figures 13 and 14). NULE non-Project levees are present west of the Sacramento River (Figure 13), with one stretch oriented north-south, and the other east-west. The non-Project levees lie directly north of Princeton, chiefly on Pleistocene alluvial fan deposits (lower member of the Modesto Formation) or fine-grained basin deposits. The non-Project foundation underseepage susceptibility is low and moderate (Figure 13).

### **Sacramento River—Colusa to Knights Landing (Figures 15 and 16)**

In contrast to the Sacramento River north of Colusa, the Sacramento River south of Colusa has a narrower channel closely bordered by artificial levees constructed over river natural levee deposits (map unit Qa). The Sacramento River does not laterally meander or migrate as much in this sub-area compared to upstream of Colusa (Figures 15 and 16). The river is sinuous and, as a consequence, subdued natural levees (map unit Qa) parallel the channel; a few abandoned and cut-off meanders lie outboard of the levees. In this setting, sandy alluvium is deposited by crevasse splays and distributary channels that overtop or breach the natural levees. The NULE Project levees rest atop this sandy alluvium and the underseepage susceptibility is correspondingly high through the entire length, and past levee performance problems have been documented (e.g., Figure 15). The NULE non-Project

levees lie west of the city of Colusa (Figure 9, Figure 15), and overlie part of the Sacramento River natural levee and extend southerly across fine-grained basin deposits. The foundation underseepage susceptibility of the non-Project levee west of Colusa is high along the river natural levee alluvium, and low along the basin deposits.

### **Butte Slough, Sutter Bypass, Wadsworth Canal, and Tisdale Bypass (Figures 15, 16, and 19)**

The NULE levee along Butte Slough sits on the right bank (southwest side) of the channel. Butte Slough channel historically funneled high water discharges from the Sacramento River southeastward into the Sutter Basin (Sutter Bypass). The Butte Slough levee sits chiefly on Holocene alluvium (map unit Qa) and basin deposits directly adjacent to the channel, resulting in high underseepage susceptibility (Figure 15).

Sutter Bypass conveys flood water from Butte Slough across the Sutter Basin, merges with the Feather River, and ultimately discharges into the Sacramento River and Yolo Bypass (Figures 16 and 19). The Sutter Bypass traverses the gently southwest-sloping transition from Sierra Nevada fan to flood basin (Figure 2; Section 4). Along this levee a thin veneer of fine-grained basin deposits (about 8 to 10 feet) overlies a coarse-grained Modesto-age alluvial fan that contains shallow, moderately developed hardpans. This specific stratigraphic relationship likely represents a geotechnical blanket condition. Sutter Bypass foundation materials are Basin over Modesto (map unit Hn/Qm; Table 5-2), and are assigned high underseepage susceptibility (Figures 16 and 19).

Wadsworth Canal lies in a similar geomorphic environment to Sutter Bypass, but is oriented sub-orthogonally to the Sutter Bypass (Figure 16). The canal runs down the gently southwest-sloping Sutter Basin where a thin veneer of fine-grained basin deposits overlies a Modesto-age alluvial surface containing moderately developed hardpans and sandy deposits. The right bank levee foundation's susceptibility to underseepage is high because of these near-surface stratigraphic conditions that could represent a geotechnical blanket layer, namely laterally extensive fine-grained soils over sandy alluvial fan deposits.

Tisdale Bypass conveys flood water from the Sacramento River eastward to the Sutter Bypass (Figure 16). The western third of the two NULE levees along the Tisdale Bypass sit atop sandy historical and Holocene alluvium deposited in crevasse splays and flood events that overtopped the natural levees of the Sacramento River. This section of the foundation deposits beneath NULE levees is assigned high underseepage susceptibility. Farther to the east, the susceptibility to underseepage abruptly changes to low based on published geologic data (Helley and Harwood, 1985). It is likely there is not an absolute change from high to low susceptibility (Figure 16), but rather a transition across this change over some distance.

### **Colusa Basin Drainage Canal and Knights Landing Ridge Cut (Figures 15, 17, 18, and 20)**

The Colusa Basin Drainage Canal (CBDC) flows from north to south from near the town of Colusa, along the eastern margins of the alluvial fans emanating from the Coast Range, to Knights Landing on the Sacramento River (Figures 15, 17, 18, and 20). Helley and Harwood

(1985) map basin deposits extending from the Colusa Basin up the alluvial fans for several miles in some cases. These deposits also show fine-grained distal alluvial fan sediments in this area. While the CBDC lies at the edge of the alluvial fans, NRCS soils mapping indicates near-surface materials are fine-grained (Figures 15, 17, 18, and 20). As a result of the geologic unit and the HSG class, the foundation deposits beneath the CBDC are assigned low underseepage susceptibility. Underseepage levee distress has not been recorded along the CBDC. A non-urban non-Project levee ties-in to the Sacramento River and the CBDC directly south of Kirkville (Figure 18). The foundation of the north-trending levee chiefly is fine-grained basin deposits (low underseepage susceptibility), except for the northern-most part that overlies part of the Sacramento River sandy alluvium and narrow channels (Figure 18).

The Knights Landing Ridge Cut canal transports water from the CBDC to the Yolo Bypass (Figure 20). The Knights Landing Ridge Cut was excavated through several topographically high abandoned arms of the Cache Creek alluvial fan and the levees that bound the canal overlie alluvial fan sediments, basin deposits, and natural levee deposits of the Sacramento River near Grays Bend. These foundation conditions generally result in low and moderate underseepage susceptibilities but also locally very high underseepage susceptibilities where the levees cross abandoned historical or Holocene channels.

#### **5.2.1.2 *Region 2***

##### **Honcut Creek, Middle Feather River, and the Western Pacific Rail Line (Figure 32)**

The NULE levees along Honcut Creek, the middle Feather River, and the Western Pacific rail line all lie north of the city of Marysville and directly east of Sutter Buttes (Figure 32). The NULE levee along Honcut Creek's southern bank is set back from the main channel of the creek, and sits on slightly higher elevation deposits of Modesto- or Riverbank-age. This foundation has mostly low susceptibility to underseepage, but there are areas of moderate and high susceptibility where the levee overlies the lower member of the Modesto Formation with HSG type B, and the upper member of the Modesto Formation with HSG type B, respectively (Figure 32). The NULE levee alignments along the middle Feather River run along the east bank of the river from the confluence with Honcut Creek southward to the city of Marysville. In most locations the levee rests atop alluvium of the Feather River (map unit Qa) or Modesto-age alluvial fan material at the top of the entrenched channel's banks. Though variable, underseepage susceptibility through this section is generally high. In contrast, the levee along the Western Pacific rail line north of Marysville does not lie adjacent to a large river (Figure 32), but rather appears to protect the railroad grade from high flows that overwhelm the adjacent Simmerly Slough and other small foothill-derived creeks. The levee sits almost entirely on Modesto and Riverbank-age alluvial fan deposits that are moderately to well-consolidated. As a result, the foundation of the levee along Western Pacific rail line generally is assigned low underseepage susceptibility (Figure 32).

##### **Bear River, Best Slough, and Feather River (Figures 33 and 34)**

This group of levees includes levees along the Bear River and its tributaries (Dry Creek, Grasshopper Slough, and Yankee Slough), levees along Best Slough as well as a levee adjacent to the Western Pacific rail line (Figure 33), and the levee on the east bank of the

Feather River from the Feather's confluence with the Bear River south to the Feather's confluence with the Sutter Bypass (Figure 34). The levees of the Bear River and its tributaries generally constrain these watercourses to narrow and straight channels (Figure 33). These levees typically overlie extensive historical alluvium and stream channel deposits derived from upstream hydraulic mining debris, and therefore are interpreted as very high to high underseepage susceptibility (map units Rob, Qa, respectively). In contrast, the levees along nearby Best Slough and the Western Pacific rail line sit on older, consolidated alluvial fan deposits of the Riverbank Formation with low permeability soils and have low underseepage susceptibility. The levee along the east bank of the Feather River south of the Feather's confluence with the Bear River generally overlies historical alluvium of crevasse splay and overbank deposition (Rcs, Rob; Table 5-2), which is assessed as having high susceptibility to underseepage. Underseepage has been recorded in the performance databases along the levees assessed as having high and very high susceptibility in this area.

### **Woodland (Figure 20)**

NULE levees near the town of Woodland sit on the north bank of Cache Creek north and east of the town (Figure 20). This levee parallels Cache Creek as the creek flows eastward across a broad alluvial fan and eventually enters the flood basin adjacent to the Sacramento River. Cache Creek regularly overtops its banks to deposit low-relief lobes of sandy alluvium across the alluvial fan; thus, many historical deposits are mapped along this creek. Even where the NULE levee along the northeast side of the Cache Creek Settling Basin approaches the low-lying flood basin, young distal alluvial fan deposits underlie the levee, as indicated by map unit Rf (Figure 20). These unconsolidated historical deposits are assigned very high underseepage susceptibility.

### **Davis (Figure 22)**

NULE levees in the Davis area include the southern levee along the South Fork of Putah Creek, the north levee along the Willow Slough Bypass canal, and a length of levee on the west side of the Yolo Bypass (Figure 22).

The South Fork of Putah Creek is an entirely man-made canal constructed after the town of Davis was repeatedly flooded by waters from the original Putah Creek channel in the late 1800s (Vaught, 2006). These levees are built directly on sandy and silty historical alluvial fan and channel deposits resulting from overbank sedimentation and flood flows emanating from the creek (units Rob, Rf, Rb, etc. on Figure 22). Holocene alluvial fan deposits probably underlie the historical deposits in the shallow subsurface, and may have local pockets of coarser distributary channel alluvium. As a result of this historical sedimentation, the foundation deposits along this section of levee are assigned very high underseepage susceptibility. Although there are no documented underseepage problems along this stretch (Figure 22), these deposits elsewhere in the study area are coincident with boils and seepage features.

Willow Slough Bypass is a canal flanked by NULE levees and carries water from Dry Slough and Willow Slough around the north side of the city of Davis to the Yolo Bypass (Figure 22). The levees overlie Holocene alluvial fan and channel deposits until they reach the Yolo Bypass where the levees enter a flood basin, and overlie generally finer-grained deposits

consisting of silts and clays. The section of NULE levee in the alluvial fan setting north of Davis has moderate underseepage susceptibility and the length of levee along the west side of the Yolo Bypass has low underseepage susceptibility, due to the generally finer materials in the shallow near subsurface.

### **East Side Canal and the Natomas Basin Cross Canal (Figures 21 and 34)**

The East Side Canal lies northeast of the American Basin (Figures 21, 34). The canal flows from north to south (Figure 34), collecting water from the small creeks draining the piedmont adjacent to the town of Lincoln. The levee adjacent to the canal overlies deposits of the Modesto Formation and so the foundation has low underseepage susceptibility.

The Natomas Basin Cross Canal is the downstream extension of the East Side Canal and flows across a variety of deposits ranging from Modesto Formation in its upper extent to Holocene basin and Sacramento River natural levee deposits in its lower extent (Figure 21). The fine-grained and moderately consolidated deposits along the northern length of the canal result generally in low underseepage susceptibility, but coarser and younger overbank deposits directly adjacent to the Sacramento River are assigned high to very high underseepage susceptibility.

At the southeastern extent of Figure 21, non-urban non-Project levees flanking drainage canals traverse generally north-south across the valley floor. The foundations sediments are interpreted as historical marsh deposits that are assigned high susceptibility to underseepage based on the potential presence of organic matter and associated permeable strata.

### **Sacramento-Feather River Confluence and Yolo Bypass Region (Figure 21)**

This section includes NULE levee foundations along the Sacramento River from Knights Landing downstream to the Sacramento Bypass, along the lower Feather River, and along the northern and eastern Yolo Bypass (Figure 21). The levees adjacent to the Sacramento River from Knights Landing downstream to the Sutter/Yolo Bypass floodway sit on natural levee deposits (Qa, Figure 21). These deposits are assessed as high underseepage susceptibility. Moving downstream along the Sacramento River, only the levee on the west bank is a NULE levee. Just north of Interstate 5 (I-5), the natural levee deposits thin laterally and vertically, and the levee approaches the flood basin environment and underlying fine-grained basin deposits. Otherwise, this levee overlies natural levee deposits (Qa) directly adjacent to the river and has high underseepage susceptibility.

NULE levees along the lower Feather River lie on the east bank of the Feather River and also bound the Sutter Bypass on its western margin (Figures 34 and 21). Both of these levees overlie alluvium derived from overbank deposition and crevasse splay formation common to the large rivers in the Sacramento Valley. As a result of this variable and sandy material under the levees, these foundations are assigned high underseepage susceptibility. The levee along the east side of the Yolo Bypass traverses a flood basin setting and overlies fine-grained flood basin deposits. As a result, the foundation underseepage susceptibility is low. In contrast, levees along the northern Yolo Bypass adjacent to the Knights Landing Ridge Cut traverse distal portions of the Cache Creek alluvial fan (Figure 21).

## **The Lower Sacramento River and Sloughs in the Delta (Figures 23, 25 to 27)**

This section describes NULE levees along the Sacramento River from directly south of the City of Sacramento downstream through the Delta to Sherman Island, the many sloughs within the Delta, and the Deep Water Ship Canal (Figures 23, 25, and 27). The levees along the lower Sacramento River overlie Holocene natural levee (Qa, Ql) and basin (Qb) deposits in the upstream areas, but these deposits transition to natural levee deposits that overlie organic-rich peat and mud deposits (Qpm) as the river approaches the Delta near Courtland and Paintersville (Figure 25). Non-urban non-Project levees are present directly east of Freeport around the Sacramento Regional Wastewater Treatment Plant, as well as along Snodgrass Slough (Figures 9 and 25). Non-urban non-Project levees east of Freeport principally overlie Pleistocene Riverbank Formation deposits that are assigned low susceptibility to underseepage. Along Snodgrass Slough, a former distributary channel of the Sacramento River, non-urban non-Project levees overlie a range of deposits and soil types, from sandy peat to fine-grained basin deposits, and the foundation underseepage susceptibility similarly ranges from very high to low (Figure 25). The non-urban Project levee along the Deep Water Ship Canal (Figure 25) traverses a flood basin that lies between the distal Putah Creek alluvial fan and the Sacramento River and related sloughs. Because the NULE levee along the Deep Water Ship Canal overlies thick flood basin materials, foundation underseepage susceptibility is low.

Generally throughout the Delta region (e.g., Figures 25 to 27), silty-sandy natural levee deposits accumulate proximal to the active channels, forming rings of higher ground around lower elevation islands of organic-rich peaty material (Atwater, 1982). As deposition of natural levee material decreases away from the channels, the component of peat and mud material increases. The natural levees along sloughs such as Elk, Sutter, Steamboat, Miner, Georgina, and Threemile Sloughs generally are mapped as Qa or Ql. As a result, NULE levees along the Sacramento River and nearby sloughs are assigned high underseepage susceptibilities except in locations where underseepage susceptibilities are very high because levees overlie peat and mud materials (map unit Qpm) or spoils from the dredging of channels (map unit Qds; west side of Figure 27). At the southeastern extent of Figure 27, non-urban non-Project levee flanks the North Mokelumne River. Much of the levee overlies peat deposits that are Group A HSG types. This foundation condition is assigned very high susceptibility to underseepage.

## **Cache Slough, Lindsey Slough, and other levees north of the Montezuma Hills (Figures 24 and 26)**

The levees along the upper extent of Cache Slough, as well as its tributaries—Shag and Hass Sloughs—generally overlie older distal alluvial fan deposits from Putah Creek (map unit Qop) and flood basin deposits (map unit Qb) (Figures 24 and 26). These deposits are probably fine-grained resulting in low underseepage susceptibility for the levees that overlie those deposits. Locally, where the levees overlie historical slough channels, very high underseepage susceptibilities are mapped. The downstream extents overlie deposits of organic-rich peaty material (map unit Qpm) that are assigned very high underseepage susceptibilities. The levees along Lindsey and Barker Sloughs and the related canals also have similar foundation conditions. The upstream extents of these levees also are assigned low underseepage susceptibilities because of the fine-grained basin and Putah Creek

alluvium, and the downstream sections have very high underseepage susceptibilities because of the presence of peat deposits. Much of the non-urban non-Project levees along the Deep Water Ship Channel (Figure 9, Figure 24) overlie fine-grained basin deposits that are interpreted to be low underseepage susceptibility foundations. Farther south, the foundation deposits change to organic-rich peat and mud that is assigned very high susceptibility to underseepage (Figure 24).

### **Lake Almanor Levees (Figure 35)**

The North Fork of the Feather River flows into Lake Almanor near the town of Chester on the northwestern margin of Lake Almanor (Figure 35). At about 3 miles west of the lake shore, the North Fork Feather River channel becomes unconfined and deposits coarse sediment, building an alluvial fan-delta into Lake Almanor (map unit Qa; Figure 35). The alluvial fan consists of alluvial fan-delta deposits with generally coarse sediment (i.e., sand and gravel). Quaternary alluvium (map unit Qa) is coarse-grained here and interpreted as having high susceptibility to underseepage based on inferred permeability.

### **Clear Lake Levees (Figure 36)**

Present-day levees north of Clear Lake parallel Rodman Slough, Middle Creek, the Tule Lake drainage, and a diversion canal for Clover and Alley Creeks (Figure 36). In the Clear Lake area (Figure 36), non-urban levees are interpreted to be underlain by about 10 feet of fine-grained lacustrine deposits (silt; map unit Qla). The lacustrine sediment was probably deposited during a high-level stage of Clear Lake that completely inundated the system of broad and flat valleys surrounding present-day Clear Lake. Floodplain width along each of the primary drainages appears greater than the erosion and sediment transport potential and meander pattern of the present-day creeks (Figure 36). This difference points to the presence of older (and now buried) alluvial sediments that were deposited during or shortly after valley incision and erosion that created the present-day landforms. It is inferred, based on the valley floor morphology, that the surficial lacustrine deposits are likely underlain by coarser-grained alluvial deposits. This inference is supported by McNitt's (1968) mapping that identified fine-grained lake deposits underlain by the alluvial Cache Formation directly south of Clear Lake. The fine-grained silty lake sediment overlying coarser-grained alluvium likely represents geotechnical blanket-layer conditions and is assigned high susceptibility to underseepage. At the southern extent of the Clear Lake levees, historically reclaimed wetland and marsh deposits underlie the present-day levees. These deposits contain organic material that, upon draining, becomes prone to compaction and settlement.

#### **5.2.2 Assessment of Levee Foundation Soft Soils**

The Level 2-I analysis provides a regional assessment of potential soft soil levee foundations based on available data (Figures 37a and 37b). For this analysis, areas of marshes, former marshes and water bodies, organic (soft) soils, and peat deposits are mapped, and it is inferred that these areas are more likely to contribute to levee instability (e.g., circular failure planes beneath levees) compared to other North NULE foundations. Marshes, former marshes and water bodies are identified by mapping from early topographic maps. Organic-rich soft soils are identified from NRCS soil maps. Peat deposits are identified from geologic maps of Helle and Harwood (1985) and Atwater (1982).

### 5.2.3 Assessment of Regional and Local Ground Subsidence

Subsidence is a decrease of land surface elevation with respect to a fixed datum, and may be caused by natural or human-induced processes. Subsidence may occur as a result of sediment pore fluid extraction (e.g., subsurface fluid or water mining) or from deformation related to deep-seated tectonic processes (Harwood and Helle, 1987). Many of the floodways, levees and canals of the Sacramento Valley traverse long distances with very gentle gradients, and may be strongly affected by small subsidence-related elevation changes. Subsidence poses a hazard to a levee system by decreasing levee crest elevations, or by changing local channel gradients driving local aggradation (which may increase flood stage) or degradation (which may cause erosion of levee foundations).

Subsidence due to groundwater extraction in the Sacramento Valley has occurred, but not as dramatically as in the San Joaquin Valley to the south, primarily because more groundwater is extracted in the San Joaquin Valley (Lofgren and Ireland, 1974). Subsidence may increase in extent or become accelerated if groundwater pumping escalates in the future. Survey data collected in the Sacramento Valley over a five-year period (1985-1989; Ikehara, 1994) showed subsidence rates ranging from less than 0.02 meters per year to greater than 0.05 meters per year (about 0.8 to 2 inches per year; Figure 38). Subsidence is greatest near the western Sacramento Valley towns of Zamora, Woodland, and Davis (Figure 38), probably because of long and sustained groundwater extraction (Lofgren and Ireland, 1974), as well as some component of tectonic down-warping (Harwood and Helle, 1987). Long-term changes in land surface elevation may affect potential flood hazard in this area.

## 6.0    IMPLICATIONS FOR NON-URBAN LEVEES

This section presents additional analysis and discussion of the levee underseepage mapping to help assess the significance and usefulness of these maps. First is a review of the available levee performance data to evaluate susceptibility class assignments in light of these data.

A key question is: are documented cases of underseepage phenomena more frequent along levees assigned to the higher susceptibility classes? In general, there is a reasonably good correlation between performance and underseepage susceptibility class.

Second, this study examines the sources of uncertainty to identify possible improvements that could help refine susceptibility hazard analysis. An overview map of North NULE Project levee historical performance and interpreted underseepage susceptibility is presented as Figure 6.

### 6.1    Associations with Historical Levee Performance

North NULE Project levee performance data are analyzed to evaluate how well underseepage performance history correlates with underseepage susceptibility mapping. A good correlation would support the geologic model and susceptibility assignments, and a poor correlation may indicate that adjustments are needed to the geologic model or to the assignment of susceptibility classes. Performance data only were available for the Project levees, therefore the analysis of historical levee performance does not include North NULE non-Project levees. However, given that the relative mileage of Project levees is about one order of magnitude greater than the non-Project levees in the North NULE area, it is judged that the analysis of only Project levees is sufficient for the 2-I analysis phase.

Preliminary performance data, described in Subsection 3.2.6, consist of documented underseepage-related performance problems totaling 55 miles of levee (line data) and 496 points (point data) along the NULE Project levees. Line and point data for seeps, boils, and failures are tabulated for each of the four susceptibility classes (Table 6-1) and graphed (Figures 7 and 8).

Point data document locations along the levees where specific seepage, boils, or failures were observed. Each performance point is assigned to a geologic unit and susceptibility class based on its location. The points are then totaled for each susceptibility class. The totals are divided by the number of miles of levee in the corresponding susceptibility class to obtain a frequency in points per mile (Table 6-1).

Line data document reaches of levees, measured in miles, where performance problems were observed. These data were edited so overlapping and duplicate lines were deleted. In addition, lines were broken into segments where they crossed geologic unit contacts. Each line segment is then assigned to a geologic unit and susceptibility class. The line segment lengths are then tabulated for each susceptibility class, and divided by the number of levee miles in the corresponding susceptibility class to obtain the percentage of levee affected.

The performance data (Table 6-1) show that documented underseepage-related performance observations are concentrated along levees mapped as having high or very high susceptibility. Performance problems (seeps, boils, and failures) in very high and high classes represent 88 percent of the total reported line-based data, and 91 percent of the point-based data. Thus, about 90 percent of recorded performance problems occur along levees designated as having very high or high susceptibility to underseepage.

Consistent with the susceptibility assignments presented in Tables 5-1 and 5-2, geologic units with the greatest concentration of underseepage-related performance problems are:

- Holocene and active channels and meanders (SRtc, SRm, ac, Hch, Rch)
- The Sutter Bypass area where Holocene fine-grained basin deposits overlie older coarse deposits of the Modesto Formation (Hn/Qm)
- Quaternary alluvium (Qa) along the banks of the Sacramento River
- Peat deposits (Qpm) in the Delta area

As expected, the data show a far greater recorded incidence of seeps and boils relative to failures. Of the total 496 performance points, 87 percent are seeps and boils, and 13 percent are failures. Similarly with the line data, about 97 percent of levee miles with documented seepage-related problems are characterized by seeps and boils, and only 3 percent are failures.

Performance data normalized for the total length of levee mapped in each class are plotted for each susceptibility class in Figures 7 and 8. Expressing performance on a per mile basis allows comparison of the frequency of problems documented along levees in each of the four susceptibility classes.

The correlation between performance and susceptibility class is relatively good, but not exact. In general, the higher the susceptibility class, the greater the frequency of performance problems. Notable exceptions are discussed below.

As shown on Figure 7, the line and point data sets both show a higher frequency of seeps and boils in the high susceptibility class relative to the very high class. Several data limitations may account for this. First, some long stretches of levee designated as having very high susceptibility have no documented performance problems, diluting their frequency in the very high susceptibility class. These stretches of very high susceptibility levees that have not experienced poor past performance include 7 miles of the Putah Creek levee, 5 miles of the Cache Creek levee, and 4 miles of discontinuous levees in the northern Sacramento River channel. The reason for a lack of documented performance problems is not clear. It may be that performance data were not gathered for these levees (the performance data are preliminary and so may not be complete), that hydraulic conditions do not drive substantial underseepage, that a high flow event sufficient to stress these levees has not occurred during the time interval of observation, or that the deposits mapped are actually less susceptible than the geologic models suggest.

Two other factors probably account for most of the observed anomalies in performance between the high and very high susceptibility classes. First, the assignment of geologic unit Hn/Qm in the Sutter Bypass area to a class of high rather than very high susceptibility results

in anomalously high frequency failure value (Figure 7) for the high susceptibility class. This geologic unit has the highest frequency per mile of performance problems of any on the map. Second, geologic unit Qa is a widely distributed unit mapped by Helle and Harwood (1985), and is assigned to the high susceptibility class. Where this unit has been mapped in more detail for ULE Program levees, it is subdivided into up to eight subunits, some of which are designated as having high susceptibility and some as having very high susceptibility. More detailed mapping that subdivides unit Qa throughout the larger NULE Program study area should result in an improved relationship between performance data and susceptibility classes.

Limitations associated with use of previous regional-scale mapping also show up in greater-than-expected failure frequency in levees designated as having low susceptibility (Figure 8). Most failures in the low susceptibility class (eight of 10 points) occur within geologic unit Qb, a unit with a similar regional scope to Qa discussed above. Inspection of relevant topographic and soils data surrounding these failure points suggests that detailed mapping would probably show that these geologic units should be assigned a higher susceptibility class.

In sum, preliminary performance data analysis for the North NULE Project levees generally support susceptibility class assignments. Approximately 90 percent of recorded underseepage-related performance problems occur along levees designated as having high and very high susceptibility. More importantly, the frequency of occurrence on an average per-mile basis is highest in levee reaches designated as having high and very high susceptibility (Figures 7 and 8). The frequency of failures is greatest in very high susceptibility (Figure 8).

Additional refinement of the geologic mapping and susceptibility assignments would probably improve the correlation between performance and susceptibility. Mapping at a detailed scale in areas covered by regional-scale mapping is indicated.

## **6.2 Sources and Degrees of Uncertainty**

This section discusses the primary sources of uncertainty affecting analysis and results interpretation. Generally, the analyses and results of this Level 2-I study are affected by two types of uncertainty. Epistemic uncertainty can be reduced by additional data or research. Aleatory uncertainty reflects inherent, natural variations in the system and likely cannot be reduced by further study.

Sources of epistemic uncertainties involve:

- The relative underseepage susceptibility classes
- Resolution and quality of existing 1:62,500-scale geologic map data
- Inferences on subsurface conditions
- Discrete changes in susceptibility class results

Aleatory uncertainty is inherent to geologic, geomorphic and stratigraphic variability.

The project team judges that the relative degrees of contribution to uncertainty are greatest in the areas of resolution and quality of the existing 1:62,500 map data and aleatory uncertainty. The lowest contribution to uncertainty are discrete changes in susceptibility class results.

These uncertainties are discussed in more detail below.

### **6.2.1 Relative Underseepage Susceptibility Classes**

The susceptibility classes developed for this analysis are internally consistent relative to each other. However, there is some uncertainty in the application of this relative scale to the actual underseepage hazard. For example: does the high susceptibility class truly reflect a significant underseepage hazard or likelihood of failure?

This study addressed possible sources of inaccuracy by analyzing levee performance case history data with respect to interpreted susceptibility classes. This provided an improved understanding of the relative susceptibility of levee foundations and offered preliminary insight on the general magnitude of poor performance in susceptibility classes (i.e., distress points per mile). Uncertainty could be further reduced through additional analysis of levee performance case history data that includes data from all categories of levee (urban or non-urban).

It is important to recognize that the susceptibility classes are considered relative to each other. Very low levee underseepage susceptibility does not mean that no underseepage will occur. Rather, it means that the other assigned classes are relatively more susceptible to levee underseepage based on their interpreted characteristics. There may be local areas of higher (or lower) underseepage susceptibility in all of the classes, although the likelihood of susceptibility is greater in areas with relatively higher susceptibility. Conversely, there may be local areas with very high susceptibility that are unlikely to experience underseepage as a result of local or site-specific geologic or geotechnical conditions. Additional characterization (more detailed geologic and geomorphic mapping) could help address and reduce local sources of uncertainty.

### **6.2.2 Resolution and Quality of Existing 1:62,500-Scale Geologic Map Data**

The precision and accuracy limitations of the existing geologic map data are detailed in Section 3.4. These limitations carry through the underseepage analysis and contribute uncertainties to analysis and results. Additionally, the quality of geologic map unit interpretation in existing 1:62,500-scale geologic data in some places may be poor.

As an example, levees constructed on upper Riverbank Formation (map unit Qru) may appear to have case histories of boils. However, close inspection of photographic, topographic, and soil information could reveal that a veneer of younger unconsolidated deposits overlying unit Qru, which should be mapped as a different geologic unit and may result in the area having a different susceptibility class. These uncertainties in existing geologic map data affect underseepage analysis results as well as contribute error into the analysis of past performance data with respect to interpreted susceptibility. These

uncertainties could be reduced by improving the resolution and quality of existing geologic map data.

### **6.2.3 Inferences on Subsurface Conditions**

A lack of reliable data about subsurface conditions and geologic deposits contributes uncertainty to the underseepage analysis. The regional scale of this study requires developing reasonable inferences on the likely character of near-surface and shallow subsurface deposits. These inferences are based on available maps and an understanding of geomorphic processes involved in the deposition or modification of sediments. These inferences are then extended to underseepage susceptibility interpretations. In some instances, no data are presently available to help constrain or verify the geologic characteristics of the deposits (e.g., narrow floodplain channels). A lack of data about subsurface conditions contributes uncertainty to susceptibility results; little supporting information exists to constrain office-based interpretations of near surface sediments.

### **6.2.4 Gradational Deposits and Mapped Contacts**

Based on the Level 2-I technical approach, changes in assigned susceptibility results occur at geologic or soil unit contacts. Abrupt changes in susceptibility class results are an outcome of performing analyses in a GIS environment. In a GIS environment, geologic or soil contacts are modeled as categorical changes when in reality, changes in geologic or soil type are likely more transitional or gradational.

An abrupt local change in the susceptibility class may be present where an actual variation in susceptibility class is gradual. A gradual change in soil type or geologic deposit over some distances reflects, at a minimum, the limiting accuracy of input data. Steps toward reducing this uncertainty could consist of developing transitional susceptibility classes (e.g., moderate-to-high) that would not necessarily simplify geotechnical evaluations of levee stability.

### **6.2.5 Map Border Effects**

Changes in assigned susceptibility can occur at boundaries between map data sources (e.g., between geologic authors, or counties of soil surveys). Changes in assigned susceptibility (e.g., from low to high) at map boundaries should be treated carefully. For example, Figure 33 shows a NULE levee on the north side of Dry Creek abruptly changing from green (low susceptibility) to red (very high susceptibility). This change occurs at the border between 1:20,000-scale mapping and 1:62,500-scale mapping. A concerted effort was made to minimize border effects but because of the regional scale of analysis, some discrepancies remain.

### **6.2.6 Stratigraphic Variability**

Analysis of geomorphic landforms and landscape relationships provide an indication of the dominant geomorphic processes operating to create or modify landforms and underlying deposits. The Sacramento Valley is aerially extensive and contains many miles of levees that extend across different landforms and deposits. Near-surface and shallow stratigraphic variability can correspondingly range from complex (high variability) to relatively simple (low

variability). Stratigraphic variability at this regional scale should consider the history of deposition, geomorphic processes and the environment of deposition (e.g., high energy vs. low energy). Subsurface variability is inferred based on the dominant geomorphic processes that were likely in effect at, or immediately prior to, the time of levee construction. Interpretations of stratigraphic variability provide information for the geotechnical engineer or geologist that may need to plan an appropriate number of subsurface borings with finite resources.

Generally, low energy depositional environments exhibit low stratigraphic variability, both vertically and laterally. For example, flood basins tend to have low stratigraphic variability in the lateral and vertical directions.

High-energy depositional environments include stream channels and alluvial fans, and generally exhibit greater stratigraphic variability. Alluvial fans may exhibit even greater stratigraphic variability both laterally and vertically because the locus of deposition shifts up and down and side to side across the fan surface through geologic time (Figure 4).

Geomorphic construction of natural levees results in moderate stratigraphic variability, because the deposits result from many individual depositional overbank events. Because of the limited range in grain sizes given the depositional process, regional variability is low in the sediments of a natural levee – less than that of alluvial fans and stream channels, but probably greater than that of flood basins.

In the Delta, variability exists in the stratigraphy of the peat and mud deposits (geologic map unit Qpm). As noted earlier, the thickness of the peat strata varies in the North NULE study area, and generally is thicker near the center of the Delta and thinner near the margins of the Delta (USACE, 1987). Additionally, the percentage of organic material in the “peat and mud” unit is variable in the subsurface (USGS, 2000). The percentage of peat encountered beneath Delta islands is variable from island to island, but also within an island. Moreover, natural levee alluvium interingers with peat and mud deposits, and can produce interspersed layers of peat and alluvium (Atwater, 1982). Lateral and vertical variability exists in peat(y) deposits.

This natural and stochastic stratigraphic variability may create conditions where, for example, there are localized low-susceptibility deposits within a given length of levee assessed as having high susceptibility. Conversely, there may also be localized very high susceptibility deposits in a given length of levee assessed as having low susceptibility.

## **7.0 SUMMARY AND RECOMMENDATIONS**

### **7.1 Summary**

The primary purpose of this Level 2-I analysis is to assess (at a regional scale) the hazard of levee underseepage, and to a lesser degree, soil settlement and ground subsidence. The technical approach for geomorphic analysis in the North and South NULE Project study areas is coordinated to develop consistent analysis results over the entire NULE region. The rationale for Level 2-I analysis is to assess regional levee underseepage susceptibility via a criteria matrix. The criteria matrix combined information about Quaternary geologic deposits, channel features mapped from historical topographic maps, and NRCS HSG. Input data were imported into a GIS and spatially intersected with NULE levee lines; susceptibility categories (very high, high, moderate, and low) were assigned to levee segments according to the cells in the matrix or table.

Because the Sacramento Valley is large, has diverse physiography, and contains many miles of levees, this assessment subdivides the North NULE Project study area into geomorphic domains having relatively consistent characteristics. Primary geomorphic domains include: older and younger alluvial fans, river floodplains and their natural levees, alluvial flood basins, and the Sacramento-San Joaquin Delta. Within each domain are individual geologic deposits that possess certain lithologic or pedogenic characteristics. Much of the North NULE levees overlie geologic deposits belonging to either natural levee or flood basin domains.

Results of the Level 2-I geomorphic analysis are depicted on a series of maps delineating interpreted foundation susceptibility to underseepage based on available soil and geologic data. The Level 2-I assessment generally confirms the conceptual model of geomorphic domains generated for the Level 1 study, but improves the level of detail and information available to assess underseepage susceptibility.

Geologic deposits interpreted as having very high underseepage susceptibility include:

- Historical and active stream channel deposits
- Hydraulic dredge spoils
- Quaternary channel meander zone
- Peat and mud deposits

Mapped geologic units interpreted as having high susceptibility include:

- Tailings from hydraulic mining
- Natural levee deposits
- Latest Pleistocene alluvial fans
- Holocene floodplain and channel deposits

Map units interpreted as having moderate susceptibility to underseepage include:

- Some flood basin deposits

- Holocene fan deposits from the Coast Ranges
- Middle to late Pleistocene alluvial fan deposits

Deposits mapped as low susceptibility include:

- Flood basin deposits with HSG C or D
- Early Pleistocene to Pliocene deposits

Levee underseepage susceptibilities within the North NULE Project study are assessed as follows:

- 14 percent are assessed as having very high underseepage susceptibility (128 miles)
- 50 percent are assessed as having high underseepage susceptibility (459 miles)
- 10 percent are assessed as having moderate underseepage susceptibility (89 miles)
- 26 percent are assessed as having low underseepage susceptibility (237 miles)

Preliminary levee performance information developed in the North NULE Project study area is analyzed to compare documented occurrences of underseepage to the mapped distribution of geologic deposits and susceptibility classes. The frequency of documented occurrences of underseepage (i.e., points per mile exposed) provide important input into the assignment and testing of susceptibility classes to specific deposit types. Consistent with the susceptibility assignments presented in Tables 5-1 and 5-2, geologic units with the greatest concentration of performance problems are:

- Holocene and active channels and meanders (SRtc, SRm, ac, Hch, Rch)
- The Sutter Bypass area where Holocene fine-grained basin deposits overlie older coarse deposits of the Modesto Formation (Hn/Qm)
- In Quaternary alluvium (Qa) along the banks of the Sacramento River
- In peat deposits (Qpm) in the Delta area.

While the correlation between performance and susceptibility class is relatively good, it is not exact.

Subsidence is greatest near the western Sacramento Valley towns of Zamora, Woodland, and Davis, probably because of long and sustained groundwater extraction (Lofgren and Ireland, 1974), as well as some component of tectonic down-warping (Harwood and Helley, 1987). Organic-rich peat deposits or former marshes are more likely to contribute to levee instability or experience settlement than foundations in other parts of the North NULE Project study area.

## 7.2 Recommendations

Based on an analysis of available data to date recommendations are as follows.

- Complete detailed surficial geologic mapping in very high and high susceptibility areas to assess the type and distribution of susceptible deposits that might be present beneath levee materials. This will help reduce uncertainty inherent in Level 2-I analyses.

- Consider additional analysis of historical levee performance data with respect to individual geologic deposits to refine the accuracy of the susceptibility framework.
- Field verify sedimentologic characteristics in small channels identified through Level 2-I mapping to improve and enhance understanding of the geologic and geotechnical characteristics of these features and deposits, refining the assessment of their likely controls on underseepage processes. Field verification techniques could consist of conventional drilling techniques (e.g., hollow stem auger, rotary wash borings), hand augering, shallow test pits (“potholes”), or shallow trenching.

## **8.0 CREDITS AND LIMITATIONS**

### **8.1 Credits**

This technical memorandum was prepared by the following personnel:

- Justin Pearce, Senior Geologist, CEG # 2421, William Lettis & Associates

Under the supervision of:

- Keith Kelson, Senior Principal Geologist, CEG # 1714, William Lettis & Associates

With assistance from:

- Janet Sowers, Senior Geologist, William Lettis & Associates
- Ashley Streig, Project Geologist, William Lettis & Associates
- Cooper Brossy, Senior Staff Geologist, William Lettis & Associates

Digital Cartography by:

- Marco Ticci, Senior GIS Analyst, William Lettis & Associates

North NULE Geomorphology Task Manager:

- Keith L. Knudsen, CEG #2042, URS Corporation

### **8.2 Limitations**

This geomorphic assessment has been performed in accordance with the standard of care commonly used as the state-of-practice in the engineering profession. Standard of care is defined as the ordinary diligence exercised by fellow practitioners in this geographic area performing the same services under similar circumstances during the same time period.

Discussions of subsurface conditions summarized in this technical memorandum are based on interpretation of geomorphic data supplemented with very limited subsurface exploration information. Variations in subsurface conditions may exist between those shown on maps and actual conditions. Due to the scale of mapping, the project team may not be able to identify all adverse conditions in levee foundation materials.

No warranty, either express or implied, is made in the furnishing of this technical memorandum that is the result of geotechnical evaluation services. URS makes no warranty that actual encountered site and subsurface conditions will exactly conform to the conditions described herein, nor that this technical memorandum's interpretations and recommendations will be sufficient for all construction planning aspects of the work. The design engineer or contractor should perform a sufficient number of independent explorations and tests as they believe necessary to verify subsurface conditions, rather than relying solely on the information presented in this report.

URS does not attest to the accuracy, completeness, or reliability of maps, data sources, geotechnical borings and other subsurface data produced by others that are included in this technical memorandum. URS has not performed independent validation or verification of data reported by others.

Data presented in this technical memorandum are time-sensitive in that they apply only to locations and conditions existing at the time of preparation of this report. The maps produced generally present conditions as they occurred in the early 1900s, as primary data interpreted for this report are from this period. Data should not be applied to any other projects in or near the area of this study nor should they be applied at a future time without appropriate verification, at which point the one verifying the data takes on the responsibility for it and any liability for its use.

This technical memorandum is for the use and benefit of DWR. Use by any other party is at their own discretion and risk.

**This technical memorandum should not to be used as a basis for design, construction, remedial action or major capital spending decisions.**

## 9.0 REFERENCES

Atwater, B.F., 1982, *Geologic Maps of the Sacramento - San Joaquin Delta, California*; USGS Miscellaneous Field Studies Map MF-1401, scale 1:24,000, Denver, Colorado

Brice, J., 1977, *Lateral Migration of The Middle Sacramento River, California*; USGS Water-Resources Investigation 77-43, 51 p.

Bryan, K., 1923, *Geology and Ground-water Resources of Sacramento Valley, California*; USGS Water-Supply Paper 495, 313 p.

Busacca, A.J., Singer, M.J., and Verosub, K.L., 1989, *Late Cenozoic Stratigraphy of the Feather and Yuba Rivers Area, California*, with a Section on Soil Development in Mixed Alluvium at Honcut Creek, USGS Bulletin 1590-G.

Department of Water Resources (DWR), 1994, *River Bank Erosion Investigation*; Compiled by Koll Buer, Northern District DWR; available from <http://www.nd.water.ca.gov/Data/index.cfm>.

Department of Water Resources (DWR), 2003, Fact Sheet: *Sacramento River Flood Control Project Weirs and Flood Relief Structures*; Compiled by Eric Butler, Department of Water Resources, 10 p.

Helley, E.J., and Harwood, D.S., 1985, *Geologic Map of The Late Cenozoic Deposits of The Sacramento Valley and Northern Sierran Foothills, California*; 1:62,500, USGS Map File MF-1790

Holmes, L.C., Watson, E.B., Harrington, G.L., Nelson, J.W., Guernsey, J.E., and Zinn, C.J., 1913, Soil map, California: *Reconnaissance Survey*, Sacramento Valley Sheet; US Department of Agriculture, Bureau of Soils. Scale 1:250,000.

Ikehara, M.E., 1994, *Global Positioning System Surveying to Monitor Land Subsidence in Sacramento Valley, California, USA*; Hydrological Sciences v. 39, pp. 417 – 429.

Llopis, J.L., Smith, E.W., and North, R.E., 2007, *Geophysical Surveys for Assessing Levee Foundation Conditions, Sacramento River Levees, Sacramento, CA*; US Army Corps of Engineers, Engineer Research and Development Center, Geotechnical and Structures Laboratory publication ERDC/GSL TR-07-21, 61p.

Lofgren, B.E., and Ireland, R.L., 1974, *Preliminary Investigation of Land Subsidence in the Sacramento Valley, California*; USGS Open File Report OFR 74-1064, 41 p.

Marchand, D. and Allwardt, A., 1981, *Late Cenozoic Stratigraphic Units, Northeastern San Joaquin Valley, California*; USGS Bulletin 1470, 78 p. 3 plates, 1:125,000 and 1:24,000-scale.

McNitt, J.R., 1967, *Geologic Map and Sections of the Lakeport Quadrangle*, Lake County, California, California Division of Mines and Geology publication, map scale 1:62,500.

Olmstead, F.H., and Davis, G.H., 1961, *Geologic Features and Ground-water Storage Capacity of the Sacramento Valley*, California; USGS Water-Supply Paper 1497, 248 p.

Page, R.W., 1986, *Geology of the Fresh Ground-water Basin of the Central Valley, California, with Texture Maps and Sections*; USGS Professional Paper 1401-C, 54 p.

Resource Consultants & Engineers, Inc. (RCE), 1992, *Sutter Bypass Geomorphic Investigation*; Consultant report to Teichert Aggregates, Sacramento, California.

Schumm, S.A., and Harvey, M.D., 1986, *Preliminary Geomorphic Evaluation Of The Sacramento River, Red Bluff To Butte Basin*, Report to U.S. Army Corps of Engineers, Sacramento District, 45 p.

Shlemon, R.J., 1967, *Landform-Soil Relationships in Northern Sacramento County, California*, [Ph.D. thesis]: Berkeley, University of California.

Strahorn, A.T., Mackie, W.W., Holmes, L.C., Westover, H.L., Van Duyne, C., 1911, *Soil Survey of the Marysville Area*, California; 1:62,500, USDA Bureau of Soils.

U.S. Army Corps of Engineers (USACE), 1987, Office Report, Sacramento – *San Joaquin Delta Levees Liquefaction Potential*; Prepared by Geotechnical Branch, US Army Engineer District, Sacramento Corps of Engineers

U. S. Geological Survey (USGS), 2000, *Delta Subsidence in California*; Fact Sheet FS-005-00, 6p.

Vaught, D. J., 2006, "A Swamplander's Vengeance: R.S. Carey And The Failure To Reclaim Putah Sink, 1855-1895," *Sacramento History Journal*, vol VI, no. 1-4, 161-176

Water Engineering and Technology (WET), 1990, *Geomorphic analysis and bank protection alternatives report for Sacramento River (RM 78-194) and Feather River (RM 0-28)*; Report to Corps of Engineers, Sacramento District, call no. TC533.G4 1990

Water Engineering and Technology (WET), 1991, *Geomorphic analysis and bank protection alternatives report for Sacramento River (RM 0-78), Feather River (RM 28-61), Yuba River (RM0-11), Bear River (RM 0-17), American River (RM 0-23)*; Report to Corps of Engineers, Sacramento District, call no. TC533.G4 1991

William Lettis & Associates, Inc. (WLA), 2007, *Surficial Geologic Map and Geomorphic Assessment of the Sutter Area*, Sutter County, California, 1:20,000-scale; Consultant report to URS for the Department of Water Resources Urban Levee Geotechnical Evaluation.

William Lettis & Associates, Inc. (WLA), 2008a, *Surficial Geologic Map and Geomorphic Assessment of the Woodland Area*, Yolo County, California, 1:20,000-scale; Consultant report to URS for the Department of Water Resources Urban Levee Geotechnical Evaluation (June 16, 2008).

William Lettis & Associates, Inc. (WLA), 2008b, *Surficial Geologic Map and Geomorphic Assessment of the Davis Area*, Yolo and Solano Counties, California, 1:20,000-scale; Consultant report to URS for the Department of Water Resources Urban Levee Geotechnical Evaluation (June 27, 2008).

**TABLES**

**A. Topographic Maps at 1:24,000 Scale.**

Original Quad Name	Current Quad Name	Date Surveyed	Date Published	Year Reprinted	Geo-Reference RMS Error
Gerber	Gerber	1947	1950	n/a	2.7 m
Los Molinos	Los Molinos	1947	1952	n/a	2.6 m
Red Bluff East	Red Bluff East	1947	1951	n/a	3.4 m

**B. Topographic Maps at 1:31,680 Scale.**

Original Quad Name	Current Quad Name	Date Surveyed	Date Published	Year Reprinted	Geo-Reference RMS Error
Chico Landing	Ord Ferry	1904-1910	Nov. 1912	1931	14.7 m
Durham	Chico	1910	Nov. 1912	n/a	16.3 m
Florin	Florin	1907	Oct. 1909	n/a	7.9 m
Butte City	Butte City	1909-1910	Mar. 1912	n/a	15.0 m
Collinsville	Antioch North	1906-1907	1918	n/a	7.3 m
Arbuckle	Arbuckle	1905	1918	n/a	11.8 m
Biggs	Biggs	1909-1910	Apr. 1912	n/a	11.7 m
Bruceville	Bruceville	1907-1908	Jul. 1910	n/a	18.1 m
Babel Slough	Clarksburg	1906	1916	n/a	33.9 m
Maine Prairie	Dozier	1906	1916	n/a	10.9 m
Gilsizer Slough	Gilsizer Slough	1909	Sep. 1911	n/a	14.2 m
Grimes	Grimes	1905-1909	Aug. 1911	n/a	12.6 m
Honcut	Honcut	1909-1910	Jan. 1912	n/a	15.2 m
Isleton	Isleton	1906-1908	Apr. 1910	n/a	15.3 m
Jersey	Jersey Island	1906-1908	Jun. 1910	n/a	7.9 m
Kirkville	Kirkville	1905	May. 1905	n/a	36.3 m
Cache Slough	Liberty Island	1906	1916	n/a	20.5 m
Llano Seco	Llano Seco	1904-1910	May. 1912	n/a	8.6 m
Compton Landing	Moulton Weir	1904	1917	n/a	11.9 m
Nelson	Nelson	1910	May. 1912	n/a	12.1 m
Rio Vista	Rio Vista	1906-1908	1910	n/a	25.2 m
Sanborn Slough	Sanborn Slough	1909-1910	Dec. 1911	n/a	18.0 m
Saxon	Saxon	1906	1916	n/a	16.2 m
Dry Creek	Shippee	1910	Jun. 1912	n/a	13.4 m
Sutter	Sutter	1909	Sep. 1911	n/a	15.8 m
Tisdale Weir	Tisdale Weir	1905-1910	Feb. 1912	n/a	9.7 m
Landlow	West of Biggs	1909-1910	Dec. 1911	n/a	13.1 m
Wheatland	Wheatland	1908	Nov. 1910	n/a	16.9 m

**B. Topographic Maps at 1:31,680 Scale.**

Original Quad Name	Current Quad Name	Date Surveyed	Date Published	Year Reprinted	Geo-Reference RMS Error
Zamora	Zamora	1905	1916	1920	15.1 m
Hamilton	Hamilton City	1904	Feb. 1914	n/a	4.5 m
Keefers	Richardson Springs	1910	Jun. 1912	1922	7.1 m
Knights Landing	Knights Landing	1905-1908	Aug. 1910	n/a	23.2 m
Marcuse	Sutter Causeway	1908	Aug. 1910	n/a	9.6 m
Marysville Buttes	Sutter Buttes	1909-1911	Nov. 1912	1943	11.8 m
Meridian	Meridian	1905 and 1909-1910	Apr. 1912	n/a	7.0 m
Nicolaus	Nicolaus	1908	Aug. 1910	n/a	4.8 m
Nord	Nord	1910	Aug. 1912	1947	9.1 m
Pennington	Pennington	1909-1911	Nov. 1912	n/a	6.3 m
Princeton	Princeton	1904	1918	n/a	5.5 m
Sheridan	Sheridan	1908	Aug. 1910	n/a	8.3 m
Yuba City	Yuba City	1909	Jul. 1911	n/a	8.5 m

**C. Topographic Maps at 1:62,500 Scale.**

Original Quad Name	Current Quad Name	Date Surveyed	Date Published	Year Reprinted	Geo-Reference RMS Error
Antioch	n/a	1906-1907	Nov. 1908	1951	14.5 m
Colusa	n/a	1904-1905	1907	1916	6.0 m
Courtland	n/a	1906	Mar. 1908	n/a	7.4 m
Davisville	n/a	1905	Mar. 1907	n/a	39.8 m
Dunnigan	n/a	1905	Feb. 1907	n/a	5.6 m
Vina	n/a	1903-1904	Nov. 1904	Sep. 1911	25.8 m
Marysville Buttes and Vicinity	n/a	1905 and 1909-1911	Nov. 1913	n/a	13.4 m
Oroville	n/a	1941-1942	1944	n/a	1.4 m
Rio Vista	n/a	1952-1953	1958	n/a	n/a
Willows	n/a	1904	Jan. 1906	Apr. 1914	13.6 m

**D. Topographic Maps at 1:125,000 Scale.**

Original Quad Name	Current Quad Name	Date Surveyed	Date Published	Year Reprinted	Geo-Reference RMS Error
Chico	n/a	1886-1888	May 1895	1932	n/a
Marysville	n/a	1886	Jan. 1895	Nov. 1904	n/a

**Table 3-1. List of Topographic Maps.**

**D. Topographic Maps at 1:125,000 Scale.**

Original Quad Name	Current Quad Name	Date Surveyed	Date Published	Year Reprinted	Geo-Reference RMS Error
Smartsville	n/a	1885-1886	Apr. 1895	1917	n/a

Age	Helley and Harwood (1985) <sup>1</sup>		Department of Water Resources (1994) <sup>2</sup>		Atwater (1982) <sup>3</sup>		WLA Urban Levee Mapping (2007, 2008) <sup>4</sup>	
	Symbol	Name	Symbol	Name	Symbol	Name	Symbol	Name
Holocene	t	Tailings (from gold mining, post-1849)					DT	Dredge tailings from gold mining
					Qds	Dredge spoils (from hydraulic dredging of channels post-1900)		
	Qsc	Stream channel deposits	SRtc	Sacramento River channels (post-1896) <sup>5</sup>			Rch	Historical channel deposits
			SRm	Sacramento River meander belt (pre-1896) <sup>6</sup>			Rb	Historical channel bar deposits
	Qa	Alluvium					Hch	Holocene channel deposits
					QI	Natural levee deposits	Rch	Historical channel deposits
							Ra	Historical alluvial deposits, undifferentiated
							Rdf	Historical distributary fan deposits
							Rcs	Historical crevasse splay deposits
							Rdc	Historical distributary channel deposits
							Rob	Historical overbank deposits
							Rsl	Historical slough deposits
							Rb	Historical channel bar deposits
							Rf	Historical alluvial fan deposits
					QI	Natural levee deposits	Rob/Qru	Historical overbank deposits overlying Upper Riverbank Fm
							Hchy	Late Holocene channel deposits
							Hfy	Late Holocene alluvial fan deposits, undifferentiated
							Hffy	Late Holocene fine-grained alluvial fan deposits
							Hch	Holocene channel deposits
							Ha	Holocene alluvial deposits, undifferentiated
							Ha(Agr)	Holocene alluvial deposits, cultivated in 1937
							Hdf	Holocene distributary fan deposits
	Qb	Undivided basin deposits			Qyp	Younger alluvium of Putah Creek	Hcs	Holocene crevasse splay deposits
							Hob	Holocene overbank deposits
							Hf	Holocene alluvial fan deposits
							Hff	Holocene fine-grained alluvial fan deposits
							Qa	Quaternary alluvial deposits, undifferentiated
							Hffy	Late Holocene fine-grained alluvial fan deposits
Middle to late Pleistocene	Qp	Peat deposits			Qpm	Peat and mud	Hff	Holocene fine-grained alluvial fan deposits
							Hn	Holocene basin deposits
	Qmu	Modesto Formation, Upper Member			Qom	Older alluvium of Montezuma Hills	Hn(Agr)	Holocene basin deposits, cultivated in 1937
							Hs	Holocene marsh deposits
	Qml	Modesto Formation, Lower Member					Hn/Qm	Holocene basin deposits overlying shallow Modesto Fm
	Qru	Riverbank Formation, Upper Member						
	Qrl	Riverbank Formation, Lower Member						
Older	Qrb, Qtl, Tla/b, Ttc	Red Bluff, Turlock Lake, and Tuscan Formations						

\*Not all geologic units are listed in this chart. All geologic units present beneath levees are listed.

<sup>1</sup>Helley, E.J., and Harwood, D.S., 1985, Geologic map of the late Cenozoic deposits of the Sacramento Valley and Northern Sierran foothills, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1790, scale 1:62,500, 5 sheets. Maps were digitized and made available by Jonathan Mulder, DWR Northern District.

<sup>2</sup>Department of Water Resources (DWR), 1994, Surface geology along the Sacramento River; Compiled by Koll Buer, Northern District DWR; obtained from Stacey Cepello from DWR Red Bluff, viewable on line at <http://www.sacramento.org/website/recwebims/viewer.htm>; Red Bluff to Colusa. This data source replaces Helley and Harwood (1985) along the Sacramento River north of Colusa.

<sup>3</sup>Atwater, B.F., 1982, Geologic Maps of the Sacramento-San Joaquin Delta, California, U.S. Geological Survey Miscellaneous Field Studies Map MF-1401, scale 1:24,000, 21 sheets.

<sup>4</sup>Geologic mapping by WLA in 2007 and 2008 as part of the Urban Levee Evaluation Project.

<sup>5</sup>Map data spanned 1896–1991; unit boundary envelopes the lateral extent of the channels, and is slightly modified from original map unit based on supplemental data from 1999 and 2004.

<sup>6</sup>Belt of meander scrolls, oxbow lakes, and channels associated with former river positions. This unit lies outside of the SRtc, and represents older (late Holocene) deposits of the Sacramento River. Individual morphologic units not delineated.

County	Soil Survey Publication Date	Time Period of Content (Corresponds to Currentness Reference)
Tehama	1967	2004-2006
Glenn	1968	2003-2006
Yolo	1972	1999-2005
Solano	1977	2001-2006
Placer	1980	1998-2006
Colusa	1983	2001-2005
Butte	1984	2005-2006
Sutter	1988	1998-2006
Sacramento	1993	1998-2006
Yuba	1997	2000-2006

Domain (Figure 2)	General Description	Age of Deposits	Geologic Consolidation	General Surface Deposit Textures	Stratigraphic Variability	Relative Permeability	Comments	Northern NULE	
								Miles	%
CRF	Coast Range alluvial fans	Holocene	Unconsolidated	sand to clay	Moderate	Low to High	East-flowing	33	4
CFo	Cascade alluvial fans (older)	Pleistocene	Semi-consolidated	sand, silt, clay, fine gravel	Moderate	Low to High	West-flowing	43	5
CFy	Cascade alluvial fans (younger)	Pleistocene	Semi-consolidated	silt and clay	Moderate	Low to High	West-flowing	18	2
CRH	Coast Range hills	Pliocene	Consolidated	gravel to clay	High	Low to Moderate	Uplands	0	0
D	Delta	Holocene	Unconsolidated	peat and clay	Low	Moderate	Saturated, organic rich	75	8
FB	Flood Basins	Holocene	Unconsolidated	silt and clay	Low	Low	Low-energy environment	193	22
FR	Feather River floodplain and natural levees	Holocene	Unconsolidated	sand, silt, and clay	High	High	South-flowing; strongly affected by mining debris	19	2
SR	Sacramento River floodplain and natural levees	Holocene	Unconsolidated	fine gravel, sand, silt and clay	Moderate	High	South-flowing; silty natural levees	315	36
SBF	Sutter Buttes fans	Pleistocene	Semi-consolidated	sand, silt, clay, fine gravel	Moderate	Low to High	From Sutter Buttes	0	0
SNFo	Sierra Nevada fans (older)	Pliocene	Consolidated	gravel to clay	High	Low to Moderate	Duripans near surface	0	0
SNFy	Sierra Nevada fans (younger)	Pleistocene	Semi-consolidated	gravel to clay	High	Low to High	Hardpans near surface	36	4
SNFy-FB	Sierra Nevada fan (y) - Flood Basin	Holocene-Pleistocene	Unconsolidated to semi-consolidated	sand, silt and clay	Low	Moderate	Transitional domain, fine-grained over coarse-grained	57	6
SRm	Sacramento River meander belt	Holocene	Unconsolidated	cobbles, gravel, sand, silt and clay	High	High	South-flowing	55	6
ST	Sierran Tributary	Holocene	Unconsolidated	gravel, sand, silt, and clay	High	High	West-flowing; strongly affected by mining debris	45	5
STs	Sierran Tributary (small)	Holocene	Unconsolidated	sand and silt	Moderate	Moderate	West-flowing	0	0

Geologic Map Unit Symbols	Geologic Deposit	NRCS Hydrologic Soil Group		
		A	B	C, D
ac, SRtc	Active stream channel	VH	VH	VH
Qds	Hydraulic dredge spoils	VH	VH	H
t	Tailings from hydraulic mining	H	H	M
Qsc, SRm	Quaternary stream channel, Late Holocene channel meander zone	VH	VH	VH
Qa, QI	Holocene alluvium and natural levee deposits, undifferentiated	H	H	H
Qp, Qpm	Peat deposits	VH	VH	VH
Qb, Qyp	Flood basin deposits, and younger alluvium of Putah Creek	M	M	L
	Alluvial fan deposits (west side, San Joaquin valley)			
	Alluvial Fan Terrace deposits (east side, San Joaquin valley)			
Qmu, Qom	Modesto Fm (upper) (Pleistocene to Holocene) and older alluvium of the Montezuma Hills (late Pleistocene)	H	H	M
Qml, Qop	Modesto Fm (lower) (Pleistocene) and older alluvium of Putah Creek (Pleistocene)	M	M	L
Qr	Riverbank Fm (Pleistocene)	L	L	L
Qrb, Qtl, Tla/b, Ttc	Pre-Riverbank Fm deposits and bedrock	L	L	L

#### Notes

Underseepage susceptibility classes:

VH = Very High

H = High

M = Moderate

L = Low

Grey shading indicates map unit that has not been shown on existing maps in the North NULE region.

Unit Symbol	Unit Name	Susceptibility Rating
DT	Dredge tailings from hydraulic mining	M
Ra	Historical alluvial deposit, undifferentiated	VH
Rb	Historical channel bar deposits	VH
Rch	Historical channel deposits	VH
Rcs	Historical crevasse splay deposits	VH
Rdc	Historical distributary channel deposits	VH
Rdf	Historical distributary fan deposits	VH
Rf	Historical alluvial fan deposits	VH
Rofc	Historical overflow channel	VH
Rob	Historical overbank deposits	VH
Rsl	Historical slough deposits	H
Rla	Historical lacustrine deposits, Clear Lake	H
W 1937	Water in 1937	H
Ha	Holocene alluvial deposits, undifferentiated	H
Ha (Agr)	Holocene alluvial deposits, cultivated in 1937	H
Hch	Holocene channel deposits	H
Hcs	Holocene crevasse splay deposits	H
Hob	Holocene overbank deposits	H
Hdf	Holocene distributary fan deposits	H
Hchy	Late Holocene channel deposits	M
Hf	Holocene alluvial fan deposits	M
Hff	Holocene fine-grained alluvial fan deposits	M
Hffy	Late Holocene fine-grained alluvial fan deposits	M
Hfy	Late Holocene alluvial fan deposits	M
Hn/Qm	Holocene basin deposits, shallow over Modesto Fm'n	H
Hn	Holocene basin deposits	L
Hn (Agr)	Holocene basin deposits, cultivated in 1937	L
Hs	Marsh deposits	H
Qa	Quaternary alluvial deposits undifferentiated	H
Qla	Quaternary lacustrine deposits, Clear Lake	M
Qa/b	Quaternary alluvium over basalt, Clear Lake	M
Pf	Pleistocene alluvial fan deposits	L
Qml	Modesto Formation; lower member	L
Qmu	Modesto Formation; upper member	M
Qrl	Riverbank Formation; lower member	L
Qru	Riverbank Formation; upper member	L
Rob/Qru	Historical overbank deposits over upper Riverbank	M

### Point Data

Performance Problem	Susceptibility Class	Count	Percent Total Points	Points per Levee Mile
Failure	VH	12	18	0.11
	H	41	62	0.09
	M	3	5	0.04
	L	10	15	0.05
	All classes	66	100	0.08
Seepage/Boils	VH	68	31	0.62
	H	329	61	0.75
	M	17	4	0.23
	L	16	4	0.08
	All classes	430	100	0.52

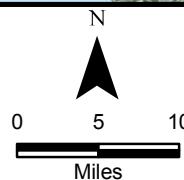
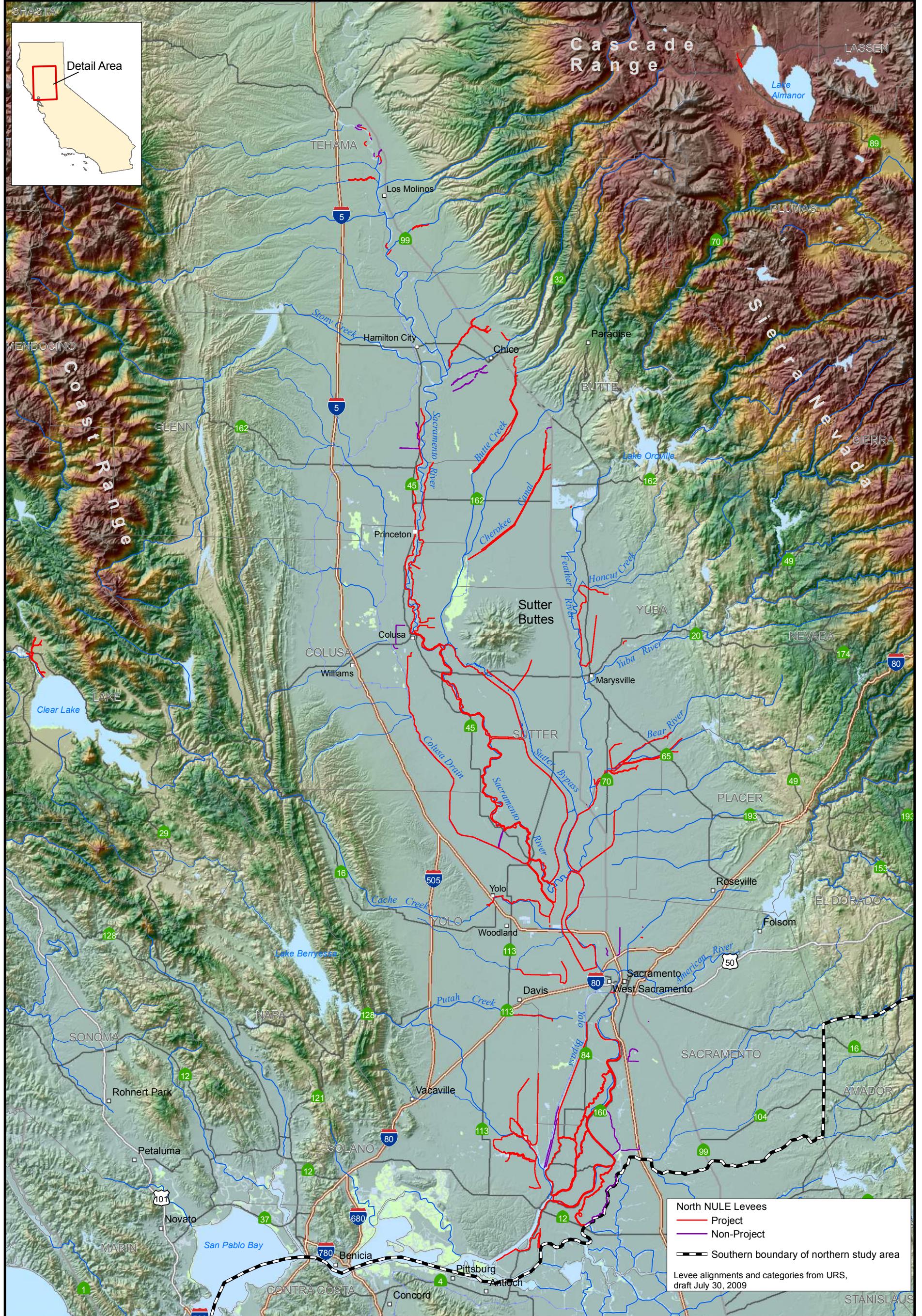
### Line Data

Performance Problem	Susceptibility Class	Miles Affected Levee	Percent Total Miles Affected	Affected Miles per Levee Mile (%)
Failure	VH	0.67	36	0.61
	H	0.64	35	0.15
	M	0.14	8	0.19
	L	0.39	21	0.20
	All classes	1.85	100	0.22
Seepage/Boils	VH	6.82	13	6.20
	H	40.84	76	9.27
	M	3.70	7	4.95
	L	2.20	4	1.11
	All classes	53.56	100	6.51

### Levee Mileage

Susceptibility Class	Levee Miles	Percent Total Miles
VH	110	13
H	440	54
M	75	9
L	198	24
All classes	823	100

**FIGURES**



Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



North NULE Levees

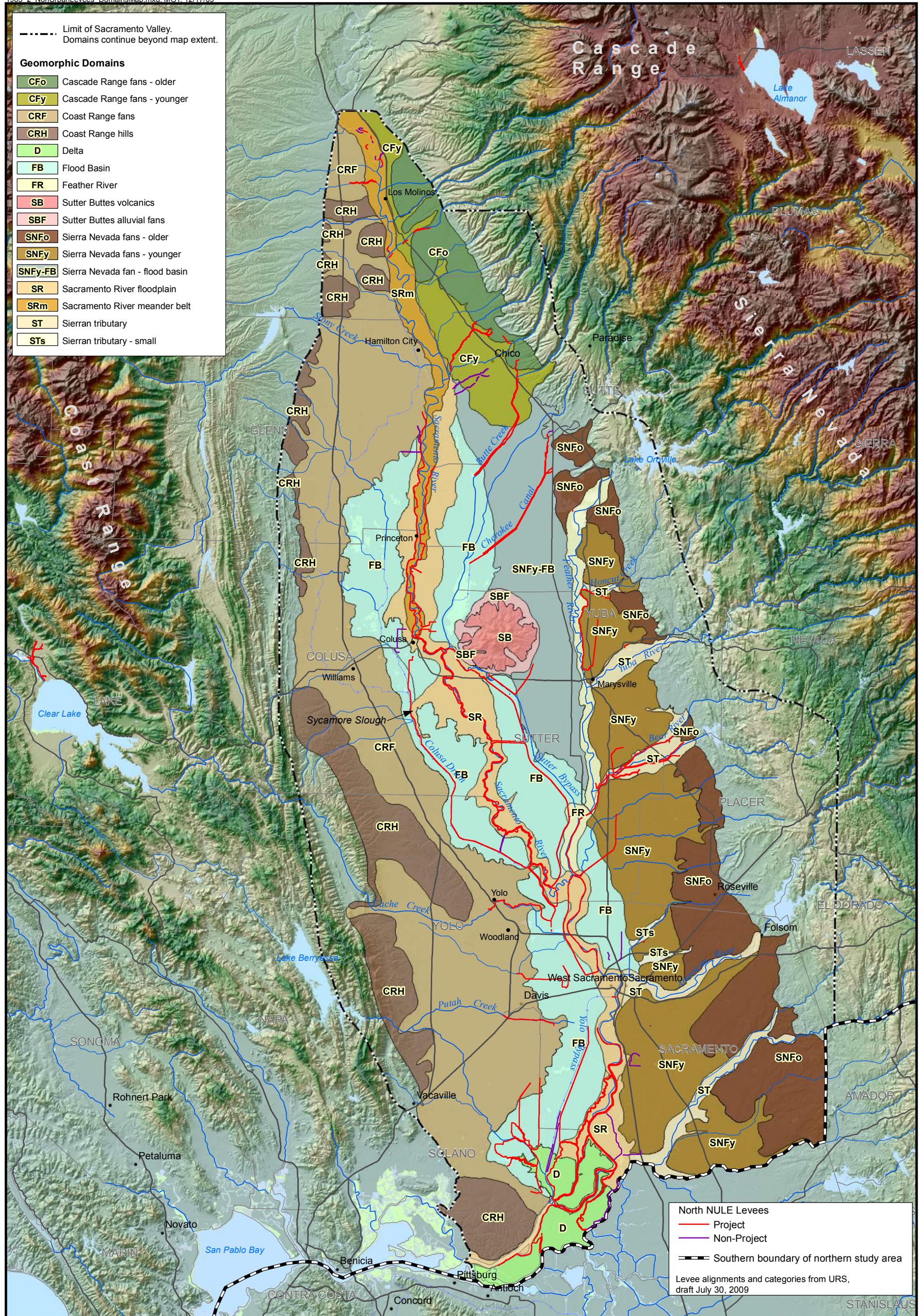
North Non-Urban Levee Evaluations

Figure  
1

— Limit of Sacramento Valley.  
Domains continue beyond map extent.

## Geomorphic Domains

<b>CFo</b>	Cascade Range fans - older
<b>CFy</b>	Cascade Range fans - younger
<b>CRF</b>	Coast Range fans
<b>CRH</b>	Coast Range hills
<b>D</b>	Delta
<b>FB</b>	Flood Basin
<b>FR</b>	Feather River
<b>SB</b>	Sutter Buttes volcanics
<b>SBF</b>	Sutter Buttes alluvial fans
<b>SNFo</b>	Sierra Nevada fans - older
<b>SNFy</b>	Sierra Nevada fans - younger
<b>SNFy-FB</b>	Sierra Nevada fan - flood basin
<b>SR</b>	Sacramento River floodplain
<b>SRm</b>	Sacramento River meander belt
<b>ST</b>	Sierran tributary
<b>STs</b>	Sierran tributary - small



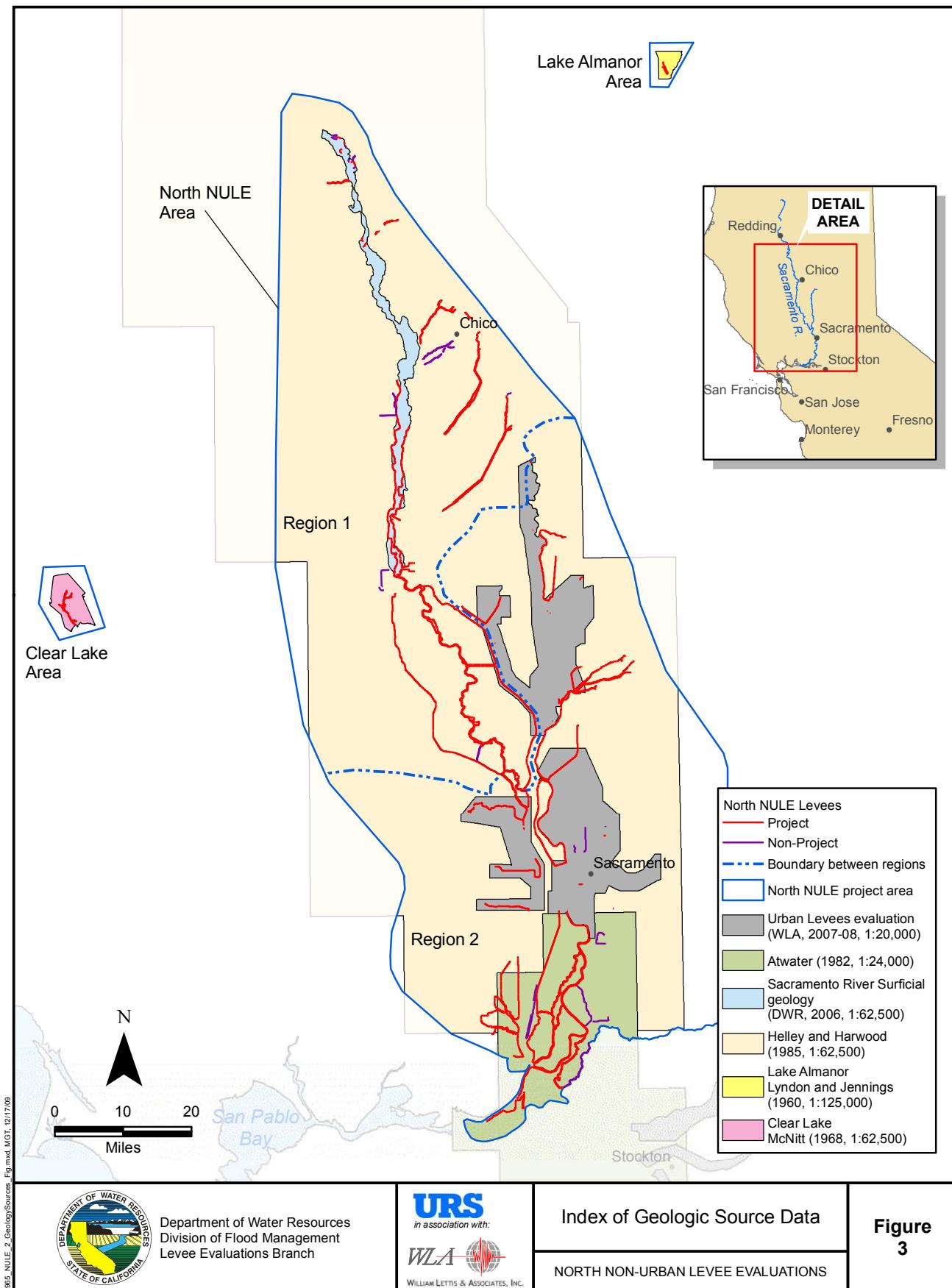
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch

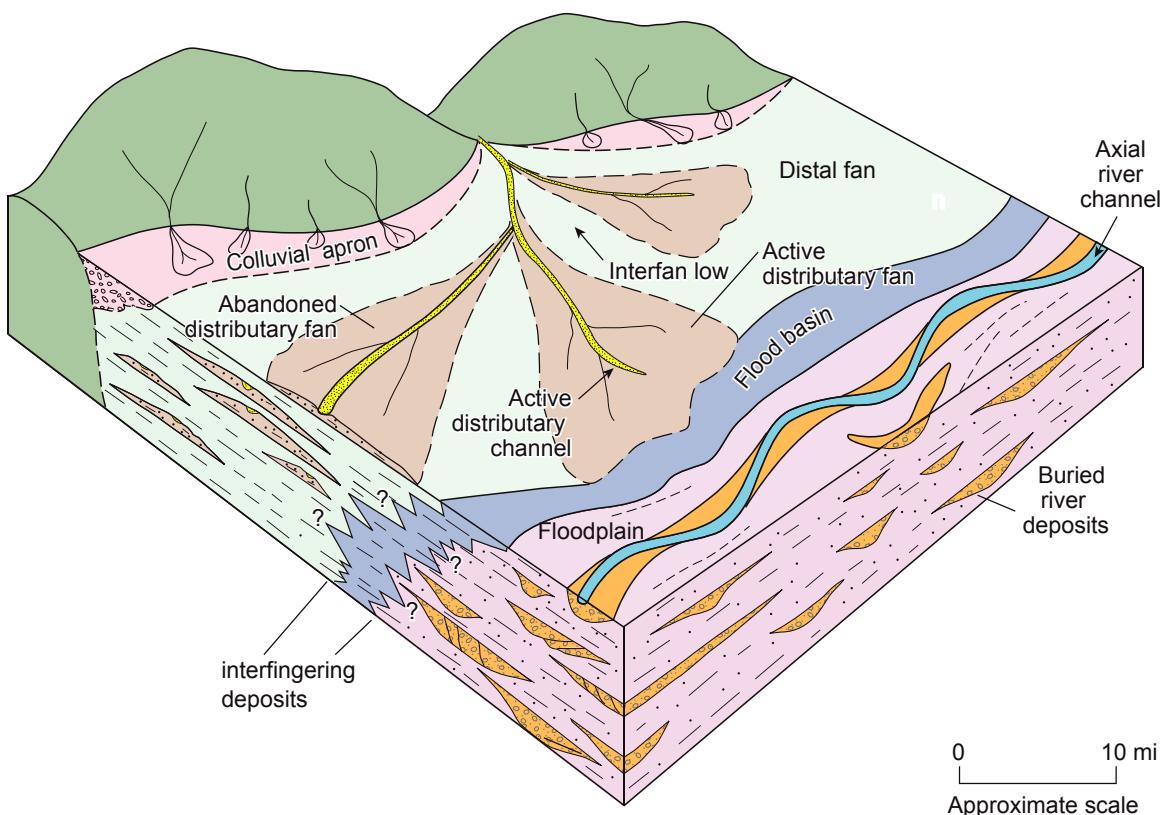


## North NULE Geomorphic Domains

## North Non-Urban Levee Evaluations

## Figure 2



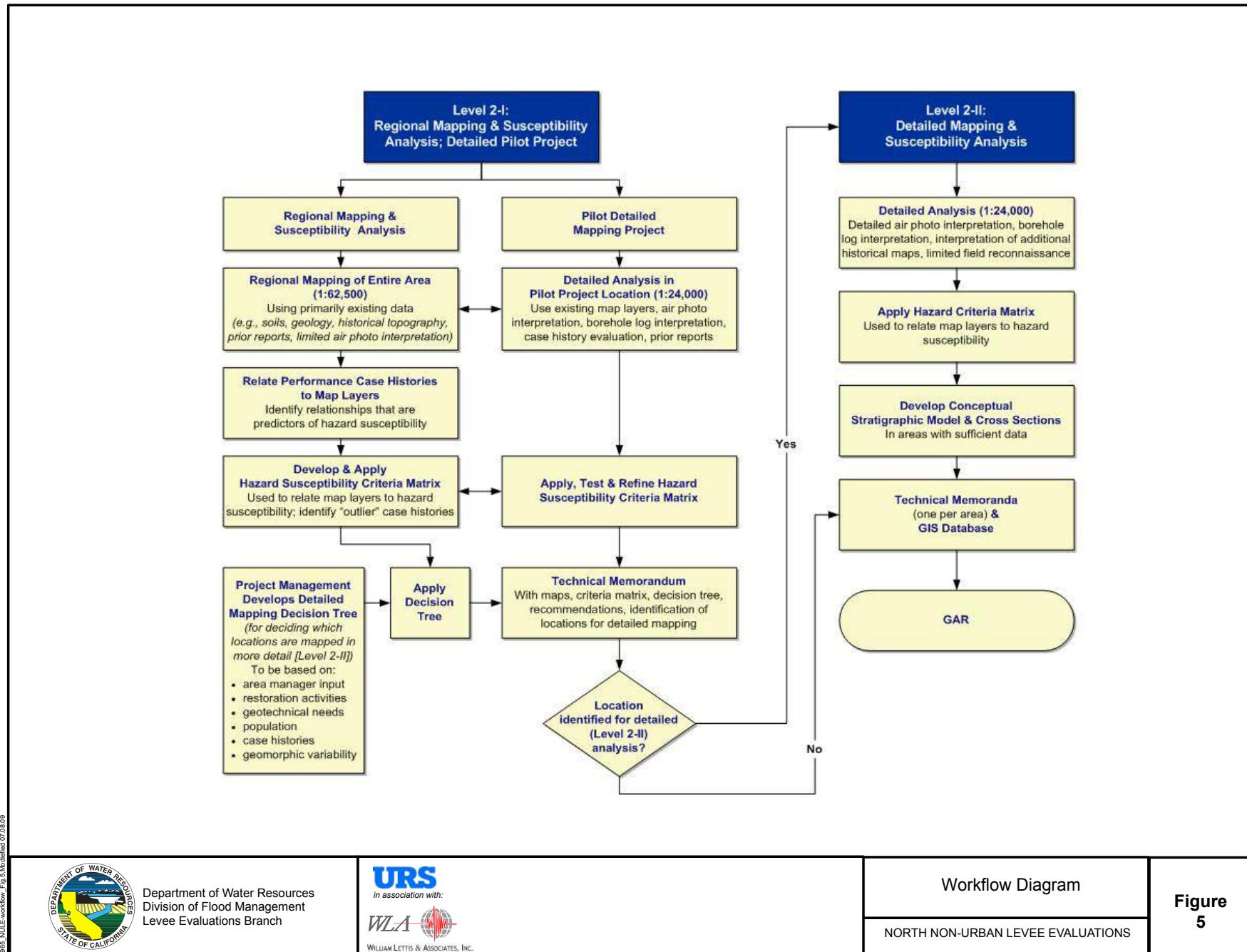


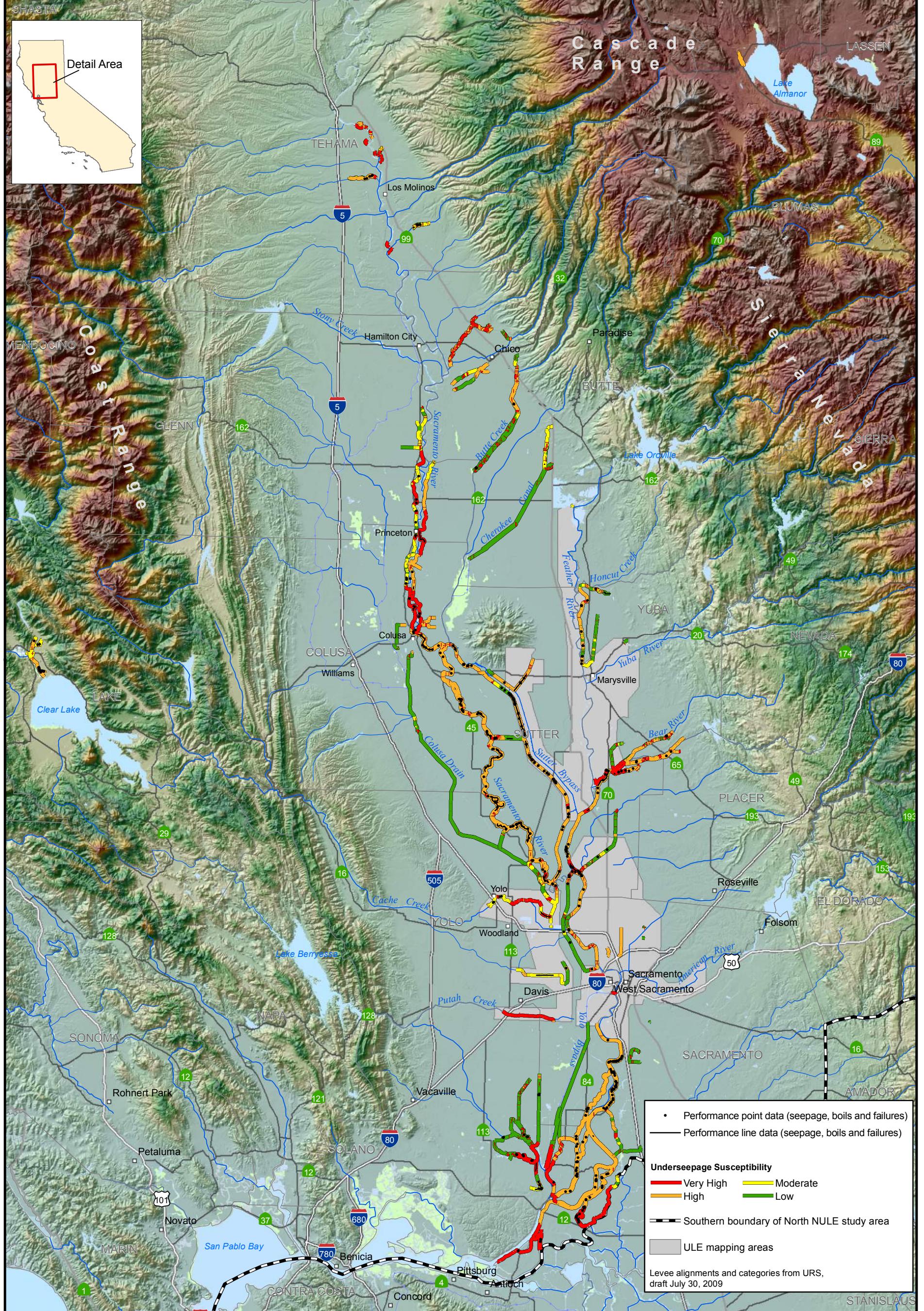
### Explanation

#### Facies      Unit      Geologic Material

Interfan and distal fan		Clay and silt with lesser sand
Proximal fan		Sand, silt, and clay
Distributary channel		Sand and fine gravel with lesser silt and clay
Flood basin		Clay with lesser silt and sand
Floodplain		Silt and sand with clay
Channel and bar		Well sorted gravel and sand
Colluvial apron		Poorly sorted gravel and sand
		Bedrock







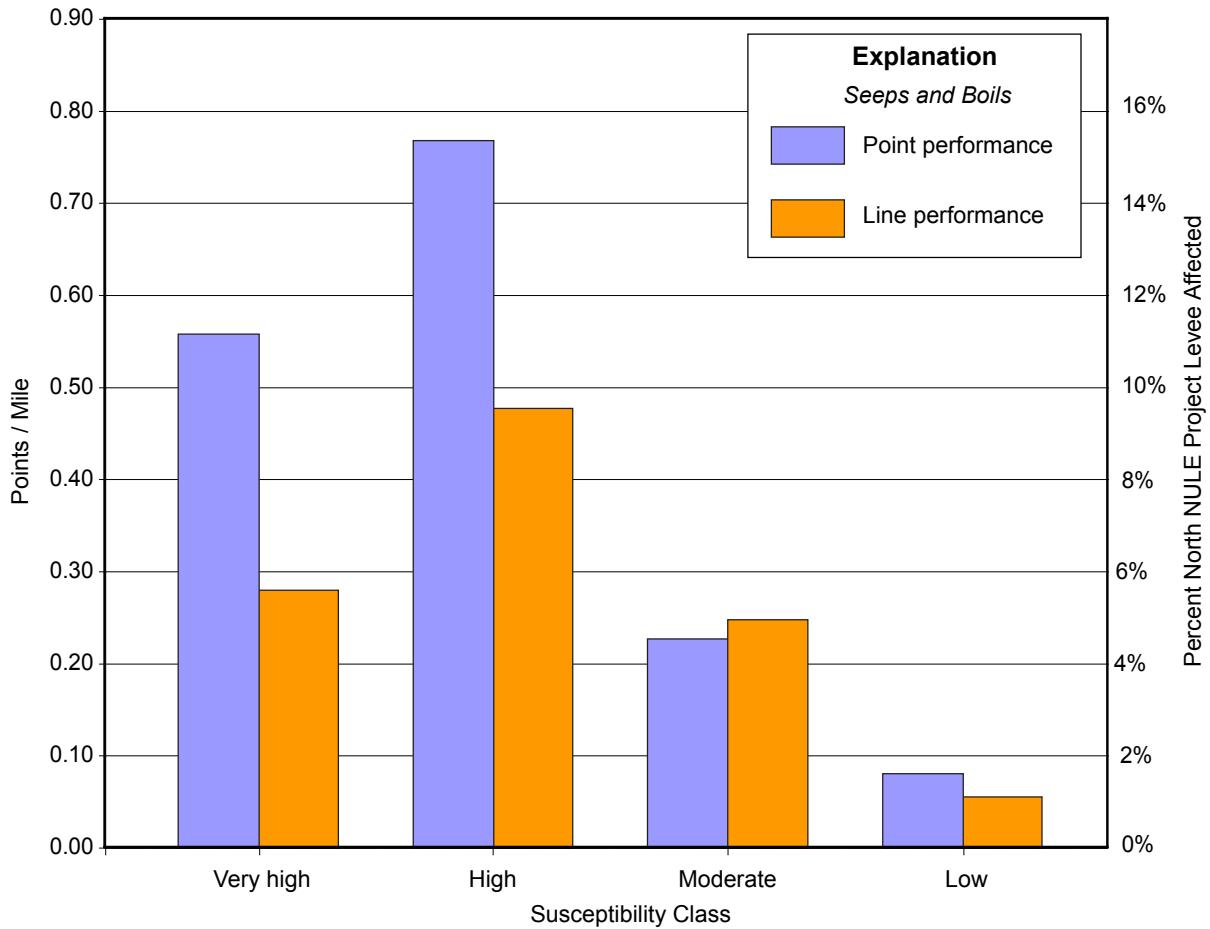
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



## North NULE Performance Map

## North Non-Urban Levee Evaluations

## Figure 6



1965\_NULE\_7\_Plot Seepage and Boil Frequency\_Fig7.Modified 12/17/09



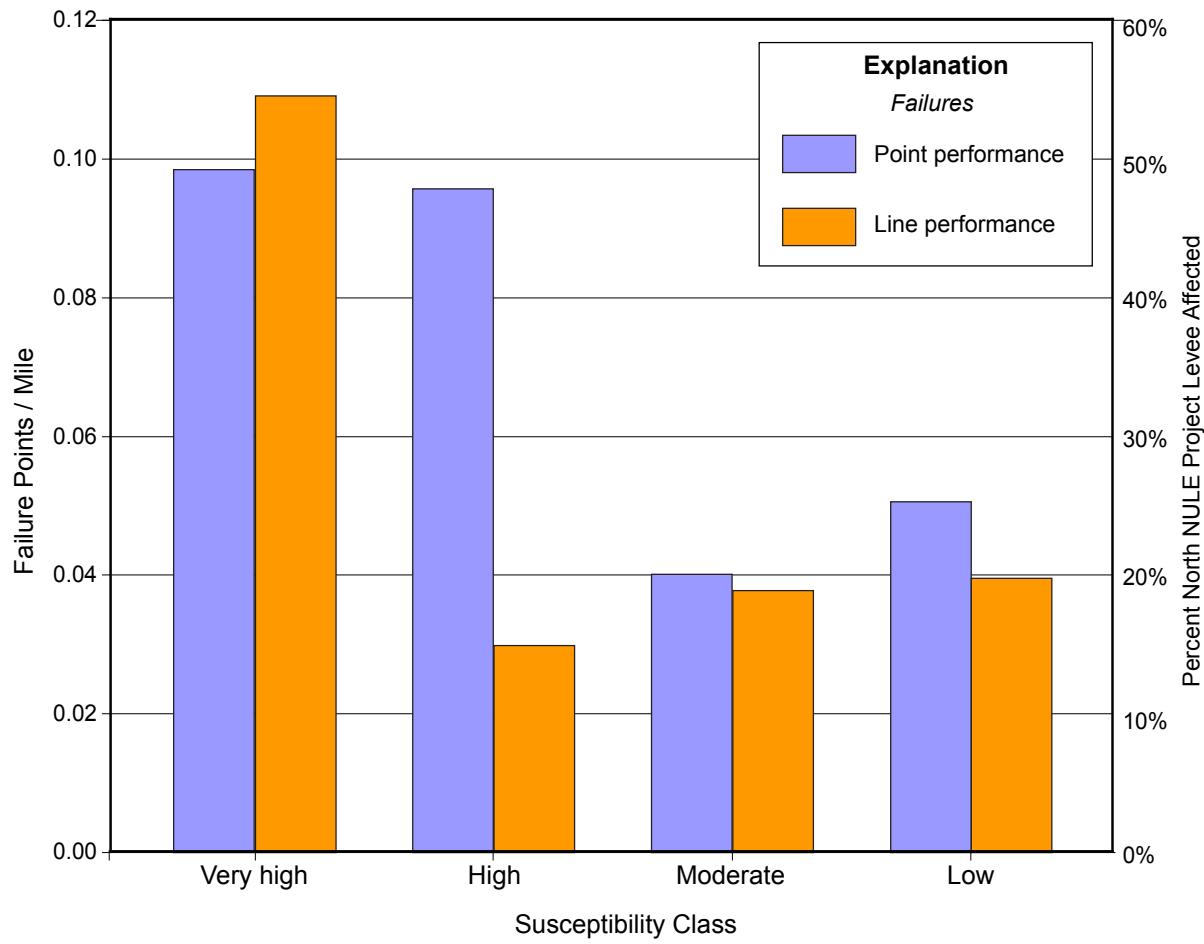
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



Plot of Seepage and Boil Frequency  
by Susceptibility Class

NORTH NON-URBAN LEVEE EVALUATIONS

**Figure**  
**7**



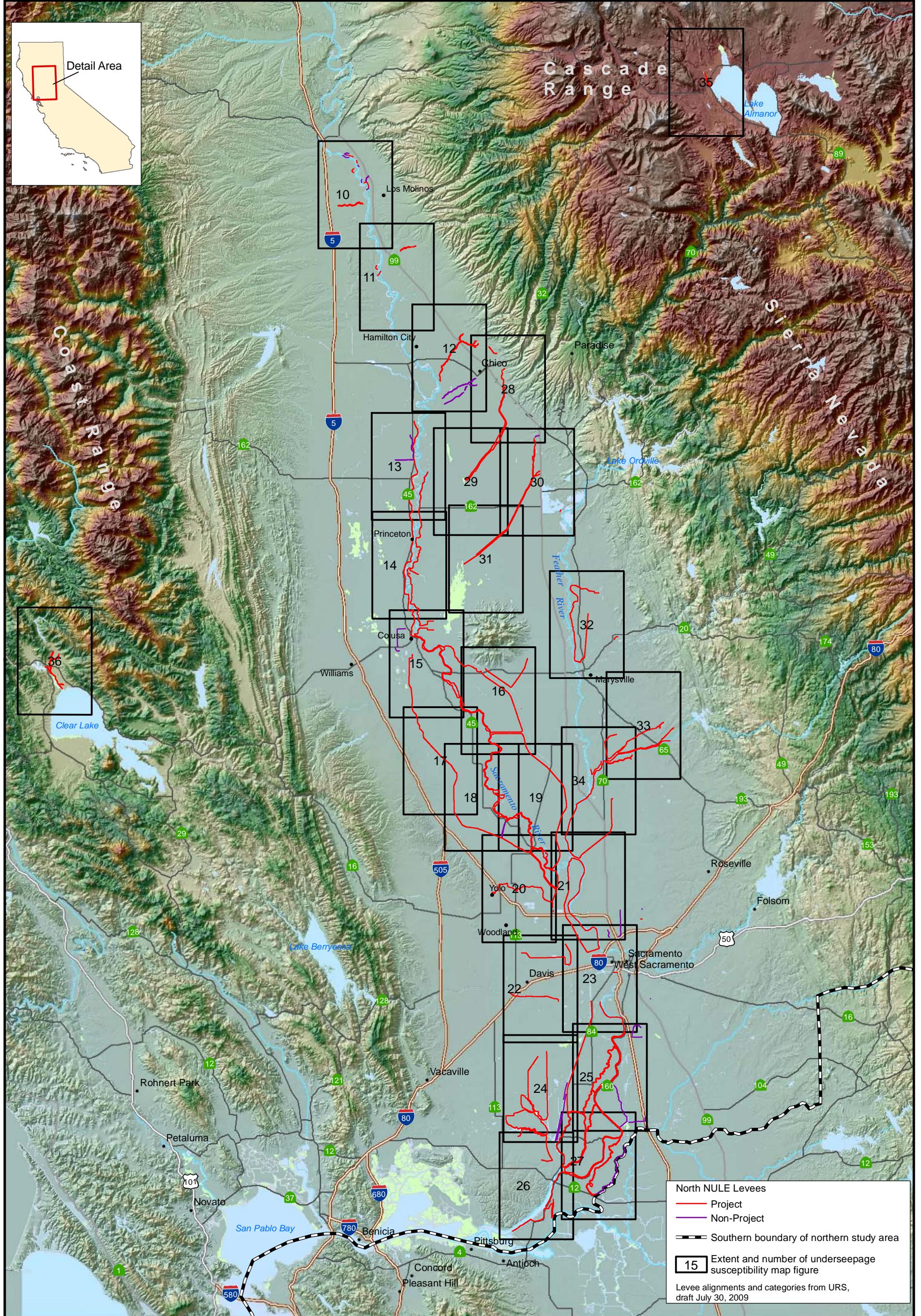
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch

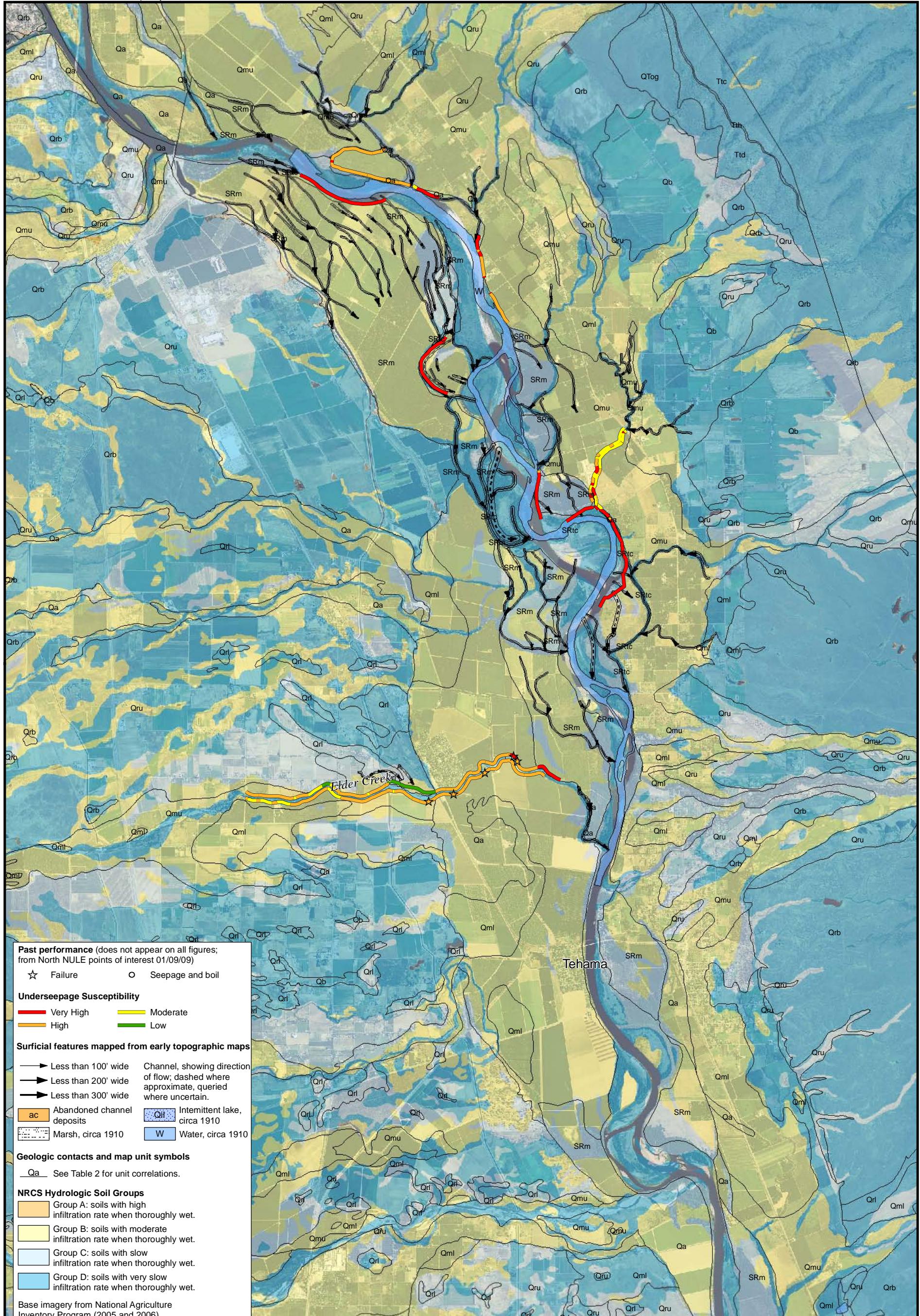


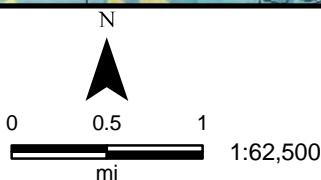
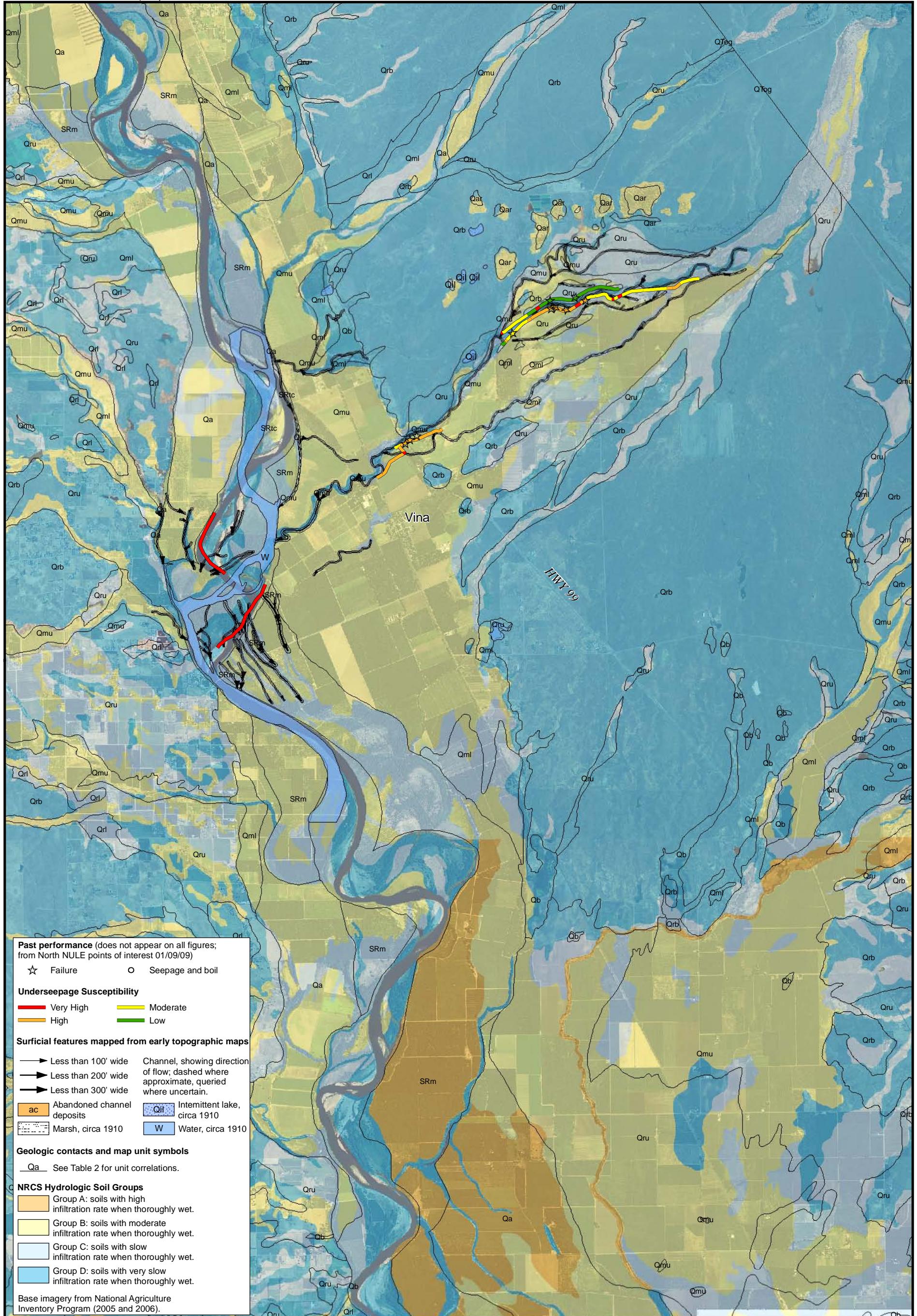
Plot of Failures  
by Susceptibility Class

NORTH NON-URBAN LEVEE EVALUATIONS

**Figure  
8**







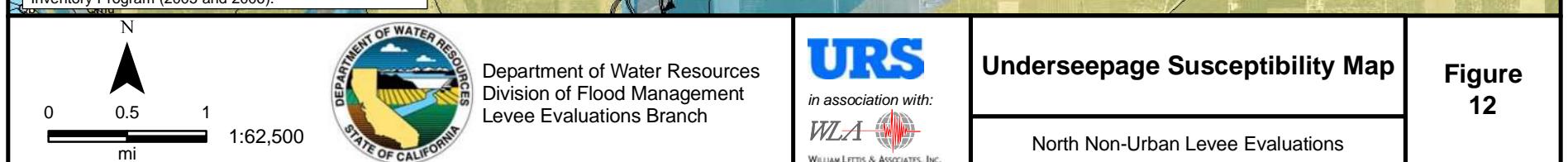
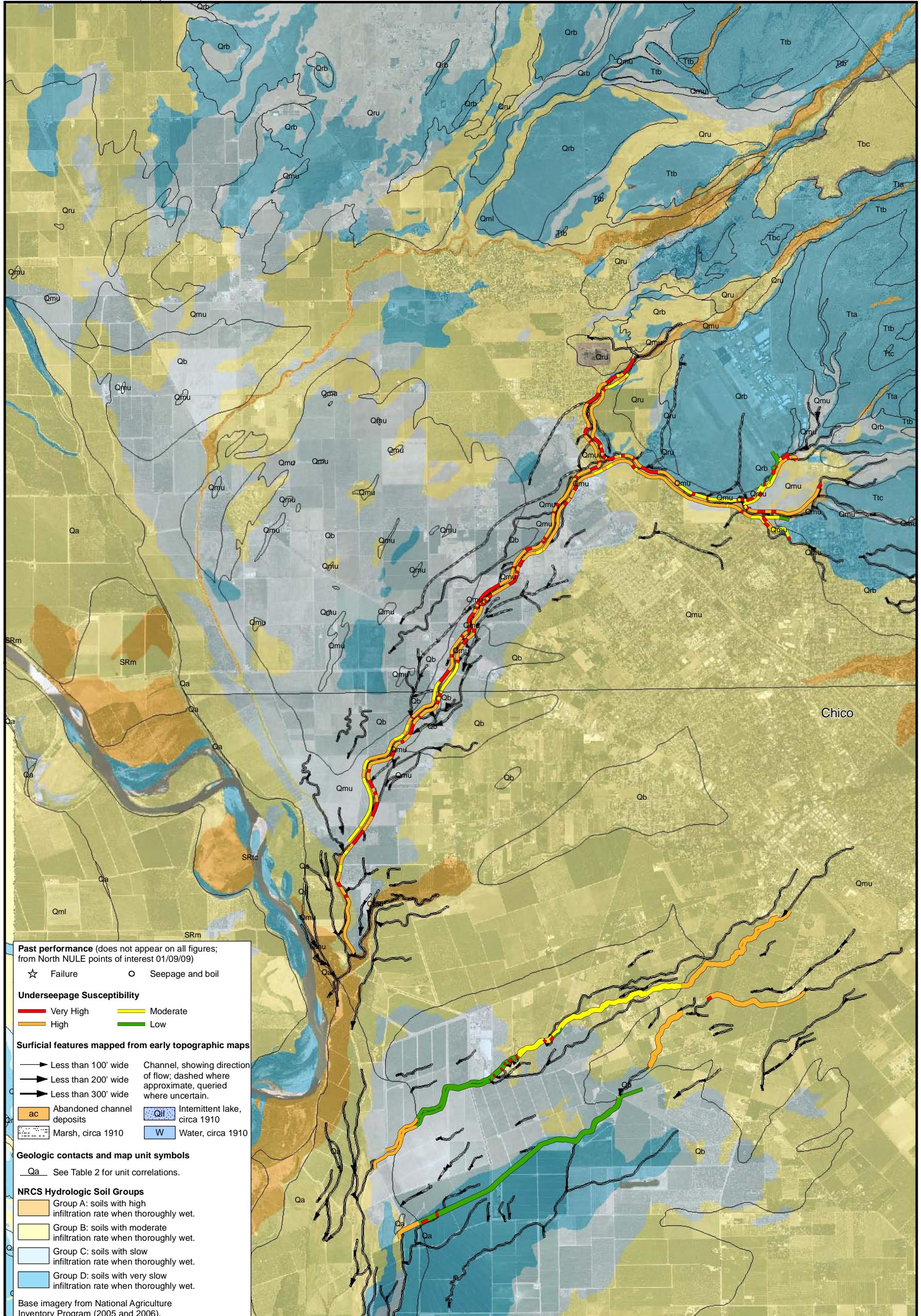
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch

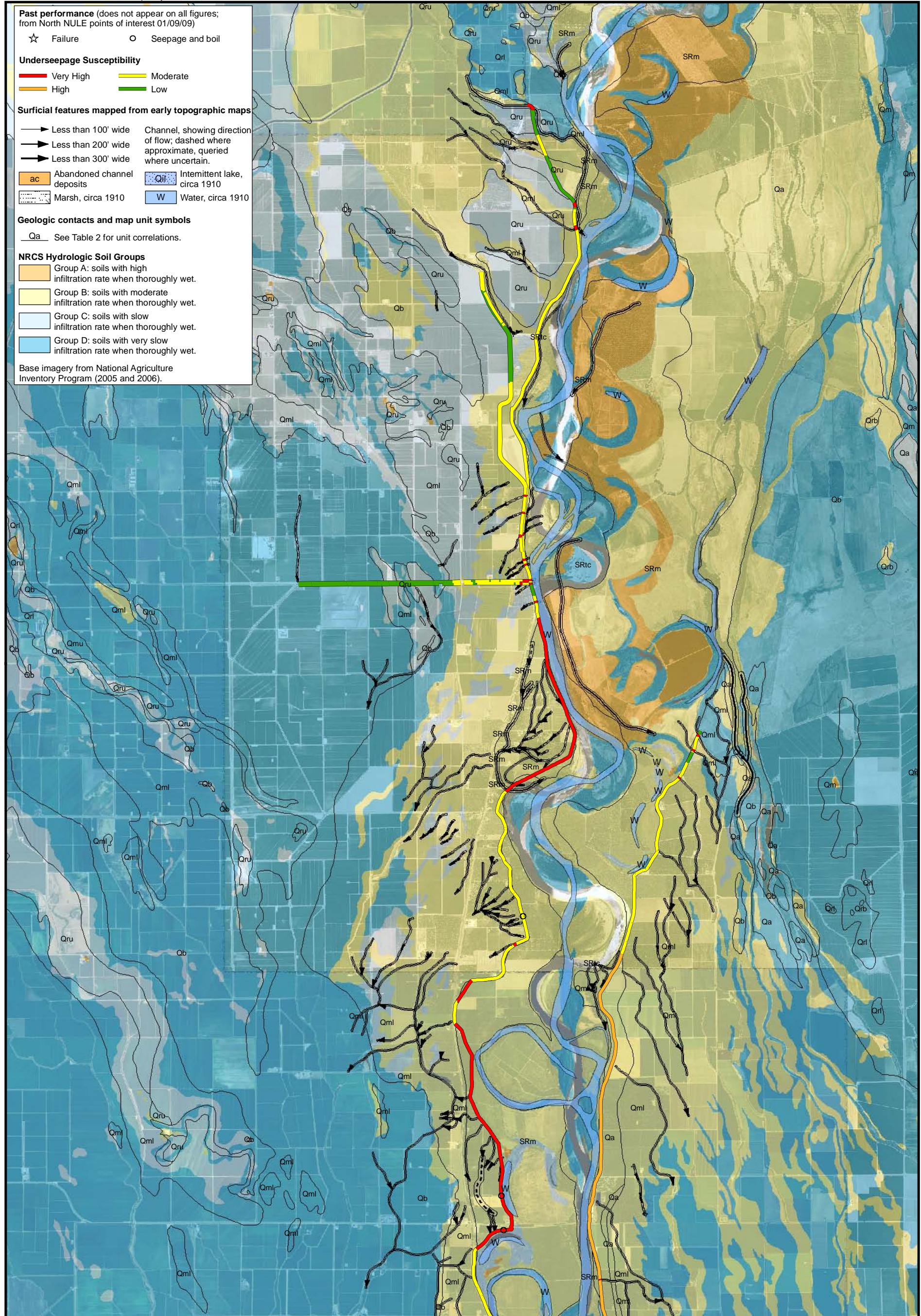


**Underseepage Susceptibility Map**

North Non-Urban Levee Evaluations

**Figure 11**





0 0.5 1  
mi



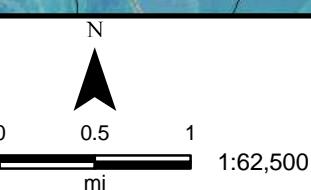
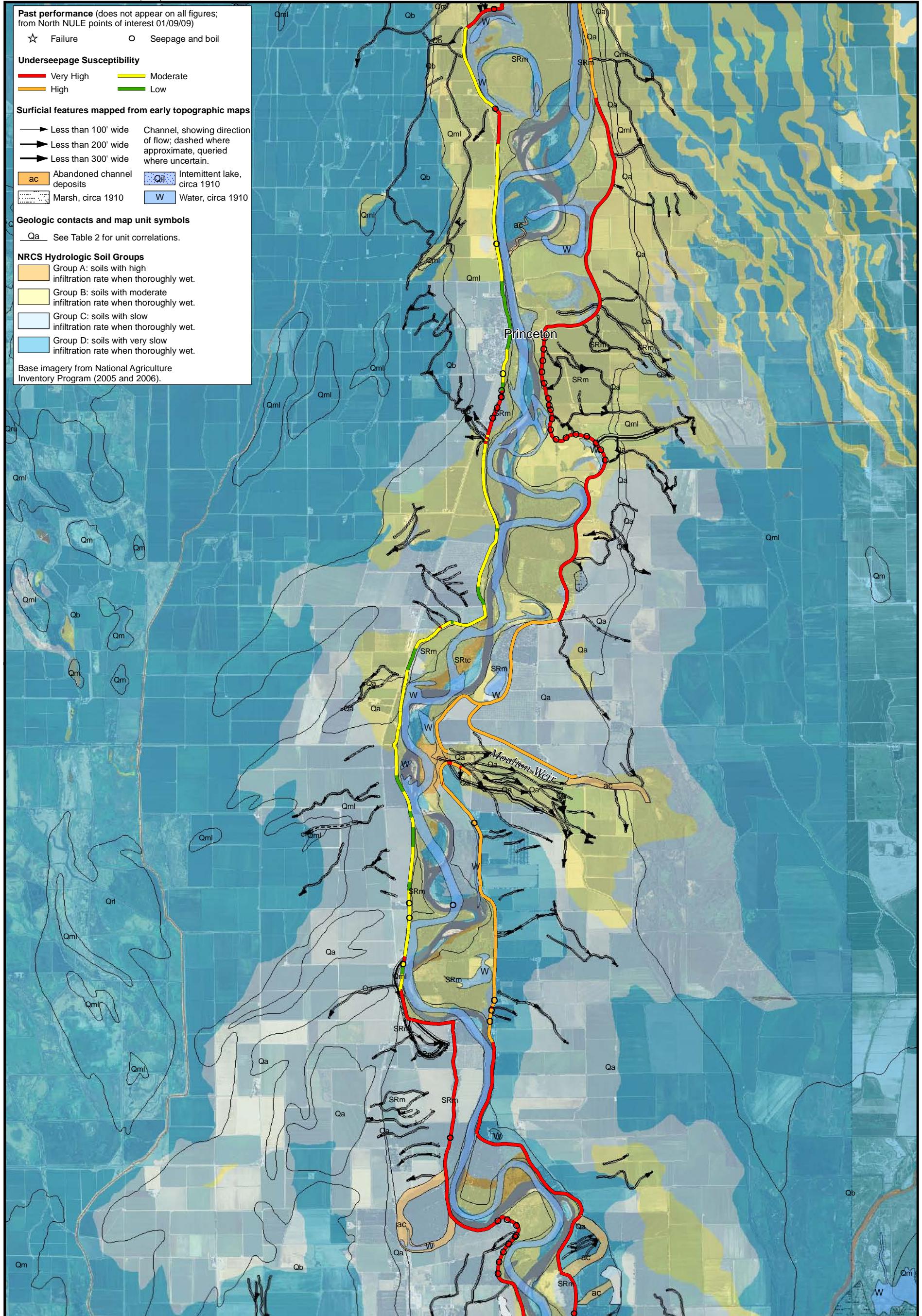
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



**Underseepage Susceptibility Map**

North Non-Urban Levee Evaluations

**Figure 13**



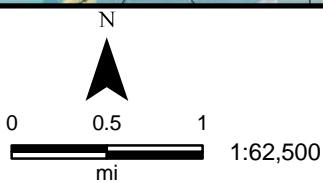
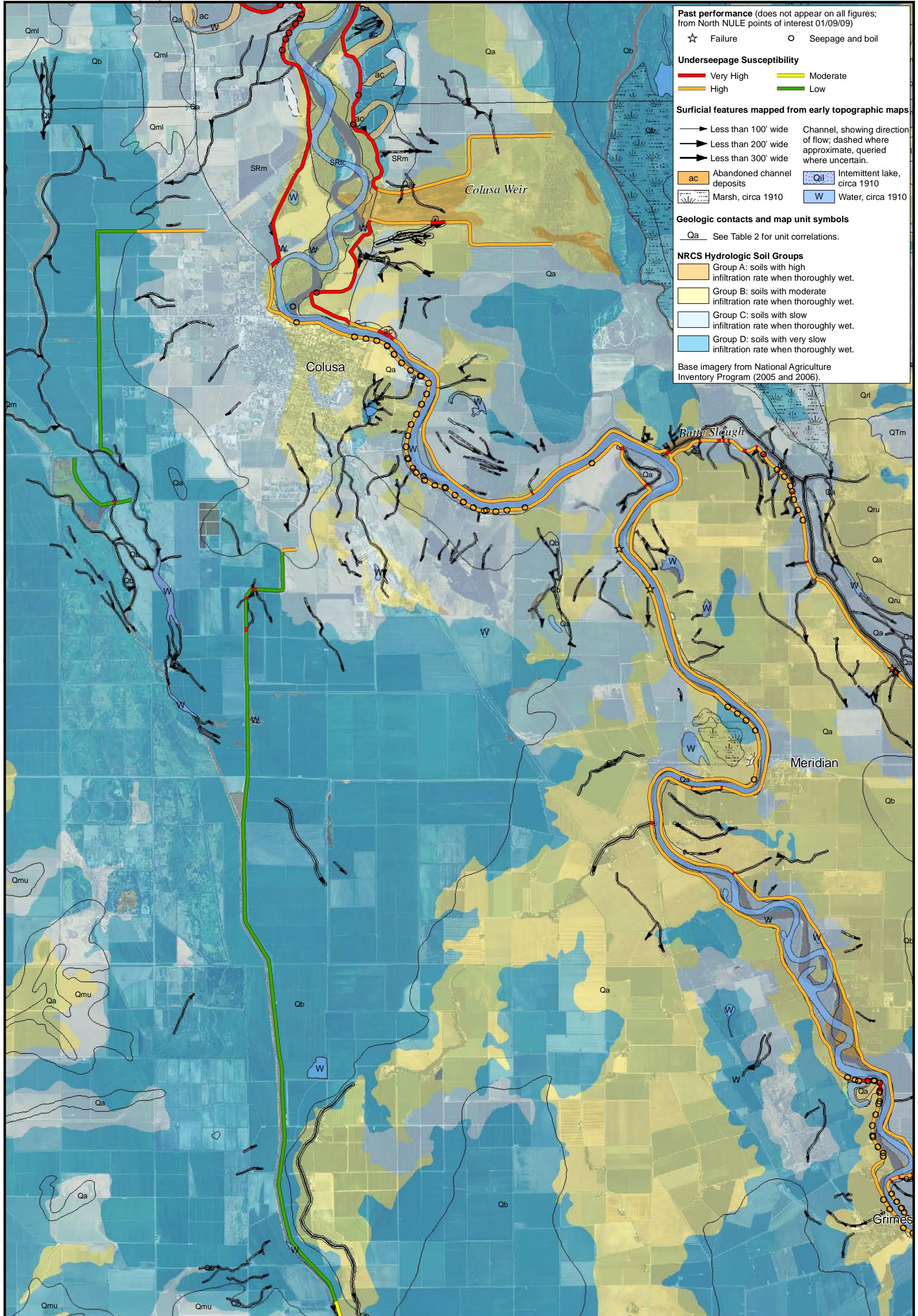
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure  
14



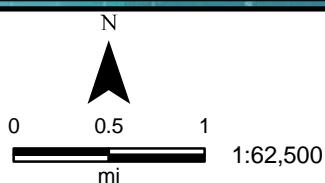
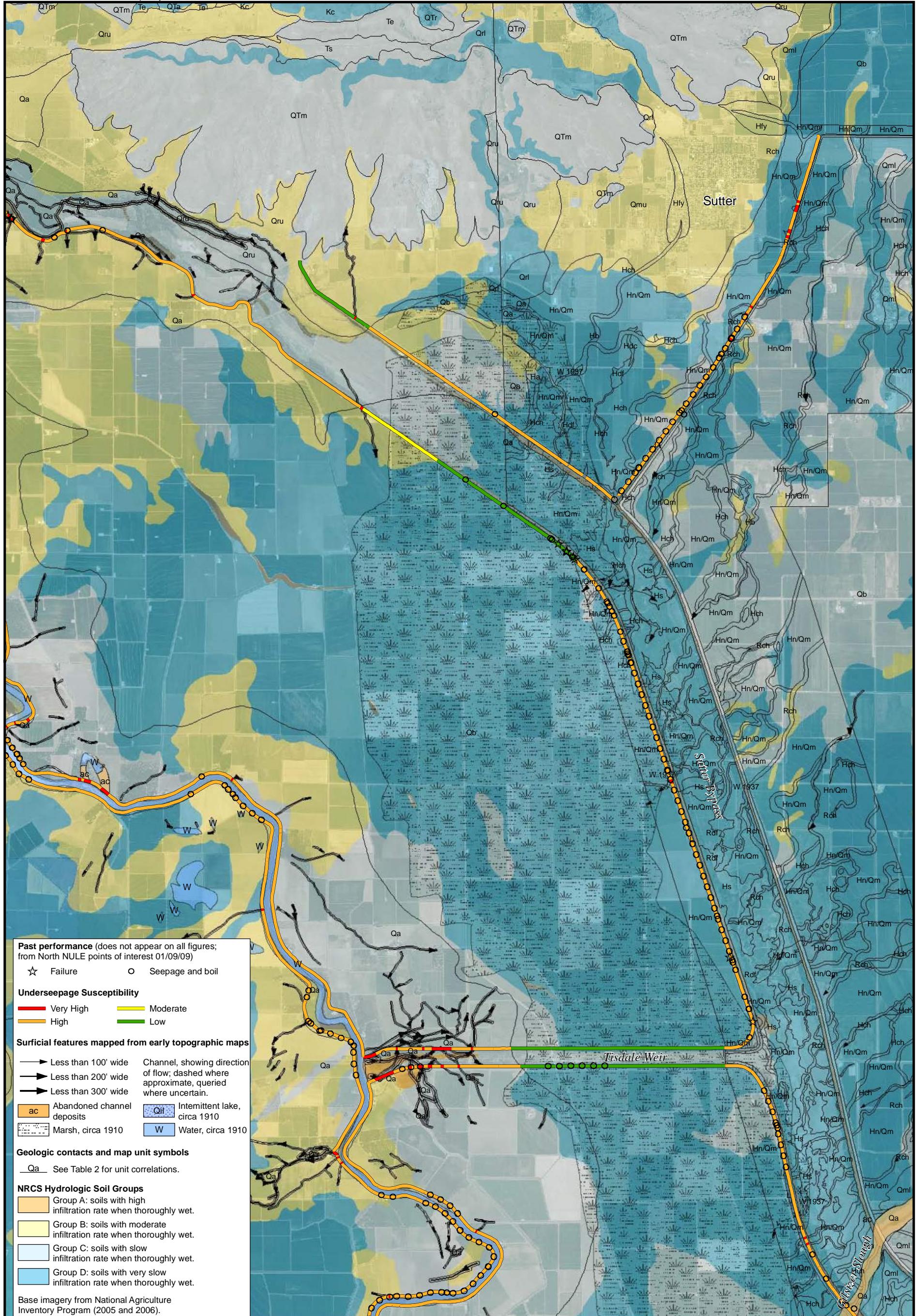
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



### Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure  
15

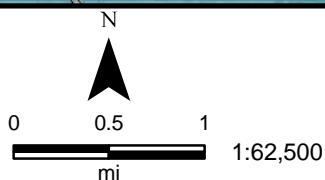
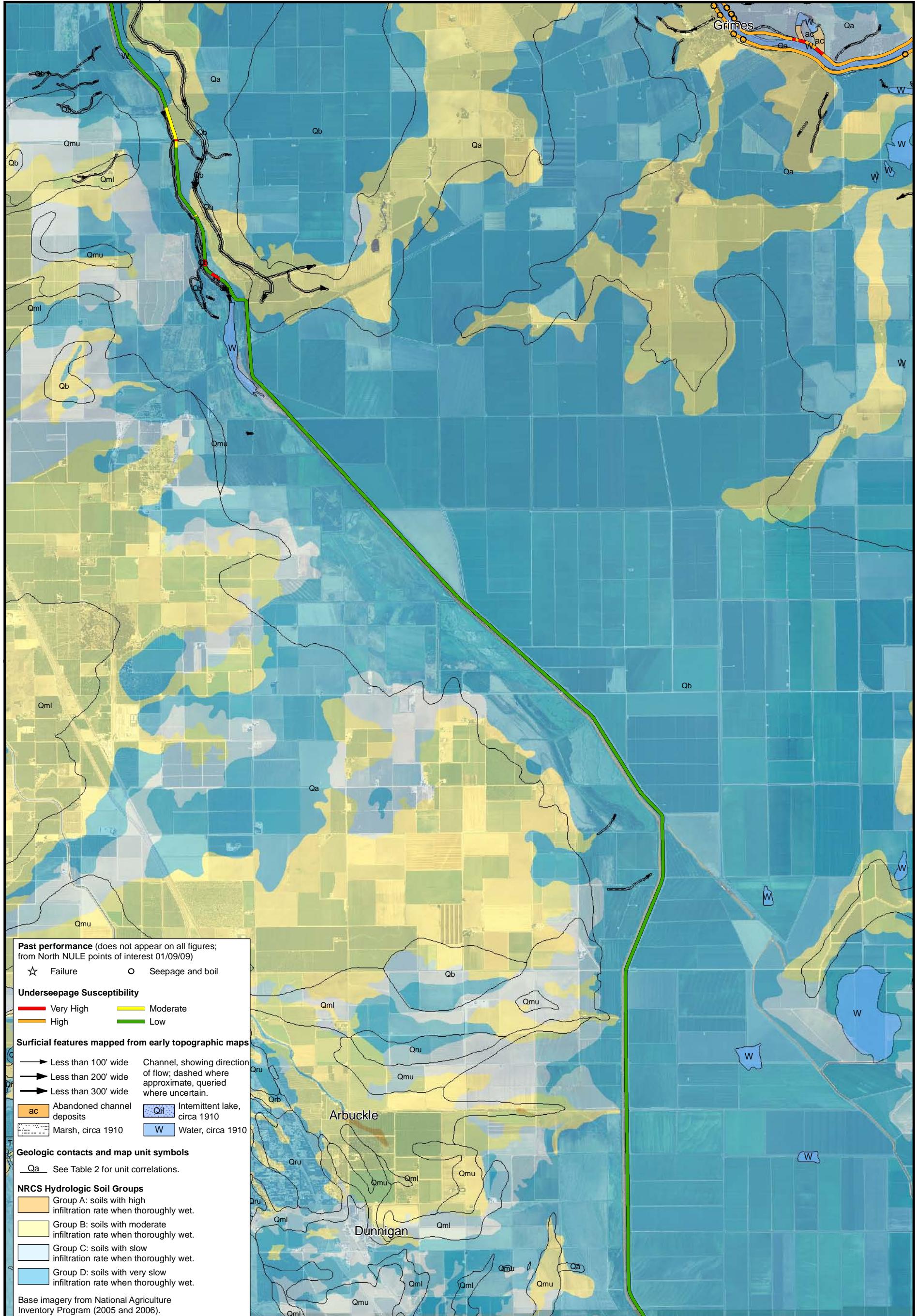


Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



Underseepage Susceptibility Map  
North Non-Urban Levee Evaluations

Figure  
16



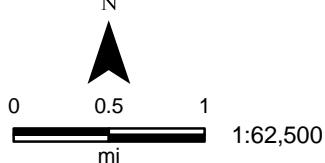
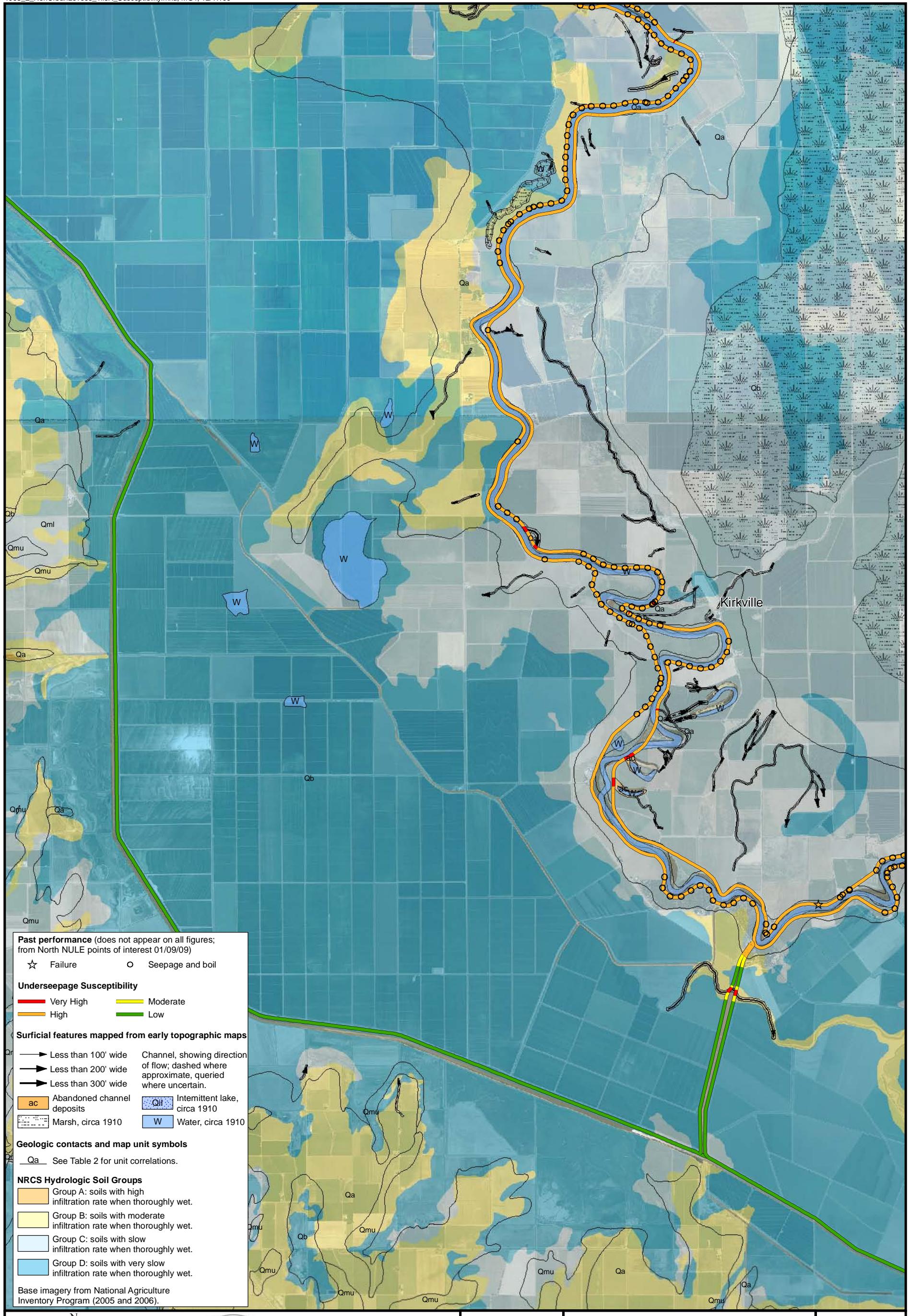
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



**Underseepage Susceptibility Map**

North Non-Urban Levee Evaluations

**Figure 17**



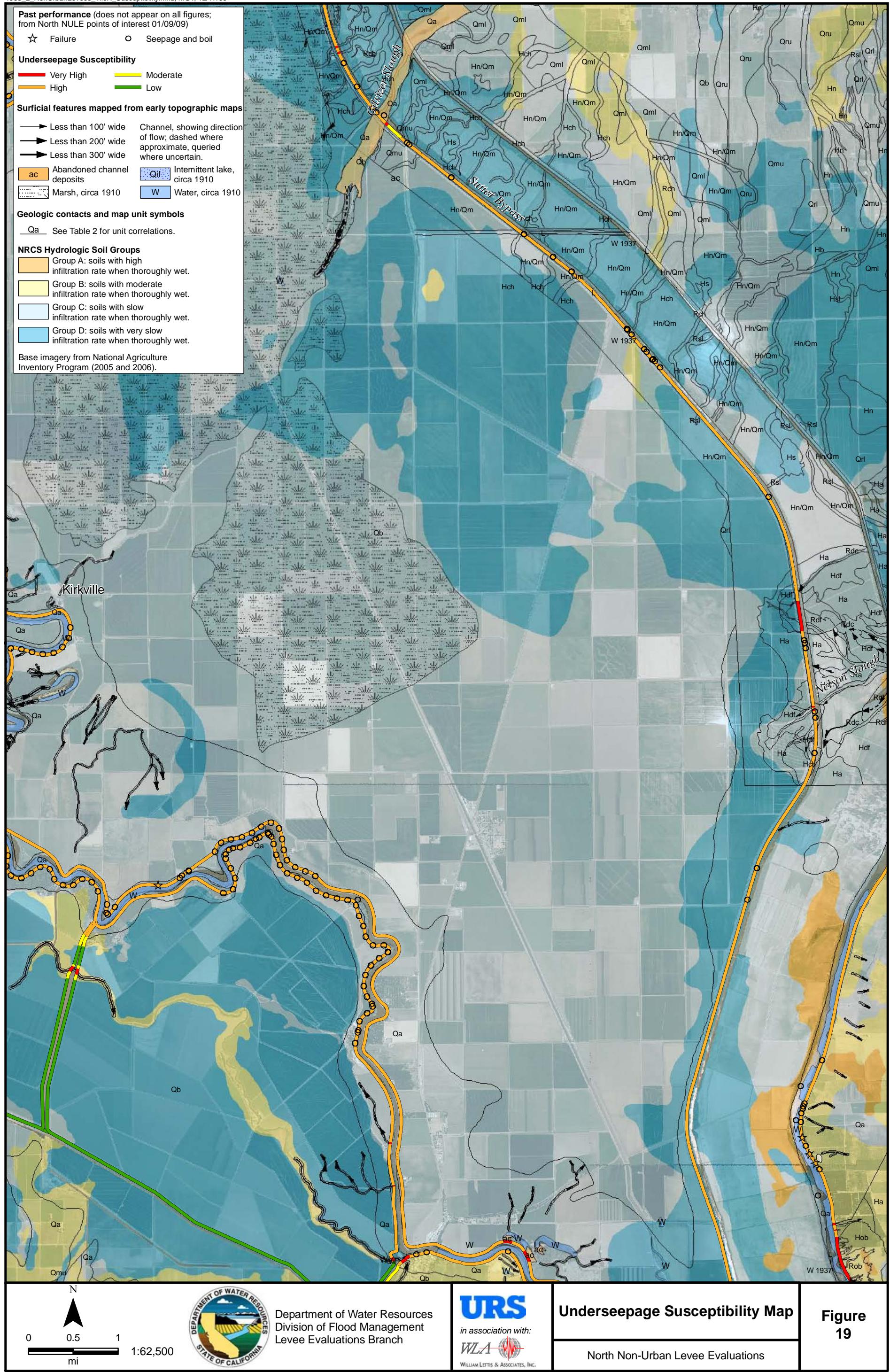
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure  
18



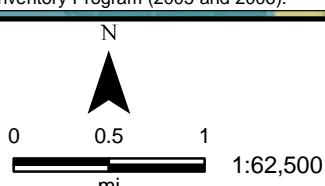
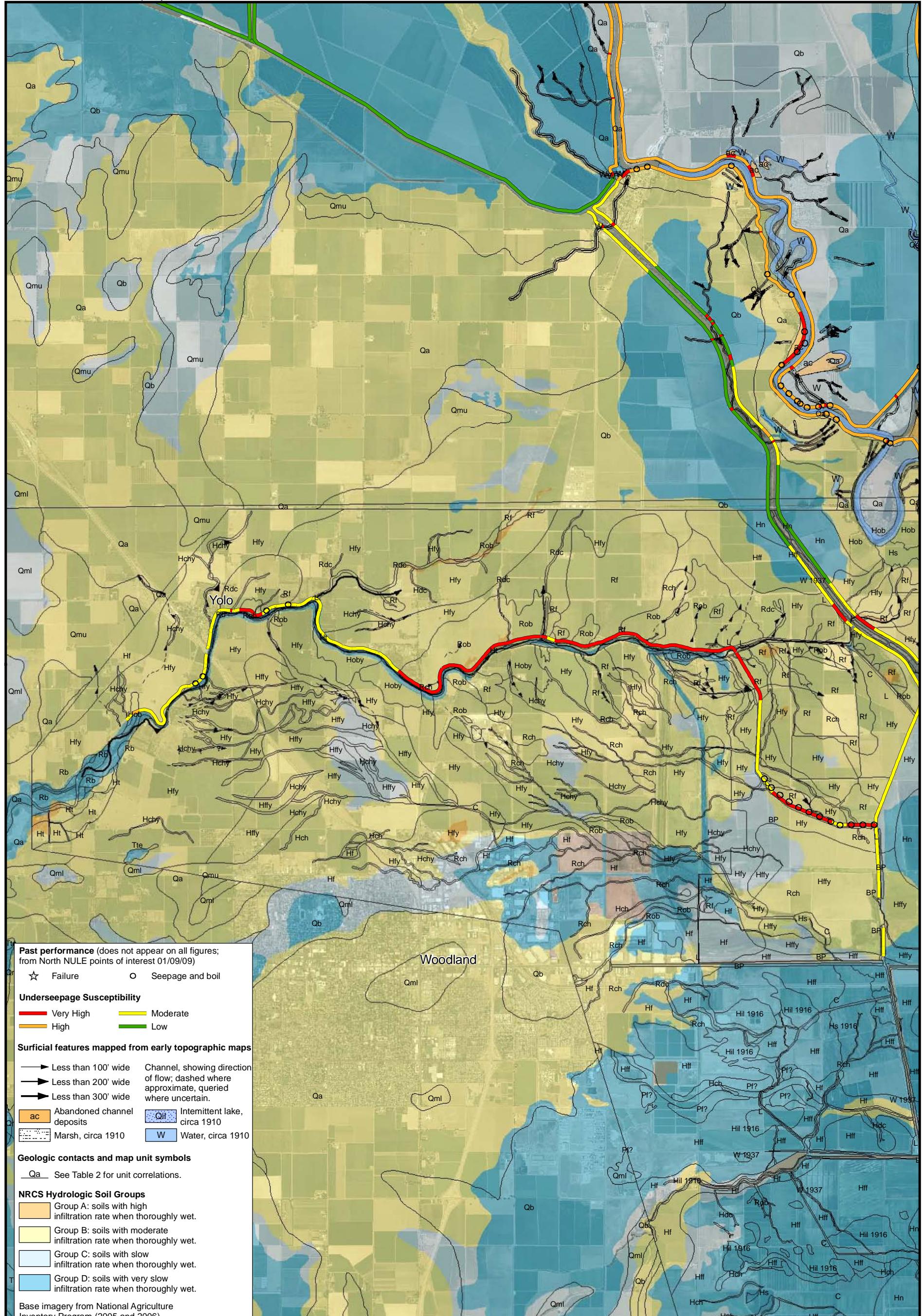
0 0.5 1  
mi



Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch

**URS**  
in association with:  
**WLA**  
WILLIAM LETTIS & ASSOCIATES, INC.

Underseepage Susceptibility Map  
North Non-Urban Levee Evaluations

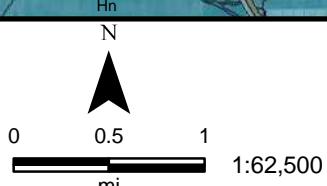
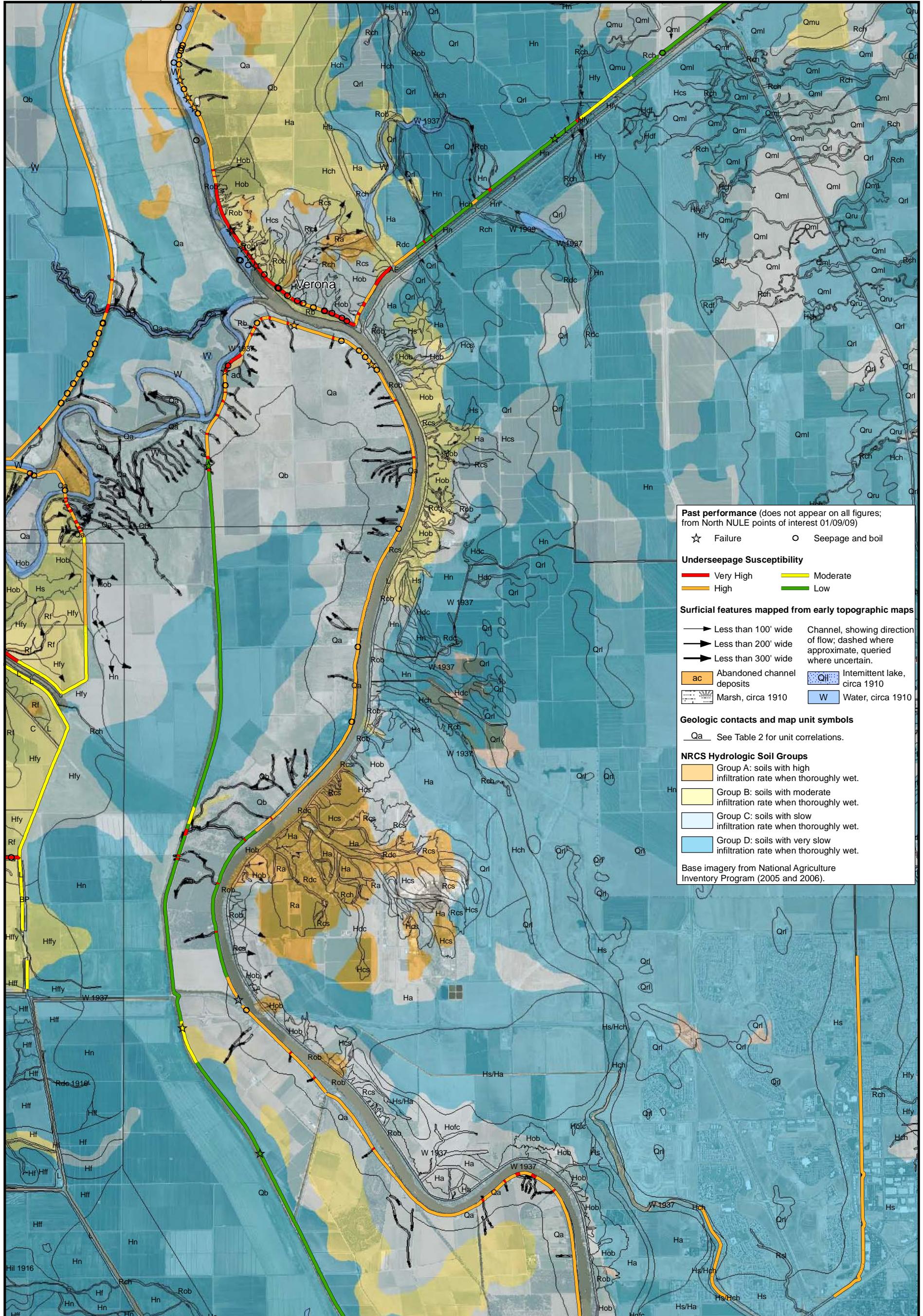


Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



**Underseepage Susceptibility Map**  
North Non-Urban Levee Evaluations

**Figure 20**



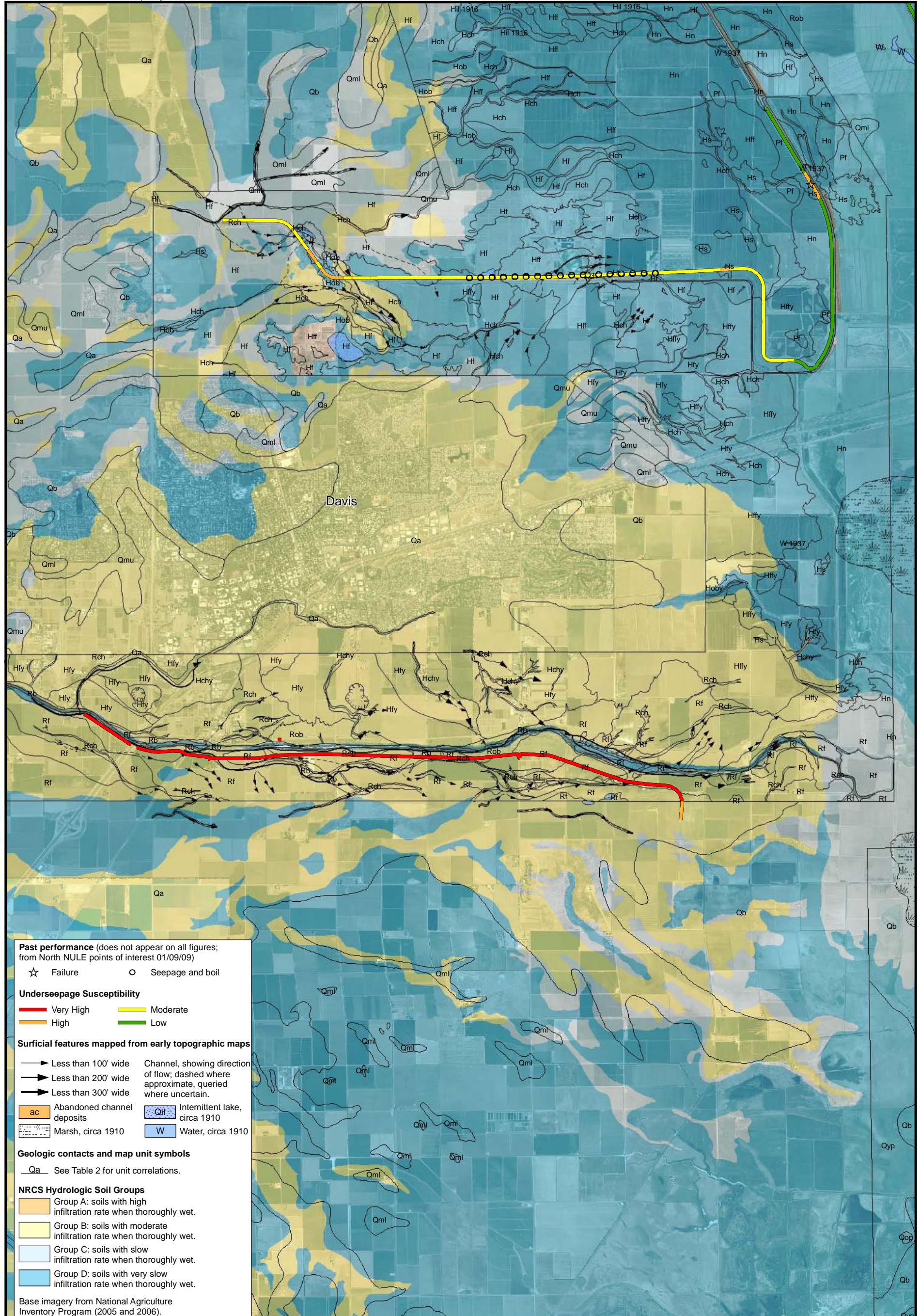
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch

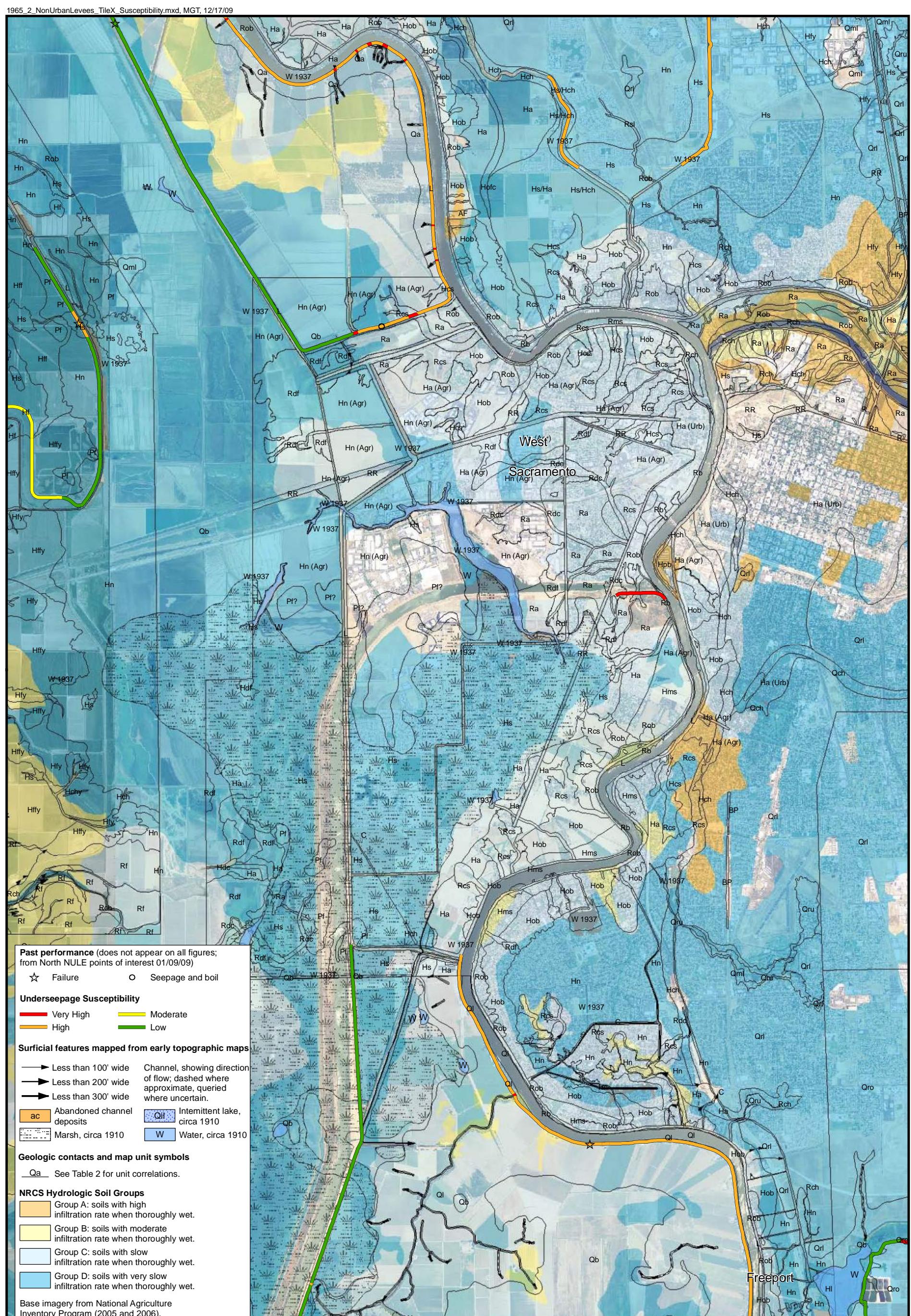


### Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

**Figure 21**





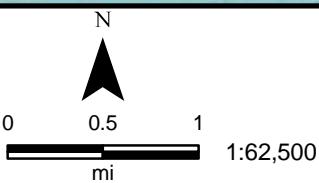
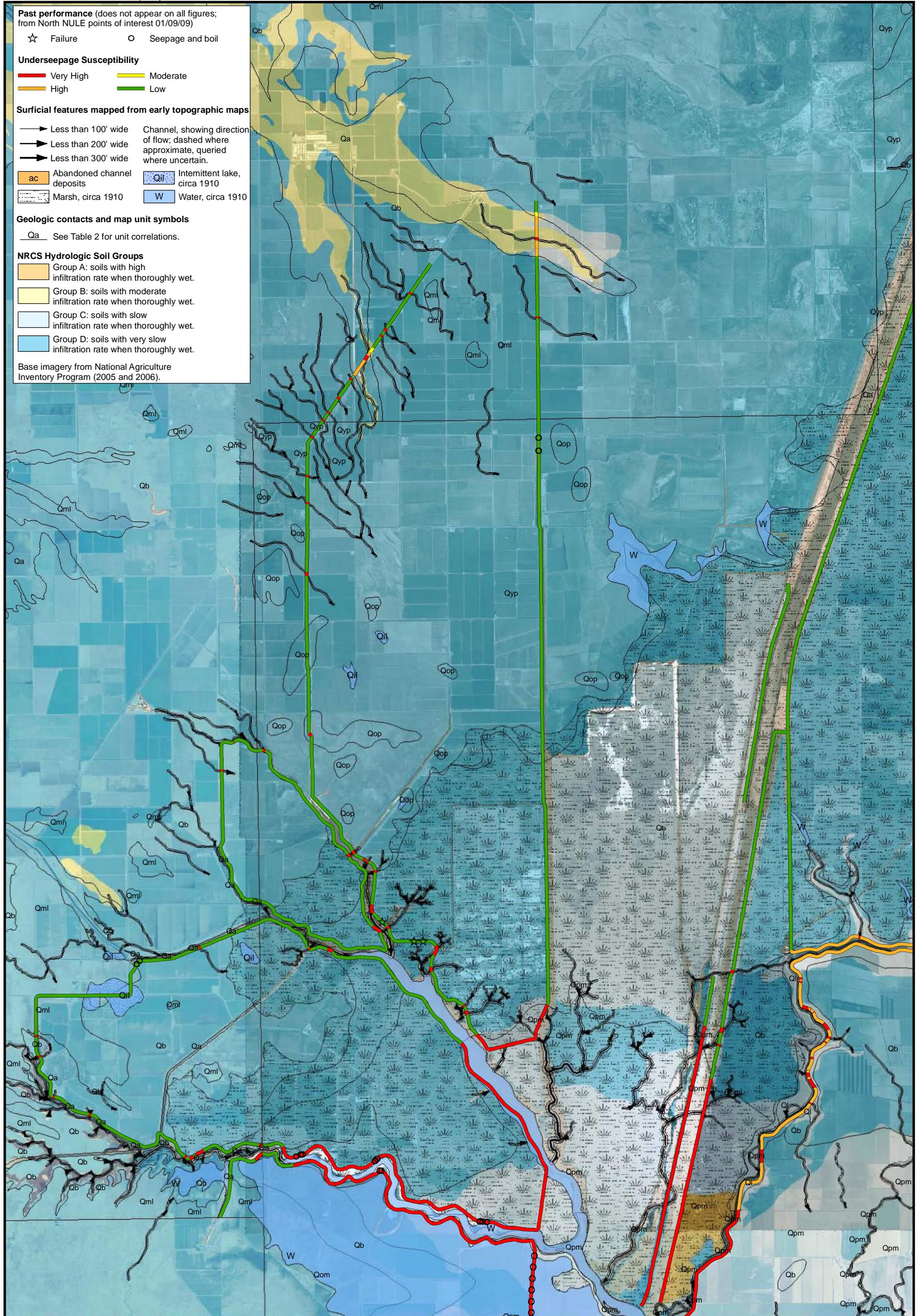
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



## Underseepage Susceptibility Map

## North Non-Urban Levee Evaluations

**Figure**  
**23**



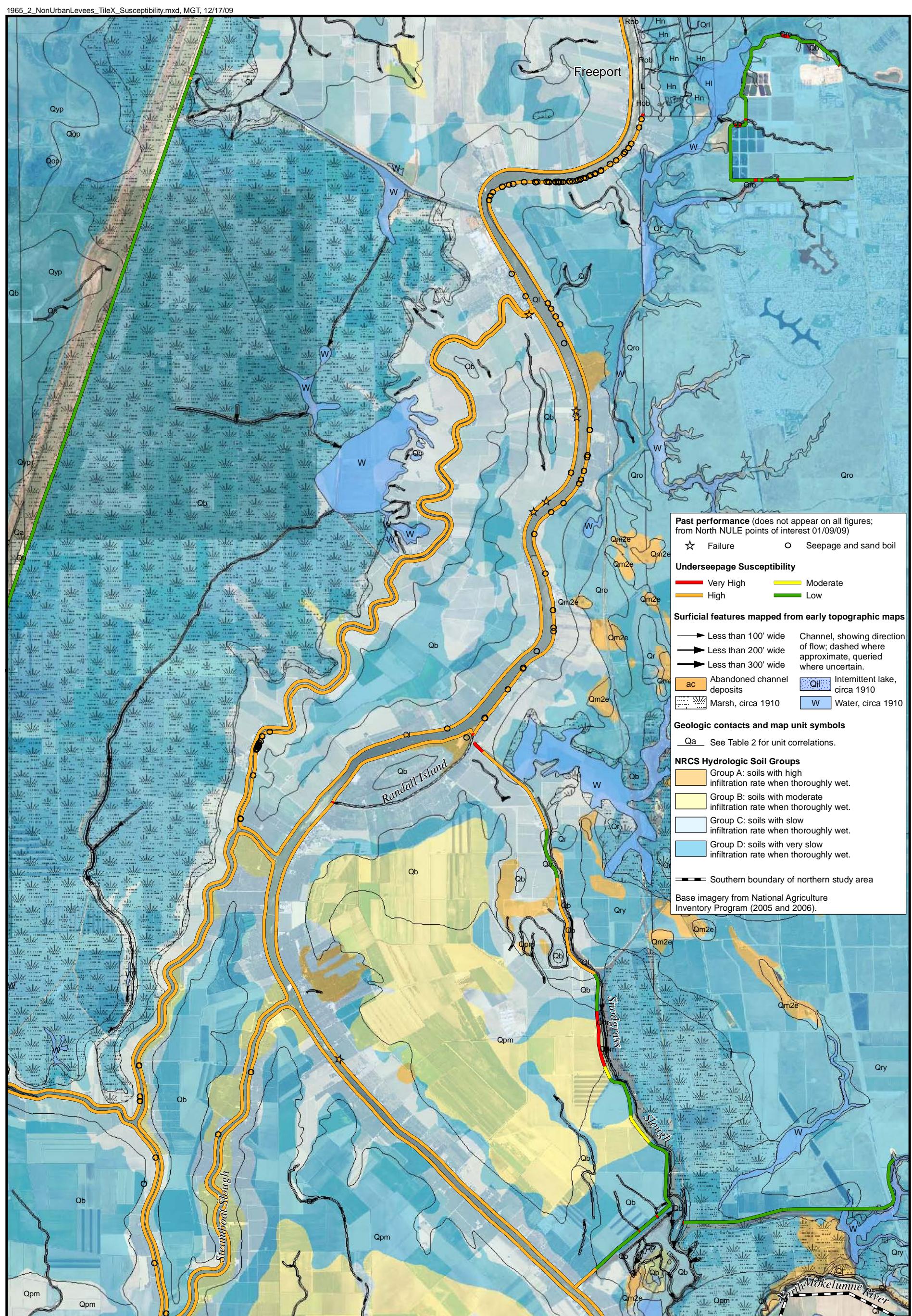
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



**Underseepage Susceptibility Map**

North Non-Urban Levee Evaluations

**Figure 24**

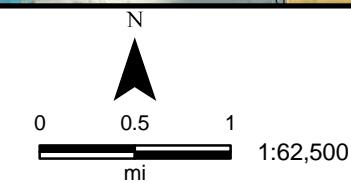
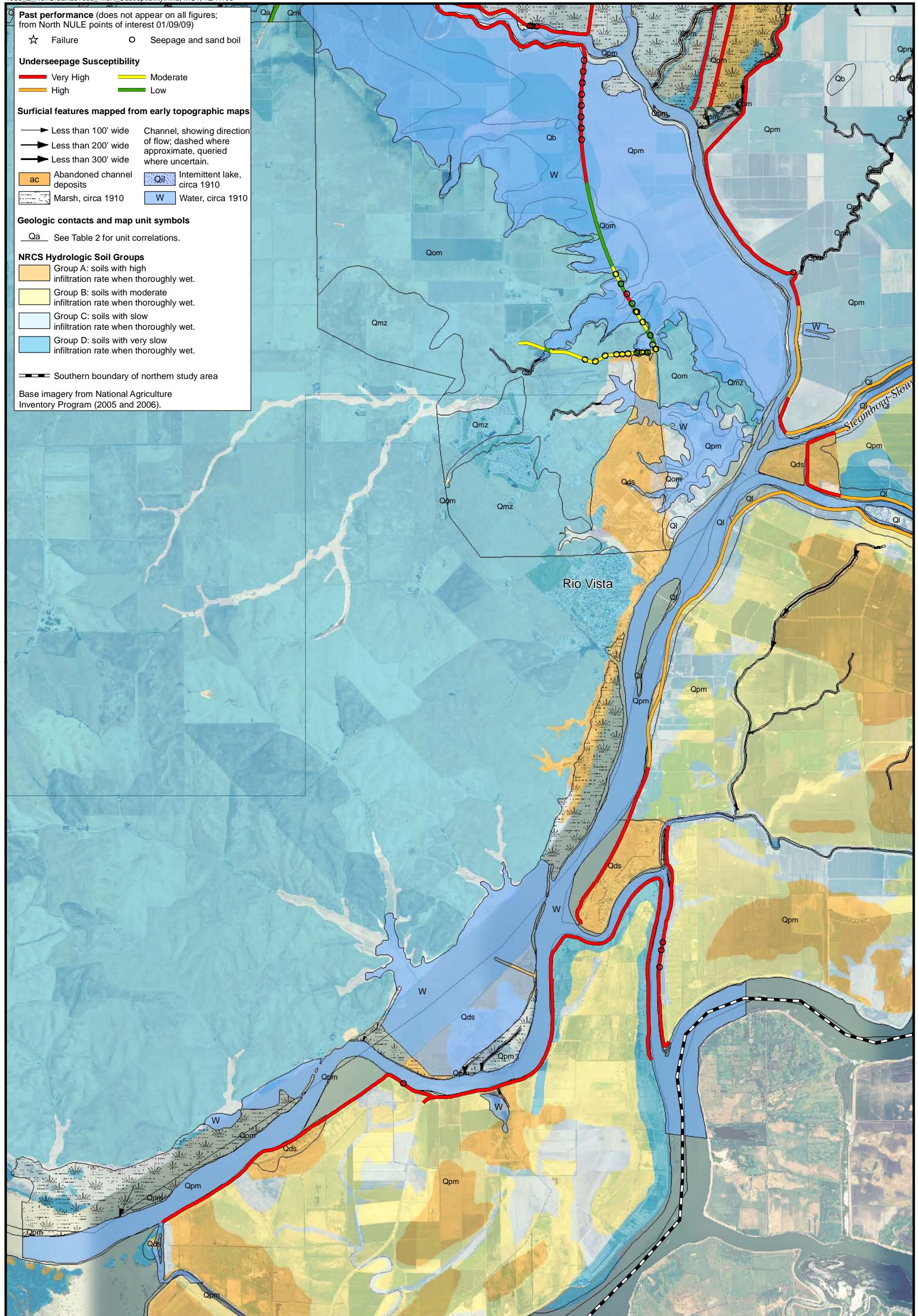


Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch

**URS**  
*in association with*  
~~WLA~~   
WILLIAM LEETE & ASSOCIATES, INC.

## Underseepage Susceptibility Map

## Figure 25



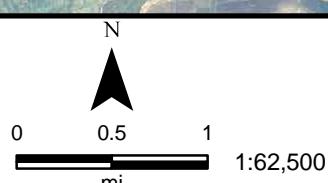
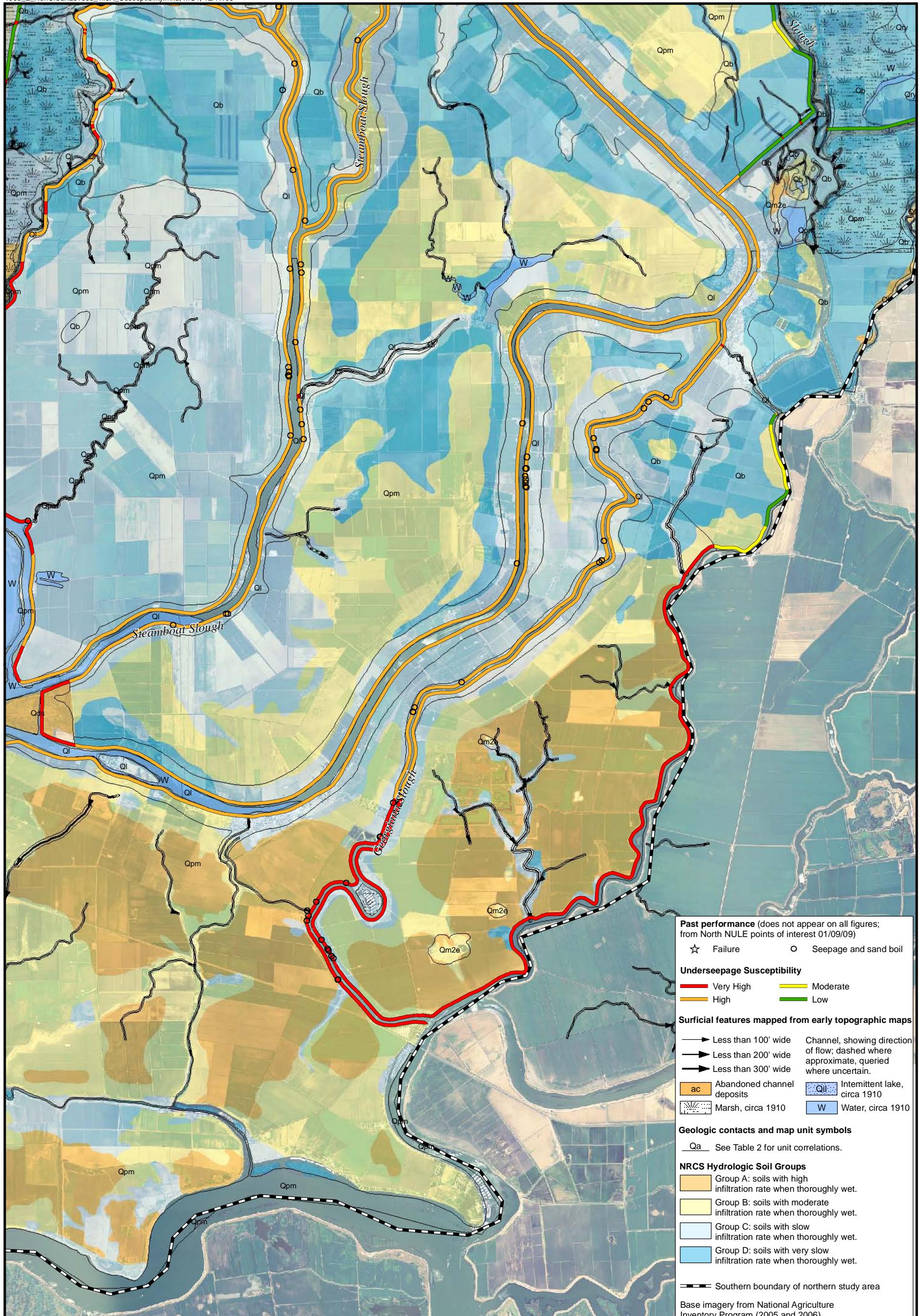
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



**Underseepage Susceptibility Map**

North Non-Urban Levee Evaluations

**Figure 26**



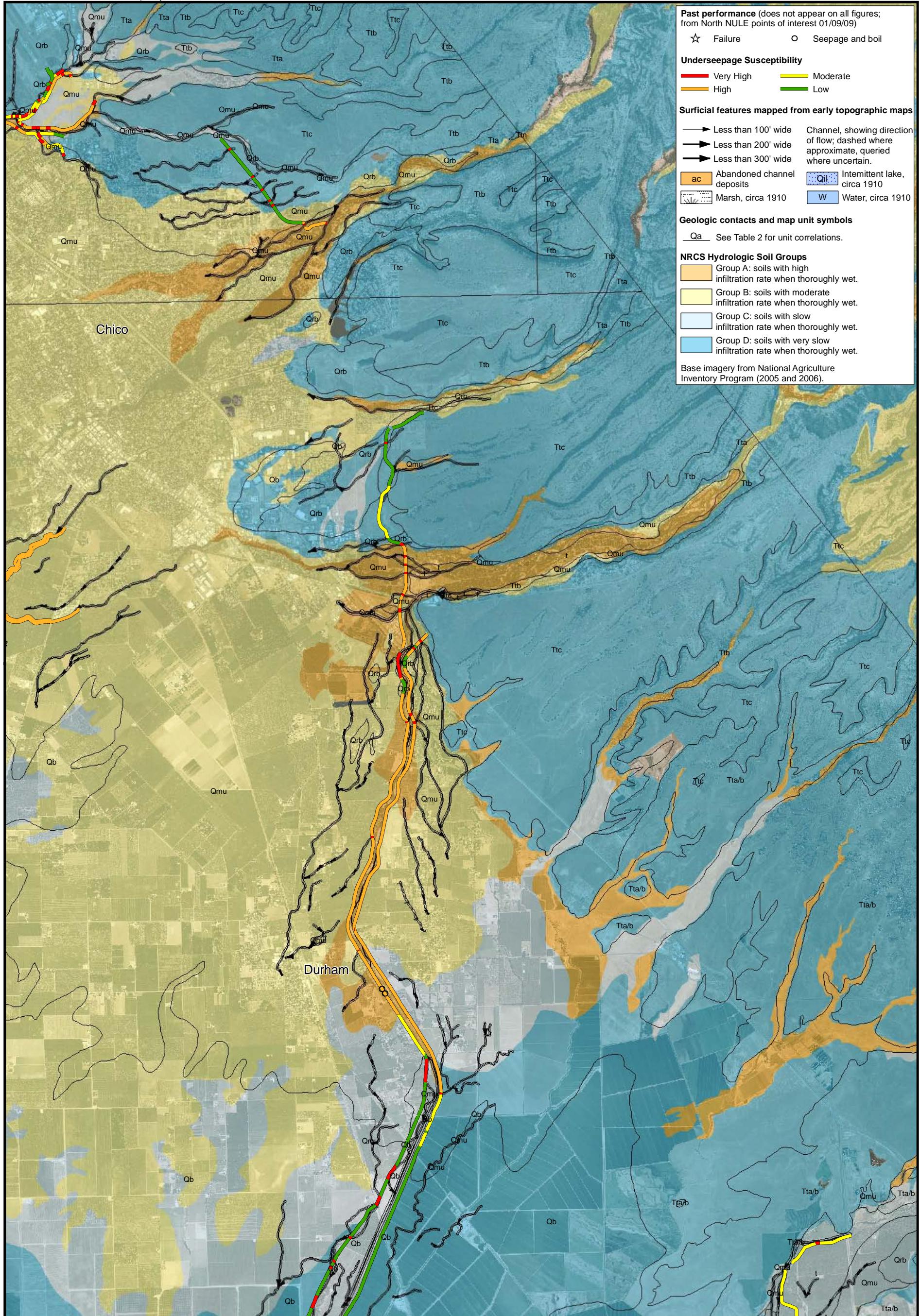
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



### Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure  
27



N

0 0.5 1  
mi

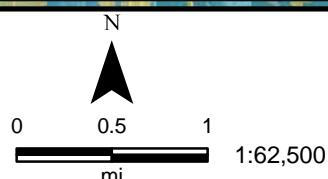
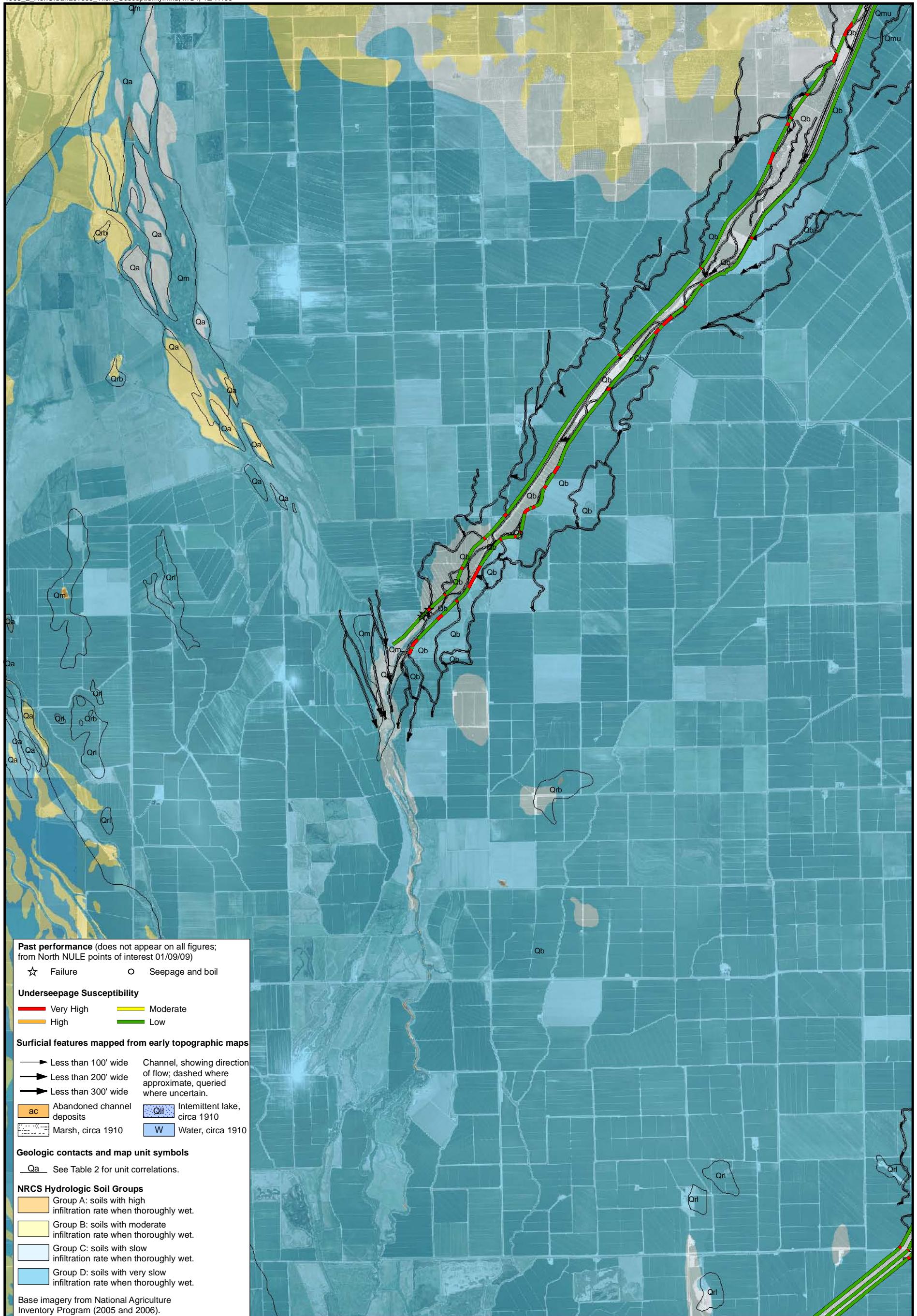
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch

**URS**  
in association with:  
**WLA**  
WILLIAM LETTIS & ASSOCIATES, INC.

Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure  
28



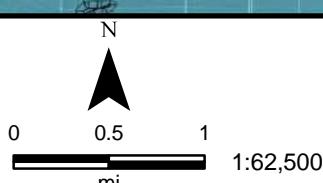
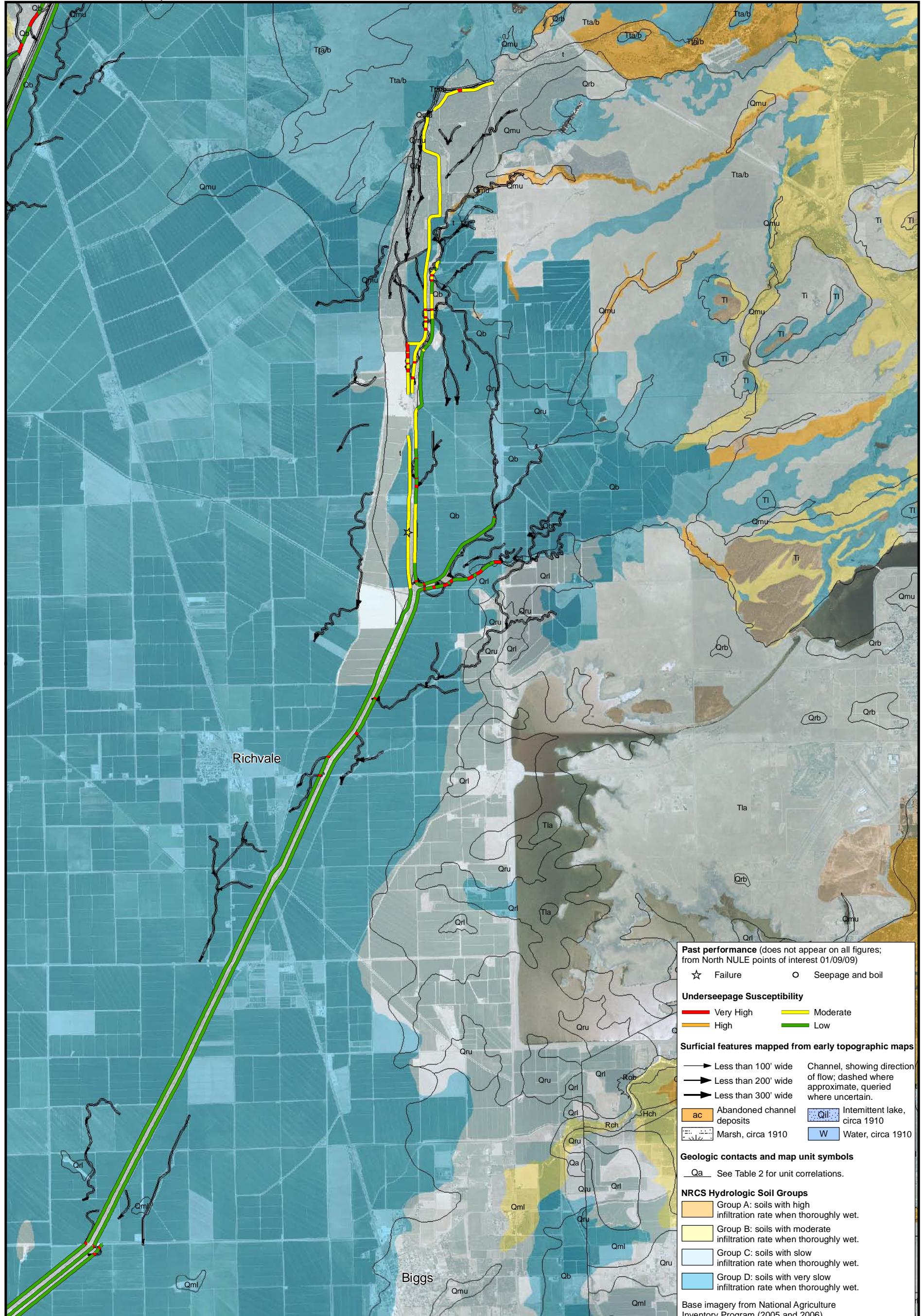
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



**Underseepage Susceptibility Map**

North Non-Urban Levee Evaluations

**Figure 29**



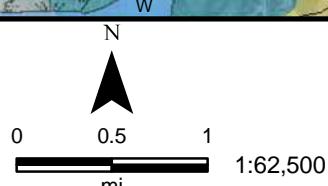
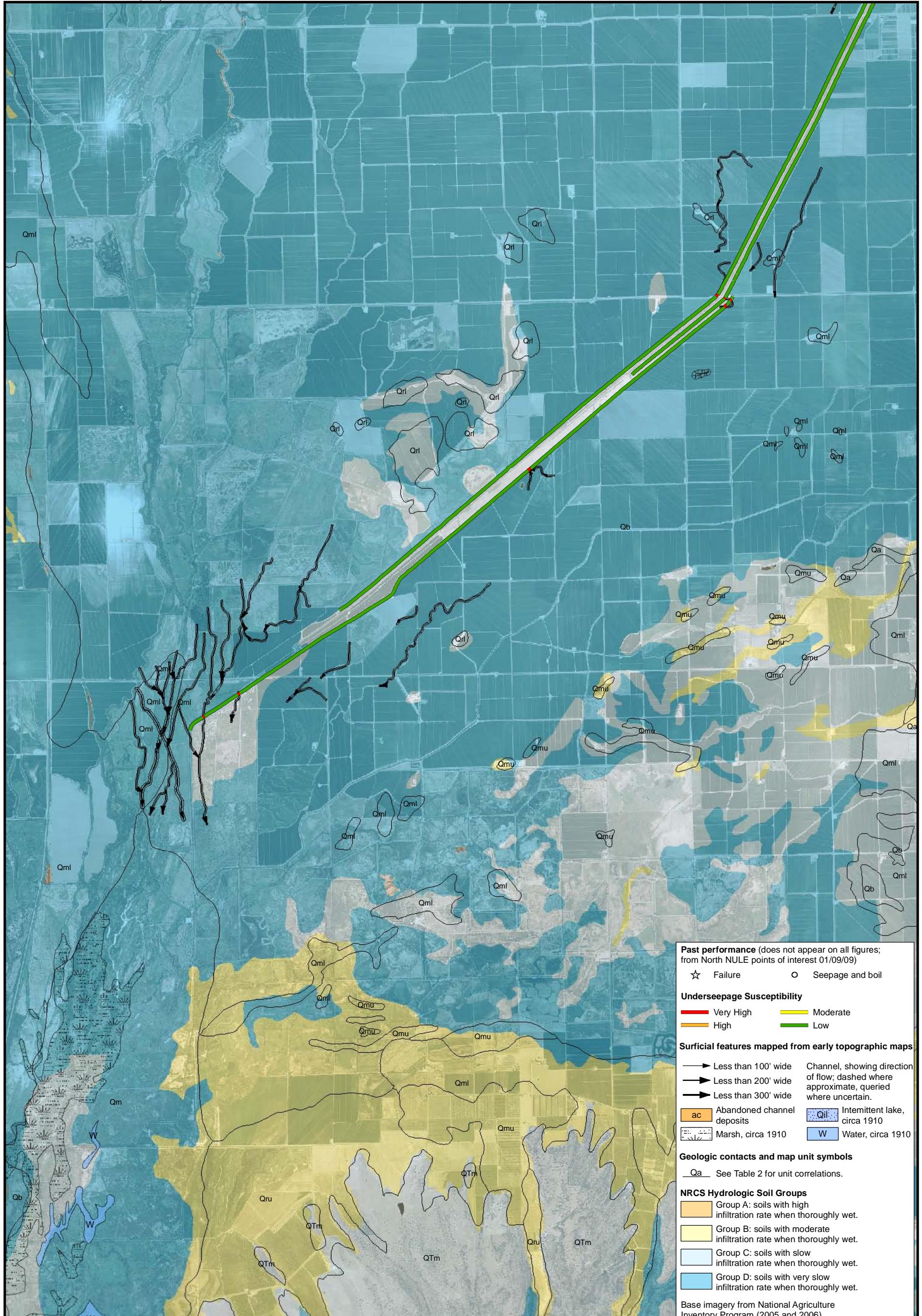
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



### Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure  
30



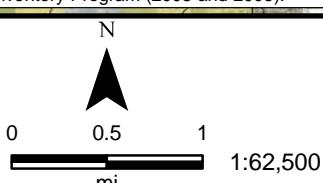
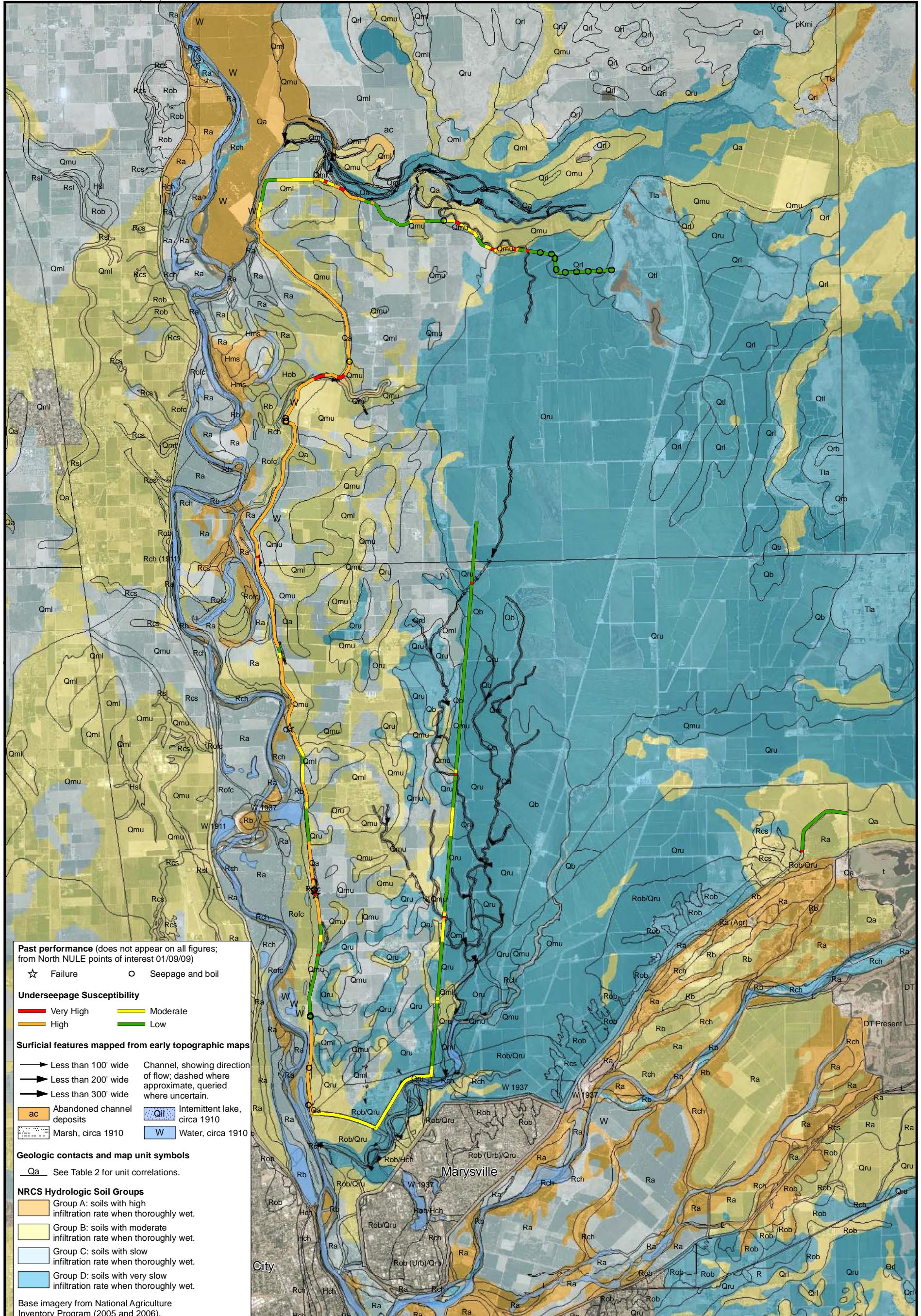
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



### Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure  
31

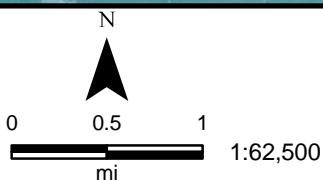
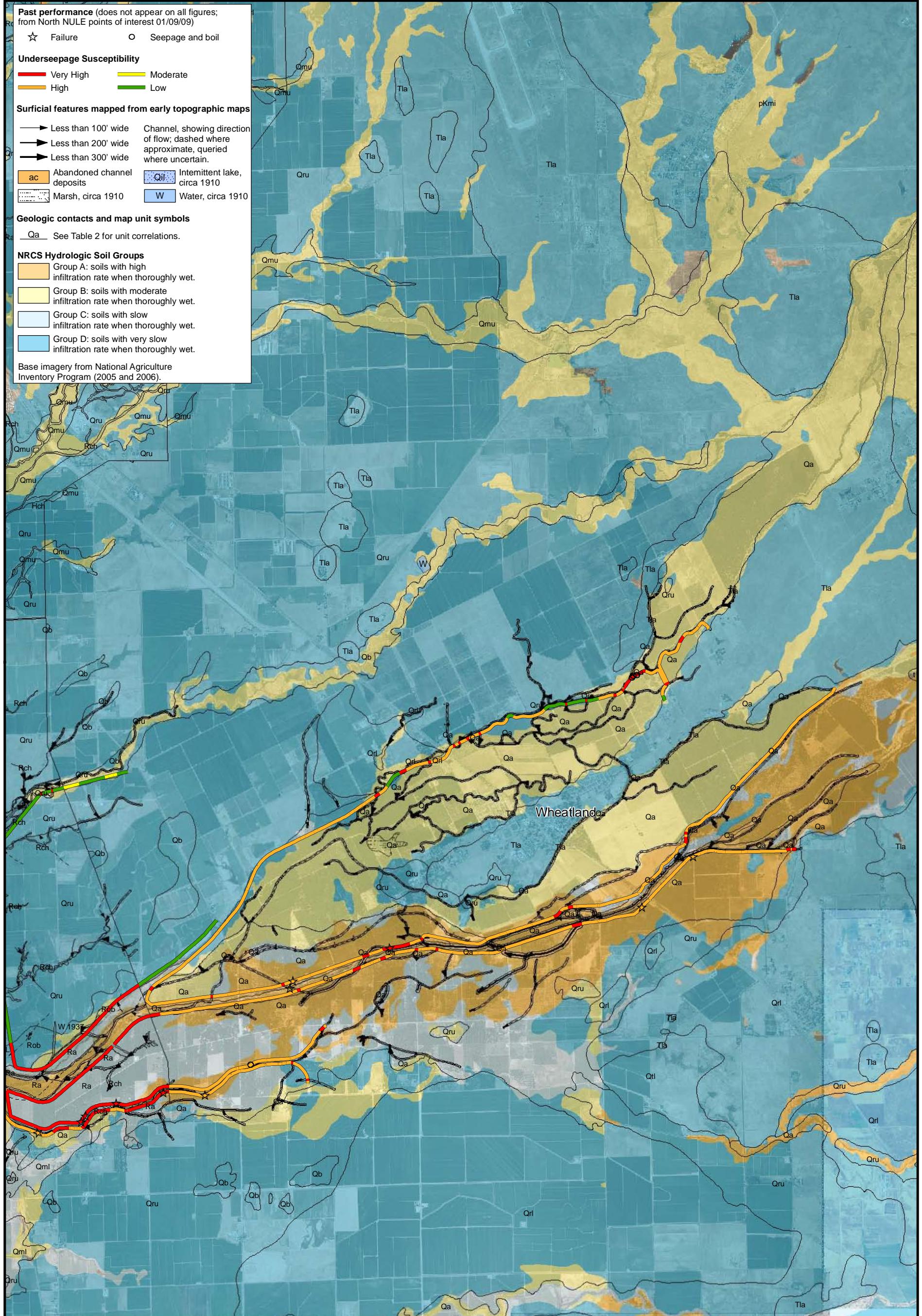


Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



**Underseepage Susceptibility Map**  
North Non-Urban Levee Evaluations

**Figure 32**



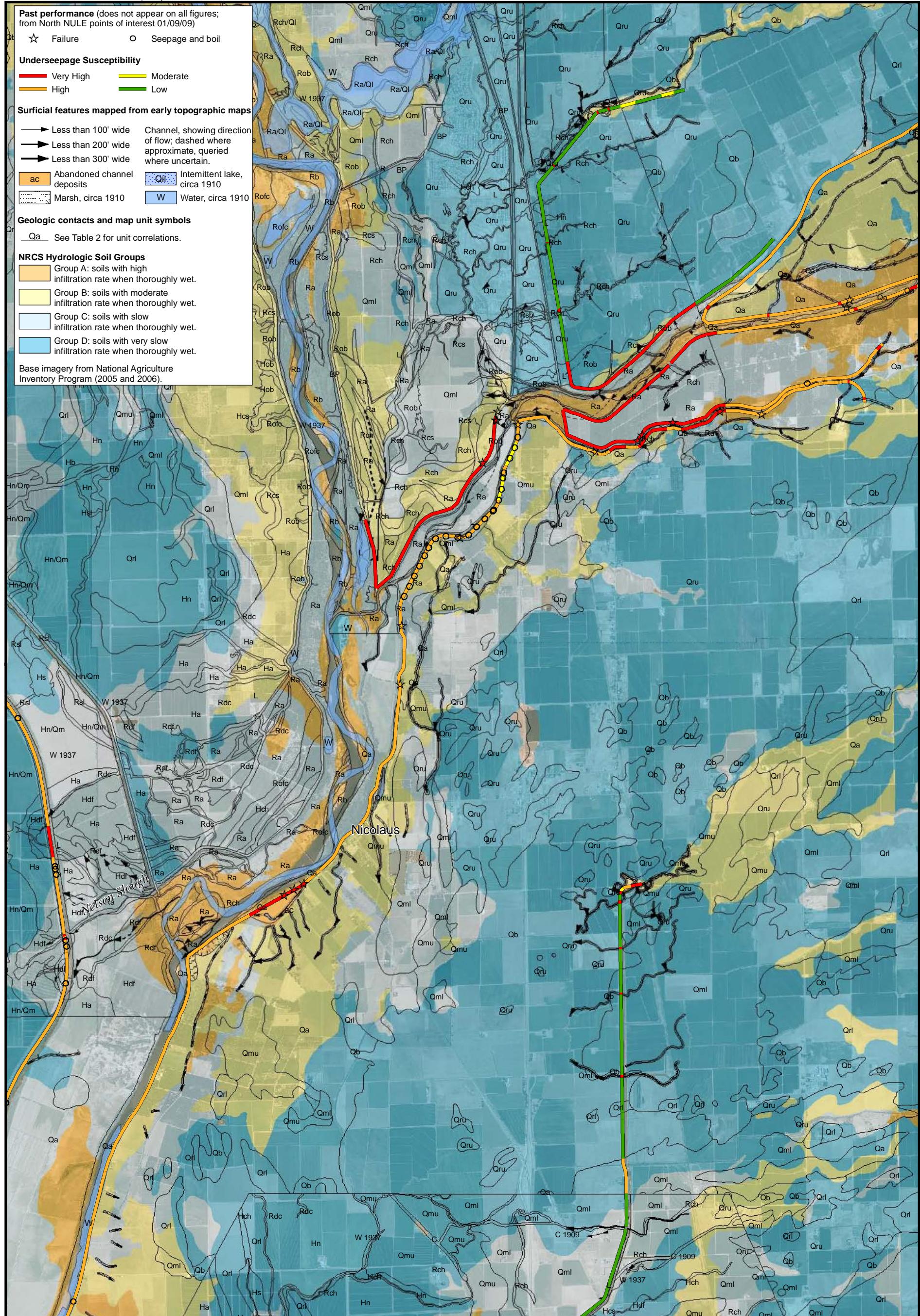
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



**Underseepage Susceptibility Map**

North Non-Urban Levee Evaluations

**Figure 33**



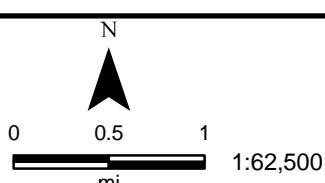
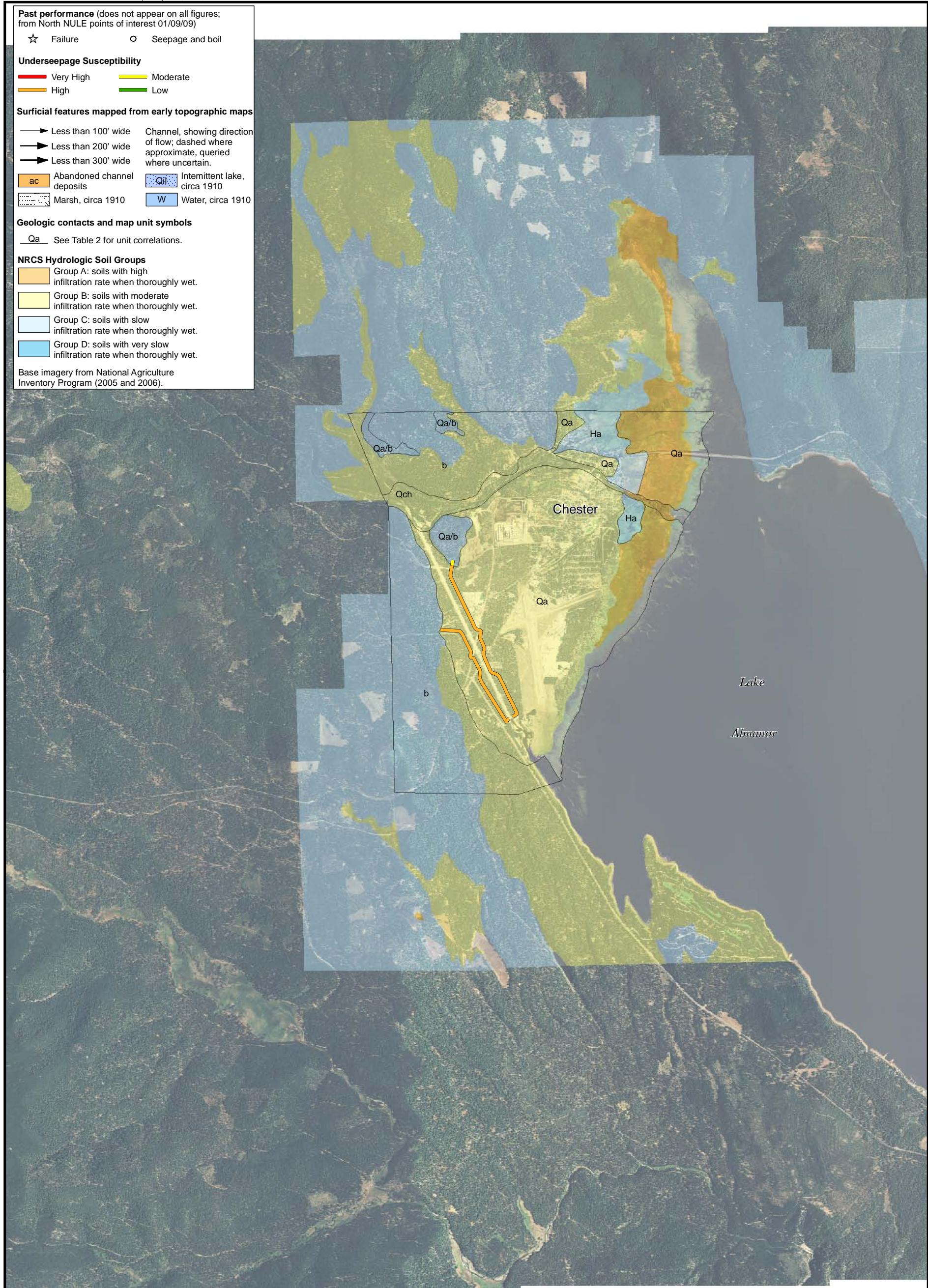
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



## Underseepage Susceptibility Map

## North Non-Urban Levee Evaluations

## Figure 34



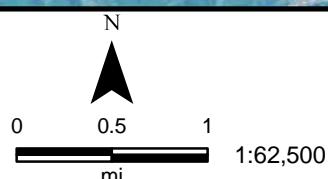
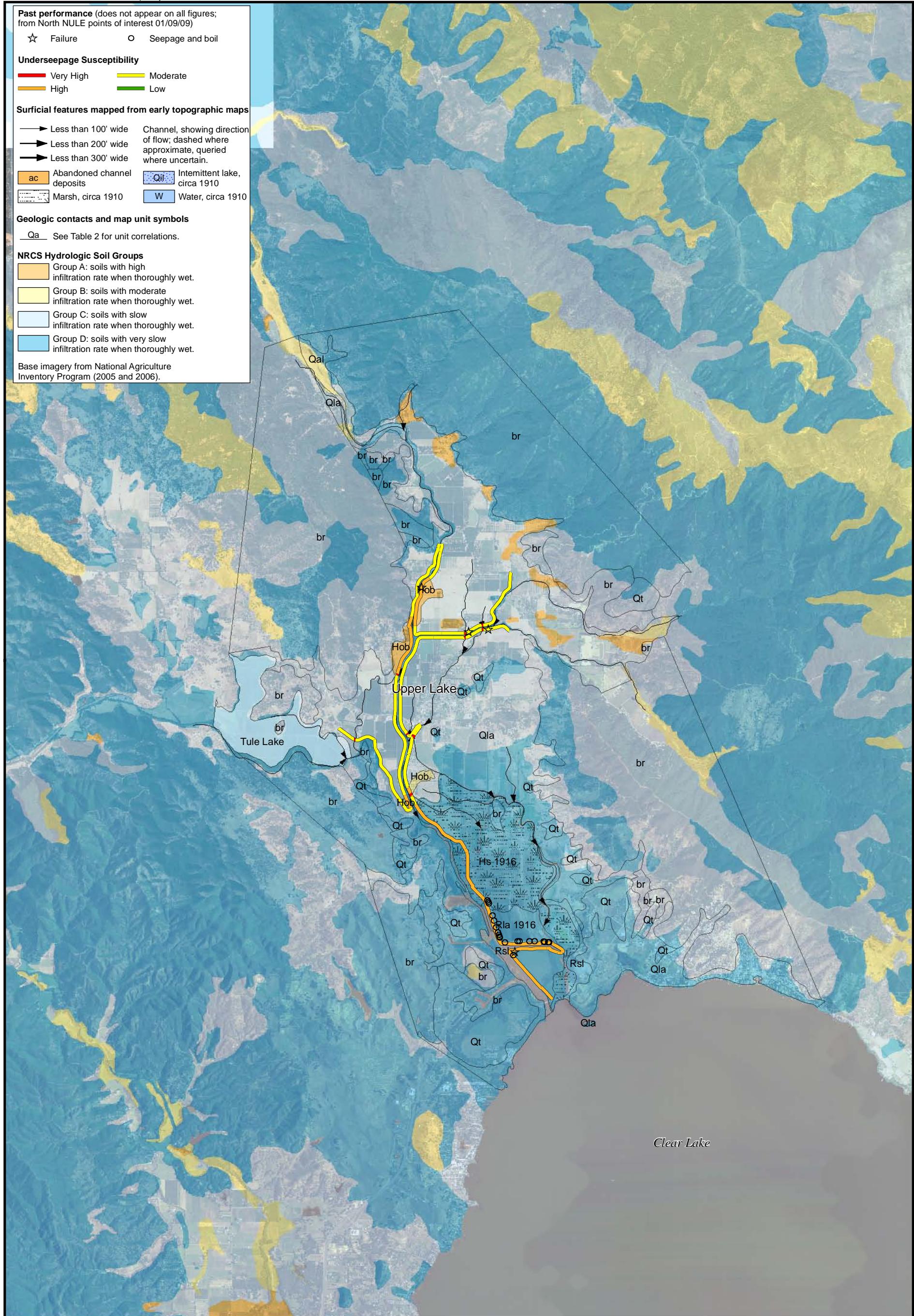
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



**Underseepage Susceptibility Map**

North Non-Urban Levee Evaluations

**Figure 35**



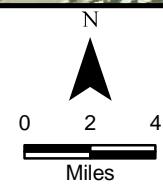
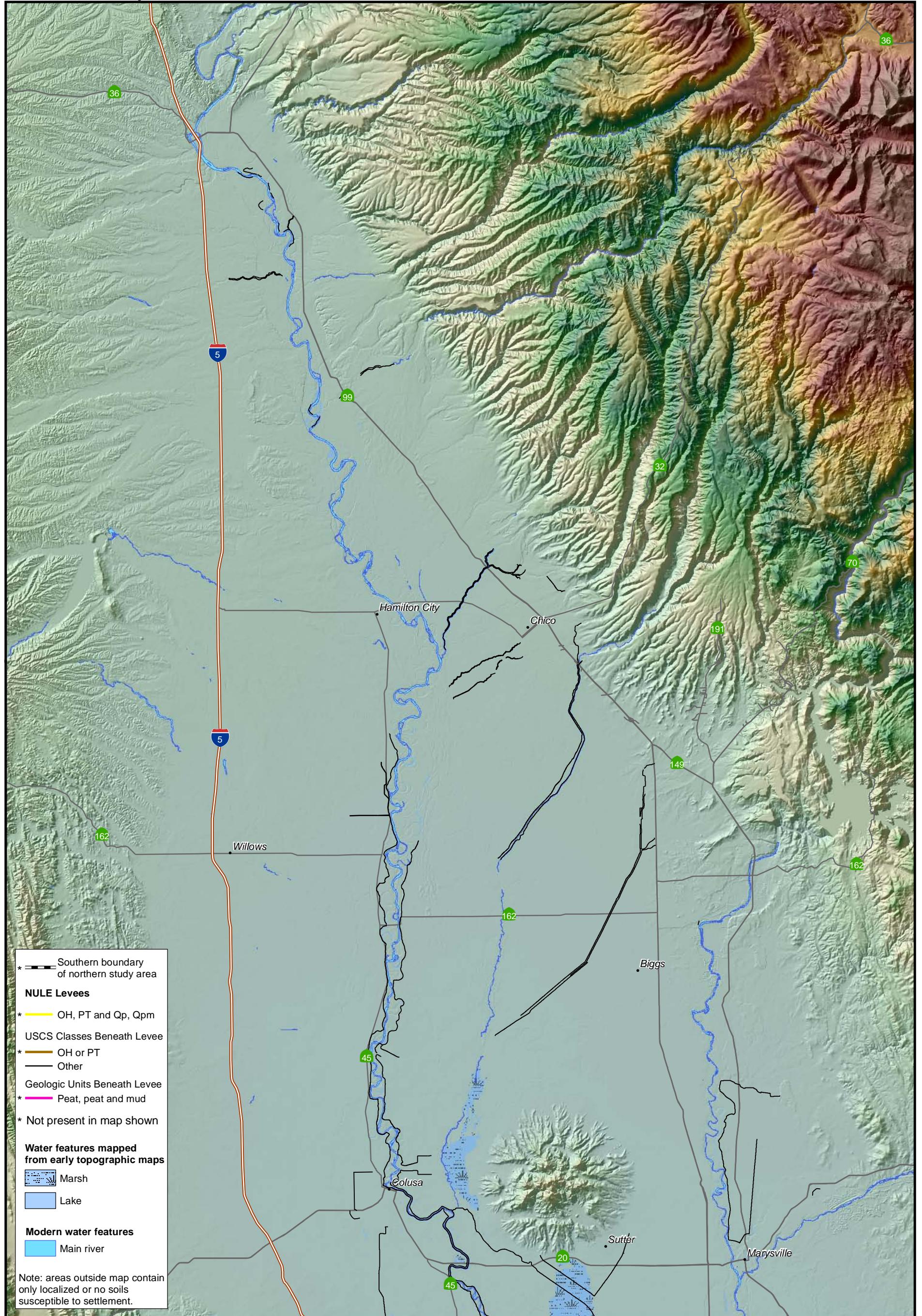
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure  
36



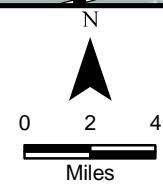
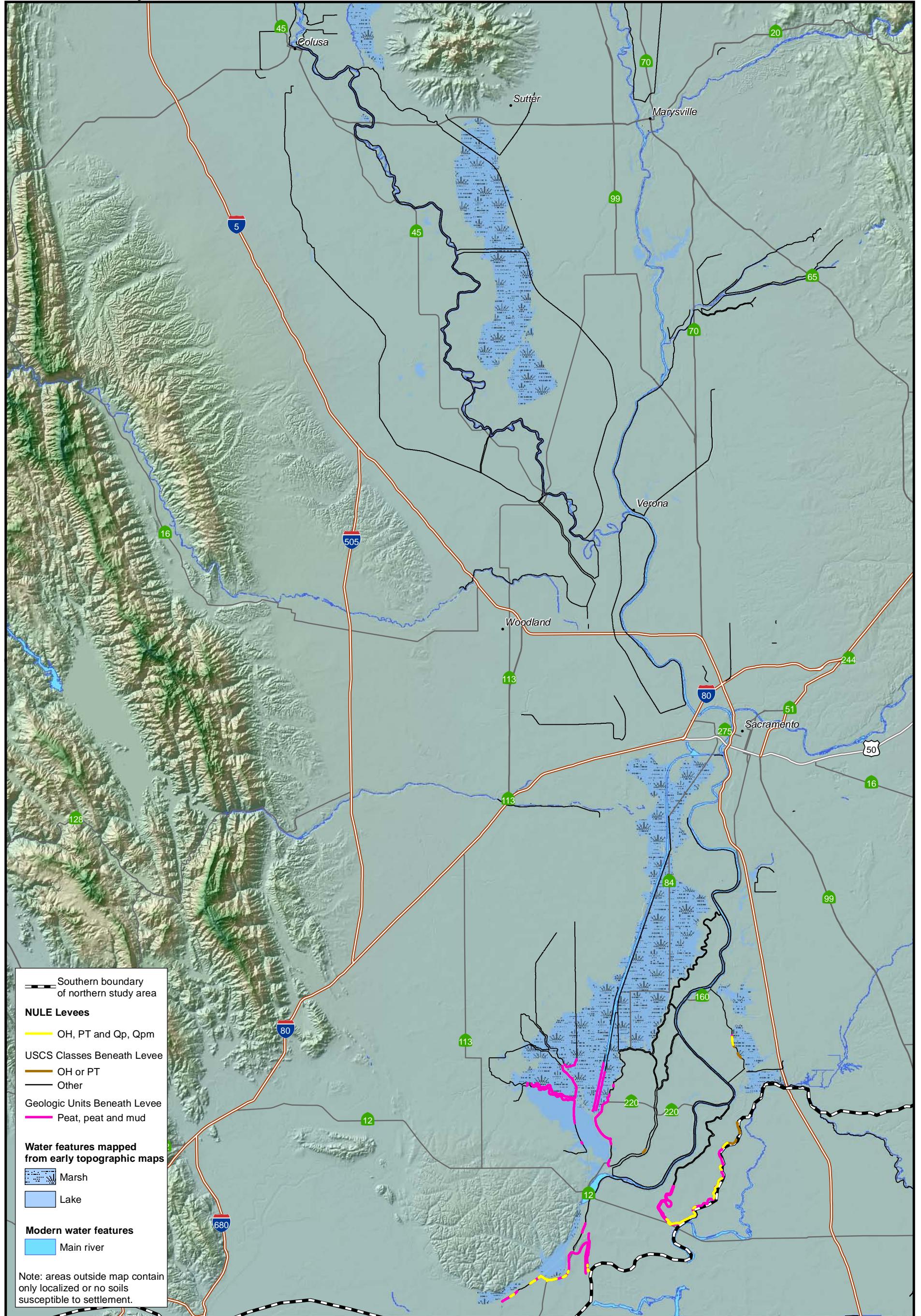
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



Map of Peat Deposits, Organic Soils,  
Historical Marshes and Wetlands

North Non-Urban Levee Evaluations

Figure  
37a



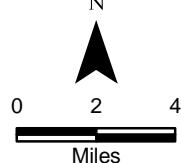
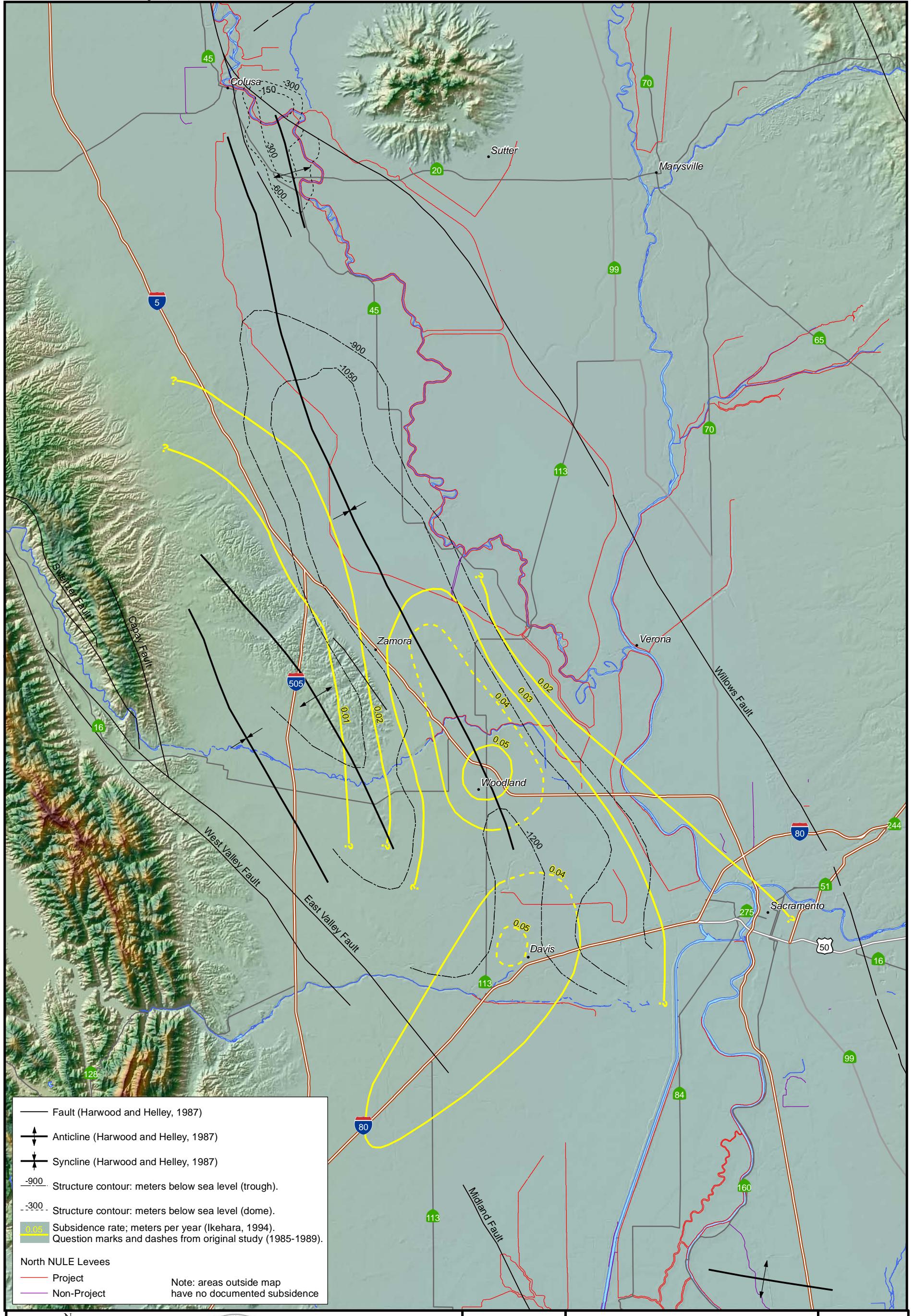
Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



Map of Peat Deposits, Organic Soils,  
Historical Marshes and Wetlands

North Non-Urban Levee Evaluations

Figure  
37b



Department of Water Resources  
Division of Flood Management  
Levee Evaluations Branch



Map of Subsidence with Structural Geologic Features

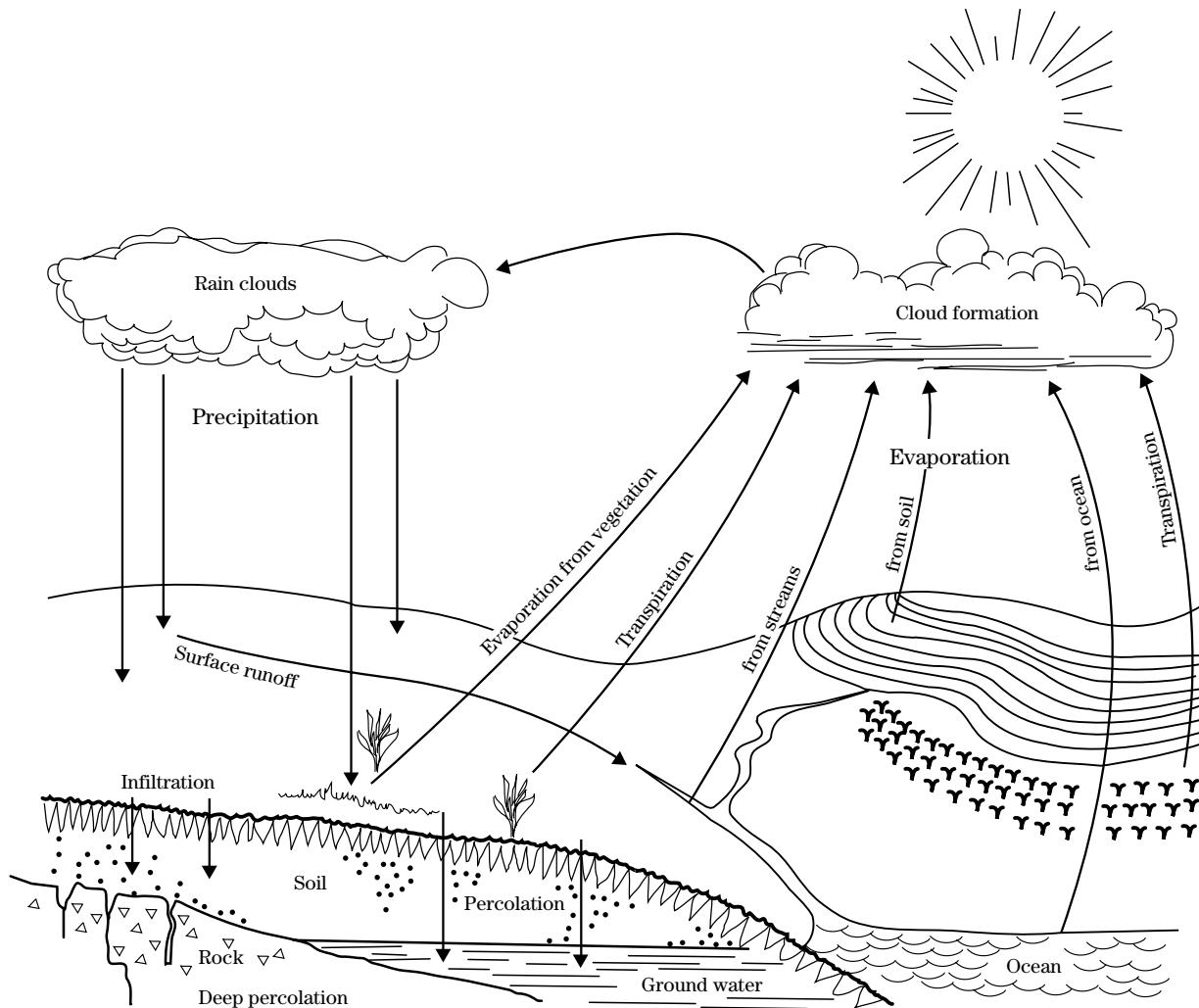
North Non-Urban Levee Evaluations

Figure  
38

**APPENDIX A**

## Chapter 7

## Hydrologic Soil Groups



(210-VI-NEH, May 2007)

---

Issued May 2007

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or a part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, SW., Washington, DC 20250-9410, or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

(210-VI-NEH, May 2007)

---

## Acknowledgments

---

Chapter 7 was originally prepared by **Victor Mockus** (retired) and reprinted with minor revisions in 1972. This version was prepared by the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) under guidance of **Jon Werner** (retired), NRCS; with assistance from **Donald E. Woodward** (retired), NRCS; **Robert Nielsen** (retired), NRCS; **Robert Dobos**, soil scientist, NRCS; and **Allen Hjelmfelt** (retired), Agricultural Research Service. It was finalized under the guidance of **Claudia C. Hoeft**, national hydraulic engineer.



---

## Preface

---

This chapter of the National Engineering Handbook (NEH) Part 630, Hydrology, represents a multi-year collaboration between soil scientists at the National Soil Survey Center (NSSC) and engineers in the Conservation Engineering Division (CED) at National Headquarters to develop an agreed upon model for classifying hydrologic soil groups.

This chapter contains the official definitions of the various hydrologic soil groups. The National Soil Survey Handbook (NSSH) references and refers users to NEH630.07 as the official hydrologic soil group (HSG) reference. Updating the hydrologic soil groups was originally planned and developed based on this perspective.

Listing HSGs by soil map unit component and not by soil series is a new concept for the engineers. Past engineering references contained lists of HSGs by soil series. Soil series are continually being defined and re-defined, and the list of soil series names changes so frequently as to make the task of maintaining a single national list virtually impossible. Therefore, no such lists will be maintained. All such references are obsolete and their use should be discontinued.

Instructions for obtaining HSG information can be found in the introduction of this chapter.



---

<b>Contents:</b>	<b>630.0700</b>	<b>Introduction</b>	<b>7-1</b>
	<b>630.0701</b>	<b>Hydrologic soil groups</b>	<b>7-1</b>
	<b>630.0702</b>	<b>Disturbed soils</b>	<b>7-5</b>
	<b>630.0703</b>	<b>References</b>	<b>7-5</b>

---

---

<b>Tables</b>	<b>Table 7-1</b>	Criteria for assignment of hydrologic soil groups when a water impermeable layer exists at a depth between 50 and 100 centimeters [20 and 40 inches]	<b>7-4</b>
	<b>Table 7-2</b>	Criteria for assignment of hydrologic soil groups when any water impermeable layer exists at a depth greater than 100 centimeters [40 inches]	<b>7-4</b>

---

---

**630.0700 Introduction**

This chapter defines four hydrologic soil groups, or HSGs, that, along with land use, management practices, and hydrologic conditions, determine a soil's associated runoff curve number (NEH630.09). Runoff curve numbers are used to estimate direct runoff from rainfall (NEH630.10).

A map unit is a collection of areas defined and named the same in terms of their soil components or miscellaneous areas or both (NSSH 627.03). Soil scientists assign map unit components to hydrologic soil groups. Map unit components assigned to a specific hydrologic soil group have similar physical and runoff characteristics. Soils in the United States, its territories, and Puerto Rico have been assigned to hydrologic soil groups. The assigned groups can be found by consulting the Natural Resources Conservation Service's (NRCS) Field Office Technical Guide; published soil survey data bases; the NRCS Soil Data Mart Web site (<http://soildatamart.nrcs.usda.gov/>); and/or the Web Soil Survey Web site (<http://websoilsurvey.nrcs.usda.gov/>).

The state soil scientist should be contacted if a soil survey does not exist for a given area or where the soils within a watershed have not been assigned to hydrologic groups.

---

**630.0701 Hydrologic soil groups**

Soils were originally assigned to hydrologic soil groups based on measured rainfall, runoff, and infiltrometer data (Musgrave 1955). Since the initial work was done to establish these groupings, assignment of soils to hydrologic soil groups has been based on the judgment of soil scientists. Assignments are made based on comparison of the characteristics of unclassified soil profiles with profiles of soils already placed into hydrologic soil groups. Most of the groupings are based on the premise that soils found within a climatic region that are similar in depth to a restrictive layer or water table, transmission rate of water, texture, structure, and degree of swelling when saturated, will have similar runoff responses. The classes are based on the following factors:

- intake and transmission of water under the conditions of maximum yearly wetness (thoroughly wet)
- soil not frozen
- bare soil surface
- maximum swelling of expansive clays

The slope of the soil surface is not considered when assigning hydrologic soil groups.

In its simplest form, hydrologic soil group is determined by the water transmitting soil layer with the lowest saturated hydraulic conductivity and depth to any layer that is more or less water impermeable (such as a fragipan or duripan) or depth to a water table (if present). The least transmissive layer can be any soil horizon that transmits water at a slower rate relative to those horizons above or below it. For example, a layer having a saturated hydraulic conductivity of 9.0 micrometers per second (1.3 inches per hour) is the least transmissive layer in a soil if the layers above and below it have a saturated hydraulic conductivity of 23 micrometers per second (3.3 inches per hour).

Water impermeable soil layers are among those types of layers recorded in the component restriction table of the National Soil Information System (NASIS) database. The saturated hydraulic conductivity of an impermeable or nearly impermeable layer may range

from essentially 0 micrometers per second (0 inches per hour) to 0.9 micrometers per second (0.1 inches per hour). For simplicity, either case is considered impermeable for hydrologic soil group purposes. In some cases, saturated hydraulic conductivity (a quantitatively measured characteristic) data are not always readily available or obtainable. In these situations, other soil properties such as texture, compaction (bulk density), strength of soil structure, clay mineralogy, and organic matter are used to estimate water movement. Tables 7-1 and 7-2 relate saturated hydraulic conductivity to hydrologic soil group.

**The four hydrologic soil groups (HSGs) are described as:**

*Group A*—Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures. Some soils having loamy sand, sandy loam, loam or silt loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

The limits on the diagnostic physical characteristics of group A are as follows. The saturated hydraulic conductivity of all soil layers exceeds 40.0 micrometers per second (5.67 inches per hour). The depth to any water impermeable layer is greater than 50 centimeters [20 inches]. The depth to the water table is greater than 60 centimeters [24 inches]. Soils that are deeper than 100 centimeters [40 inches] to a water impermeable layer are in group A if the saturated hydraulic conductivity of all soil layers within 100 centimeters [40 inches] of the surface exceeds 10 micrometers per second (1.42 inches per hour).

*Group B*—Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Some soils having loam, silt loam, silt, or sandy clay loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

The limits on the diagnostic physical characteristics of group B are as follows. The saturated hydraulic

conductivity in the least transmissive layer between the surface and 50 centimeters [20 inches] ranges from 10.0 micrometers per second (1.42 inches per hour) to 40.0 micrometers per second (5.67 inches per hour). The depth to any water impermeable layer is greater than 50 centimeters [20 inches]. The depth to the water table is greater than 60 centimeters [24 inches]. Soils that are deeper than 100 centimeters [40 inches] to a water impermeable layer or water table are in group B if the saturated hydraulic conductivity of all soil layers within 100 centimeters [40 inches] of the surface exceeds 4.0 micrometers per second (0.57 inches per hour) but is less than 10.0 micrometers per second (1.42 inches per hour).

*Group C*—Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Some soils having clay, silty clay, or sandy clay textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

The limits on the diagnostic physical characteristics of group C are as follows. The saturated hydraulic conductivity in the least transmissive layer between the surface and 50 centimeters [20 inches] is between 1.0 micrometers per second (0.14 inches per hour) and 10.0 micrometers per second (1.42 inches per hour). The depth to any water impermeable layer is greater than 50 centimeters [20 inches]. The depth to the water table is greater than 60 centimeters [24 inches]. Soils that are deeper than 100 centimeters [40 inches] to a restriction or water table are in group C if the saturated hydraulic conductivity of all soil layers within 100 centimeters [40 inches] of the surface exceeds 0.40 micrometers per second (0.06 inches per hour) but is less than 4.0 micrometers per second (0.57 inches per hour).

*Group D*—Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential. All soils with a depth to a water impermeable layer less than 50 centimeters [20 inches] and all soils with a water table

within 60 centimeters [24 inches] of the surface are in this group, although some may have a dual classification, as described in the next section, if they can be adequately drained.

The limits on the physical diagnostic characteristics of group D are as follows. For soils with a water impermeable layer at a depth between 50 centimeters and 100 centimeters [20 and 40 inches], the saturated hydraulic conductivity in the least transmissive soil layer is less than or equal to 1.0 micrometers per second (0.14 inches per hour). For soils that are deeper than 100 centimeters [40 inches] to a restriction or water table, the saturated hydraulic conductivity of all soil layers within 100 centimeters [40 inches] of the surface is less than or equal to 0.40 micrometers per second (0.06 inches per hour).

***Dual hydrologic soil groups***—Certain wet soils are placed in group D based solely on the presence of a water table within 60 centimeters [24 inches] of the surface even though the saturated hydraulic conductivity may be favorable for water transmission. If these soils can be adequately drained, then they are assigned to dual hydrologic soil groups (A/D, B/D, and C/D) based on their saturated hydraulic conductivity and the water table depth when drained. The first letter applies to the drained condition and the second to the undrained condition. For the purpose of hydrologic soil group, adequately drained means that the seasonal high water table is kept at least 60 centimeters [24 inches] below the surface in a soil where it would be higher in a natural state.

***Matrix of hydrologic soil group assignment criteria***—The decision matrix in tables 7-1 and 7-2 can be used to determine a soil's hydrologic soil group. Check both tables before making a final decision. If saturated hydraulic conductivity data are available and deemed to be reliable, then these data, along with water table depth information, should be used to place the soil into the appropriate hydrologic soil group. If these data are not available, the hydrologic soil group is determined by observing the properties of the soil in the field. Factors such as texture, compaction (bulk density), strength of soil structure, clay mineralogy, and organic matter are considered in estimating the hydraulic conductivity of each layer in the soil profile. The depth and hydraulic conductivity of any water impermeable layer and the depth to any high water table are used to determine correct hydrologic soil group

for the soil. The property that is most limiting to water movement generally determines the soil's hydrologic group. In anomalous situations, when adjustments to hydrologic soil group become necessary, they shall be made by the NRCS state soil scientist in consultation with the state conservation engineer.

**Table 7-1** Criteria for assignment of hydrologic soil groups when a water impermeable layer exists at a depth between 50 and 100 centimeters [20 and 40 inches]

Soil property	Hydrologic soil group A	Hydrologic soil group B	Hydrologic soil group C	Hydrologic soil group D
Saturated hydraulic conductivity of the least transmissive layer	>40.0 $\mu\text{m/s}$ (>5.67 in/h)	$\leq 40.0$ to $>10.0$ $\mu\text{m/s}$ ( $\leq 5.67$ to $>1.42$ in/h)	$\leq 10.0$ to $>1.0$ $\mu\text{m/s}$ ( $\leq 1.42$ to $>0.14$ in/h)	$\leq 1.0$ $\mu\text{m/s}$ ( $\leq 0.14$ in/h)
	and	and	and	and/or
Depth to water impermeable layer	50 to 100 cm [20 to 40 in]	50 to 100 cm [20 to 40 in]	50 to 100 cm [20 to 40 in]	<50 cm [<20 in]
	and	and	and	and/or
Depth to high water table	60 to 100 cm [24 to 40 in]	60 to 100 cm [24 to 40 in]	60 to 100 cm [24 to 40 in]	<60 cm [<24 in]

**Table 7-2** Criteria for assignment of hydrologic soil groups when any water impermeable layer exists at a depth greater than 100 centimeters [40 inches]

Soil property	Hydrologic soil group A	Hydrologic soil group B	Hydrologic soil group C	Hydrologic soil group D
Saturated hydraulic conductivity of the least transmissive layer	>10 $\mu\text{m/s}$ (>1.42 in/h)	$\leq 10.0$ to $>4.0$ $\mu\text{m/s}$ ( $\leq 1.42$ to $>57$ in/h)	$\leq 4.0$ to $>0.40$ $\mu\text{m/s}$ ( $\leq 0.57$ to $>0.06$ in/h)	$\leq 0.40$ $\mu\text{m/s}$ ( $\leq 0.06$ in/h)
	and	and	and	and/or
Depth to water impermeable layer	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]
	and	and	and	and/or
Depth to high water table	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]

## 630.0702 Disturbed soils

As a result of construction and other disturbances, the soil profile can be altered from its natural state and the listed group assignments generally no longer apply, nor can any supposition based on the natural soil be made that will accurately describe the hydrologic properties of the disturbed soil. In these circumstances, an onsite investigation should be made to determine the hydrologic soil group. A general set of guidelines for estimating saturated hydraulic conductivity from field observable characteristics is presented in the Soil Survey Manual (Soil Survey Staff 1993).

## 630.0703 References

Musgrave, G.W. 1955. How much of the rain enters the soil? *In* Water: U.S. Department of Agriculture. Yearbook. Washington, DC. pp. 151–159.

Nielsen, R.D., and A.T. Hjelmfelt. 1998. Hydrologic soil group assessment. Water Resources Engineering 98. *In* Abt, Young-Pezeshk, and Watson (eds.), Proc. of Internat. Water Resources Eng. Conf., Am. Soc. Civil Engr: pp. 1297–1302.

Rawls, W.J., and D.L. Brakensiek. 1983. A procedure to predict Green-Ampt infiltration parameters. *In* Advances in infiltration. Proc. of the National Conference on Advances in Infiltration. Chicago, IL.

U.S. Department of Agriculture, Natural Resources Conservation Service. 1993. Soil Survey Manual. Agricultural Handbook No. 18, chapter 3. U.S. Government Printing Office, Washington, DC.

U.S. Department of Agriculture, Natural Resources Conservation Service. 1993. National Engineering Handbook, title 210–VI. Part 630, chapters 9 and 10. Washington, DC. Available online at <http://directives.sc.egov.usda.gov/>.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2005. National Soil Survey Handbook, title 430–VI. Washington, DC. Available online at <http://soils.usda.gov/technical/handbook/>.

# **Preliminary Existing Condition Stability, Seepage and Settlement Evaluation**

## **Sacramento River and Georgiana Slough East Levees**

**Community of East Walnut Grove, California**

**California Department of Water Resources Small  
Community Flood Risk Reduction Program**

### **APPENDIX D**

**RD 554 5-Year Plan with Appendices**

# Reclamation District 554

## Five-Year Plan

September 2012



Prepared By:



P.O. Box 929  
Walnut Grove, CA  
(916) 776-2277

Prepared For:  
State of California  
Department of Water Resources  
1416 9<sup>th</sup> Street  
Sacramento, CA 95814

## Table of Contents

Section 1 Executive Summary .....	1-1
Section 2 Brief Flood History of RD 554.....	2-1
Section 3 An Inventory of Assets Protected by the RD 554 Levee System.....	3-1
Section 4 Consequences of a Levee Breach or Failure .....	4-1
Section 5 Future Goals for the RD 554 Levee System.....	5-1
Section 6 Assessment of the Existing RD 554 Levee System.....	6-1
Section 7 Data Collection and Monitoring .....	7-1
Section 8 Identification of Opportunities for Multi Objective Projects .....	8-1
Section 9 Proposed Work to Reduce the District's Vulnerability to Flood.....	9-1

## List of Exhibits/Appendices

### Exhibits

1-1.	Location and Vicinity Map .....	1-3
4-1.	Economic Consequences of a Levee Breach.....	4-5
5-1.	Strategy to Meet the Desired Level of Protection-Project Timeline .....	5-2
5-2.	Strategy to Meet the Desired Level of Protection-Five-Year Budget.....	5-3
6-1.	Levee Assessment Map.....	6-3
9-1.	Five Year Plan Proposed Major Projects.....	9-3
9-2.	Typical Levee Landside Fill and Minor Crown Raising Cross Section.....	9-4
9-3.	Typical Landside Toe Strengthening Cross Section.....	9-5

### Appendices

- A. Five-Year Plan Requirements
- B. Available Data
- C. Levee Crest Elevation Survey
- D. Bathymetric Data
- E. Electromagnetic Data
- F. Five Year Plan Cost Estimation Tables
- G. Drainage Ditch Map
- H. Department of Fish and Game Levee Log
- I. Emergency Response Plan

## Executive Summary

The Five Year Plan document was developed to provide an integrated work plan outlining the anticipated repairs and improvements scheduled for flood protection infrastructure around East Walnut Grove, spanning the five years period commencing 2012-2013. The Plan is required by the Department of Water Resources (DWR) for all Special Projects funding under the Levee Subventions Program Guidelines. As outlined in Attachment A of the Interim Guidelines published by DWR, the Plan must include: history, assets, consequences of a levee breach, and a schedule of the proposed improvement projects.

Reclamation District 554 (RD 554), the upper portion of Tyler island, manages the levee system that protects the eastern portion of the town of Walnut Grove. Walnut Grove is the only community in the Delta that is developed on both sides of the Sacramento River. It was named one of the Delta legacy towns through SB X71, the *California Delta Governance & Planning Bill*, and is considered to be the hub of the Delta. As the districts largest asset, the eastern segment of Walnut Grove houses the primary commercial corridor and the historical residential and commercial districts. The upper portion of Tyler Island has never flooded since Walnut Grove was founded and the reclamation district was established in the late 1800's. The Delta Cross Channel and stretch of Georgiana Slough that border RD 554 are part of the State Water Project (SWP) and act as aqueducts to send fresher water to the pumps in Tracy. Any type of failure of this system could degrade water quality and disrupt the State Water Project.

If a flood were to occur in this district, one third of Walnut Grove residents and most of the community's businesses would be adversely affected. RD 554 is separated from the rest of Tyler Island by a dry cross levee along Old Walnut Grove Road. If one of the main levees bordering the waterways were to fail, the district would likely breach the cross levee to reduce the impact on eastern Walnut Grove, and thereby flood lower Tyler Island. This would increase the economic consequences associated with a break on RD 554 to include losses on the rest of Tyler Island.

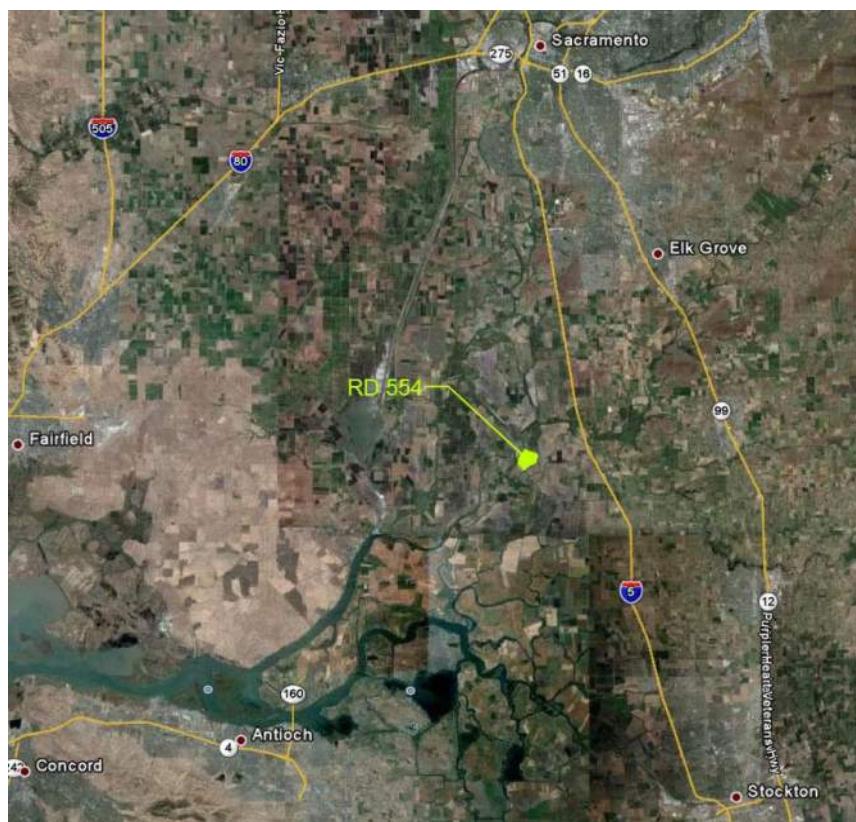
This report uses the 1972 flood of Brannan-Andrus Island to gauge inundation time since Tyler Island is somewhat similar in size and location in the Delta. It took 8 weeks to pump out Brannan-Andrus after the levee break. The higher elevations on the northern end were dry in four weeks followed by the lower south end. In light of this information, this report assumes an average 5-week inundation period for the entire island but only five days on RD 554, to determine flood-related costs. Flood-related costs would be those associated with business and resident displacement, as well as production loss from business and infrastructure closures. Based on the PPIC report, *Comparing Futures for the Sacramento-San Joaquin Delta: Technical Appendix B*, we estimate the average cost to repair a levee breach and pump out the island is 25 million. Costs associated with inundation were derived from the *Delta Risk Management Strategy, Economic Consequences Technical Memorandum*.

On Tyler Island (including RD 554), the estimated cost per day of inundation could be \$185,000, with a one time displacement cost of \$2.1 million. If a flood event were to occur before February to October, delaying planting, it is assumed that all crops will be lost for the year. The economic impact of this could be approximately \$78.4 million. This figure includes crop production losses for the year, crop reestablishment

costs, the costs per day multiplied by the assumed inundation period, and the estimated cost to repair the breach.

Reclamation District 554 considers protection of the eastern portion of Walnut Grove from inundation a high priority. To do so, the levees need to continue to meet FEMA's urban levee design standards and with the exception of a small area on Snodgrass Slough, the trustees believe the levees do meet FEMA requirements. From surveys and visual inspection there are a few areas along the Snodgrass Slough levee crown that need minor raising. Also reaches along Snodgrass Slough and the cross levee have landside slope deficiencies. In 2008-09 the engineering effort to design a stability upgrade was authorized. That effort is only now getting underway because of project budgeting delays and setbacks. If mitigation is needed for the planned levee improvement project, there are on-island habitat creation opportunities near the base of the TV transmission tower and a decommissioned sewer pond site.

RD 554's future goal is to maintain or exceed the FEMA Urban levee standard. The following plan determines the schedule of work and the financing for levee improvement work to be done in the upcoming five years.

**Exhibit 1-1: Location and Vicinity Map**

## Brief Flood History of RD 554

Reclamation District 554 protects the urban, eastern side of Walnut Grove, 374 acres of cropland, and the Walnut Grove Marina service area. Walnut Grove was established in 1850 by John Sharp and became a thriving agricultural center and shipping port by 1865. The levee district was established August 25, 1893. There has never been a levee failure or flood event since the inception of Walnut Grove or RD 554.

In 1986, lower Tyler Island flooded and threatened to flood RD 554. At that time, an effort was undertaken to enhance the cross levee height by adding a berm on the lower Tyler side of the levee to insure that the urban area did not get flooded. The added height was not necessary when the water crested but the emergency construction paved the way for the more permanent configuration that exists today. That levee upgrade then led to a successful LOMAR for eastern Walnut Grove and its Zone 'X' determination in 1987.

## An Inventory of Assets Protected by the RD 554 Levee System

Reclamation District 554 is the upper 452-acre portion of Tyler Island that is separately protected by 3.58 miles of levee. The district includes the east Walnut Grove urban area. It is the only town in the Delta that is interdependent and occupies both sides of the Sacramento River. The main commercial corridor is on this side of Walnut Grove along with the main sewer collection system and key government services. But the majority of the land use on this small district is rural/agricultural since the urban area is only 77 acres.

RD 554 is bordered by Sacramento River, Georgiana Slough, Snodgrass Slough, the Delta Cross Channel, and the cross levee between RD 554 and RD 563 (lower Tyler Island). Levees along the Sacramento River, Georgiana Slough, and the Delta Cross Channel are federal project levees (1.6 miles). The Cross Channel, Snodgrass Slough, and the cross-levee are non-project levees (1.98 miles), but are still held to the project levee standard. Reclamation District 554 manages levee inspections, levee maintenance, and two pumping stations on the island. The pumping stations are both located along Snodgrass Slough. See Appendix G for drainage ditch and pumping station locations. The standard island elevation is about +2.0' with a minimum elevation of --1.0' and a maximum of +11.0' NAVD88.

With the adoption of the Delta Protection Act in 1992, Walnut Grove was placed in the Primary Zone of the legal Delta, which was established to protect the agriculture, wildlife habitat, and recreation uses within the Delta. The urban footprint of East Walnut Grove has grown about one-third more than its original size since the early 1900's. There are approximately 77 acres of developed land with a population of about 300. In this area, there are three nationally registered historic districts, the Walnut Grove Chinese and Japanese American Historical Districts, and the Walnut Grove Commercial/Residential Historic District. There are three nationally registered historical buildings, Guaken Hall, The Imperial Theatre, and the Jean Harvie Community Center. See Figure 2 for locations (California-Sacramento County-Historic Districts).

Sacramento County zoning designates low density residential along the Sacramento River, intensive and extensive industrial along Walnut Grove-Thornton Road/J11, and cropland on the rest of the island. There are about 127 residential structures ranging from single family units to multi-family (5 to 9 units) (URS - Impact to Infrastructure Table 7-1a). Institutional buildings include: a church, fire station, sheriff sub-station,

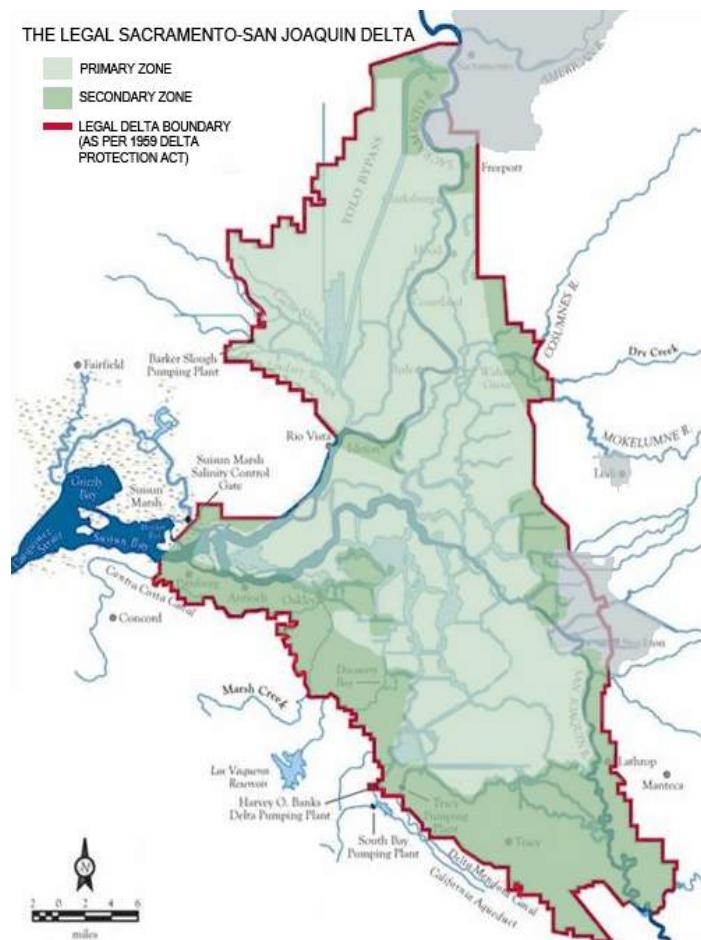


Figure 1 – Map of the legal Delta. Source: Delta Protection Commission

elementary school, library, and post office. The island supports 37 businesses including the Bank of Rio Vista and one major marina, Walnut Grove Marina, on Snodgrass Slough. This marina has 201 berths, storage, and RV/camping facilities. Along the Sacramento River are two side-tie docks one private and one for public use. Each dock is about 250' in length. There is also one public fishing access area located by the bridge along the cross channel.

Agriculture takes up the majority of land area on RD 554, about 375 acres. The crop breakdown is as follows:

<u>Crop</u>	<u>Acreage</u>
Corn	200
Field Crops (safflower, wheat)	100
Vineyard	75

*\*Note: Acreage varies each year. The acreage above is taken from crops grown in 2011.*

On lower Tyler Island the crop breakdown is as follows:

<u>Crop</u>	<u>Acreage</u>
Corn	3,277
Alfalfa	2,037
Vineyard	1,593
Rice	392
Truck Crops	395
Tomato	618

*\*Note: Acreage varies each year. The acreage above is taken from DRMS Economic Consequences report.*

RD 554 levees protect the east portion of Walnut Grove and some critical structures that serve the entire community and outlying areas. Walnut Grove/Thornton Road/J11 spans a little over a mile on RD 554 to serve as a connection from Walnut Grove and Highway 160 to Interstate 5. Also, as previously mentioned, the Sacramento Area Sewer District's sewer line that serves both east and west Walnut Grove is located on RD 554.



Figure 2 – Historic Sites – Walnut Grove

Due to the urban nature of RD 554 there are only a few areas of freshwater wetland, upland, and riparian habitats. The size of the island and development that has taken place over time, has resulted in mostly ruderal vegetation. See Figure 3 for a map of vegetation types. According to the Department of Fish and Game Levee Log (Appendix H), riparian, scrub shrub, and freshwater marsh habitat types exist on and adjacent to the levees. The estimated amount of each type of habitat per lineal foot is:

	Waterside	Landside
Riparian	2223 lf (3.66 ac.), 29 single trees	1710 lf (1.35 ac.), 15 single trees
Scrub Shrub	880 lf (0.62 ac.), 23 single trees	1700 lf (1 ac), 40 single trees
Freshwater Marsh	1229 lf (0.37 ac.)	0 lf

(Note: These estimates are for non-project levees comprising the location of proposed projects in this plan.)

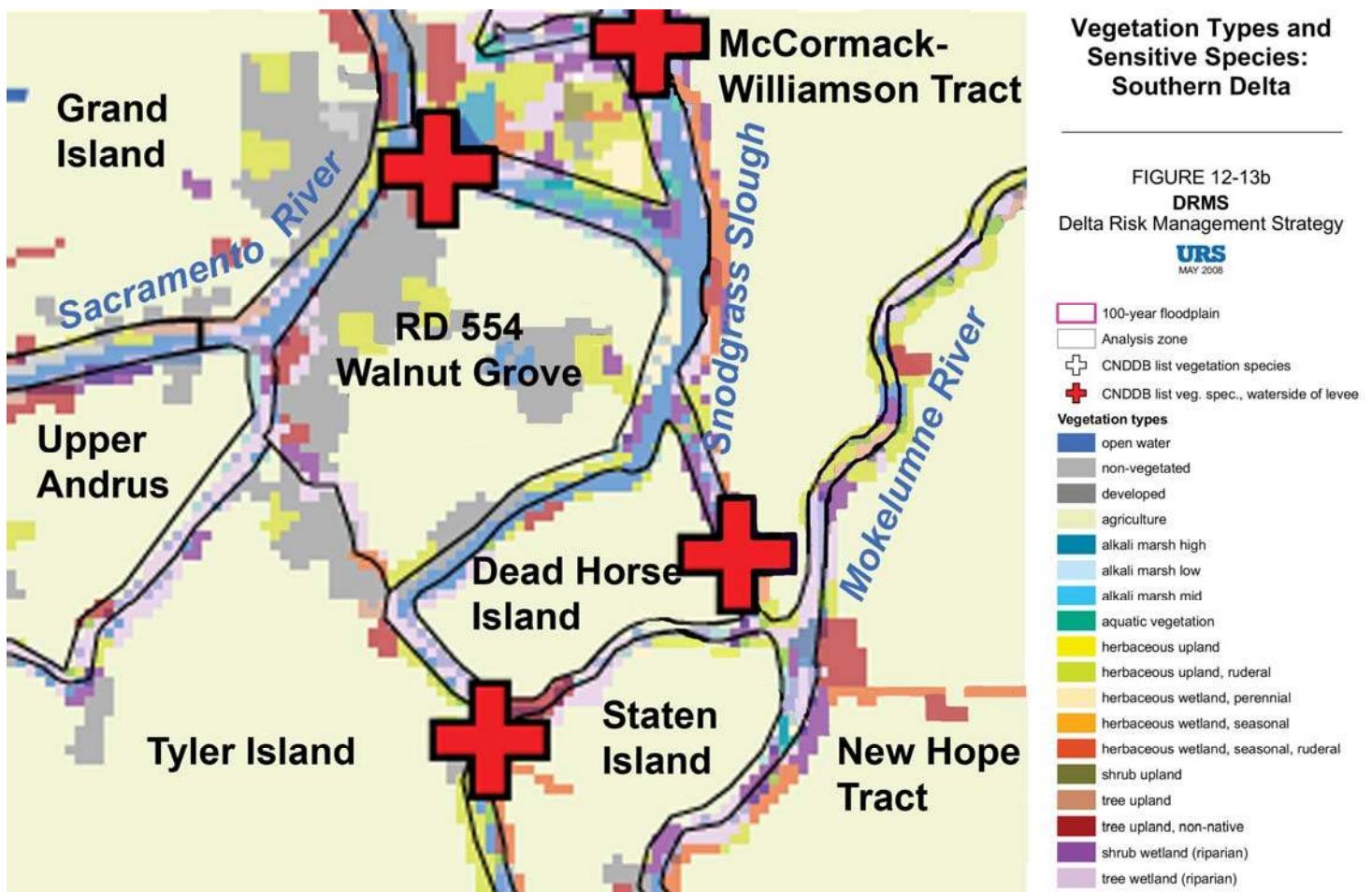


Figure 3 – Vegetation Map Source: URS [May 2008]

## Consequences of a Levee Breach or Failure

To repair a levee breach and pump out the island the average cost has been estimated to be approximately \$25 million. But the total truly depends on access, the size and severity of the breach, volume of water to be pumped out, weather conditions, etc. The \$25 million figure assumes costs for \$5/cuyd of on-island replacement fill, 15/cuyd of off-island fill, 6% per linear foot of engineering costs, and \$5/foot for rip rap (Suddeth 25). The Jones Tract failure in 2004 is the most recent levee failure to provide insight into determining what a levee breach could cost today. It has been publicized that the 500-foot levee breach cost approximately \$90 million for the repair, recovery, and associated damage (Suddeth 2). Many knowledgeable locals consider that figure inflated by as much as a factor of two.

Not only would a breach inundate RD 554, it would overtop (or by an intentional breach) the dry cross levee and flood the rest of Tyler Island. Flood waters would flow down to the lower part of the island since it is at a lower elevation than RD 554. The lowest elevation on the southern part of Tyler Island is -15.0 feet (NAVD 88) according to the LIDAR survey supplied by DWR. By the same survey, the lowest elevation on RD 554 is -1.0 feet. As a result, this report also includes the costs of inundation of lower Tyler Island's assets into the total cost of a breach on RD 554.

### *Residential*

According to 2000 Census data and the *Delta Risk Management Strategy (DRMS)* the population on RD 554 is approximately 300, with 177 residential units. It is assumed that 65% or 115 households are expected to be occupied. On lower Tyler Island the population is approximately 80, with an assumed 18 occupied households (URS A-1-2). Inundation of the structures will not only damage the structure and possessions therein but also will displace the residents. The costs associated with inundation are taken from FEMA's method for estimating displacement. This includes a one-time cost of \$500 per flooded household, a cost of \$500 per month of inundation per household, and a monthly rental cost of \$747.

For RD 554, it is estimated that there could be a one-time displacement cost of \$57,500 for all occupied households along with an additional \$4,780 per day to house these residents elsewhere. On lower Tyler Island, the estimated one-time displacement could be \$9000 and an additional \$756 per day. The Walnut Grove Marina adds a transient population that is difficult to quantify since there are no statistics covering that element to determine associated costs. Furthermore, this number would fluctuate with the seasons. To house this population in emergency shelters it is estimated to cost \$85 a day (URS 8). As there would be sufficient time to evacuate, the costs to accommodate this unique group of part-time residents may not be significant. But the marina would be shut down until the island was pumped out.

### *Commercial*

Commercial structures will be adversely impacted from the time they are inundated through the time it takes to repair such damage and damage to surrounding infrastructure. There are about 48 businesses on the all of Tyler Island. Any business flooded assumes a one-time displacement cost of \$1000, for an estimated total of \$48,000 (URS 11-12). Upon inundation, the businesses are assumed to have \$74,000 of lost output value, \$3,700 of lost profit, and \$22,200 of lost value added per business day (URS A-26). "Value added" is the sum of wages and salaries, proprietor's incomes, other property income, and indirect business taxes (URS 67). It is estimated that 33 jobs could be lost per day over the duration of inundation.

Overall, a flood could cost Walnut Grove and Tyler Island businesses an estimated \$113,000 per day (URS A-26). Some businesses may be unable to recover from a flood and could possibly be lost as the result of a flood event. Even west side residents and business would be affected because the sewer service may have to be curtailed.

### ***Agriculture***

Crops grown on Tyler Island are generally alfalfa, wheat, corn, pears, truck crops, tomatoes, rice, and wine grapes. This plan used the *DRMS* data sources to assess the cost affects on agriculture from a levee failure. Agriculture losses from floods result in: permanent crop loss, field clean-up and rehabilitation, and annual production losses. Tyler Island has a total of 8,687 acres of crops listed above (see Exhibit 4-1 for acreage/cost of individual crops). According to the *DRMS* report, the average cost for rehabilitation and field clean up is \$235 per acre. This involves the removal of debris and sediment deposits after floodwaters have receded. Silt and debris can also clog drainage and irrigation ditches adding a variable cost to rehabilitation. The estimated total one-time cost for clean-up and rehabilitation is estimated to be \$2.7 million. If inundation lasts longer than 14 days, it is assumed that the crops will be permanently lost. Any flood event that occurs between planting and harvest, could completely destroy the crops.

Reestablishment of a lost crop dramatically increases economic losses.

The inundation period is assumed to be five weeks on lower Tyler Island, meaning all crops on the lower end could potentially be lost in a flood event. However, due to the smaller size of RD 554 and an assumed inundation period of five days, not all crops may be lost. Crop establishment costs are estimated as follows: \$407/acre for alfalfa, \$545/acre for field crops, \$1,432/acre for truck crops, \$977/acre corn, \$9,200/acre for pear orchards, \$2,440/acre for tomato, \$392/acre for rice, and \$13,402/acre for vineyards (University of California 2011). Not including clean-up costs, reestablishment of all crops on the island could total an estimated \$29 million.

In addition to reestablishment costs, a flood event will cause annual crop production losses that would be dependent on time needed for clean up, when and how long inundation occurs, and time required for the crops to produce a harvestable yield. As previously mentioned, if a flood occurs before planting or harvesting, it will be lost for the year. This report adds two months before planting season for dewatering, clean up, and rehabilitation before planting preparation can begin. Planting on Tyler Island cannot occur after April and harvest begins in October. As a result, the critical flood season for crops really occurs between February and October (URS 17). This report uses gross annual crop returns per acre only. Operating and overhead costs are not included, as these costs can vary depending on individual farm operations and production (URS Economic Consequences 17).

On all of Tyler Island crop re-establishment costs, which require field clean up and replanting, are estimated to be \$29 million. This figure is largely variable as production costs are tied to projected yields based on inundation periods. If an event occurs between February and October, pushing the planting to the following year, annual production losses could be about \$15.1 million. Not included in these costs is the cost of farm equipment that could be lost in a flood. For example, the cost of equipment involved in alfalfa production is about \$20,000. This cost, however, would be difficult to quantify because the equipment could be moved to higher ground or could be used for multiple crops (UC Davis). Overall, a flood event occurring between February and October could cost the agricultural sector approximately \$46.1 million.

Degraded water quality from salinity intrusion can also reduce crop yields. Not all crops respond to salinity levels in a similar manner, some crops can produce acceptable yields at a much greater salinity level. According to the *DRMS* report if a 3-levee breach scenario were to occur in the south western islands of Brannan-Andrus, Sherman, and Bacon Islands the Low Salinity Zone (0 – 2.2 ppt) gradient is expected to move up to lower parts of Brannan-Andrus Island in a 3-levee breach scenario with failures on Brannan-Andrus, Sherman, and Bacon Islands. It is unlikely that any substantial amount of salt water will reach this area, if so the crops most likely affected would be pears, corn, and tomatoes.

### ***Water Quality***

Due to the urban nature of a portion of RD 554, a flood could release household and commercial chemicals potentially contaminating the surrounding waterways. A flood could also suspend sediment, metals, fertilizers, and pesticides that are attached to soil particles. Increased sedimentation of the waterway can reduce the amount of sunlight to reach submerged aquatic plants and also smother fish larvae and harm fish by clogging their gills. The extent of the affects on fish and aquatic species from suspended sediment and chemicals depend on the quantities of pollutants, amount of dilution, and frequency of freshwater releases (Section 12 12-13).

Besides those listed above, other potential in-island pollutant sources could degrade water quality on the island and in the waterways. A long inundation period could create anoxic conditions in the soil can release toxic substances, such as manganese that is naturally occurring but can be dangerous to health in high concentrations. Other toxic substances such as, organochlorine “legacy” pesticides that, although have been banned for over 20 years, slowly degrade in the environment and can still be present in soils where it was applied. This can have harmful affects on fish species in terms of reducing food production, namely a primary producer, phytoplankton if released into the waterway (Section 12-14). Although not harmful in small traces, “legacy” pesticides can become more concentrated through bioamplification and not only harm fish species but terrestrial and avian species as well.

### ***Infrastructure***

Levee failure on Reclamation District 554 could cause direct physical damage to the island’s infrastructure. If a break was to occur in the north inundating Walnut Grove/Thornton Road/J11, it would disrupt the island’s connection to Highway 160 or 1-5, delaying up to 1,500 trips. The cost due to lost trips is small but the estimated time delay could cost \$48,000 per day, \$53,000 if 10% are assumed to be truck trips. Walnut Grove’s surface streets could be inundated affecting the area on a local level by removing access to the town’s businesses and services. This cost and trip data was obtained from *the DRMS Technical Memorandum on Economic Consequences*. To determine economic impacts from road inundation and closure, the report used increased travel time and expense for person to go an alternate route, increased congestion on alternate routes, lost trips, and business costs related to delays. The cost analysis assumes a cost of \$13.45/hour for lost auto trips and \$71.05/hr for lost truck trips.

The district also houses a FM radio and television transmission tower with support facilities serving KOVR, KXTV, and KQCA. This 2049' tower currently serves the Stockton-Sacramento-Modesto broadcasting area stations and radio stations (Fybush). The transmitter building is on stilts so the equipment will not be

affected in a flood. But a flood could still restrict maintenance access to the building, and potentially interfere with broadcasting if there is a lengthy power disruption.

RD 554 levees form a portion of the State Water Project (SWP) that runs through the Delta. Delta Cross Channel and Georgiana Slough flows feed the San Joaquin River which flows directly to the SWP pumps in the south of the Delta. A RD 554 levee failure could disrupt the flows in these channels, and flows into the San Joaquin River, and ultimately to the State Water project, depending on the timing when such an event occurred.

Overall, residential, commercial, agriculture, and infrastructure losses due to a flood event on all of Tyler Island could cost approximately \$185,000 per day. The one-time/direct cost of the event to relocate the residents and businesses and reestablish cropland would be around \$2.2 million. Assuming an inundation residence period 5 days on RD 554 (upper Tyler) a flood event there could cost approximately \$1.6 million. Lower Tyler with an assumed inundation residence period of 5 weeks (35 days), a flood event could cost approximately \$27.2 million of direct and indirect costs. These figure includes daily losses to residents and business, one-time costs of displacement, rehabilitation costs of cropland, and reestablishment and annual production loss costs for vineyards and orchards. A flood event occurring between February and October, that would delay planting until the next season and is assumed to kill all crops, could add up to approximately \$78.3 million of direct and indirect costs for both districts. This figure includes the estimated costs associated with repairing the breach and pumping out the islands, about \$30 million. For a more detailed breakdown of costs refer to Exhibit 4-1: Economic Consequence of a Levee Breach.

## Exhibit 4-1: Economic Consequences of a Levee Breach

### **RECLAMATION DISTRICT 554 (UPPER TYLER ISLAND)**

#### **COMMERCIAL**

(Agricultural Structures, Retail Trade, Wholesale Trade, Personal and Repair Services, Banks, Hospitals, Medical Offices, Entertainment and Recreation)

<b>Estimated Impacts and Costs to Businesses due to Lost Business Sales/Day</b>						
Businesses	Output Value	Years Employment	Labor Income	Value Added	Lost Profit	One-time cost if flooded
37	\$ 6,900	0.09	\$ 2,800	\$ 4,100	\$ 300	\$ 37,000

<b>Highway Cost per Day</b>					<b>Government Office Cost/Day</b>	
Road Closure	Travel Time Delay	Trips Foregone	Total	10% Truck Trips	Count	Cost per Day Lost
J11 (0.16 miles)	\$ 1,500 48,345	small small	\$ 48,345	\$ 53,180	3	\$ 3,000

#### **RESIDENTIAL**

##### **Residential Lost Use and Displacement Cost, 2005**

Population	No. of Households	No. of Residential Units	No. of Occupied Units (HH)	Household Displacement/Day	Added Cost per Event*
300	150	177	115	\$ 4,780	\$ 57,500

\*assuming one time cost of \$500 per household unit

#### **AGRICULTURAL**

##### **Crop Reestablishment Costs (inundation Feb to Oct)**

Crop	Corn	Field Crops	Vineyard	Total
Acres	200	100	75	
Cost/Acre	\$ 977	\$ 545	\$ 13,402	
Reestab Cost	\$ 195,400	\$ 54,500	\$ 1,005,150	\$ 1,255,050
\$235/Ac. Rehab.	\$ 47,000	\$ 23,500	\$ 17,625	\$ 88,125
Total Cost/Acre	\$ 242,400	\$ 78,000	\$ 1,022,775	\$ 1,343,175

##### **Annual Production Loss until Harvestable Yield**

Crop	Corn	Field Crops	Vineyard	Total
Acres	235	7	77	
Gross Return/Ac.	\$ 1,020	\$ 400	\$ 3,850	
Total	\$ 239,700	\$ 2,800	\$ 296,450	\$ 538,950

<b>Total Loss/Day</b>	\$ 75,060
<b>One Time Cost</b>	\$ 182,625
<b>Total Loss (assuming 5 day inundation)</b>	\$ 1,566,926
<b>Total Loss (Feb to Oct)</b>	\$ 2,351,926

## LOWER TYLER ISLAND

## COMMERCIAL

(Agricultural Structures, Retail Trade, Wholesale Trade, Personal and Repair Services, Banks, Hospitals, Medical Offices, Entertainment and Recreation)

Estimated Impacts and Costs to Businesses due to Lost Business Sales/Day						
Businesses	Output Value	Years Employment	Labor Income	Value Added	Lost Profit	One-time cost if flooded
11	\$ 67,200	0.22	\$ 9,800	\$ 18,100	\$ 3,400	\$ 11,000

Natural Gas-Producing Wells & Production of Average Dollar Value of Production per Day		
Annual Production (mcf)	No. Producing Wells	Gross Value of Production/Day
1,244,520	9	\$ 11,600

## RESIDENTIAL

Residential Lost Use and Displacement Cost, 2005					
Population	Households	No. of Residential Units	No. of Occupied Units (HH)	Household Displacement/Day	Added Cost per Event*
80	22	30	18	\$ 756	\$ 9,000

\*assuming one time cost of \$500 per household unit

## AGRICULTURE

Crop Reestablishment Costs (inundation 15+ days or Feb to Oct)							
Crop	Alfalfa	Corn	Rice	Truck	Vineyard	Tomato	Total
Acres	2,037	3,277	392	395	1,593	618	
Cost/Acre	\$ 505	\$ 977	\$ 216	\$ 1,432	\$ 13,402	\$ 2,440	
Reestab. Cost	\$ 1,028,685	\$ 3,201,629	\$ 84,672	\$ 565,640	\$ 21,349,386	\$ 1,507,920	\$ 27,737,932
\$235/Ac. Rehab.	\$ 478,695	\$ 770,095	\$ 92,120	\$ 92,825	\$ 374,355	\$ 145,230	\$ 1,953,320
Total Cost/Acre	\$ 1,507,380	\$ 3,971,724	\$ 176,792	\$ 658,465	\$ 21,723,741	\$ 1,653,150	\$ 29,691,252

## Annual Production Loss until Harvestable Yield

Crop	Alfalfa	Corn	Rice	Truck	Vineyard	Tomato	Total
Acres	2037	3,277	392	395	1,593	618	
Gross Return/Ac	\$ 1,540	\$ 1,020	\$ 880	\$ 4,200	\$ 3,850	\$ 2,450	
Total	\$ 3,136,980	\$ 3,342,540	\$ 344,960	\$ 1,659,000	\$ 6,133,050	\$ 1,514,100	\$ 14,616,530

Total Loss/Day	\$ 110,856
One Time Cost	\$ 1,973,320
Total Loss (assuming 5 week inundation)	\$ 27,204,259
Total Loss (Feb to Oct)	\$ 45,990,622

## UPPER AND LOWER TYLER ISLAND

Total Loss/Day	\$ 185,916
One Time Cost	\$ 2,155,945
Total Loss (assuming inundation time)	\$ 28,771,185
Total Loss (Feb to Oct)	\$ 48,342,548

UC Davis Agriculture &amp; Resource Economics; Current Cost and Return Studies (2005-2008)

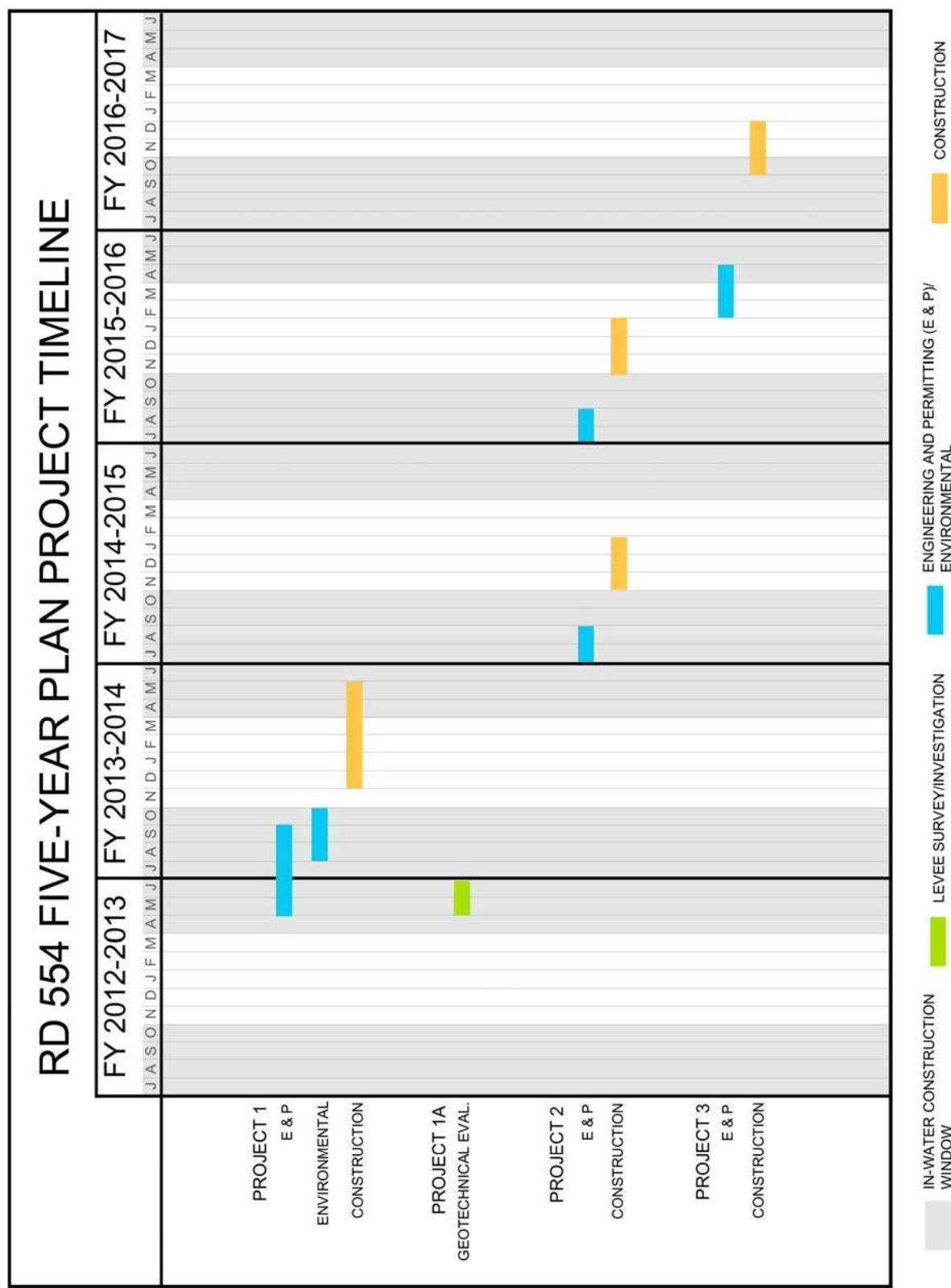
## Goals for the RD 554 Levee System

There are two crucial long term objectives for Reclamation District 554- maintain levee height and improve stability, to increase the factor of safety. The District's first priority is to address any FEMA urban engineering standards or geometry deficiencies within the levee system. This objective primarily requires adding back slope to improve levee stability. The second priority is to fill the Old Tyler Island Slough to strengthen the dry levee toe and thereby improve levee stability if lower Tyler was to flood. See Exhibits 5-1 and 5-2 for the District's project timeline and budget planning strategies to achieve the goals stated above.

The main obstacle to meeting the District's 5-year project goals would be loss of Special Project support and a significant reduction in State Subventions Program assistance. Under current conditions there does not appear to be any additional funding possibilities beyond the District's resources and the State for Delta levee work on RD 554. It appears that the Corps of Engineers will not be able to participate as originally anticipated because of a lack of funding in the Federal budget for levee stability projects for the next five years. Other than local and state financial obstacles, the District does not believe there are any other obstacles to performing its planned levee projects.

*Note: Dates on the Project Funding Agreement WG-09-2.0 and WG-10-1.0 will be amended to be consistent with the Five Year Plan Budget.*

## Exhibit 5-1: Strategy to Meet the Desired Level of Protection-Project Timeline



**Exhibit 5-2: Strategy to Meet the Desired Level of Protection-Five-Year Budget**

RECLAMATION DISTRICT 554 5-YEAR PLAN BUDGET						
		FY 2012-2013	FY 2013-2014	FY 2014-2015	FY 2015-2016	FY 2016-2017
Maintenance	State Reimbursement (75%)	\$15,000	\$15,000	\$0	\$0	\$0
	District (25%+3000)	\$8,000	\$8,000	\$3,000	\$3,000	\$4,000
Rehab	State Reimbursement (75%)	\$0	\$0	\$90,000	\$88,500	\$71,462
	District (25%)	\$0	\$0	\$30,000	\$32,500	\$23,821
Special Projects	Stability Berm-State	\$0	\$704,000	\$0	\$0	\$0
	Stability Berm-District	\$0	\$234,667	\$0	\$0	\$0
Geotechnical Engineering -State		\$112,000	\$0	\$0	\$0	\$0
Geotechnical Engineering -District		\$38,000	\$0	\$0	\$0	\$0
<b>YEAR TOTAL</b>		<b>\$173,000</b>	<b>\$961,667</b>	<b>\$123,000</b>	<b>\$124,000</b>	<b>\$102,283</b>
<b>FIVE YEAR TOTAL</b>						<b>\$1,483,950</b>

PROPOSED PROJECT COST ESTIMATES	
Project 1	\$1,027,843
Project 2	\$110,785
Project 3	\$95,283
<b>ESTIMATED TOTAL</b>	<b>\$1,233,911</b>

\*does not include 17% for engineering and environmental costs

## Assessment of the Existing RD 554 Levee System

Reclamation District 554 is comprised of 3.58 miles of levee. *According to the District's survey in November of 2008 100% of the current levee system exceeds the PL84-99 levee height standard and 98.6% exceeds the FEMA urban levee height standard. Sixty-six percent of the levees meet the PL84-99 landside slope requirements.* The only project levees in this system are along the Sacramento River and Georgiana Slough. The USACE project levee geometry standard, which exceeds FEMA, requires the levees to have a 2:1 landside slope, 3:1 waterside slope, and a 20-foot wide crown width that has 3' freeboard above the 100-year flood level.

The remaining non-project levees, Snodgrass Slough, Delta Cross Channel, and the Tyler Island Cross levee *must meet the PL84-99 levee standards slope standards and FEMA height standards in order to retain FEMA certification for the legacy town of Walnut Grove. This requires that the levees have a 3:1 landside slope, 2:1 waterside slope, and a 16-foot wide crown width and have 3' freeboard above the 100-year flood level.* There are also new engineering standards that have to be met in a geotechnical evaluation of the levees. Minor crown raising is needed in a few areas along Snodgrass Slough and the dry cross levee to respond to elevation deficiencies. The levee along Snodgrass Slough also has landside slope deficiencies and stability issues that must be addressed as well. *There are no known seepage deficiencies on the island. See Exhibit 6-1 Levee Assessment Exhibit.*

### **Sacramento River**

The entire stretch of levee along the Sacramento River meets USACE project levee design standards. In 2006, a DWR 1210 feet erosion repair and mitigation berm project was constructed along the waterside of the levee to address waterside toe erosion concerns. From a more recent visual levee survey, stations 40+00 and 22+00 show some minor waterside erosion.

### **Georgiana Slough**

The entire stretch along Georgiana Slough, stations 0+00 to 15+00 meet the USACE project levee design standard.

### **Snodgrass Slough**

RD 554's 2008-2009 levee survey shows areas where the landside slope does not meet the 3 to 1 criteria. This area spans from stations 80+00 to 147+50. Stations 126+40 to 129+25, 137+15 to 140+70, 143+80 to 147+85 and 150+00 to 153+70 exhibit some minor crown elevation deficiencies to below the FEMA urban levee standard when measured against the more recent USACE 100-year flood stage data. Otherwise the rest of the levee reach meets that standard.

### **Delta Cross Channel**

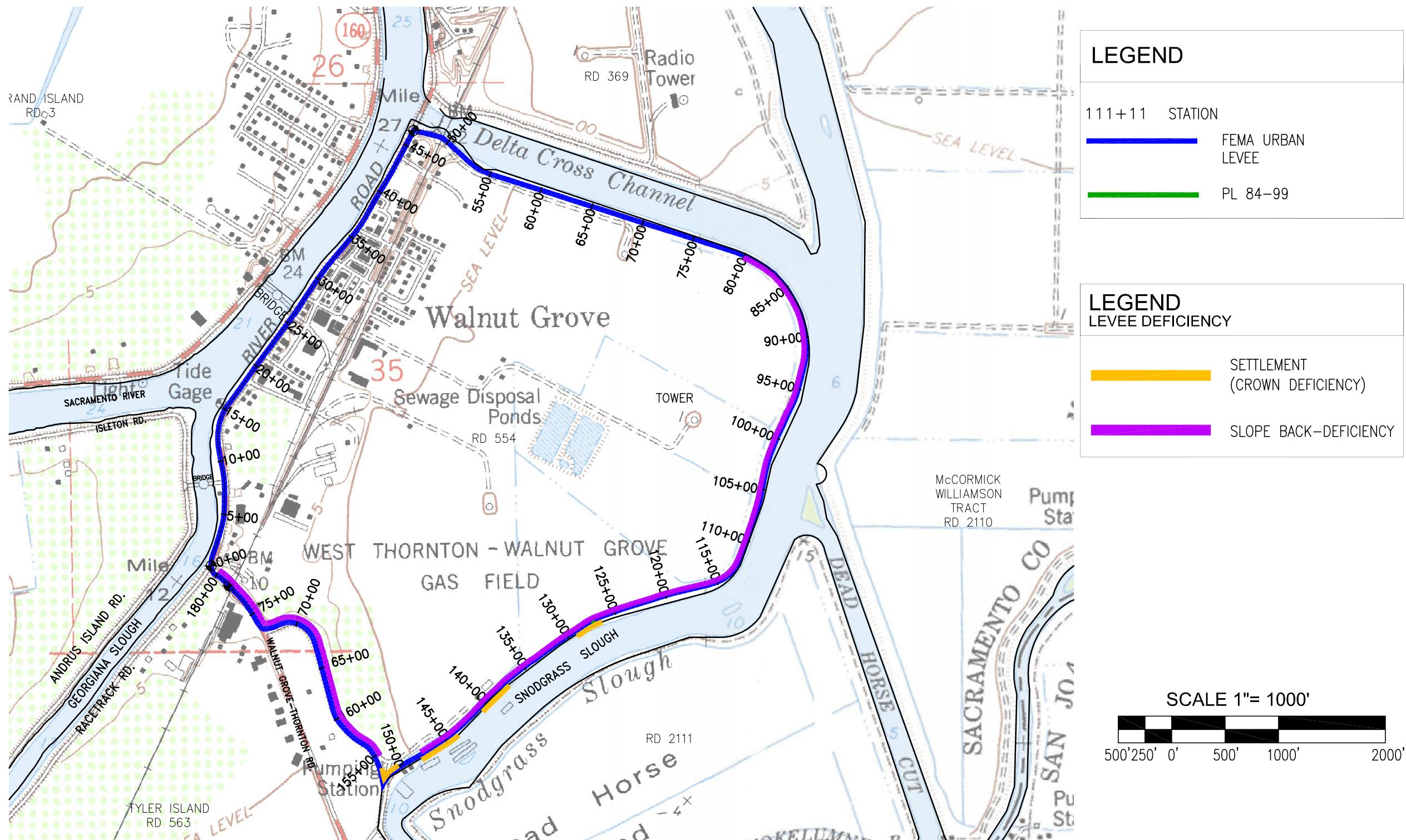
The levee meets the FEMA urban levee geometry design standard for the entire stretch. At station 80+00 to 87+00 near the bend of the channel to Snodgrass Slough there is some minor waterside erosion that could compromise the levee geometry.

## Dry Cross Levee

Most of the dry Cross Levee meets the FEMA urban levee geometry design standard. According to the 2008-2009 survey, some slope instability occurs from station 172+50 to 179+00 and the junction with the Snodgrass Slough levee, station 154+00 is not properly graded to meet FEMA elevation standards, in the most technical sense.

In general, comparing the most recent profile survey with one performed by DWR in 1999, indicated no signs of levee settlement.

# RECLAMATION DISTRICT 554 LEVEE ASSESSMENT



	<p>DESIGNED BY: GILBERT LABRIE DRAWN BY: E. PAPPALARDO REVIEWED BY: GILBERT LABRIE SUBMITTED BY: PROJECT MANAGER DATE: 12/30/2010</p> <p><b>DCC</b> ENGINEERING CO., INC. P.O. BOX 929, WALNUT GROVE, CA 95690 Tel (916)776-2277 Fax (916)776-2282</p>	<p>PLANNING PERMITTING ARCHITECTURE CIVIL ENGINEERING PROJECT MANAGEMENT</p> <p>RECLAMATION DISTRICT 554 ASSESSMENT OF EXISTING LEVEE SYSTEM</p>	<p>EXHIBIT 6-1 ASSESSMENT OF EXISTING LEVEE SYSTEM</p> <p>SCALE: 1"=1000'</p>
			<p>7702.06 SHEET REFERENCE NUMBER: 6-3</p>

## Data Collection and Monitoring

Reclamation District 554 does both visual monitoring and field surveys of the levee system. After the completion of each levee project or improvement, as-built surveys are performed and documented. An electromagnetic survey was also conducted September 2008 on all district levees. The report identified four areas that require "further attention". It is anticipated that the results of a second phase survey could lead to some field investigations at some specific locations. Please See Appendix E - Electromagnetic Data for a *Levee Subsurface Conductance Study* report.

The district performs more thorough monitoring at various problematic sites. The frequency of monitoring these sites is determined by the severity of the problem and the history for that particular section of levee. The more severe the issue, the more frequent it is monitored. At this stage of observation, a geotechnical consultant is called in to provide technical expertise and recommend what additional investigating steps may need to be taken to better understand the problem and engineer a repair solution, if possible.

Prior to constructing any levee improvement or rehabilitation project listed in this document, the District will have a geotechnical investigation performed on all levees along the Sacramento River, Georgiana Slough, Snodgrass Slough, Delta Cross Channel, and the dry land cross levee. This investigation will take place in year one (see Exhibit 5-1).

## Identification of Opportunities for Multi Objective Projects

*Due to the developed nature of the island multi-objective projects are limited to habitat mitigation required by levee projects and the decommissioned sewer ponds. Overall the District does not have the resources to perform any multi-objective projects as stated under Section 5 of the Five Year Plan Requirements.*

***Ecosystem Restoration and habitat enhancement*** - *There are no opportunities for ecosystem restoration or habitat enhancement outside of mitigation for current proposed projects due to lack of opportunity and District resources to perform such projects.*

**Subsidence Reversal** - Currently the district does not have any opportunities to sequester subsidence. All of the farmable land is owned privately with the exception of the decommissioned sewer pond areas currently owned by the Sacramento Area Sewer District (approx. 20 acres). The District is planning on utilizing some of this area for development of habitat mitigation to offset any impacts of the proposed levee improvement projects. The District directors do not attempt to influence what kinds of crops are grown on the island in an effort to sequester subsidence. *Furthermore any subsidence projects would not assist with levee stability.*

**Emergency Response Plan** - RD 554 is endorsing the proposed Sacramento-San Joaquin Delta Regional Flood Response project. The District plans on participating within its resources in the implementation of this regional project and emergency coordination systems. The district is currently in the process of approving an emergency response and evacuation plan. See Appendix I for Reclamation District RD 554's draft emergency response and evacuation plan.

***Water Quality and Supply Reliability*** - *The island is bordered by channels that are part of the State Water Project system. Any failure in the levee system would disrupt this system and degrade water quality. The district does not have any direct opportunities to benefit water quality and supply reliability outside of repairing and upgrading the levee system to reduce the likelihood of a failure.*

## Proposed Work to Reduce the District’s Vulnerability to Flood

In order to reduce RD 554’s vulnerability to failure, crown raising and, landside fill and landside toe strengthening will be implemented where the district has observed erosion and slumping along the cross levee. The type and location of work are listed below. See Exhibit 9-1 for proposed work areas.

<u>Project 1:</u>	<u>Snodgrass Slough Landside Fill and Minor Crown Raising</u>
Project Description:	Project consists of land side fill and some minor crown raising to bring the levee section into compliance with PL84-99 design standard. Total project work is located between Stations 80+00 and 147+50. Minor crown raising is concentrated between Station 139+00 and 140+00. The project requires the placement of approx. 900 tons of AB for crown raising improvements and approx. 65,611 of fill on the landside slope of the levee (See Exhibits 9-1 and 9-2)
Goals:	Achieve PL84-99 levee geometry standard.
Cost:	\$1,089,137
CEQA:	Initial Study, Mitigated Negative Declaration
Permit Consult:	Central Valley Flood Protection Board
Potential Impacts:	6 valley oak trees, 341 lineal feet of coast live oak and 23 single trees, 1 Freemont cottonwood, 1 Oregon ash tree, 3 arroyo willow trees, 1 Godding's black willow and 937 lineal feet of valley and coast live oak trees ( <i>1.34 acres riparian forest</i> ). <i>All impacts are on the landside slope of the levee.</i>
Mitigation:	On-Island site utilizing a decommissioned sewer pond area.

<u>Project 2:</u>	<u>Snodgrass Slough Road and Old Walnut Grove Road Crown Raising</u>
Project Description:	Project consists of 4 separate work areas occurring at the approach ramp to and intersection of Snodgrass Slough and Old Walnut Grove Road.
Work Area 1:	Stations 126+40 to 129+25. Place approx. 806 tons of AB and approx. 91 tons of AC
Work Area 2:	Stations 137+15 to 140+70. Place approx. 931 tons of AB and approx. 106 tons of AC
Work Area 3:	Stations 143+80 to 147+85. Place approx. 957 tons of AB and approx. 106 tons of AC
Work Area 4:	Stations 150+00 to 153+70. Place approx. 1,070 tons of AB, approx. 226 tons of AC, and approx. 550 tons of fill. (See Exhibits 9-1 and 9-2)
Goals:	<i>To meet FEMA urban levee standard by correcting elevation deficiencies and to restore the level of over-topping protection provided the urban area on the island.</i>
Cost:	\$100,000
CEQA:	Initial Study, Categorical exemption.
<i>Permit Consult:</i>	Central Valley Flood Protection Board
Potential Impacts:	<p>Work Area 1: none</p> <p>Work Area 2: 1 coast live oak tree and 236 lineal feet of valley and coast live oak trees (<i>0.05 ac. riparian forest and 0.04 ac. shrub scrub</i>)</p> <p>Work Area 3: 75 lineal feet of valley oak and 2 single trees, 70 lineal feet of coast live oak and white alder trees, 79 lineal feet of palm trees, and 1 coast live oak tree (<i>0.13 ac. riparian forest</i>)</p> <p>Work Area 4: 1 valley oak tree, 52 lineal feet of edible fig trees, 250 lineal feet of scrub shrub (<i>0.12 ac. shrub scrub</i>)</p> <p><i>The work is focused on the levee crown so it may affect vegetation on the upper portions of the waterside or landside slopes of the levee.</i></p>
Mitigation:	On-Island site utilizing a decommissioned sewer pond area.
<u>Project 3:</u>	<u>Fill of Former Tyler Slough along Old Walnut Grove Road</u>
Project Description:	Project consists of land side toe strengthening along the left bank of the Tyler Island cross levee. Project work is located between station 154+74 and 180+00. The work consists of the placement of approx. 16,500 tons of fill. (See Exhibits 9-1 and 9-3)
Goals:	<i>Meet FEMA urban levee standard to ensure that the level of protection that would be provided by the dry levee separating RD 554 and RD 563 is adequate for the urban area on the island.</i>
Cost:	\$265,650
CEQA:	Initial Study, Mitigated Negative Declaration.
<i>Permit Consult:</i>	Department of Fish and Game
Potential Impacts:	1810' lineal feet of scrub shrub and riparian forest on the landside. ( <i>1.13 ac. shrub scrub</i> ).
Mitigation:	On-Island site utilizing a decommissioned sewer pond area.

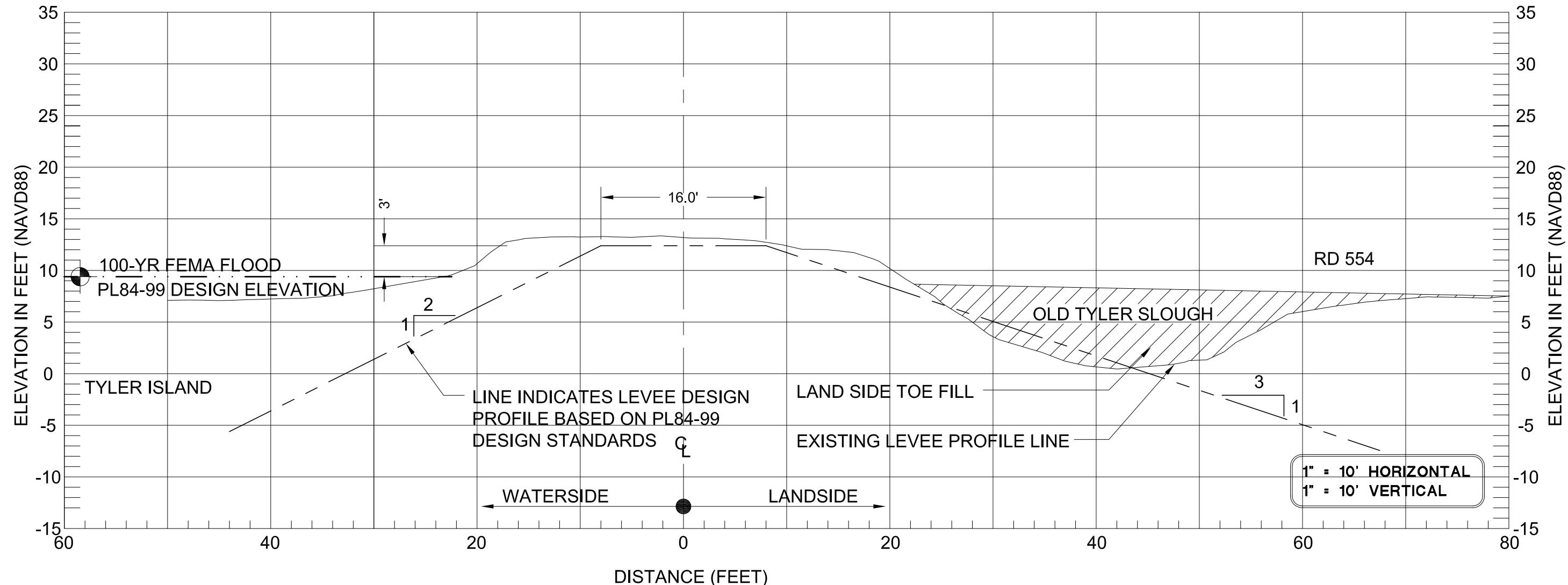
The proposed projects will be designed to minimize habitat impacts but will need to address some potential impacts to ensure there will not be any net loss of habitat. An on-island mitigation area will be developed in concert with the Department of Fish and Game to mitigate for those impacts.

One such area would be the sewer ponds that were decommissioned in 2011. The Sacramento Regional County Sanitation District was charged to remove all waste and rock solids in the two treatment ponds totaling 6 acres (5000-10,000 cubic yard) and possibly in the percolation beds, 14.5 acres total (15,000-30,000 additional cubic yards). All solids were removed and transported to a permitted landfill or land application parcel for disposal. After soils were removed and the Central Valley Regional Water Quality Control Board was required to test the soils to ensure they are clear of contamination (DERA 2010).



Figure 4 – RD 554 Potential habitat mitigation areas.

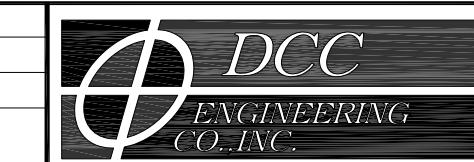
RECLAMATION DISTRICT NO. 554  
TYLER CROSS LEVEE  
TYPICAL CROSS SECTION



NOTES:  
1)

DESIGNED BY: DRAWN BY: NAME
REV BY: GIL LABRIE
SUBMITTED BY:
DATE: 12-30-2011

PLANNING PERMITTING ARCHITECTURE CIVIL ENGINEERING PROJECT MANAGEMENT
<b>DCC</b> ENGINEERING CO., INC. P.O. BOX 929, WALNUT GROVE, CA 95690 Tel (916)776-2277 Fax (916)776-2282



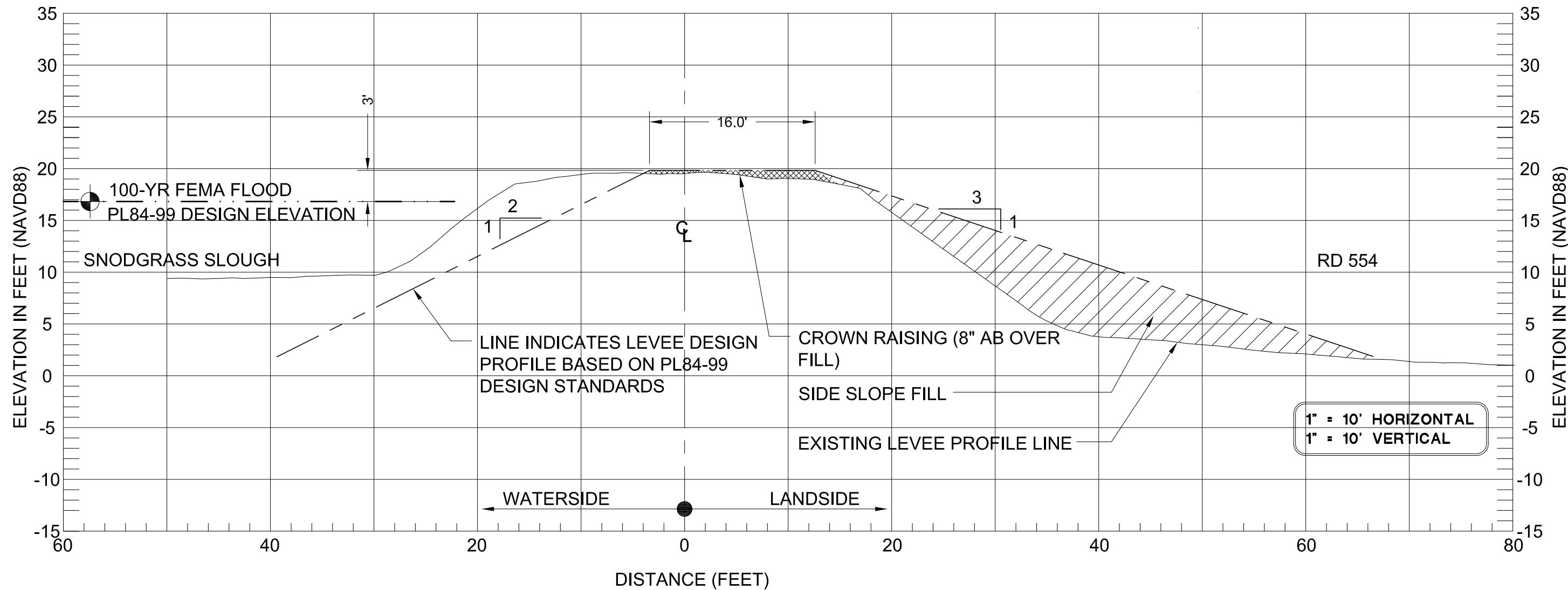
PLANNING  
PERMITTING  
ARCHITECTURE  
CIVIL ENGINEERING  
PROJECT MANAGEMENT

RECLAMATION DISTRICT 554  
EAST WALNUT GROVE

EXHIBIT 9-3  
LAND SIDE TOE  
STRENGTHENING  
TYLER CROSS LEVEE

7580.06  
SHEET  
NUMBER:  
9-5

RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
TYPICAL CROSS SECTION



NOTES:  
1)

DESIGNED BY:  
DRAWN BY: NAME  
REV BY: GIL LABRIE  
SUBMITTED BY:  
DATE: 12-30-2011

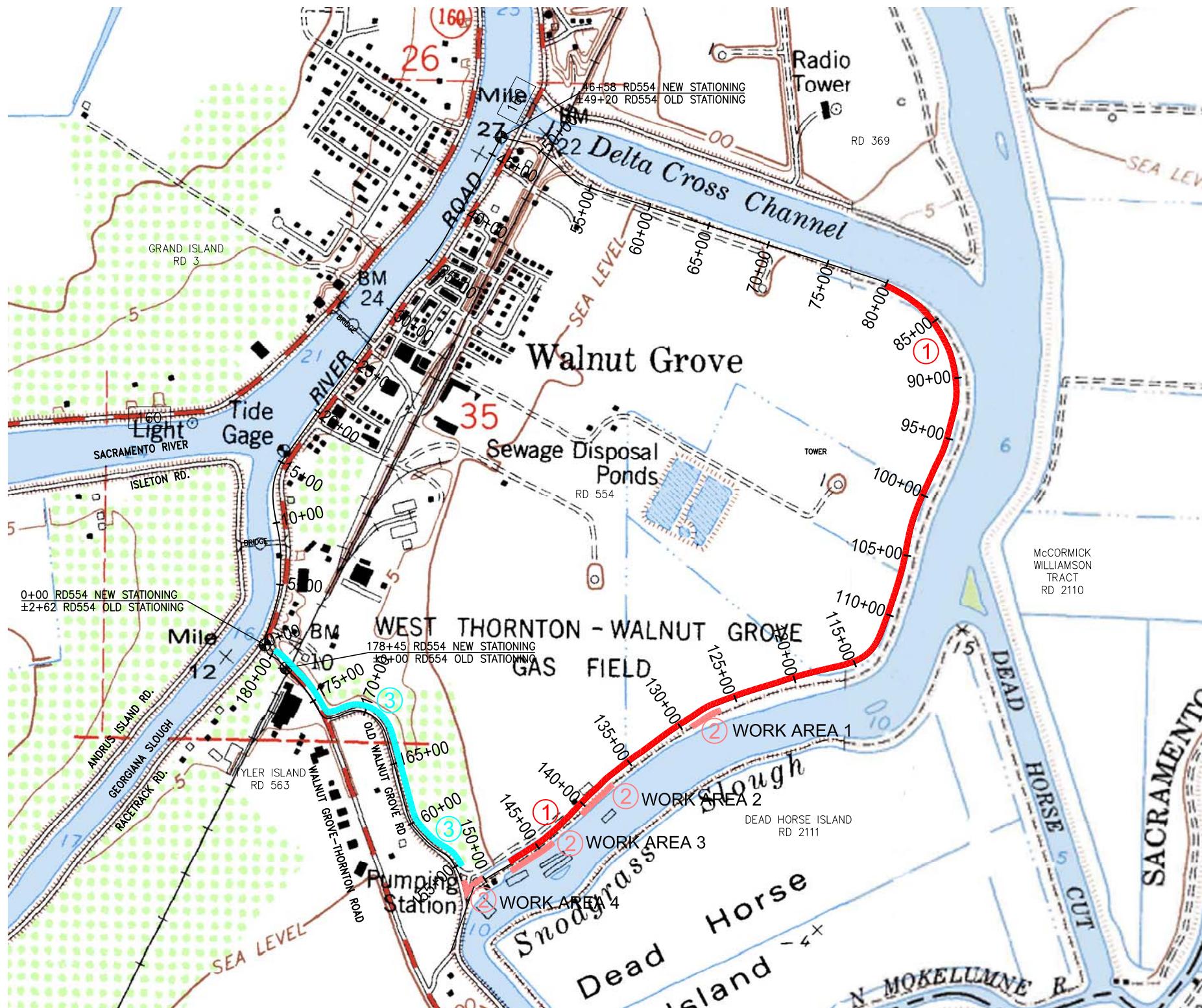


PLANNING  
PERMITTING  
ARCHITECTURE  
CIVIL ENGINEERING  
PROJECT MANAGEMENT

RECLAMATION DISTRICT 554  
EAST WALNUT GROVE

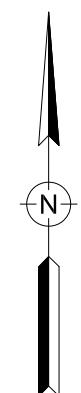
EXHIBIT 9-2  
LEVEE LAND SIDE FILL & MINOR  
CROWN RAISING  
SNODGRASS SLOUGH

7580.06  
SHEET  
NUMBER:  
9-4



## LEGEND

- # PROJECT NUMBER INDICATOR
- ① LAND SIDE FILL PLACEMENT AND MINOR CROWN RAISING - YEAR 3 (PRIORITY 1)
- ② CROWN RAISING AT THE INTERSECTION OF SNODGRASS SLOUGH AND OLD WALNUT GROVE ROAD - YEAR 4 (PRIORITY 2)
- ③ LAND SIDE TOE STRENGTHENING FORMER TYLER SLOUGH DRY LEVEE ALONG OLD WALNUT GROVE ROAD - YEAR 5 (PRIORITY 3)



0 1000' 1500' 2000'  
SCALE: 1"=1000'

### NOTES:

1)

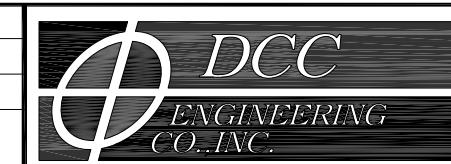
DESIGNED BY:

DRAWN BY: NAME

REV BY: GIL LABRIE

SUBMITTED BY:

DATE: 12-30-2011



P.O. BOX 929, WALNUT GROVE, CA 95690 Tel (916)776-2277 Fax (916)776-2282

PLANNING  
PERMITTING  
ARCHITECTURE  
CIVIL ENGINEERING  
PROJECT MANAGEMENT

RECLAMATION DISTRICT 554  
EAST WALNUT GROVE

EXHIBIT 9-1  
5-YEAR PLAN PROPOSED  
MAJOR PROJECTS  
SNODGRASS SLOUGH AND TYLER CROSS  
LEVEE

7580.06  
SHEET  
NUMBER:  
9-3

## References

California-Sacramento County-Historic Districts. (n.d.). *National Register of Historic Places*. Retrieved June 17, 2010, from <http://www.nationalregisterofhistoricplaces.com/ca/Sacramento/districts.html>

Delta Protection Commission. (2011, October 10). *Public Draft: Economic Sustainability Plan for the Sacramento-San Joaquin Delta*. Retrieved from [http://www.delta.ca.gov/res/docs/ESP\\_10\\_10\\_11.pdf](http://www.delta.ca.gov/res/docs/ESP_10_10_11.pdf)

Fybush, S. (2005, November 11). *The Tall Towers of Walnut Grove, CA*. Retrieved October 7, 2011, from <http://www.fybush.com/sites/2005/site-051111.html>

Grattan, S. R. (2002). Irrigation Water Salinity and Crop Production. In *Farm Water Quality Planning* (ANR Publication No. 8066, pp. 4-5). Retrieved from Agriculture and Natural Resources, University of California website: <http://anrcatalog.ucdavis.edu/pdf/8066.pdf>

Sacramento County. (n.d.). Delta Protection Element. In *Sacramento County General Plan*. Retrieved June 22, 2010, from Planning & Community Development website: <http://www.msa2.saccounty.net/planning/Pages/GeneralPlanUpdate.aspx>

--DERA-Department of Environmental Review and Assessment. (2010). *Walnut Grove Wastewater Treatment Plant Decommissioning Negative Declaration*. Retrieved from Sacramento County Department of Environmental Review and Assessment website: [http://www.dera.saccounty.net/portals/0/docs/EnvDocs\\_Notices/201070081020110614122942.pdf](http://www.dera.saccounty.net/portals/0/docs/EnvDocs_Notices/201070081020110614122942.pdf)

Suddeth, R., Mount, J., & Lund, J. (2008, August). Levee Decisions and Sustainability for the Delta. In *Comparing Futures for the Sacramento-San Joaquin Delta* (Technical Appendix B). Retrieved from Public Policy Institute of California website: [http://www.ppic.org/content/pubs/other/708EHR\\_appendixB.pdf](http://www.ppic.org/content/pubs/other/708EHR_appendixB.pdf)

University of California, Davis. (2005-2009). Current Cost and Return Studies. In *Agriculture & Resource Economics* (af-sv-08, as-vn-07, gr-sv-08, pr-nc-06-1, ri-vn-07-2, sa-sv-05-2, tm-sv-07-2, wh-vs-08). Retrieved from <http://coststudies.ucdavis.edu/current>

URS Corporation, & Jack R. Benjamin & Associates, Inc. (2008, May). Economic Consequences. In *Technical Memorandum: Delta Risk Management Strategy (DRMS)*. Retrieved from [http://www.water.ca.gov/floodmgmt/dsmo/sab/drmsp/docs/Economic\\_Consequences\\_TM.pdf](http://www.water.ca.gov/floodmgmt/dsmo/sab/drmsp/docs/Economic_Consequences_TM.pdf)

--(2008, July). Impact to Ecosystem. In *Technical Memorandum: Delta Risk Management Strategy (DRMS)*. Retrieved from [http://www.water.ca.gov/floodmgmt/dsmo/sab/drmsp/docs/Impact\\_to\\_Ecosystem\\_TM.pdf](http://www.water.ca.gov/floodmgmt/dsmo/sab/drmsp/docs/Impact_to_Ecosystem_TM.pdf)

---(2007, June). Impact to Infrastructure. In *Technical Memorandum: Delta Risk Management Strategy (DRMS)*. Retrieved from  
[http://www.water.ca.gov/floodmgmt/dsмо/sab/drmsp/docs/Impact\\_to\\_Infrastructure\\_TM.pdf](http://www.water.ca.gov/floodmgmt/dsмо/sab/drmsp/docs/Impact_to_Infrastructure_TM.pdf)

---(2008, December). Section 12, Consequences Modeling. In *Delta Risk Management Strategy*. Retrieved from  
[http://www.water.ca.gov/floodmgmt/dsмо/sab/drmsp/docs/Risk\\_Report\\_Section\\_12\\_Final.pdf](http://www.water.ca.gov/floodmgmt/dsмо/sab/drmsp/docs/Risk_Report_Section_12_Final.pdf)

---(2008, December). Section 9, Sunny-Day Risk Analysis. In *Delta Risk Management Strategy* (pp. 9-2 to 9-4). Retrieved from  
[http://www.water.ca.gov/floodmgmt/dsмо/sab/drmsp/docs/Risk\\_Report\\_Section\\_9\\_Final.pdf](http://www.water.ca.gov/floodmgmt/dsмо/sab/drmsp/docs/Risk_Report_Section_9_Final.pdf)

US Census Bureau. (2000). *2000 Census* [Data file]. Retrieved from  
<http://www.census.gov/main/www/>

Walnut Grove Chamber of Commerce. (n.d.). *Walnut Grove Area Page* [Walnut Grove History]. Retrieved August 15, 2011, from <http://www.walnutgrove.com/index.html>

## Appendix A: Five-Year Plan Requirements

**Requirements for the Five-Year Plan****1. Assessment of the status of existing levee system and future goals**

*The Plan should provide a clear description of the following:*

*a. Describe historical flood problems, including:*

- ◊ *Dates of events*
- ◊ *Estimated flood frequencies of events*
- ◊ *Levee performance during these events,*
- ◊ *Consequences of events*

*b. What is the existing level of protection provided by the levee system? Include the source of this information. Specifically,*

- ◊ *What portion of the levee is below or at HMP Standard?*
- ◊ *What portion of the levee is at PL84-99?*
- ◊ *What portion of the levee is above PL84-99?*

*c. What level of protection is expected to be achieved at the end of the five years? Provide justifications in support of the anticipated outcomes.*

**2. Strategy to meet desired level of protection**

*The Plan should elaborate on the desired level of protection at the end of five years (item "c" above) and discuss the following:*

- a. A complete description of the desired level of protection as a goal to achieve in the next five years.*
- b. Phasing of the work, including a description of recommended projects needed to achieve the five year goal*
- c. Total estimated cost of the work and its distribution on a project-by-project basis over the five years*
- d. Potential cost sharing with other partners*
- e. Schedule of work*
- f. Discussion of potential obstacles to meet the desired goal*

**3. Identification of need for improvements to alleviate or minimize existing hazards**

*The Plan should provide an inventory of the local and non-local assets/critical infrastructures, both public and private, being protected by the levees. Local assets are those for which the*

*Local Agency can levy assessments for flood protection; non-local assets are those the Local Agency cannot levy assessments. The Local Agency should identify public benefits where applicable, such as:*

- ◊ *Water quality*
- ◊ *Recreation*
- ◊ *Navigation*
- ◊ *Fish and wildlife*
- ◊ *Protection of State Infrastructure*
- ◊ *Other*

#### **4. Identification of the risks for current land use based on the existing assets**

*The Plan needs to discuss risks associated with levee failure. In particular:*

- ◊ *Consequences of levee failure or breach*
- ◊ *Existing deficiencies in the system, including existing seepage, boils, or voids under the levee*
- ◊ *Urgency of repair work*

#### **5. Identification of opportunities for multi-objective projects**

*The Plan should, at a minimum, describe opportunities and significant constraints for achieving the following objectives:*

- ◊ *Ecosystem restoration and habitat enhancement component*
- ◊ *Reversing land subsidence.*
- ◊ *Ensuring adequate and effective emergency response plans*
- ◊ *Benefitting water quality*
- ◊ *Improving water supply reliability*

#### **6. Habitat Mitigation and Enhancement**

The plan should describe how work to be carried out under the plan will meet the requirements of Water Code Sections 12314 which requires no net loss of habitat and consistency with net habitat improvement. The plan should describe the following:

##### **a. Baseline habitat conditions prior to the plan**

- b. The anticipated impact to habitats and anticipated extent of the impact based on the identified needs for levee repair and other work outlined in the plan
- c. How the requirements for no net loss of habitat, and net habitat enhancement will be met.

**7. Compliance with CEQA and obtaining required permits**

*The Plan should describe all of the following:*

- a. Types of permits and environmental compliance documents required*
- b. Status of the environmental documentation*
- c. Status of the permit process*

## **Appendix B: Available Data**

**(See attached disc for data)**

## Appendix C: Levee Crown Elevation Survey

(See attached disc for data)

## Appendix D: Bathymetric Data

(See attached disc for data)

## Appendix E: Electromagnetic Anomaly Data

## **Introduction to Walnut Grove Subsurface Conductivity Study**

One of the primary intentions of this study is to generate a working document that can be utilized by the State of California employees, District Board, their consultants and district employees to preserve the integrity of the levee system in a more knowledgeable systematic manner, and establish a list of items that will originate a base for a phase two study.

### **Accomplishments**

The results of this study are many. Identified were unknowns, anomaly areas, soil changes and an extensive inventory of events in the levee. Areas that should placed under closer (phase two) were identified. Conductivity profiles were obtained that should be a valuable tool that can be utilized to observe changes in the soil density or water content

## **Introduction to Conductance Studies**

The instrument used in this study is a patented inductive electromagnetic exploration system manufactured by Geonics Ltd of Canada. The Geonics EM 31-3 was chosen as the primary instrument because of its ease of operation, mobility and ability to provide continuous data.

The basic principal behind the EM 31-3 is as follows: A transmitter coil located on one end of the instrument induces circular eddy current loops in the subsurface (fig. 1). The magnitude of these loops is in direct proportion to the terrain conductivity within the volume of the field. A part of the magnetic field from each loop is intercepted by 3 receiver coils and results in an output voltage which is related to the terrain conductivity.

The assumed maximum depth of the magnetic loops into the earth is 6 meters or approximately 19.5 feet below the level of the instrument. The instrument indicates conductivity from 0.00 millisiemens per meter (mS/n) to 1000 millisiemens per meter on three (3) range settings which encompass a wide range of soil conditions. The magnetic field produce is approximately 12 feet in diameter on the horizontal plane at ground level and 6 feet in diameter at 9 at a depth of 9 feet (fig. 2 and fig 3).

## Factors Affecting Subsurface Terrain Conductivity

The subsurface conductivity is determined for terrain by the following factors:

- 1) Moisture content: the extent to which pores in the soil are filled with water.
- 2) Soil type: sand, loam, clay, silt, peat or any combination of these.
- 3) Concentration of dissolved electrolytes such as water with higher or lower salt content.
- 4) Temperature and phase state of the pore water.
- 5) Presence of foreign objects: wood debris, concrete, metal or plastic pipes.

## The Study

The following is a draft report of the results of a subsurface electrical conductance study on the levee system of *Walnut Grove, Reclamation District #554, in Sacramento County*.

The study was begun on *September 15<sup>th</sup>* and completed on *October 15<sup>th</sup>, 2008*. The temperature was from *85 degrees to 95 degrees*. The stationing runs in a counterclockwise direction and the starting station is just north of a PG&E power pole near the west fence of Blue Anchor. The stationing has the staring point (3813.38781919, N, 12130.39920301, W) and run a clockwise direction (CSI stationing appears to be reclamation stationing plus 279'). Three traverses were performed. One traverse were located on the Waterside shoulder (WSS), another was performed in the road center line (CL) and the final traverse was performed on Land side shoulder (LSS). The total study consisted of 18,043 feet for total *3.41 miles*.

The Walnut Grove project an excellent example of how environmental conditions can hamper a project. The west side of the project went through the commercial section of Walnut grove. Traffic was halted for the duration of the three traverses but there were many parked vehicles still present. The effect of these parked vehicles is obvious on the conductivity profiles. There were several unknown signal observed. Because of the number of parked vehicles it is very difficult to determine if the signals are vehicles or actually pipes. The whole area on the west side needs to be checked in the phase two portion of the study.

Portions of the east section conductivity profiles display erratic profiles. It is felt the these erratic signals are from transmission of the various antennas on the tower.

### **Explanation of Procedures Used in Conductance Study**

The first step consisted of a preliminary drive to locate any possible traverse problem. The next step was the performing of traverses at the WSS, CL and LSS. Step number three was analyzing the data and determining which areas required further examination to conclude which locations could be potential problem locations. Step number four consisted of examining the potential problem areas. Extensive time and careful analysis were spent on each suspect area. These results yielded the possible depth, dimension, and possibly the type of anomaly. Also all unknown signals were reviewed by confirming their possible depth, location and orientation in the levee.

**(See attached disc for data)**

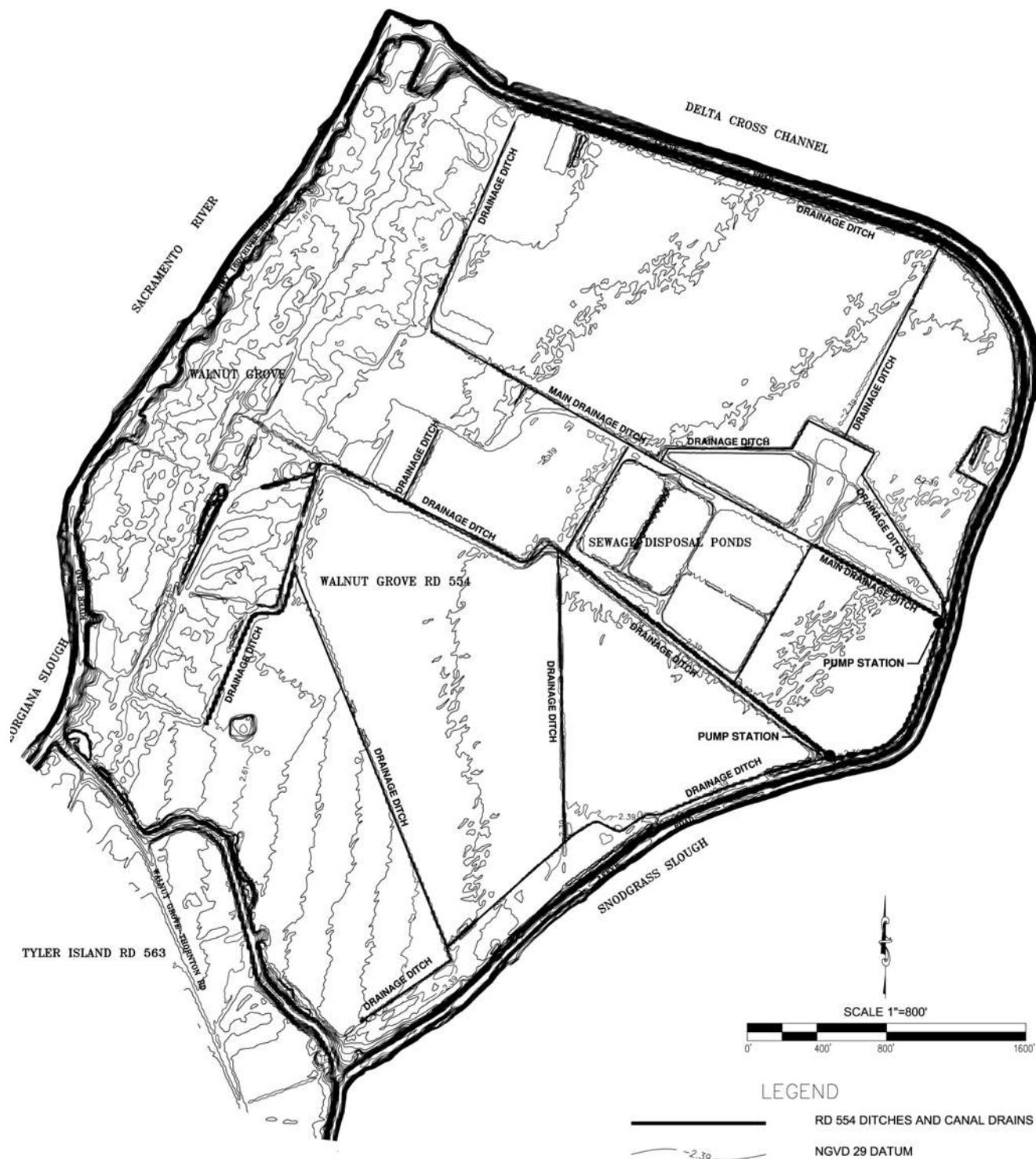
## Appendix F: Five-Year Plan Cost Estimation Tables

Table 1A -RD 544 Quantity Calculations & Associated Construction Cost

### Table 1B -RD 544 Quantity Calculations & Associated Construction Cost

### Table 1C -RD 544 Quantity Calculations & Associated Construction Cost

## Appendix G: Reclamation District 554 Drainage Ditch Map



## Appendix H: Department of Fish and Game Levee Log

## Walnut Grove Habitat Assessment

## Levee Log for Walnut Grove (9/13/07)

**Key to Levee Log:** Side: Water (W) or Land (L) side of levee. Station Begin/End: DMI readings (feet from panel station zero). Height: Height of individual tree or average height of a linear strip of habitat. Width: Average width of a linear strip of habitat. Habitat Type: See Table 1 for definitions. Species: Dominant species present for a said habitat type. Length: Length of habitat type (canopy edge to canopy edge). Notes: Other observations, habitat cover percentage, photo log, DMI/stationing panel descrepancies.

Side	Start	End	Length	Height	Width	Habit Type	Species Code	Ratio	Levee Location	Notes
W	0+00		single tree							Start new 0+00 station @ DCC Gravel Bridge (Downstream of Gates) - Photo
W	72		single tree	20		RF	FRLA	2:3	L	
W	112	335	223	20	60	RF	ALRH, QULO, QUAG, JUCA			SRA 50%
NOTE	222		single tree							GATE
L	222		single tree	20		RF	QULO	1:1	L	2 trees
W	387		single tree	40		RF	QULO, POFR	1:2	M	2 trees
W	441	541	100	25	40	RF	QULO, SALA, QUAG			
L	446		single tree	20		RF	JUCA	1:1	L	
W	590		single tree	15		SS	QULO	2:1		
L	590		single tree	25		RF	SAGO	3:2	L	
W	652		single tree	20		RF	ALRH	2:3	L	SRA, 2 trees
W	652	1240	588	5	15	FM	ROCA			
W	791		single tree	20	35	RF	SALA	1:2	L	SRA
W	815	960	145	25	45	RF	FRLA, ALRH, SALA			SRA, RUDI understory
W	967		single tree	30		RF	QULO	1:2	L	2 trees
W	1012		single tree	25		RF	SAGO	3:2	L	
W	1064	1172	108	15	30	SS	FRLA, SAEX, QULO, SALA, SAGO			
W	1240	1387	147	15	30	SS	SAGO, ARLH, FRLA, POFR			SRA 50%
W	1431		single tree	35		RF	ALRH, UNK		L	SRA 50%, 2 trees
W	1387	1415	28		15	FM	SCR			
W	1490		single tree	15		SS	ALRH	1:1	L	SRA
W	1524		single tree	10		SS	QULO, QUAG	1:1	L	2 trees
W	1563	1604	41	10	10	SS	ALRH			
W	1675	1764	89	20	30	RF	QULO, ALRH, FRLA			SRA 50%
W	1811	1930	119	20	30	RF	QULO, ALRH, FRLA			SRA 50%
W	1959	2037	78	10	30	SS	ROCA, ALRH, FRLA			SRA 50%
W	2094	2175	81	20	25	RF	QULO, ALRH, FRLA			SRA 50%
W	2285	2441	156	20	40	RF	QULO, ALRH, SALA, FRLA			
W	2386	2696	310		15	FM	SCR			45% Coverage
W	2481	2696	215	20	40	RF	QULO, FRLA, PLRA, ALRH			SRA 50%, 90% Coverage
W	2717	2792	75	20	50	RF	QULO, JUCA, ALRH, ROCA			

## Walnut Grove Habitat Assessment

L	2763	2802	39	20	40	RF	QULO	1:1	L	2 trees
W	2817	2917	100	15	30	SS	QULO, JUCA, ALRH, ROCA	3:2	M	SRA 50%, some SCR, 80% coverage
W	2967		single tree	15		SS	ALRH	3:2	L	
W	3032		single tree	15		SS	QULO			
W	3091		single tree	15		SS	ALRH			
W	3122		single tree	15		RF	FRLA, QULO			2 trees
W	3180	3324	144	20	40	RF	QULO, FRLA, SAME			
W	3339	3393	54	25	40	RF	SAGO, POFR, QULO			One QULO high on levee
W	3393	3450	57	10	25	SS	QULO, FRLA			
W	3476		single tree	40		RF	POFR	1:1	L	2 other trees - SAGO & FRLA
W	3491		single tree	15		SS	QULO	2:3	H	
W	3513	3592	79		5	FM	SCR			
W	3520	3867	347	20	50	RF	QULO, FRLA			75%
W	3887		single tree	10		SS	SAME	1:1	L	
W	3900	4030	130	25	40	RF	QULO			
L	3990		single tree	10		SS	QULO	2:1	H	
W	4270		single tree	10		SS	CEO	1:1	L	
W	4498	4697	199		30	FM	SCR			
L	4616		single tree	10		SS	QUAG	1:1	H	
W	4770		single tree	10		SS	QULO	3:2	H	
W	4929		single tree	25		RF	POFR	2:1	M	2 Trees, SALA
W	5000		single tree	15		SS	ALRH	2:3	M	
W	5062		single tree	10		SS	ALRH	2:3	M	
L	5608		single tree	10		SS	QUAG	1:1	H	Pump station near toe drain
L	5764		single tree	10		SS	SAL	1:1	L	
W	5782		single tree	15		SS	QULO	2:3	H	
L	5823		single tree	15		SS	QULO	3:2	H	
W	5843		single tree	15		SS	ALRH	2:3	M	
L	5843		single tree	25		RF	QUAG	1:1	L	3 small QUAG adjacent to
W	5911		single tree	35		RF	QULO	1:1	H	
L	6003		single tree	25		RF	QUAG	1:1	H	QULO behind
W	6022	6095	73	15	30	SS	ALRH			SRA
L	6133		single tree	10		SS	QULO	1:2	H	
W	6129		single tree	20		RF	ALRH	1:1	L	SRA
L	6184		single tree	15		SS	SALA, SAGO, SAME	1:2	L-M	
W	6192		single tree	15		SS	ALRH	1:2	L	2 trees
W	6276		single tree	10		SS	ALRH	1:1	M	
L	6276		single tree	15		SS	SAGO	2:3	L	toe drain
W	6307		single tree	10		SS	ALRH	2:3	M	
L	6318		single tree	15		SS	QUAG	2:3	M	
W	6415	6513	98	15	25	SS	ALRH, SALA, FRLA, QUAG			
L	6513	6561	48	15		SS	QUAG			
L	6732		single tree	15	55	SS	QUAG	2:3	H	Landside metal steps
W	6747	6802	55		10	FM	SCR			
NOTE	6909		single tree							No wake zone sign
W	6981		single tree	15		SS	FRLA	3:2	L	
L	7114	7164	50	25	30	RF	QUAG			
W	7188		single tree	15		SS	JURE	2:3	L	

## Walnut Grove Habitat Assessment

W	7421		single tree						Power lines / Box , Gate
W	7477		single tree	15		SS	QUAG	1:2	H
W	7715	7762	47	20	25	RF	ALRH, FRLA		
W	7857		single tree	25		RF	SAGO	1:1	M
L	7907		single tree	20		RF	QUAG	1:1	L
W	7907		single tree	20		RF	ALRH	2:3	L
W	7956		single tree	10		SS	QUAG	1:1	M
L	8026		single tree	15		SS	QUAG	1:1	L
L	8061		single tree	15		SS	QUAG	3:2	H
W	8101	8175	74	25	45	RF	AULO, SALA, QUAG		
L	8107	8334	227	20	30	RF	QUAG, QULO		
W	8303	8388	85	15	45	SS	SALA, QUAG		
L	8363	8576	213	20	30	RF	QUAG		
W	8419		single tree	20		RF	QUAG	2:3	H
L	8419		single tree	50		RF	POFR, SAGO	3:2	L
L	8475		single tree	35		RF	QUAG	1:1	L
W	8478		single tree	25		RF	ALRH	2:3	L
W	8488	8618	130	15	20	SS	QUAG		
L	8495		single tree	30		RF	QUAG	3:2	M
W	8544		single tree	20		RF	ALRH	1:2	L
W	8602		single tree	15		SS	CEO	1:2	L
L	8609	8649	40	25	30	RF	QUAG		
W	8618		single tree	25		RF	QUAG	3:2	M
W	8691		single tree	20		RF	ALRH	3:2	L
L	8691		single tree	25		RF	QUAG	1:1	H
W	8727		single tree	25		RF	QUAG	1:1	H
L	8739	8975	236	30		RF	QUAG, QULO		
NOTE			single tree						Power Lines Crossing / Box
W	9047		single tree	25		RF	ALRH	3:2	L
L	9070	9313	243	30	40	RF	QUAG		
W	9097		single tree	20		RF	QUAG	1:1	H
L	9165		single tree	20		RF	FRLA	1:2	M
W	9165		single tree	20		RF	QULO	2:1	H
W	9201		single tree	25		RF	QUAG	1:1	H
W	9215	9276	61	10	25	SS	SALA, CEO		
L	9351	10052	701	30	40	RF	QUAG, QULO		
W	9383	9458	75	30	30	RF	QULO		
W	9542		single tree	20		RF	ALRH	3:2	L
W	9553	9623	70	30	40	RF	QUAG, ARLH		PALM
L	9633		single tree	40		RF	QULO	3:2	L
W	9633	9712	79	45	10	RF	PALM		SAME, QUAG, CEOC mixed
L	9666		single tree	25		RF	QULO	2:3	L
W	9771		single tree	15		SS	QUAG	1:2	H
NOTE	9966		single tree						Center of "Marina" Sign
W	9988	10052	64	10	30	SS	FICA		
W	10062		single tree	30		RF	QULO	3:2	L

\* Document Subject to Change or Revision Without Notice

## Appendix I: Emergency Response Plan

**EMERGENCY RESPONSE AND EVACUATION PLAN  
RECLAMATION DISTRICT 554 – WALNUT GROVE (EAST)**

**P.O. Box 984, Walnut Grove, California 95690-0984  
Phone No. (916)-776-1945**

As part of the hazard mitigation effort, the following emergency response and evacuation plan will be implemented by Reclamation District 554 (RD 554) when an emergency flood event is anticipated or imminent. An emergency flood event typically occurs in one of two ways: 1) the Federal/State Flood Control Center, based on weather forecasts, predicts that high tide river stages at I-Street Bridge and Michigan Bar are expected to reach Monitor Stage or Flood Stage; or 2) the RD554 trustees, based on levee monitoring conducted by RD personnel, declare an emergency due to potential flooding of the lands within the District as a result of a combination of high tides, inclement weather, and levee conditions. The Department of Water Resources has determined that:

Sacramento River at the I Street Bridge	Monitor Stage	= 25.0 feet
	Flood Stage	= 31.0 feet

Cosumnes River at Michigan Bar	Monitor Stage	= 7.0 feet
	Flood Stage	= 12.0 feet

Monitor stage is the stage at which the RD is required to conduct mandatory patrols of flood control levees. Flood Stage is the stage at which over-bank flows are of sufficient magnitude to cause considerable inundation of land and roads and/or significant threat to life and property.

River conditions for the Sacramento and Cosumnes River Basins can be obtained by calling the DWR Flood Center recording at 1-800-952-5530 or via the Internet at <http://cdec.water.ca.gov/misc/realStations.html>

**EMERGENCY RESPONSE PLAN**

- 1) In the event an emergency flood event is anticipated or is imminent, continuous 24-hour levee patrols will be organized immediately by the RD and each patrol unit will consist of the following:
  - a) Two persons, with at least one of the persons experienced in flood fighting techniques, will make up each patrol unit.
  - b) Each patrol unit will be equipped with either a mobile radio or telephone and basic flood fighting equipment.
  - c) Each levee patrol unit will patrol for 12-hour shifts and be responsible for approximately 15 miles of levee. Patrol will seek to identify, mark locations, and monitor problems including, but not limited to: wave wash/erosion, boils/seepage, cracking, sloughing, or noticeable settling. Levee patrol units will record activities on daily logs, which will be passed on to subsequent patrol units.

- 2) The Delta-Suisun Marsh Office of the Department of Water Resources will assist the RD by supplying volunteers for patrolling and monitoring levees. All DWR personnel, once called to monitor, will report to District office (see location on attached map) using their own personal vehicles. One or two volunteers will be asked to assist in driving State Vehicles (pickup trucks) from Sacramento to the District office. These trucks will be used to patrol and monitor the levees.
- 3) When flood fight seems imminent the RD will organize an on-island crew composed of four equipment operators to operate the large equipment and vehicles and local and DWR volunteers to perform other flood fight duties.
- 4) Materials and equipment necessary for flood fight work and levee patrol units are stored at the District office and at other nearby locations that are maintained by the District. RD554 personnel will provide the materials and equipment, and stockpile them at the District office and/or at strategic locations around the island as needed. The district will also contact vendors that to provide necessary equipment and materials that cannot be stored on the island (see vendor contact list). An equipment and materials list is provided below:

<b>Personnel Equipment/Tools</b>
Cell Phone or two way radio
Flashlight
Rain gear, boots, hard hat, goggles
Cigarette lighter powered spotlight
Life jackets
Aluminum field case with Patrol Logs and Flood Fighting Handbook
Blanket
Shovels
Single jack sledge hammer (2 lbs)
Utility Knife
Pliers
Car window breaker
Digital camera to email pictures to the <a href="mailto:floodcenter@water.ca.gov">floodcenter@water.ca.gov</a>
Barricades
Pruning shears to remove brush
Coffee

<b>Large Equipment/Vehicles</b>
Bulldozers (2)
Backhoes (2)
Pile Driver
Pick ups (5)
4-Wheel tractor
Evacuation vans (9)
Flat bed truck (40')

Stockpile Location	Materials
Dredge site	Sand
District Office	Sand Bags
District Office	Marker lath (stakes)
District Office	Permanent markers
District Office	Survey flagging
District Office	Mil Plastic (Visqueen) 20 feet x 100 feet rolls
District Office	Rope for lifeline
District Office	Buttons (if not available, use small rocks)
District Office	Stakes 2 feet long by 1-inch x 3-inch
District Office	Twine
Barges (located at emergency stage)	Rock (4 barges)
District Office	Lumber (2x10 & 2x12)
Dredge site	Sheet Piles (100 LF)

Material	Vendor	Contact Phone
Rock (barge)	Dutra	415-721-1391
Rock (greenstone)	Reed	
Rock (side dump)\	Chachini	
Pile Driver	DDM	510-769-8707
Bulldozer	Holt	
Bulldozer	Ten Co	
	US Rentals	
	Big 4	

- 5) A digital camera will be available to levee patrols so that they can take pictures of damaged areas that are in imminent danger of causing a levee failure/flooding. This will facilitate rapid verification to the Flood Operations Center (FOC) personnel that an imminent danger of flooding exists so they can dispatch flood fight crews in a timely manner. The pictures will be sent to the FOC via the Internet (FOC Internet address is [floodcenter@water.ca.gov](mailto:floodcenter@water.ca.gov)) at the District Secretary's office. A computer is available at the District Secretary's office and pictures can be downloaded and attached to an email that can then be sent to the FOC. Levee patrol units and RD personnel will be trained in how to download pictures from the camera and email them to the FOC.

## EVACUATION PLAN

- 1) In the event the District has prior notice or otherwise believes a levee failure appears imminent or has occurred, District personnel will immediately notify the following agencies:

<b>Sacramento County Sheriff</b> Florin Service Center  7000 65 <sup>th</sup> Street Sacramento, CA 95823  (916) 876-8309 Emergency dispatch: (916) 874-5111 Non-emergency dispatch: (916) 874-5115 Emergency 9-1-1	<b>Department of Water Resources</b> <b>Division of Flood Management.</b> State-Federal Flood Operations Center  Toll-free public line (recording) (800) 952-5530  Email: <a href="mailto:flood_center@water.ca.gov">flood_center@water.ca.gov</a>  Bus (916) 574-2619 Fax (916) 574-2798  Operations Line (916) 574-2623 (non-public)
<b>Sacramento County Office of Emergency Services</b>  711 G Street/OES Sacramento, CA 95814  Bus. (916) 874-4670 Bus. Fax (916) 874-7080 24-hr Duty Officer (916) 875-5000	<b>California Highway Patrol</b> Valley Division Communications Center  3165 Gold Valley Drive Rancho Cordova, California 95670  (916) 861-1333 24-hr (916) 861-1363 FAX (916) 466-2097
<b>U.S. Army Corps of Engineers</b> Sacramento District  Emergency Operations Center 1325 J Street Sacramento, California 95814-2922  (916-557-7236) Emergency Mgmt (916) 557-6911 FAX (916) 557-7852	<b>California Emergency Management Agency</b> Headquarters  State Warning Center 3650 Schriever Avenue Mather, California 95655  Main No. (916) 845-8510 Bus. 24-hr (916) 845-8911 FAX (916) 845-8910

- 2) The Sacramento County Sheriff will alert Island residents.
- 3) If, however, the District does not have prior notice of a possible levee failure (e.g. earthquake or other unpredictable Act of God or disaster), and Island residents are informed or believe that some act has taken place that could jeopardize the integrity of the District's levees, then Island residents are advised to move to the levee crown and evacuate as soon as possible. If during such an unpredictable event, a resident has actual knowledge of an actual levee breach, that resident should call these numbers in the following order:

- a. Emergency - 911
- b. Trustee, Pete Budnick (916) 776-1841 (bus)
- c. Engineer, DCC Engineering (916) 776-2277

4) Approximately 300 people live on the eastern side of Walnut Grove with a majority of the population and businesses residing along the Sacramento River. The southern end of the island is at the lowest elevation, at approximately sea level. Any flooding that would occur on the island would run to the southern end of the island, filling up from there to an estimated average depth of 7 feet. In order to keep the town from becoming inundated by flood waters the district plans to break the Tyler Island cross levee.

5) Evacuation routes will be limited to passable perimeter levee roadways, unless evacuees are told otherwise by the Sheriff. The island will be evacuated with traffic routed along the perimeter levee roads, exiting the island via the Tyler Island, Georgiana Slough, Walnut Grove, or Delta Cross Channel Bridges, whichever allows the quickest and safest evacuation. District personnel will ensure that all gates on the levee crowns are unlocked and will remain open during emergency flood events. In the event you encounter a locked gate during your evacuation please call Pete Budnick (916) 776-1841. Unless directed differently by Mr. Budnick, remain on the levee crown at the locked gate until someone comes to unlock it. **Please take caution on the interior island roads, while they are mostly above sea level, there still is danger from flooding.**

6) All mobile or farming equipment shall be moved to high ground located at wide areas along the base or side of the levee. Equipment **will not be allowed to park on the levee crown** so as to avoid blocking evacuation routes or emergency vehicle access routes.

# MAP OF EVACUATION ROUTE

RECLAMATION DISTRICT 554  
WALNUT GROVE (EAST)

SCALE: 1" = approx.1000'

DELTA CROSS  
CHANNEL BRIDGE

WALNUT GROVE  
BRIDGE

HIGHWAY

Light Tide Gage

SLETON RD

Georgiana  
Slough

RIVER

GEORGIANA  
SLOUGH BRIDGE

WEST THORNTON - WALNUT GROVE  
GAS FIELD

OLD WALNUT  
THORNTON RD

River

ROAD

ROAD

PATROL

USE PERIMETER LEVEE ROADS  
TO EXIT AT CLOSEST BRIDGE

WARNING: DO NOT USE INTERIOR  
ISLAND ROADS OR WALNUT  
GROVE-THORNTON ROAD/J11

SEA LEVEL

Pumping  
Station

OLD WALNUT  
THORNTON RD

HORSE CUT

N. MOKELOMNE R.  
Mile 10

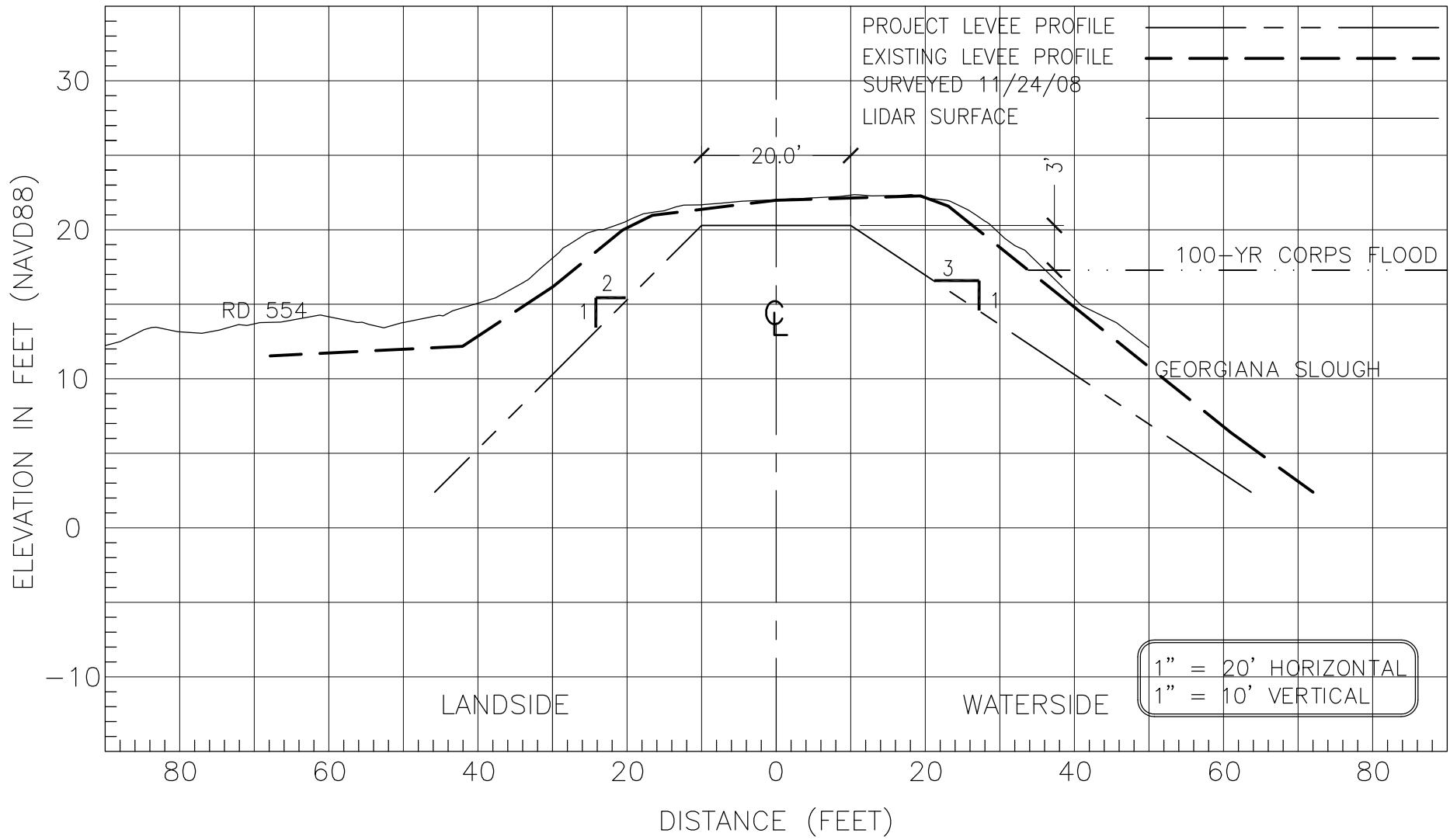


## **Appendix B: Available Data**

**(See attached disc for data)**

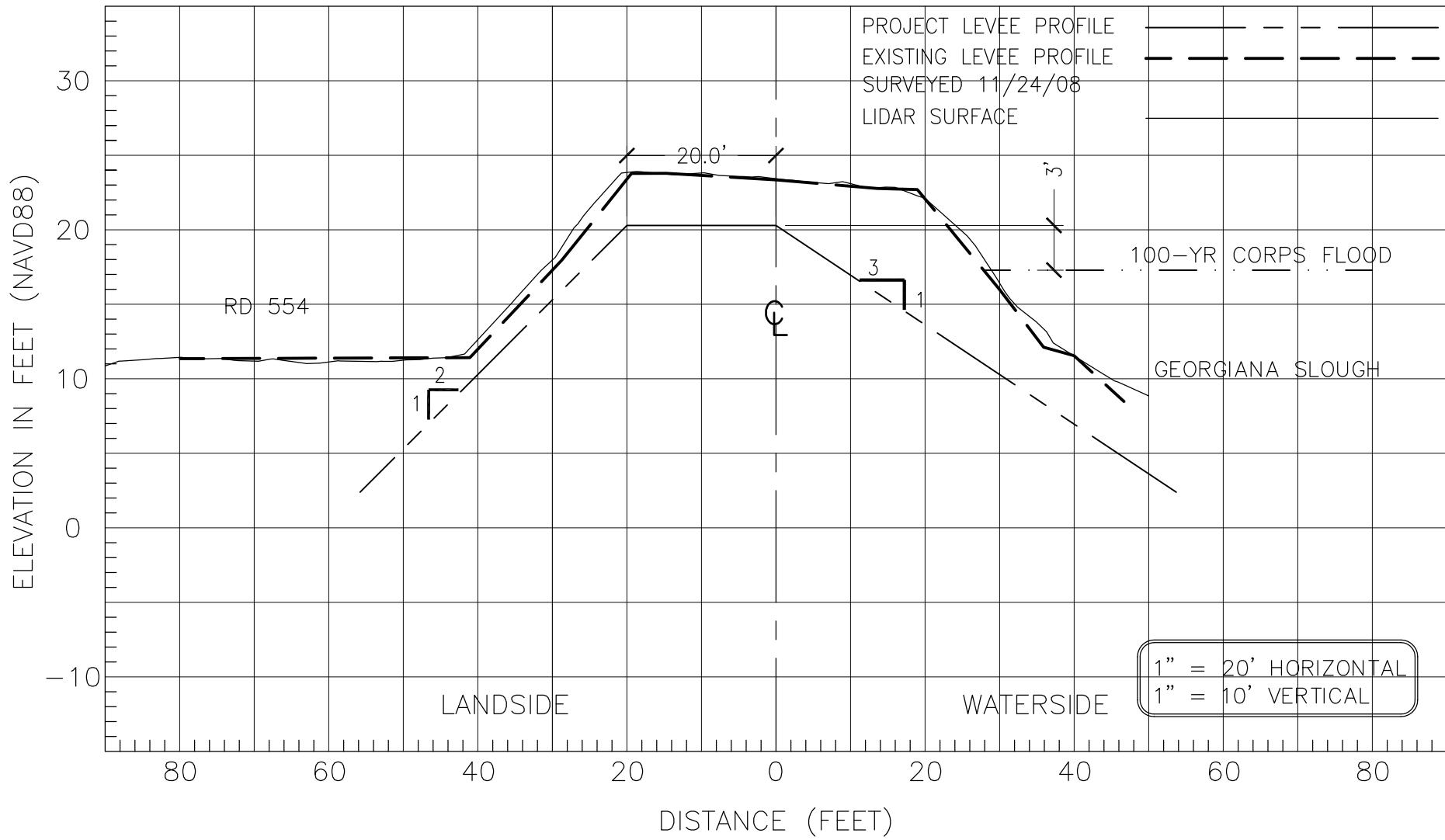
RECLAMATION DISTRICT NO. 554  
GEORGIANA SLOUGH (LEFT BANK)  
LEVEE CROSS SECTION STATION 00+53

PRINT DATE: 8-5-2011



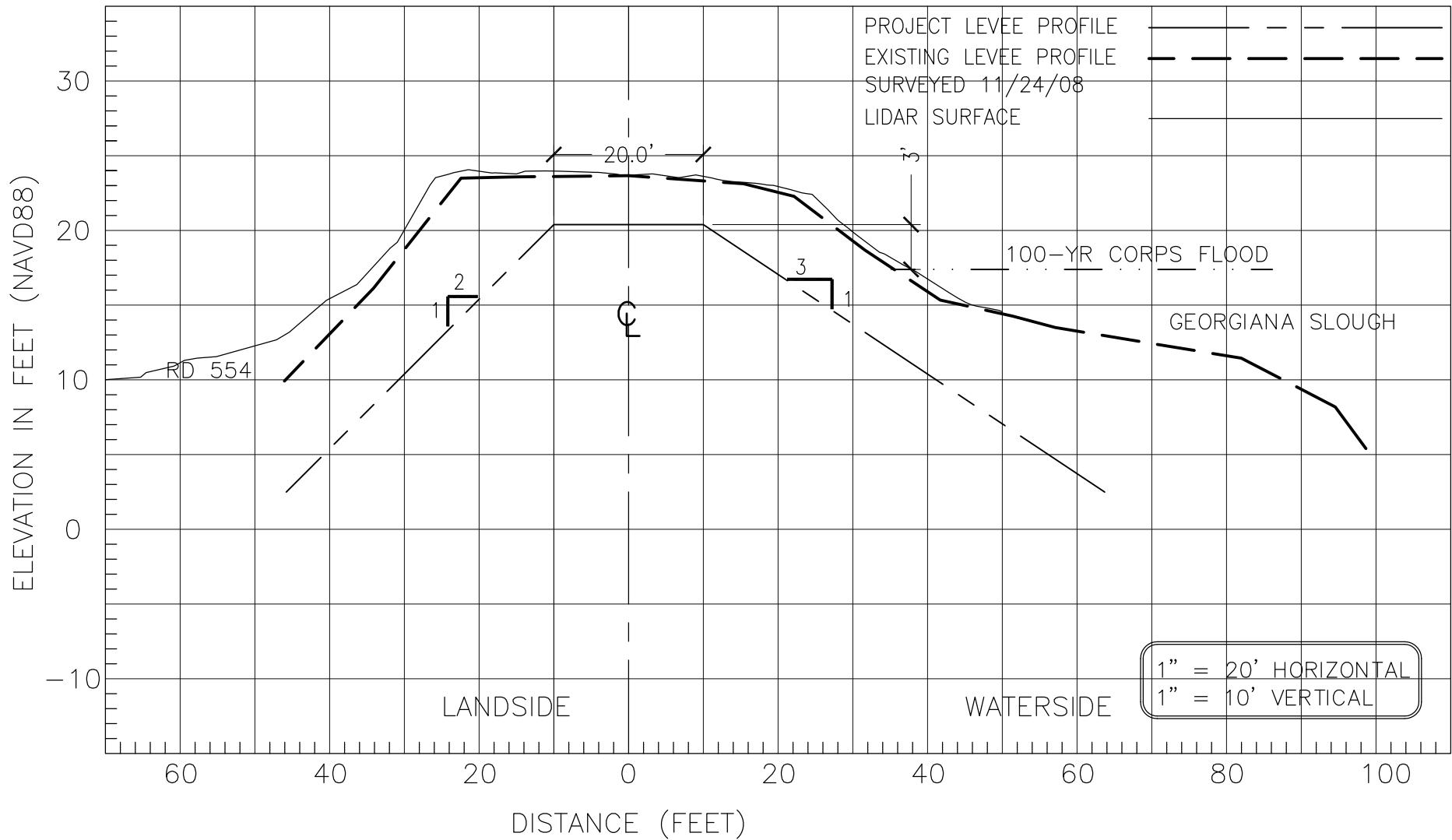
RECLAMATION DISTRICT NO. 554  
GEORGIANA SLOUGH (LEFT BANK)  
LEVEE CROSS SECTION STATION 5+00

PRINT DATE: 8-5-2011



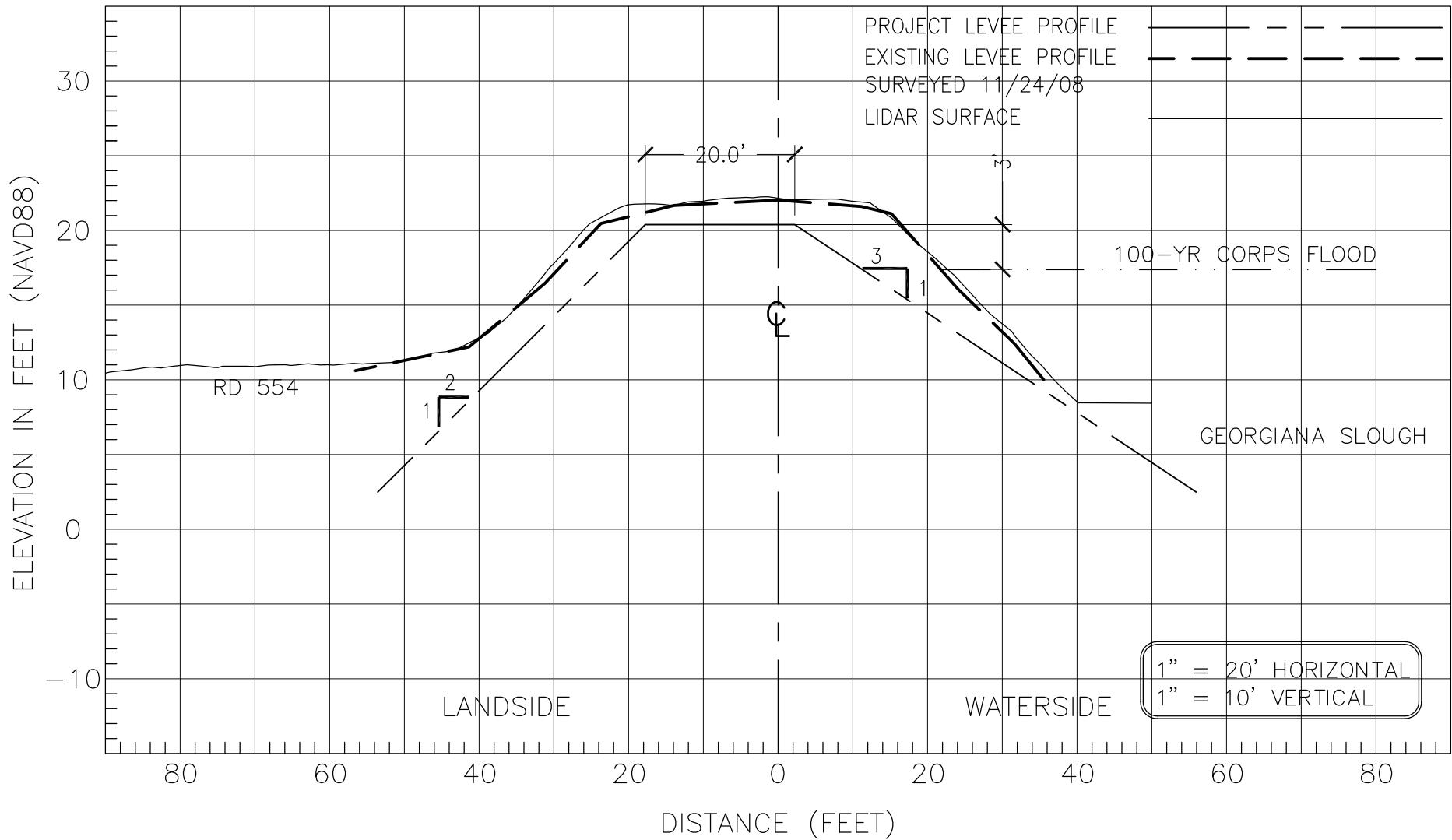
RECLAMATION DISTRICT NO. 554  
GEORGIANA SLOUGH (LEFT BANK)  
LEVEE CROSS SECTION STATION 9+67

PRINT DATE: 8-5-2011



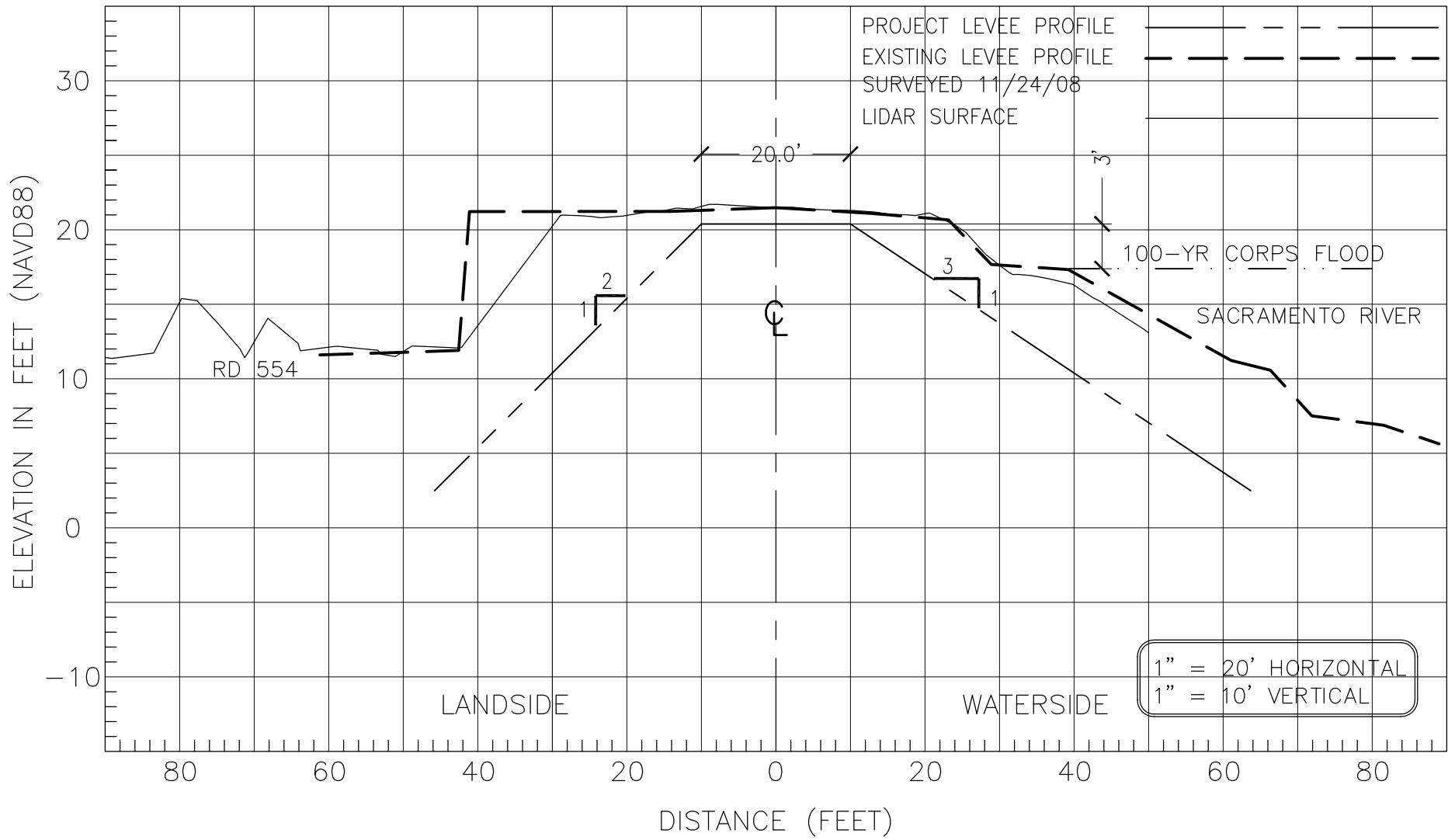
RECLAMATION DISTRICT NO. 554  
GEORGIANA SLOUGH (LEFT BANK)  
LEVEE CROSS SECTION STATION 15+00

PRINT DATE: 8-5-2011



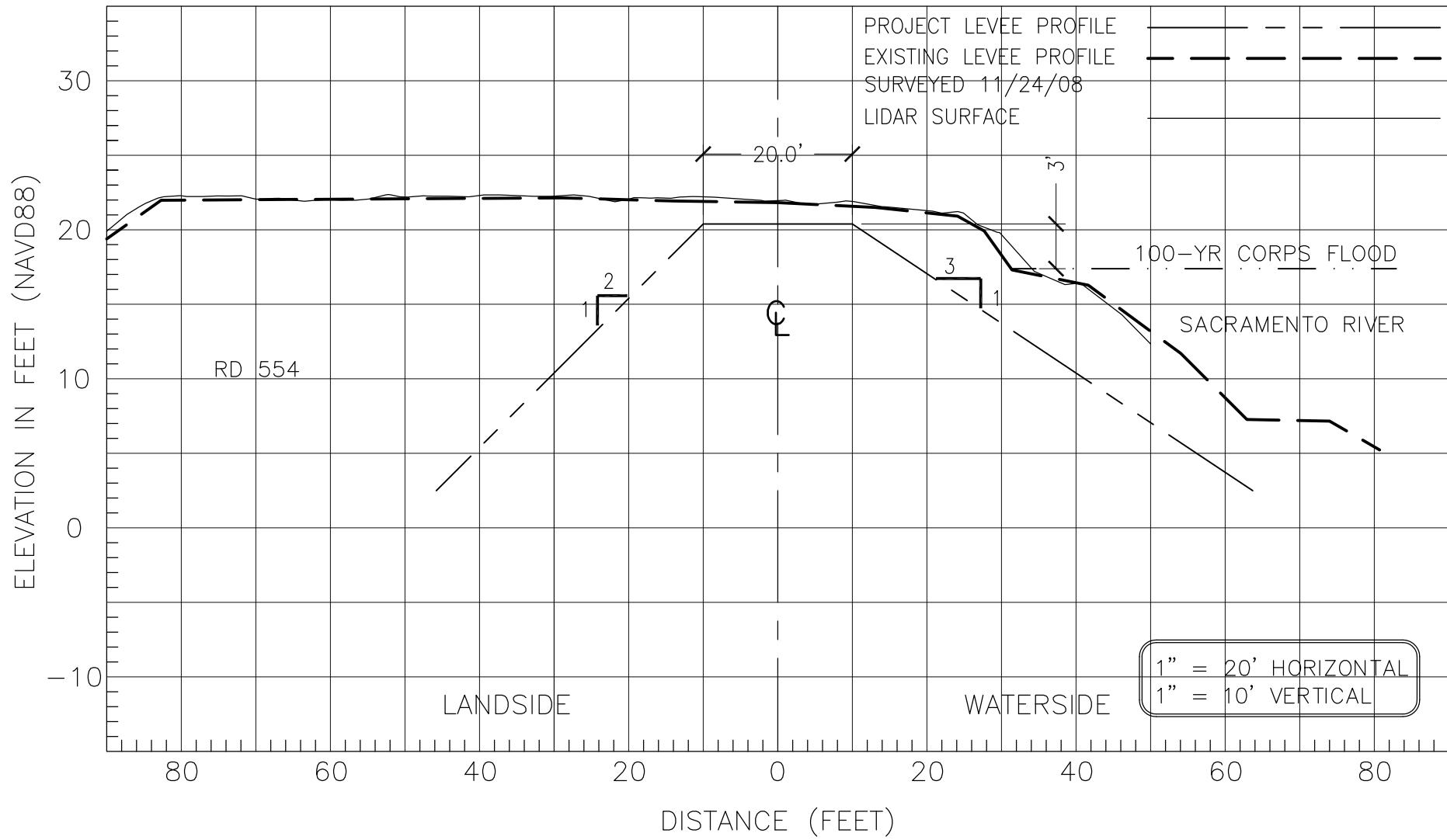
RECLAMATION DISTRICT NO. 554  
SACRAMENTO RIVER (LEFT BANK)  
LEVEE CROSS SECTION STATION 20+00

PRINT DATE: 8-5-2011



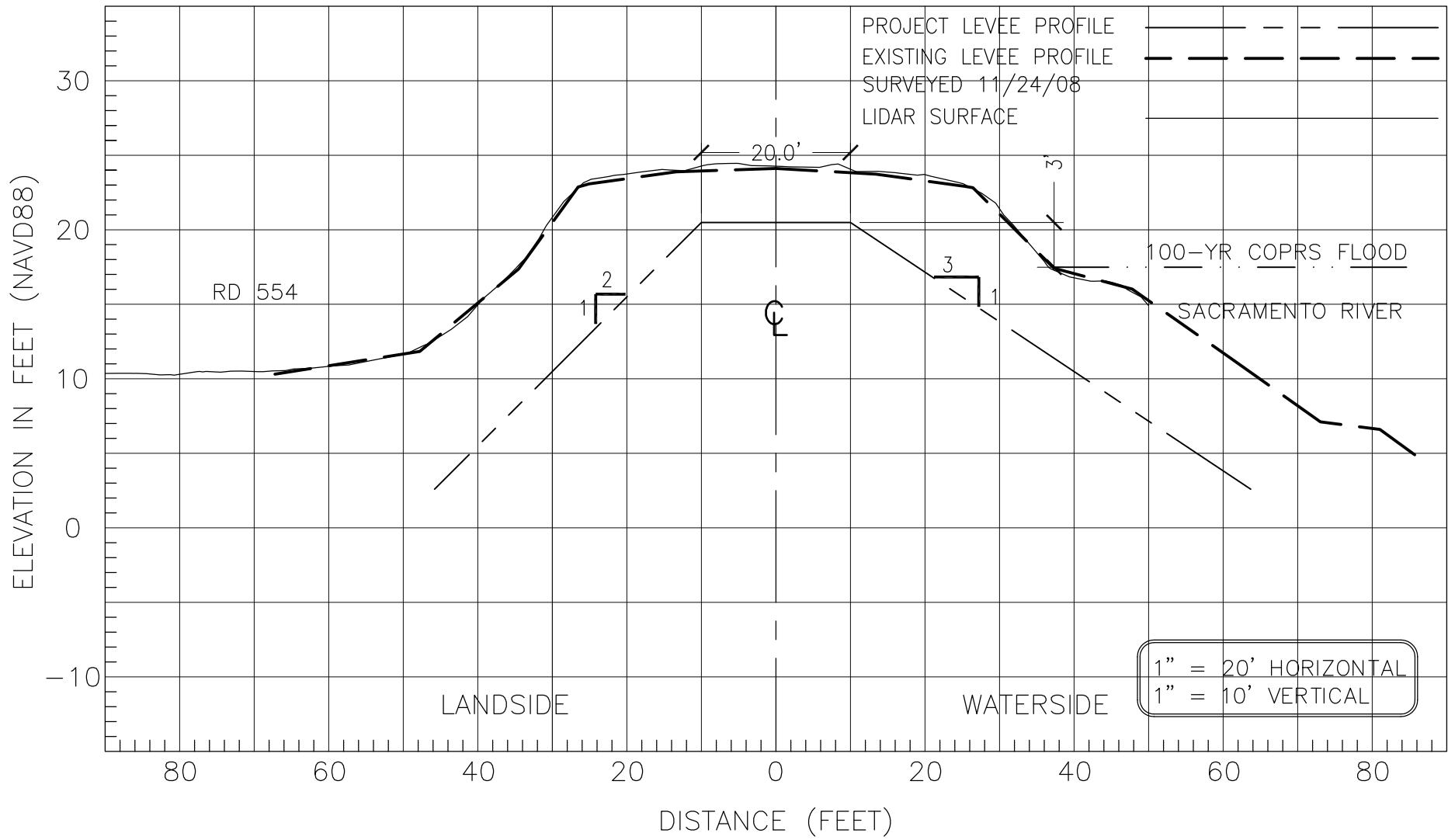
RECLAMATION DISTRICT NO. 554  
SACRAMENTO RIVER (LEFT BANK)  
LEVEE CROSS SECTION STATION 23+21

PRINT DATE: 8-5-2011



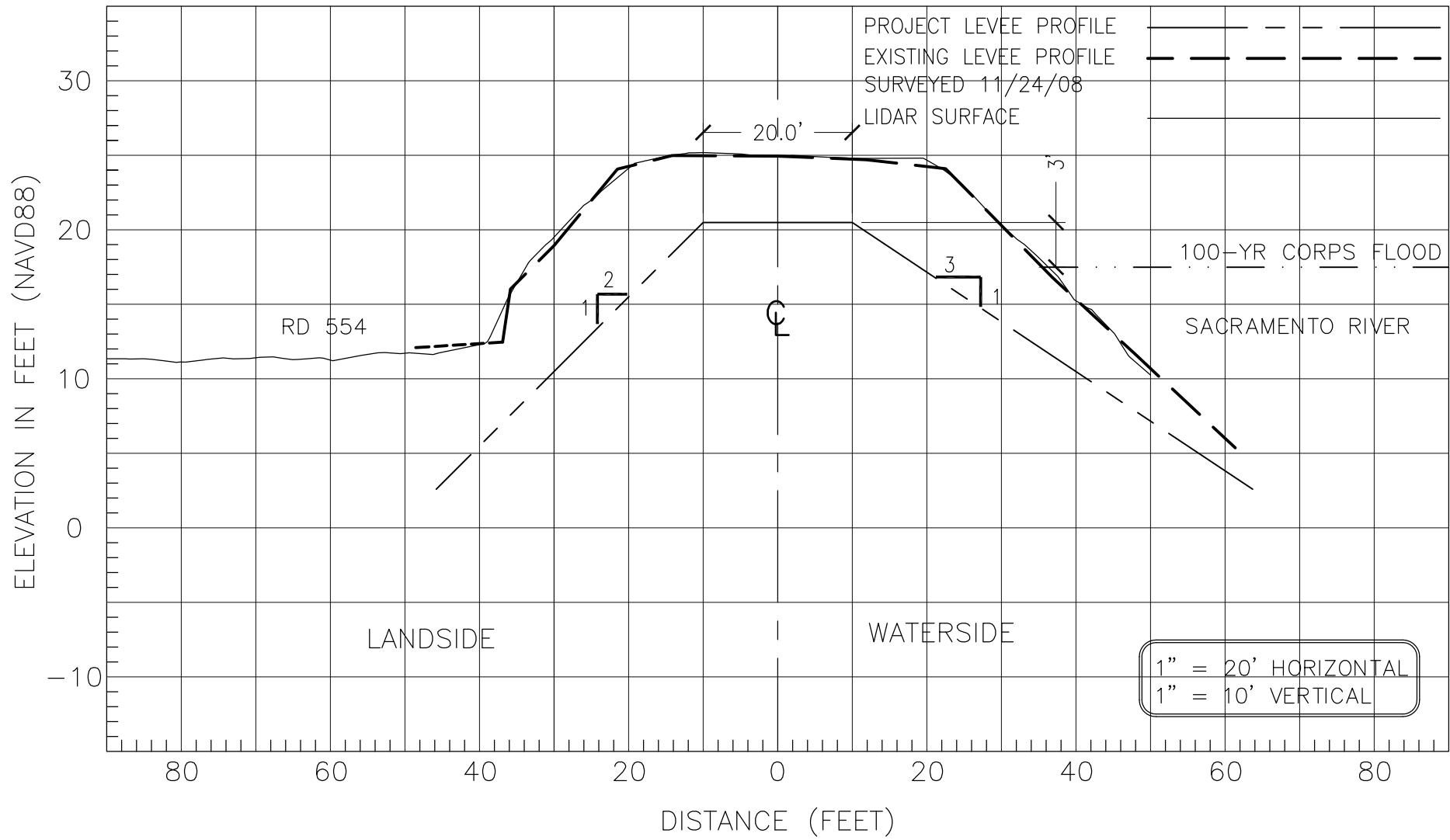
RECLAMATION DISTRICT NO. 554  
SACRAMENTO RIVER (LEFT BANK)  
LEVEE CROSS SECTION STATION 24+89

PRINT DATE: 8-5-2011



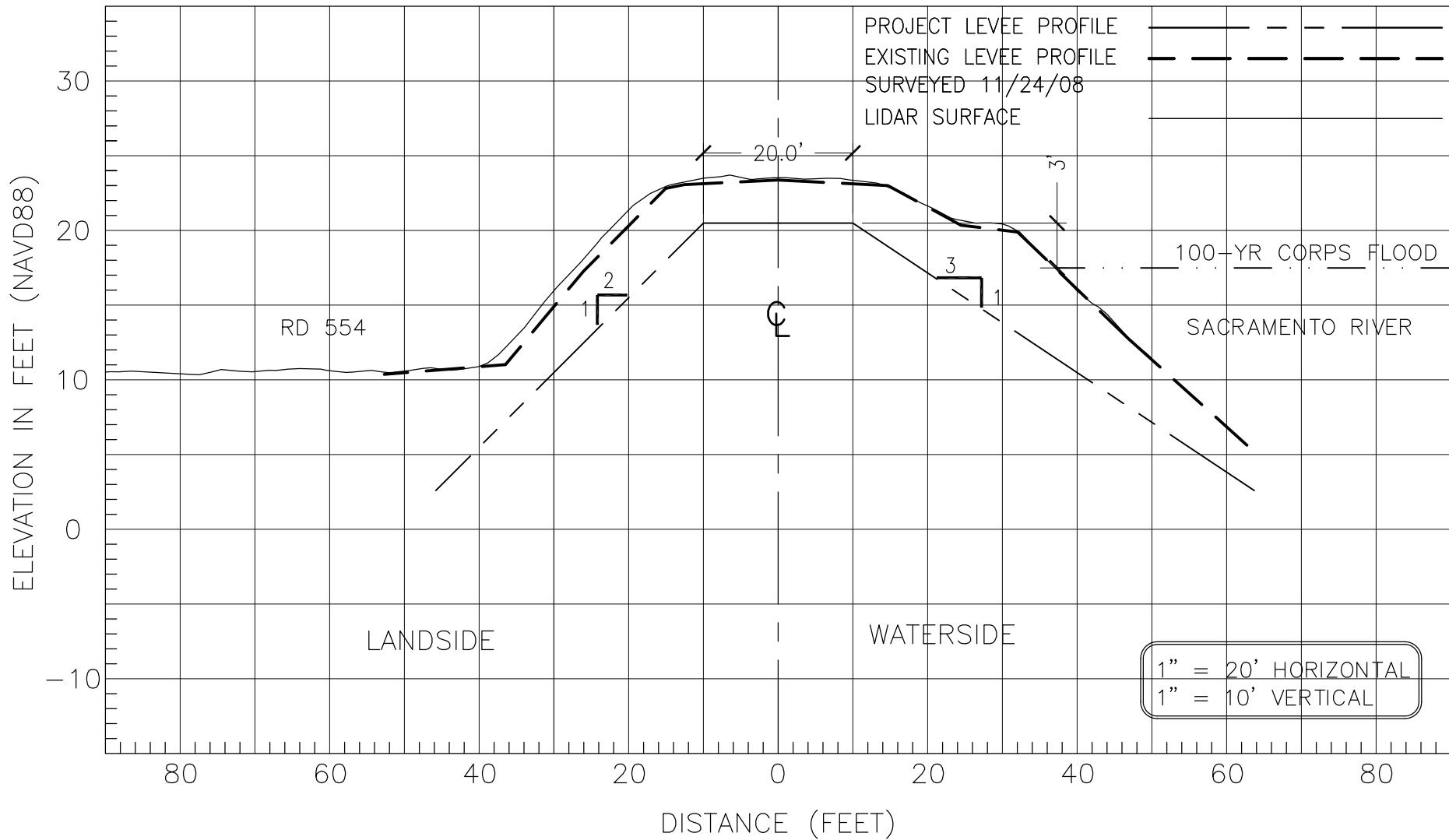
RECLAMATION DISTRICT NO. 554  
SACRAMENTO RIVER (LEFT BANK)  
LEVEE CROSS SECTION STATION 29+32

PRINT DATE: 8-5-2011



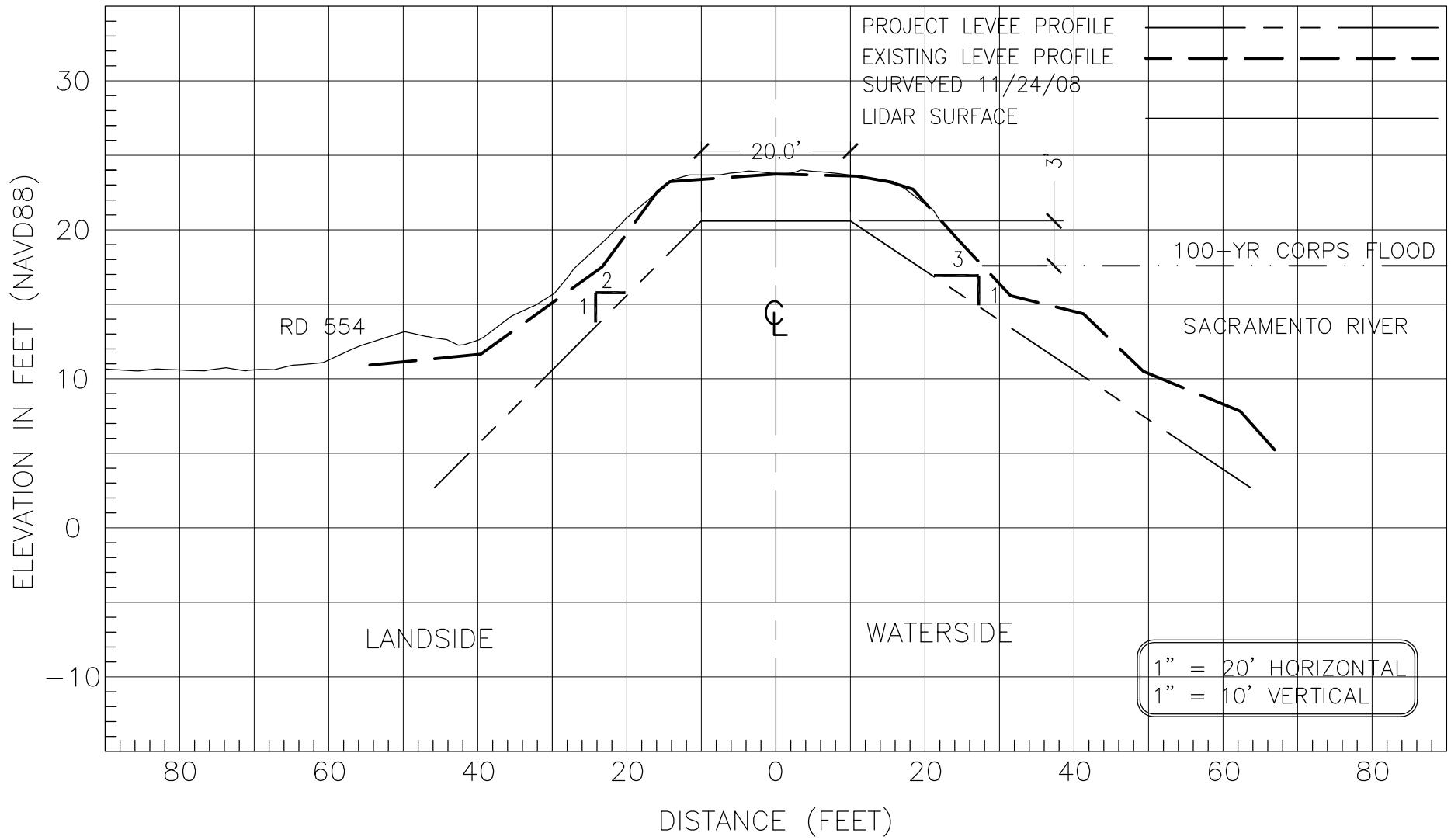
RECLAMATION DISTRICT NO. 554  
SACRAMENTO RIVER (LEFT BANK)  
LEVEE CROSS SECTION STATION 35+50

PRINT DATE: 8-5-2011



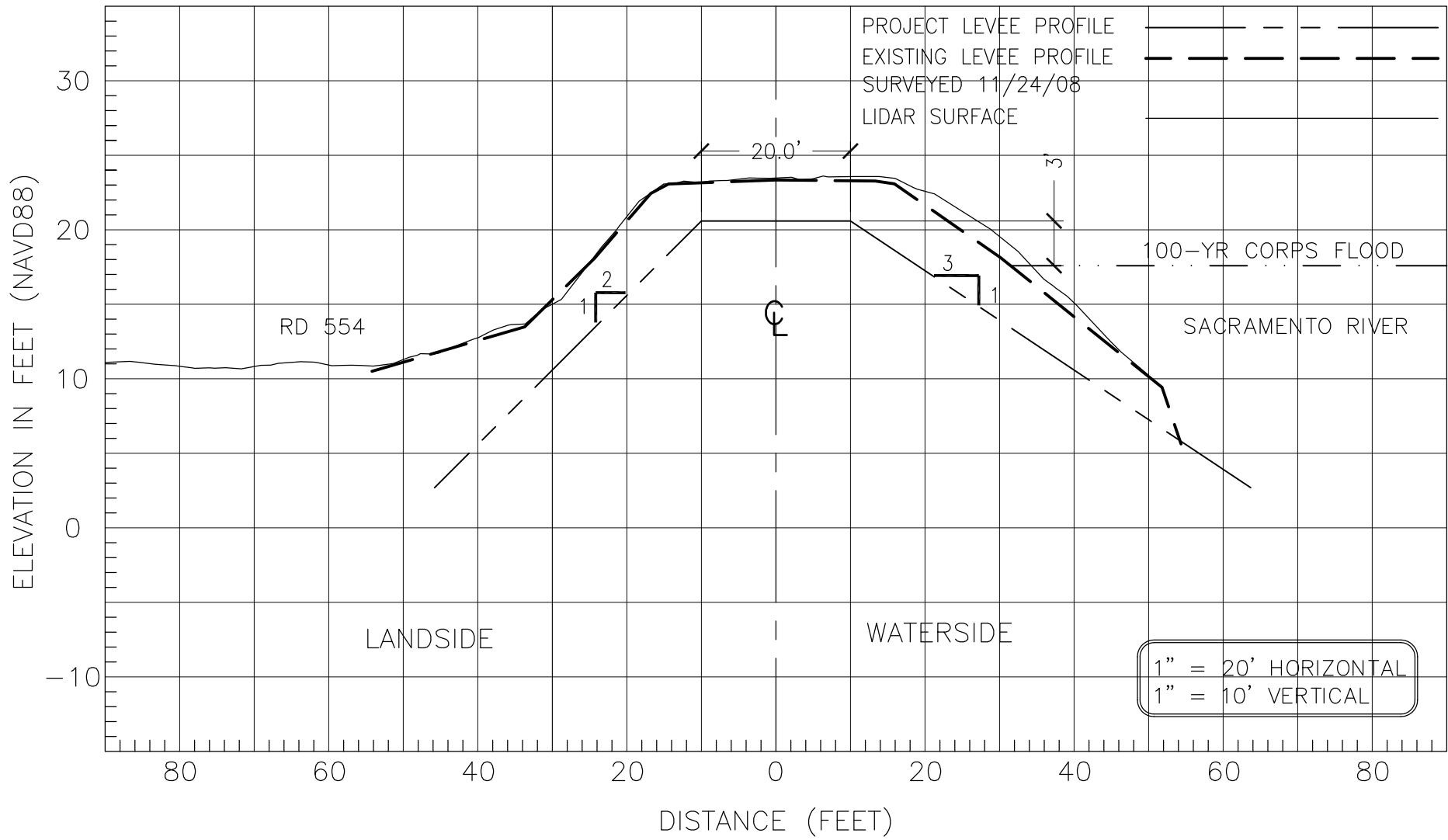
RECLAMATION DISTRICT NO. 554  
SACRAMENTO RIVER (LEFT BANK)  
LEVEE CROSS SECTION STATION 39+60

PRINT DATE: 8-5-2011



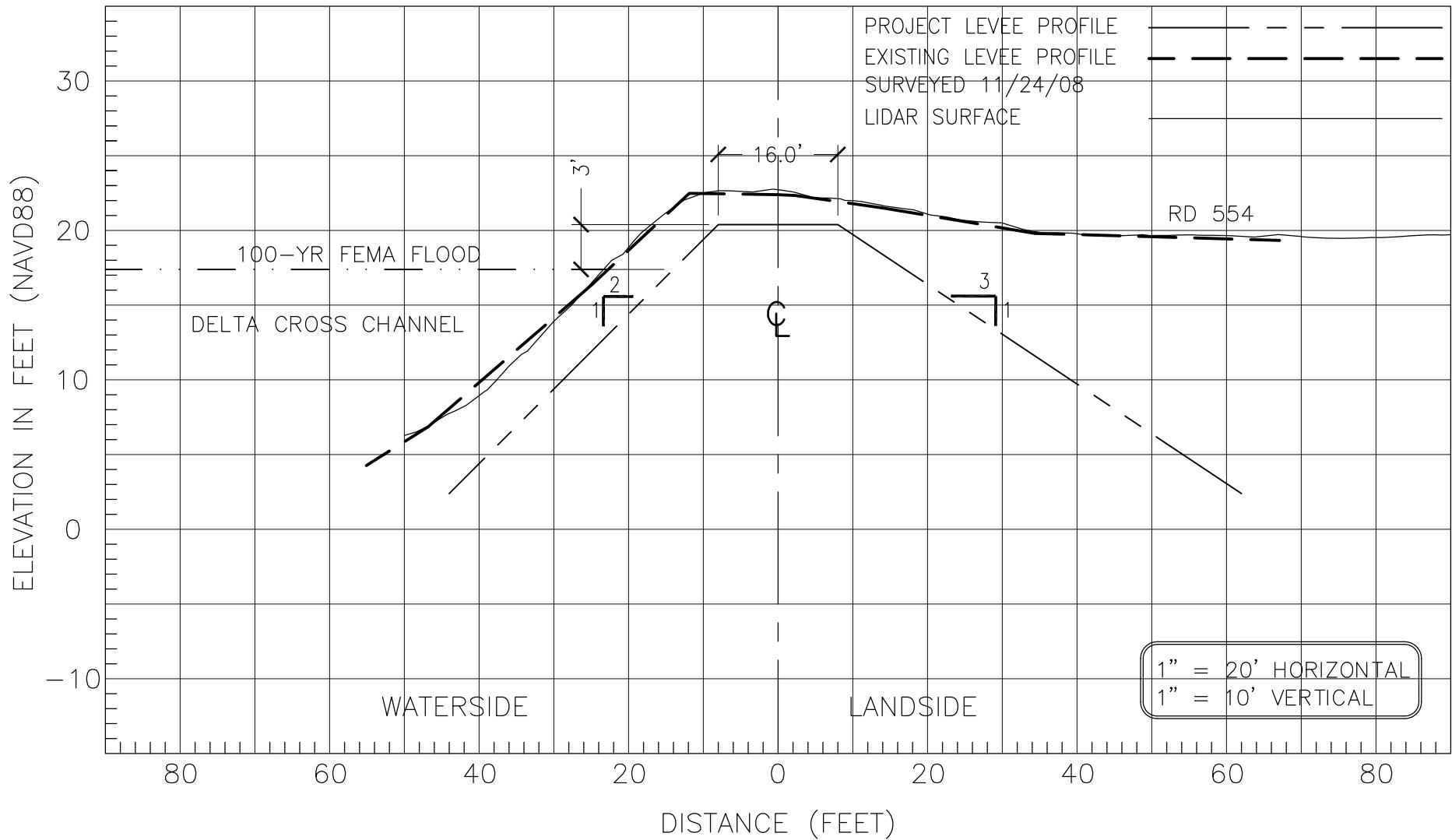
RECLAMATION DISTRICT NO. 554  
SACRAMENTO RIVER (LEFT BANK)  
LEVEE CROSS SECTION STATION 45+56

PRINT DATE: 8-5-2011



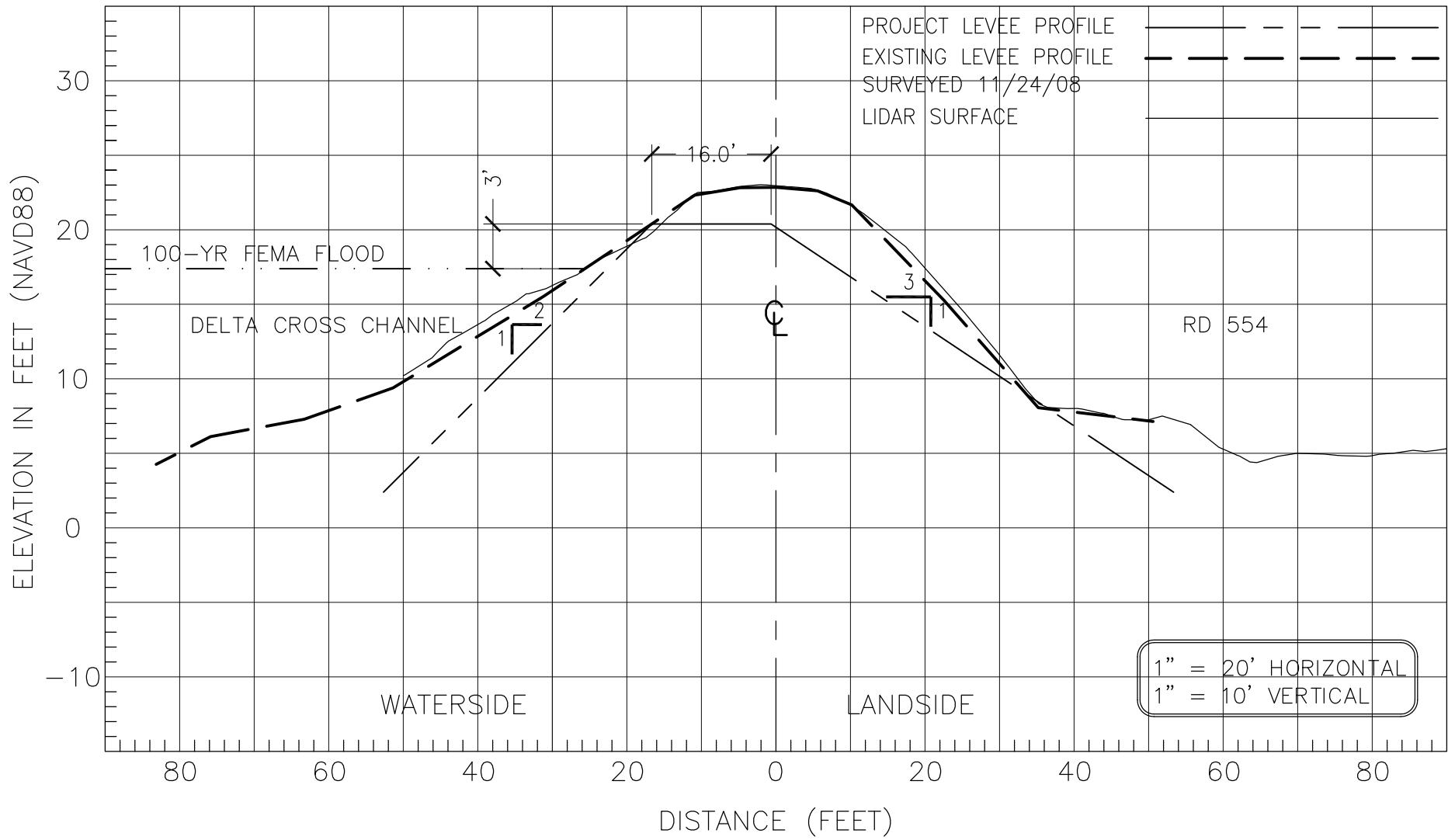
RECLAMATION DISTRICT NO. 554  
DELTA CROSS CHANNEL (RIGHT BANK)  
LEVEE CROSS SECTION STATION 50+35

PRINT DATE: 8-5-2011



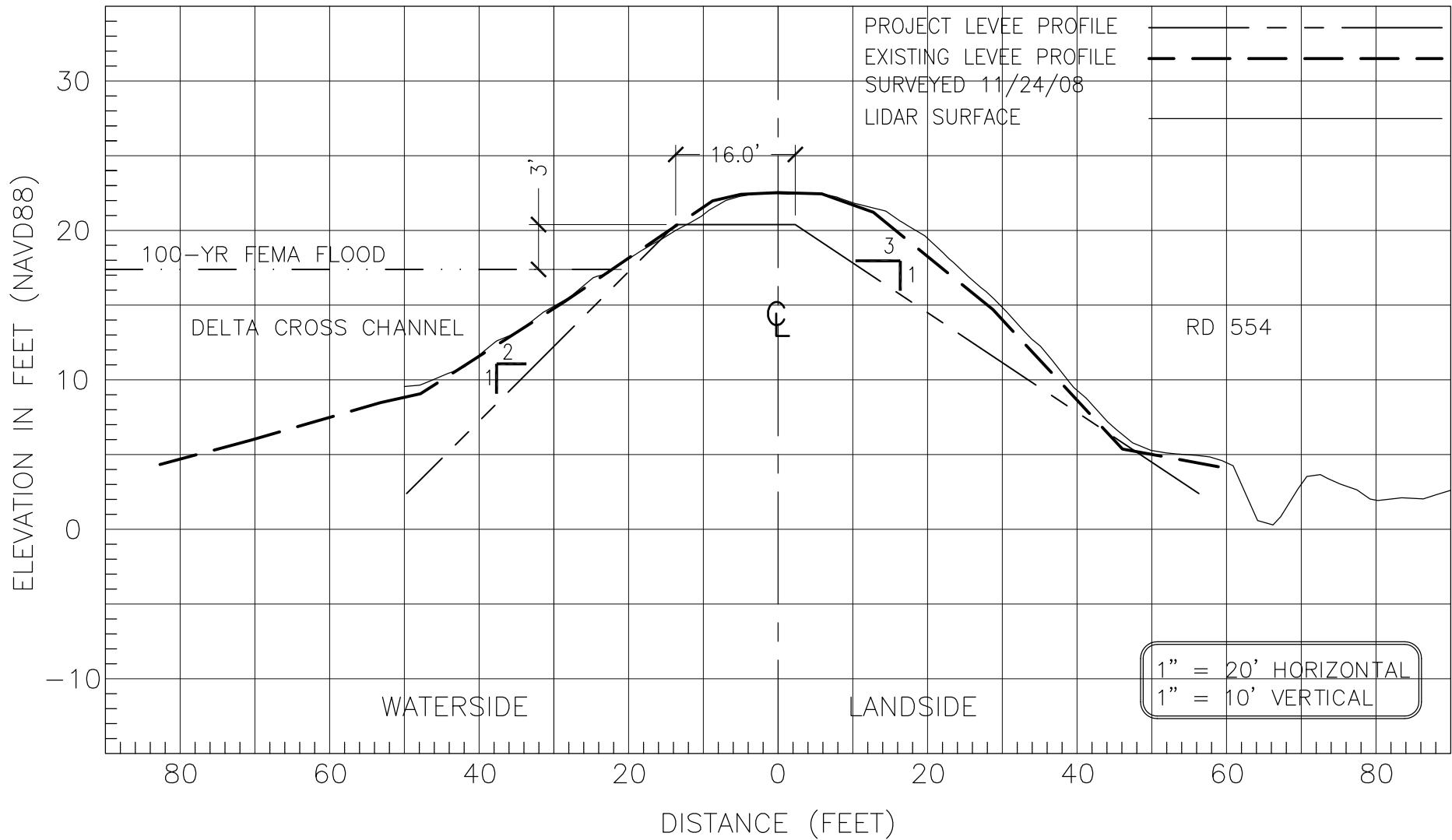
RECLAMATION DISTRICT NO. 554  
DELTA CROSS CHANNEL (RIGHT BANK)  
LEVEE CROSS SECTION STATION 55+30

PRINT DATE: 8-5-2011



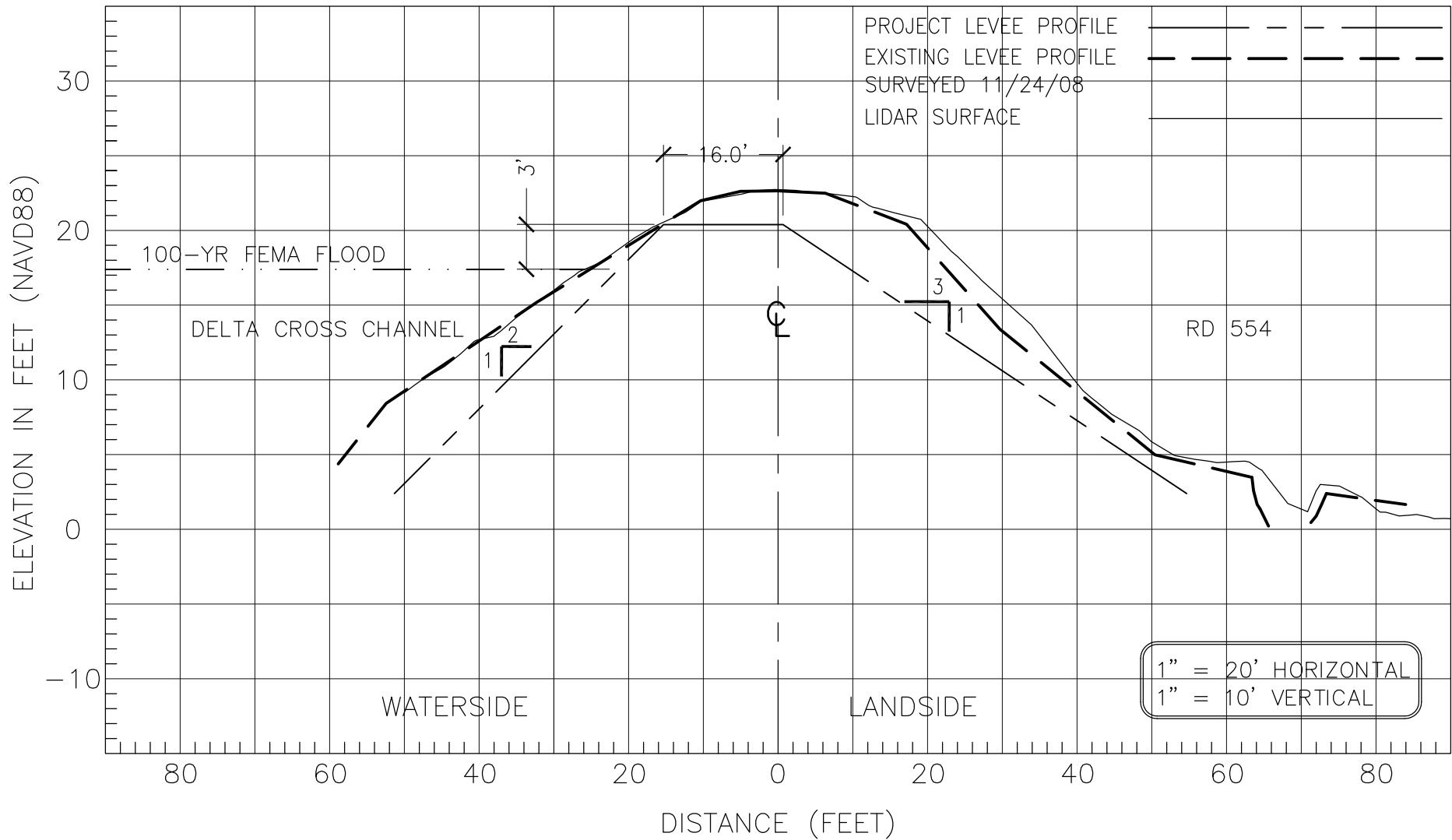
RECLAMATION DISTRICT NO. 554  
DELTA CROSS CHANNEL (RIGHT BANK)  
LEVEE CROSS SECTION STATION 60+00

PRINT DATE: 8-5-2011



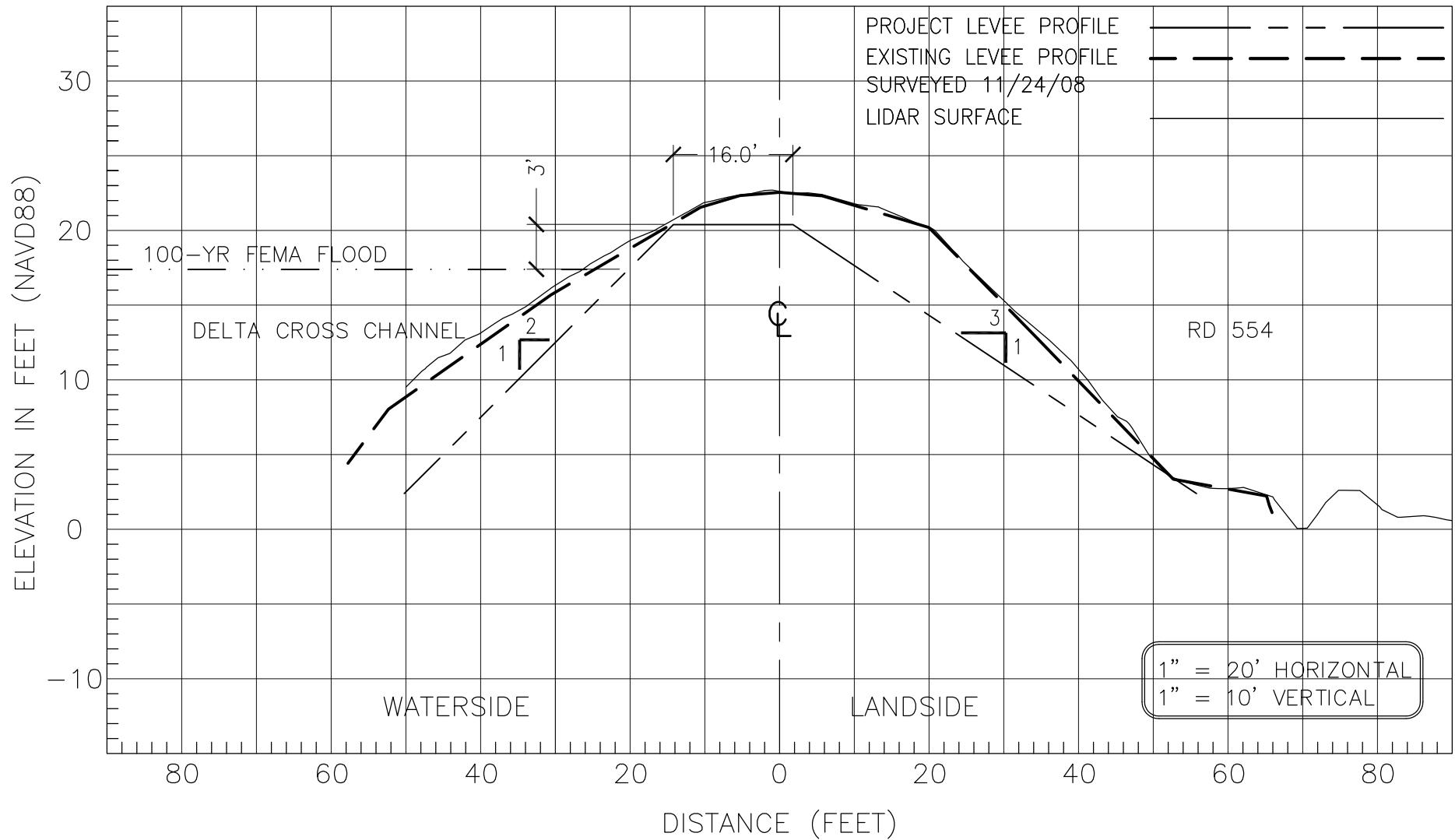
RECLAMATION DISTRICT NO. 554  
DELTA CROSS CHANNEL (RIGHT BANK)  
LEVEE CROSS SECTION STATION 65+00

PRINT DATE: 8-5-2011



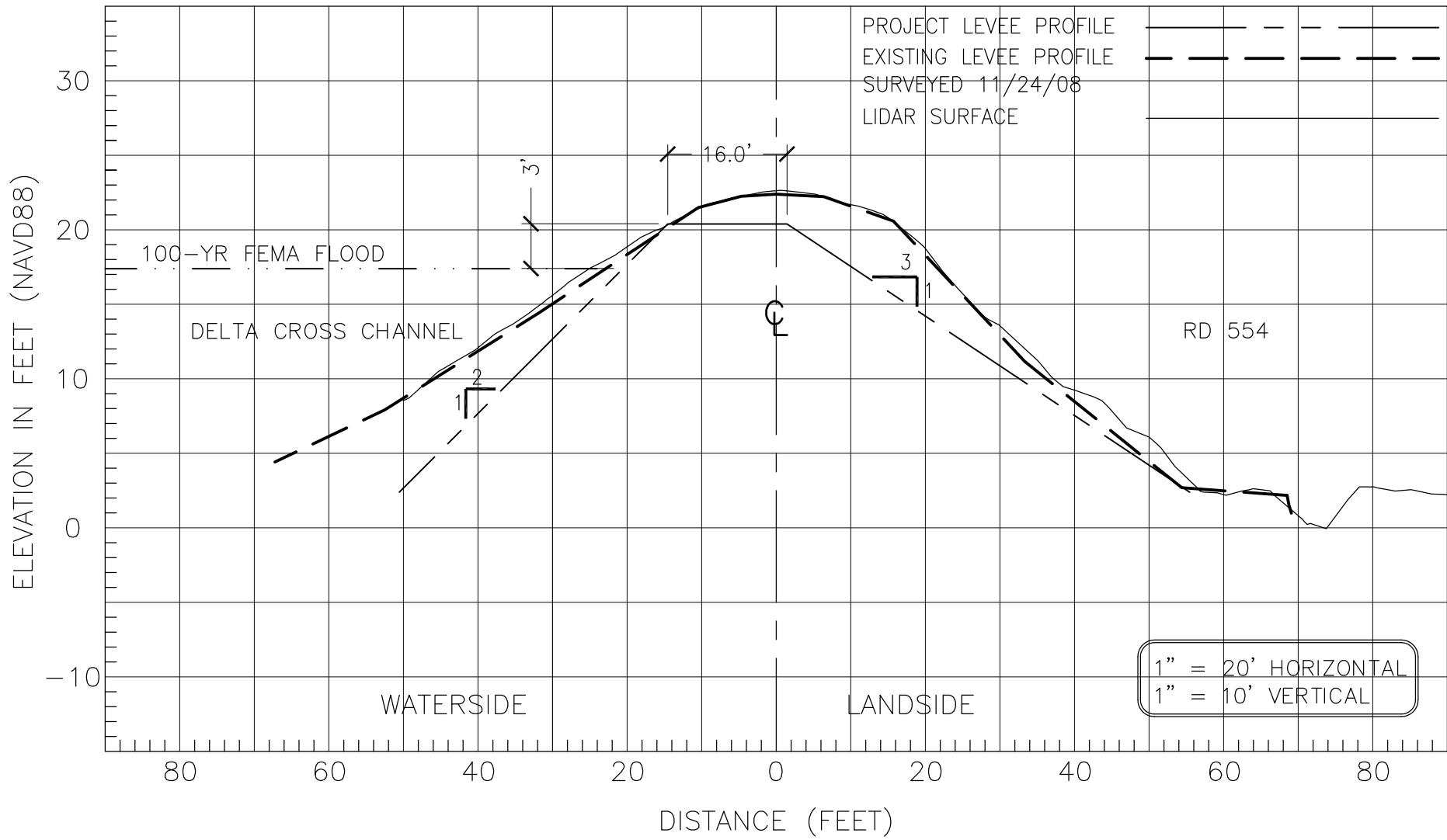
RECLAMATION DISTRICT NO. 554  
DELTA CROSS CHANNEL (RIGHT BANK)  
LEVEE CROSS SECTION STATION 70+09

PRINT DATE: 8-5-2011



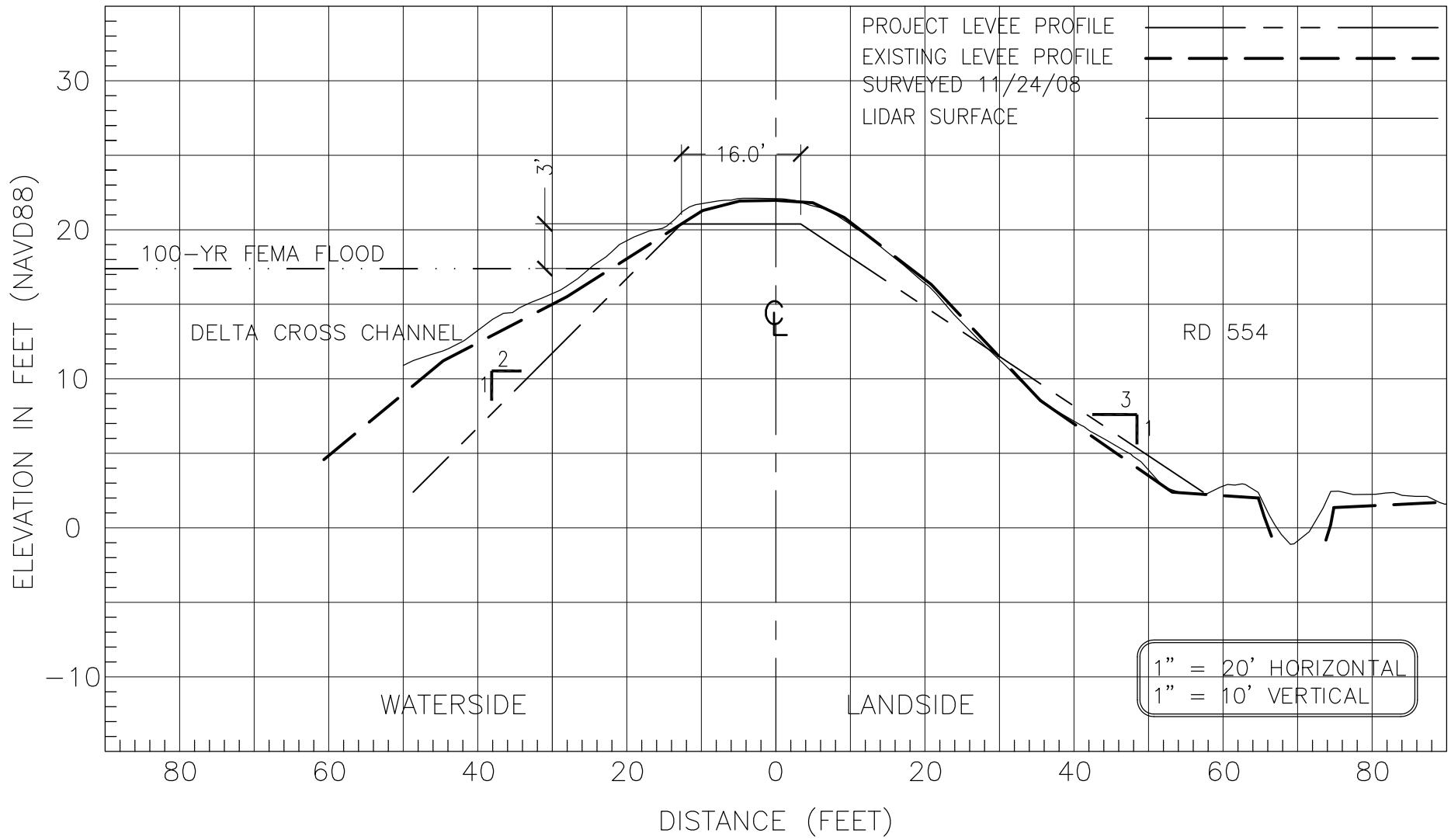
RECLAMATION DISTRICT NO. 554  
DELTA CROSS CHANNEL (RIGHT BANK)  
LEVEE CROSS SECTION STATION 75+00

PRINT DATE: 8-5-2011



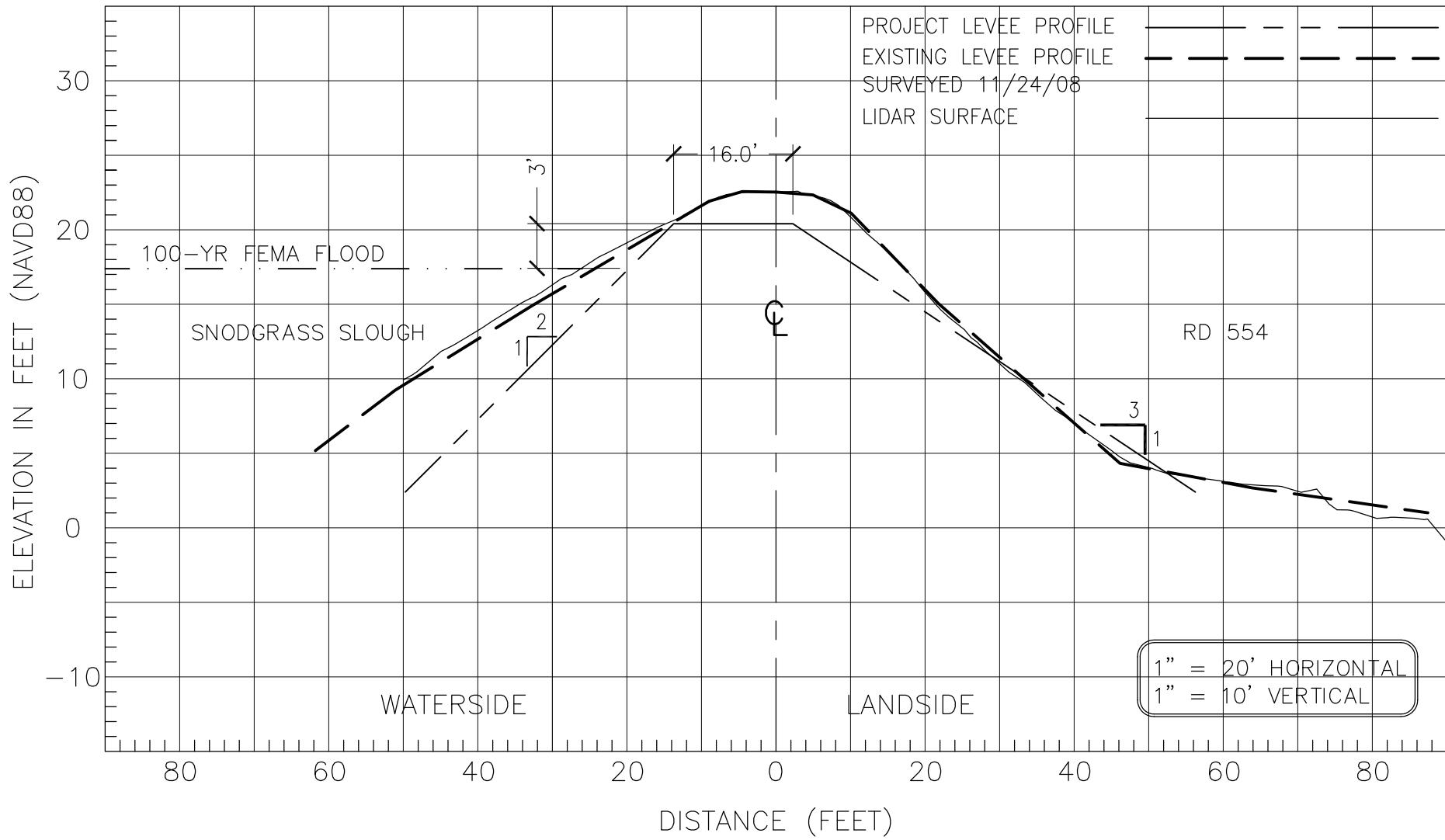
RECLAMATION DISTRICT NO. 554  
DELTA CROSS CHANNEL (RIGHT BANK)  
LEVEE CROSS SECTION STATION 80+00

PRINT DATE: 8-5-2011



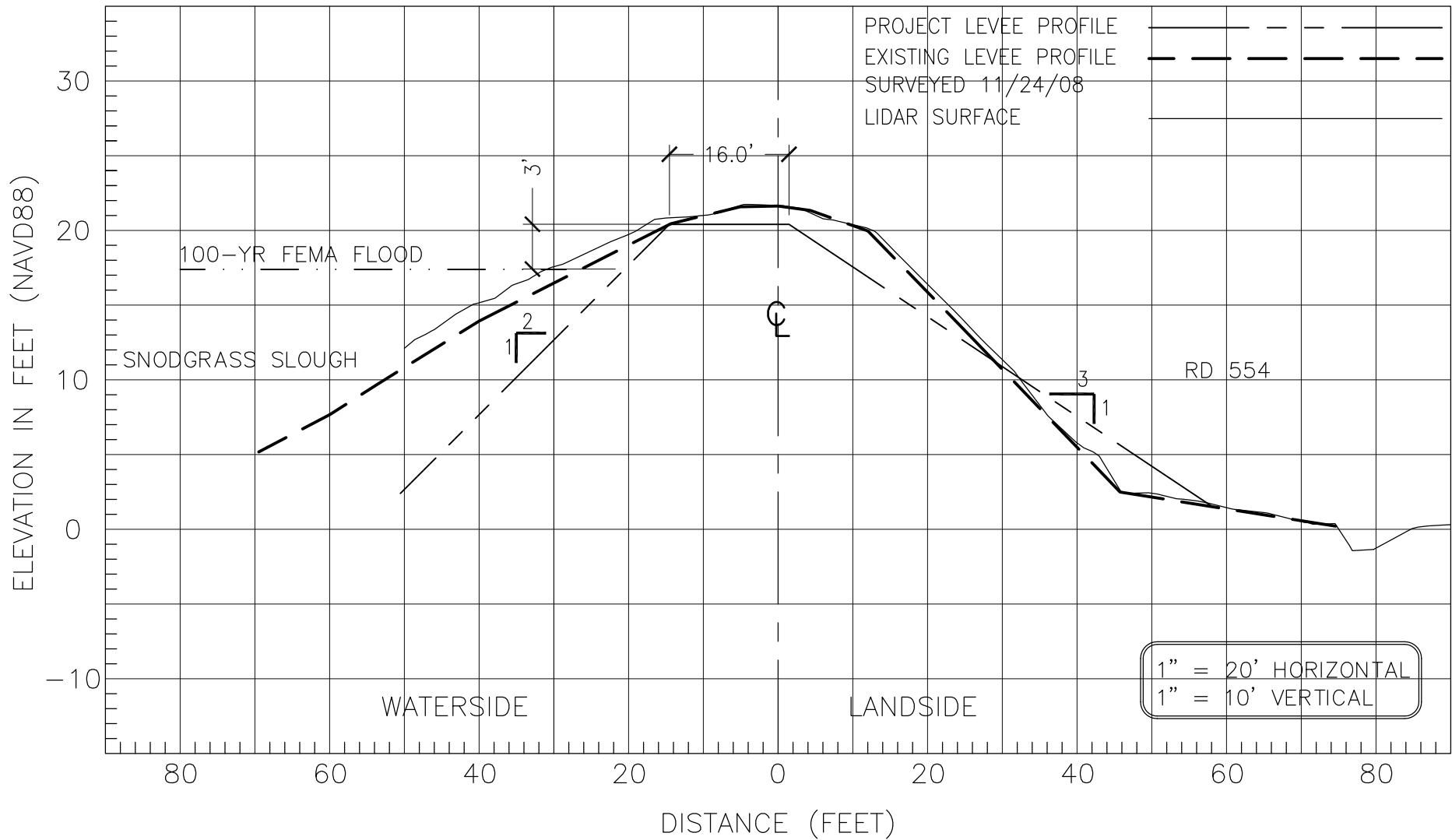
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 85+00

PRINT DATE: 8-5-2011



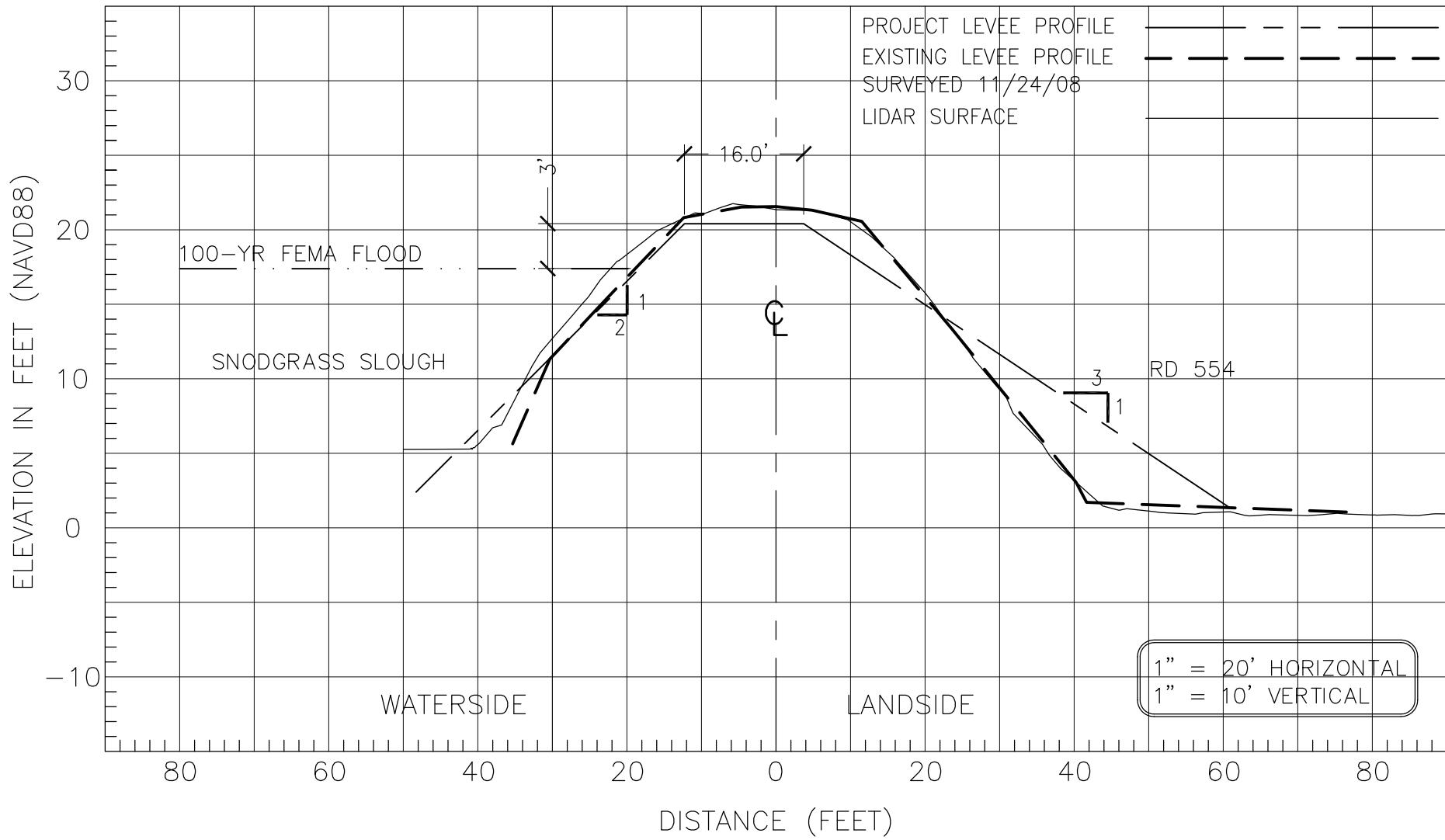
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 90+00

PRINT DATE: 8-5-2011



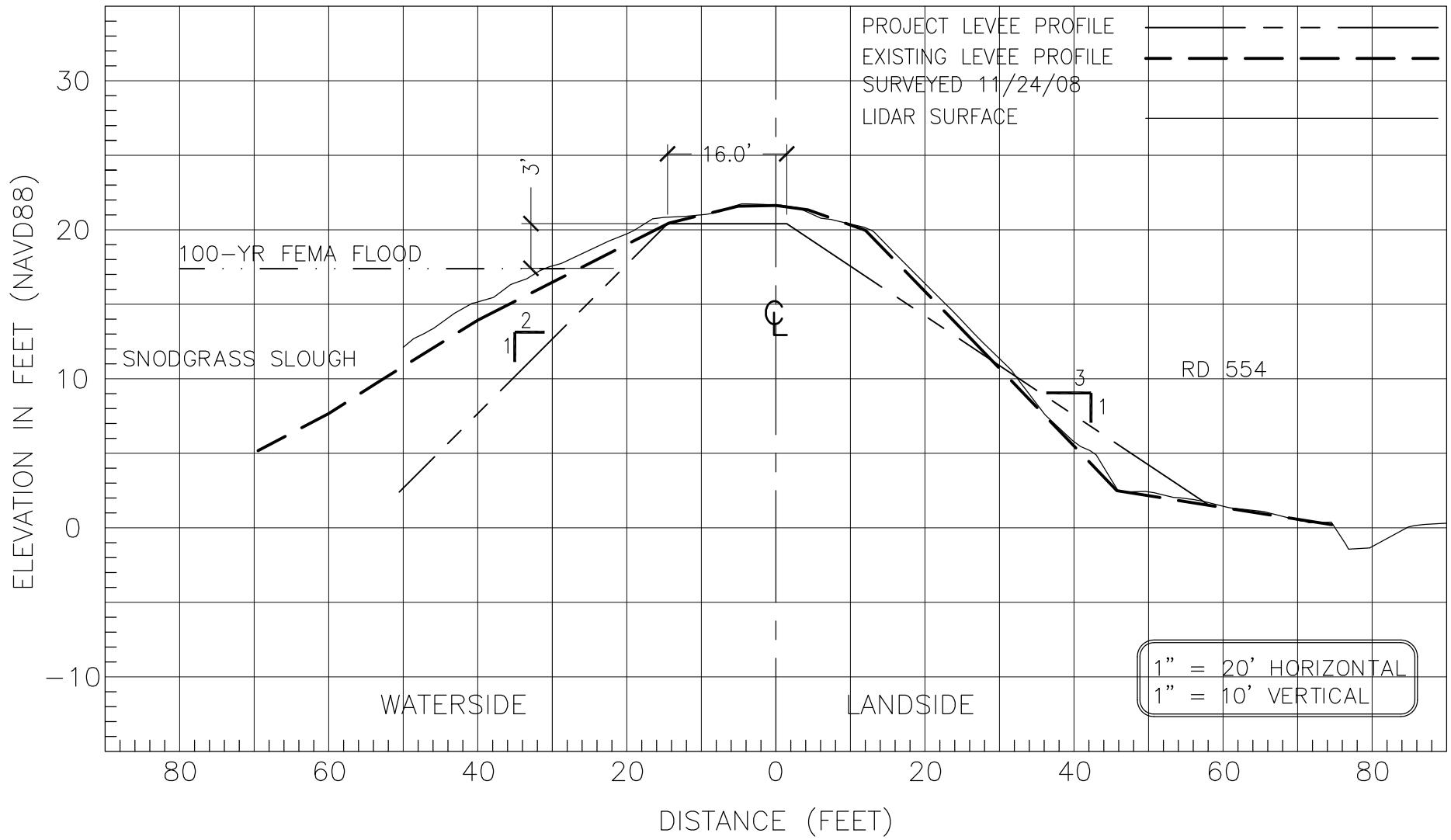
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 95+00

PRINT DATE: 8-5-2011



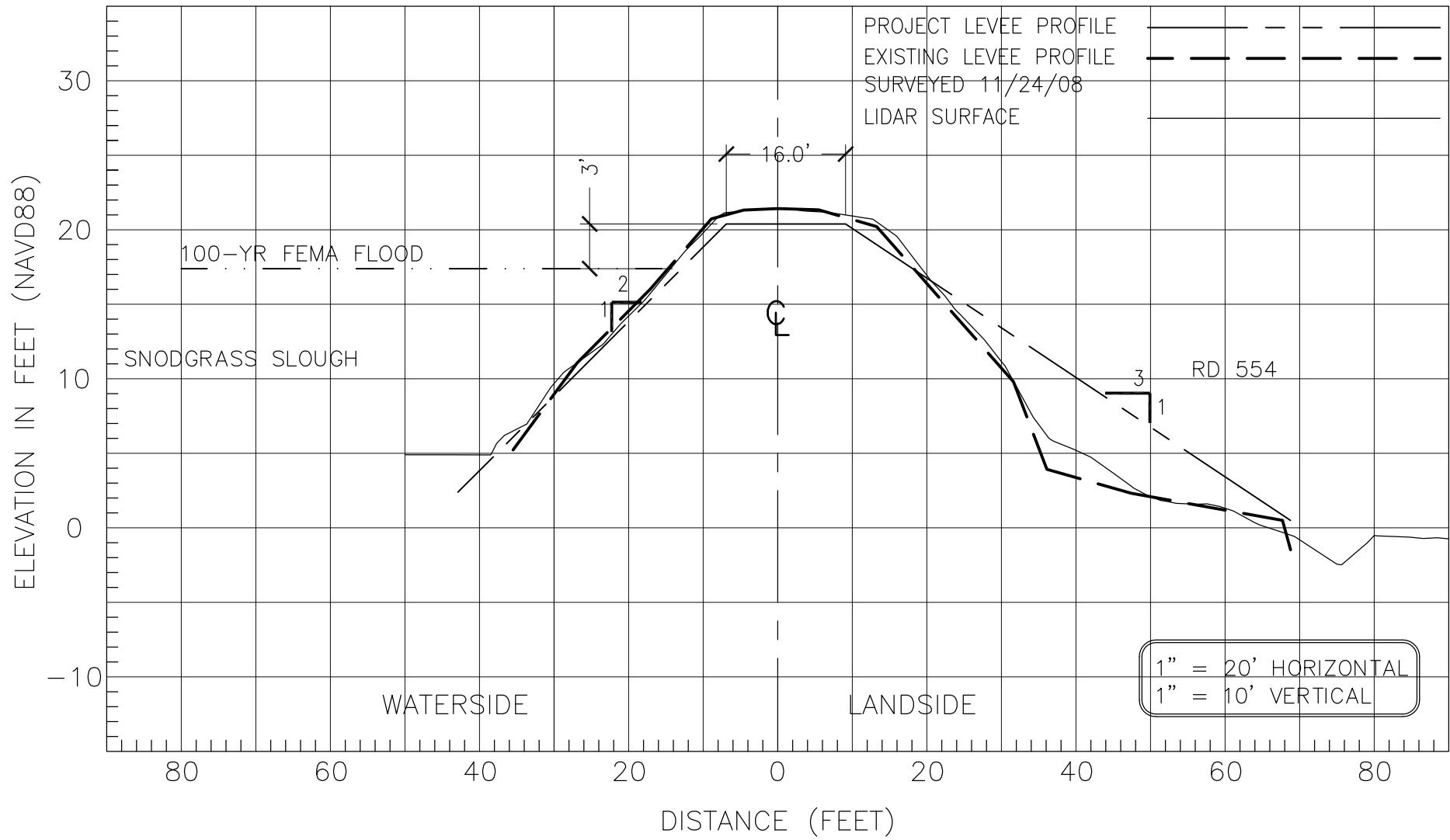
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 90+00

PRINT DATE: 8-5-2011



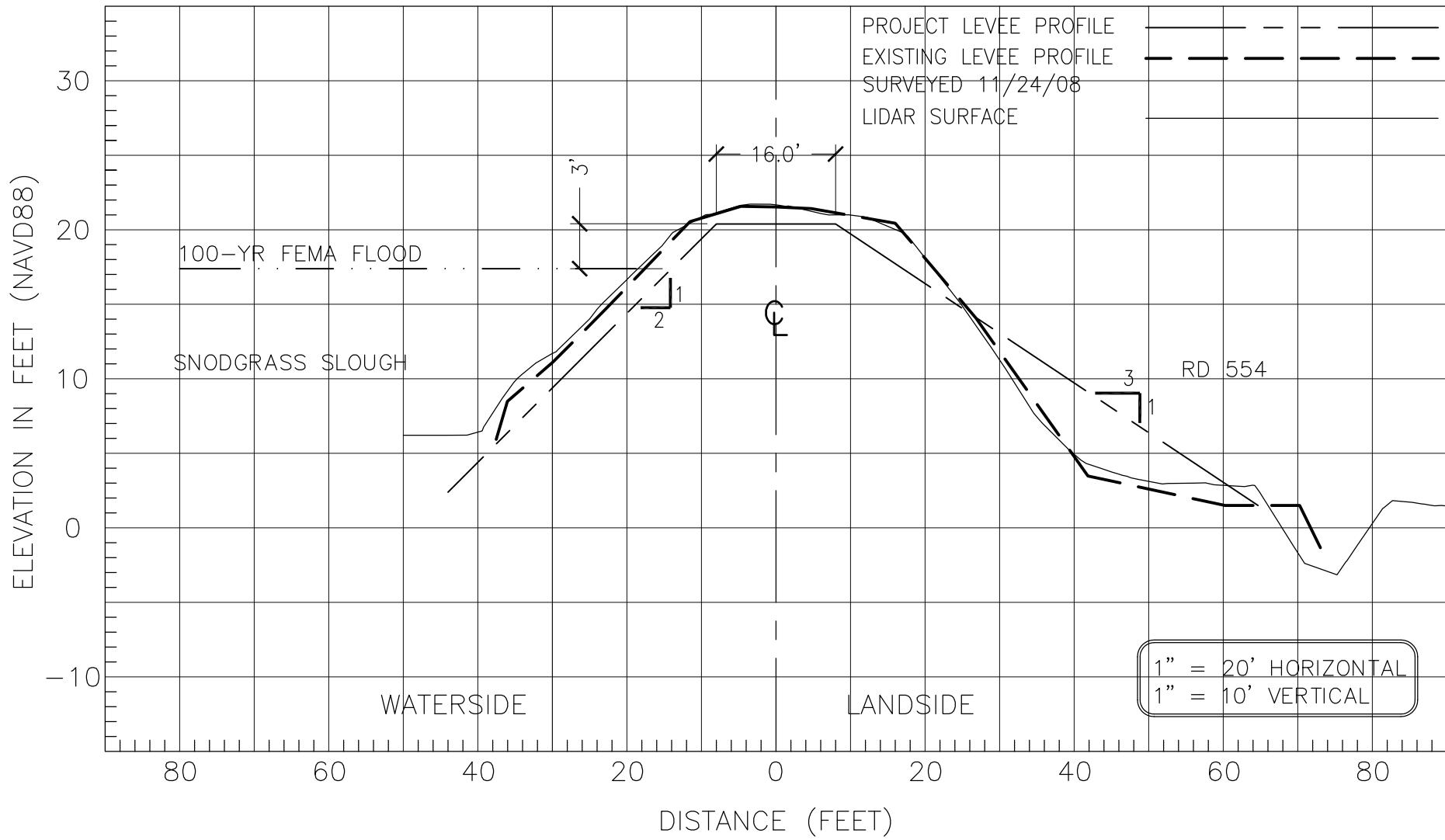
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 99+44

PRINT DATE: 8-5-2011



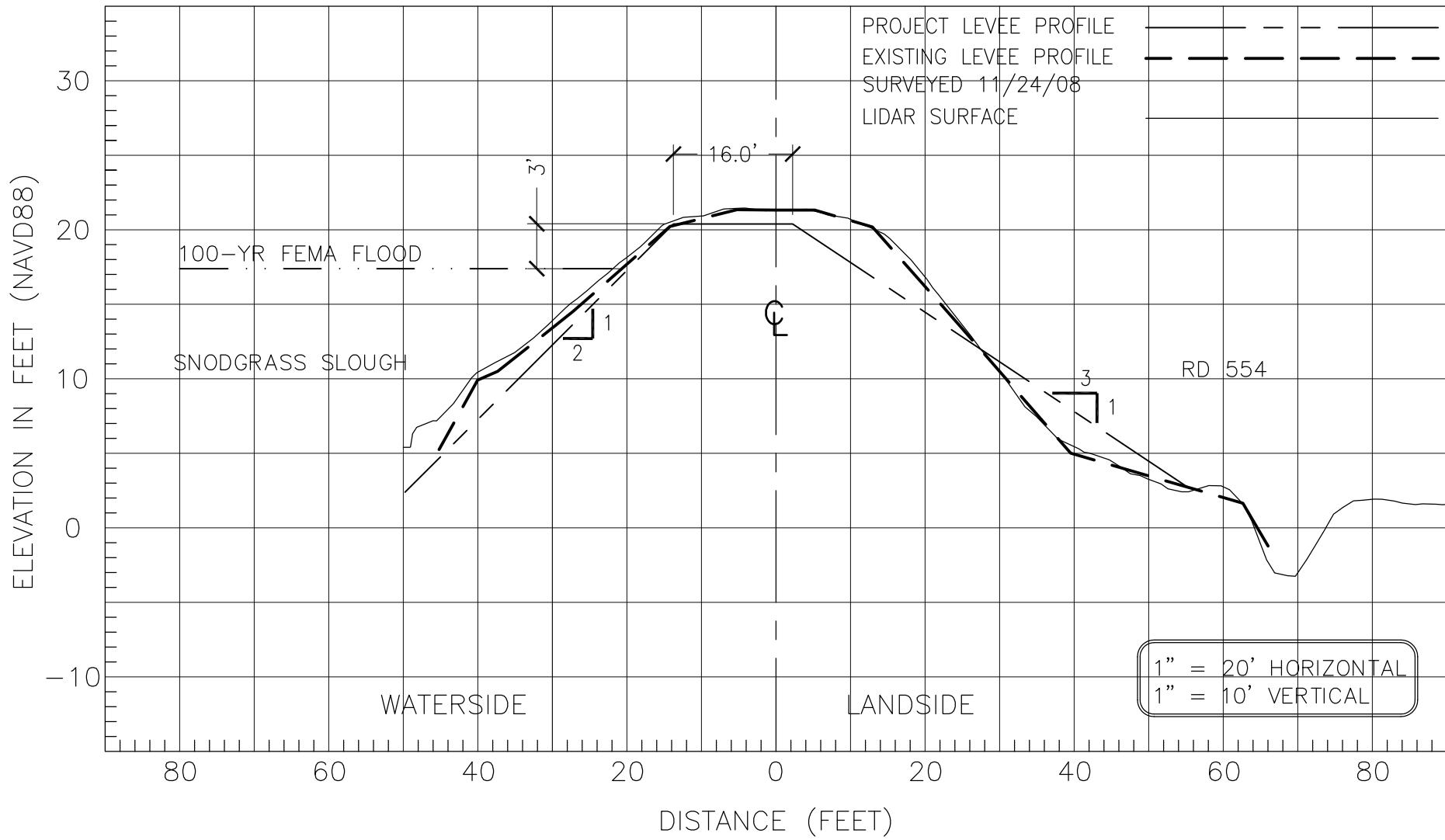
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 111+03

PRINT DATE: 8-5-2011



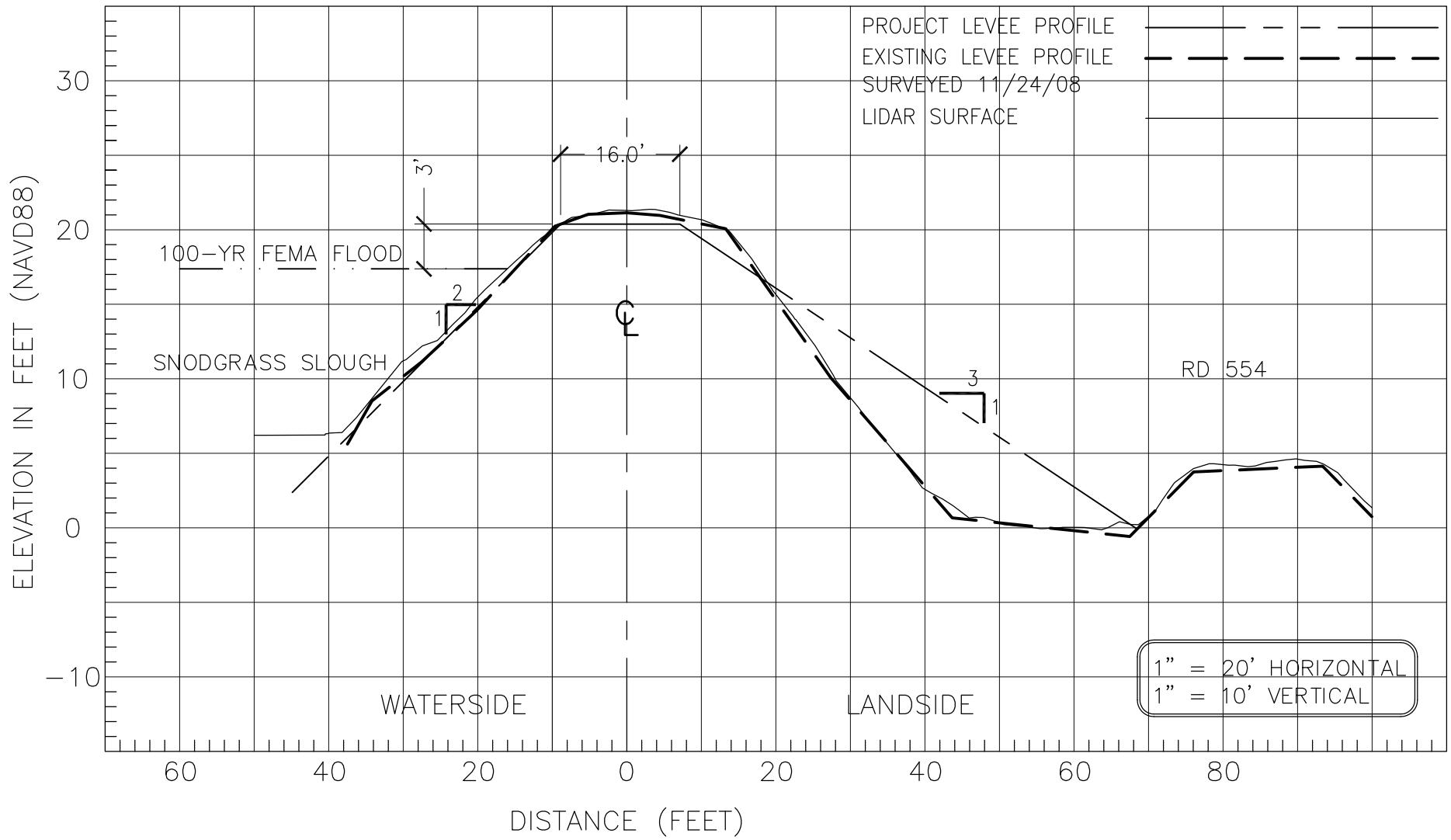
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 114+96

PRINT DATE: 8-5-2011



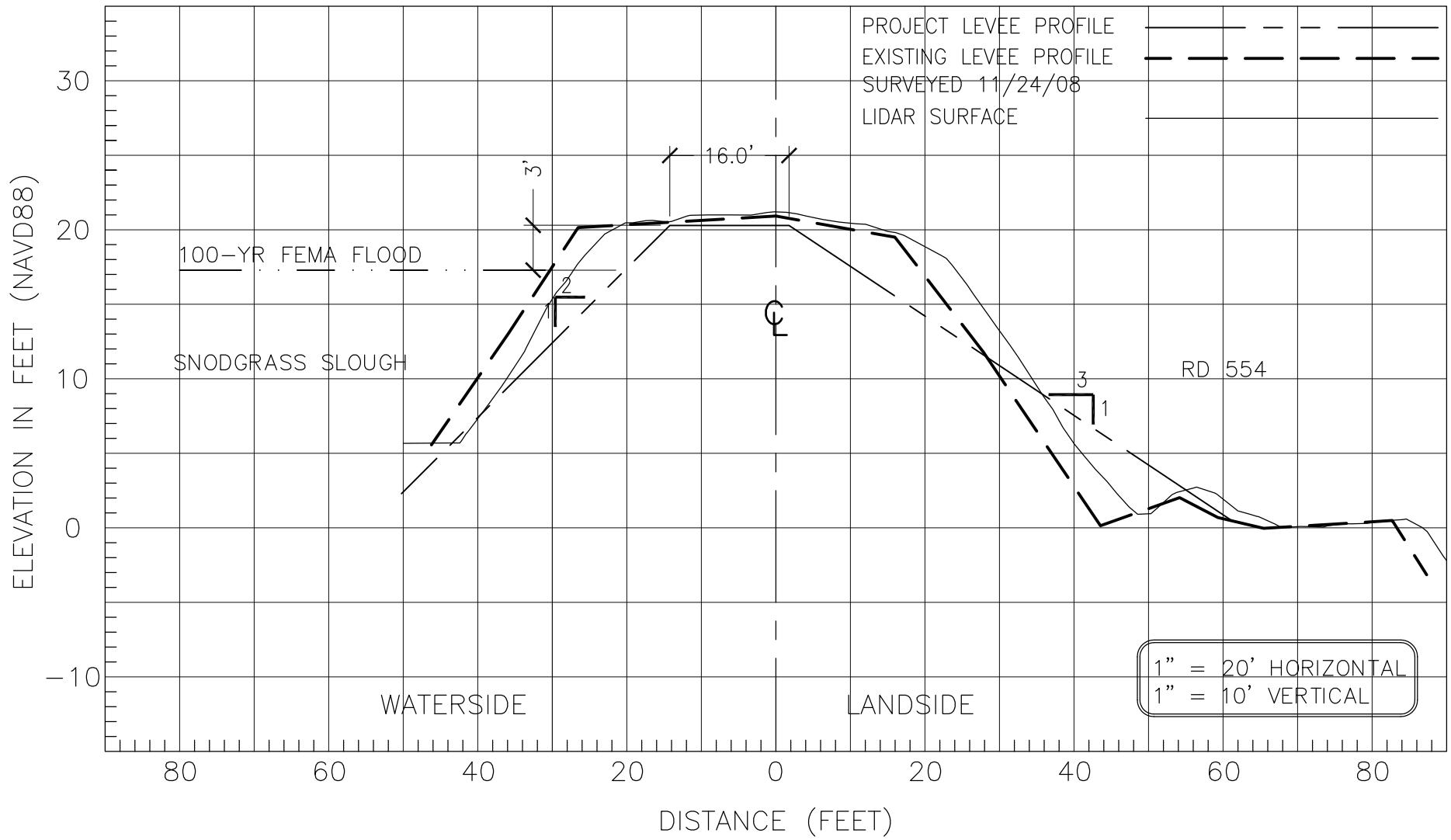
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 119+93

PRINT DATE: 8-5-2011



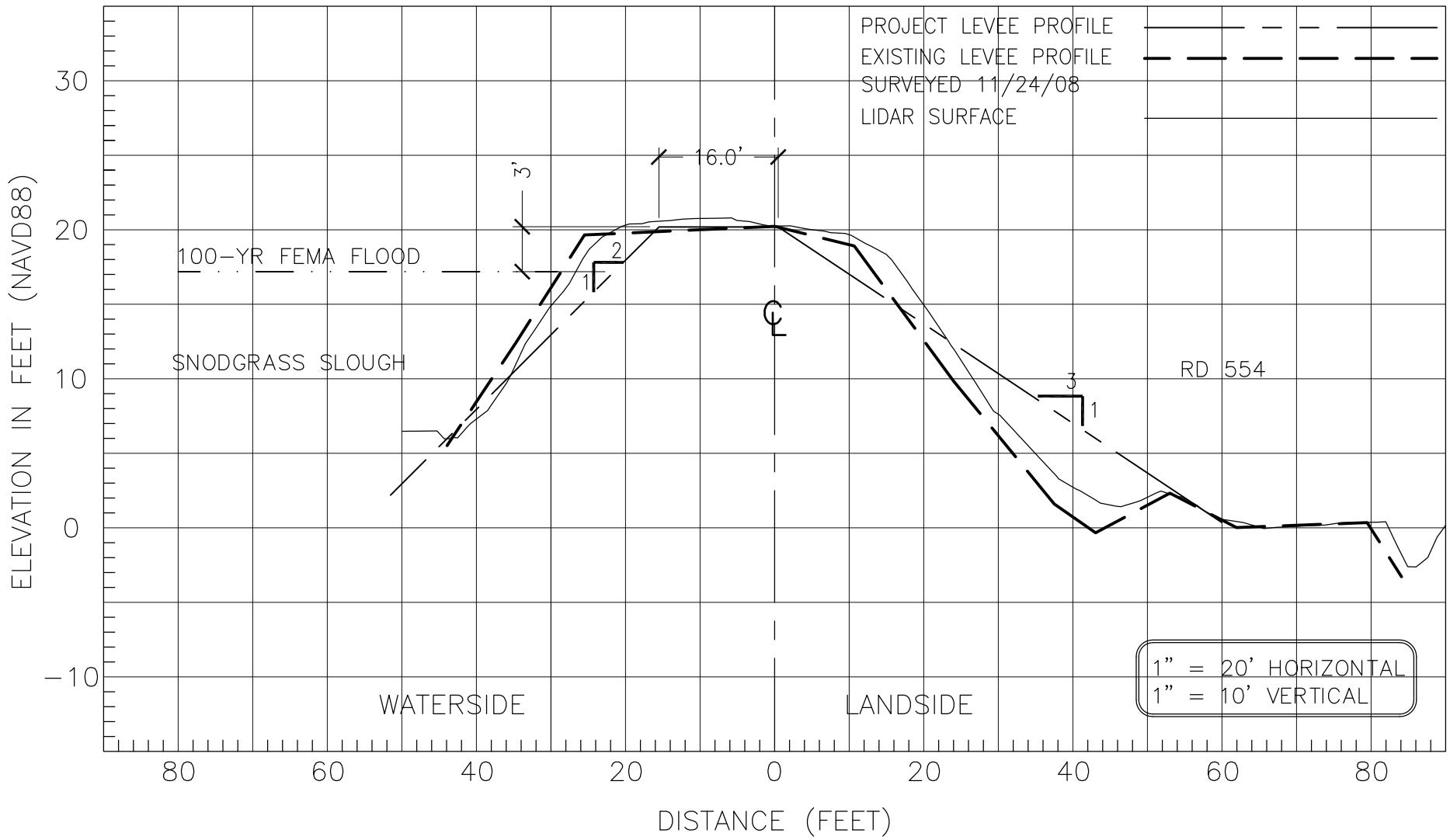
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 124+97

PRINT DATE: 8-5-2011



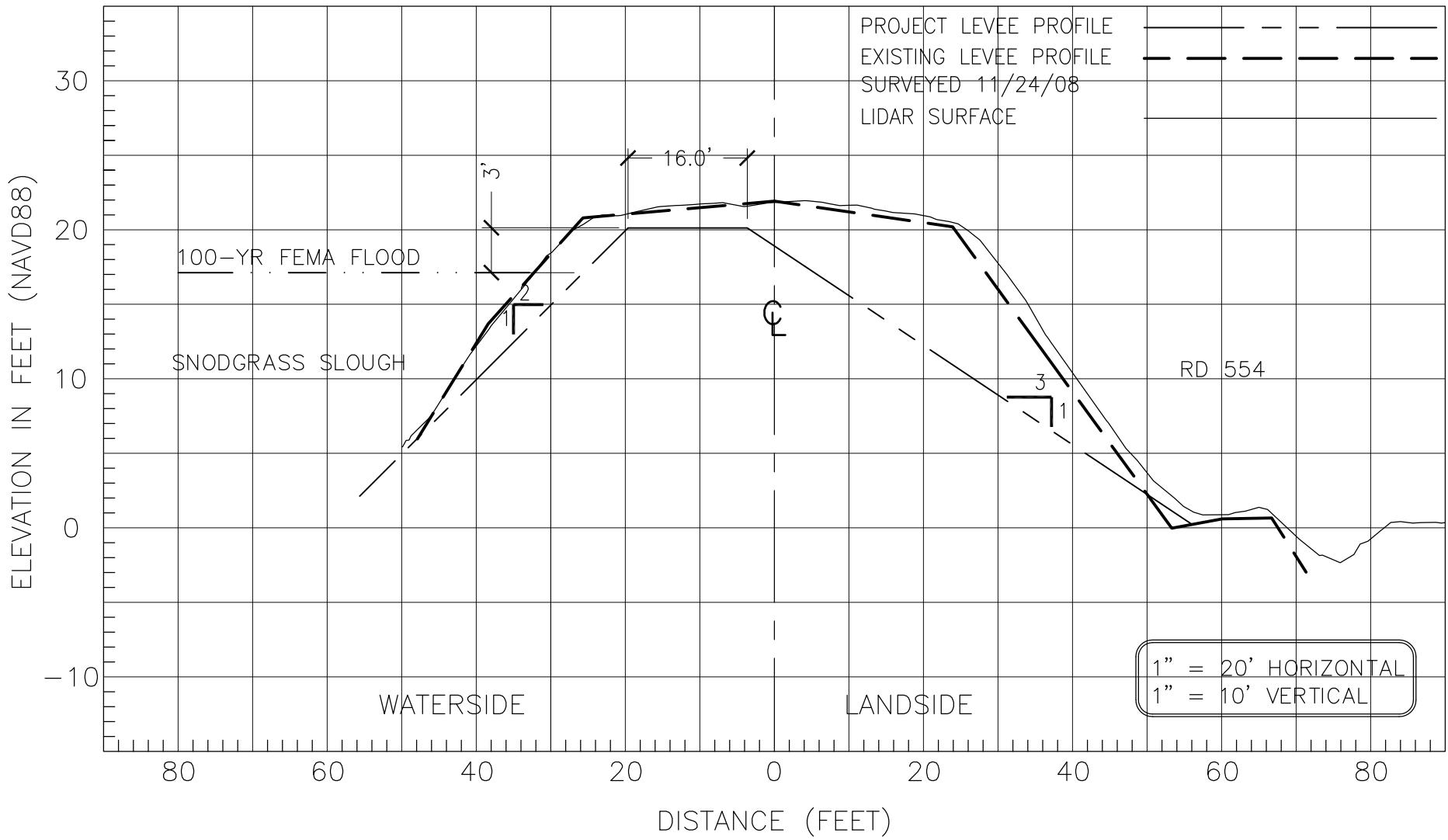
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 127+50

PRINT DATE: 8-5-2011



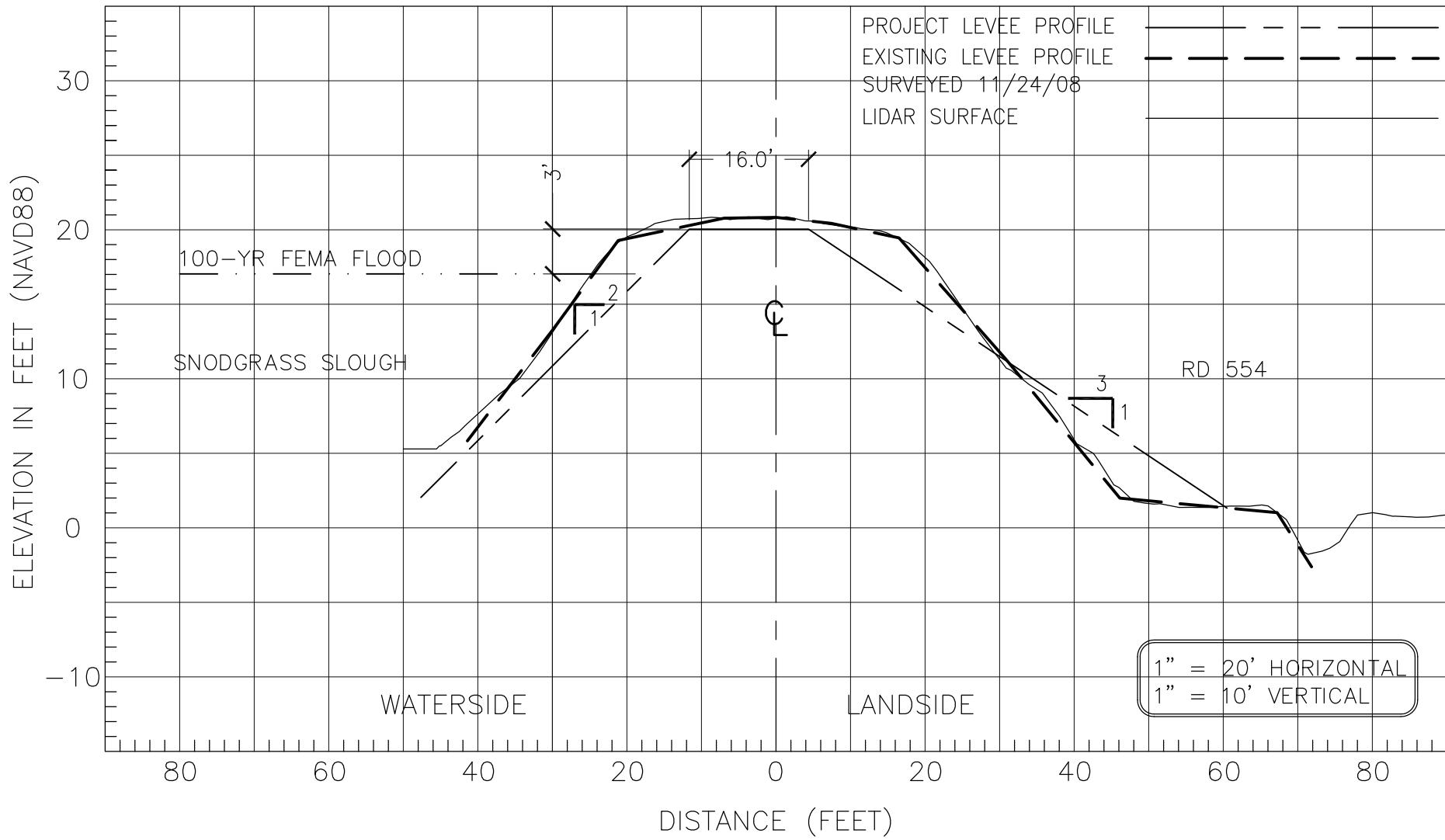
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 129+98

PRINT DATE: 8-5-2011



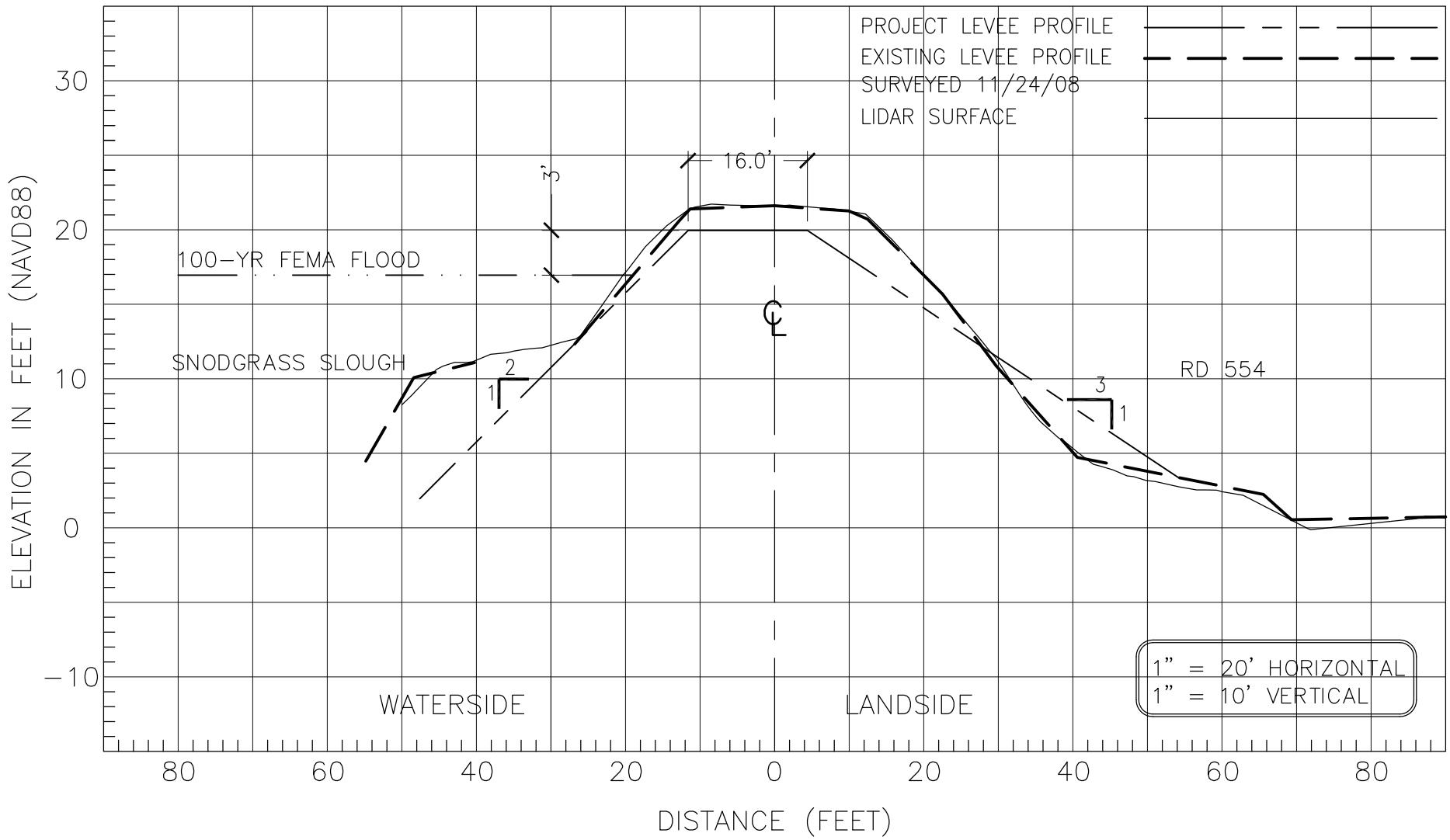
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 132+50

PRINT DATE: 8-5-2011



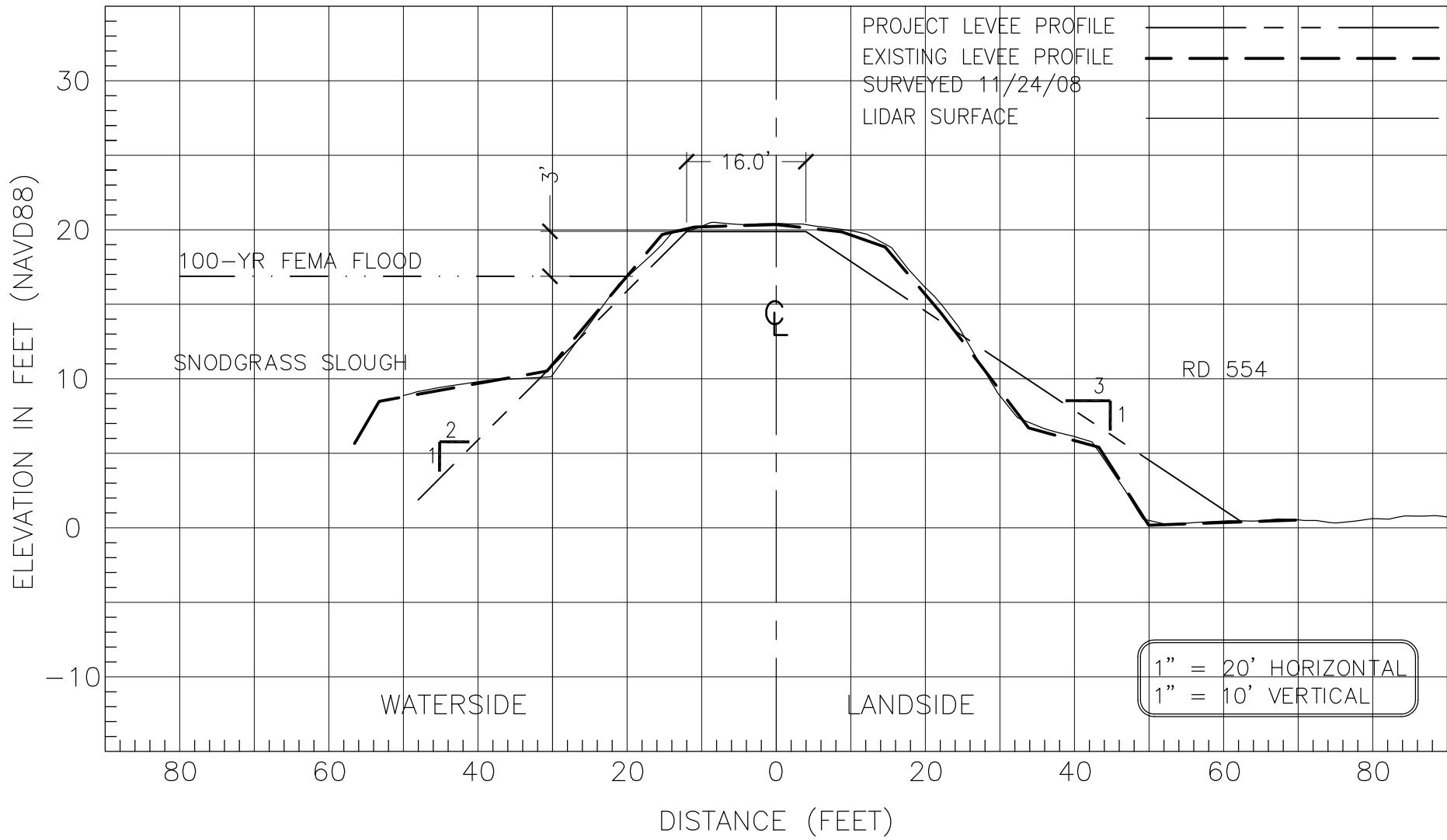
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 135+00

PRINT DATE: 8-5-2011



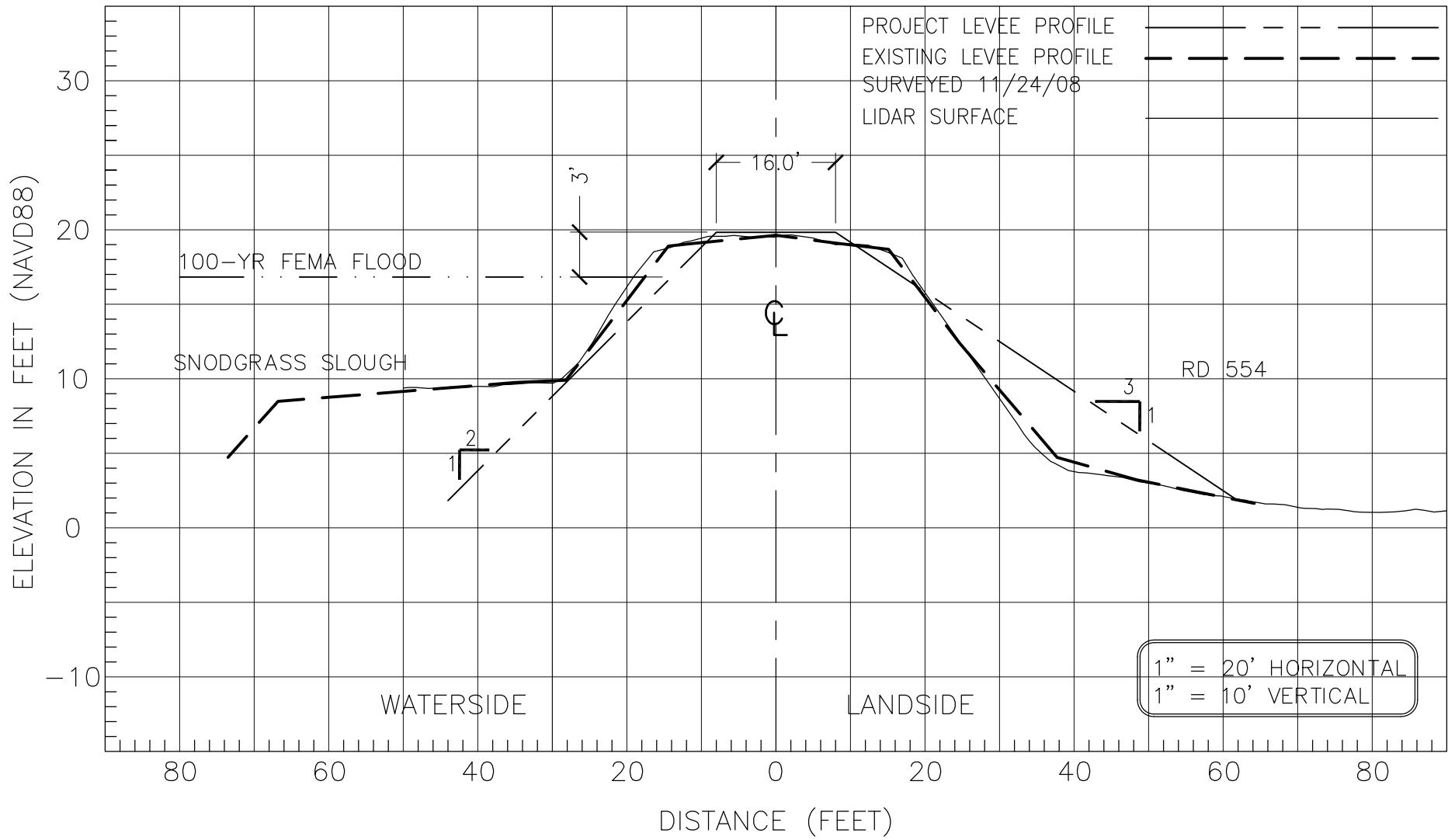
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 137+50

PRINT DATE: 8-5-2011



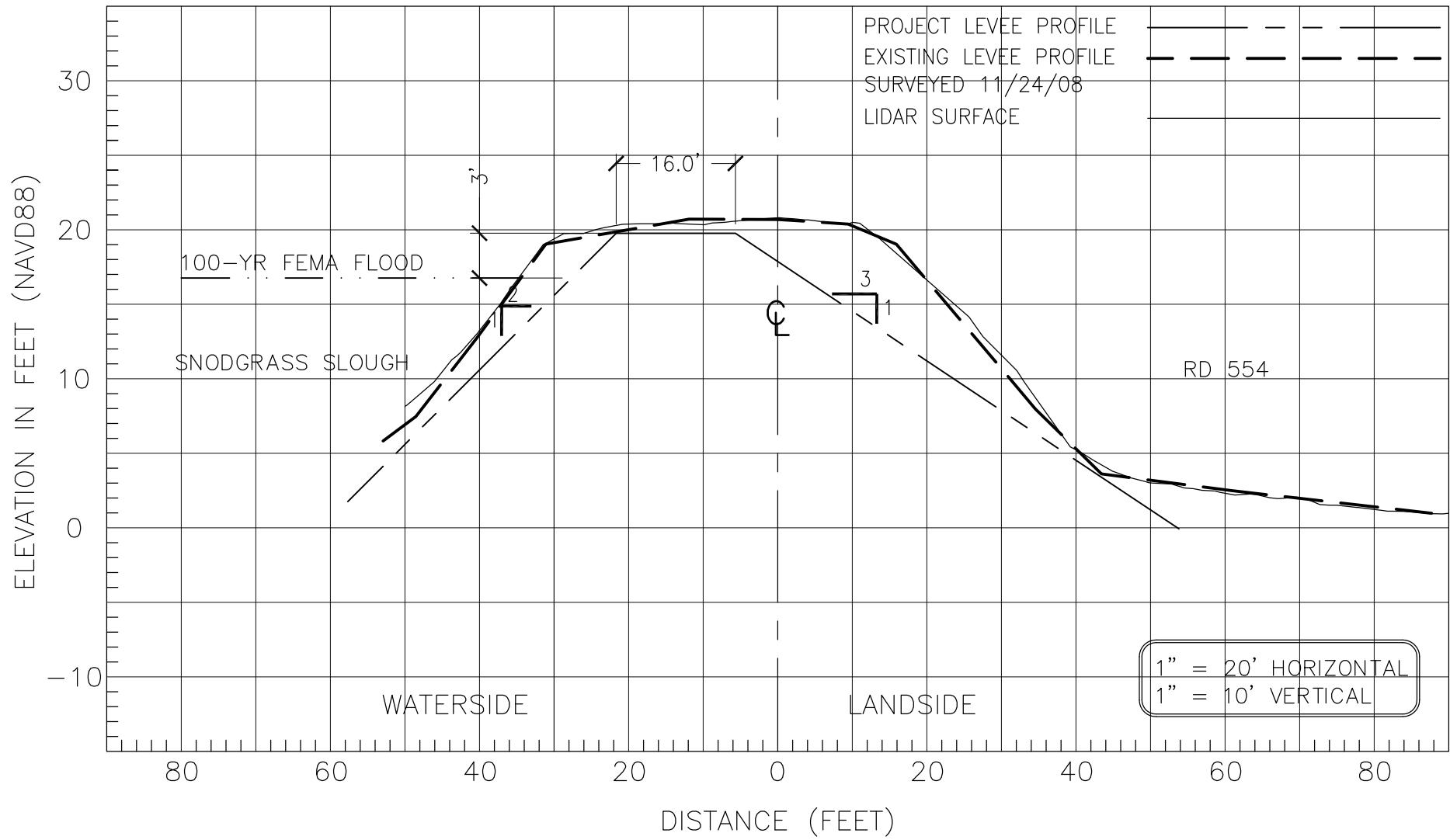
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 139+59

PRINT DATE: 8-5-2011



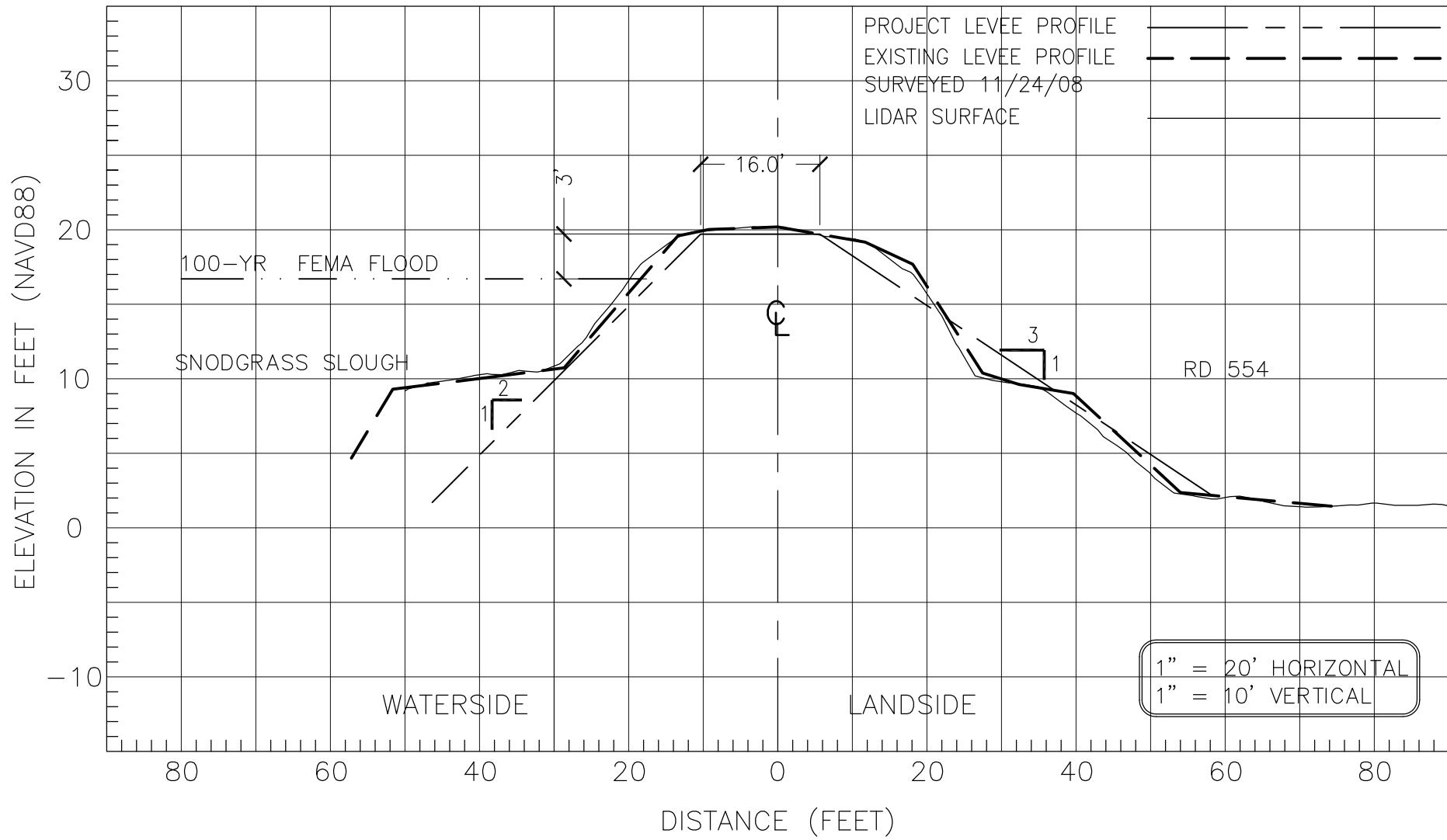
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 142+63

PRINT DATE: 8-5-2011



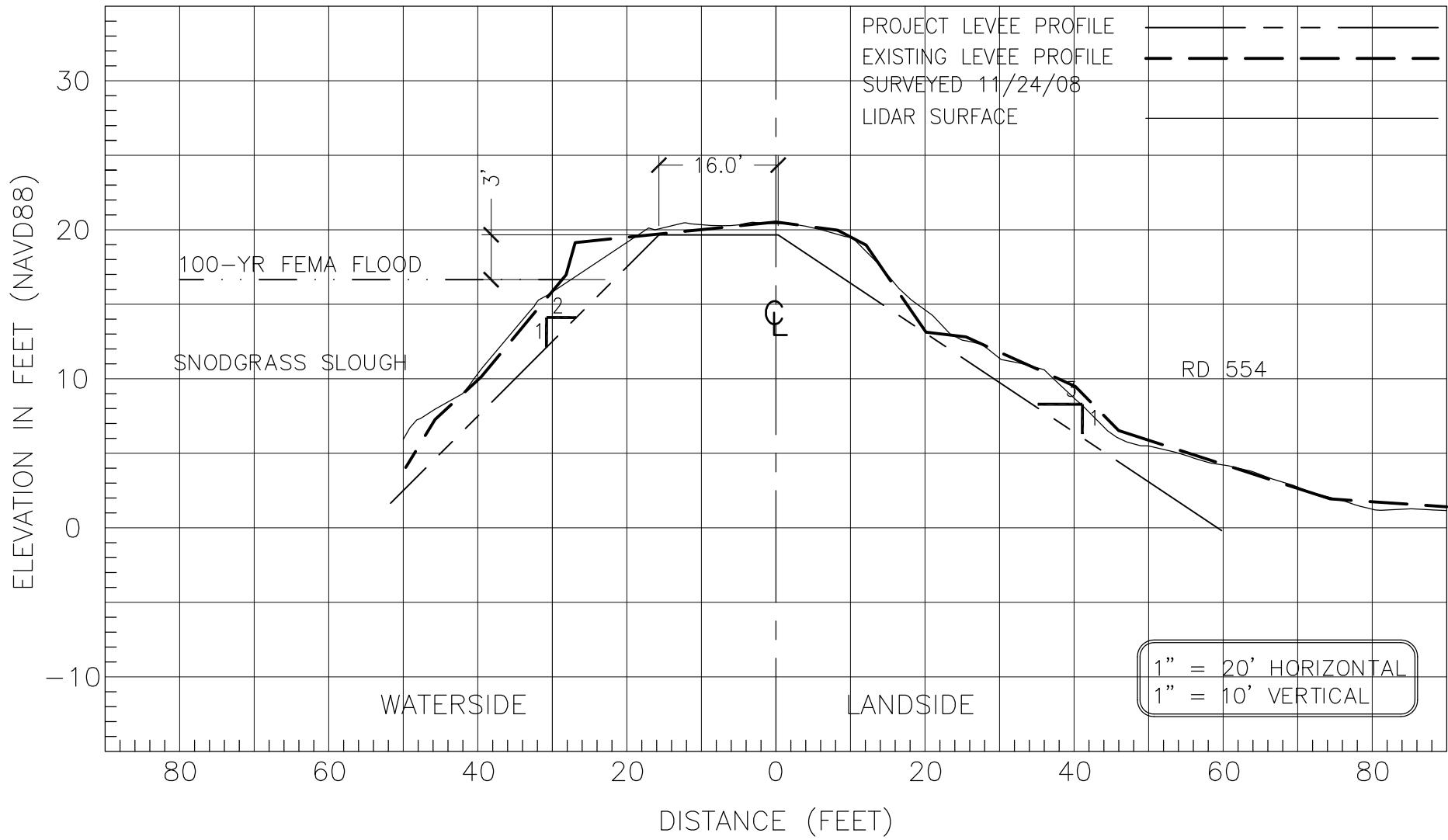
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 145+00

PRINT DATE: 8-5-2011



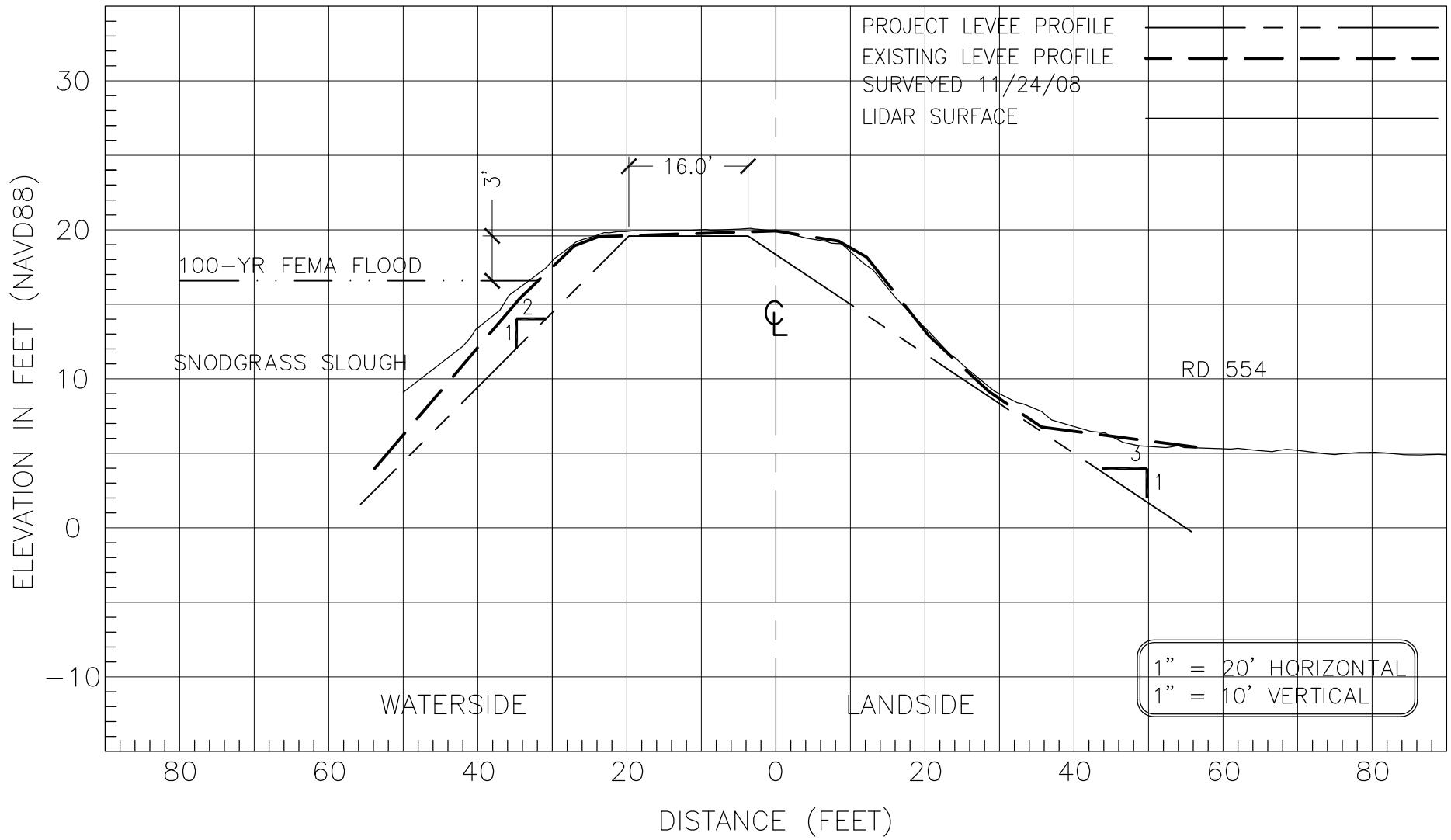
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 147+50

PRINT DATE: 8-5-2011



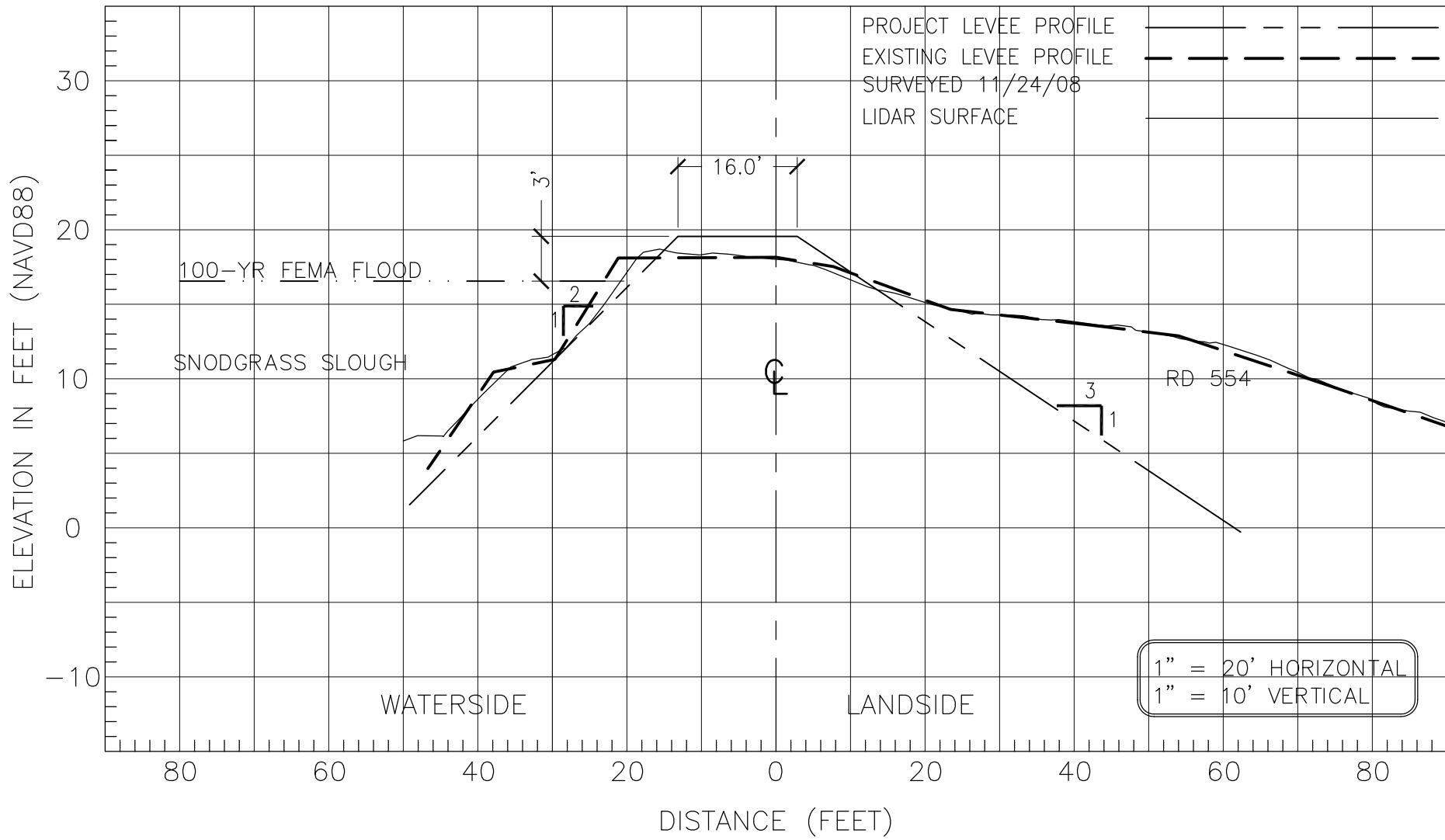
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 150+63

PRINT DATE: 8-5-2011



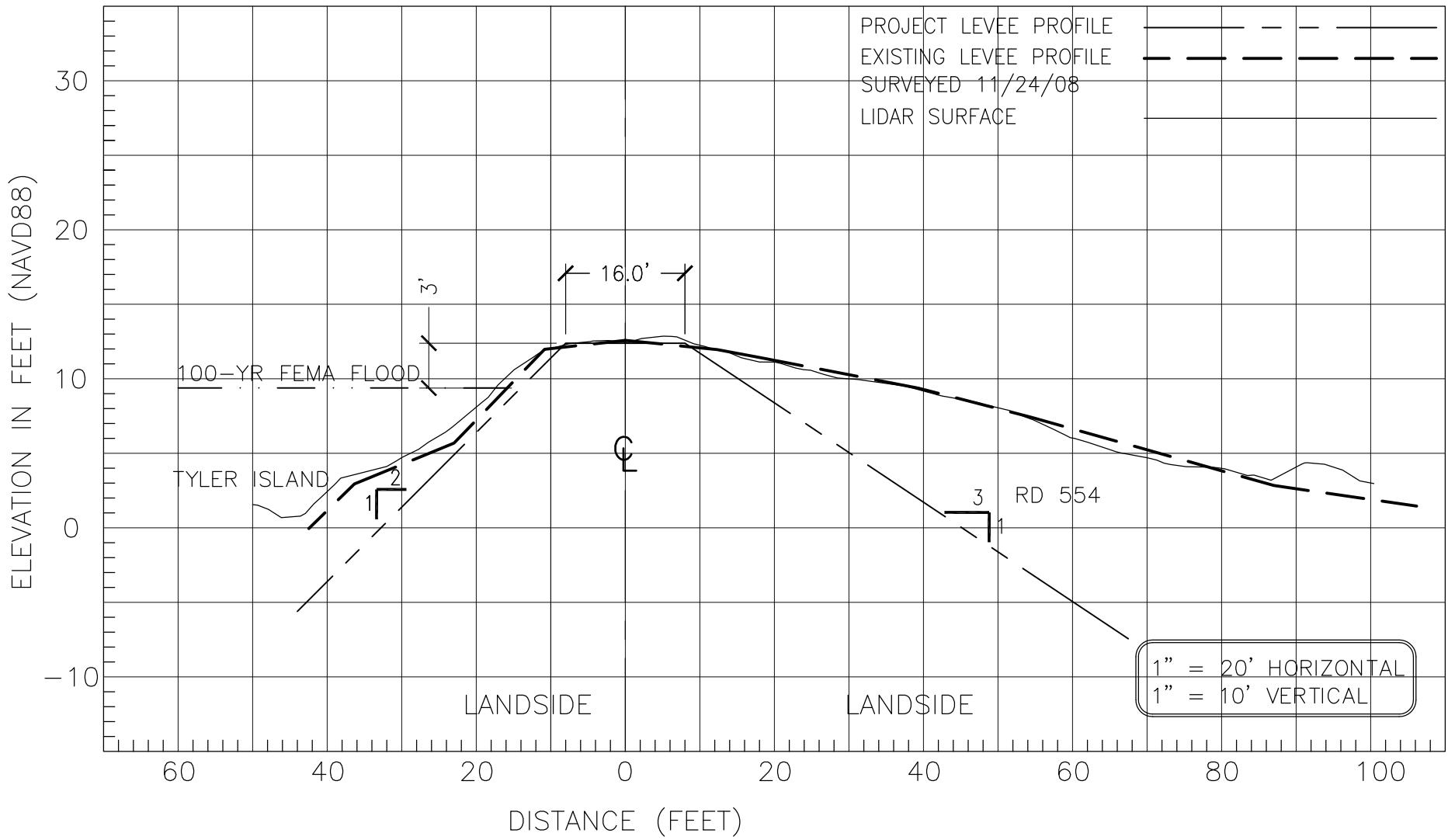
RECLAMATION DISTRICT NO. 554  
SNODGRASS SLOUGH (RIGHT BANK)  
LEVEE CROSS SECTION STATION 151+73

PRINT DATE: 8-5-2011



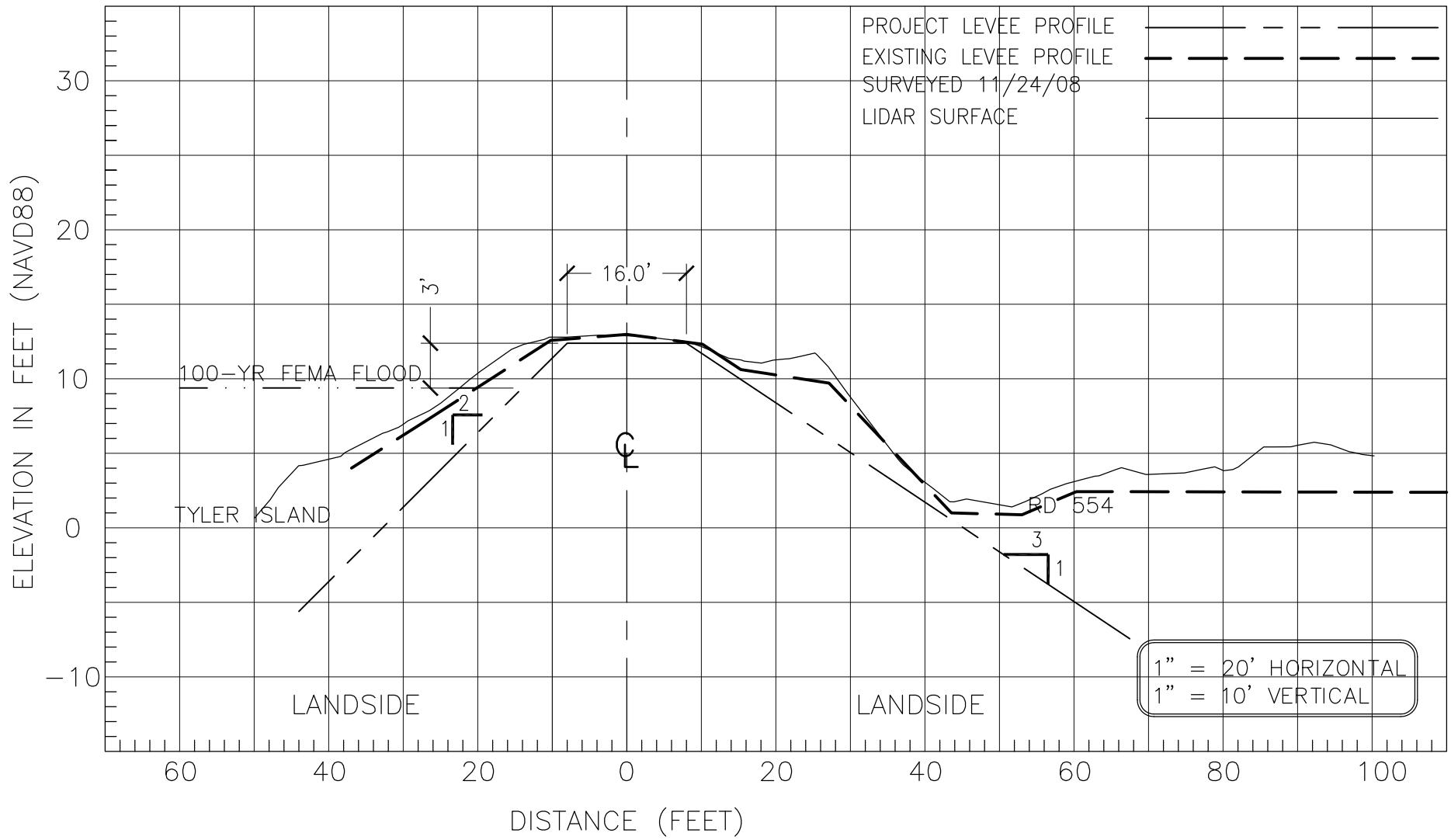
RECLAMATION DISTRICT NO. 554  
TYLER ISLAND CROSS LEVEE  
LEVEE CROSS SECTION STATION 154+74

PRINT DATE: 8-5-2011



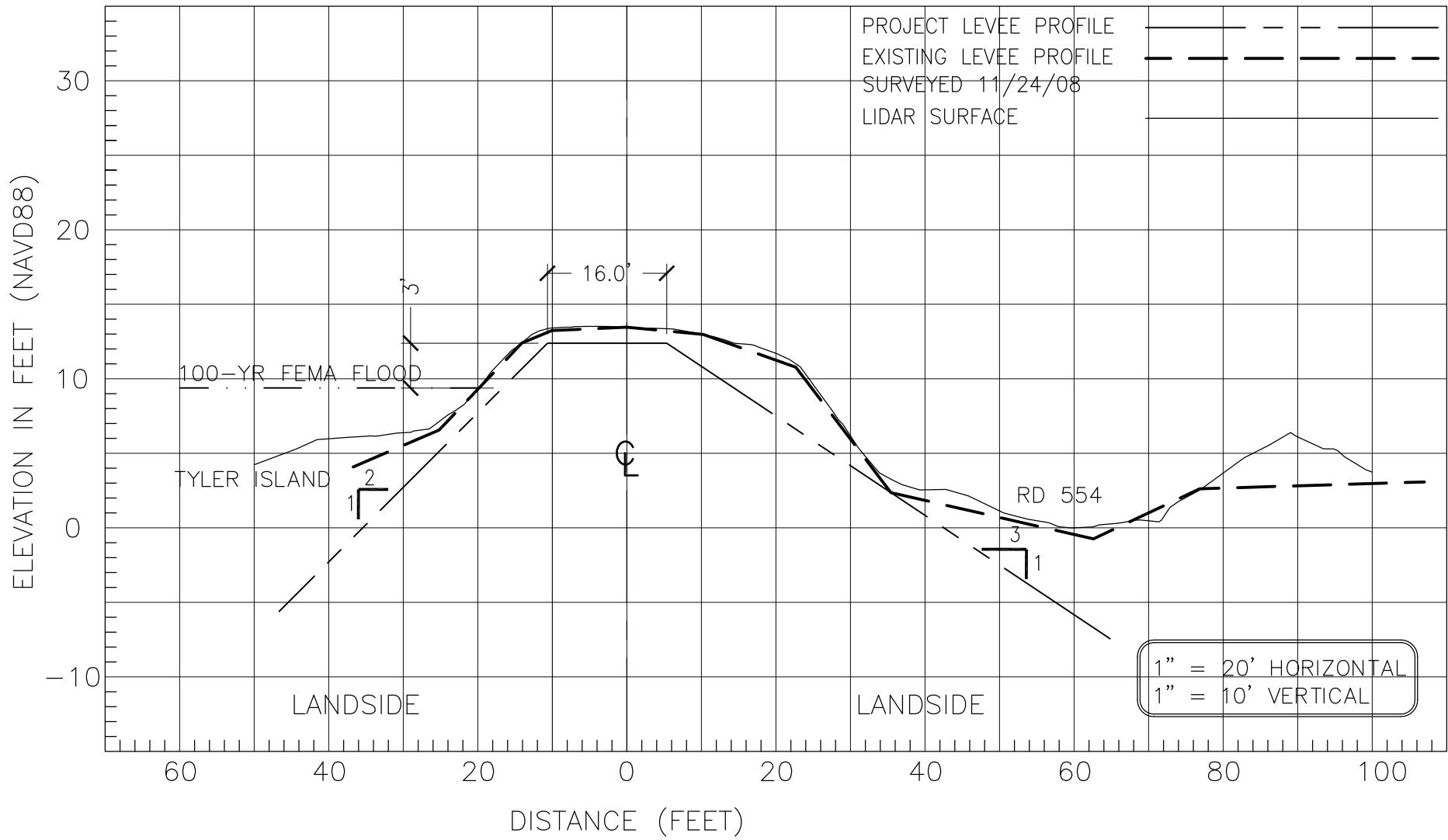
RECLAMATION DISTRICT NO. 554  
TYLER ISLAND CROSS LEVEE  
LEVEE CROSS SECTION STATION 157+50

PRINT DATE: 8-5-2011



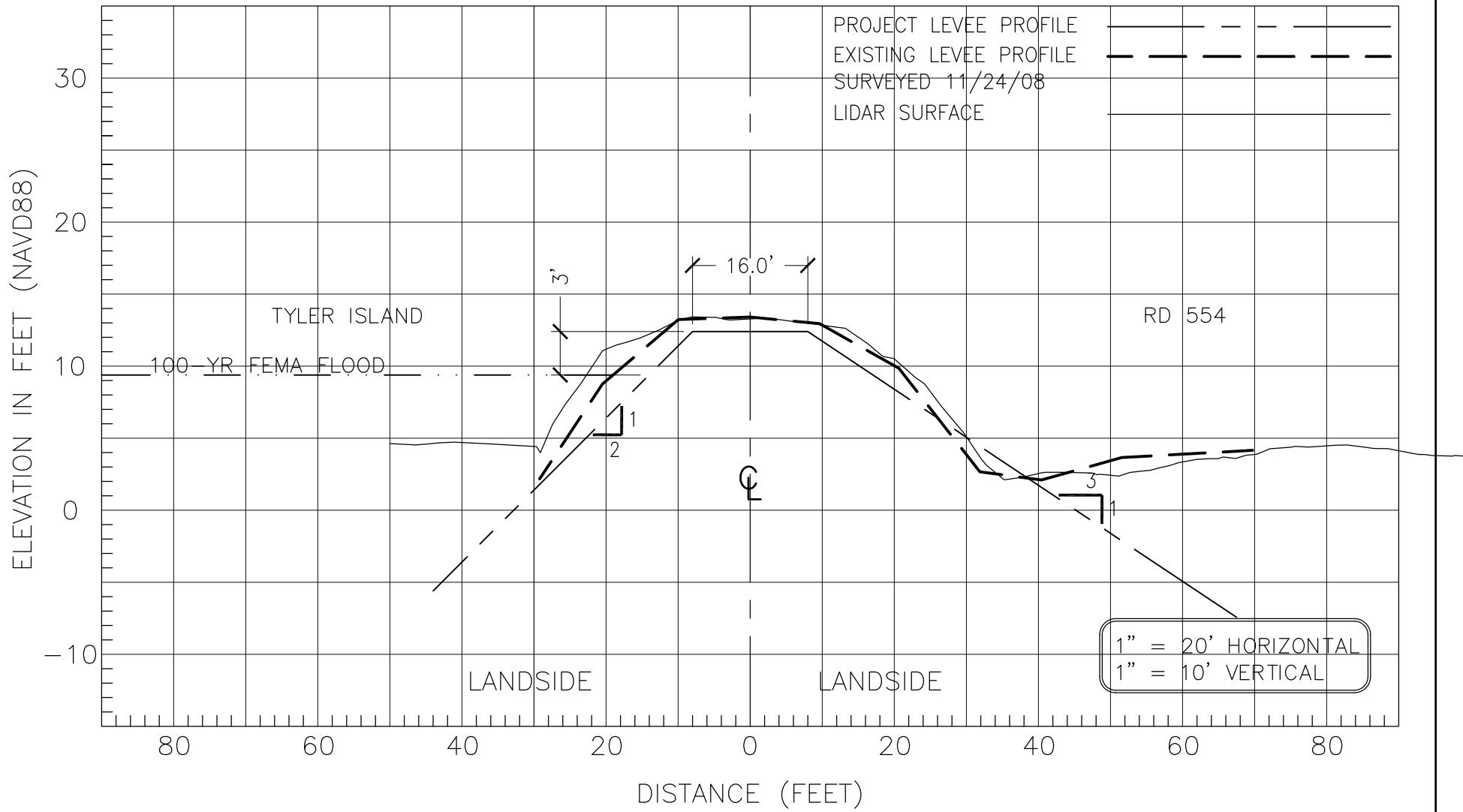
RECLAMATION DISTRICT NO. 554  
TYLER ISLAND CROSS LEVEE  
LEVEE CROSS SECTION STATION 159+36

PRINT DATE: 8-5-2011



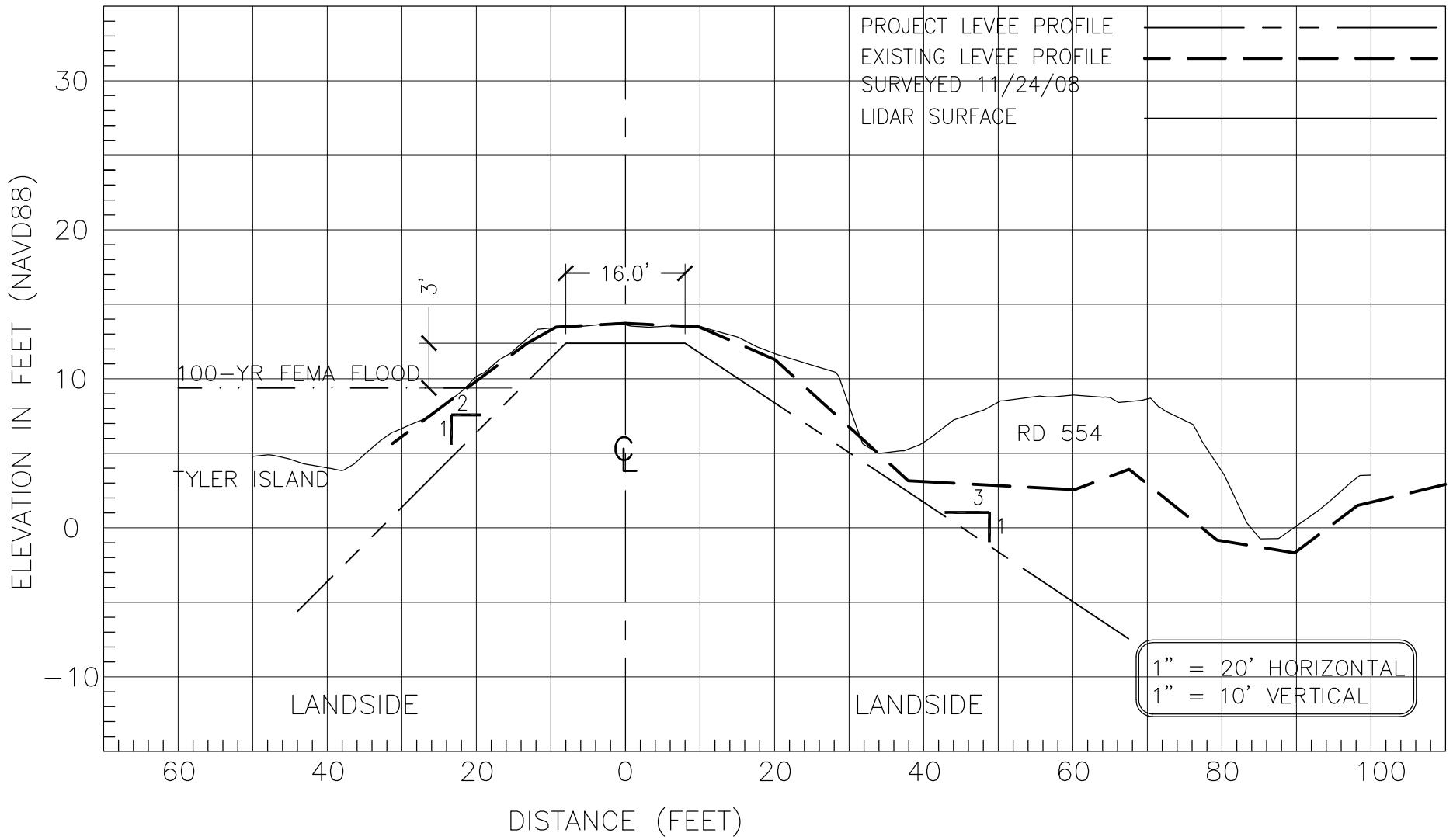
RECLAMATION DISTRICT NO. 554  
TYLER ISLAND CROSS LEVEE  
LEVEE CROSS SECTION STATION 163+11

PRINT DATE: 8-5-2011



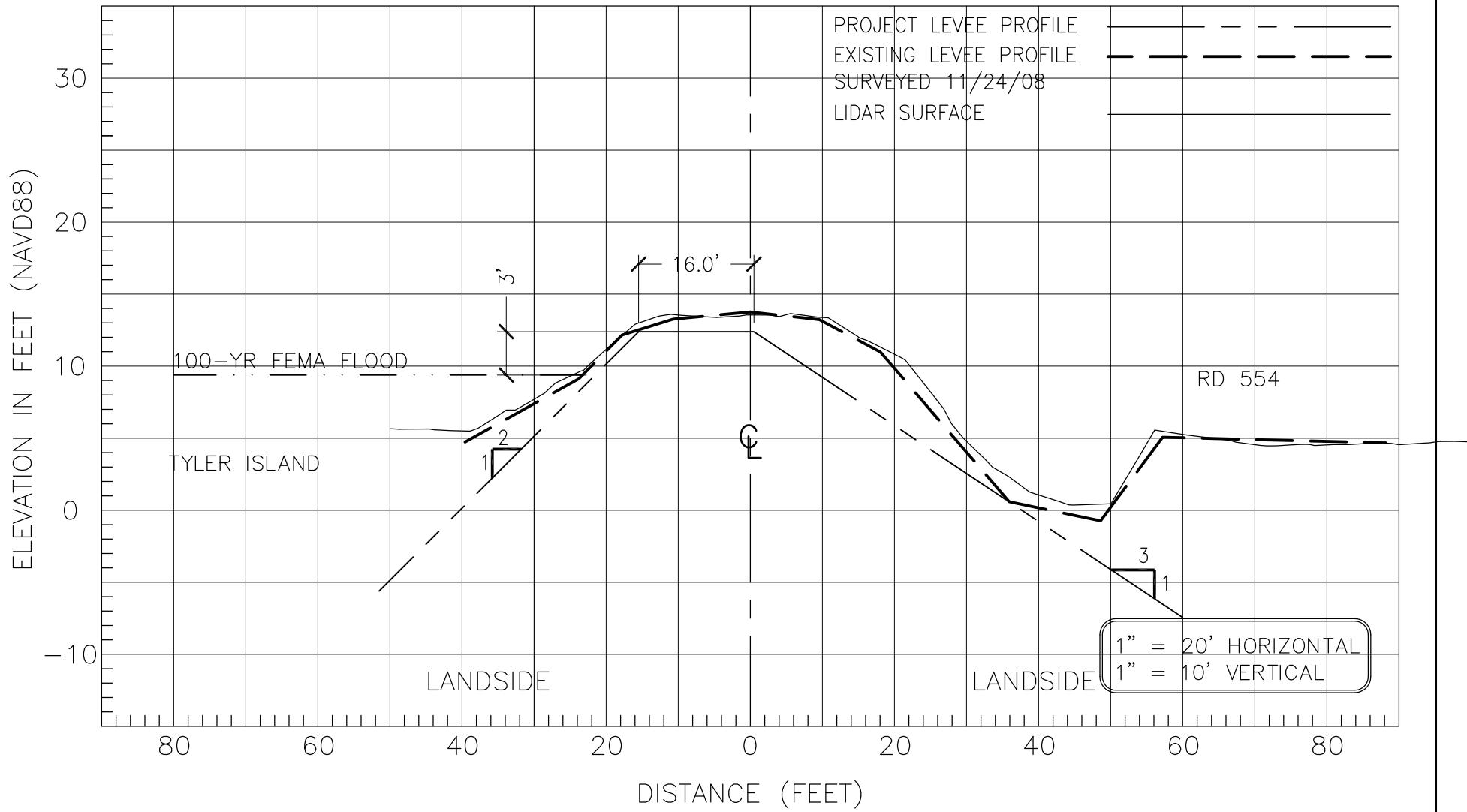
RECLAMATION DISTRICT NO. 554  
TYLER ISLAND CROSS LEVEE  
LEVEE CROSS SECTION STATION 165+00

PRINT DATE: 8-5-2011



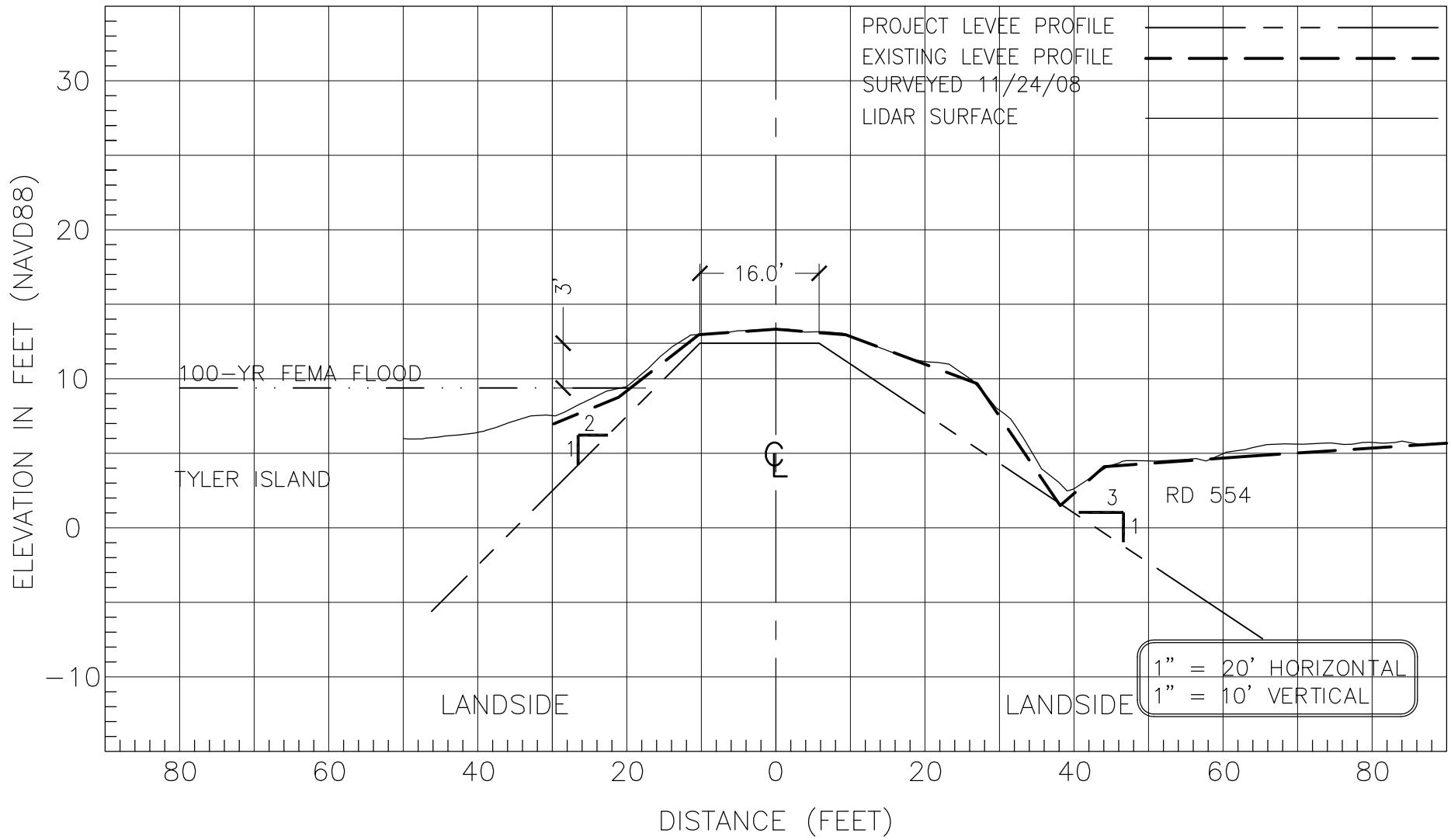
RECLAMATION DISTRICT NO. 554  
TYLER ISLAND CROSS LEVEE  
LEVEE CROSS SECTION STATION 167+40

PRINT DATE: 8-5-2011



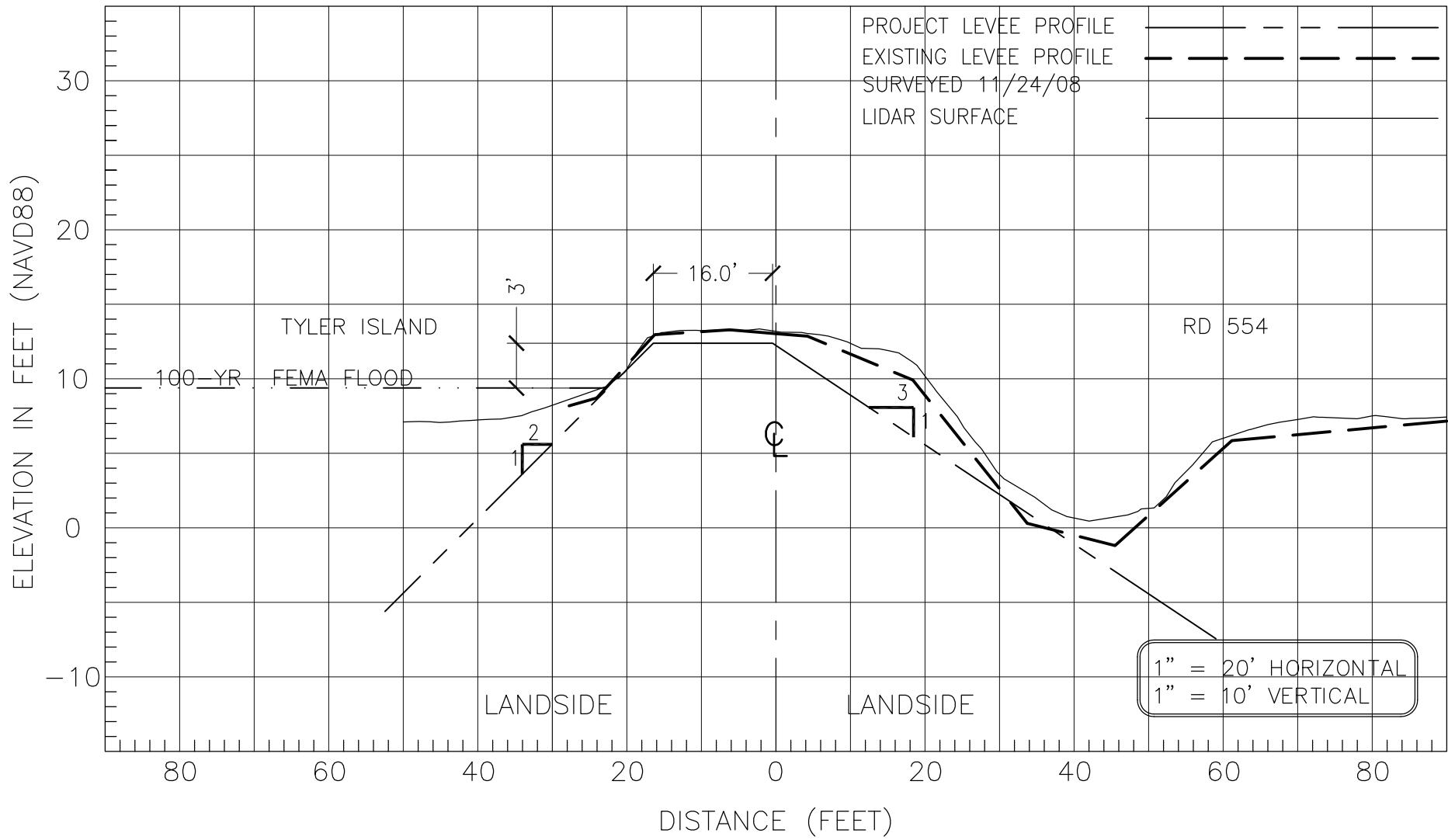
RECLAMATION DISTRICT NO. 554  
TYLER ISLAND CROSS LEVEE  
LEVEE CROSS SECTION STATION 169+92

PRINT DATE: 8-5-2011



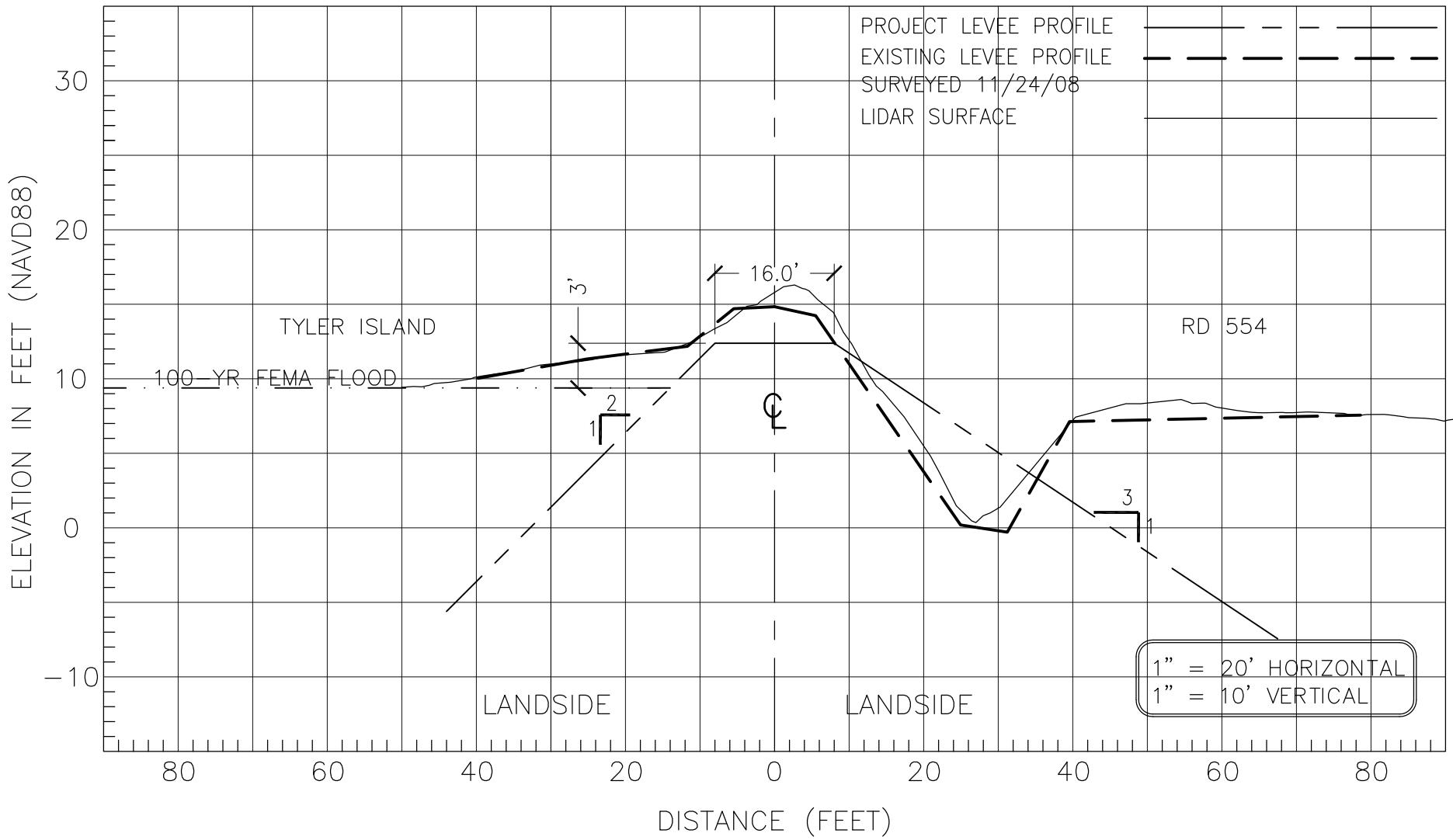
RECLAMATION DISTRICT NO. 554  
TYLER ISLAND CROSS LEVEE  
LEVEE CROSS SECTION STATION 172+50

PRINT DATE: 8-5-2011



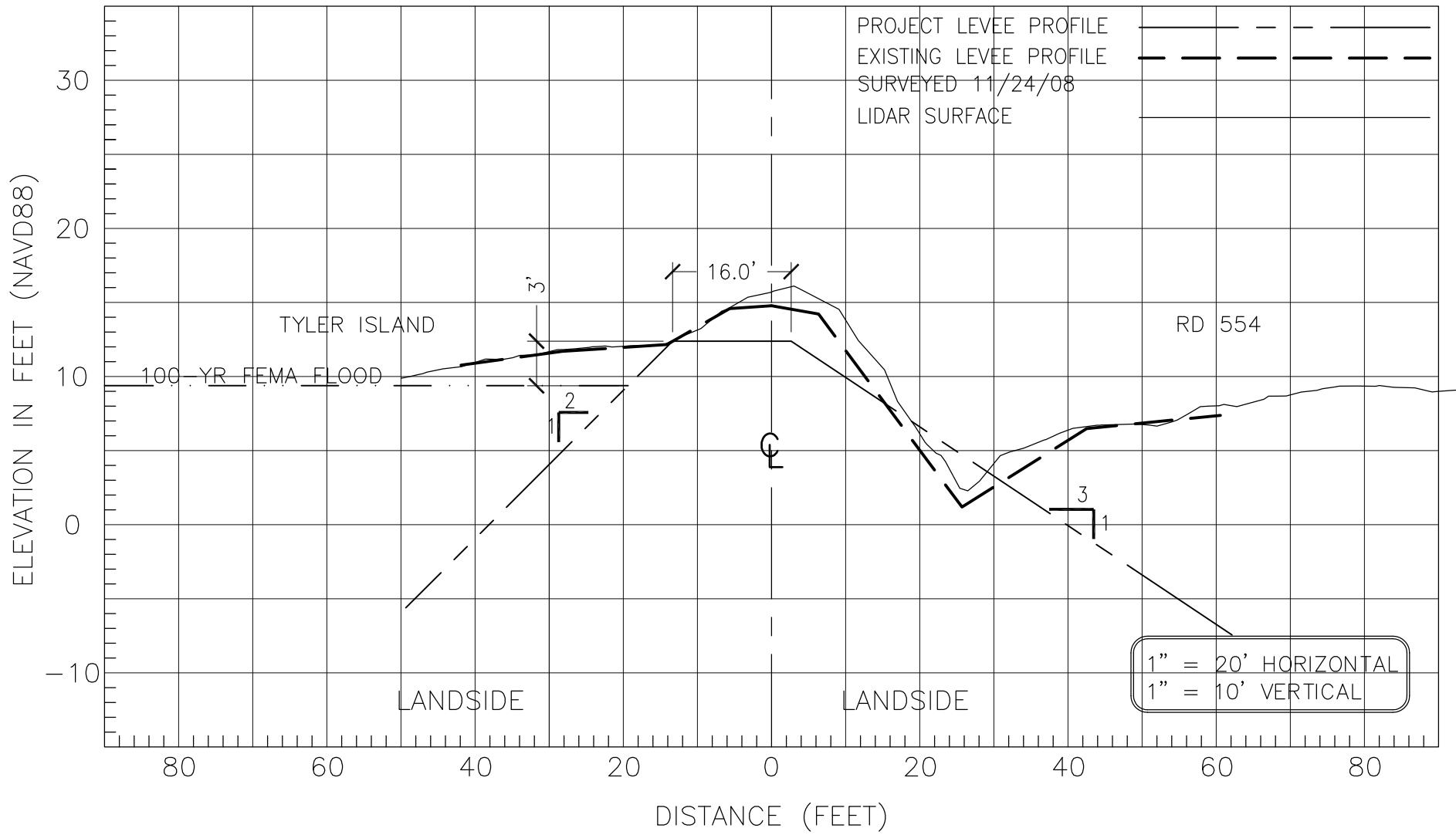
RECLAMATION DISTRICT NO. 554  
TYLER ISLAND CROSS LEVEE  
LEVEE CROSS SECTION STATION 175+00

PRINT DATE: 8-5-2011



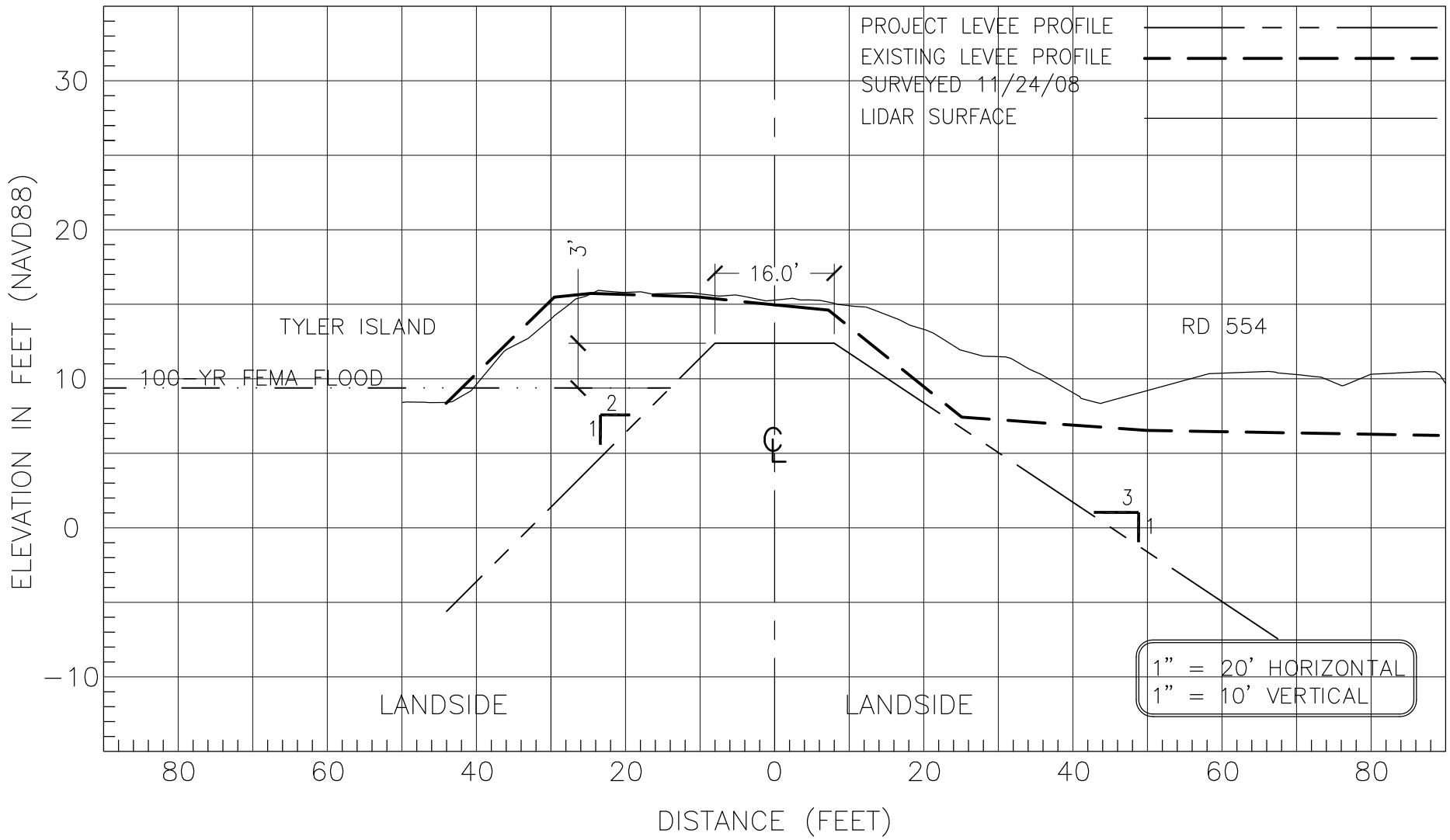
RECLAMATION DISTRICT NO. 554  
TYLER ISLAND CROSS LEVEE  
LEVEE CROSS SECTION STATION 177+16

PRINT DATE: 8-5-2011



RECLAMATION DISTRICT NO. 554  
TYLER ISLAND CROSS LEVEE  
LEVEE CROSS SECTION STATION 180+00

PRINT DATE: 8-5-2011

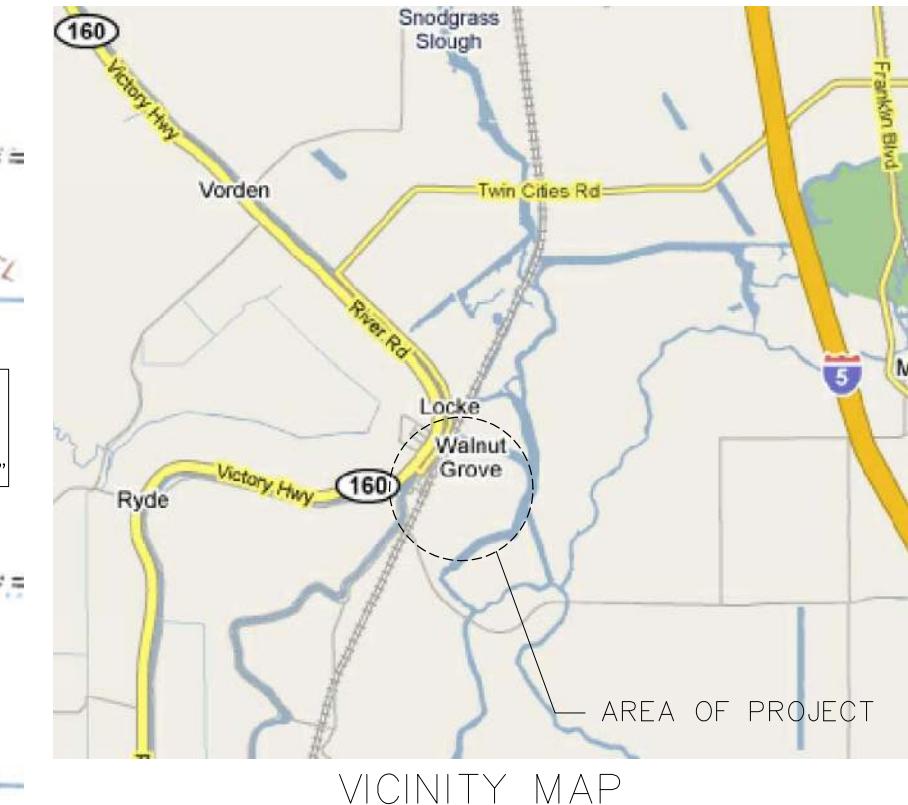
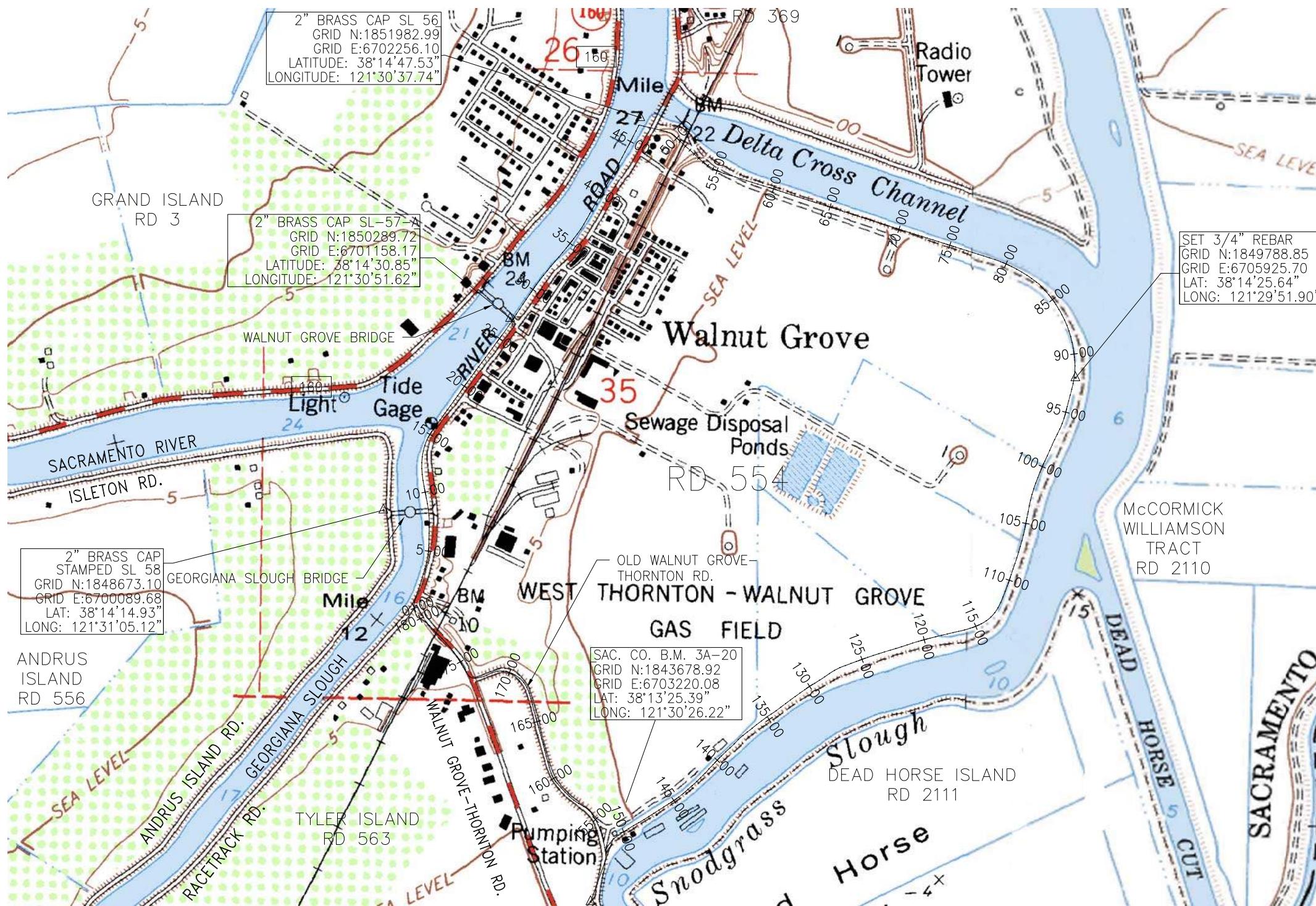


## Appendix C: Levee Crown Elevation Survey

(See attached disc for data)

# RECLAMATION DISTRICT 554

LEVEE CENTERLINE PROFILE FOR  
GEORGIANA SLOUGH, SACRAMENTO RIVER, DELTA CROSS CHANNEL  
SNODGRASS SLOUGH AND TYLER ISLAND CROSS LEVEE  
NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD 88)



SCALE 1"=1000'  




P.O. BOX 929, WALNUT GROVE, CA 95690 Tel (916)776-2277 Fax (916)776-2288

PLANNING  
PERMITTING  
ARCHITECTURE  
CIVIL ENGINEERING  
PROJECT MANAGEMENT

DESIGNED BY: GIL LABRIE  
DRAWN BY: JAVIER MEDINA  
SUBMITTED BY: \_\_\_\_\_  
PROJECT ENGINEER  
DATE: 8-8-2011

RECLAMATION  
DISTRICT  
554

STATIONING MAP AND COVER  
SHEET

7580.03.01  
SHEET  
REFERENCE  
NUMBER:  
C-1  
1 OF 10

## NOTES:

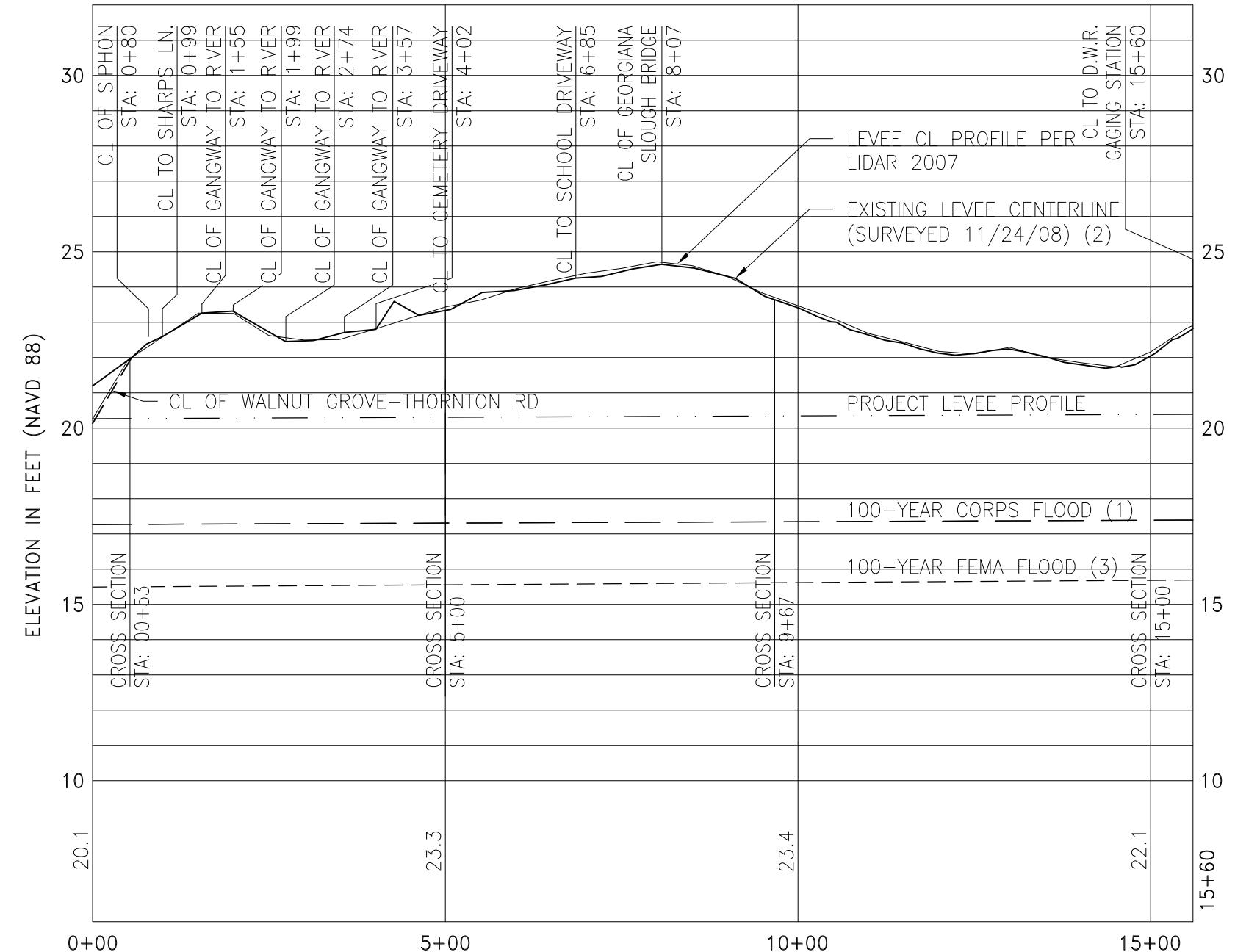
(1) THE 100-YEAR FLOOD LINE IS BASED ON THE CORPS OF ENGINEERS DATA, CHART 71A DATED FEBRUARY 1992. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON.

(2) THE LEVEE CENTERLINE ELEVATIONS ARE BASED ON A FIELD SURVEY PERFORMED BY DCC ENGINEERING CO., INC. ON OCTOBER 20 AND 21, 2008.

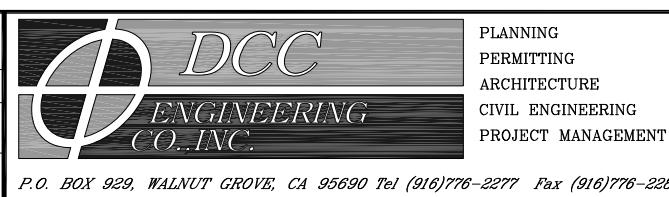
(3) THE 100-YEAR FLOOD LINE IS PER FEMA FIRM MAP COMMUNITY-PANEL-NUMBER 060262 0560 C, MAP REVISED SEPTEMBER 30, 1988. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON.

4) THE FIELD SURVEY DATA FOR THIS PROJECT IS BASED ON NAVD88 AND NAD83 DATUMS.

# GEORGIANA SLOUGH LEVEE CENTERLINE PROFILE



REV.	DATE	BY	DESCRIPTION	APPROVED	DATE



RECLAMATION  
DISTRICT  
554

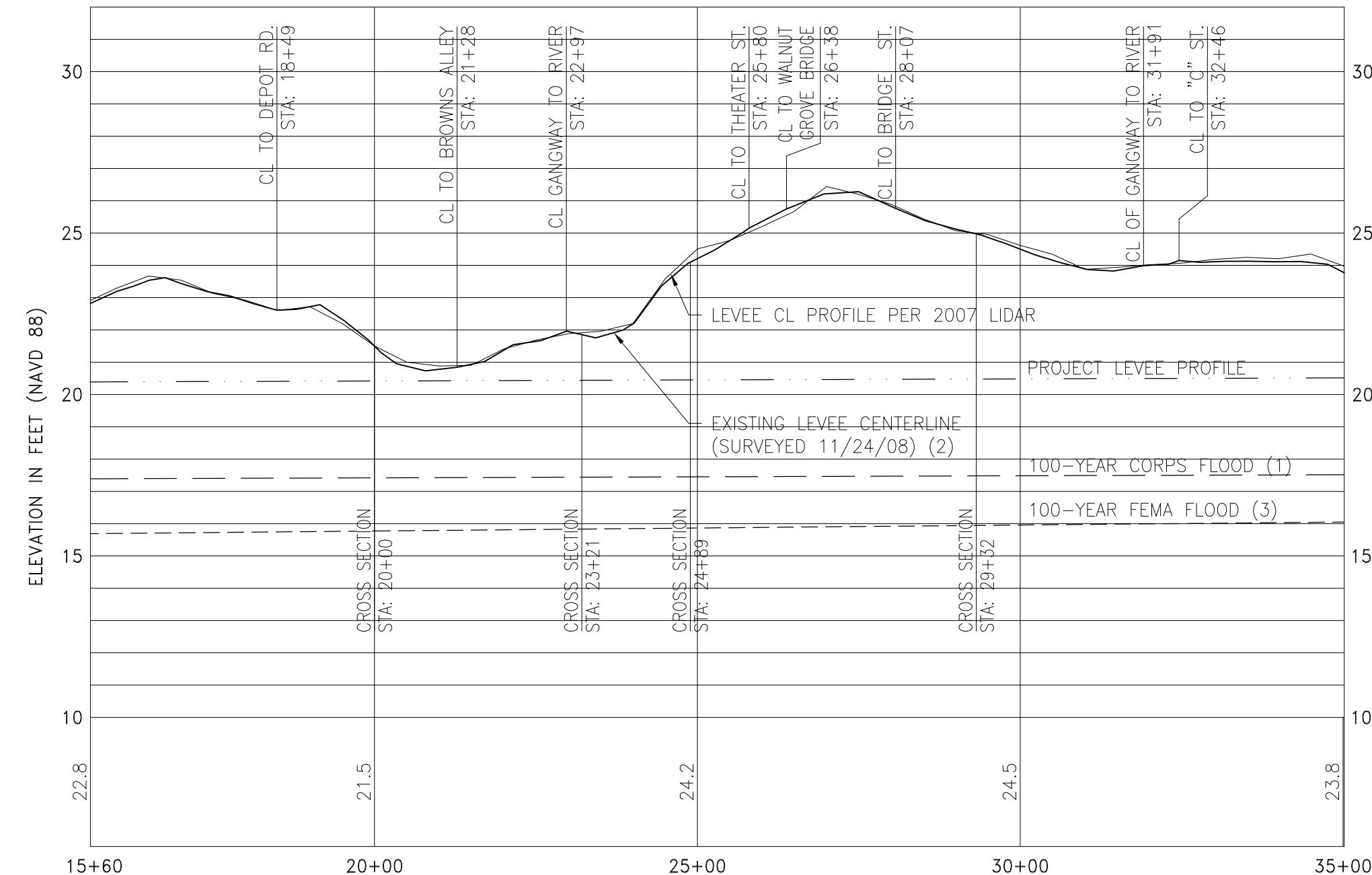
GEORGIANA SLOUGH  
LEVEE CENTERLINE PROFILE  
STATIONS 0+55 TO 15+60  
SCALES: HORZ. 1"=200'  
VERT. 1"=4'

7580.03.01  
SHEET  
REFERENCE  
NUMBER:  
C-2  
2 OF 10

## NOTES:

- (1) THE 100-YEAR FLOOD LINE IS BASED ON THE CORPS OF ENGINEERS DATA, CHART 71A DATED FEBRUARY 1992. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON.
- (2) THE LEVEE CENTERLINE ELEVATIONS ARE BASED ON A FIELD SURVEY PERFORMED BY DCC ENGINEERING CO., INC. ON OCTOBER 20 AND 21, 2008.
- (3) THE 100-YEAR FLOOD LINE IS PER FEMA FIRM MAP COMMUNITY-PANEL-NUMBER 060262 0560 C, MAP REVISED SEPTEMBER 30, 1988. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON.
- 4) THE FIELD SURVEY DATA FOR THIS PROJECT IS BASED ON NAVD88 AND NAD83 DATUMS.

## SACRAMENTO RIVER LEVEE CENTERLINE PROFILE



				APPROVED BY: _____
				REG. NO.:
				EXP. DATE:
				DATE:
REV.	DATE	BY	DESCRIPTION	APPROVED DATE



PLANNING PERMITTING ARCHITECTURE CIVIL ENGINEERING PROJECT MANAGEMENT	DESIGNED BY: GIL LABRIE
	DRAWN BY: JAVIER MEDINA
	SUBMITTED BY: PROJECT ENGINEER
	DATE: 8-8-2011

**RECLAMATION DISTRICT**  
 554

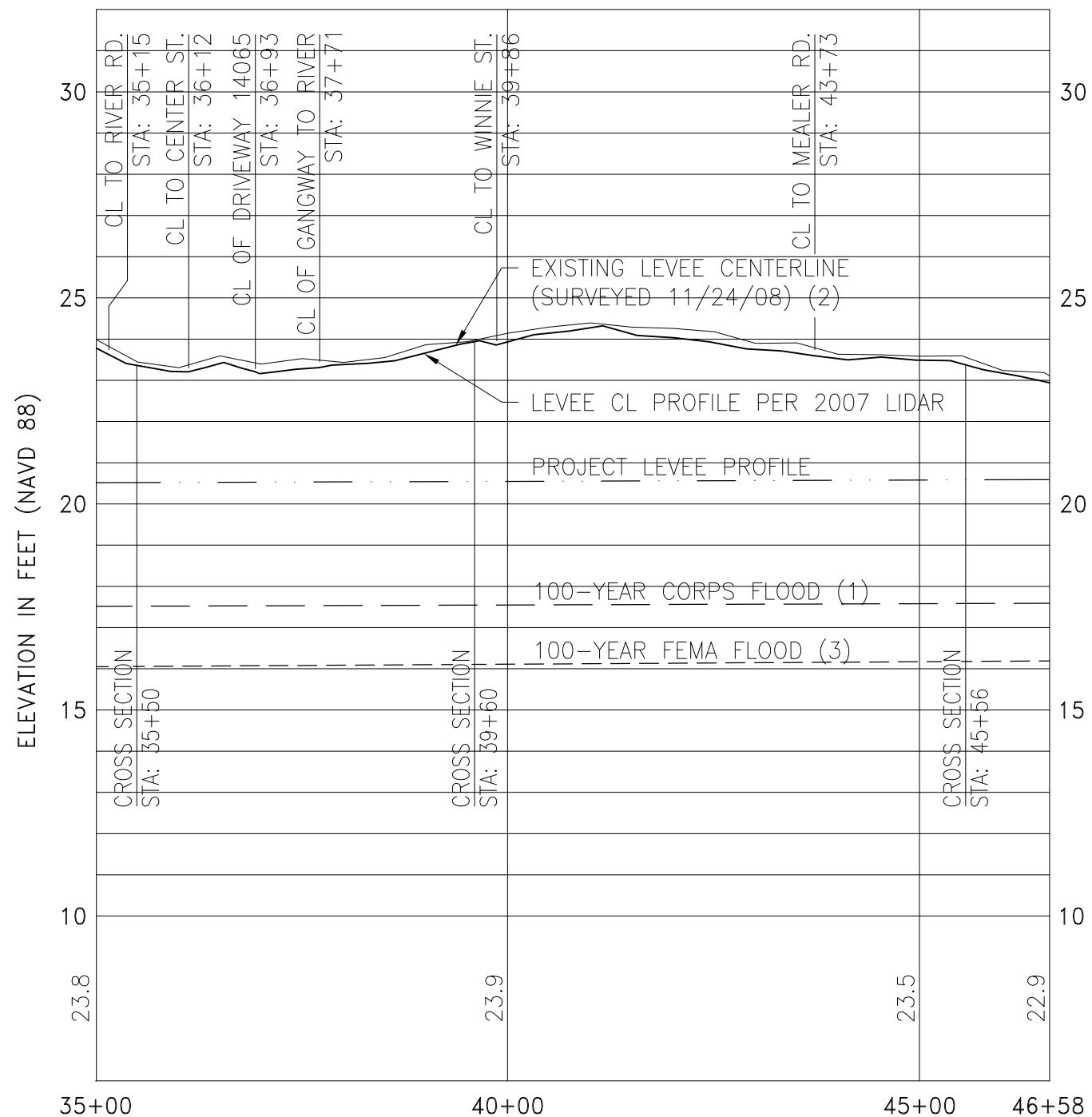
SACRAMENTO RIVER  
 LEVEE CENTERLINE PROFILE  
 STATIONS 15+60 TO 35+00  
 SCALES: HORZ. 1"=200'  
 VERT. 1"=4'  
 3 OF 10

7580.03.01  
 SHEET  
 REFERENCE  
 NUMBER:  
**C-3**

## NOTES:

- (1) THE 100-YEAR FLOOD LINE IS BASED ON THE CORPS OF ENGINEERS DATA CHART 71A DATED FEBRUARY 1992. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON.
- (2) THE LEVEE CENTERLINE ELEVATIONS ARE BASED ON A FIELD SURVEY PERFORMED BY DCC ENGINEERING CO., INC. ON OCTOBER 20 AND 21, 2008.
- (3) THE 100-YEAR FLOOD LINE IS PER FEMA FIRM MAP COMMUNITY-PANEL-NUMBER 060262 0560 C, MAP REVISED SEPTEMBER 30, 1988. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON.
- 4) THE FIELD SURVEY DATA FOR THIS PROJECT IS BASED ON NAVD88 AND NAD83 DATUMS.

# SACRAMENTO RIVER LEVEE CENTERLINE PROFILE



P.O. BOX 929, WALNUT GROVE, CA 95690 Tel (916)776-2277 Fax (916)776-2282

PLANNING  
PERMITTING  
ARCHITECTURE  
CIVIL ENGINEERING  
PROJECT MANAGEMENT

DESIGNED BY: GIL LABRIE  
DRAWN BY: JAVIER MEDINA  
SUBMITTED  
BY: \_\_\_\_\_ PROJECT ENGINEER  
DATE: 8-8-2011

# RECLAMATION DISTRICT 554

SACRAMENTO RIVER  
LEVEE CENTERLINE PROFILE  
STATIONS 35+00 TO 46+58

7580.03.01  
SHEET  
REFERENCE  
NUMBER:  
C-4  
4.05.10

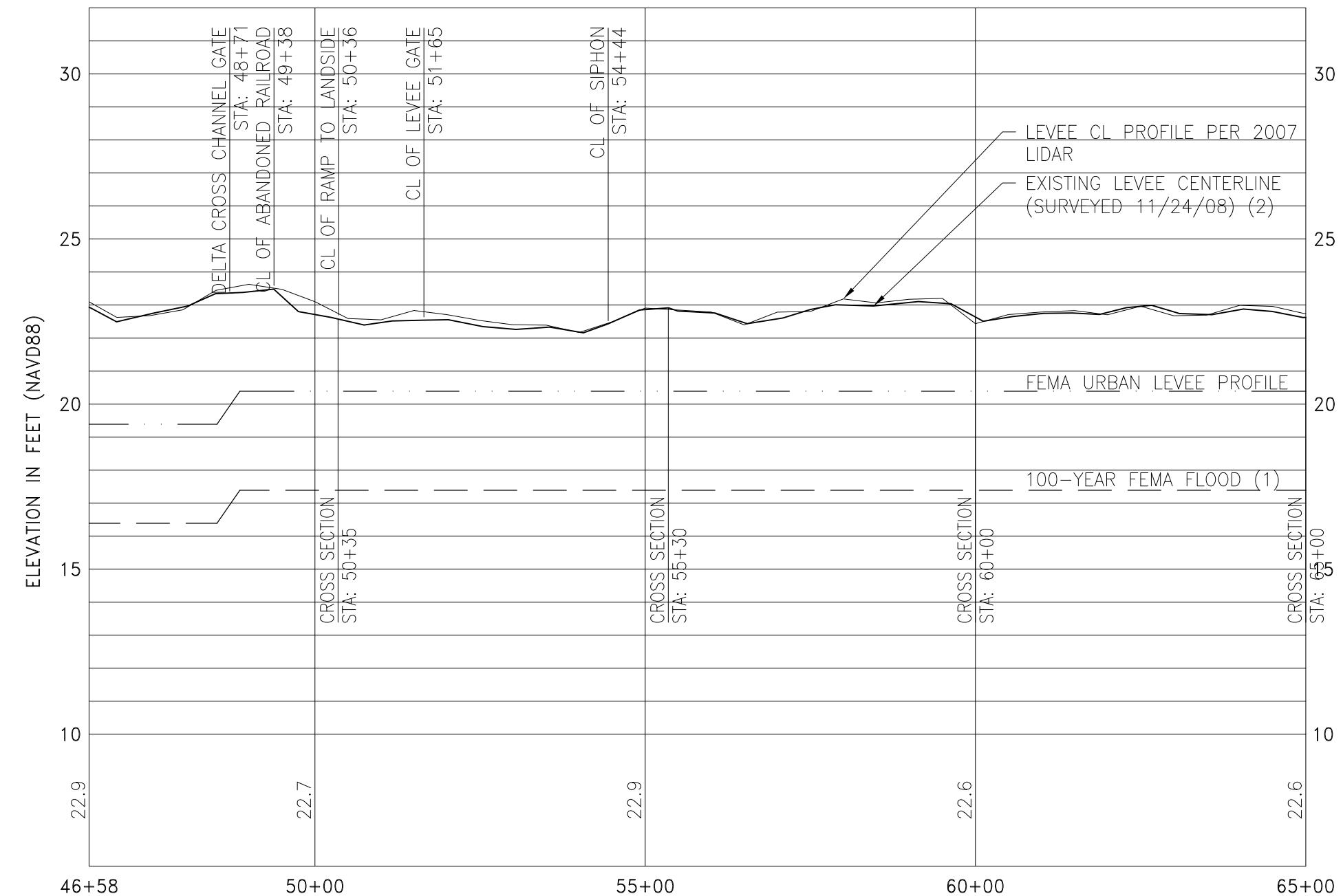
## NOTES:

(1) THE 100-YEAR FLOOD LINE IS BASED PER FEMA FIRM MAP COMMUNITY-PANEL-NUMBER 060262 0560C MAP REVISED SEPTEMBER 30, 1988 AND 060262 0580D MAP REVISED FEBRUARY 4, 1998. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON.

(2) THE LEVEE CENTERLINE ELEVATIONS ARE BASED ON A FIELD SURVEY PERFORMED BY DCC ENGINEERING CO., INC. ON OCTOBER 20, 21 2008.

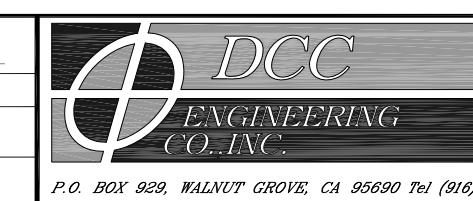
3) THE FIELD SURVEY DATA FOR THIS PROJECT IS BASED ON NAVD88 AND NAD83 DATUMS.

## DELTA CROSS CHANNEL LEVEE CENTERLINE PROFILE



REV.	DATE	BY	DESCRIPTION	APPROVED	DATE

APPROVED BY:  
\_\_\_\_\_  
REG. NO.:  
EXP. DATE:  
DATE:



PLANNING  
PERMITTING  
ARCHITECTURE  
CIVIL ENGINEERING  
PROJECT MANAGEMENT

DESIGNED BY: GIL LABRIE  
DRAWN BY: JAVIER MEDINA  
SUBMITTED BY:  
PROJECT ENGINEER  
DATE: 8-8-2011

RECLAMATION  
DISTRICT  
554

DELTA CROSS CHANNEL  
LEVEE CENTERLINE PROFILE  
STATIONS 46+58 TO 65+00  
SCALES: HORZ. 1"=200'  
VERT. 1"=4'

7580.03.01  
SHEET  
REFERENCE  
NUMBER:  
C-5  
5 OF 10

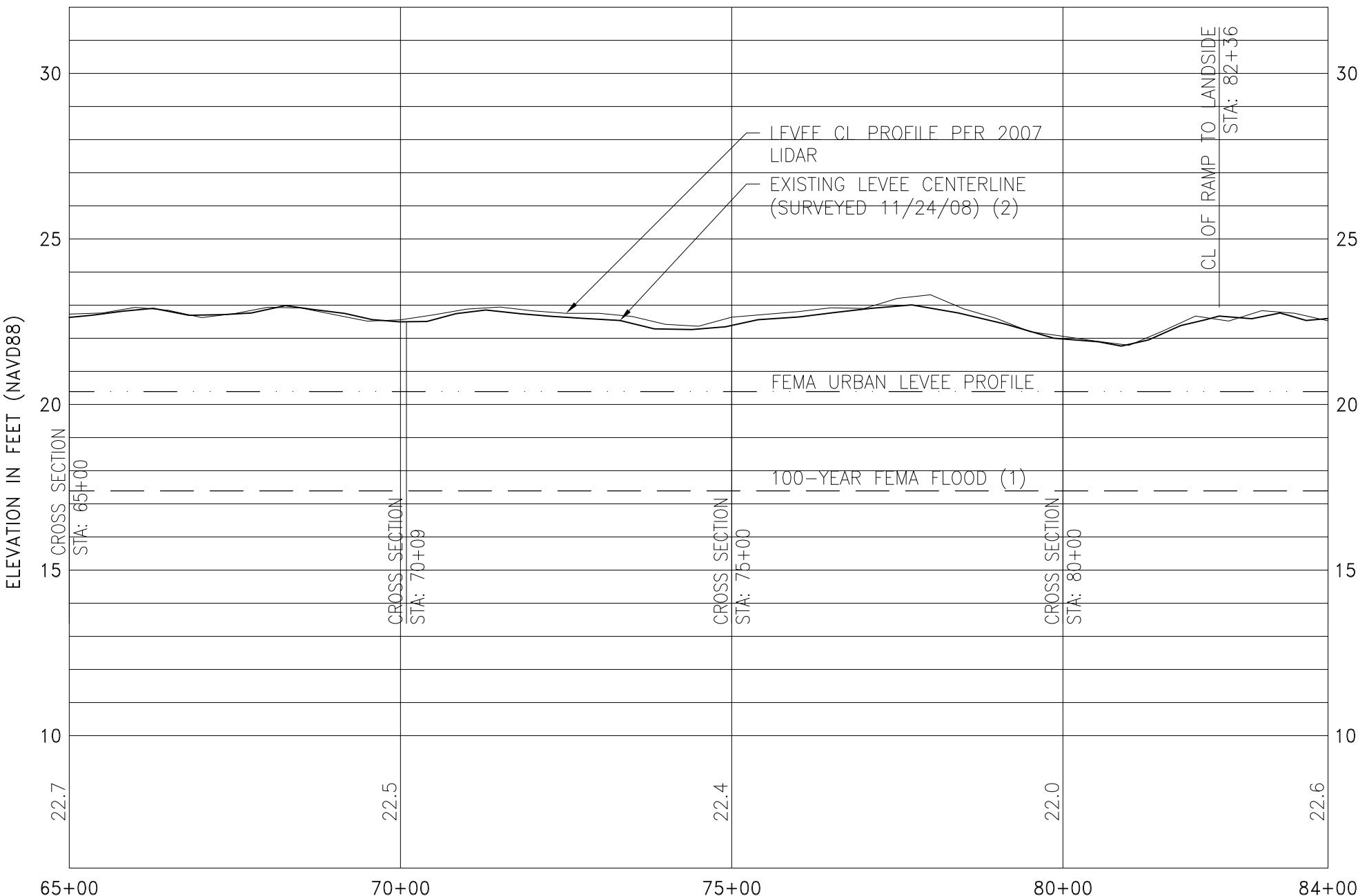
## NOTES:

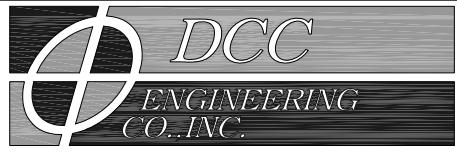
(1) THE 100-YEAR FLOOD LINE IS BASED PER FEMA FIRM MAP COMMUNITY-PANEL-NUMBER 060262 0560C MAP REVISED SEPTEMBER 30, 1988 AND 060262 0580D MAP REVISED FEBRUARY 4, 1998. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON.

(2) THE LEVEE CENTERLINE ELEVATIONS ARE BASED ON A FIELD SURVEY PERFORMED BY DCC ENGINEERING CO., INC. ON OCTOBER 20, 21 2008.

3) THE FIELD SURVEY DATA FOR THIS PROJECT IS BASED ON NAVD88 AND NAD83 DATUMS.

## DELTA CROSS CHANNEL LEVEE CENTERLINE PROFILE



				APPROVED BY: _____ REG. NO.: EXP. DATE: DATE:	 <b>DCC</b> ENGINEERING CO., INC. P.O. BOX 929, WALNUT GROVE, CA 95690 Tel (916)776-2277 Fax (916)776-2282	PLANNING PERMITTING ARCHITECTURE CIVIL ENGINEERING PROJECT MANAGEMENT	DESIGNED BY: GIL LABRIE DRAWN BY: JAVIER MEDINA SUBMITTED BY: PROJECT ENGINEER DATE: 8-8-2011	RECLAMATION DISTRICT 554	DELTA CROSS CHANNEL LEVEE CENTERLINE PROFILE STATIONS 65+00 TO 84+00 SCALES: HORZ. 1"=200' VERT. 1"=4'	7580.03.01 SHEET REFERENCE NUMBER: <b>C-6</b> 6 OF 10
REV.	DATE	BY	DESCRIPTION	APPROVED	DATE					

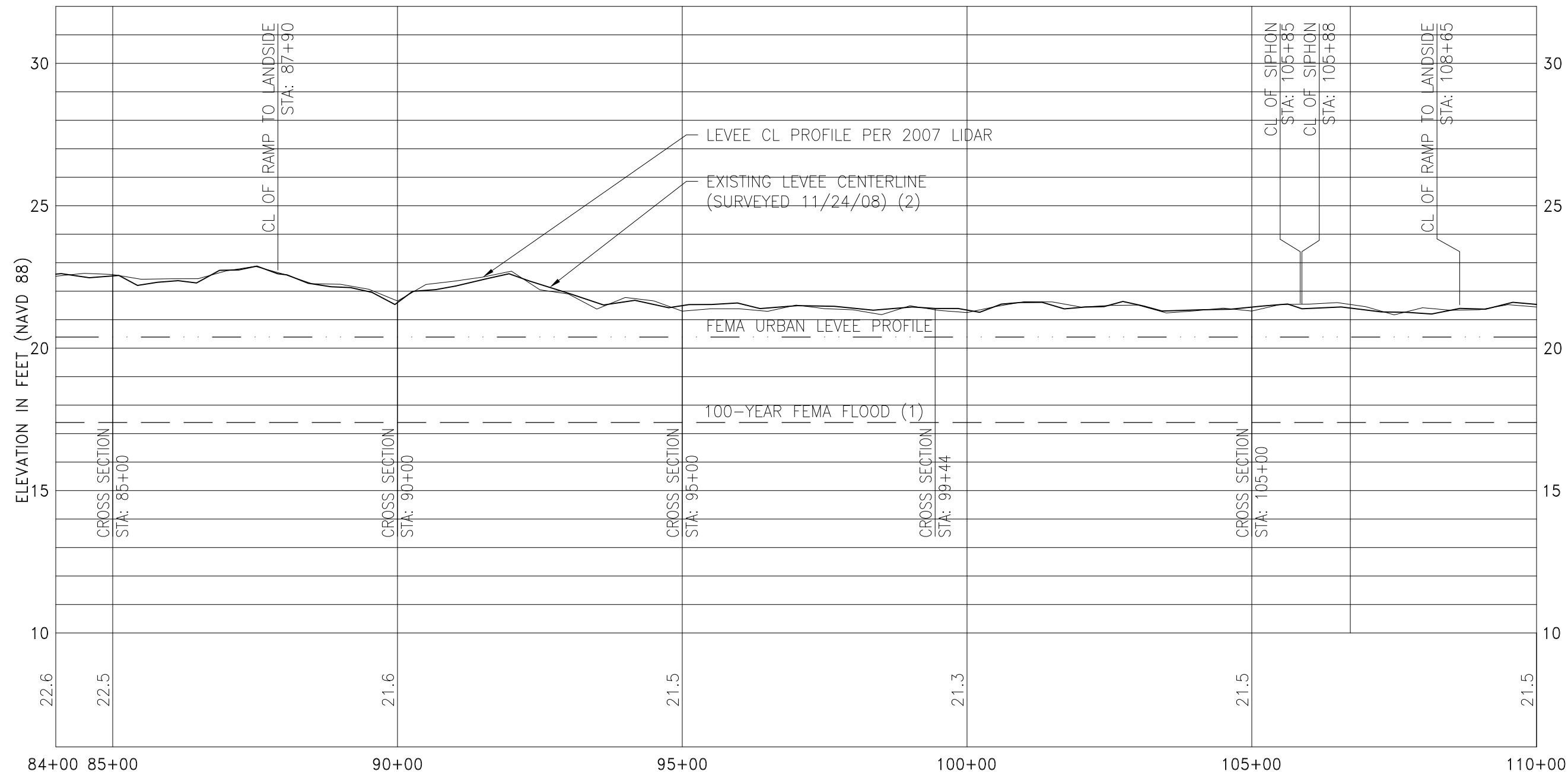
## NOTES:

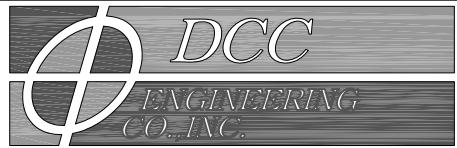
(1) THE 100-YEAR FLOOD LINE IS BASED PER FEMA FIRM MAP COMMUNITY-PANEL-NUMBER 060262 0560C MAP REVISED SEPTEMBER 30, 1988 AND 060262 0580D MAP REVISED FEBRUARY 4, 1998. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON.

(2) THE LEVEE CENTERLINE ELEVATIONS ARE BASED ON A FIELD SURVEY PERFORMED BY DCC ENGINEERING CO., INC. ON OCTOBER 20, 21 2008.

3) THE FIELD SURVEY DATA FOR THIS PROJECT IS BASED ON NAVD88 AND NAD83 DATUMS.

## SNODGRASS SLOUGH LEVEE CENTERLINE PROFILE



APPROVED BY:	 <p><b>DCC</b> ENGINEERING CO., INC.</p> <p>P.O. BOX 929, WALNUT GROVE, CA 95690 Tel (916)776-2277 Fax (916)776-2282</p>			PLANNING PERMITTING ARCHITECTURE CIVIL ENGINEERING PROJECT MANAGEMENT	DESIGNED BY: GIL LABRIE	<b>RECLAMATION DISTRICT</b> 554	SNODGRASS SLOUGH LEVEE CENTERLINE PROFILE STATIONS 84+00 TO 110+00	7580.03.01
REG. NO.:				DRAWN BY: JAVIER MEDINA				
EXP. DATE:				SUBMITTED BY:	PROJECT ENGINEER			
DATE:				DATE: 8-8-2011				
REV. DATE BY	DESCRIPTION	APPROVED	DATE				SCALES: HORZ. 1"=200' VERT. 1"=4'	7 OF 10

SHEET  
REFERENCE  
NUMBER:  
**C-7**

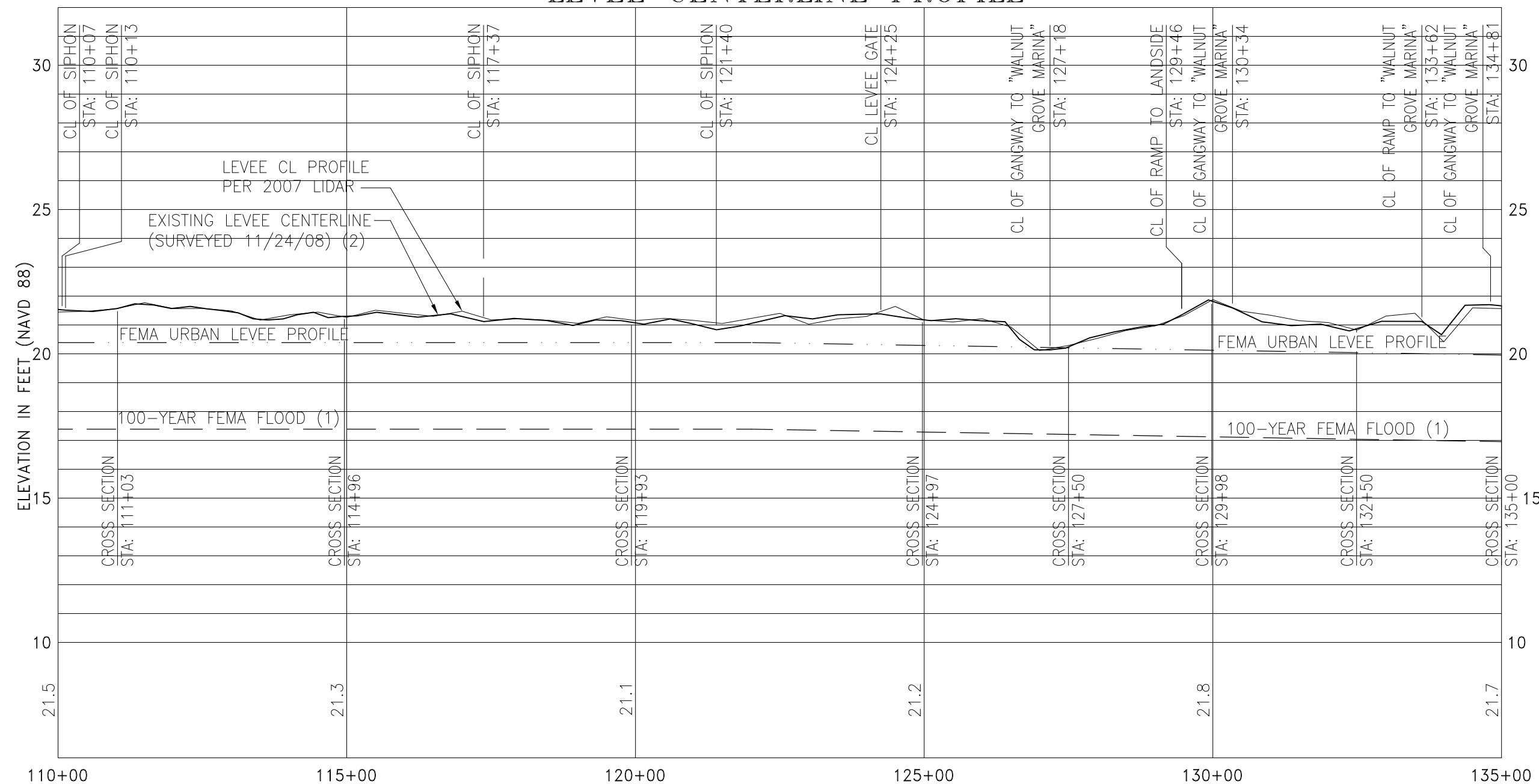
## NOTES

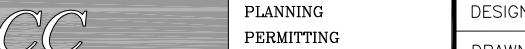
(1) THE 100-YEAR FLOOD LINE IS BASED PER FEMA FIRM MAP COMMUNITY-PANEL-NUMBER 060262 0560C MAP REVISED SEPTEMBER 30, 1988 AND 060262 0580D MAP REVISED FEBRUARY 4, 1998. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON.

(2) THE LEVEE CENTERLINE ELEVATIONS ARE BASED ON A FIELD SURVEY PERFORMED BY DCC ENGINEERING CO., INC. ON OCTOBER 20, 21 2008.

3) THE FIELD SURVEY DATA FOR THIS PROJECT IS BASED ON NAVD88 AND NAD83 DATUMS.

## SNODGRASS SLOUGH LEVEE CENTERLINE PROFILE



					APPROVED BY: _____ REG. NO.: EXP. DATE: DATE:	 DCC ENGINEERING CO., INC. P.O. BOX 929, WALNUT GROVE, CA 95690 Tel (916)776-2277 Fax (916)776-2282	PLANNING PERMITTING ARCHITECTURE CIVIL ENGINEERING PROJECT MANAGEMENT	DESIGNED BY: GIL LABRIE DRAWN BY: JAVIER MEDINA SUBMITTED BY: PROJECT ENGINEER DATE: 8-8-2011	RECLAMATION DISTRICT 554	SNODGRASS SLOUGH LEVEE CENTERLINE PROFILE STATIONS 110+00 TO 135+00 SCALES: HORZ. 1"=200' VERT. 1"=4'	7580.03.01 SHEET REFERENCE NUMBER: C-8 8 OF 10
REV.	DATE	BY	DESCRIPTION	APPROVED	DATE						

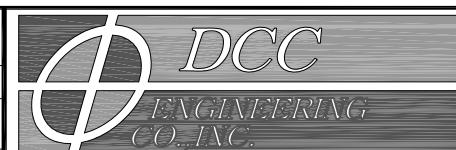
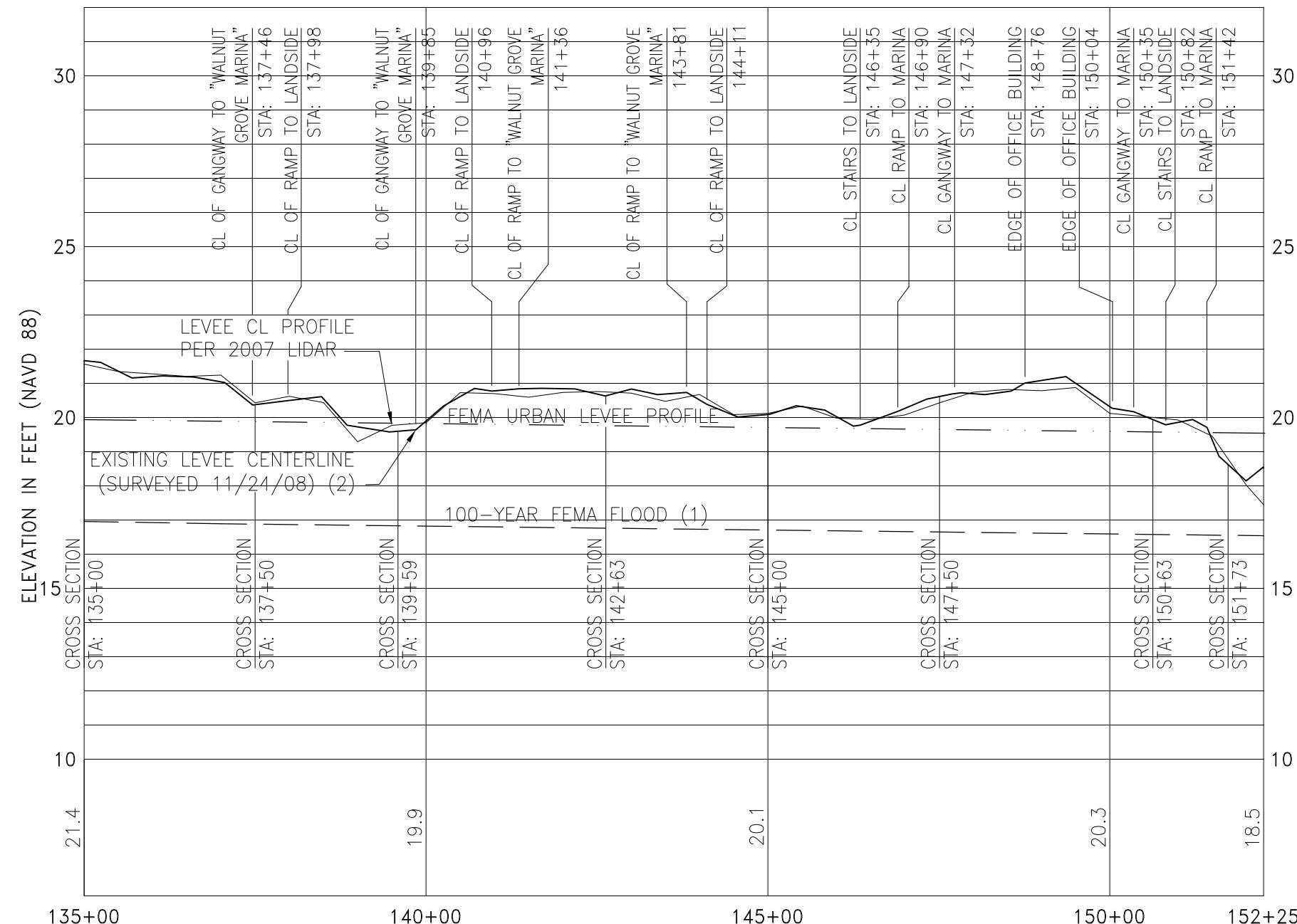
## NOTES

(1) THE 100-YEAR FLOOD LINE IS BASED PER FEMA FIRM MAP COMMUNITY-PANEL-NUMBER 060262 0560C MAP REVISED SEPTEMBER 30, 1988 AND 060262 0580D MAP REVISED FEBRUARY 4, 1998. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON.

(2) THE LEVEE CENTERLINE ELEVATIONS ARE BASED ON A FIELD SURVEY PERFORMED BY DCC ENGINEERING CO., INC. ON OCTOBER 20, 21 2008.

3) THE FIELD SURVEY DATA FOR THIS PROJECT IS BASED ON NAVD88 AND NAD83 DATUMS.

# SNODGRASS SLOUGH LEVEE CENTERLINE PROFILE



P.O. BOX 9222, WALNUT GROVE, CA 95690 Tel (916)776-2277 Fax (916)776-2282

PLANNING  
PERMITTING  
ARCHITECTURE  
CIVIL ENGINEERING  
PROJECT MANAGEMENT

DESIGNED BY: GIL LABRIE  
DRAWN BY: JAVIER MEDINA  
SUBMITTED BY: \_\_\_\_\_  
PROJECT ENGINEER  
DATE: 8-8-2011

RECLAMATION  
DISTRICT  
554

SNODGRASS SLOUGH  
LEVEE CENTERLINE PROFILE  
STATIONS 135+00 TO 152+25

7580.03.01  
SHEET  
REFERENCE  
NUMBER:  
C-9  
9 OF 10

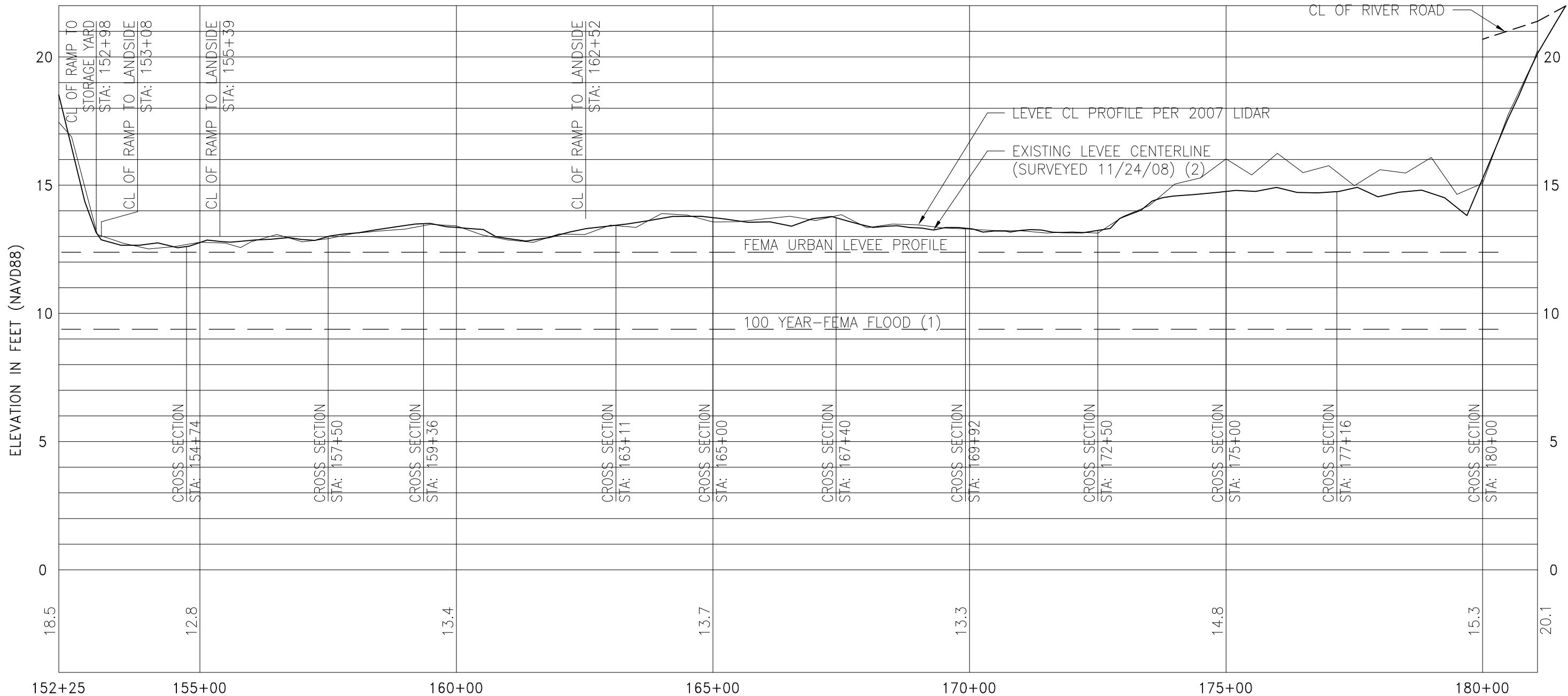
## NOTES:

(1) THE 100-YEAR FLOOD LINE IS BASED PER FEMA FIRM MAP COMMUNITY-PANEL-NUMBER 060262 0560C MAP REVISED SEPTEMBER 30, 1988. THE ELEVATIONS WERE CONVERTED TO NAVD88 BY USING CORPSCON 6.0.1. PROGRAM, VERTCON

(2) THE LEVEE CENTERLINE ELEVATIONS ARE BASED ON A FIELD SURVEY PERFORMED BY DCC ENGINEERING CO., INC. ON OCTOBER 20, 21 2008.

3) THE FIELD SURVEY DATA FOR THIS PROJECT IS BASED ON NAD 83 AND NAVD 88 DATUMS.

## TYLER ISLAND CROSS LEVEE LEVEE CENTERLINE PROFILE



APPROVED BY:	 <p>DCC ENGINEERING CO. INC.</p> <p>P.O. BOX 929, WALNUT GROVE, CA 95690 Tel (916)776-2277 Fax (916)776-2282</p>			PLANNING PERMITTING ARCHITECTURE CIVIL ENGINEERING PROJECT MANAGEMENT	DESIGNED BY: GIL LABRIE DRAWN BY: JAVIER MEDINA SUBMITTED BY: PROJECT ENGINEER DATE: 8-8-2010	RECLAMATION DISTRICT 554	TYLER ISLAND CROSS LEVEE LEVEE CENTERLINE PROFILE STATIONS 152+25 TO 181+07 SCALES: HORZ. 1"=200', VERT. 1"=4'	7580.03.01 C-10 10 OF 10
REG. NO.:								
EXP. DATE:								
DATE:								
REV. DATE BY	DESCRIPTION	APPROVED	DATE					



Levee Subsurface Conductance Study

Prepared For

**WALNUT GROVE**

**RECLAMATION DISTRICT #554**

Prepared September, 2008

Copy date April 20, 2009 version

By Conductance Subsurface Instrumentation, LLC

Levee Subsurface Conductance Study

(Digital)

Prepared For

Walnut Grove

RECLAMATION DISTRICT #554

Prepared October 28, 2008

By

Conductance Subsurface Instrumentation, LLC

Michael L. Stefani

AGREEMENT .....	5
INTRODUCTION TO WALNUT GROVE SUBSURFACE CONDUCTIVITY STUDY .....	7
INTRODUCTION TO CONDUCTANCE STUDIES .....	8
FACTORS AFFECTING SUBSURFACE TERRAIN CONDUCTIVITY .....	9
THE STUDY .....	10
EXPLANATION OF PROCEDURES USED IN CONDUCTANCE STUDY .....	12
WALNUT GROVE PARTS.....	13
WALNUT GROVE 1 METER CONDUCTIVITY .....	14
WALNUT GROVE 2 METER CONDUCTIVITY .....	15
WALNUT GROVE 4 METER CONDUCTIVITY .....	16
ELEVATIONS .....	17
DEFINITION OF EVENTS.....	18
DEFINITION OF TERMS .....	20
GENERAL TERMS USED IN TABLES.....	21
DRAWINGS.....	22
PROFILE ARRANGEMENT .....	27
READING OF TEXT BOXES IN PROFILES .....	28
CONDUCTIVITY GENERALIZATIONS .....	29
<b>FURTHER STUDIES.....</b>	<b>30</b>
<b>AREAS NEEDING FURTHER ATTENTION (PHASE TWO) .....</b>	<b>32</b>
WALNUT GROVE FURTHER ATTENTION MAPS .....	33

<b>REPORT TABLE .....</b>	<b>34</b>
<b>ANOMALY AREAS.....</b>	<b>41</b>
<b>AREAS NEEDING FURTHER ATTENTION (PHASE TWO) .....</b>	<b>42</b>
<b>CARS ON LEVEE.....</b>	<b>42</b>
<b>COMMENTS .....</b>	<b>44</b>
<b>DRAIN STATION PIPES.....</b>	<b>45</b>
<b>ELECTRICAL LINES.....</b>	<b>46</b>
<b>GATES .....</b>	<b>46</b>
<b>PHONE LINES .....</b>	<b>48</b>
<b>SIPHON PIPES .....</b>	<b>48</b>
<b>SOIL CHANGES .....</b>	<b>49</b>
<b>STARTING POINTS .....</b>	<b>50</b>
<b>UNKNOWNS .....</b>	<b>51</b>
<b>SUBSURFACE CONDUCTIVITY IS NOT A PANACEA .....</b>	<b>53</b>
<b>DEVLOPMENT OF SUBSURFACE CONDUCTIVITY STUDIES.....</b>	<b>55</b>
<b>WALNUT GROVE BASE MAP .....</b>	<b>58</b>
<b>WALNUT GROVE ANOMALY MAP.....</b>	<b>59</b>
<b>WALNUT GROVE SOIL CHANGE MAP.....</b>	<b>60</b>
<b>WALNUT GROVE UNKNOWN MAP .....</b>	<b>61</b>
<b>WALNUT GROVE FURTHER ATTENTION MAP .....</b>	<b>62</b>
<b>CONCLUSIONS.....</b>	<b>63</b>

## AGREEMENT

THIS AGREEMENT is made by and between MICHAEL STEFANI, doing business as Conductive Subsurface Instrumentation (CSI) and his Client. The agreement pertains to the initial work performed by Mr. Stefani and any subsequent work performed by Mr. Stefani at the request of the Client. Mr. Stefani is in the business of performing subsurface conductive studies of delta island levees. To do this, Mr. Stefani uses a testing instrument which measures the conductivity of the soil that forms the levee. Mr. Stefani interprets the test results and gives opinions concerning the subsurface condition of the levee including the presence of anomalies that are detected. Mr. Stefani then prepares a report for his client which contains the test results and Mr. Stefani's opinions and conclusions concerning the testing and the identification of specific findings detected below the surface of the levee. The Client can use Mr. Stefani's report to make decisions relating to what levee work may need to be done and when to do the work.

By the terms of this agreement, Client acknowledges that Client understands that Mr. Stefani's opinions and conclusions are not based upon an exact science. Instead, Mr. Stefani's opinions are based upon the test results which show the subsurface conductivity of the levee and Mr. Stefani's experience in using the testing instrument and his experience in interpreting the test data. Based upon the

foregoing, Client agrees that Mr. Stefani cannot make any guarantee or any express or implied warranty concerning the subsurface condition of the levees that he tests. In addition, Client agrees that Mr. Stefani assumes no liability concerning the test results, his opinions and conclusions or the lack thereof. Client hereby acknowledges that Client understands that the subsurface test instrument does have limitations and that the interpretation of the test results is a matter of opinion.

Dated: November 22, 2008

A handwritten signature in black ink that reads "Michael L. Stefani". The signature is fluid and cursive, with "Michael" on the left and "L. Stefani" on the right. The "L" in "L. Stefani" is particularly stylized with a small circle at the top.

By: Michael L. Stefani

## **Introduction to Walnut Grove Subsurface Conductivity Study**

One of the primary intentions of this study is to generate a working document than can be utilized by the State of California employees, District Board, their consultants and district employees to preserve the integrity of the levee system in a more knowledgeable systematic manner, and establish a list of items that will originate a base for a phase two study.

### **Accomplishments**

The results of this study are many. Identified were unknowns, anomaly areas, soil changes and an extensive inventory of events in the levee.

Areas that should placed under closer (phase two) were identified. Conductivity profiles were obtained that should be a valuable tool that can be utilized to observe changes in the soil density or water content

## **Introduction to Conductance Studies**

The instrument used in this study is a patented inductive electromagnetic exploration system manufactured by Geonics Ltd of Canada. The Geonics EM 31-3 was chosen as the primary instrument because of its ease of operation, mobility and ability to provide continuous data.

The basic principal behind the EM 31-3 is as follows: A transmitter coil located on one end of the instrument induces circular eddy current loops in the subsurface (fig. 1). The magnitude of these loops is in direct proportion to the terrain conductivity within the volume of the field. A part of the magnetic field from each loop is intercepted by 3 receiver coils and results in an output voltage which is related to the terrain conductivity.

The assumed maximum depth of the magnetic loops into the earth is 6 meters or approximately 19.5 feet below the level of the instrument. The instrument indicates conductivity from 0.00 millisiemens per meter (mS/n) to 1000 millisiemens per meter on three (3) range settings which encompass a wide range of soil conditions. The magnetic field produce is approximately 12 feet in diameter on the horizontal plane at ground level and 6 feet in diameter at 9 at a depth of 9 feet (fig. 2 and fig 3).

## **Factors Affecting Subsurface Terrain Conductivity**

The subsurface conductivity is determined for terrain by the following factors:

- 1) Moisture content: the extent to which pores in the soil are filled with water.
- 2) Soil type: sand, loam, clay, silt, peat or any combination of these.
- 3) Concentration of dissolved electrolytes such as water with higher or lower salt content.
- 4) Temperature and phase state of the pore water.
- 5) Presence of foreign objects: wood debris, concrete, metal or plastic pipes.

## The Study

The following is a draft report of the results of a subsurface electrical conductance study on the levee system of *Walnut Grove, Reclamation District #554, in Sacramento County*.

The study was begun on *September 15<sup>th</sup>* and completed on *October 15<sup>th</sup>, 2008*. The temperature was from *85 degrees to 95 degrees*. The stationing runs in a counterclockwise direction and the starting station is just north of a PG&E power pole near the west fence of Blue Anchor. The stationing has the staring point (3813.38781919, N, 12130.39920301, W) and run a clockwise direction (CSI stationing appears to be reclamation stationing plus 279'). Three traverses were performed. One traverse were located on the Waterside shoulder (WSS), another was performed in the road center line (CL) and the final traverse was performed on Land side shoulder (LSS). The total study consisted of 18,043 feet for total *3.41 miles*.

The Walnut Grove project an excellent example of how environmental conditions can hamper a project. The west side of the project went through the commercial section of Walnut grove. Traffic was halted for the duration of the three traverses but there were many parked vehicles

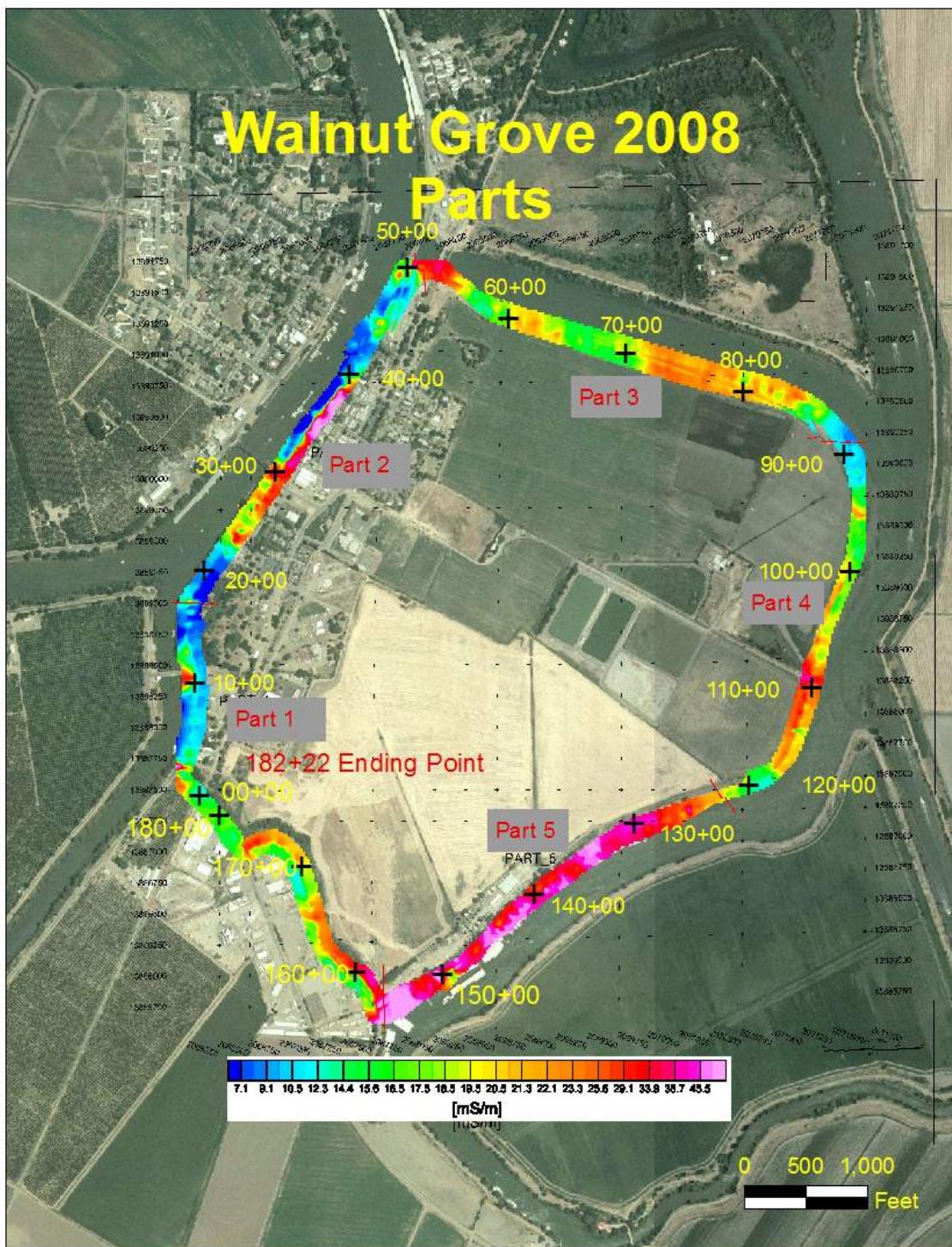
still present. The effect of these parked vehicles is obvious on the conductivity profiles. There were several unknown signal observed. Because of the number of parked vehicles it is very difficult to determine if the signals are vehicles or actually pipes. The whole area on the west side needs to be checked in the phase two portion of the study.

Portions of the east section conductivity profiles display erratic profiles. It is felt the these erratic signals are from transmission of the various antennas on the tower

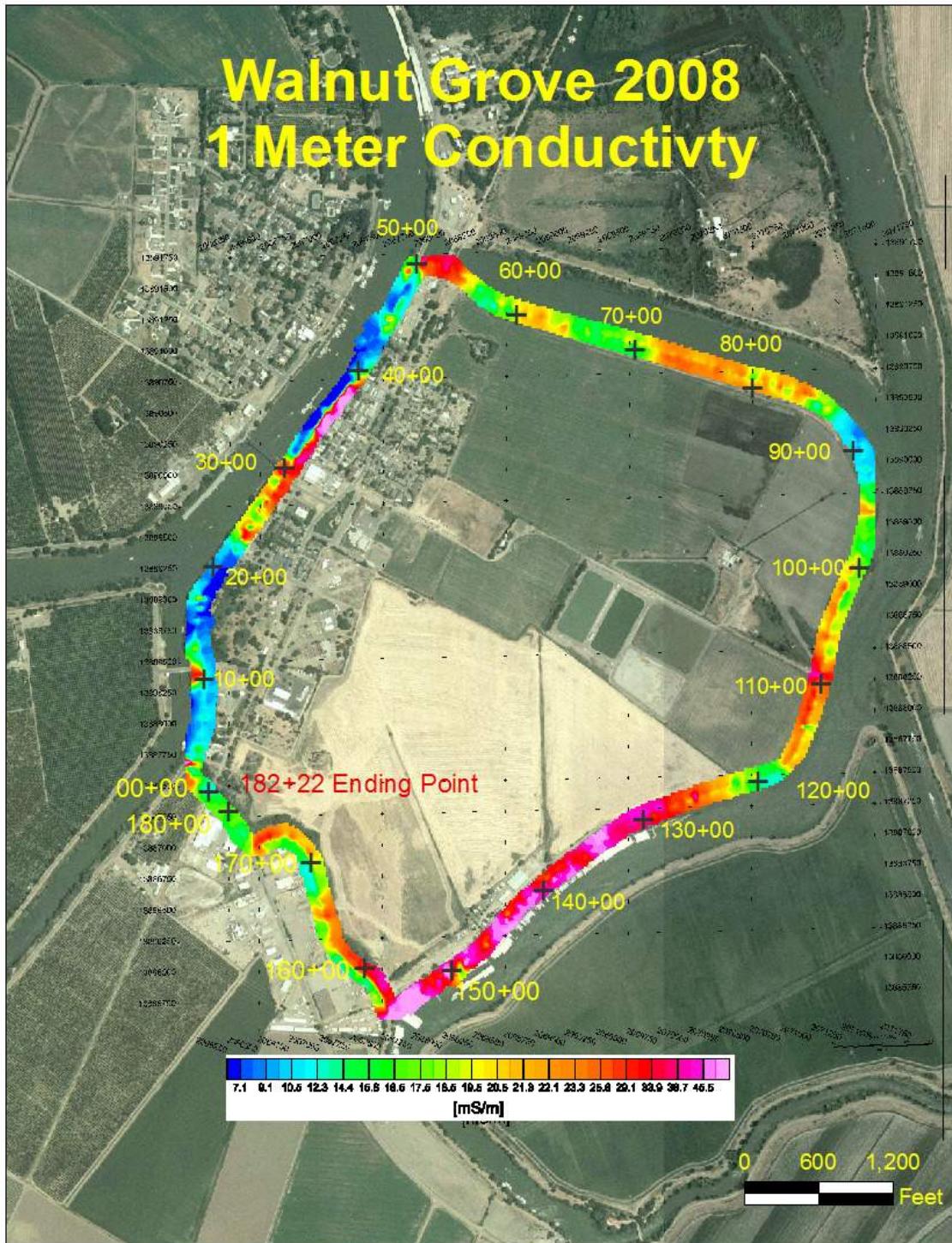
## **Explanation of Procedures Used in Conductance Study**

The first step consisted of a preliminary drive to locate any possible traverse problem. The next step was the performing of traverses at the WSS, CL and LSS. Step number three was analyzing the data and determining which areas required further examination to conclude which locations could be potential problem locations. Step number four consisted of examining the potential problem areas. Extensive time and careful analysis were spent on each suspect area. These results yielded the possible depth, dimension, and possibly the type of anomaly. Also all unknown signals were reviewed by confirming their possible depth, location and orientation in the levee.

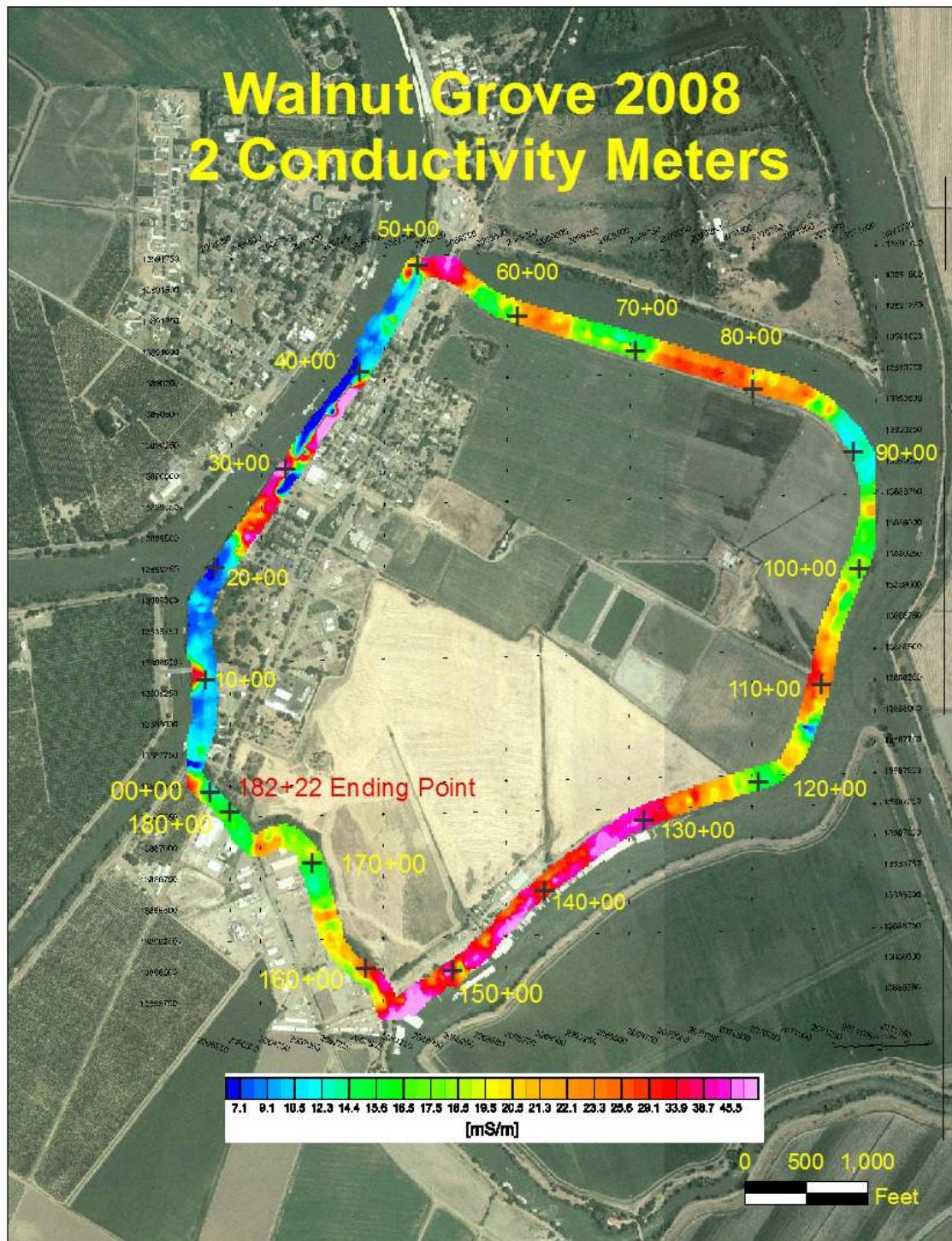
## Walnut Grove Parts



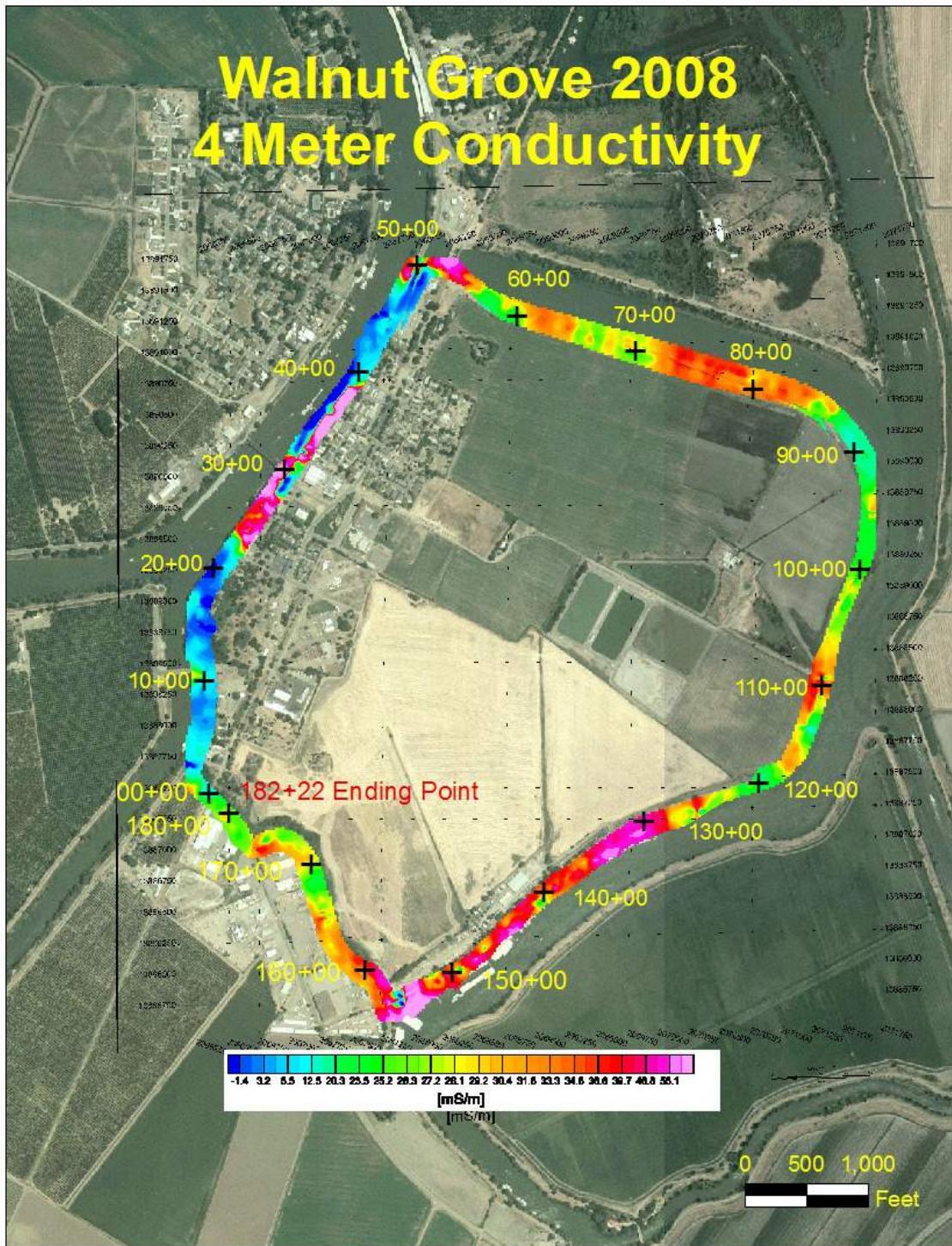
## Walnut Grove 1 Meter Conductivity



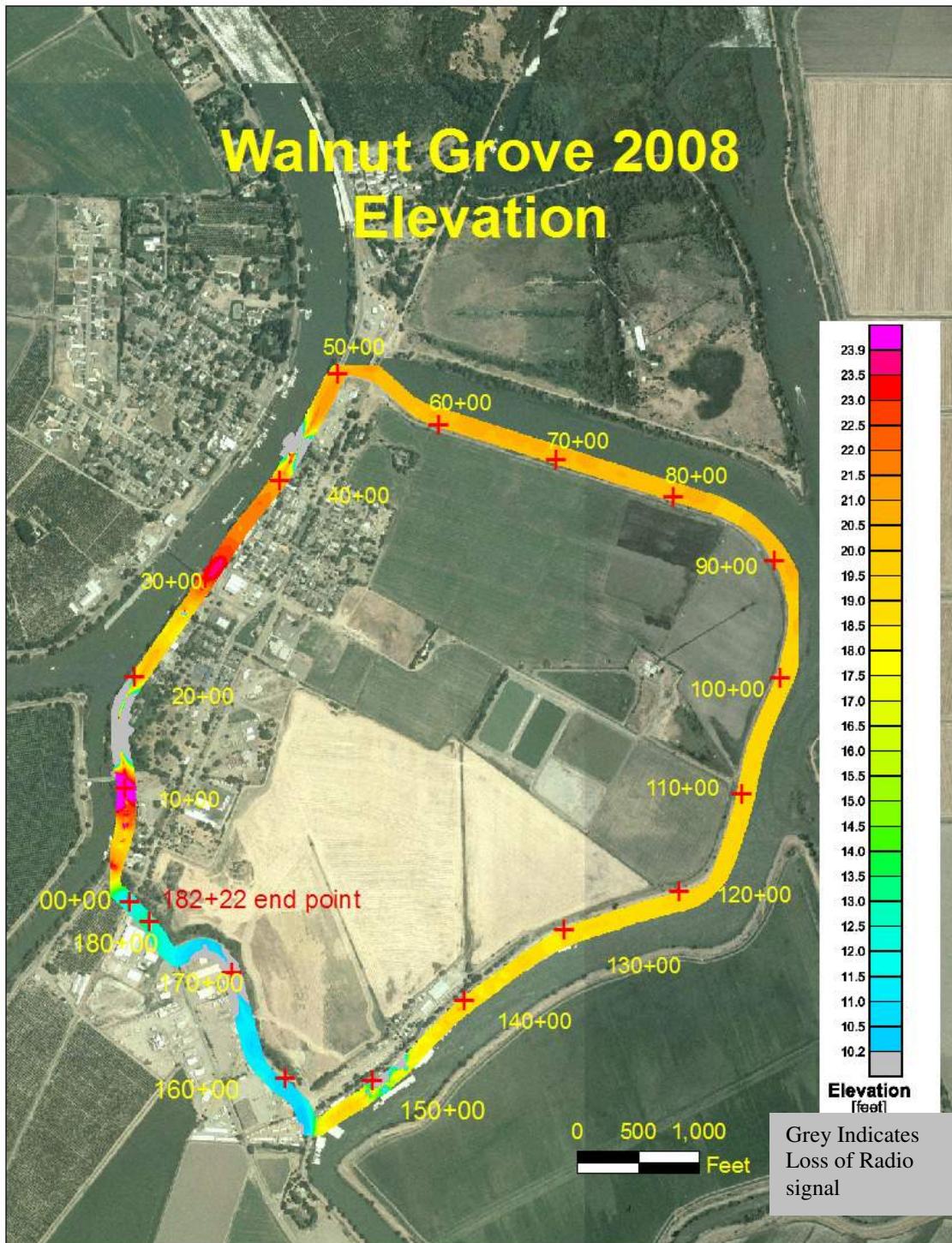
## Walnut Grove 2 Meter Conductivity



## Walnut Grove 4 Meter Conductivity



## Elevations



## **Definition of Events**

**Anomaly areas-** The criteria for anomaly areas in a CSI study is a length of levee that displays an unusual pattern in that levee system. Some patterns occur in many different levee lengths. Some patterns are unique to a particular levee system. It is from experience with hundreds of miles of levee studies and over a thousand excavations that the definition of anomaly areas has evolved (see anomaly table starting page 54 for examples).

**Areas for future study** A levee length that for various reasons is felt by CSI staff to justify phase two attention.

**Comments** - Comments are simply notations concerning the conductivity profiles that indicate a minor deviation from the general patterns in that levee system. Comments also are used as notes made in the field to emphasize or make note of a non event occurrence

**Drain Stations pipes** are location of drain pumps.

**Electrical lines** are the location of electrical supplies crossing below or above the levee surface.

**Gas lines** are the locations of gas line crossing the levee.

**Gates** are the locations of gates on the levee.

**Irrigation Pumps** are the locations of irrigation pump pipes.

**Phone lines** are the location of phone lines.

**Reclamation Stations** – These are the location of Reclamation District Stations with a reference to the stationing used by CSI.

**Siphon pipes** – Is a list the locations of siphon pipes.

**Soil Changes-** These are areas that display conductivity profile changes over a broad area and are likely the locations of soil changes from various depths.

No borings were performed in these locations. These areas exhibit

conductivity profiles that change over a large area.

**Supply Lines** – These are the location of water supply lines.

**Unknowns** - Unknowns are defined by CSI as a signal running perpendicular to the levee. Unknowns tend to generate a signal similar to a metal pipe or cable running across the levee. Through previous excavations it has been observed that many unknowns have turned out to be pipes that had been abandoned and forgotten. It has been observed, when excavated, these pipes (anything from 16 inch diameter abandoned siphons to 1 inch diameter supply lines) at depths of 1 foot to 18 feet, had the potential of transporting of water into a levee system and possibly having a destabilization effect on that levee section (see tables for examples).

## **Definition of Terms**

**LSS** (Land side shoulder): point on crown of the levee adjacent to land side slope adjacent to land side.

**CL** (Center line): The center of the levee or roadway.

**WSS** (Water Side Shoulder): point on crown of the levee adjacent to the slope on water's edge.

To identify a particular point in the levee system a location procedure has been adopted for these reports for this and other reports. For example, when the location of LSS+10 is given the point described is 10 feet towards the inside of the LSS point. All positive numbers (+) indicate distances toward the inside of the levee. All minus (-) numbers indicate distances toward the outside of the levee (towards the water) (see fig. 5).

## **General terms Used in Tables**

**EM stations** are (format-###,###) a number the software utilizes and to assign longitudes and latitudes to particular events.

**Stations** are (format-###+##) locations of various events utilized by CSI. This stationing matches or hopefully approximates district stationing.

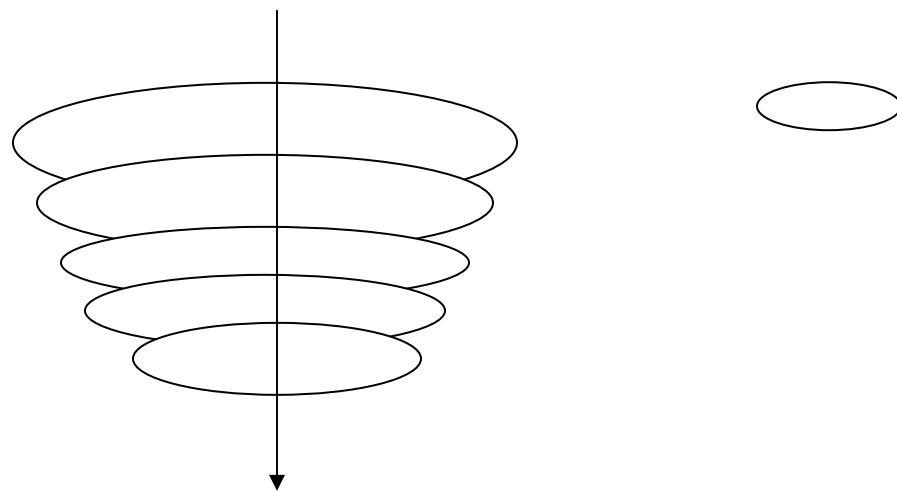
**Events** are different categories of objects or occasions in the levee.

**Latitudes and Longitudes** are utilized to ascertain GPS positioning of various events. These are based on UTM Zone 10, horizontal datum NAD 83.

## Drawings

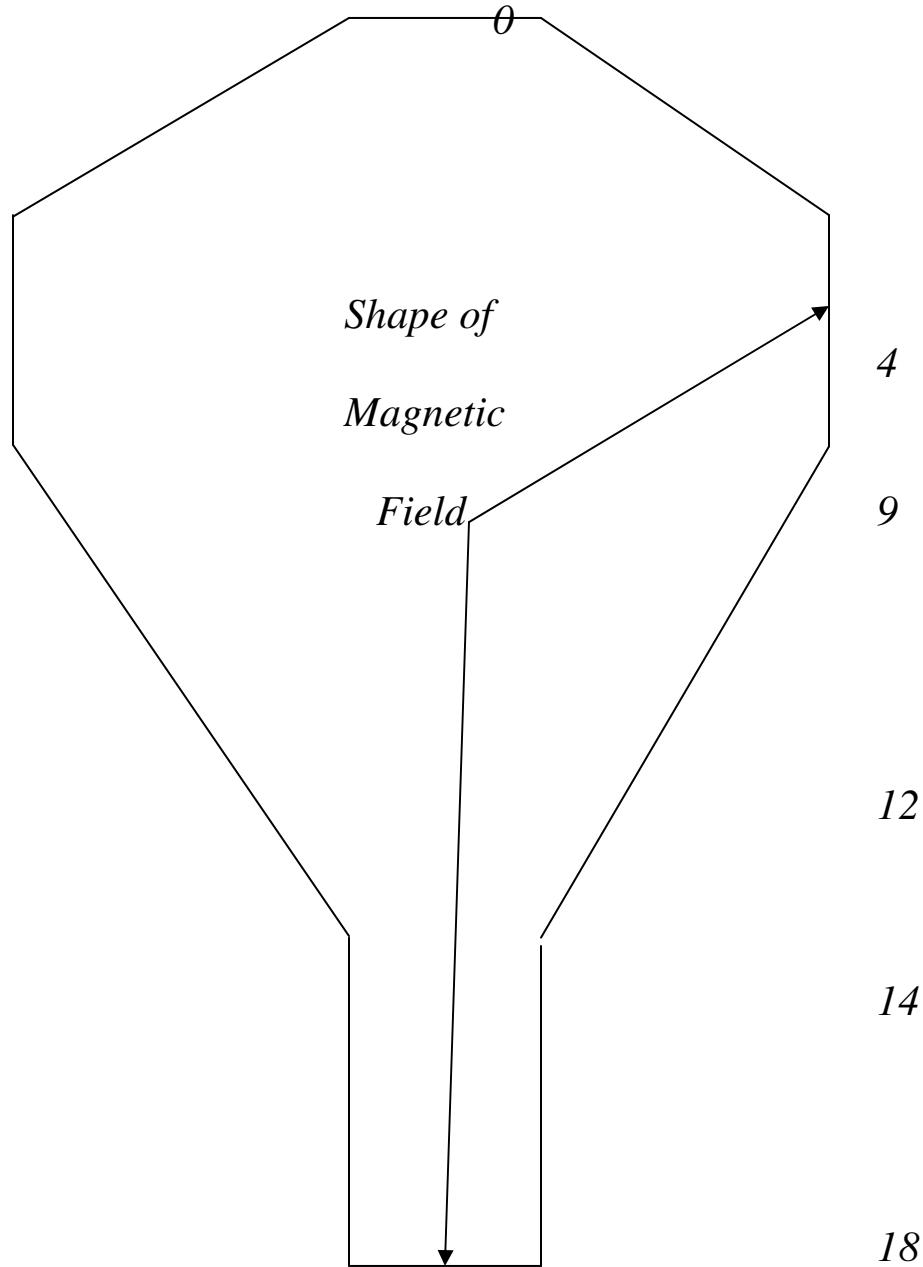
Transmitter

Receiver

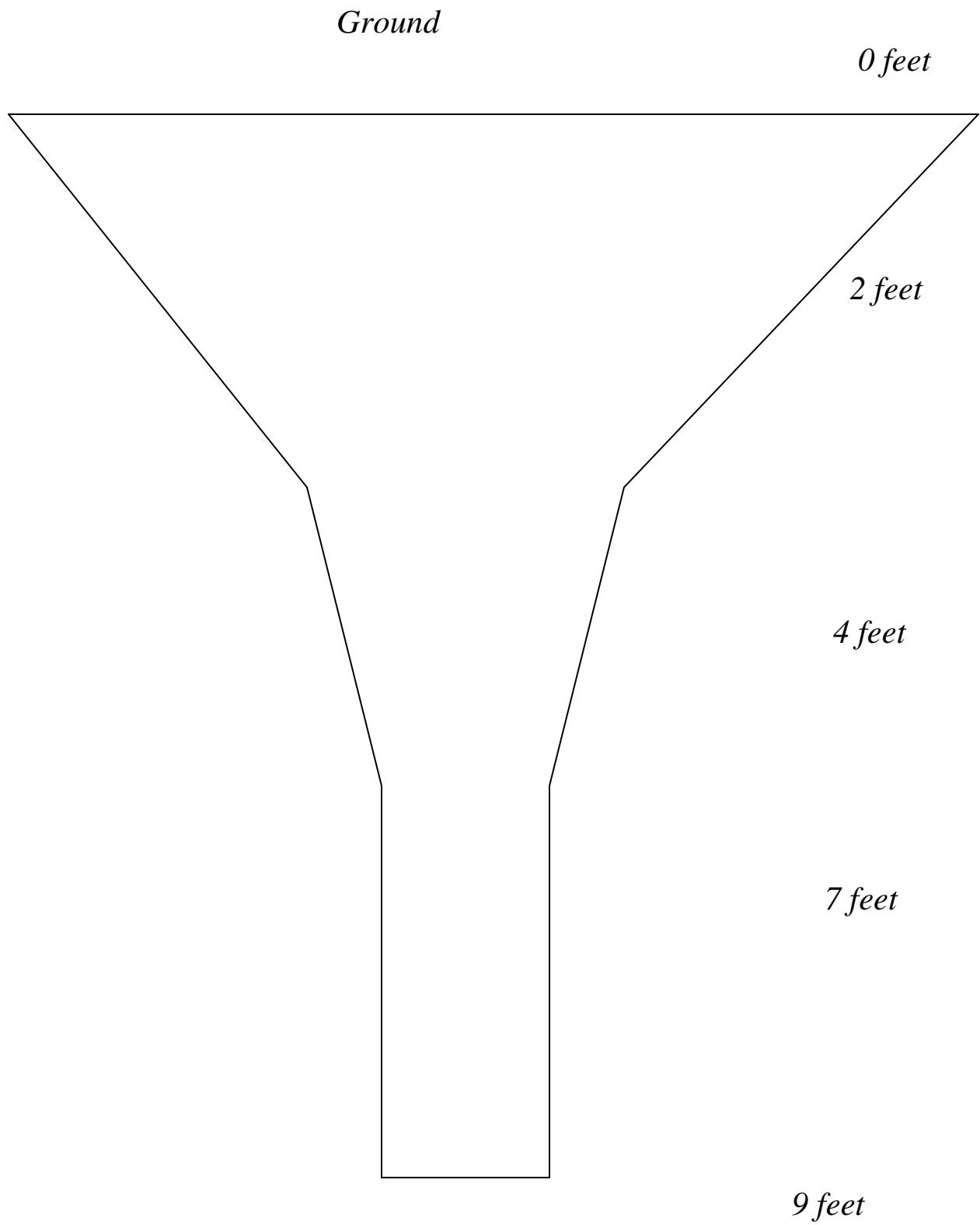


*Figure 1 Induced Current Flow in Ground*

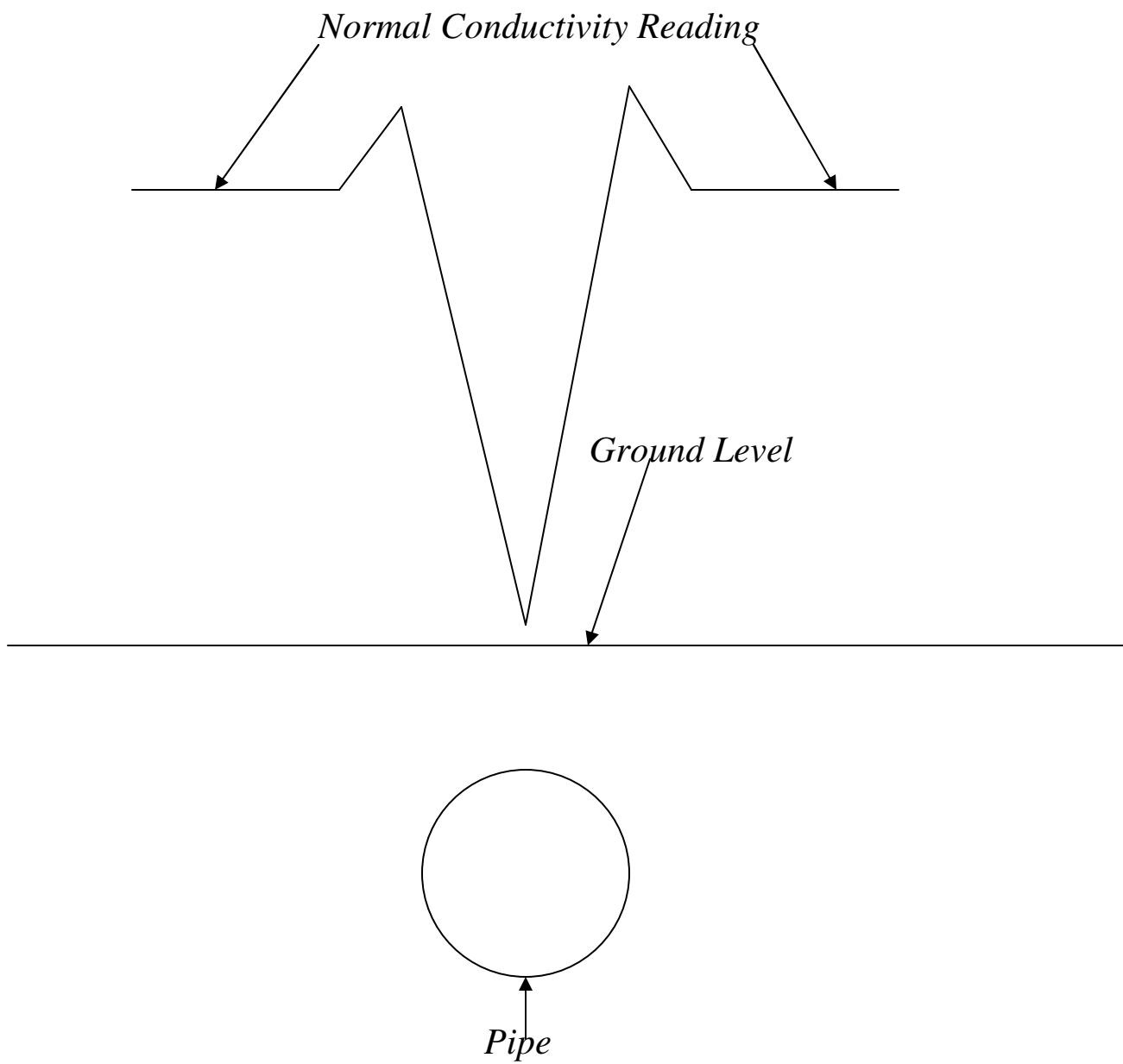
*Ground-full depth  
Depth in Feet*



*Figure 2 Instrument at 4 meter spacing. – Deep Depth*



*Figure 3 Instrument at 2 meter spacing.*

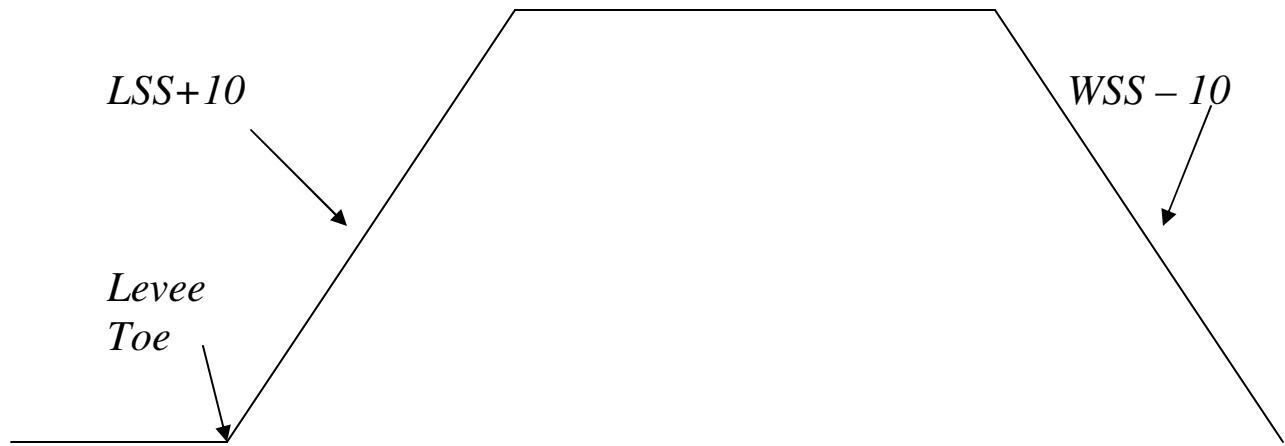


*Figure 4 Typical Response over a Pipe*

*Center Line (CL)*  
*Crown (Cr)*

*Land Side Shoulder*

*Water Side Shoulder*



*Figure 5 Levee Cross Section*

## **Profile Arrangement**

**EM stations** are (format-###, ###) a number the software utilizes and to assign longitudes and latitudes to particular events.

**Stations** are (format-###+##) locations of various events utilized by CSI. This stationing matches or hopefully approximates district stationing.

**Events** are different categories of objects or occasions in the levee.

**Latitudes and Longitudes** are utilized to ascertain GPS positioning of various events. These are based on UTM Zone 10, horizontal datum NAD 83.

## Reading of text boxes in profiles

# refers to the event number  
Station Refers to Measured Distance  
Em Sta refers to Em Station  
“Refers to diameter in inches  
‘Refers to depth in feet

Event      # Station      Em Sta.   Latitude      Longitude      “      “

Irrigation Pump Pipe	4	0138+38	10,854.00	3812.28247,n	12127.20440,w	16	1
-------------------------	---	---------	-----------	--------------	---------------	----	---

## Conductivity Generalizations

The overall conductivity patterns are best noted on the conductivity maps on pages 13 thru 15 of the modeling section of this study. It should be understood that soils with uniform **lower conductivity** are made up with higher **sand and or lower water** content. Also soils with a uniform **higher conductivity** are made up with **higher clay and or higher water** content. Soils with higher **water** content will tend to have a **higher conductivity** value. Soils with lower **water** content will tend to have a **lower conductivity** value.

## Further Studies

Any yellow highlighting is meant to refer to areas of Further Studies.

At the present time there are 4 areas that where it is felt a phase two study should be utilized. A phase two study would involve a short traverse with either the Em 31 and or the En 31-3 (when feasible) at different locations on the water and land side slopes, possibly followed by some borings. Before excavation truthing, **true** three dimensional modeling would yield very useful information at these sites. Finally, the use excavation or other truthing procedures would also be useful and aid in the eventual actual repair.

Many of the further study areas are classified as “unknowns” and are most likely pipes of various sizes and at various depths. The “unknowns” grouped for phase two display distinct unknown conductivity profiles. They tend to be 4’-5’ or greater in depth and their profiles tend to be visible in all three traverses (Ls, Cl and Ws, see tables for examples).

Another group of areas suggested for phase two study are some anomaly areas. There are 5 total. These anomaly areas listed are the most severe of the anomalies and should be returned to. Through the use of conductivity studies is now possible to better define the locations. Phase

two should consist of further traverses with at least the EM-31 and if feasible the EM 31-3 in various locations on the water side slope and land slope

All the above areas are located in the table labeled Areas for Further Attention starting on page 31 followed by maps on page 34

## Areas Needing Further Attention (Phase Two)

4 total

### Areas needing further attention

2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion	Possible Depth (feet)
Walnut Grove	5983	0048+88	Further Attention	1	3814.78199013,N	12130.62287793,W		
Walnut Grove	10426	0094+93	Further Attention	2	3814.42440987,N	12129.86833409,W		
Walnut Grove	11550	0105+33	Further Attention	3	3814.26104362,N	12129.94440022,W		
Walnut Grove	18729	0173+57	Further Attention	4	3814.02223867,N	12130.89733954,W		

## Walnut Grove Further Attention Maps



## Report Table

### Report Query

CompanyNumber	2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)	Possible Depth (feet)
39	Walnut Grove	0		Starting Point	1						
39	Walnut Grove	73	0000+83	Comment	1	3814.09147603,N	12131.00925810,W	Power pole			
39	Walnut Grove	107	0000+89	Comment	2	3814.09154623,N	12131.00932902,W	Sign pole (J11)			
39	Walnut Grove	127	0001+14	Comment	3	3814.09208293,N	12131.01127934,W	dirt road and asphalt road			
39	Walnut Grove	162	0001+62	Soil Change	1	3814.09477275,N	12131.01747823,W				
39	Walnut Grove	391	0003+27	Irrigation Pump Pipe	1	3814.12675709,N	12131.02902690,W		8	4	
39	Walnut Grove	1350	0010+62	Comment	4	3814.24836499,N	12131.00577846,W	center line Georgiana Slough Bridge			
39	Walnut Grove	1716	0014+16	Anomaly Area	1	3814.28892868,N	12131.01334015,W				
39	Walnut Grove	1510	0015+10	Car on levee	1	3814.26871934,N	12131.01134941,W				
39	Walnut Grove	1606	0016+06	Car on levee	2	3814.27537298,N	12131.01371075,W				
39	Walnut Grove	2276	0016+93	Phone Line	1	3814.34303226,N	12131.00904420,W	at angle from sign			
39	Walnut	1710	0017+10	Car on	3	3814.28688336,N	12131.01646695,W				

### Report Query

CompanyNumber	2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)	Possible Depth (feet)
	Grove			levee							
39	Walnut Grove	2133	0021+33	Car on levee	4	3814.31149397,N	12131.01554629,W				
39	Walnut Grove	2976	0022+73	Unknown	1	3814.42051546,N	12130.94064901,W	difficult to id, in front 14205 address			
39	Walnut Grove	3359	0026+27	Unknown	2	3814.46833483,N	12130.89570060,W	difficult to id, post office door			
39	Walnut Grove	2700	0027+00	Car on levee	5	3814.38545648,N	12130.97361294,W				
39	Walnut Grove	2861	0028+61	Car on levee	6	3814.40432679,N	12130.95366301,W				
39	Walnut Grove	3640	0029+04	Comment	5	3814.50309,n	12130.85931,w	center line Walnut grove bridge			
39	Walnut Grove	3033	0030+33	Car on levee	7	3814.42712872,N	12130.93219990,W				
39	Walnut Grove	3043	0030+43	Car on levee	8	3814.42719678,N	12130.93450301,W				
39	Walnut Grove	3770	0030+74	Unknown	3	3814.52679818,N	12130.84237904,W	center line of Bridge Road			
39	Walnut Grove	3118	0031+18	Car on levee	9	3814.43503845,N	12130.92698823,W				
39	Walnut Grove	3161	0031+61	Car on levee	10	3814.44249839,N	12130.91798778,W				
39	Walnut Grove	3172	0031+72	Car on levee	11	3814.44265409,N	12130.91973317,W				

### Report Query

CompanyNumber	2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)	Possible Depth (feet)
39	Walnut Grove	3379	0033+79	Car on levee	12	3814.46935630,N	12130.89297236,W				
39	Walnut Grove	4175	0035+13	Unknown	4	3814.58107352,N	12130.79334051,W	centerline of C street			
39	Walnut Grove	3781	0037+81	Car on levee	13	3814.52082403,N	12130.84538495,W				
39	Walnut Grove	4651	0038+93	Unknown	5	3814.63328336,N	12130.73885710,W	south side of spa factory, 14099 address			
39	Walnut Grove	5350	0043+39	Unknown	6	3814.69546286,N	12130.69122433,W				
39	Walnut Grove	5869	0043+83	Phone Line	2	3814.76864152,N	12130.63985811,W	patch in road			
39	Walnut Grove	4550	0045+50	Car on levee	14	3814.60920530,N	12130.76110722,W				
39	Walnut Grove	5983	0048+88	Further Attention	1	3814.78199013,N	12130.62287793,W				
39	Walnut Grove	5983	0048+88	Unknown	7	3814.77870721,N	12130.62112265,W				
39	Walnut Grove	6030	0051+21	Comment	6	3814.77147756,N	12130.58208383,W	File change,			
39	Walnut Grove	6228	0052+63	Unknown	8	3814.76369592,N	12130.56726614,W	deep			
39	Walnut Grove	5689	0054+22	Gate	1	3814.74482,n	12130.54009,w	north			
39	Walnut Grove	5508	0056+99	Flood Gate	1	3814.71772,n	12130.49435,w	deep			

### Report Query

CompanyNumber	2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)	Possible Depth (feet)
39	Walnut Grove	4828	0066+43	Comment	7	381466903,n	12130758,w	State gauge in channel			
39	Walnut Grove	6654	0066+54	Soil Change	2	3814.72521999,N	12130.51121527,W				
39	Walnut Grove	6760	0067+60	Comment	8	3814.71281854,N	12130.47986448,W	Erratic signal Source not determined most likely antenna on TV tower.			
39	Walnut Grove	7653	0076+53	Comment	9	3814.68915195,N	12130.38547773,W	Erratic Signal Source not determined Most likely antenna on TV tower.			
39	Walnut Grove	8258	0082+58	Comment	10	3814.65780736,N	12130.26338658,W	Erratic Signal Source Not determined Most likely antenna on TV tower			
39	Walnut Grove	9378	0093+78	Comment	11	3814.57516332,N	12129.96169244,W	Erratic signal source not determined most likely antennas on TV tower.			
39	Walnut Grove	10476	0094+93	Further Attention	2	3814.42440987,N	12129.86833409,W				

### Report Query

CompanyNumber	2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)	Possible Depth (feet)
	39 Walnut Grove	10476	0094+93	Unknown	9	3814.42440987,N	12129.86833409,W				
	39 Walnut Grove	9879	0098+79	Soil Change	3	3814.51640350,N	12129.89029939,W	Most visible on land side			
	39 Walnut Grove	11550	0105+33	Further Attention	3	3814.26104362,N	12129.94440022,W				
	39 Walnut Grove	11550	0105+53	Unknown	10	3814.26104362,N	12129.94440022,W				
	39 Walnut Grove	11839	0108+60	Drain Station Pipe	1	3814.20966337,N	12129.95823319,W				
	39 Walnut Grove	11843	0108+64	Drain Station Pipe	2	3814.21066876,N	12129.95791947,W		10	2	
	39 Walnut Grove	11298	0112+85	Siphon	1	3814.30287154,N	12129.92515458,W	cut off llss+40', not capped	6	2	
	39 Walnut Grove	12291	0112+90	Siphon	2	3814.14330194,N	12129.98530762,W		16	2	
	39 Walnut Grove	12994	0120+12	Drain Station Pipe	3	3814.07231560,N	12130.09251912,W		14	4	
	39 Walnut Grove	13416	0124+18	Irrigation Pump Pipe	2	3814.05480861,N	12130.17395560,W		14	3	
	39 Walnut Grove	13215	0127+05	Gate	2	3814.04199,n	12130.22915,w	south gate			
	39 Walnut Grove	13769	0128+79	Car on levee	15	3814.03229387,N	12130.26389389,W				

### Report Query

CompanyNumber	2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)	Possible Depth (feet)
39	Walnut Grove	13190	0131+90	Car on levee	16	3814.04146973,N	12130.22864574,W				
39	Walnut Grove	13269	0132+69	Comment	12	3814.06277352,N	12130.14254476,W	Marina Starts/Visible on C.L.			
39	Walnut Grove	13289	0132+89	Comment	13	3814.06096902,N	12130.15197472,W	Erratic Signal Source not determined Most likely Antenna on TV tower.			
39	Walnut Grove	13753	0137+53	Car on levee	17	3813.99076636,N	12130.35263983,W				
39	Walnut Grove	14216	0142+16	Car on levee	18	3813.95481386,N	12130.41853522,W				
39	Walnut Grove	15392	0142+62	Electrical	1	3813.90104261,N	12130.49759059,W	overhead			
39	Walnut Grove	14562	0145+62	Car on levee	19	3813.92679750,N	12130.46327283,W				
39	Walnut Grove	14750	0147+50	Car on levee	20	3813.94700338,N	12130.43230620,W				
39	Walnut Grove	14760	0147+60	Car on levee	21	3813.90710510,N	12130.49015283,W				
39	Walnut Grove	16204	0149+21	Car on levee	22	3813.83126024,N	12130.60172319,W				
39	Walnut Grove	15050	0150+50	Car on levee	23	3813.92708550,N	12130.46323582,W				
39	Walnut Grove	15064	0150+64	Car on levee	24	3813.87616804,N	12130.52637396,W				
39	Walnut	16588	0153+40	Unknown	12	3813.79451467,N	12130.67537138,W				

### Report Query

CompanyNumber	2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)	Possible Depth (feet)
	Grove										
39	Walnut Grove	15698	0156+98	Car on levee	25	3813.83372473,N	12130.59752224,W				
39	Walnut Grove	16440	0164+40	Car on levee	26	3813.80925274,N	12130.64816963,W				
39	Walnut Grove	17817	0164+76	Electrical	2	3813.91833900,N	12130.80543885,W	overhead			
39	Walnut Grove	16755	0167+55	Comment	14	3813.79387875,N	12130.70357690,W	Marina Ends/Visible On C.L			
39	Walnut Grove	18734	0173+57	Unknown	13	3814.02114488,N	12130.89738251,W				
39	Walnut Grove	18729	0173+57	Further Attention	4	3814.02223867,N	12130.89733954,W				
39	Walnut Grove	19134	0177+36	Comment	15	3814.04338585,N	12130.95637943,W	sign, right turn, 20 mph			
39	Walnut Grove	19434	0182+94	Ending Point	1	3814.0809200,n	12130.99609,w				
39	Walnut Grove	19331	0193+31	Comment	16	3814.06848539,N	12130.98213835,W	sign, Rotary			

## Anomaly Areas

1 total



Examples of Anomalies Areas found elsewhere by CSI

1 total

### Anomaly Areas

2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion	Depth (feet)	Possible Depth (feet)	Anomaly Area Location
Walnut Grove	1716	0017+16	Anomaly Area	1	3814.28892868,N	12131.01334015,W				

## Areas Needing Further Attention (Phase Two)

4 total

### Areas needing further attention

2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion	Possible Depth (feet)
Walnut Grove	5983	0048+88	Further Attention	1	3814.78199013,N	12130.62287793,W		
Walnut Grove	10476	0094+93	Further Attention	2	3814.42440987,N	12129.86833409,W		
Walnut Grove	11550	0105+33	Further Attention	3	3814.26104362,N	12129.94440022,W		
Walnut Grove	18729	0173+57	Further Attention	4	3814.02223867,N	12130.89733954,		

## Cars on Levee

26- Total

### Cars on Levee

2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion
Walnut Grove	1510	0015+10	Car on levee	1	3814.26871934,N	12131.01134941,W	
Walnut Grove	1606	0016+06	Car on levee	2	3814.27537298,N	12131.01371075,W	
Walnut Grove	1710	0017+10	Car on levee	3	3814.28688336,N	12131.01646695,W	
Walnut Grove	2133	0021+33	Car on levee	4	3814.31149397,N	12131.01554629,W	
Walnut Grove	2700	0027+00	Car on levee	5	3814.38545648,N	12130.97361294,W	
Walnut Grove	2861	0028+61	Car on levee	6	3814.40432679,N	12130.95366301,W	
Walnut Grove	3033	0030+33	Car on levee	7	3814.42712872,N	12130.93219990,W	
Walnut Grove	3043	0030+43	Car on levee	8	3814.42719678,N	12130.93450301,W	
Walnut Grove	3118	0031+18	Car on levee	9	3814.43503845,N	12130.92698823,W	
Walnut Grove	3161	0031+61	Car on levee	10	3814.44249839,N	12130.91798778,W	
Walnut Grove	3172	0031+72	Car on levee	11	3814.44265409,N	12130.91973317,W	
Walnut Grove	3379	0033+79	Car on levee	12	3814.46935630,N	12130.89297236,W	

### Cars on Levee

2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion
Walnut Grove	3781	0037+81	Car on levee	13	3814.52082403,N	12130.84538495,W	
Walnut Grove	4550	0045+50	Car on levee	14	3814.60920530,N	12130.76110722,W	
Walnut Grove	13769	0128+79	Car on levee	15	3814.03229387,N	12130.26389389,W	
Walnut Grove	13190	0131+90	Car on levee	16	3814.04146973,N	12130.22864574,W	
Walnut Grove	13753	0137+53	Car on levee	17	3813.99076636,N	12130.35263983,W	
Walnut Grove	14216	0142+16	Car on levee	18	3813.95481386,N	12130.41853522,W	
Walnut Grove	14562	0145+62	Car on levee	19	3813.92679750,N	12130.46327283,W	
Walnut Grove	14750	0147+50	Car on levee	20	3813.94700338,N	12130.43230620,W	
Walnut Grove	14760	0147+60	Car on levee	21	3813.90710510,N	12130.49015283,W	
Walnut Grove	16204	0149+21	Car on levee	22	3813.83126024,N	12130.60172319,W	
Walnut Grove	15050	0150+50	Car on levee	23	3813.92708550,N	12130.46323582,W	
Walnut Grove	15064	0150+64	Car on levee	24	3813.87616804,N	12130.52637396,W	
Walnut Grove	15698	0156+98	Car on levee	25	3813.83372473,N	12130.59752224,W	
Walnut Grove	16440	0164+40	Car on levee	26	3813.80925274,N	12130.64816963,W	

## Comments

16 Totals

Comments							
2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion
Walnut Grove	73	0000+83	Comment	1	3814.09147603,N	12131.00925810,W	Power pole
Walnut Grove	107	0000+89	Comment	2	3814.09154623,N	12131.00932902,W	Sign pole (J11)
Walnut Grove	127	0001+14	Comment	3	3814.09208293,N	12131.01127934,W	dirt road and asphalt road
Walnut Grove	1350	0010+62	Comment	4	3814.24836499,N	12131.00577846,W	center line Georgiana Slough Bridge
Walnut Grove	3640	0029+04	Comment	5	3814.50309,n	12130.85931,w	center line Walnut grove bridge
Walnut Grove	6030	0051+21	Comment	6	3814.77147756,N	12130.58208383,W	File change,
Walnut Grove	4828	0066+43	Comment	7	381466903,n	12130758,w	State gauge in channel
Walnut Grove	6760	0067+60	Comment	8	3814.71281854,N	12130.47986448,W	Erratic signal Source not determined most likely antenna on TV tower.
Walnut Grove	7653	0076+53	Comment	9	3814.68915195,N	12130.38547773,W	Erratic Signal Source not determined Most likely antenna on TV tower.
Walnut Grove	8258	0082+58	Comment	10	3814.65780736,N	12130.26338658,W	Erratic Signal Source Not determined Most likely antenna on TV tower

### Comments

2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion
Walnut Grove	9378	0093+78	Comment	11	3814.57516332,N	12129.96169244,W	Erratic signal source not determined most likely antennas on TV tower.
Walnut Grove	13269	0132+69	Comment	12	3814.06277352,N	12130.14254476,W	Marina Starts/ Visible on C.L.
Walnut Grove	13289	0132+89	Comment	13	3814.06096902,N	12130.15197472,W	Erratic Signal Source not determined Most likely Antenna on TV tower.
Walnut Grove	16755	0167+55	Comment	14	3813.79387875,N	12130.70357690,W	Marina Ends/ Visible On C.L
Walnut Grove	19134	0177+36	Comment	15	3814.04338585,N	12130.95637943,W	sign, right turn, 20 mph
Walnut Grove	19331	0193+31	Comment	16	3814.06848539,N	12130.98213835,W	sign, Rotary

### Drain Station Pipes

3- Total

### Drain Station Pipes

2nd Name	Event	Event #	Em Station	Station	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)
Walnut Grove	Drain Station Pipe	1	11839	0108+60	3814.20966337,N	12129.95823319,W			
Walnut Grove	Drain Station Pipe	2	11843	0108+64	3814.21066876,N	12129.95791947,W		10	2
Walnut Grove	Drain Station Pipe	3	12994	0120+12	3814.07231560,N	12130.09251912,W		14	4

## Electrical Lines

2 total

Electrical Lines							
2nd Name	Event	Event #	Em Station	Station	Latitude	Longitude	Discussion
Walnut Grove	Electrical	1	15392	0142+62	3813.90104261,N	12130.49759059,W	overhead
Walnut Grove	Electrical	2	17817	0164+76	3813.91833900,N	12130.80543885,W	overhead

## Gates

2 total

Gates							
2nd Name	Event	Event #	Em Station	Station	Latitude	Longitude	Discussion
Walnut Grove	Gate	1	5689	0054+22	3814.74482,n	12130.54009,w	north
Walnut Grove	Gate	2	13215	0127+05	3814.04199,n	12130.22915,w	south gate

## Irrigation Lines

2 total

### Irrigation Pump pipes

2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)
Walnut Grove	391	0003+27	Irrigation Pump Pipe	1	3814.12675709,N	12131.02902690,W		8	4
Walnut Grove	13416	0124+18	Irrigation Pump Pipe	2	3814.05480861,N	12130.17395560,W		14	3

## Phone Lines

### Phone Lines

2nd Name	Event #	Em Station	Station	Event	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)	Possible Depth (feet)	Anomaly Area Location
Walnut Grove	1	2276	0016+93	Phone Line	3814.34303226,N	12131.00904420,W	at angle from sign				
Walnut Grove	2	5869	0043+83	Phone Line	3814.76864152,N	12130.63985811,W	patch in road				

## Siphon Pipes

2 total

### Siphon Pipes

2nd Name	Station	Em Station	Event	Event #	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)	Possible Depth (feet)
Walnut Grove	0112+85	11298	Siphon	1	3814.30287154,N	12129.92515458,W	cut off llss+40', not capped	6	2	
Walnut Grove	0112+90	12291	Siphon	2	3814.14330194,N	12129.98530762,W		16	2	

## Soil Changes

4 total

Soil Changes											
2nd Name	Em Station	Station	Event #	Event	Latitude	Longitude	Discussion	Pipe Diameter (in)	Depth (feet)	Possible Depth (feet)	Anomaly Area Location
Walnut Grove	162	0001+62	1	Soil Change	3814.09477275,N	12131.01747823,W					
Walnut Grove	6654	0066+54	2	Soil Change	3814.72521999,N	12130.51121527,W					
Walnut Grove	9879	0098+79	3	Soil Change	3814.51640350,N	12129.89029939,W	Most visible on land side				

## Starting Points

1 total

### Starting Point

Company Number	2nd Name	Em Station	Station	Event	Event #	Latitude	Longitude	Discussion
39	Walnut Grove	0	0000+00	Starting Point	1	3814.0809200,n	12130.99609,w	

## Unknowns

13 total

Examples of unknowns **found elsewhere** by CSI



### Unknowns

2nd Name	Station	Em Station	Event	Event #	Latitude	Longitude	Discussion	Possible Depth (feet)
Walnut Grove	0022+73	2976	Unknown	1	3814.42051546,N	12130.94064901,W	difficult to id, in front 14205 address	
Walnut Grove	0026+27	3359	Unknown	2	3814.46833483,N	12130.89570060,W	difficult to id, post office door	
Walnut Grove	0030+74	3770	Unknown	3	3814.52679818,N	12130.84237904,W	center line of Bridge Road	
Walnut	0035+13	4175	Unknown	4	3814.58107352,N	12130.79334051,W	centerline of C street	

Unknowns									
2nd Name	Station	Em Station	Event	Event #	Latitude	Longitude	Discussion	Possible Depth (feet)	
Grove									
Walnut Grove	0038+93	4651	Unknown	5	3814.63328336,N	12130.73885710,W	south side of spa factory, 14099 address		
Walnut Grove	0043+39	5350	Unknown	6	3814.69546286,N	12130.69122433,W			
Walnut Grove	0048+88	5983	Unknown	7	3814.77870721,N	12130.62112265,W			
Walnut Grove	0052+63	6228	Unknown	8	3814.76369592,N	12130.56726614,W	deep		
Walnut Grove	0094+93	10476	Unknown	9	3814.42440987,N	12129.86833409,W			
Walnut Grove	0105+53	11550	Unknown	10	3814.26104362,N	12129.94440022,W			
Walnut Grove	0115+50	11550	Unknown	11	3814.25881648,N	12129.94570831,W			
Walnut Grove	0153+40	16588	Unknown	12	3813.79451467,N	12130.67537138,W			
Walnut Grove	0173+57	18734	Unknown	13	3814.02114488,N	12130.89738251,W			

## **SUBSURFACE CONDUCTIVITY IS NOT A PANACEA**

Subsurface conductivity studies have some limits imposed by various physical laws and should not be looked upon as a magic cure-all. Metal objects such as cars around a marina, equipment yards and garbage piles made up of metal debris (both above ground and below) can and do create issues with some gathered data. Other properties make it difficult to allow a bottom line statement of what is causing the anomaly like readings. Experience from examining conductivity profiles is not the only answer to these problems but one of the most important when analyses data is performed. Another issue that has become apparent in this study is the introduction of sub meter accurate GPS, utilized for both location and elevation. It has become evident that tree canopies can and do create interference with the radio communications between the “rover” and the “base station”. But as long as personnel are aware of such difficulties and backup location determination is utilized, problem areas can usually be relocated within a two meter accuracy zone. The location of radio signal loss is apparent in the elevation section of this report on pages 23 and 24. The grey section is where the signal occurred because of tree canopy and or other environmental interference.

Depth determination is not as exact with as with some other types of equipment that can be utilized even though computer modeling helps to deal with the issue.

## **DEVELOPMENT OF SUBSURFACE CONDUCTIVITY STUDIES**

When CSI was asked to evaluate the use the Geonics' EM-31 in 1982 by the Central Delta Water Agency to analyze and possibly determine areas of levees that could have difficulty surviving periods of high water there were no standards for CSI to follow. The manufacture was able to offer little guidance. Utilizing the EM-31 for levee analysis was the proverbial "shot in the dark". The instrument provided an analog signal and the output was recorded on a portable strip chart recorder. One person carried the Em-31 and one person carried the recorder. CSI personnel worked as team and walked many miles and experimented with various levels of recorder speed and Em-31 settings. Miles of levees were traversed and miles of dirt roads in farms were recorded. CSI was able to arrive at what was felt to be "best settings". Certain signals became apparent (metals laying perpendicular to the traverses such as pipes and buried cables). It was observed that any particular length would have its own conductivity profile signature. These signatures were found be relatively unique to a particular levee length.

The most obvious event that occurred were unknowns, defined by CSI (as explained earlier) as metallic signals perpendicular to direction of travel

and with no visible source. In over 80 percent of the cases these unknowns, when excavated, turned to be abandoned pipes that ranged in with diameter from 1 inch to 16 inches and depths of 1 foot to over 18 feet or more in depth. The next event that became apparent was anomaly areas. There the conductivity profiles had certain characteristics that did not match (in the view of CSI personnel) that, of the surrounding areas. Upon excavation these yielded wet spots, natural piping through sand layers, flood gates and other areas of possible concern. There was not set pattern in the early 80's and it would be difficult to say there is one now.

Over the years CSI developed techniques to enhance the information derived from the data. CSI was one of the first to develop a non-conductive carrier in order to make studies many miles in length feasible. CSI utilized the carrier and decided to perform two traverses, one at "full depth" with the dipoles in vertical position and a second traverse at "half depth" with the dipoles carried in horizontal position. By comparing the two profiles more analysis was able to be performed over the entire length of the study areas.

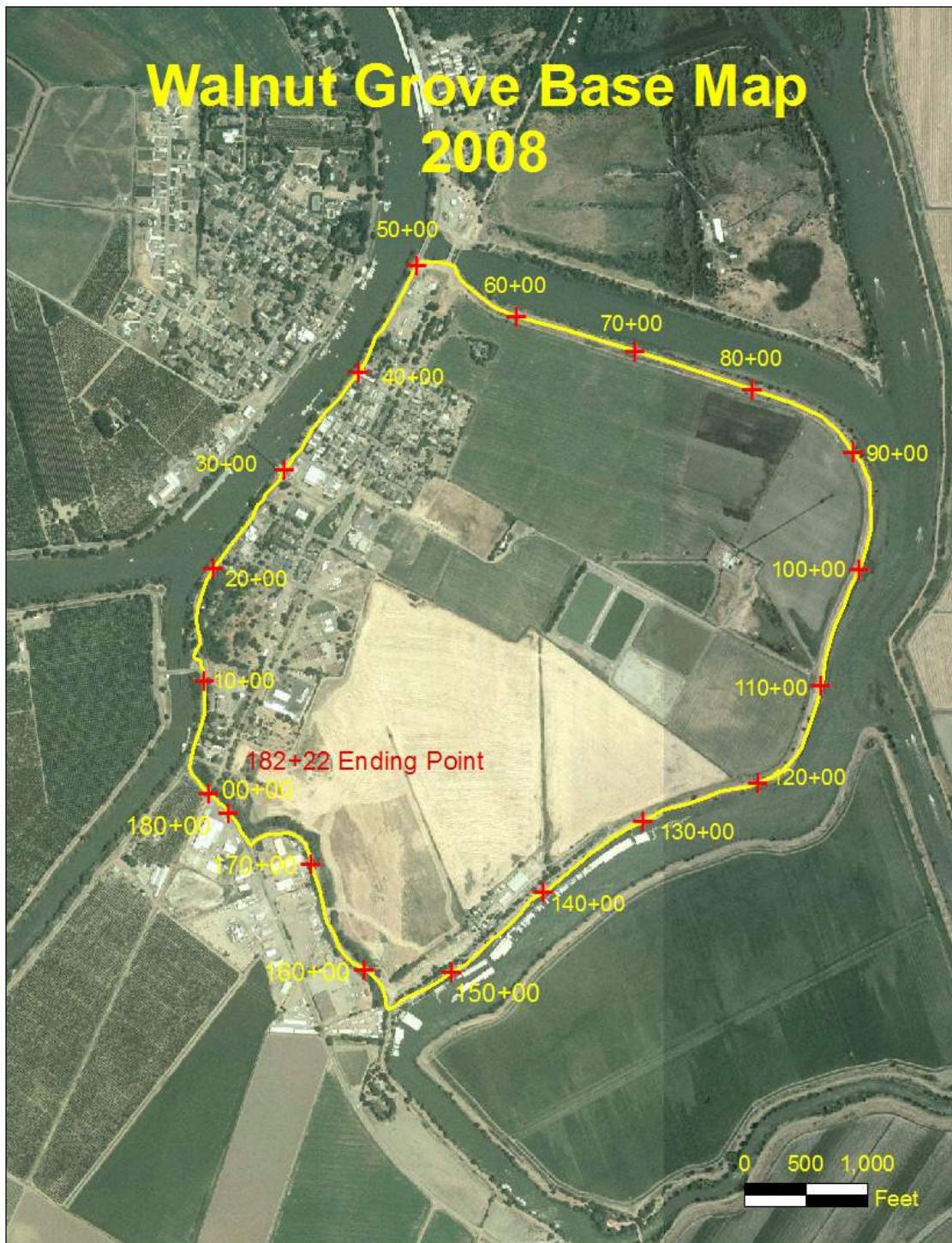
After several years Geonics' converted the Em31 (and developed the Em31-3 that allowed information to be derived from 3 depths at the same time) into a digital device and along with other developers, engineered

software that allowed even greater interpretation of the conductivity signals.

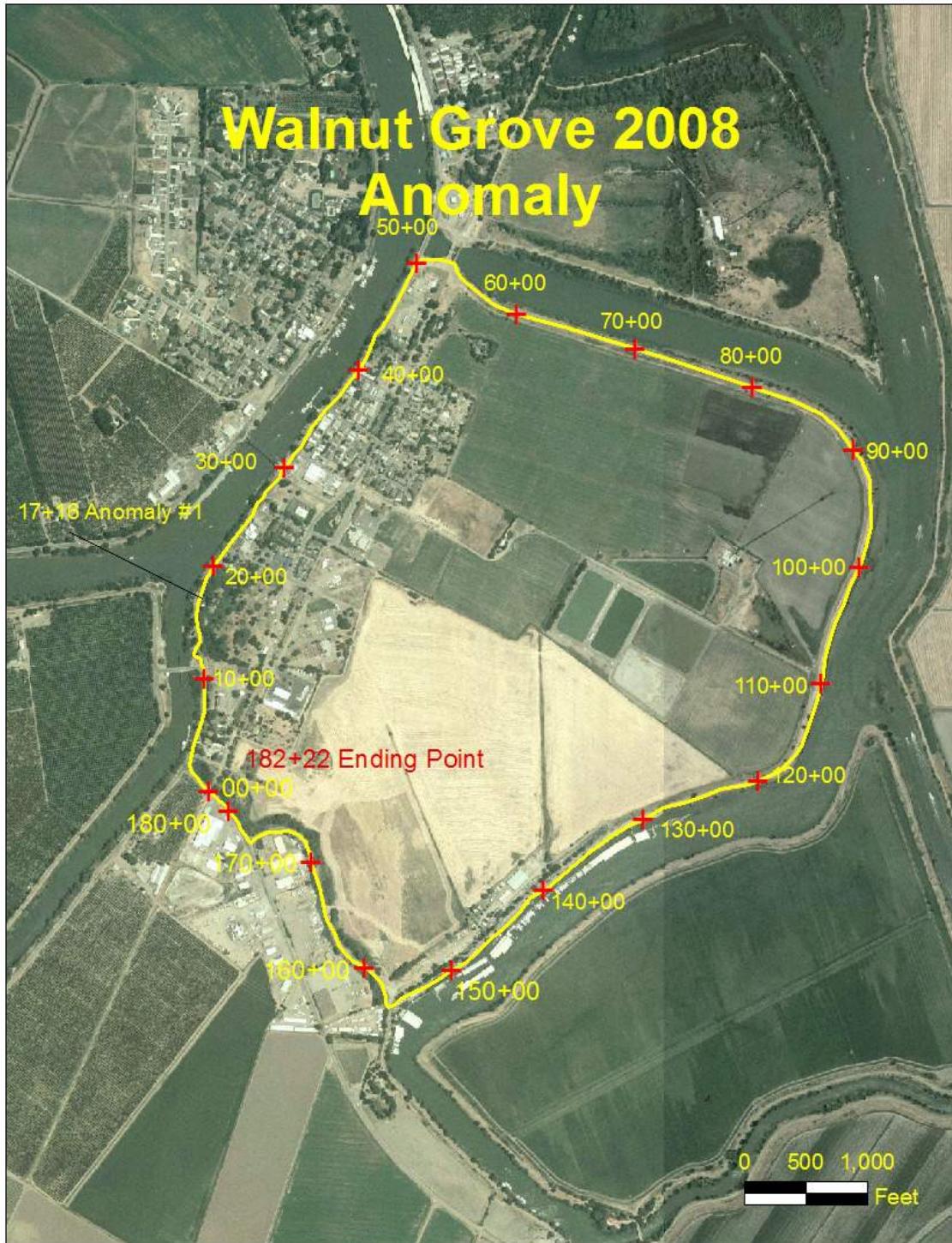
Software allowing computer modeling that followed allowed further enhanced interpretation was one of those the software packages developed.

Conductivity studies have many advantages over other types of studies. There is very little set up time required. The study can be continuous (constant readings with no gap of information); quick analysis in the field has proven to be possible and very important to local personnel is the affordable cost for many cash strapped agencies. The repeatability of the studies with comparisons is also valuable tool.

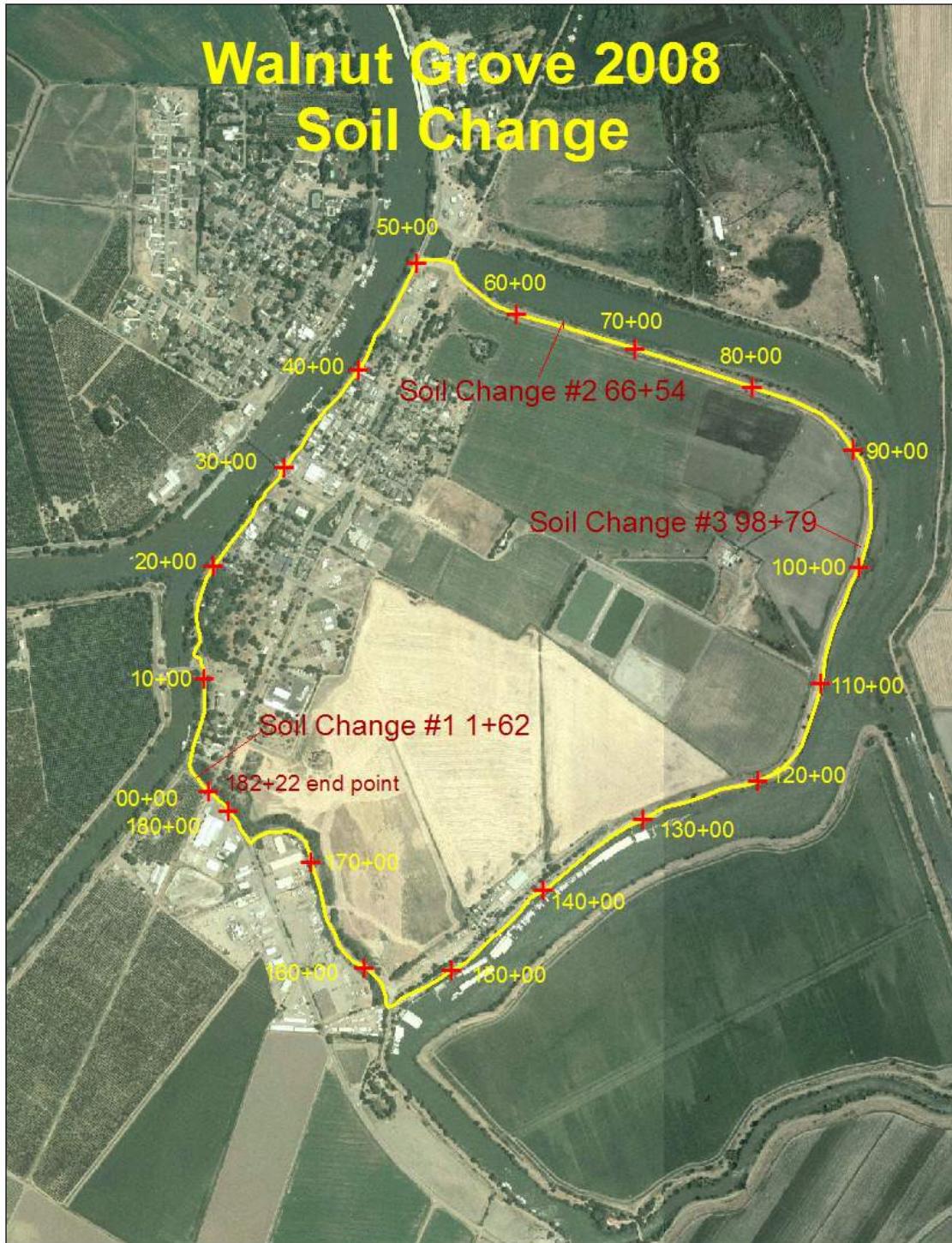
# Walnut Grove Base Map



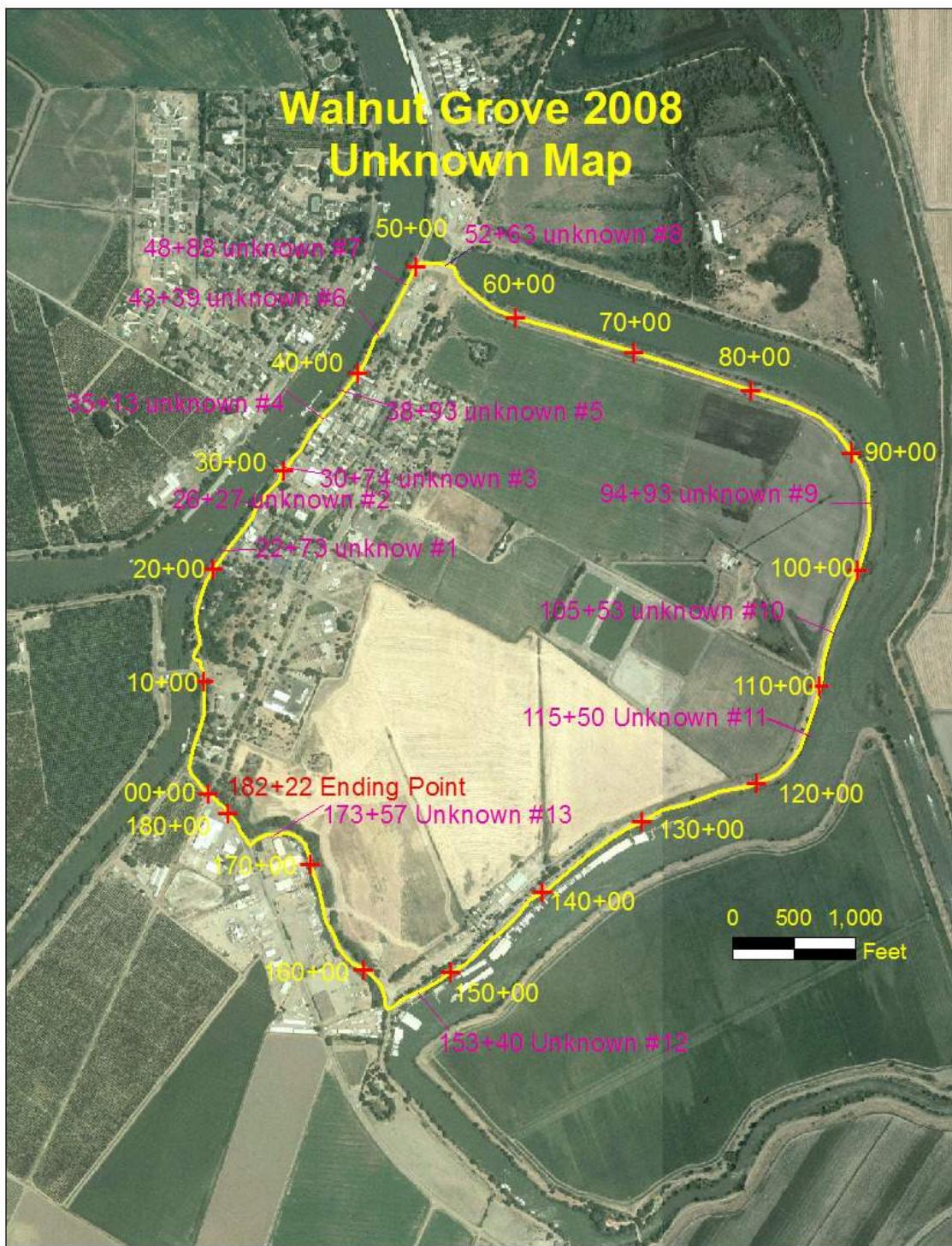
## Walnut Grove Anomaly Map



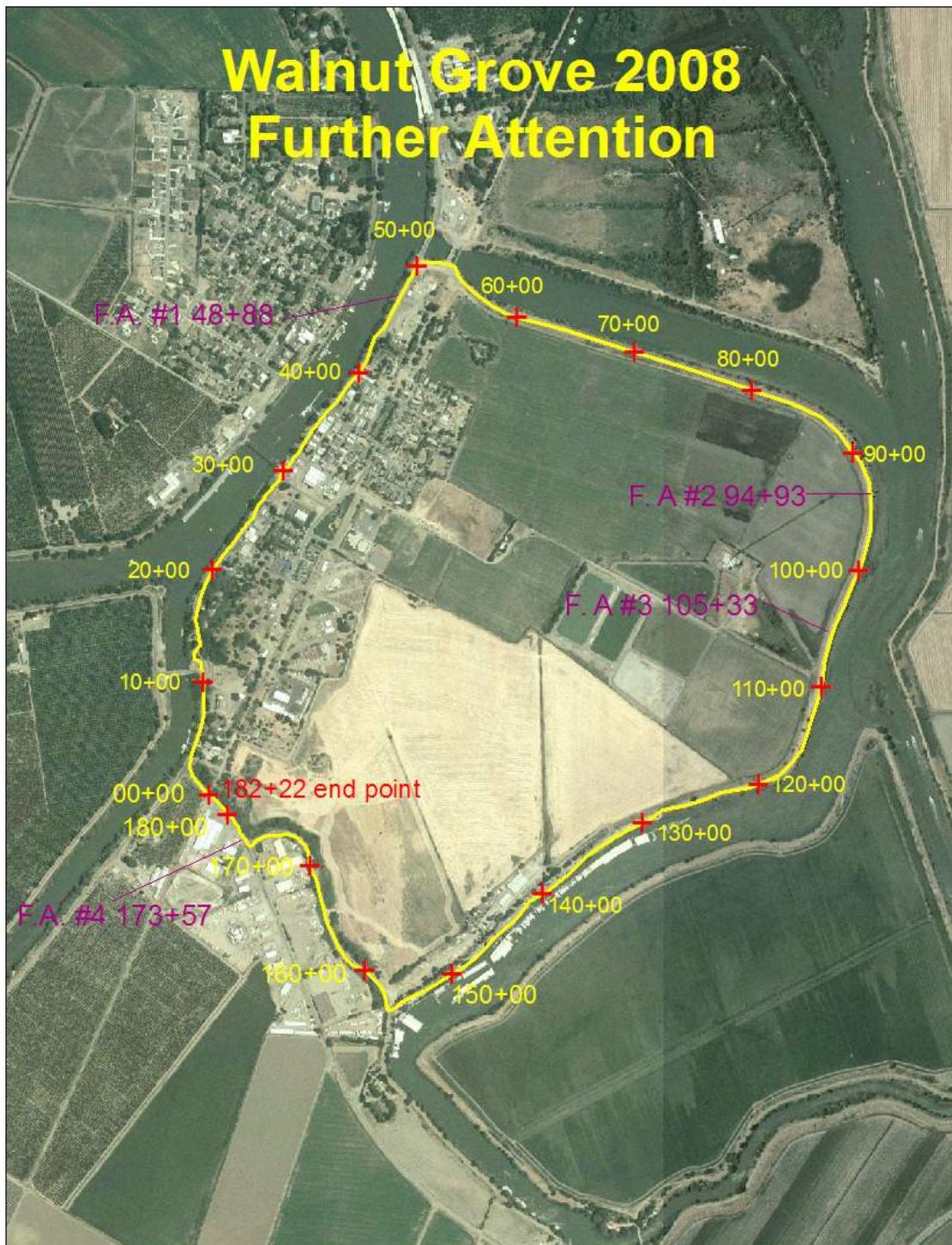
## Walnut Grove Soil Change Map



## Walnut Grove Unknown Map



## Walnut Grove Further Attention Map



## Conclusions

4 locations identified as Areas for Further Attention (phase 2 studies).

- 1 anomaly area was counted
- 2 electrical lines were observed
- 3 Drain Station Pipes were inventoried.
- 2 gates were registered.
- 2 Irrigation pump pipe was seen
- 2 Phone line was counted
- 2 Siphon Pipes were documented
- 2 Soil Changes were noted
- 13 unknown were cataloged. Four were classified as Areas for Further Attention.

# **Preliminary Existing Condition Stability, Seepage and Settlement Evaluation**

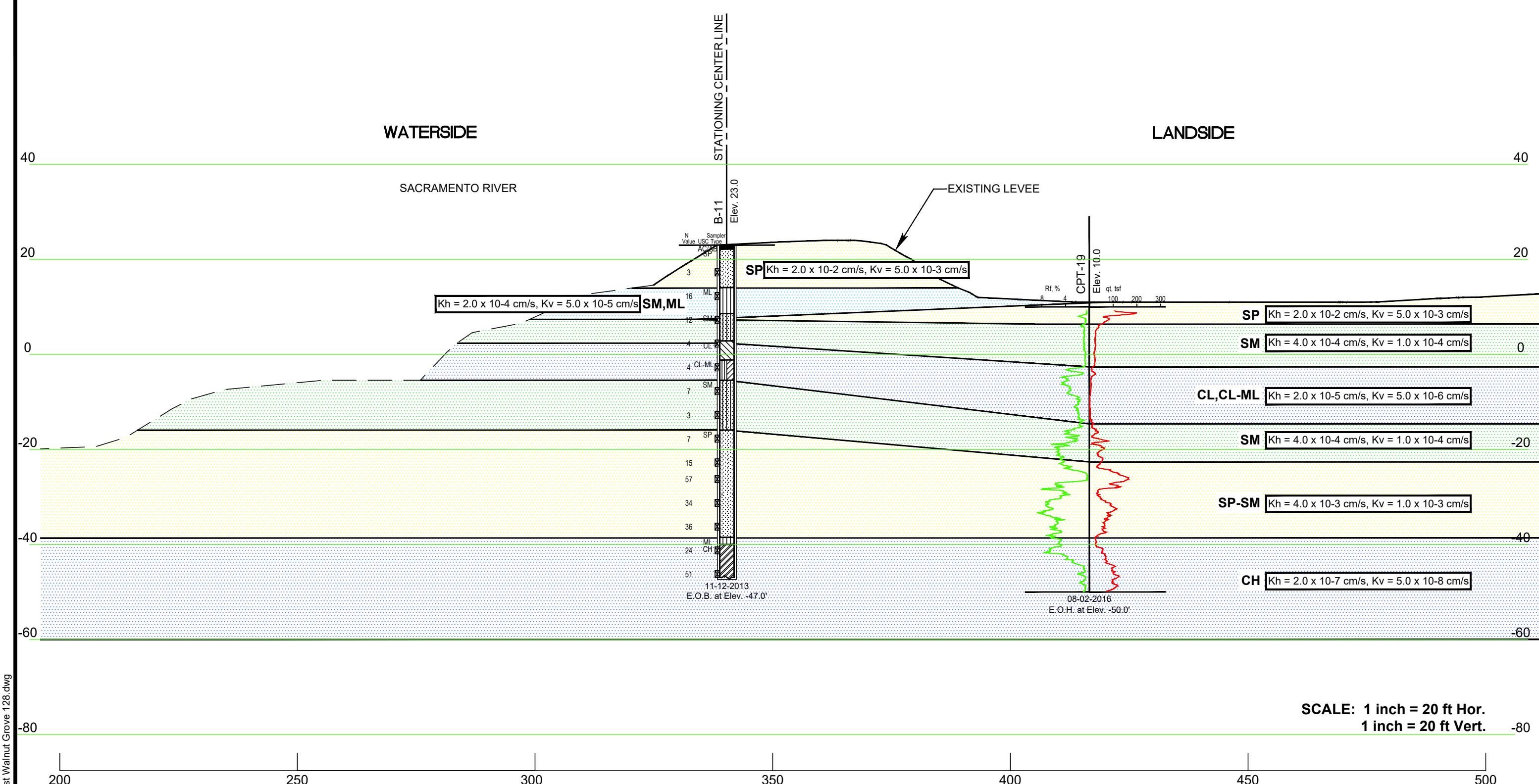
## **Sacramento River and Georgiana Slough East Levees**

**Community of East Walnut Grove, California**

**California Department of Water Resources Small  
Community Flood Risk Reduction Program**

### **APPENDIX E**

**Seepage and Slope Stability Evaluations by Blackburn**

**LEGEND**

**Kv, Kh =**  
- Hydraulic Conductivity  
Values for Soil Layers

**NOTES:**  
Cross section created from RD 554 Lidar 2017, received 04-03-2020 and Sacramento and Georgiana USACE 1997 river hydrology provided by GEI Consultants 2020.

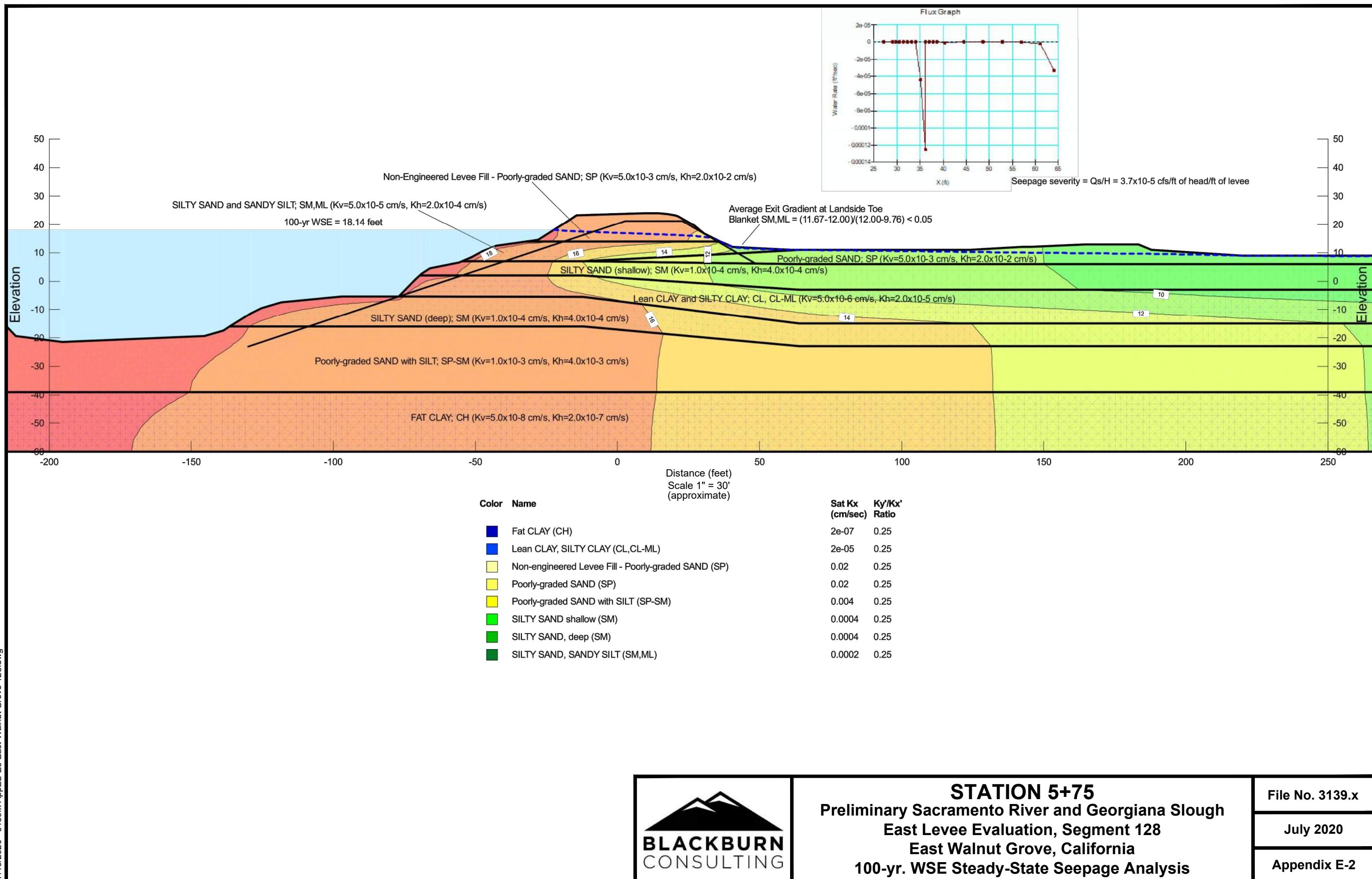


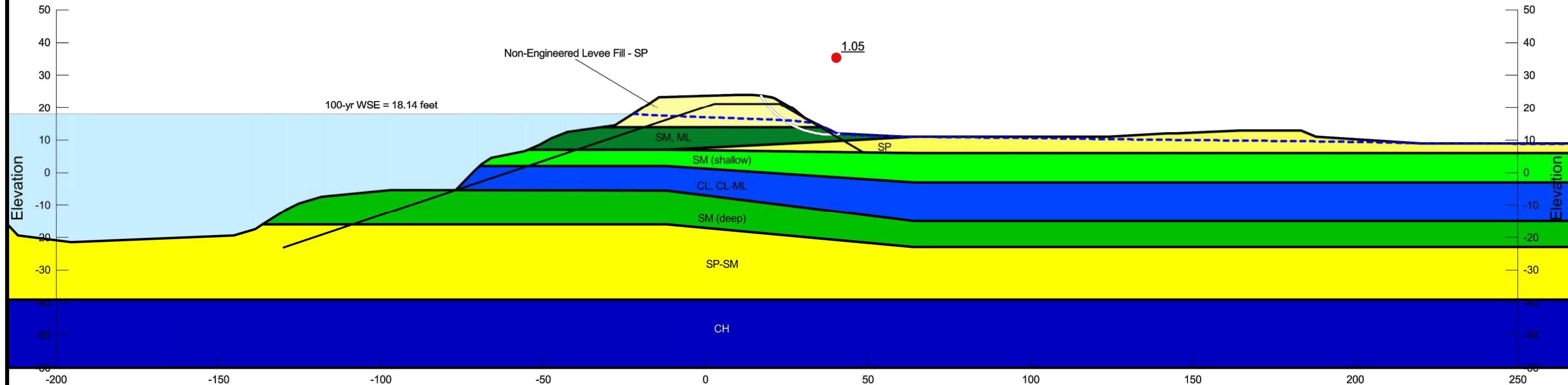
**STATION 5+75**  
Preliminary Sacramento River and Georgiana Slough  
East Levee Evaluation, Segment 128  
East Walnut Grove, California  
Subsurface Profile Used in Analyses

File No. 3139.x

July 2020

Appendix E-1





**Color Name**

Distance (feet)  
Scale 1" = 30'  
(approximate)

Color	Name	(approximate)	Unit Weight (pcf)	Cohesion' (psf)	Phi (°)
■	Fat CLAY (CH)		115	100	28
■	Lean CLAY, SILTY CLAY (CL,CL-ML)		115	50	28
■	Non-engineered Levee Fill - Poorly-graded SAND (SP)		120	0	28
■	Poorly-graded SAND (SP)		120	0	32
■	Poorly-graded SAND with SILT (SP-SM)		125	0	34
■	SILTY SAND shallow (SM)		120	0	30
■	SILTY SAND, deep (SM)		125	0	32
■	SILTY SAND, SANDY SILT (SM,ML)		120	0	32

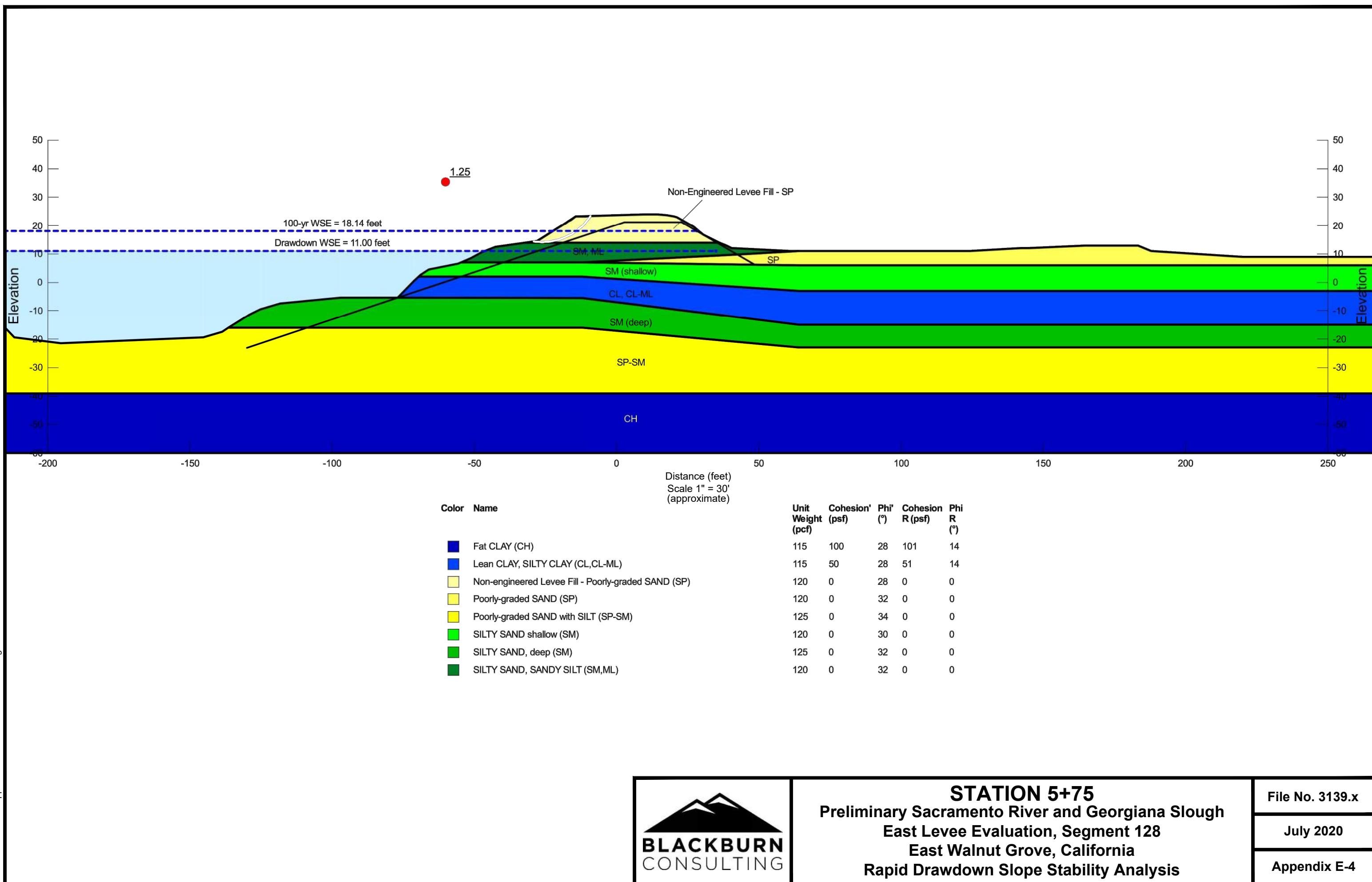


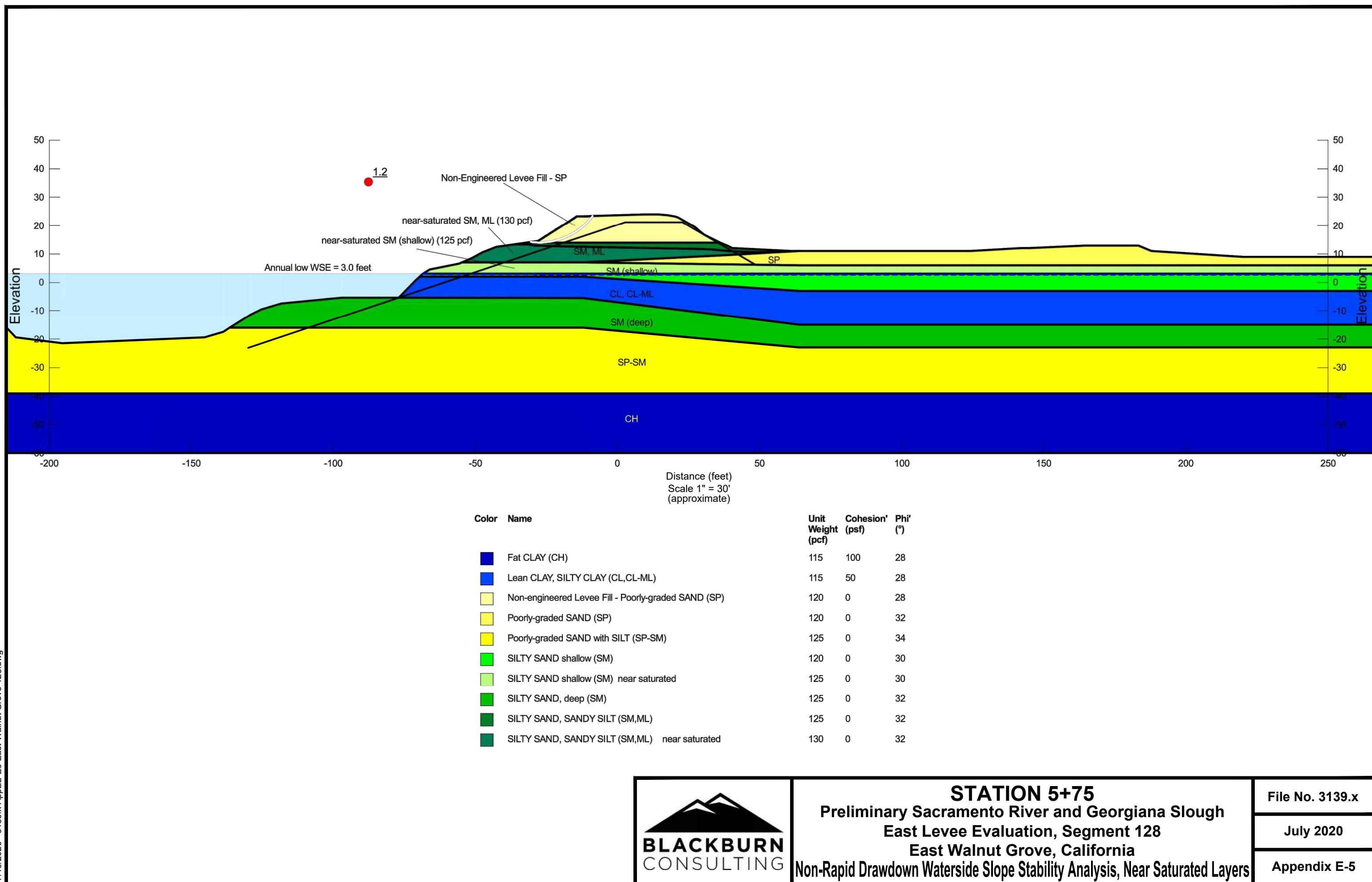
**STATION 5+75**  
**Preliminary Sacramento River and Georgiana Slough**  
**East Levee Evaluation, Segment 128**  
**East Walnut Grove, California**  
**100-yr. WSE Steady-State Slope Stability Analysis**

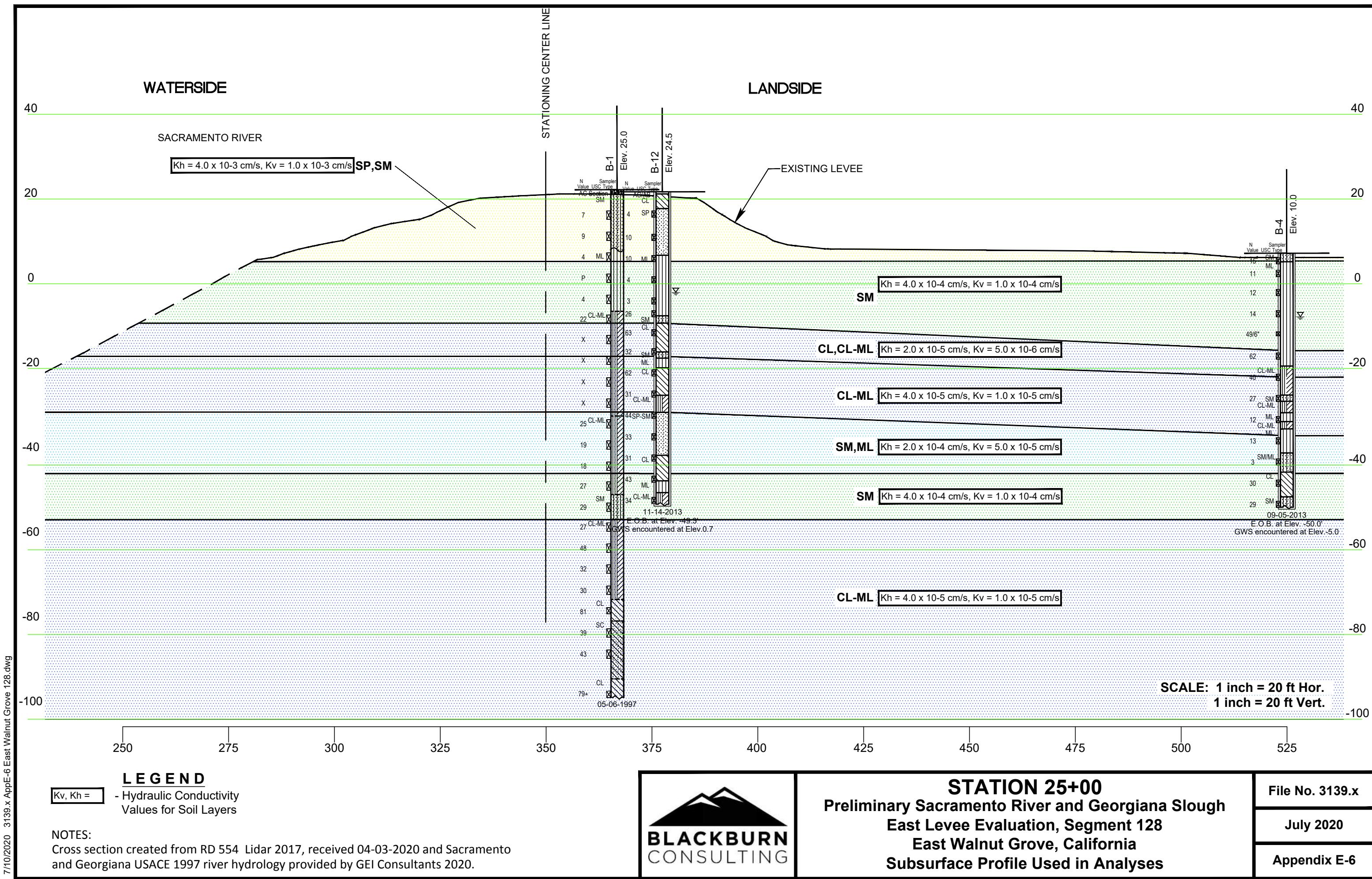
File No. 3139-x

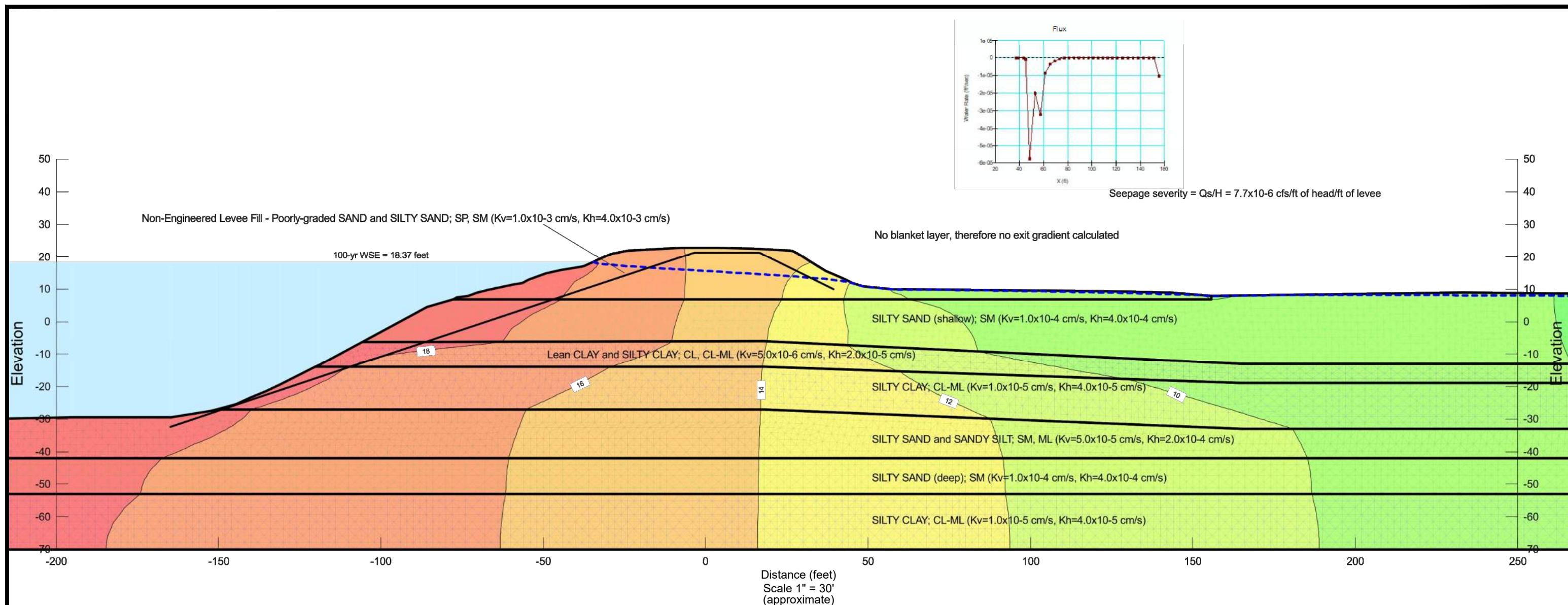
July 2020

## Appendix E-3

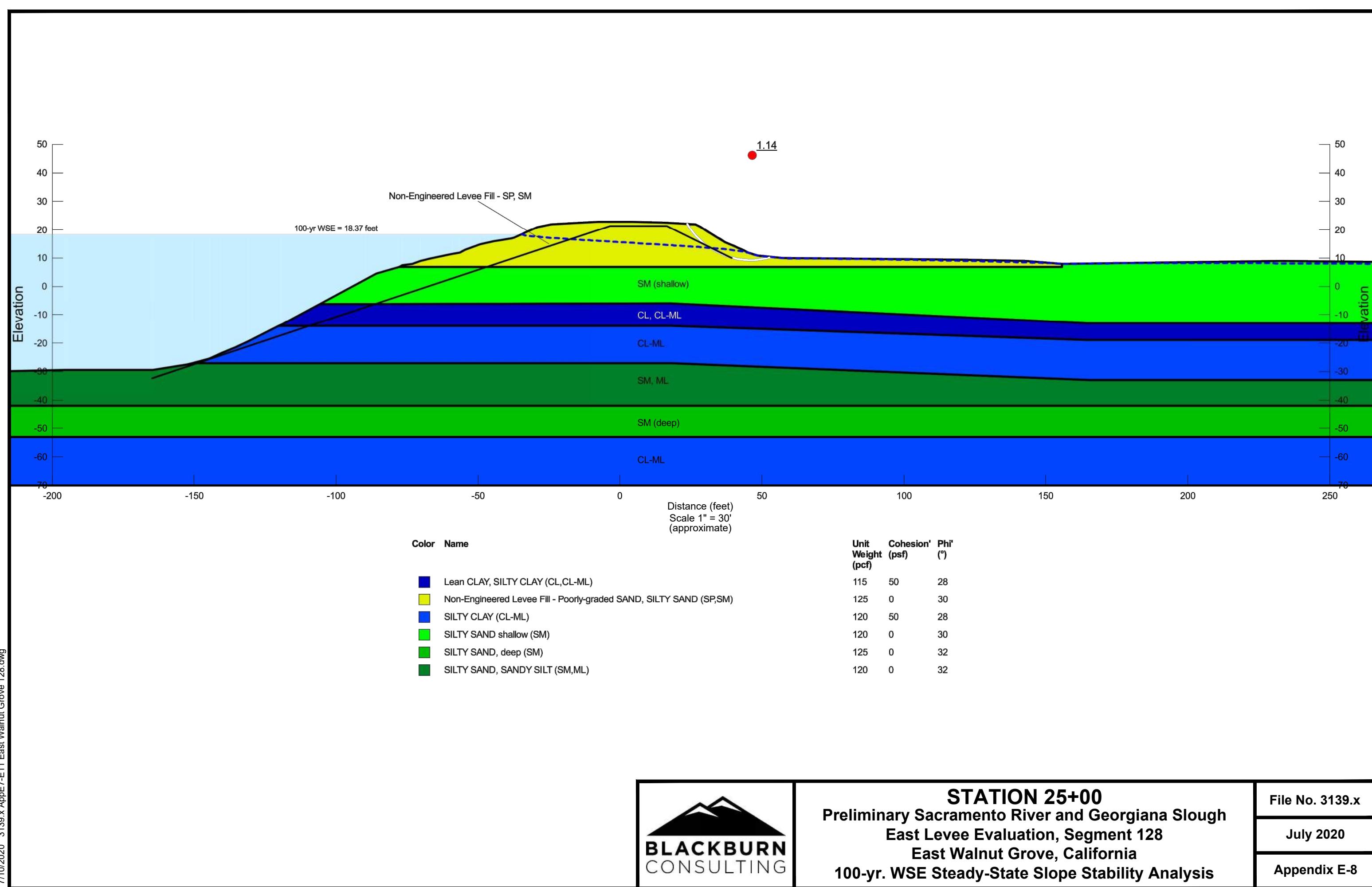


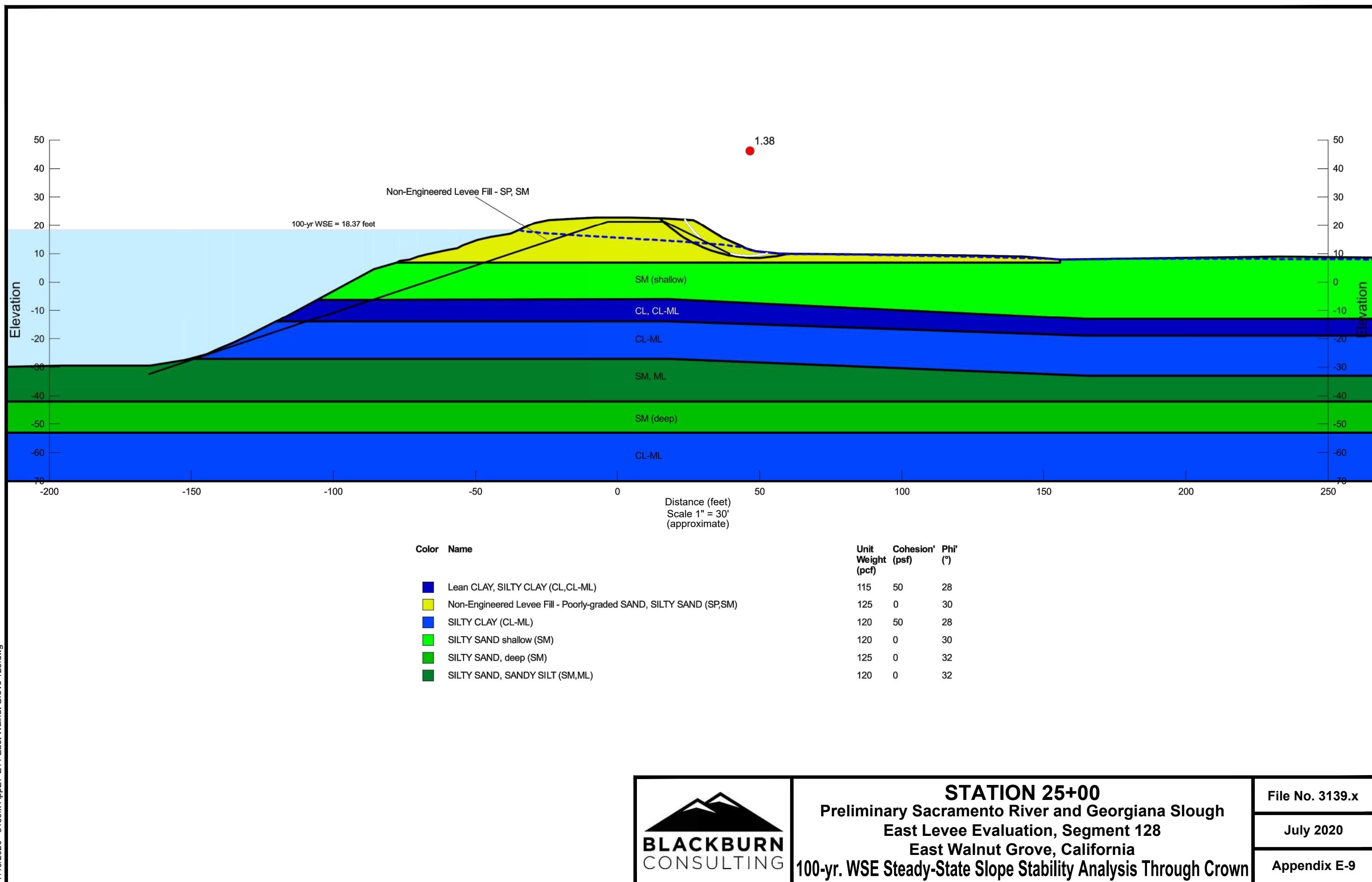


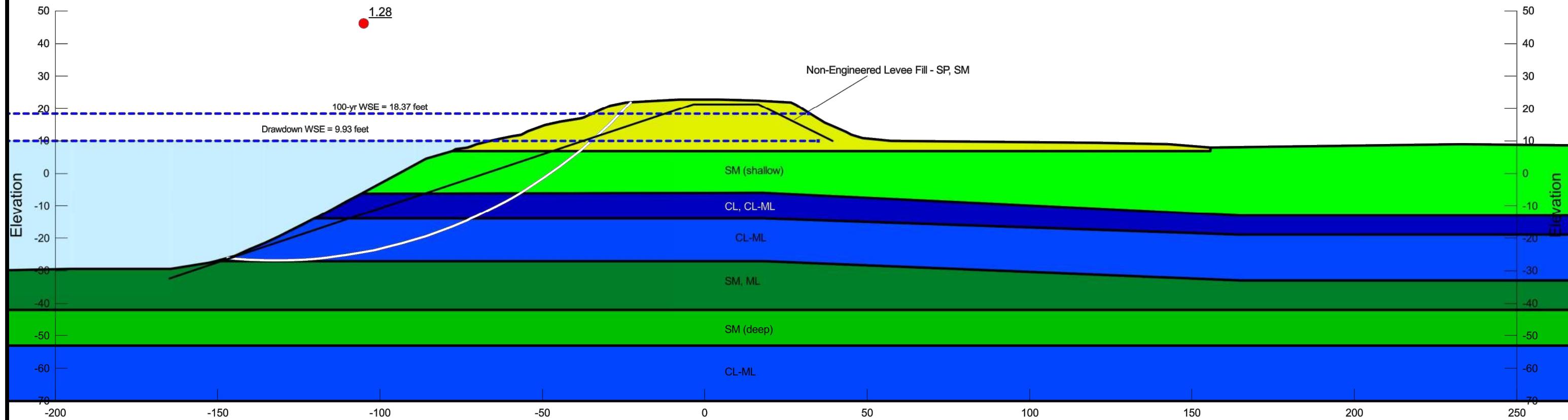




Name	Sat Kx (cm/sec)	Ky'/Kx Ratio
Lean CLAY, SILTY CLAY (CL,CL-ML)	2e-05	0.25
Non-Engineered Levee Fill - Poorly-graded SAND, SILTY SAND (SP,SM)	0.004	0.25
SILTY CLAY (CL-ML)	4e-05	0.25
SILTY SAND shallow (SM)	0.0004	0.25
SILTY SAND, deep (SM)	0.0004	0.25
SILTY SAND, SANDY SILT (SM,ML)	0.0002	0.25

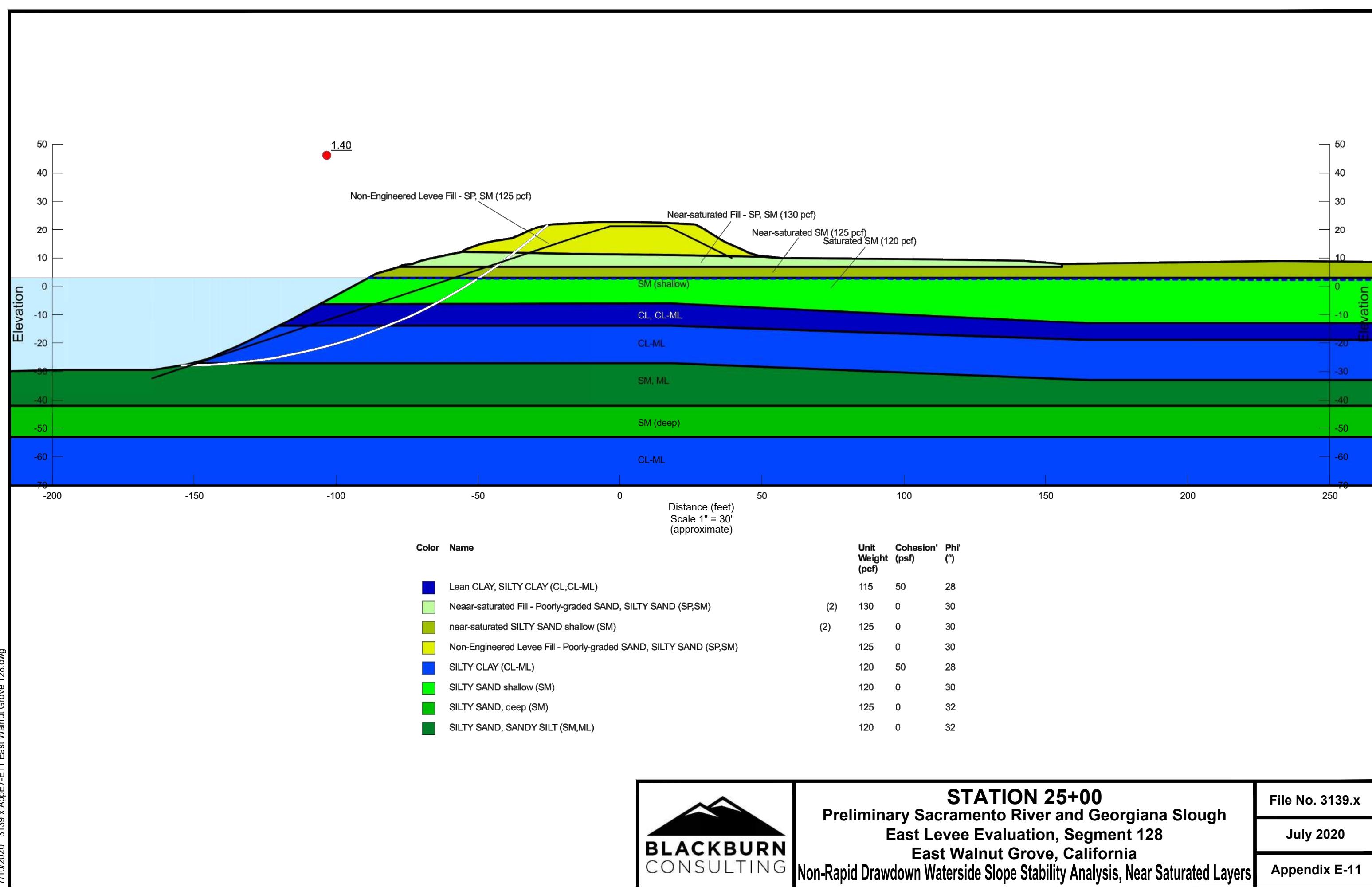


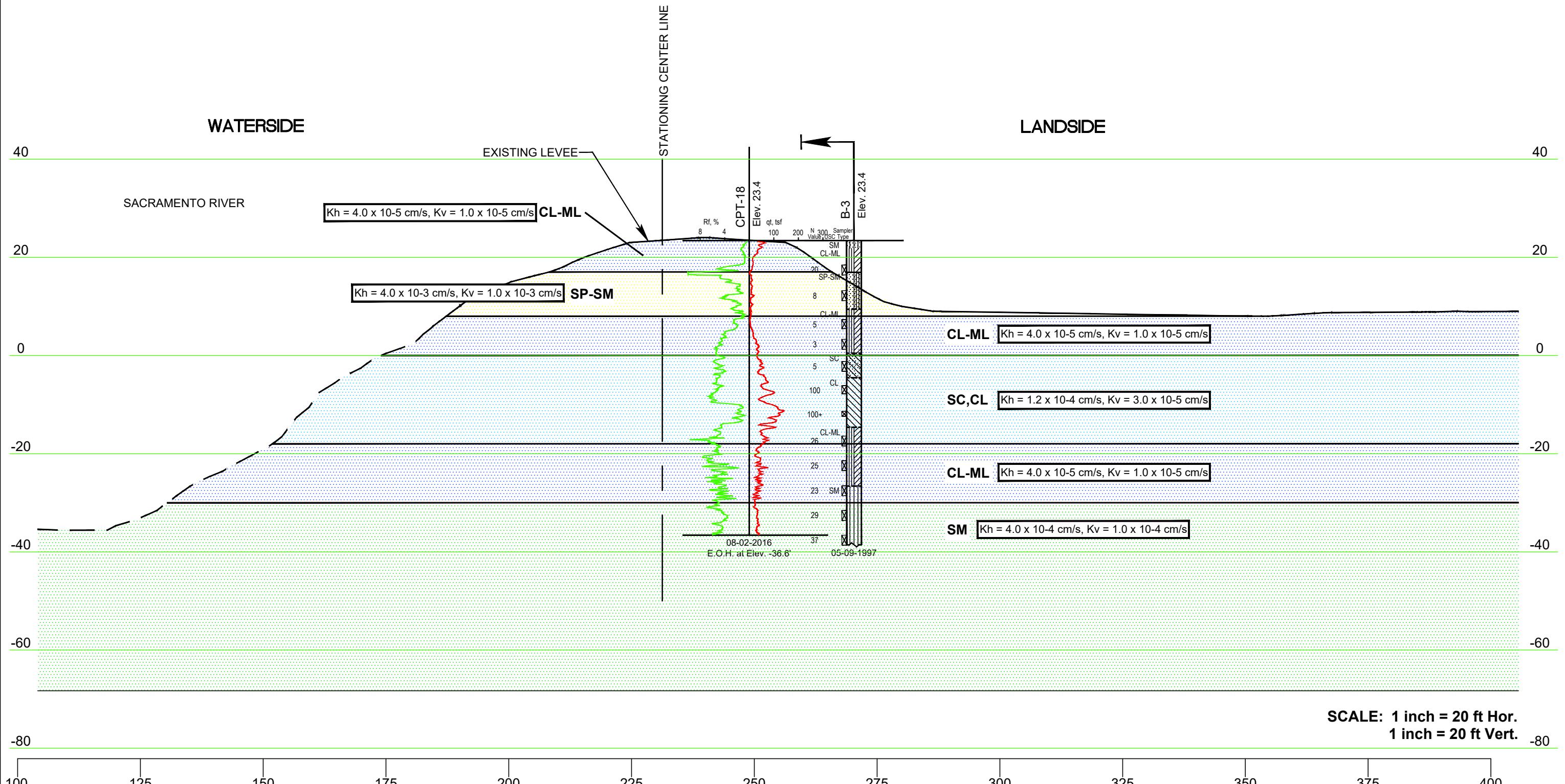




**STATION 25+00**  
Preliminary Sacramento River and Georgiana Slough  
East Levee Evaluation, Segment 128  
East Walnut Grove, California  
Rapid Drawdown Slope Stability Analysis

File No. 3139.x  
July 2020  
Appendix E-10





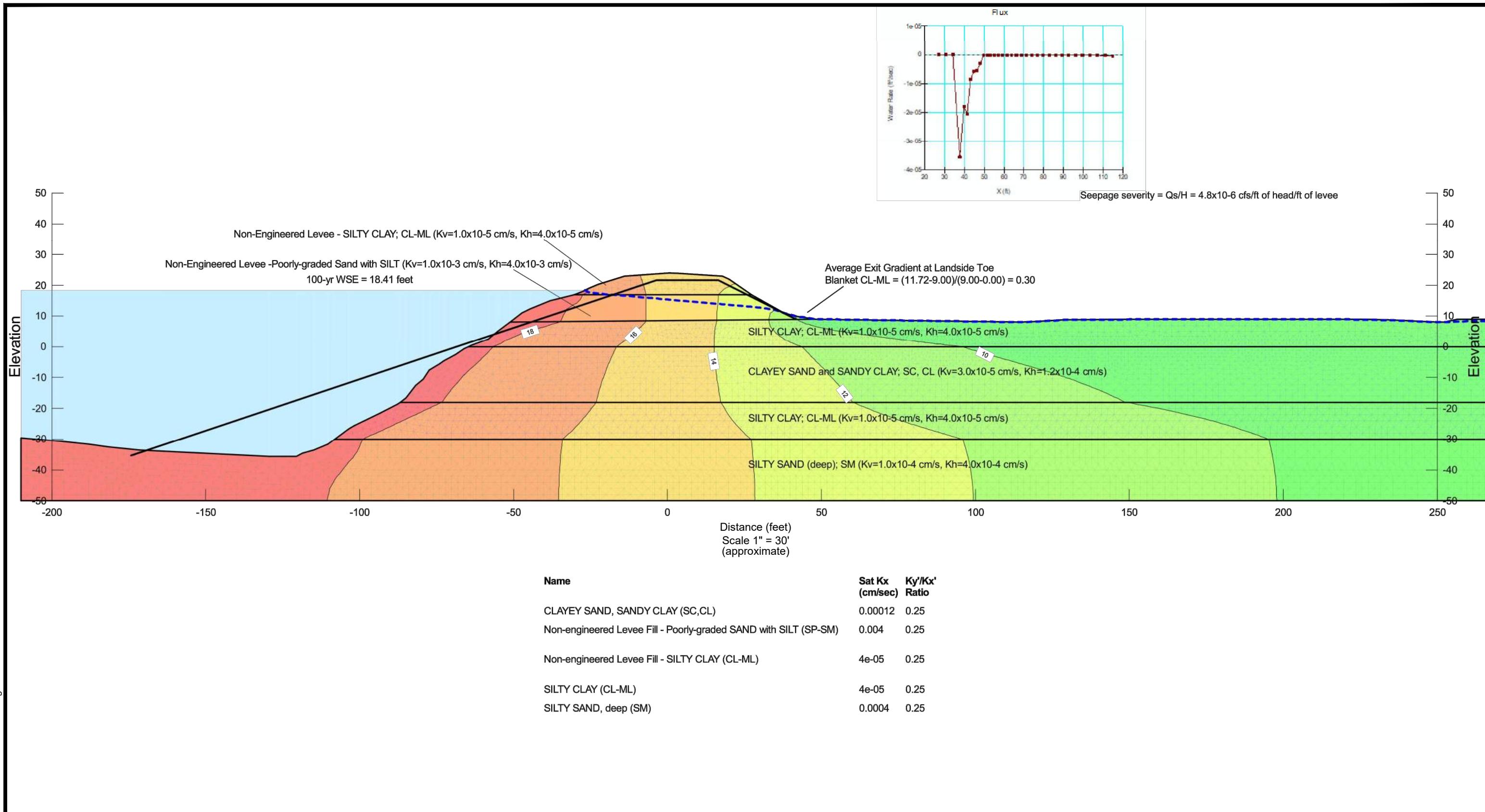
**LEGEND**  
Kv, Kh =  
- Hydraulic Conductivity  
Values for Soil Layers

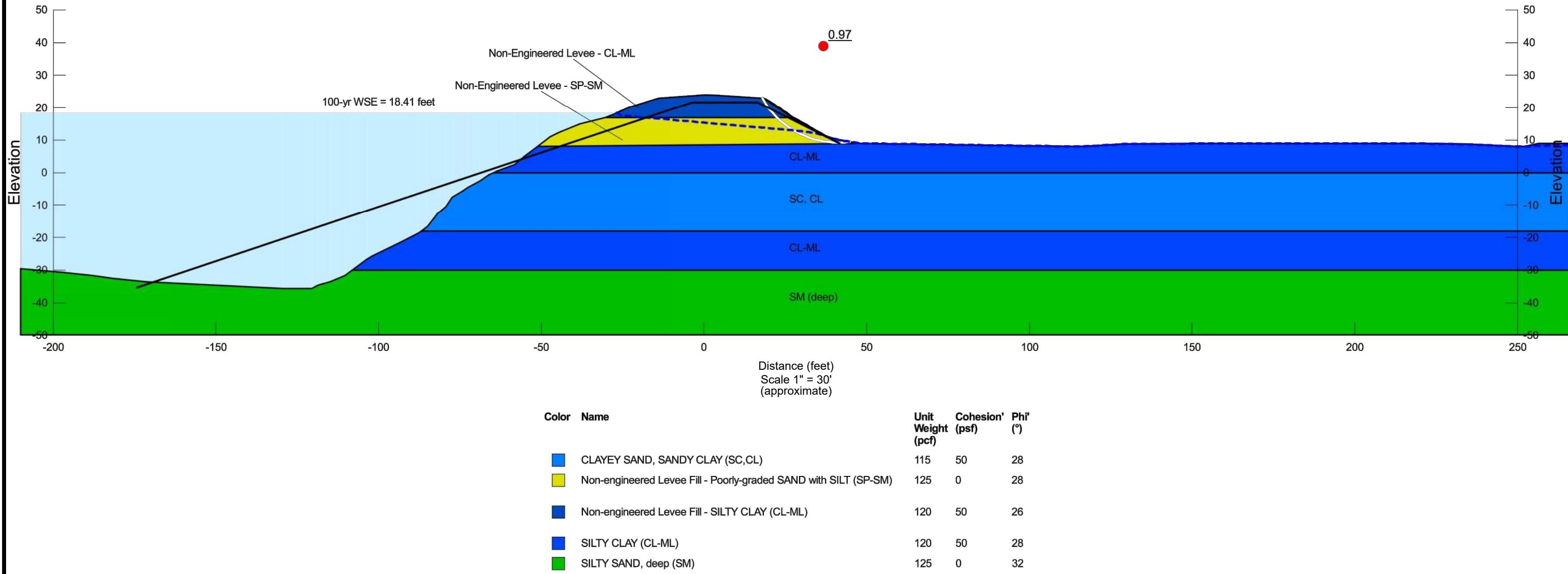
**NOTES:**  
Cross section created from RD 554 Lidar 2017, received 04-03-2020 and Sacramento  
and Georgiana USACE 1997 river hydrology provided by GEI Consultants 2020.



**STATION 42+25**  
Preliminary Sacramento River and Georgiana Slough  
East Levee Evaluation, Segment 128  
East Walnut Grove, California  
Subsurface Profile Used in Analyses

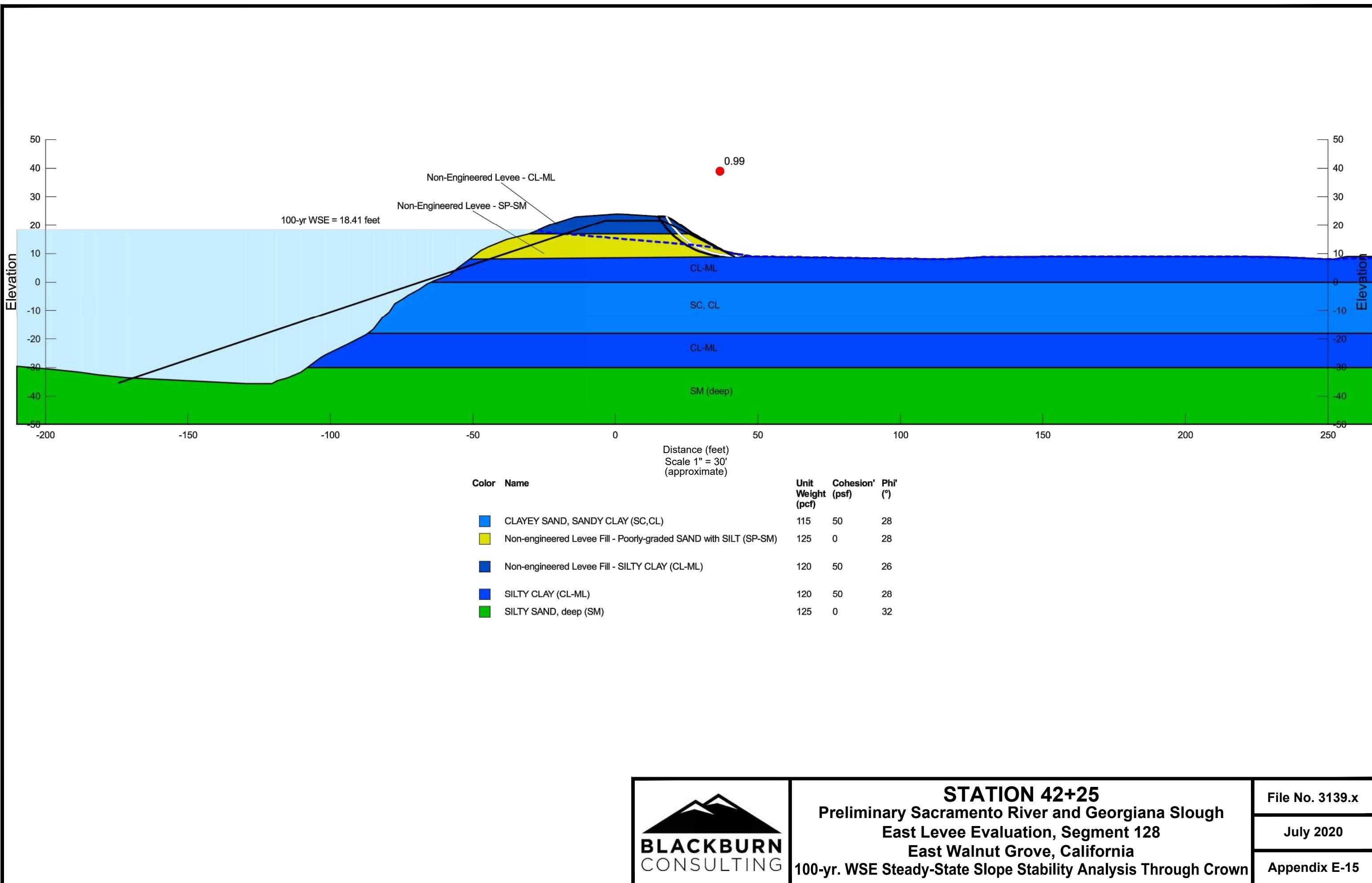
File No. 3139.x  
July 2020  
Appendix E-12

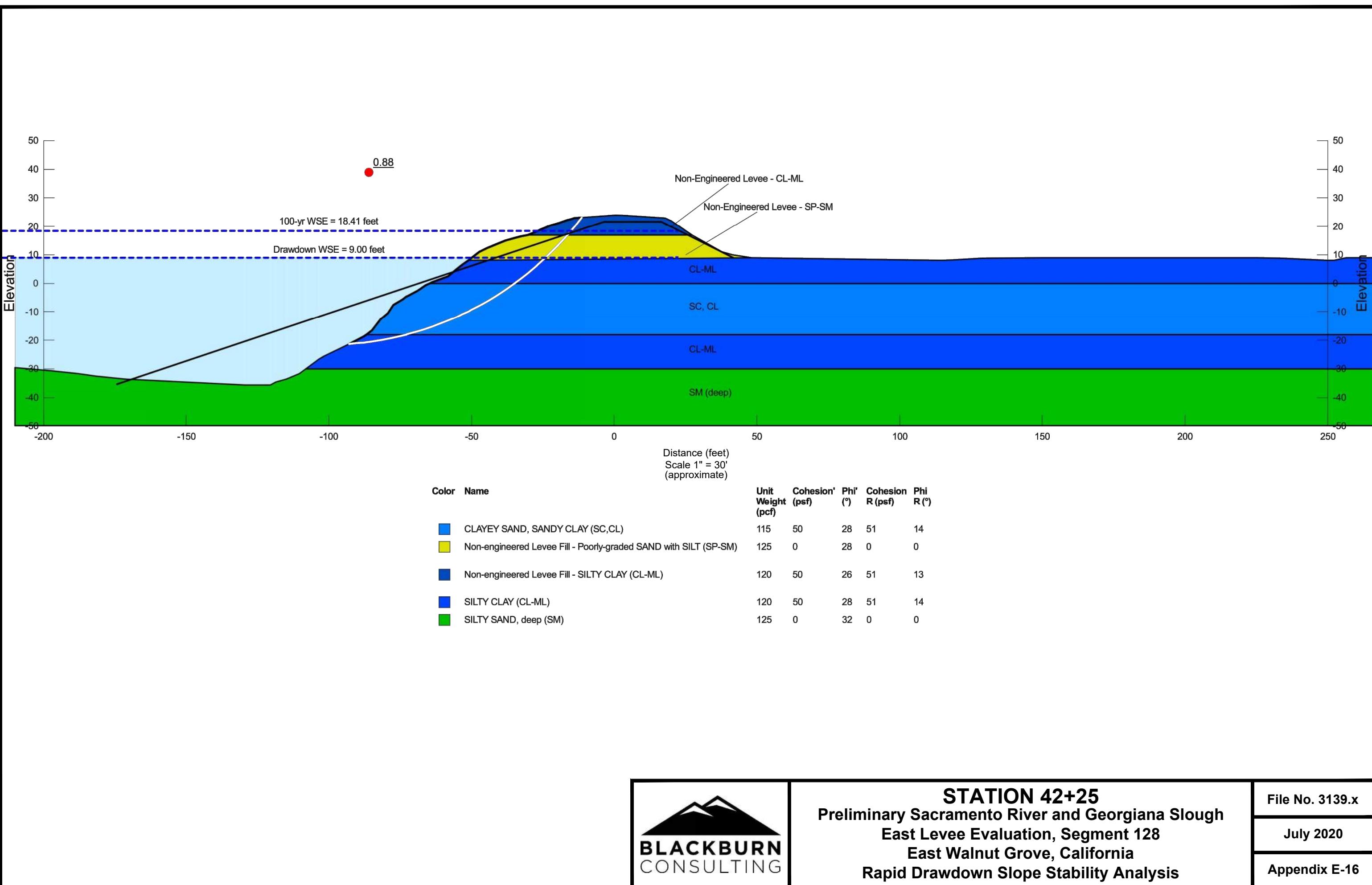


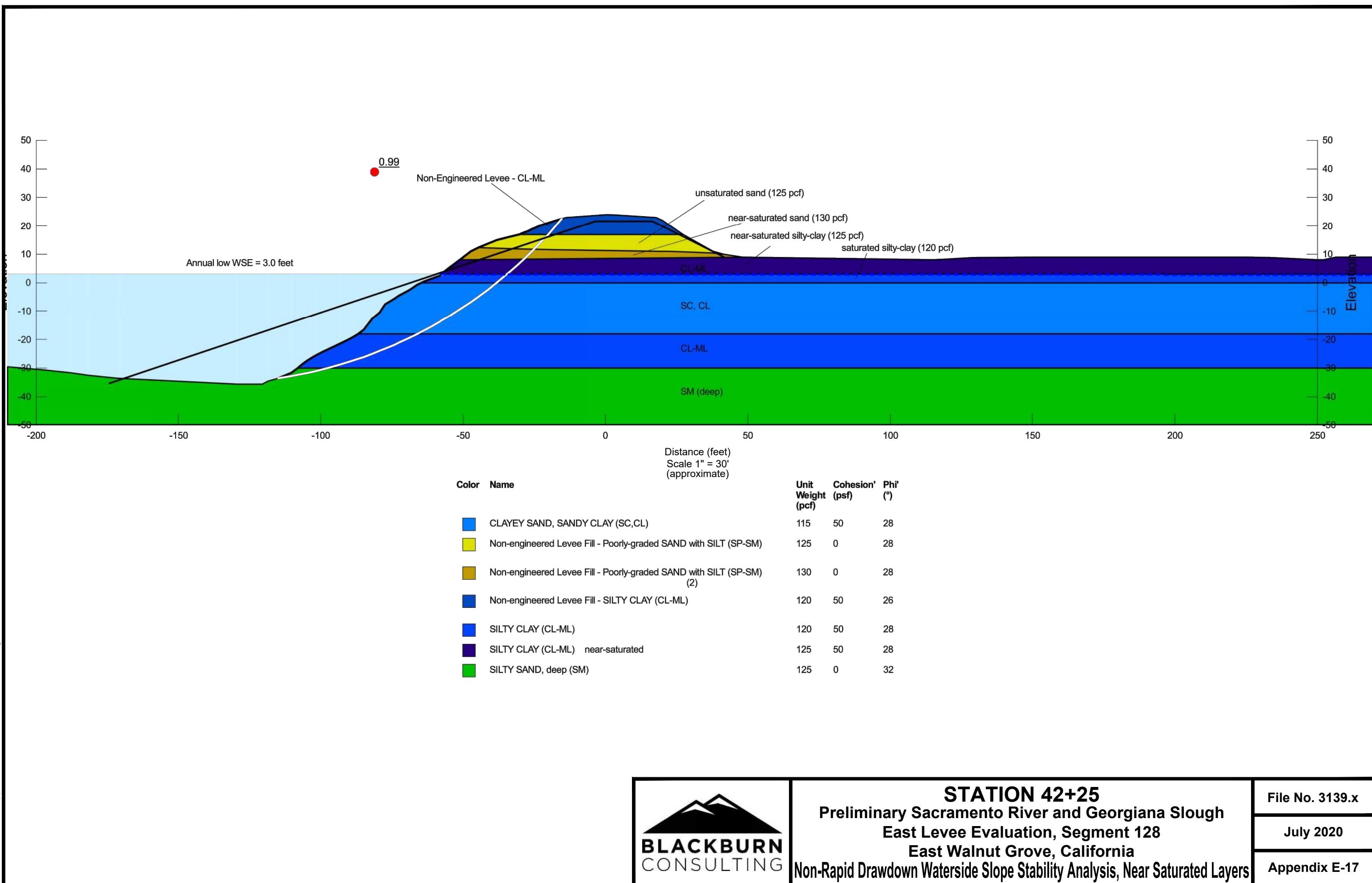


**STATION 42+25**  
Preliminary Sacramento River and Georgiana Slough  
East Levee Evaluation, Segment 128  
East Walnut Grove, California  
100-yr. WSE Steady-State Slope Stability Analysis

File No. 3139.x  
July 2020  
Appendix E-14







# **Preliminary Existing Condition Stability, Seepage and Settlement Evaluation**

## **Sacramento River and Georgiana Slough East Levees**

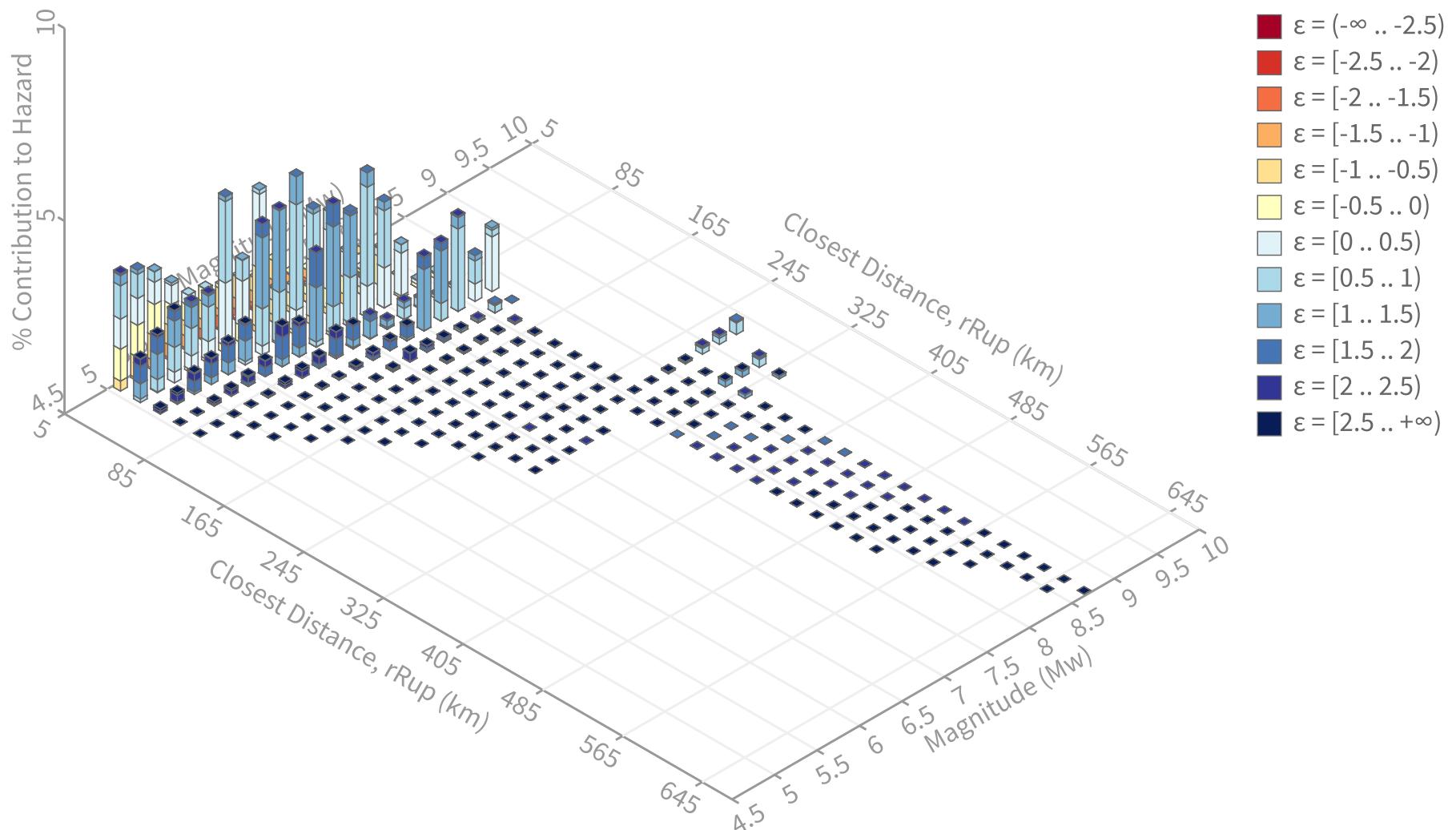
**Community of East Walnut Grove, California**

**California Department of Water Resources Small  
Community Flood Risk Reduction Program**

## **APPENDIX F**

**Seismic Evaluation by Blackburn**

# PSH Deaggregation East Walnut Grove



### ***Summary -- Liquefaction Analysis***

Project: East Walnut Grove Levee Evaluation - Reach A

BCI No.: 3139.X

Date: 7/1/2020

**Location: B-4**

By: DWC

Boring Elevation: 19.9 feet  
 Ground Water Elevation: 8.4 feet (For Liquefaction Analysis)

Hammer Energy (ER):	60	%
Ground Water Depth:	20.1	feet (At Time of Drilling)
Ground Water Depth:	11.5	feet (For Liquefaction Analysis)

Soil Layer	
Granular	
Cohesive	

Distance to Fault (R) =	34.9	mile
Moment Magnitude, $M_w$ =	6.7	
PGA =	0.14	g

Liquefaction Factor of Safety (FS):

## Summary -- Liquefaction Analysis

Project: East Walnut Grove Levee Evaluation - Reach B

BCI No.: 3139.X

Date: 7/1/2020

Location: B-1

By: DWC

Boring Elevation: 25.9 feet  
Ground Water Elevation: 10.4 feet (For Liquefaction Analysis)

Hammer Energy (ER): 60 %  
Ground Water Depth: 23.0 feet (At Time of Drilling)  
Ground Water Depth: 15.5 feet (For Liquefaction Analysis)

Distance to Fault (R) = 34.9 miles  
Moment Magnitude,  $M_w$  = 6.7  
PGA = 0.14 g

Liquefaction Factor of Safety (FS): 1.0

Soil Layer	
Granular	
Cohesive	

Sample Number	Input Data										Overburden Stress						Liquefaction Analysis						Strength Parameters		Liquefaction Factor of Safety					
	Sample Depth	Depth to Bottom of Layer	Layer Thickness	Soil Type	Total Unit Weight	Field N	Fines	PI	Average Mean Grain Size D50	Total Stress	Effective Stress at Time of Drilling	Effective Stress for Liquefaction Analysis	N <sub>SPT</sub>	(N <sub>1</sub> ) <sub>60</sub> NCEER	(N <sub>1</sub> ) <sub>60</sub> Boulanger	(N <sub>1</sub> ) <sub>60</sub> Cetin	(N <sub>1</sub> ) <sub>60</sub> CS	(N <sub>1</sub> ) <sub>60</sub> CS Boulanger	(N <sub>1</sub> ) <sub>60</sub> CS Cetin	(N <sub>1</sub> ) <sub>60</sub>	Effective Friction Angle (φ')	Factor of Safety (FS)								
	(feet)	(feet)	(feet)	(USCS)	(pcf)	(bpf)	%	%	(mm)	(psf)	(psf)	(psf)	(bpf)	(bpf)	(bpf)	(bpf)	(bpf)	(bpf)	(bpf)	(degrees)	NCEES (FS)	FS ≤ 1.0	Cetin (FS)	FS ≤ 1.0	Boulanger (FS)	FS ≤ 1.0				
1	5.0	7.5	7.5	SP-SM	80	7	3	--	--	400	400	400	7	9	8	9	9	8	11	30	unsaturated	--	unsaturated	--	unsaturated	--				
2	10.0	13.0	5.5	SM	104	9	38	--	--	860	860	860	9	11	11	19	17	14	12	30	unsaturated	--	unsaturated	--	unsaturated	--				
3	15.0	17.5	4.5	CL-ML	122	4	65	21	--	1416	1416	1416	4	4	4	4	4	4	4	27	unsaturated	--	unsaturated	--	unsaturated	--				
4	20.0	22.5	5.0	CL-ML	123	0	69	20	--	2029	2029	1748	0	0	0	0	0	0	0	25	NL	--	NL	--	NL	--				
5	25.0	29.0	6.5	CL-ML	123	4	68	19	--	2644	2519	2051	4	3	4	3	4	4	4	25	NL	--	NL	--	NL	--				
6	30.0	32.5	3.5	CL	136	22	75	--	--	3272	2835	2367	22	18	18	18	18	18	19	32	7.39	--	7.88	--	7.57	--				
7	35.0	37.5	5.0	CL	127	62	75	--	--	3929	3180	2712	62	51	49	51	51	49	52	43	18.13	--	19.38	--	18.51	--				
8	40.0	42.5	5.0	CL	128	41	75	--	--	4567	3506	3038	41	32	31	32	32	31	33	36	10.81	--	11.45	--	10.99	--				
9	45.0	47.5	5.0	CL	138	49	75	--	--	5232	3859	3391	49	36	36	36	36	36	38	36	11.85	--	12.49	--	11.97	--				
10	50.0	54.0	6.5	CL	122	26	75	--	--	5882	4197	3729	26	18	18	18	18	18	20	32	5.89	--	6.08	--	5.90	--				
11	55.0	57.5	3.5	CL-ML	126	25	70	--	--	6496	4499	4031	25	17	17	17	17	17	18	32	5.41	--	5.40	--	5.36	--				
12	60.0	62.5	5.0	CL-ML	121	19	70	--	--	7113	4804	4336	19	13	13	13	13	13	13	31	3.98	--	3.80	--	3.87	--				
13	65.0	67.5	5.0	CL-ML	121	18	70	--	--	7718	5097	4629	18	12	12	12	12	12	12	31	3.70	--	2.31	--	3.52	--				
14	70.0	72.0	4.5	CL-ML	125	27	70	--	--	8333	5400	4932	27	17	17	17	17	17	18	32	5.48	--	3.24	--	5.06	--				
15	75.0	78.0	6.0	SM	124	29	20	--	--	8955	5710	5242	29	18	18	23	22	20	19	32	2.87	--	1.39	--	2.85	--				
16	80.0	82.5	4.5	CL-ML	114	27	75	--	--	9555	5998	5530	27	16	16	16	16	16	17	32	5.26	--	2.86	--	4.70	--				

### ***Summary -- Liquefaction Analysis***

Project: East Walnut Grove Levee Evaluation - Reach C

BCI No.: 3139.X

Date: 7/1/2020

**Location: B-3**

By: DWC

Boring Elevation:	23.4	feet
Ground Water Elevation:	10.4	feet (For Liquefaction Analysis)

Hammer Energy (ER):	60	%
Ground Water Depth:	19.0	feet (At Time of Drilling)
Ground Water Depth:	13.0	feet (For Liquefaction Analysis)

Soil Layer	
Granular	
Cohesive	

Distance to Fault (R) =	34.9	mile
Moment Magnitude, $M_w$ =	6.7	
PGA =	0.14	g

Liquefaction Factor of Safety (FS):