UPDATED EXISTING GEOTECHNICAL DATA

TECHNICAL MEMORANDUM

Community of East Walnut Grove, California

California Department of Water Resources
Small Community Flood Risk Reduction Program

March 2020

Prepared for:

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Subject: **UPDATED EXISTING GEOTECHNICAL DATA TECHNICAL MEMORANDUM**
Community of East Walnut Grove, California
California Department of Water Resources Small Community Flood Risk Reduction Program

Dear Mr. Twitchell,

Blackburn Consulting (BCI) prepared this Updated Existing Geotechnical Data Technical Memorandum (TM) for the Community of East Walnut Grove (in particular, the portion of Reclamation District 554 south of Delta Cross Channel), as part of the California Department of Water Resources (DWR) Small Community Flood Risk Reduction Program. BCI prepared this TM in accordance with our XX/XX/XXXX Subconsultant Agreement with GEI Consultants, Inc. This TM updates the previous TM dated August 13, 2019.

Please call if you have questions or require additional information.

Sincerely,

BLACKBURN CONSULTING
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Copies: 1 to Addressee (PDF)

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1 INTRODUCTION

This Updated Technical Memorandum (TM) summarizes existing geotechnical information and past performance and identifies recommendations for further subsurface investigation for the levees that protect the community of East Walnut Grove in Sacramento County. The levee segments covered in this TM per the Non-Urban Leve Evaluation (NULE) segment numbering system are:

- NULE Segment 128 along the left banks of the Sacramento River and Georgiana Slough (west boundary of East Walnut Grove).
- NULE Segment 1052 along the right bank of the Delta Cross Channel (North boundary of East Walnut Grove).
- NULE Segment 1051 along the right bank of Snodgrass Slough (East boundary of East Walnut Grove), and
- The "dry cross 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.

These levees encompass areas of Reclamation District 554 (RD 554) south of the Delta Cross Channel. All stationing referenced in this TM is based on the 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. 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.

Existing levee conditions and geotechnical information for the levees covered in this TM are primarily available from the Department of Water Resources (DWR) Division of Flood Management's NULE project, 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. We also used the following to develop this TM:

- The RD 554 5-Year-Plan developed by DCC Engineering Co, Inc. to provide a workplan outlining anticipated repairs/improvements.
- Subsurface explorations (borings and Cone Penetrometer soundings) performed by Raney Geotechnical, Inc. along the levees encompassing East Walnut Grove.
- Subsurface explorations performed within the RD 554 levees for design or retrofitting of the bridges accessing East Walnut Grove.

A summary of existing information for each levee segment follows.

2 NULE SEGMENT 128 – SACRAMENTO RIVER AND GEORGIANA SLOUGH

The NULE Segment 128 levee extends 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 confluence 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'. The levee segment is approximately 0.9 miles long (0.6 miles along the Sacramento River and 0.3 miles along Georgiana

Slough). The Sacramento River flows from north to south along this SPFC levee reach. The United States Army Corps of Engineers (USACE) 1955/1957 design water surface elevation (DWSE), as provided by DWR, is 16.90 feet (NAVD 88) or 14.47 (NGVD 29).

2.1 Levee Construction History and Improvements

Per the 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 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 at 31+15 in 1976 and along approximately 745 feet at Station 38+75 in 2006. Additional rock revetments have been placed from approximate Station 11+15 to 13+85, 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 improvements or repairs were planned at the time California DWR published the April 2011 NULE Geotechnical Assessment Report (GAR).

Figure 3 shows past levee improvements based on available information.

2.2 Past Performance

Levee performance summarized in this TM is based primarily on NULE GAR project information obtained from reviewed documents and interviews with maintenance personnel. Table 2.1 and Figure 4 present past performance events based on available information.

Table 2.1 Levee Past Performance

Flood Season	Reported Event	Approximate Location (RD 554 Stationing)	Mitigation
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

2.3 Levee Freeboard and Geometry

Both the LiDAR survey referenced in the NULE GAR and the RD 554 2008-2009 survey indicate an existing minimum freeboard of 3 feet above the USACE 1955/1957 DWSE throughout the segment.

Table 2.2 presents existing levee geometry per the NULE GAR.

Table 2.2 Levee Geometry			
Height above Landside toe (ft.)	**Landside Slope (Horizontal: Vertical)**	**Crest Width (ft.)**	**Waterside Slope (Horizontal: Vertical)**
10 to 15	1.7:1 to 2.8:1	30 to 60	2.2:1 to 3:1

2.4 Existing Subsurface Explorations

In 2013 through 2016 Raney Geotechnical, Inc (Raney) drilled 3 borings and 3 Cone Penetrometer Tests (CPTs) along the alignment of Segment 128. According to the Raney boring logs, the levee prism mainly consists 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 levee prism.

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.

3 NULE SEGMENT 1052 – DELTA CROSS CHANNEL

The NULE Segment 1052 levee extends along the right (south) bank of the Delta Cross Channel in Sacramento County. The levee segment is approximately 0.8 miles long with project stationing running west to east (Figure 2). The gated channel flows from west to east along this non-SPFC levee. No USACE 1955/1957 DWSE was available for this levee segment as this levee is a Non-Project levee. Radial gates near the Sacramento River control flow through this controlled diversion channel and normally remain closed November 1st through May 20th every year and any time the flows in the Sacramento River at Locke are greater than 20,000 cubic feet per second (cfs) to 25,000 cfs (References: State Water Resources Control Board Decision 1641 (March 2000); and the California DWR Delta Flood Emergency Management Plan Supplement A (October 2018).

3.1 Levee Construction History and Improvements

The United States Bureau of Reclamation (USBR) built the Delta Cross Channel levee in 1949 with material excavated during channel construction. Excavated materials may have been supplemented by off-site borrow material. Construction documents state that the waterside embankment was compacted, but the landside embankment was not.

No major rehabilitations have been performed on the channel embankment. Riprap was placed at the two erosion sites repaired in 1985 (Table 3.1). In 2004, rock slope revetment was placed to mitigate additional erosion sites (Table 3.1).

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

Figure 3 shows past levee improvements based on available information.

3.2 Past Performance

Levee performance summarized in this TM is based primarily on NULE GAR project information obtained from reviewed documents and interviews with maintenance personnel. Table 3.1 and Figure 4 present past performance events based on available information.

Table 3.1 Levee Past Performance

Flood Season	Reported Event	Approximate Location (RD 554 Stationing)	Mitigation
1985	2 erosion sites	Between 58+35 & 63+35 and between 78+35 & 83+35	Placed riprap
2004	3 erosion sites	68+35 – 73+35	Rock slope revetment
2006	Underseepage	Near 73+35	Not documented
2010	Depression and Landside erosion	Near 66+35	Not documented
2010	Multiple erosion sites	46+35 – 72+35	Not documented

3.3 Levee Freeboard and Geometry

The NULE GAR report did not assess freeboard because a 1955/1957 DWSE was not available for this Non-Project levee segment. RD 554 compared its 2008-2009 survey with the 2016 100-yr Base Flood Elevation (BFE) or 17.00 (NAVD 88) and concluded that the existing geometry of this segment meets FEMA height standards necessary to retain FEMA certification (3 ft above 100-yr flood level).

USBR designed landside slopes to 2H:1V and waterside slopes to 3H:1V. Table 3.2 presents levee geometry per the NULE GAR.

Table 3.2 Levee Geometry

Height above Landside toe (ft)	Landside Slope (Horizontal: Vertical)	Crest Width (ft)	Waterside Slope (Horizontal: Vertical)
15 to 21	1.7:1 to 2:1	15 to 20	2.8:1 to 3.5:1

An unlined ditch runs along the landside toe from approximately Station 55+35 to 88+35 and drains easterly. The ditch is about 2 to 3 feet deep and 5 to 10 feet wide.

3.4 Existing Subsurface Explorations

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 prism 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 ground surface.

USBR drilled 17 borings ranging from 15 to 100 feet deep for design and construction of the Delta Cross Channel, including 6 borings along the proposed centerline of Segment 1052. These borings generally agree with the 1997 seismic retrofit boring except that they show the foundation soil consists of a 3- to 4-foot-thick loam and peaty silt layer rather than the clayey sandy silt. USBR boring logs and locations were not available at the time of writing this TM.

Raney drilled 3 borings in 2013 along the alignment of Segment 1052. According to the Raney boring logs, the levee embankment predominantly consists of medium stiff to stiff sandy silty clay. Boring 6 shows a 3- to 4-foot-thick layer of soft peaty silt, which does not appear in the Delta Cross Channel borings near the Sacramento River. Beneath the levee embankment, Raney's borings show a 15- to 20-foot thick medium stiff to very stiff silty sandy clay overlying interbedded layers of medium dense to dense sand and hard silt and clay to a depth of 55 feet.

Raney also pushed 5 Cone Penetrometer Tests (CPTs) within this segment. CPT-1 generally supported the findings of the borings near the western end of the segment. CPT-9 generally showed similar soil conditions, however, the deep sand layers appeared approximately 15 feet deeper. This may be explained by the geomorphology; CPT-9 was pushed in Holocene overbank deposits while CPT-1 was pushed in Recent overbank deposits (Section 8). In the eastern portion of the alignment, 2 of the CPTs (CPT-2 and -3) somewhat agree with the borings with several significant discrepancies. CPT-3 shows very stiff fine-grained material where the boring shows soft organic soil, and CPT-2 shows clayey silts and sandy silts near elevation -20 feet where the nearby boring identifies fat clay. CPT-9 differs from the other explorations the most, especially below 35 feet deep where it identifies an approximately 7-foot-thick layer of clean sand. Below the sand layer it identifies clay where the other explorations identify silty sand and sandy silt.

4 NULE SEGMENT 1051 – SNODGRASS SLOUGH

The Non-Project NULE Segment 1051 levee extends along the right (west) bank of Snodgrass Slough from the confluence of Snodgrass Slough and the Delta Cross Channel southward and downstream to the confluence of Snodgrass Slough and the North Mokelumne River. The levee segment is approximately 1.7 miles long. For this levee evaluation, we only considered the portion of the levee north (or upstream) of the RD 554 "dry cross levee" described in Section 5 of this TM. The slough flows from north to south along this Non-SPFC levee. No USACE 1955/1957 DWSE is available for this Non-Project levee.

4.1 Levee Construction History and Improvements

Per the NULE documents, local interests constructed the Segment 1051 levees prior to 1906. Documentation of construction methods or materials was not available.

No improvements or repairs were planned at the time the April 2011 NULE GAR was published; however, the RD 554 Five-Year Plan of 2012 states the need to raise the levee crown and flatten the landside slope in multiple areas to mitigate freeboard, slope deficiencies, and stability issues.

4.2 Past Performance

Levee performance summarized in this TM is based primarily on NULE Geotechnical Assessment Report (GAR) project information obtained from reviewed documents and interviews with maintenance personnel. The NULE GAR found no documented reports of erosion, overtopping, underseepage, through seepage, or slope instability in Segment 1051 north of the RD 554 "dry cross levee".

4.3 Levee Freeboard and Geometry

The NULE GAR report did not assess freeboard because a 1955/1957 DWSE was not available. RD 554 compared its 2008-2009 survey with the 2016 100-yr Base Flood Elevation (BFE) of 17.00 (NAVD 88) and concluded that portions of the existing geometry of this segment do not meet FEMA height standards necessary to retain FEMA certification (3 ft above 100-yr flood level).

Table 4.2 presents levee geometry per the NULE GAR.

Table 4.2 Levee Geometry

Height above Landside toe (ft)	Landside Slope (Horizontal: Vertical)	Crest Width (ft)	Waterside Slope (Horizontal: Vertical)
14 to 21	1.5:1 to 2:1	20 to 35	1.5:1 to 3:1

The PL84-99 levee standards require a 3H:1V landside slope and 2H:1V waterside slope. The 2008-2009 RD 554 survey showed this segment meets the waterside requirements but does not meet the landside requirements from approximate RD 554 Station 80+00 to 147+50. Although NULE Segment 1052 includes Station 80+00 to 88+37, we included the deficiency in this portion of the report because the failure to meet the landside slope requirements is one continuous deficiency.

An unlined ditch runs along the landside toe from approximately RD 554 Station 135+15 to the northern end of the segment near RD 554 Station 88+37. The ditch is about 1 to 5 feet deep and 10 to 15 feet wide. There are also several ditches that run at an angle to the levee and terminate near the landside toe.

4.4 Existing Subsurface Explorations

Two borings were drilled near the landside toe for the 1992 North Delta Seepage Monitoring Study. The boring logs indicate the foundation soil consists of about 12 feet of soft to moderately soft, moderately moist organic and inorganic clay underlain by interbedded layers of saturated sand, saturated silt, and very stiff saturated clay to the maximum explored depth of 20 feet.

Raney drilled 4 borings in 2013 along the alignment of Segment 1052, one of which (Boring 8) was not available at the time of writing this TM. According to the boring logs, the levee embankment consists of medium dense silty sand and stiff to very stiff sandy silty clay above stiff to very stiff clay and silty clay. The foundation soil is generally soft to medium stiff silty clays and clayey silt with varying amounts of sand in the upper 10 feet, which becomes stiff to very stiff to depths of about 20 to 25 feet below the levee. This soil is underlain by interbedded layers of medium dense to dense sand, and stiff to very stiff silt and clay to the maximum 57-foot depths explored.

Raney also pushed 10 CPTs within this levee segment, one of which (CPT-4) was not available at the time of writing this TM. The CPTs in this segment somewhat agree with the borings. However, CPTs 5 and 7 indicated lenses of sensitive fine-grained material in the levee embankment. CPTs 5 and 10 indicated no organic soil right below the levee although the nearby borings identified some. The most notable difference is a roughly 3- to 5-foot-thick layer of sand to silty sand that appears in about half the CPTs near elevation -20 feet. This layer appears intermittent, as if it interlayers with a silty clayey spoil. The available CPTs from approximate station 90+00 to 115+00 show that below this intermittent sand layer, there is an approximately 10-foot-thick layer of stiff to very stiff silt and clay; however, the borings within this stretch identify a sand to silty sand at the same elevation. Near the same elevations, CPTs 10, 20, and 21 suggest that the material has more sand than the nearby explorations. CPTs 11, 13, and 14 indicate sand and silty sand below approximate elevation -45 feet; the borings did not go as deep as these CPTs.

5 “DRY CROSS LEVEE”

The Dry Cross Levee intersects with the NULE segment 1051 levee and follows the alignment of Old Walnut Grove – Thornton Rd for approximately 0.39 miles until it meets with Walnut Grove – Thornton Rd. It then follows Walnut Grove – Thornton Rd. for approximately 0.15 miles and ends where Segment 128 and Segment 130 meet (NULE Segment 130 continues in-line with Segment 128 and runs south and downstream along Georgianna Slough to protect RD 563 – Tyler Island). The dry cross levee runs SE to NW and “separates” East Walnut Grove (RD 554) from the rest of Tyler Island (RD 563) to the south.

The DWR NULE program did not evaluate the dry cross levee, thus there is no GAR for the subject “Dry Cross Levee”.

5.1 Levee Construction History and Improvements

The Dry Cross Levee was built as a flood fight measure during the 1986 flood event to protect the RD 554 portion of East Walnut Grove from flooding from a levee breach which occurred farther south within RD 563 – Tyler Island. It was an emergency effort that led to its current configuration.

The RD 554 Five-Year Plan of 2012 states that improving prism geometry and grading as well as filling the Old Tyler Island Slough to strengthen the landward, north levee toe of the dry cross levee, is a “crucial long term objective.”

5.2 Past Performance

Since the threat of overtopping in 1986, there have been no documented reports of erosion, overtopping, underseepage, or through seepage for the dry cross levee.

5.3 Levee Freeboard and Geometry

RD 554 compared its 2008-2009 survey with the 2016 100-yr Base Flood Elevation of 17.00 (NAVD 88) and concluded the east end of this segment does not meet FEMA height standards necessary to retain FEMA certification (3 ft above 100-yr flood level).

The 2008-2009 RD 554 survey found much of the levee geometry meets FEMA and PL84-99 standards for project levees. However, from approximate RD 554 Station 172+50 to 179+00 and at the southeasterly junction with the Segment 1051 levee, the dry cross levee does not meet the latest geometry standards.

5.4 Existing Subsurface Explorations

Raney drilled 1 boring in 2013 along the dry cross levee alignment. This boring indicates that the levee consists of medium dense silty clay and sandy silt with gravel and underlain by an approximately 3-foot-thick layer of loose silty sand, which overlies approximately 10 feet of medium stiff to very stiff clayey silts with varying amounts of sand that is very stiff to hard to approximately 35 feet below the levee. This clayey silt layer is underlain by a 20-foot-thick layer of medium dense to dense clean sand over interbedded layers of dense to very dense sand, and hard silt and clay to a depth of 68 feet.

Raney also pushed 3 CPTs within this levee segment. Stick logs were available, however full CPT logs were not available for 2 of the CPTs at the time of writing this TM. The CPT logs generally agree with the nearby Raney boring in the upper 40 feet. However, the thick sandy layer only appears in 1 CPT and has a considerably higher fines content. The 2 CPTs east of the Raney boring show silty clays and clayey silts with sand lenses to the maximum depth explored.

6 SUBSURFACE CONDUCTIVITY STUDY

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 levees considered in this TM and analyzed the data obtained to determine locations of pipes, soil 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 data for Segment 128. Portions of the east section of the study display erratic conductivity profiles, likely due to transmissions from the KXTV/KOVR transmission tower. 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 4 potential problems areas which CSI “felt” justified further attention. Table 6.1 presents the locations of areas justifying further attention in the CSI report.

Table 6.1 Areas Requiring Further Attention

Approximate RD 554 Station	46+30	92+25	105+35	173+55
Levee Segment	128	1051	1051	Dry

See Appendix C for the complete Levee Subsurface Conductance Study Report.

7 AVAILABLE GEOTECHNICAL INFORMATION

The DWR NULE project included an assessment (Phase 1 only) of the levees protecting the community of East Walnut Grove on all sides except to the south (the study did not evaluate the dry cross levee). The assessment was based solely on non-intrusive studies and readily available data; no subsurface explorations were completed for this study.

Assessment data such as historical reports, interviews with personnel, construction records, levee performance records, and other data provided by relevant agencies were collected and reviewed for the study. The NULE GAR characterizes the existing condition of the Non-Urban levees using the collected information and geomorphic studies and topographical surveys which were also completed.

NULE GAR segment specific write-ups for each of the segments protecting East Walnut Grove (NULE Segments 128, 1052, 1051) are attached in Appendix A.

8 GEOMORPHIC SETTING

Geomorphology mapping developed for the DWR NULE project (see Appendix B) indicates three main deposits underlie the RD 554 levees: Recent Overbank Deposits (Rob), Holocene age Overbank Deposits (Hob), and Holocene age basin deposits (Hn).

The western portion of the island, including Segment 128 and approximately 1100 feet of the western portion of Segment 1052 along the Delta Cross Channel, is underlain by Recent Overbank Deposits (interbedded silt, sand, and clay layers which vary laterally in extent and character). The center of the island, including approximately 500 feet of Segment 1052, is underlain by Holocene age Overbank Deposits (silt, clay, and lesser sand). The east portion of the island, including approximately 2100 feet of the eastern portion of Segment 1052 and much of Segment 1051, is underlain by Holocene age Basin deposits (fine sand, silt, and clay). The northeast corner of the island has Recent Overflow Channel Deposits (Rofc, sand, silt, and clay) underlying approximately 500 feet of Segment 1052. The dry cross levee is largely underlain by Recent Slough Deposits (Rsl; silt, clay, and sand).

All these deposits, except the Recent Overflow Channel Deposits, nearly converge in the lower portion of Segment 1051. Recent Overbank Deposits underlie the southern 2800 feet of Segment 1051 except for about 100 feet from approximate Station 151+15 to 152+15, which is underlain by Recent Slough Deposits. Just north of the Recent Overbank Deposits, approximately 400 feet of the levee is underlain by Holocene age Overbank Deposits.

Several of the exploratory borings indicate that lenses of organic clay and/or peat may exist below, waterside and landside of the Delta Cross Channel, Snodgrass Slough and Georgiana Slough levees.

9 UNDERSTANDING OF EXISTING GEOTECHNICAL CONDITIONS

The NULE GAR assessments of the levee segments described above were based on readily available information and considered four potential failure mechanisms (underseepage, slope stability, through seepage and erosion). The NULE assessment looked at past performance and compared it to levee composition, geometry, hydraulic head, penetrations, ditches, and animal activity. Assessment was made at a single WSE for each segment. Segment 128 was assessed at the 1955/1957 WSE, while Segments 1052 and 1051 were assessed by DWR using a DWSE 1.5 feet below the levee crest.

Hazard levels were assigned and evaluated for each failure mechanism. The hazard levels were defined as:

- Hazard Level A – Low likelihood of levee failure (or the need to flood-fight to prevent levee failure) at the assessment WSE.

- Hazard Level B – Moderate likelihood of levee failure (or the need to flood-fight to prevent levee failure) at the assessment WSE.
- Hazard Level C – High likelihood of levee failure (or the need to flood-fight to prevent levee failure) at the assessment WSE.
- Lacking Sufficient Data (Category LD) – The existing information available at the time of the assessment was insufficient to assign a hazard level, or there is poor correlation between hazard indicators and past performance. Category LD is further divided into 'LD (A, B, or C)' and 'LD (A or B)' based on whether there was sufficient data to rule out hazard level C.

Hazard categories for the East Walnut Grove levee segments are summarized in Table 8.1

Table 8.1 Failure Mode Assessment Summary

Levee Reach	Overall	Under Seepage	Slope Stability	Through Seepage	Erosion
Segment 128 – Sac. River and Georgiana Slough	A	A	A	A	A
Segment 1052 – Delta Cross Channel	B	B	LD (A or B)	A	B
Segment 1051 – Snodgrass Slough	LD (A, B, or C)	LD (A, B, or C)	LD (A, B, or C)	LD (A, B, or C)	A

More discussion can be found in the attached NULE GAR.

10 CONCLUSIONS AND RECOMMENDATIONS

Geotechnical understanding of the levee prism and foundation is crucial to properly evaluate existing conditions and necessary improvements to achieve an urban level of flood protection. As discussed above, limited information is available for the levee system protecting East Walnut Grove. It will be necessary to gain further understanding of the subsurface conditions to evaluate slope stability, through seepage, underseepage and settlement, and potential improvements. Additional review of the Raney borings and CPTs, and supplemental field data will be required to: (1) complete a feasibility-level geotechnical evaluation; (2) define what is needed to conduct a FEMA accreditation process; (3) and develop cost estimates for remedial repairs.

Blackburn's review of the Raney laboratory and additional Raney CPT logs supports the need for further subsurface exploration. As noted in the subsurface exploration summaries of each segment, the CPT stick logs Raney provided in October of 2019 indicate highly variable soil profiles that will require greater definition.

Proposed site-specific geotechnical explorations to advance FEMA accreditation and remedial repair recommendations will be outlined in a separate geotechnical investigation plan after preliminary geotechnical evaluations are complete using all of the existing information. In addition to using the existing exploratory borings and CPTs, the investigation program will include supplemental exploratory borings and CPTs, collection of soil samples and in-situ data, detailed descriptions of embankment and foundation conditions, and laboratory testing to support geotechnical evaluations for certification or necessary improvements.

11 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.

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

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UPDATED EXISTING GEOTECHNICAL DATA

TECHNICAL MEMORANDUM

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: Existing Explorations
Figure 3: Levee History and Improvements
Figure 4: Past Performance Issues

SCALE 1"=20,000'

blackburn consulting

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West Sacramento, CA 95691
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Fax: (916) 375-8709
www.blackburnconsulting.com

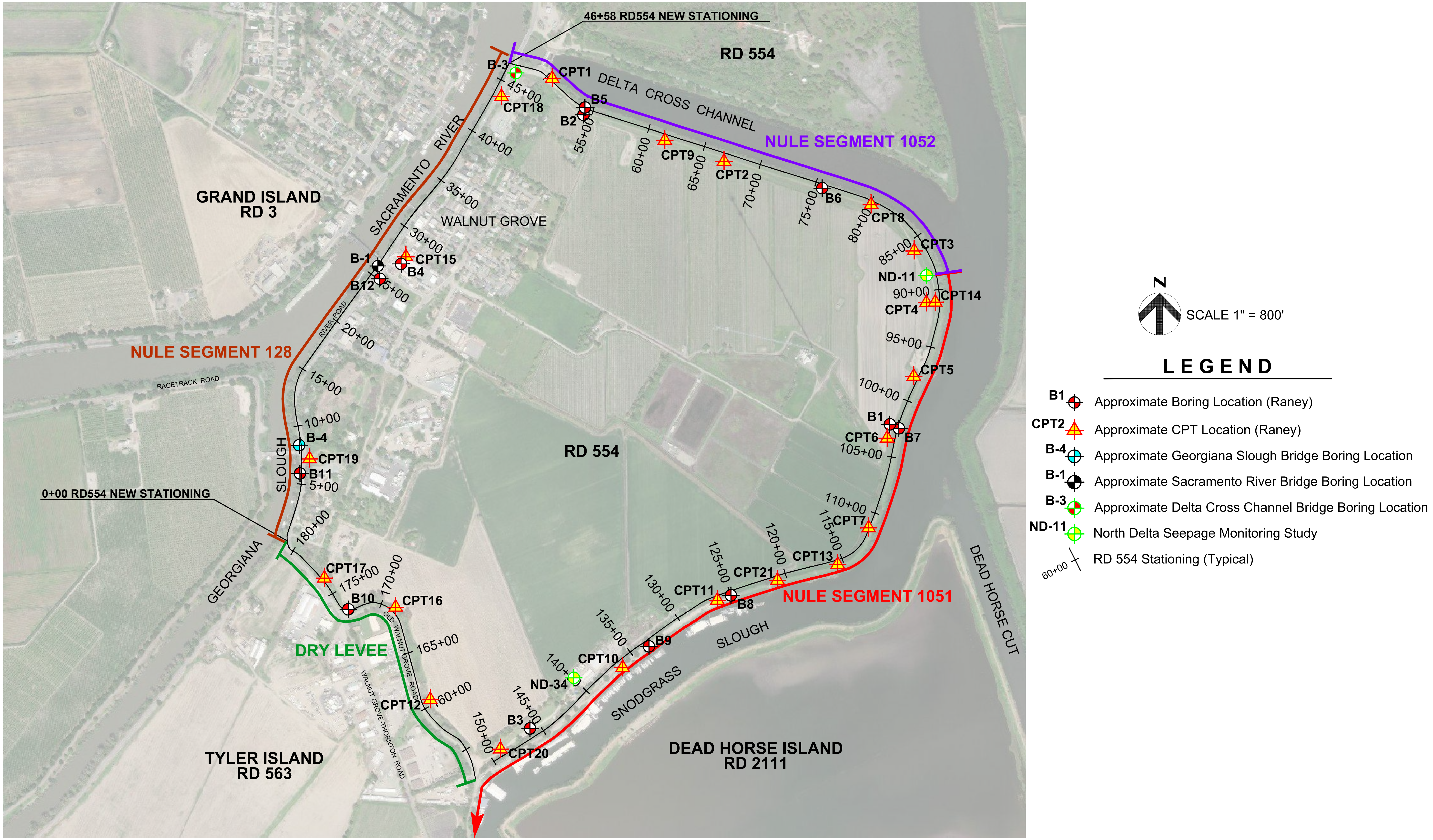
VICINITY MAP
RD 554, East Walnut Grove
Walnut Grove, California

File No. 3139.x

March 2020

Figure 1

2/4/2020 3139.x Fig1 East Walnut Grove.dwg



2/4/2020 3139.x Fig2 East Walnut Grove.dwg

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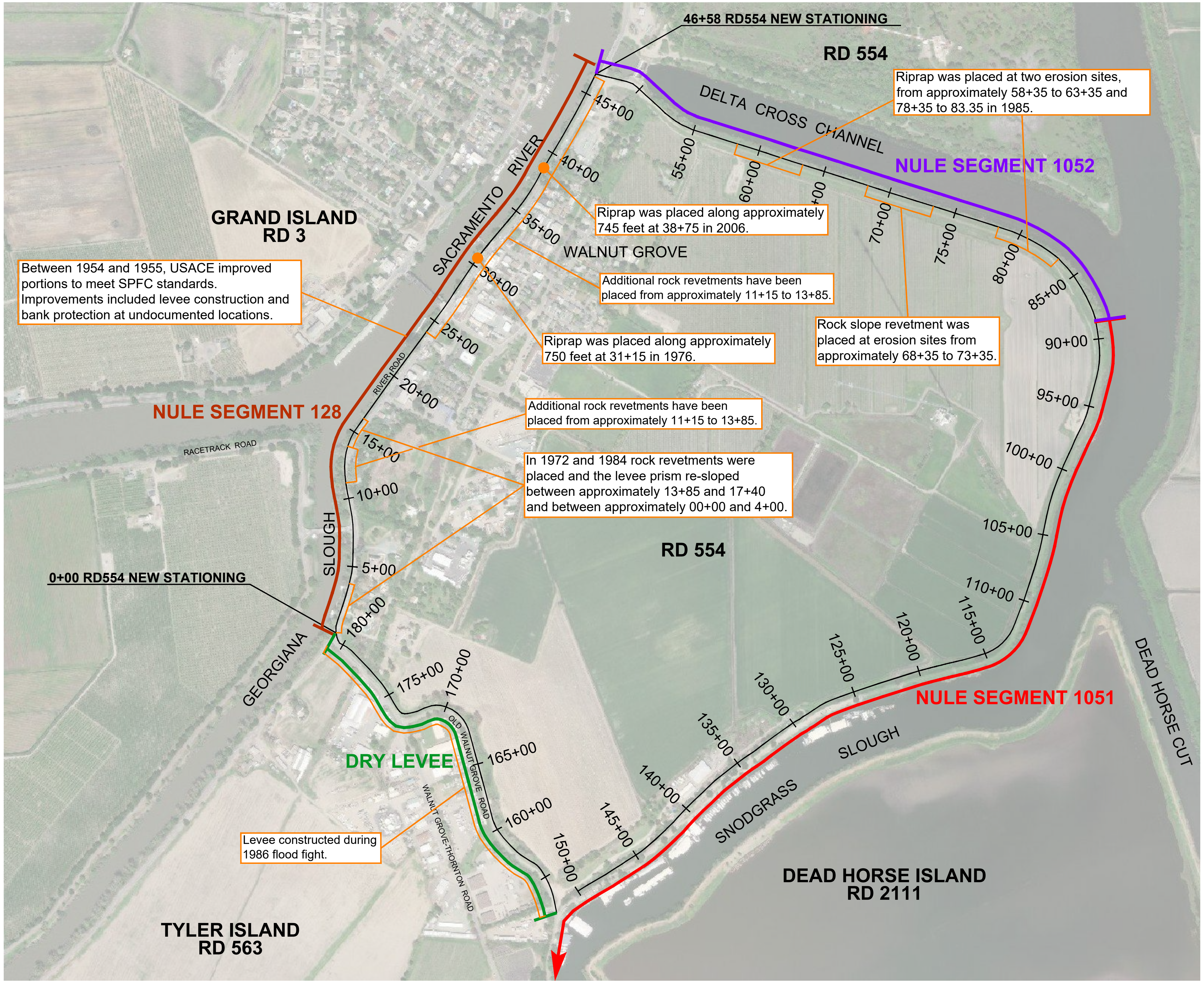
EXISTING EXPLORATIONS
RD 554, East Walnut Grove
Walnut Grove, California

File No. 3139.x
March 2020
Figure 2



Riprap was placed at two erosion sites, from approximately 58+35 to 63+35 and 78+35 to 83.35 in 1985.

Riprap was placed along approximately 745 feet at 38+75 in 2006.

Between 1954 and 1955, USACE improved portions to meet SPFC standards. Improvements included levee construction and bank protection at undocumented locations.

Additional rock revetments have been placed from approximately 11+15 to 13+85.

Riprap was placed along approximately 750 feet at 31+15 in 1976.

Rock slope revetment was placed at erosion sites from approximately 68+35 to 73+35.

Additional rock revetments have been placed from approximately 11+15 to 13+85.

In 1972 and 1984 rock revetments were placed and the levee prism re-sloped between approximately 13+85 and 17+40 and between approximately 00+00 and 4+00.

Levee constructed during 1986 flood fight.

N

SCALE 1" = 800'

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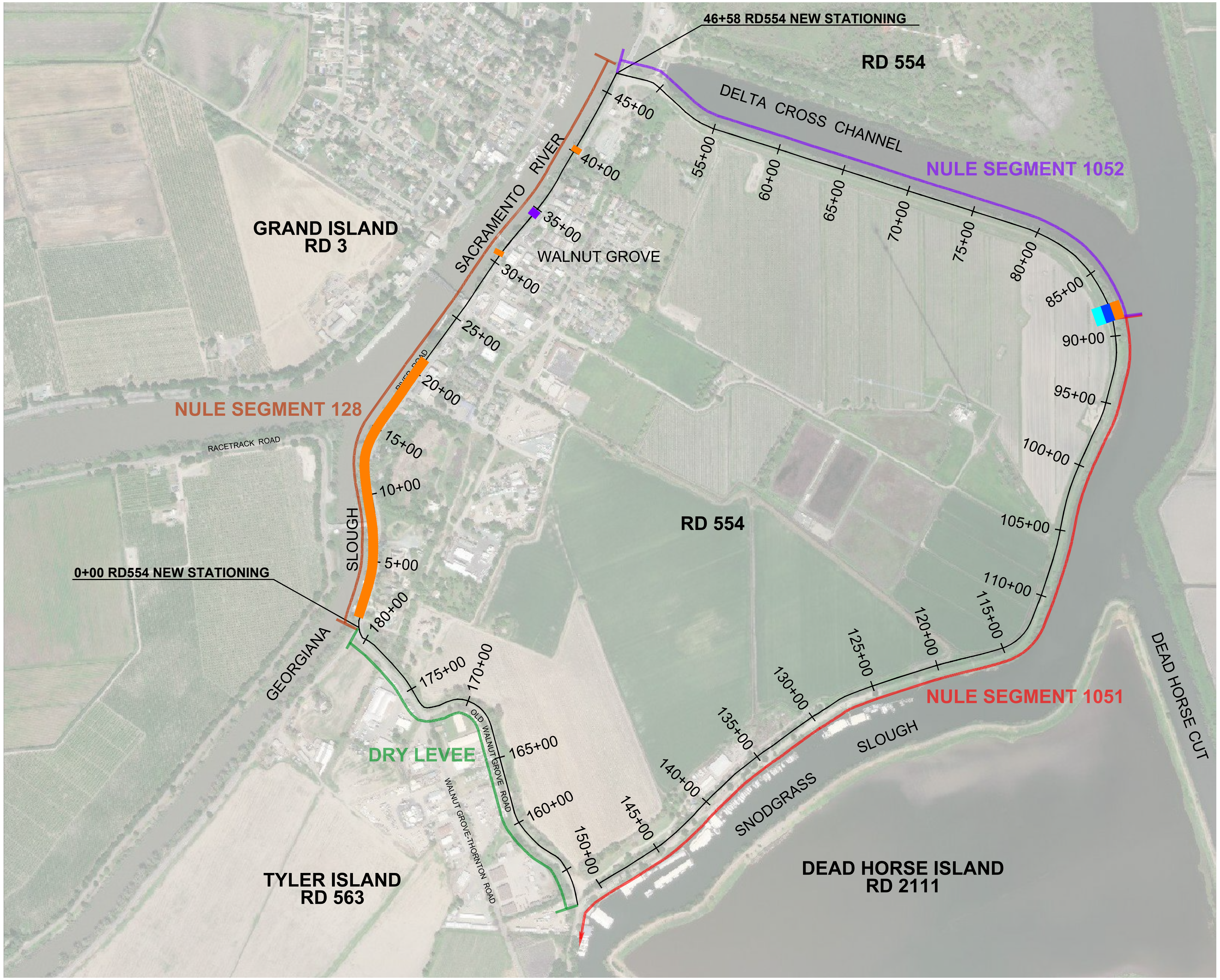
LEVEE HISTORY and IMPROVEMENTS
RD 554, East Walnut Grove
Walnut Grove, California

File No. 3139.x

March 2020

Figure 3

2/4/2020 3139.x Fig3 East Walnut Grove.dwg



N

SCALE 1" = 800'

LEGEND

🟧	Erosion
🟦	Underseepage
🟦	Depression and Landside Erosion
🟪	Toe Failure

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PAST PERFORMANCE ISSUES
RD 554, East Walnut Grove
Walnut Grove, California

File No. 3139.x

March 2020

Figure 4

2/4/2020 3139.x Fig4 East Walnut Grove.dwg

APPENDIX A

NULE GAR Segment Write-Ups

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

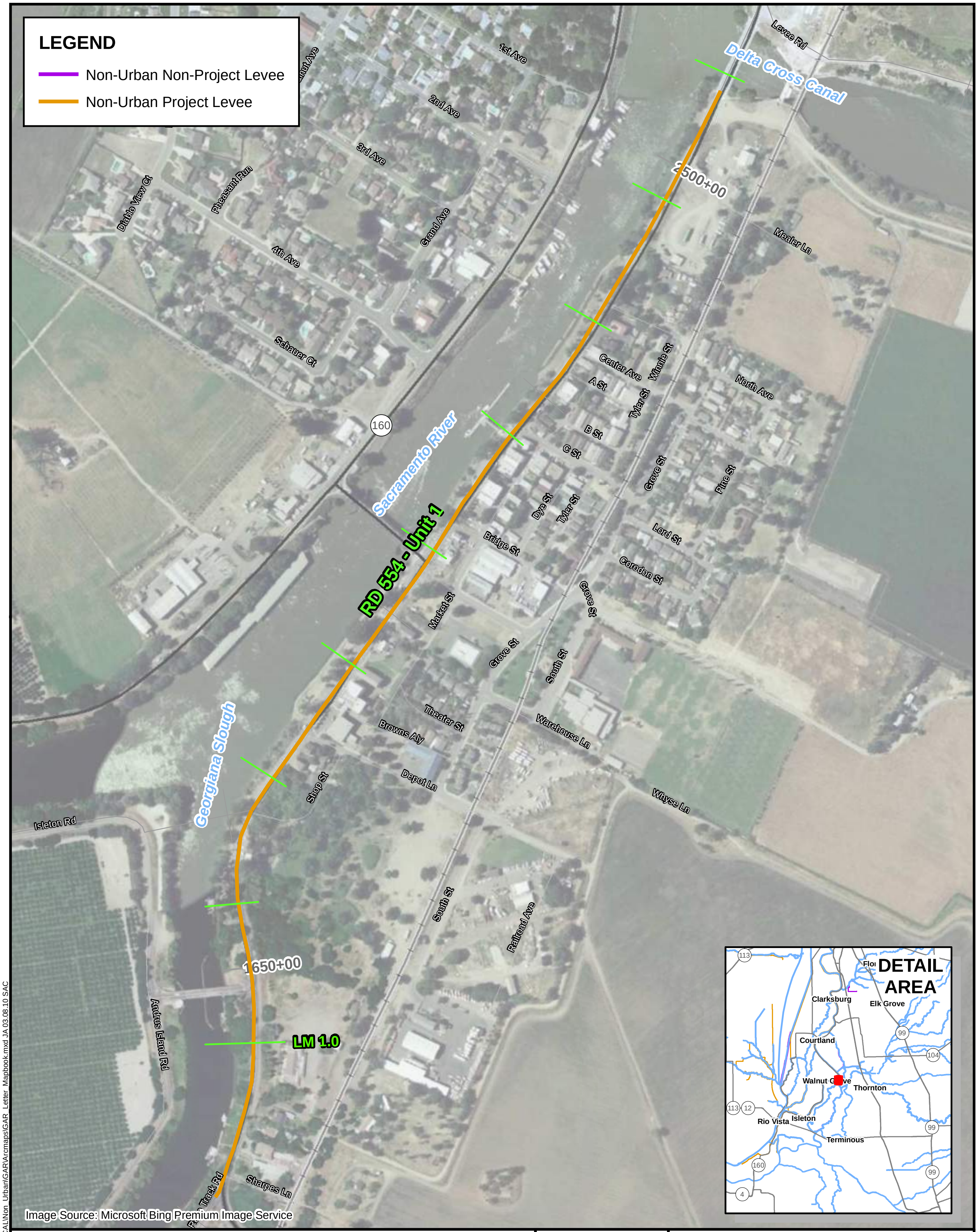
Using the LiDAR data, the levee geometry was compared with a standard levee prism defined by the Segment 128 1953 MOU geometric criteria. This check was performed by assessing whether the levee indicated by topography developed from the LiDAR data was larger than or equal to the standard levee prism 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.



0 250 500

Feet

N

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

L:\Projects\DWR\GEOTECHNICAL\Non Urban\GAR\Arcmaps\GAR Letter Mapbook.mxd JA 03.08.10 SAC

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

Levee Segment Name:	RD 0554 - south portion	
Levee Segment Number:	128	
Brief Description of Segment/Reach:	RD 0554 - Walnut Grove - south of Delta Cross Channel	
Local Maintenance Authority:	RD 0554	
Freeboard Evaluation Criterion (ft):	3	
Water Side Slope Design Criterion:	3H : 1V	Enter Other Criterion
Land Side Slope Design Criterion:	2H : 1V	Enter Other Criterion
North or South NULE?	North	

	Begin	End
NULE Station (ft):	2470+93	2502+38
Levee Mile:	0	0.9
Segment/Reach Length:	0.6 (miles)	3145 (feet)
Crest Width Design Criterion (ft):	20	
Design Guidance Document:	1953 MOU	
Project or Non-Project Levee?	Project	

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**		
		Rating (1 to 72)	**Ranking (out of 117)**		**Rating (1 to 47)**	**Ranking (out of 117)**	
Are there erosion occurrences compiled in the Ayres study?	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**					
		Rating (1 to 100)	**Ranking (out of 67)**				
Are there erosion occurrences compiled in the DWR study?							
	Comments:						

Past overtopping or near overtopping?:	Never overtopped	**Comments:**	N/A
Past breach in area?	None Identified	**Comments:**	N/A

HAZARD INDICATORS

I- LEVEE COMPOSITION - *at selected cross section* - Interpreted from Borings, Test Pits, field reconnaissance, NRCS maps, and analyst's interpretation of this assemblage of information

	Value (where applicable)	Best Estimate Rating	Minimum Credible Rating	Maximum Credible Rating	Explanation & Comments
Composition of levee material *for through seepage assessment*		*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 *for stability assessment*		*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 *for underseepage assessment*	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 *for stability assessment*	1:24,000	*1 - Not dispersive*	*1 - Not dispersive*	*1 - Not dispersive*	SAR map shows soils are likely not dispersive
Piping potential *for underseepage assessment*	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 *for through-seepage assessment*	1:24,000	*4 - High*	*2 - Low*	*4 - High*	Borings on levee on adjacent segments show sand and silt.
Soft soils *for stability assessment*	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? *for through-seepage assessment*		*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? *for underseepage assessment*	No ditch	1			0
Is a landside ditch or borrow pit present within 200 ft of toe? *for stability assessment*	No ditch	1			0
Is waterside blanket present? *for underseepage assessment*	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.		

IV- TOPOGRAPHIC & ELEVATION INFORMATION - *at selected cross section(s)*

	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**	
Report elevations in NAVD 88	**Value** (where applicable)	**Rating** [1 (good) to 5 (bad)]	**Value** (where applicable)	**Rating** [1 (good) to 5 (bad)]	**Value** (where applicable)	**Rating** [1 (good) to 5 (bad)]
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

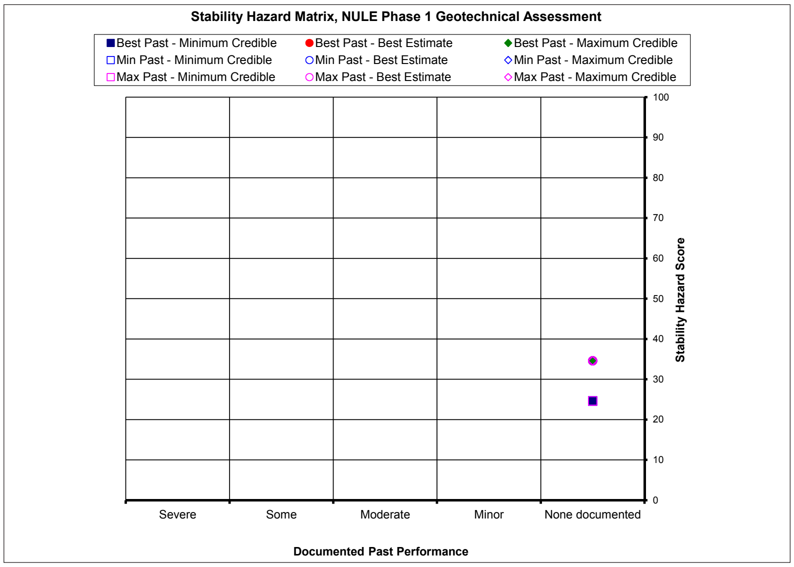
Existing constructed mitigation (List all)	Resloping and placement of rock revetment of Segment 128 occurred between LM 0.77 and LM 0.84 in 1972 (Doc-4261) and between LM 1.06 and LM 1.15 in 1984 (Doc-4261). Improvements also include riverbank protection work performed under the Sacramento River Bank 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?	None Identified	
If yes, describe nature of the breach and how it has been mitigated?		

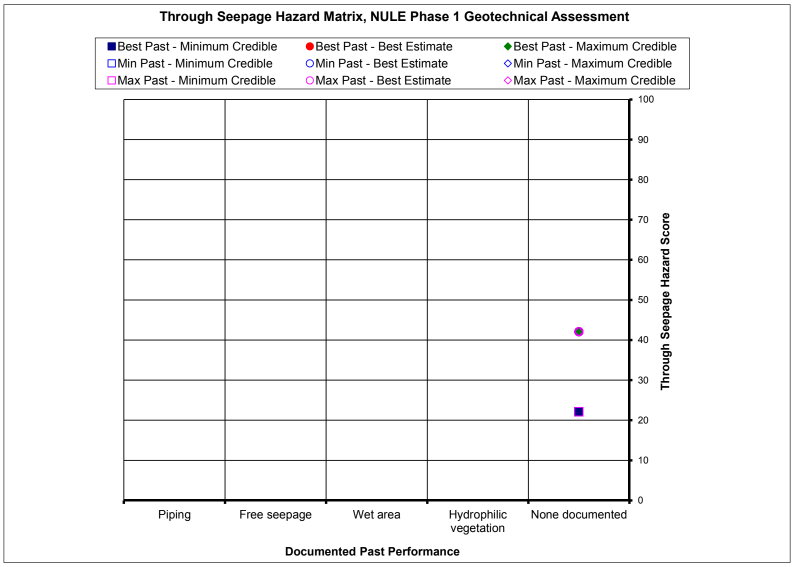
SUMMARY

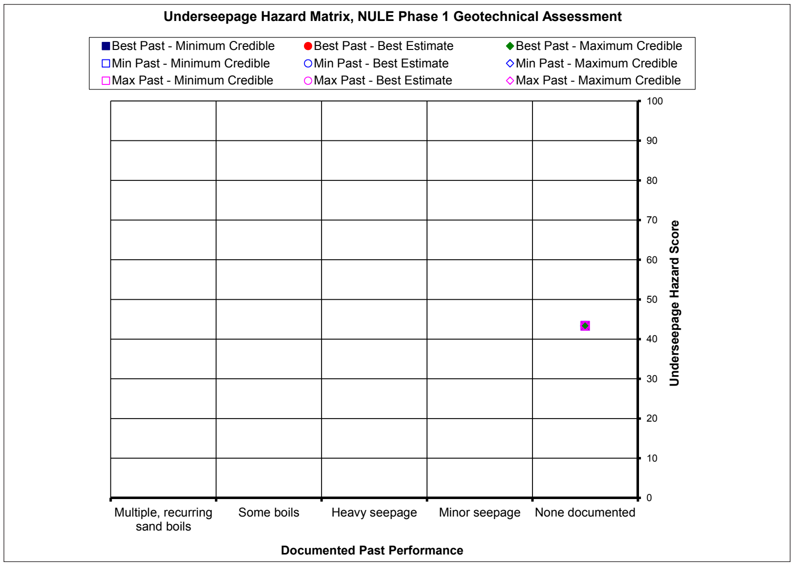
Failure Mode	**Weighted Hazard Indicator Score (Best)**	**Weighted Hazard Indicator Score (Minimum Credible)**	**Weighted Hazard Indicator Score (Maximum Credible)**	**Past performance issues?**	**Are past performance and Weighted Hazard Indicator Score consistent?**	**Levee categorization**
Underseepage	**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	Evaluation Date:	2/9/2010
Checked By:	TK	Check Date:	2/9/2010
Senior Reviewer:	Review Team	Review Date:	2/10/2010


Stability Hazard Matrix, NULE Phase 1 Geotechnical Assessment


Through Seepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment


Underseepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment

Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

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Segment 128 LAT Results
Geotechnical Assessment Report

NORTH NON-URBAN LEVEE EVALUATIONS

RD 0554/RD 0563, SEGMENT 1051 SUMMARY

This segment summary presents collected information and the assessment results for Segment 1051. The summary is based on available data at the time of assessment. The amount of detail available is variable. Known pertinent details are included. For information on the data collection and assessment procedures, see Volume 1, Section 2.0 of this report.

This summary is organized in 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 1051: Segment Description and Assessment Summary

Segment 1051 is a non-urban Non-Project levee on the right bank of Snodgrass Slough in Sacramento County, California. The segment extends from the confluence of the Mokelumne River and the Snodgrass Slough northward to the confluence of the Delta Cross Canal and the Snodgrass Slough. The following table summarizes segment information.

Segment 1051 Information

Maintenance Authority	Unit	Levee Miles	NULE Stationing
RD 0563	-	0 to 0.47	Snodgrass Slough Right Bank (SDSS-R) 1000+00 to 1025+00
RD 0554	-	0 to 1.21	Snodgrass Slough Right Bank (SDSS-R) 1025+00 to 1088+80

Since 1955/1957 design water surface elevation is not available, and as directed by DWR, the segment was assessed for each potential failure mode with water at 1.5 feet below the levee crest. The following table presents the Segment 1051 categorizations for each potential failure mode.

Segment 1051 Potential Failure Mode Assessment Summary

Potential Failure Mode	Categorization
Underseepage	LD (A, B or C)
Stability	LD (A, B or C)
Through Seepage	LD (A, B or C)
Erosion	Hazard Level A

Based on these NULE Phase 1 levee assessments, the potential failure mode categorizations for underseepage, stability and through seepage are all Lacking Sufficient Data. The categorization for erosion is Hazard Level A. If additional data were obtained, to resolve the LD's , the overall categorization for Segment 1051 would be Hazard Level A or Hazard Level B or Hazard Level C.

Segment 1051: Levee Segment History

Levee segment history described below is based on a review of documents 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

According to historical topographic maps (Isleton, 1:31,680), Segment 1051's levees were initially constructed by local interests prior to 1906. Specific documentation about construction methods was not available. The following table presents the 1953 MOU geometric criteria for Segment 1051.

Segment 1051 Geometric Criteria

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

Performance

Levee performance information was obtained from reviewed documents and interviews with maintenance personnel. According to the available information, there are no documented reports of erosion, overtopping, underseepage, through seepage or slope instability in Segment 1051.

Improvements

No documented improvements are available for Segment 1051.

Planned Improvements

According to available documents, no improvements to Segment 1051 are currently scheduled. RD 0554 is currently planning to evaluate and improve the levee between NULE Stations 1025+00 and 1088+80 to secure FEMA certification (Doc-8710).

Segment 1051: General Levee Conditions

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

Levee Geometry

Segment 1051 levee heights range from about 14 to 21 feet above the landside toe. Including rounded shoulders, crest width is approximately 20 to 35 feet and LiDAR survey data indicate the landside slopes are about 1.5H:1V to 2H:1V. The waterside slopes are approximately 1.5H:1V to 3H:1V. A ditch is near the landside toe of Segment 1051 from about NULE Station 1042+00 to the northern end of the segment. The ditch is unlined, is about 10 to 15 feet wide and varies from 1 to 5 feet deep.

Penetrations

According to available penetration information (Doc-8720, Doc-8824), seven pipes penetrate the segment.

Animal Activity

Animal activity was not reported in reviewed documents. However, animal activity was noted during an interview (Doc-8710). Animal activity control is part of the routine maintenance program. Animal persistence based on data from DWR is not available for Segment 1051.

Maintenance

DWR assessments were not available for Segment 1051.

Other Features

Segment 1051 has several ditches that are at an angle to the levee. The ditches are near NULE Stations 1042+50, 1048+50, 1059+00 and 1072+00.

Segment 1051: 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, review of other available geologic and soil maps, data contained in reports reviewed, and general knowledge of levee conditions in the area. This section summarizes the team’s understanding of geotechnical conditions in Segment 1051.

In Segment 1051, the levee foundation consists of organic clay, clay, sand and silt and the levees may consist of sand and silty sand.

Geomorphic Setting

According to the *Level 2-II Geomorphic Assessment*, Segment 1051 between NULE Stations 1032+00 and 1088+80 overlies basin deposits (fine sand, silt, and clay). The levee between NULE Stations 1000+00 and 1025+00 and between Stations 1026+00 and 1028+00 overlies recent overbank deposits (Rob) consisting of interbedded silt, sand and clay that likely interfinger with adjacent flood plain silt and clay sediments, and are likely to vary laterally in extent and character. Overbank deposits (silt, clay, and lesser sand) are mapped between NULE Stations 1028+00 and 1032+00. Slough deposits (silt, clay, and sand) are mapped between NULE Stations 1025+00 and 1026+00.

Geotechnical Investigations

Geotechnical investigation for Segment 1051 includes two borings from the 1992 North Delta Seepage Monitoring Study (Doc-8306). These borings were drilled near the landside levee toe to a depth of about 20 feet near NULE Stations 1037+00 and 1088+00. Boring logs indicate soil encountered in the foundation consist of organic clay underlain by clay, sand and silt. The foundation predominantly consists of about 12 feet of organic and inorganic clay underlain by layers of sand, silt and clay to the maximum explored depth of 20 feet. One of the borings noted “water flowed from the hole at 14 feet.”

Two borings drilled by USBR for the Delta Cross Canal at the east end of Segment 1052 near the northern end of Segment 1051 found a peaty silt layer at the ground surface about 4 feet thick underlain by interbedded sand, silt and clay layers.

Other Subsurface Information

The USCS soil map available for portions of Segment 1051 indicates the levee mostly overlies fine-grained materials (CH, CL-ML and CL). The USCS map does not indicate the variation of soil types shown in level 2-II mapping or the variation found in borings.

Levee Composition

Based on available geotechnical information and details obtained from the interview with the RD, Segment 1051 may consist of sand and silty sand (Doc-8710).

Segment 1051: Geotechnical Assessment Results

The overall Segment 1051 categorization is LD (A, B or C). As discussed in Volume 1, Section 2.0 of this report, the overall assessment is based on the individual potential failure mode categorizations. For this segment, the potential failure mode categorizations for underseepage, stability and through seepage are all Lacking Sufficient Data. The categorization for erosion is Hazard Level A. If additional data were obtained, to resolve the LD’s , the overall categorization for Segment 1051 would be Hazard Level A or Hazard Level B or Hazard Level C.

A WHIS was calculated for each potential failure mode at the assessment water surface elevation: the top of levee less 1.5 feet, based on identified geologic, geometric, and other hazards. A rating for past performance was assigned based on documented performance events. The categorizations for each potential failure mode are discussed below.

Underseepage

Segment 1051 Underseepage Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	**Minimum Credible**	**Maximum Credible**	**Best Estimate**	**Minimum Credible**	**Maximum Credible**	
78	65	79	None Documented	None Documented	None Documented	LD (A, B or C)

The levees in Segment 1051 are 14 to 21 feet high, resulting in a relatively high differential water head. The levee in the southern portion of the segment overlies overbank deposits that are highly susceptible to underseepage and the remaining levee overlies a 4- to 14-foot-thick organic clay that overlies interbedded layers of sand, silt and clay. The segment has no reported underseepage. Given inconsistency between the WHIS, which suggests that underseepage is likely to occur, and the absence of past reported underseepage, Segment 1051 is categorized as Lacking Sufficient Data for the underseepage potential failure mode. If additional data were obtained, to resolve the LD, underseepage failure mode would be Hazard Level A or Hazard Level B or Hazard Level C.

Stability

Segment 1051 Stability Assessment Results*

WHIS			Performance Summary			Categorization
Best Estimate	**Minimum Credible**	**Maximum Credible**	**Best Estimate**	**Minimum Credible**	**Maximum Credible**	
79	69	79	None Documented	None Documented	None Documented	LD (A, B or C)*

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

The Segment 1051 levee prism may consist of sand and silty sand, and a portion overlies organic clay. The levee height is up to 21 feet above the levee toe. The segment has no reported slope instability. Given inconsistency between the WHIS, which suggests that instability is likely to occur, and the absence of past performance data, Segment 1051 is categorized as Lacking Sufficient Data for the stability potential failure mode. If additional data were obtained, to resolve the LD, stability failure mode would be Hazard Level A or Hazard Level B or Hazard Level C.

Through Seepage

Segment 1051 Through Seepage Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	**Minimum Credible**	**Maximum Credible**	**Best Estimate**	**Minimum Credible**	**Maximum Credible**	
78	58	85	None Documented	None Documented	None Documented	LD (A, B or C)

Segment 1051 may consists of sand and silt. The levee is 14 to 21 feet high, resulting in relatively high differential water head between the assessment water surface elevation and the levee toe. The segment has no reported through seepage. Given inconsistency between the WHIS, which suggests that through seepage is likely to occur, and the absence of past through seepage, Segment 1051 is categorized as Lacking Sufficient Data for the through seepage failure mode. If additional data were obtained, to resolve the LD, through seepage failure mode would be Hazard Level A or Hazard Level B or Hazard Level C.

Erosion

Segment 1051 is categorized as Hazard Level A for erosion. The segment has no reported waterside erosion events. According to LiDAR data, minor erosion of the waterside slope may be occurring along about 20 percent of the segment.

Segment 1051: Other Levee Assessments

Freeboard

Freeboard was not assessed because a 1955/1957 water surface elevation was not available.

Overtopping

Overtopping was considered only based 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 overtopping risk to NULE Project levees. Documents indicate this levee segment overtopped in 1996. However, such overtopping was related to debris blocking flows under the Walnut Grove Thornton Bridge, raising water levels in Snodgrass Slough.

Geometry

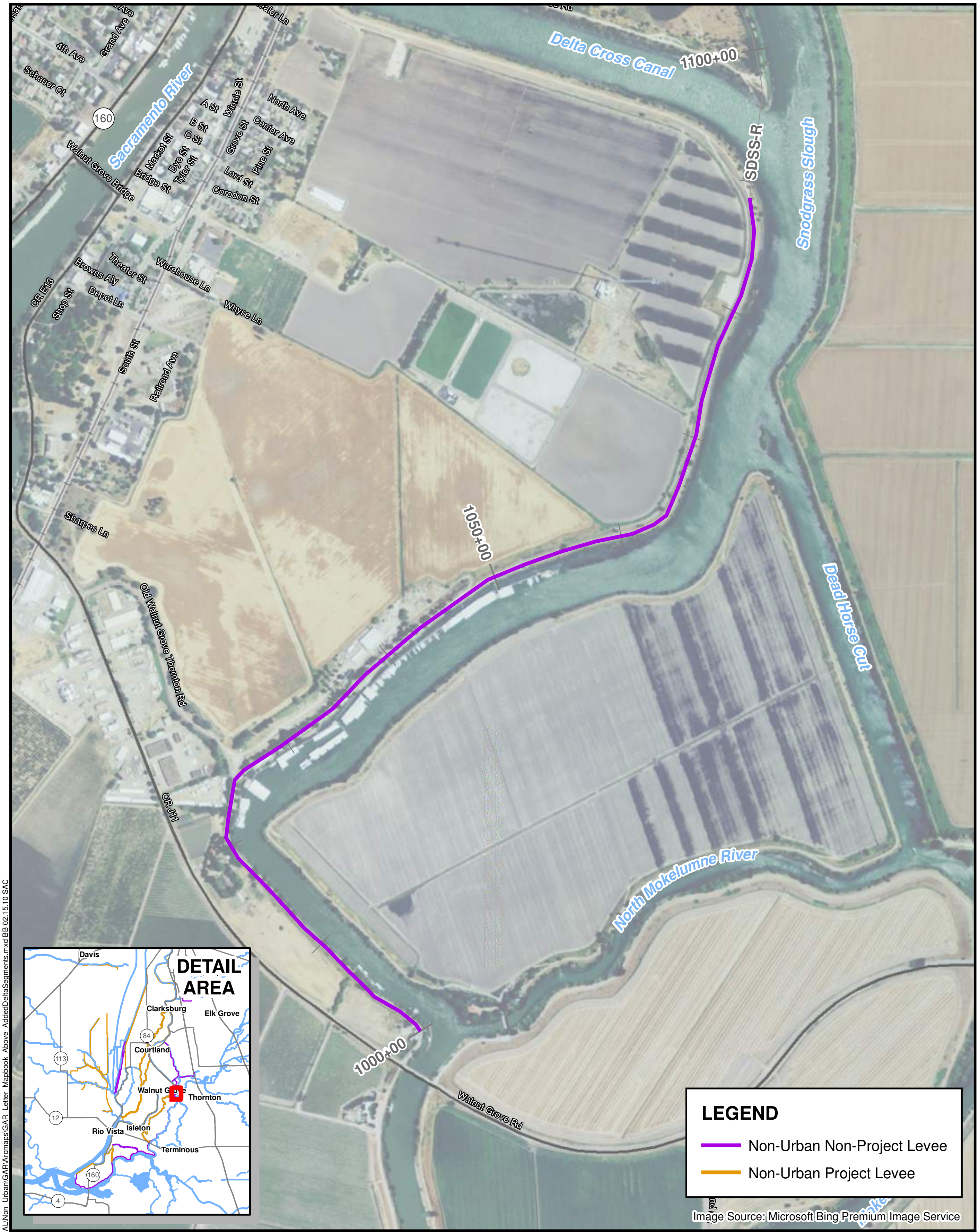
Using LiDAR data, Segment 1051 levee geometry was compared to a standard levee prism as defined by the 1953 MOU. This comparison assessed whether the levee, indicated by topography developed from LiDAR data, was larger than or equal to the standard levee prism at any given cross-section. Wide levees could meet this requirement even where levee slopes are steeper than those described in the 1953 MOU. For Segment 1051, approximately 75 percent of the levee is smaller than the standard levee prism.

Segment 1051: Hazard Mitigation

The following table identifies hazards for the levee segment and the estimated extent of the hazard. Comments are provided to help identify potential remedial requirements.

Segment 1051 Hazards

Hazard	Extent (percent)	Comments
Underseepage	100	Based on available boring data and Level 2-II Geomorphic Assessment, the segment is underlain mainly by overbank deposits at the south end and by a clay layer overlying interbedded sand, silt and clay deposits under the remainder of the segment.
Stability	60	Based on available boring Data and Level 2-II Geomorphic Assessment, the northern portion of the segment may be underlain by organic material.
Through Seepage	100	Levee may consist of sand and silty sand.



0 500 1,000

Feet

N

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Segment 1051

Geotechnical Assessment Report

NORTH NON-URBAN LEVEE EVALUATIONS

L:\Projects\DWR\GEOTECHNICAL\Non Urban\GAR\Arcmaps\GAR_Letter_Mapbook_Above_AddedDeltaSegments.mxd BB 02.15.10 SAC

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

Levee Segment Name:	Snodgrass Slough west bank levee south of Delta Cross Canal - Levee adjacent to	
Levee Segment Number:	1051	
Brief Description of Segment/Reach:	Snodgrass Slough west bank levee south of Delta Cross Canal - Levee adjacent to Segment 128	
Local Maintenance Authority:	RD 0563 and RD 0554	
Freeboard Evaluation Criterion (ft):	Not Applicable	
Water Side Slope Design Criterion:	3H : 1V	Enter Other Criterion
Land Side Slope Design Criterion:	2H : 1V	Enter Other Criterion
North or South NULE?	North	

	Begin	End
NULE Station (ft):	1000+00	1088+80
Levee Mile:	Enter	Enter
Segment/Reach Length:	1.7 (miles)	8880 (feet)
Crest Width Design Criterion (ft):	20	
Design Guidance Document:	1953 MOU	
Project or Non-Project Levee?	Non-Project	

LEVEE CONSTRUCTION

Describe what is known about construction of this levee segment:	Based on historical topographic maps (Isleton, 1:31,680), the Segment 1051 levees were initially constructed by local interests prior to 1906. Specific documentation of the construction methods for the levee were 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*	No reported past performance data
Landside slope stability		*None documented*	*None documented*	*None documented*	No reported past performance data
Through seepage		*None documented*	*None documented*	*None documented*	No reported past performance data

In addition to Ayres 2008/DWR 2009 studies, are there erosion occurrences identified in this study?	No	**If yes, please describe:**					
North NULE	**Erosion sites from the Ayres 2008 study**	**Ayres Methodology 2**			**Ayres Methodology 4**		
		Rating (1 to 72)	**Ranking (out of 117)**		**Rating (1 to 47)**	**Ranking (out of 117)**	
Are there erosion occurrences compiled in the Ayres study?	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**					
		Rating (1 to 100)	**Ranking (out of 67)**				
Are there erosion occurrences compiled in the DWR study?							
	Comments:						

Past overtopping or near overtopping?:	Overtopped	**Comments:**	One reported overtopping occurred in 1996.
Past breach in area?	None Identified	**Comments:**	N/A

HAZARD INDICATORS

I- LEVEE COMPOSITION - *at selected cross section* - Interpreted from Borings, Test Pits, field reconnaissance, NRCS maps, and analyst's interpretation of this assemblage of information

	Value (where applicable)	Best Estimate Rating	Minimum Credible Rating	Maximum Credible Rating	Explanation & Comments
Composition of levee material *for through seepage assessment*		*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 available information, the Segment 1051 levee may consist of sand and silty sand (Doc-8710).
Composition of levee material *for stability assessment*		*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 available boring Data (Doc-8306) and Level 2-II Geomorphic Assessment.

II- GEOLOGY - *at selected cross section*

	(Scale of mapping)				
Underseepage susceptibility *for underseepage assessment*	1:24,000	*5 - Very high*	*4 - High*	*5 - Very high*	Based on Level 2-II Geomorphic Assessment, the assessment section overlies overbank deposits.
Dispersive soils *for stability assessment*	1:24,000	*1 - Not dispersive*	*1 - Not dispersive*	*1 - Not dispersive*	SAR map shows soils are not likely dispersive.
Piping potential *for underseepage assessment*	1:24,000	*4 - High*	*2 - Low*	*5 - Very high*	Based on Level 2-II Geomorphic Assessment.
Piping potential *for through-seepage assessment*	1:24,000	*4 - High*	*2 - Low*	*5 - Very high*	Based on available information, the Segment 1051 levee may consist of sand and silty sand (Doc-8710).
Soft soils *for stability assessment*	1:24,000	*5 - Present*	*5 - Present*	*5 - Present*	Based on available boring data and Level 2-II Geomorphic Assessment.

III- OTHER INDICATORS - *at selected cross section*

Animal persistence/burrows? *for through-seepage assessment*		*2 -Low*	*2 -Low*	*3 - Medium*	Based on Interview, Animal control program exists for the segment.
Is a landside ditch or borrow pit present within 200 ft of toe? *for underseepage assessment*	No ditch	1			0
Is a landside ditch or borrow pit present within 200 ft of toe? *for stability assessment*	Ditch within 50 ft of toe	4			A ditch located at about 30 feet from landside levee toe.
Is waterside blanket present? *for underseepage assessment*	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:**	Based on the available penetration information, 7 pipes penetrate the levee segment.		
DWR's LMA maintenance rating from Maintenance Deficiency Summary Report:	LMA Not rated by DWR	**Notes:**	Non-project levee, not rated by DWR		

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Segment 1051 LAT Results
Geotechnical Assessment Report

NORTH NON-URBAN LEVEE EVALUATIONS

IV- TOPOGRAPHIC & ELEVATION INFORMATION - *at selected cross section(s)*

	Default cross section (used for Underseepage assessment)		Would you like to evaluate a different cross-section for **Stability**?	Yes	Would you like to evaluate a different cross-section for **Through Seepage**?	Yes
	Cross-section Station	1015+00	**Cross-section Station**	1070+00	**Cross-section Station**	1070+00
	Underseepage		**Stability**		**Through Seepage**	
Report elevations in NAVD 88	**Value** (where applicable)	**Rating** [1 (good) to 5 (bad)]	**Value** (where applicable)	**Rating** [1 (good) to 5 (bad)]	**Value** (where applicable)	**Rating** [1 (good) to 5 (bad)]
Levee crest elevation (ft)	17		21		21	
Levee toe elevation (landside) (ft)	1		0		0	
Levee crest width (ft)	22	1	20	1	20	1
Evaluation water elevation (ft)	15.5		19.5		19.5	
Levee slope - landside (xH : 1V); **Enter x**	2	3	1.6	5	1.6	5
Levee slope - waterside (xH : 1V); **Enter x**	2				1.8	
Freeboard above evaluation flood elevation (ft) (= levee crest elevation - evaluation water elevation)	1.5					
Levee height (ft) (= levee crest elevation - landside toe elevation)	16.0	4	21.0	5	21.0	5
Levee prism base width (ft)	86.0				91.4	
Head (ft) (= evaluation water level - landside toe elevation)	14.5	3	19.5	4	19.5	4
Head-to-base-width ratio (= head / base width)	0.169	4			0.2	5
Base-width to head ratio (= base width / head)	6				5	

V- ANOMALIES

	Anomalies?	Description	Effect on Performance
Underseepage	Yes	The segment has several ditches that are at an angle to the levee. The ditches are located near NULE stations 1042+50, 1048+50, 1059+00 and 1072+00.	Potential locations for underseepage
Stability	No	NA	NA
Through Seepage	No	NA	NA
Erosion	No	NA	NA

MITIGATION AND PAST BREACHES

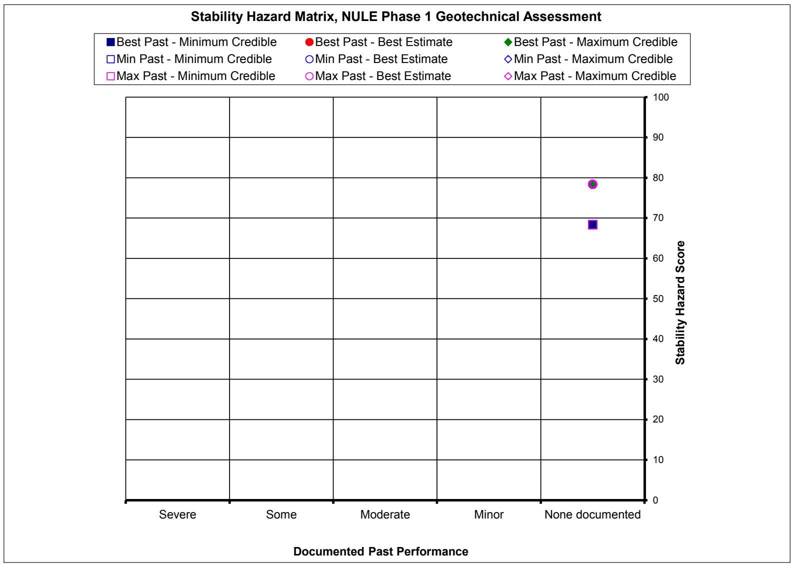
Existing constructed mitigation (List all)	Based on available documents, no documented improvements are available for Segment 1051.
Has there been a past breach?	None Identified
If yes, describe nature of the breach and how it has been mitigated?	

SUMMARY

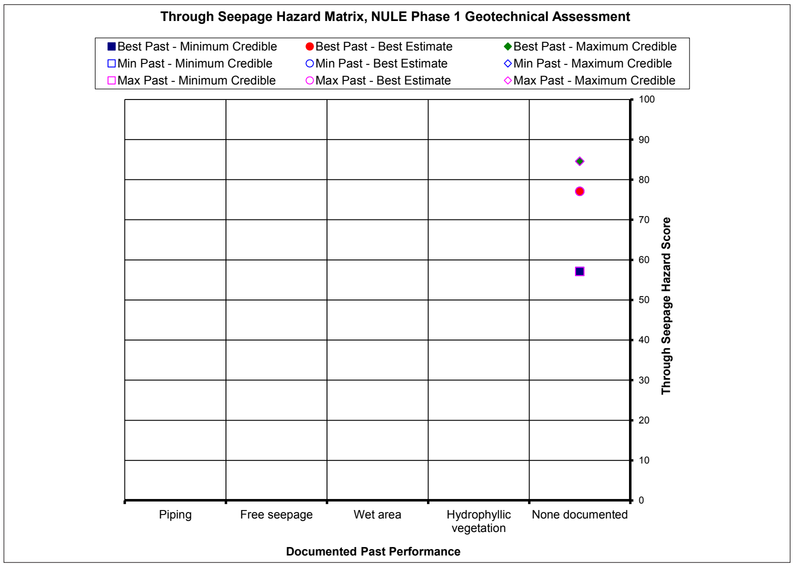
Failure Mode	Weighted Hazard Indicator Score (Best)	Weighted Hazard Indicator Score (Minimum Credible)	Weighted Hazard Indicator Score (Maximum Credible)	Past performance issues?	Are past performance and Weighted Hazard Indicator Score consistent?	Levee categorization
Underseepage	**78**	65	79	None documented	No	***Hazard Level LD***
Justification:	The segment has no reported underseepage. The high WHIS is inconsistent with reported past performance. Given the hazard indicators, and if additional data were obtained to resolve the LD, it would be LD (A, B or C).					
Suggested additional data:	Need to check the RDs for past performance data; do geotechnical investigation.					
Stability	**79**	69	79	None documented	No	***Hazard Level LD***
Justification:	The segment has no reported slope instability. The high WHIS is inconsistent with reported past performance. Given the hazard indicators, and if additional data were obtained to resolve the LD, it would be LD (A, B or C).					
Suggested additional data:	Need to check the RDs for past performance data; do geotechnical investigation.					
Through Seepage	**78**	58	85	None documented	No	***Hazard Level LD***
Justification:	The relatively high WHIS is inconsistent with the past performance data of no documented through seepage events. Given the hazard indicators, and if additional data were obtained to resolve the LD, it would be LD (A, B or C).					
Suggested additional data:	Need to confirm that the RD has no other reported past performance; do geotechnical investigation.					
Erosion				No		***Hazard Level A***
Justification:	The segment has no reported past performance data available for erosion. Based on LiDAR data, about 20% of the segment has minor erosion on the waterside slope.					
Suggested additional data:	N/A					

Freeboard Check	Does levee pass freeboard check?	**Not Applicable**	
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?	**No**	
Provide details about where along segment (and by how much) levee does not pass geometry check:	75% of the segment did not pass the geometry check. The locations where the segment did not pass the geometry check are NULE Stations 1012+50 to 1022+50 and 1032+50 to 1088+80.		
Are there anomalies along the segment with respect to geometry?	No	Describe anomalies:	0
Summary Characterization of Levee Segment	Hazard Level LD	**Comment / Justification:**	The categorizations for underseepage, stability and through-seepage are Lacking Sufficient Data. The categorization for erosion is Hazard Level A. Based on the estimated WHIS for underseepage, slope stability and through-seepage failure modes, the overall categorization for the segment is Lacking Sufficient Data. If additional data were obtained, it would be LD (A, B or C). Therefore, the overall categorization for the segment is Lacking Sufficient Data.

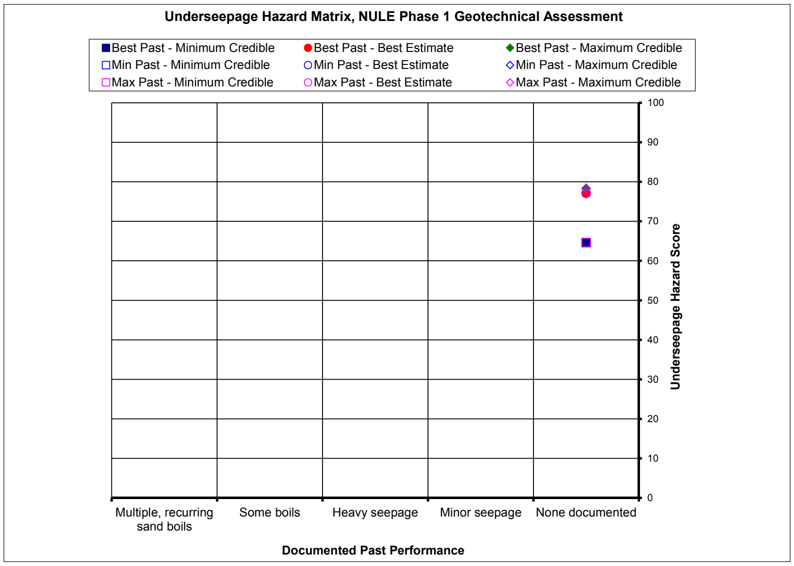
Evaluator:	Kanax	Evaluation Date:	10/16/2010
Checked By:	Sathish	Check Date:	10/16/2010
Senior Reviewer:	SP, DM, RC	Review Date:	2/10/2011



Stability Hazard Matrix, NULE Phase 1 Geotechnical Assessment



Through Seepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment



Underseepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment

UNITED STATES BUREAU OF RECLAMATION, SEGMENT 1052 SUMMARY

This segment summary presents collected information and the assessment results for Segment 1052. The summary is based on available data at the time of assessment. The amount of detail available is variable. Known pertinent details are included. For information about the data collection and assessment procedures, see Volume 1, Section 2.0 of this report.

This summary is organized in 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 1052: Segment Description and Assessment Summary

Segment 1052 is a non-urban Non-Project levee on the right (south) bank of Delta Cross Canal in Sacramento County, California. The segment extends from the confluence of the Snodgrass Slough and the Delta Cross Canal westward to the confluence of the Delta Cross Canal and the Sacramento River. The following table summarizes segment information.

Segment 1052 Information

Maintenance Authority	Unit	Levee Miles	NULE Stationing
USBR	-	0 to 0.80	Delta Cross Canal Right Bank (DCCN-R) 1000+00 to 1042+00

Since 1955/1957 design water surface elevation is not available, and as directed by DWR, the segment was assessed for each potential failure mode with water at 1.5 feet below the levee crest. The following table presents the Segment 1052 categorizations for each potential failure mode.

Segment 1052 Potential Failure Mode Assessment Summary

Potential Failure Mode	Categorization
Underseepage	Hazard Level B
Stability	LD (A or B)
Through Seepage	Hazard Level A
Erosion	Hazard Level B

Based on these NULE Phase 1 levee assessments, underseepage and erosion are Hazard Level B. Through seepage is Hazard Level A. Stability is categorized as Lacking Sufficient

Data. If additional data were obtained, it is very unlikely that the LD for stability failure mode would be categorized as Hazard Level C. Because at least one of the segment’s other failure modes is already categorized as Hazard Level B, and the LD failure mode would not be categorized as Hazard Level C, the overall categorization for the segment is Hazard Level B.

Segment 1052: Levee Segment History

Levee segment history described below is based on a review of documents 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

The Delta Cross Canal is a controlled diversion canal between the Sacramento River and Snodgrass Slough. This canal was constructed in 1949 by USBR as part of the Central Valley Project. The canal has a bottom width of 210 feet and a capacity of 3,500 cubic feet per second. Flow in the canal is controlled by radial gates near the Sacramento River (Doc-8711).

According to the specifications for construction, suitable materials from canal excavation were used for levee construction. It was also specified that “if canal excavation at any section does not furnish sufficient suitable material for embankments the contacting officer will designate where additional material shall be procured.” It could not be determined whether additional materials were procured. The construction drawings and specifications note that the waterside portion of the embankment was compacted and the landside portions were not compacted.

According to a USBR staff, the embankment consists of sand, gravel, and clay. The canal embankment’s waterside slopes were designed to 3H:1V and the landside slopes were designed to 2H:1V. No major rehabilitations have been performed on the canal embankment (Doc-8711).

The following table presents the 1953 MOU geometric criteria for Segment 1052.

Segment 1052 Geometric Criteria

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

Performance

Levee performance information was obtained from reviewed documents and interviews with maintenance personnel. According to the available information, performance events in Segment 1052 include erosion reported in 2004 and 2010, underseepage reported in 2006 and depressions observed in 2010. There are no documented reports of overtopping, slope instability or through seepage. The following table summarizes reported performance events.

Segment 1052 Reported Levee Performance Events

Flood Season	Reported Performance Event	Approximate Location (NULE Station)	Mitigation
2010	Multiple erosion locations observed during the field reconnaissance performed in December 2010 (Doc-8711).	1016+00 - 1042+00	Not performed
2010	Depression and landside erosion observed during the field reconnaissance in December 2010 (Doc-8711).	Near 1022+00	Not performed
2006	Seepage observed by USBR engineer on Jan 25, 2006. (USBR Documentation)	Near 1015+00	Not documented
2004	Three erosion sites were identified and mitigated in 2004 (Doc-8711, USBR Documentation).	Three locations between Stations 1015+00 and 1020+00.	Rock slope revetment placed in 2004.
1985	Two erosion locations were repaired in 1985 (USBR Documentation).	Approximately Between 1005+00 and1010+00 And approximately between 1025+00 and 1030+00	Riprap was placed .

Underseepage

Segment 1052 has one reported underseepage site near NULE Station 1015+00 (Doc-8711). This seepage was observed by a USBR engineer on January 25, 2006 and was reported as “The line of seeps was only a foot above the ditch water level, with the wet spot extending 2 or more feet above the ditch water level. There was a slight flow but nothing boiling“ (USBR documentation).

Erosion

Segment 1052 has three reported erosion sites between NULE Stations 1016+00 and 1042+00 (Doc-8711). None of the erosion events were described as affecting the levee crown. Rock slope revetment was placed at identified erosion sites between NULE Stations 1015+00 and 1020+00 in 2004 (Doc-8711).

Two erosion sites (approximately between NULE Stations 1005+00 and 1010+00, and approximately between NULE Stations 1025+00 and 1030+00) were repaired in 1985 by placing riprap along the waterside slope (USBR documentation).

Anomalies

In 2010, a localized depression and landside erosion were observed during field reconnaissance near NULE Station 1022+00 (Doc-8711).

Improvements

According to available documents, a rock slope revetment was placed between NULE Stations 1015+00 and 1020+00 in 2004 (Doc-8711) and erosion repairs were performed as part of the 1985 Levee Erosion Control Plan approximately between NULE Stations 1005+00 and 1010+00, and approximately between NULE Stations 1025+00 and 1030+00.

Planned Improvements

According to the available documents, no improvements to Segment 1052 are currently scheduled.

Segment 1052: General Levee Conditions

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

Levee Geometry

Segment 1052 levee heights range from about 15 to 21 feet above the landside toe. Including rounded shoulders, crest width ranges from 15 to 20 feet and LiDAR survey data indicate the landside slope is about 1.7H:1V to 2H:1V. The waterside slope is approximately 2.8H:1V to 3.5H:1V. A ditch is near the landside toe of Segment 1052 from about NULE Station 1000+00 to 1033+00. The ditch is unlined, is about 5 to 10 feet wide, and varies from about 2 to 3 feet deep.

Penetrations

Information about penetrations through the segment was not available.

Animal Activity

Animal burrows were observed during field reconnaissance performed in December 2010 (Doc-8711). Animal persistence based on data from DWR is not available for Segment 1052.

Maintenance

DWR assessments were not available for Segment 1052.

Other Features

Segment 1052 has one ditch that is at an angle to the levee near NULE Station 1007+00. A pump station is near NULE Station 1035+00. A railroad bridge is near NULE Station 1039+00. There is a radial gate structure near NULE Station 1039+00. The River Road Bridge is at the west end of the segment.

Segment 1052: 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, review of other available geologic and soil maps, data contained in reports reviewed, and general knowledge of levee conditions in the area. This section summarizes the team's understanding of geotechnical conditions in Segment 1052.

In Segment 1052, the levee foundation consists mainly of clay and loam overlying interbedded sand, silt and clay. The levees may be composed of sand, gravel, and clay.

Geomorphic Setting

According to the *Level 2-II Geomorphic Assessment*, Segment 1052 between NULE Stations 1005+00 and 1026+00 overlies basin deposits (fine sand, silt, and clay). The levee between NULE Stations 1031+00 and 1042+00 overlies recent overbank deposits consisting of interbedded silt, sand and clay that likely interfinger adjacent flood plain silt and clay sediments and are likely to vary laterally in extent and character. Overbank deposits (silt, clay, and lesser sand) are mapped between NULE Stations 1026+00 and 1031+00. Overflow channel deposits (sand, silt, and clay) are mapped between NULE Stations 1000+00 and 1005+00.

Geotechnical Investigations

Seventeen borings were drilled by USBR as part of Delta Cross Canal construction. Six of these borings were drilled along the proposed centerline of Segment 1052. The borings range in depth from 15 to 100 feet. According to the stick logs for the six borings, soil in the foundation consists of a 3- to 4-foot-thick loam and peaty silt layers overlying 2 to 12 feet of clay overlying interbedded layers of sand, silt and clay. Two of the stick logs at the east end of the segment show 4-foot thick peaty silt layer at the ground surface.

Other Subsurface Information

The USCS soil map available for portions of Segment 1052 indicates the existing levee mostly overlies fine-grained materials (CH, CL-ML and CL). The NRCS USCS map does not indicate the variation of soil types shown in level 2-II mapping.

Levee Composition

Available data indicate that Segment 1052 may consist of sand, gravel, and clay (Doc-8711).

Segment 1052: Geotechnical Assessment Results

Segment 1052's overall categorization is Hazard Level B. As discussed in Volume 1, Section 2.0 of this report, the overall assessment is based on the individual potential failure mode categorizations. For this segment, underseepage and erosion are Hazard Level B. Through seepage is Hazard Level A. Stability is categorized as Lacking Sufficient Data. If additional data were obtained, it is very unlikely that the LD for stability failure mode would be categorized as Hazard Level C. Because at least one of the segment's other failure modes is already categorized as Hazard Level B, and the LD failure mode would not be categorized as Hazard Level C, the overall categorization for the segment is Hazard Level B.

A WHIS was calculated for each potential failure mode at the assessment water surface elevation, the top of levee less 1.5 feet, based on identified geologic, geometric, and other hazards. A rating for past performance was assigned based on documented performance events. The categorizations for each potential failure mode are discussed below.

Underseepage

Segment 1052 Underseepage Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	Minimum Credible	Maximum Credible	Best Estimate	Minimum Credible	Maximum Credible	
78	65	79	Heavy seepage	Minor seepage	Heavy seepage	Hazard Level B

The levee in Segment 1052 is 15 to 21 feet high, resulting in relatively high differential water head. The levee overlies overbank and basin deposits that are highly susceptible to underseepage. Available boring data also show a possible thin blanket condition along the entire segment. The segment has one reported underseepage event that was described as seepage and slight flow observed on the slope of the toe ditch. Given the consistency between the WHIS, which suggests that underseepage is likely to occur, and the presence of past reported underseepage, Segment 1052 is categorized as Hazard Level B for the underseepage potential failure mode.

Stability

Segment 1052 Stability Assessment Results*

WHIS			Performance Summary			Categorization
Best Estimate	Minimum Credible	Maximum Credible	Best Estimate	Minimum Credible	Maximum Credible	
60	40	65	None Documented	None Documented	None Documented	LD (A or B)

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

Segment 1052 may overlie organic soils. The levee height is up to 21 feet above the levee toe. The segment has no reported past slope instability occurrences. Given the inconsistency between the WHIS, which suggests that instability is likely to occur, and the absence of past performance data, Segment 1052 is categorized as Lacking Sufficient Data for the stability potential failure mode. Given the hazard indicators, and if additional data were obtained to resolve the LD, it is very unlikely that the additional data would result in re-categorization to Hazard Level C.

Through Seepage

Segment 1052 Through Seepage Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	**Minimum Credible**	**Maximum Credible**	**Best Estimate**	**Minimum Credible**	**Maximum Credible**	
55	43	63	None Documented	None Documented	None Documented	Hazard Level A

Segment 1052 may be composed of sand, gravel, and clay. The levee composition of sand and gravel would suggest that through seepage could occur. However, the waterside of the levees are engineered fill (i.e. fills that were placed in horizontal lifts, moisture conditioned and compacted). The levees are 15 to 21 feet high. The segment has no reported through seepage. Given the consistency between the WHIS and the absence of past through seepage, Segment 1052 is categorized as Hazard Level A for the through seepage failure mode.

Erosion

Segment 1052 is categorized as Hazard Level B for erosion. The segment has multiple reported erosion events reported in 1985, 2004 and 2010. However, none of the erosion events were described as affecting the levee crown. According to LiDAR data, erosion of the waterside slope may be occurring along about 10 percent of the segment.

Segment 1052: Other Levee Assessments

Freeboard

Freeboard was not assessed because a 1955/1957 water surface elevation was not available.

Overtopping

Overtopping was considered only based 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 overtopping risk to NULE Project levees. According to on available documents, this levee segment has not overtopped in the past.

Geometry

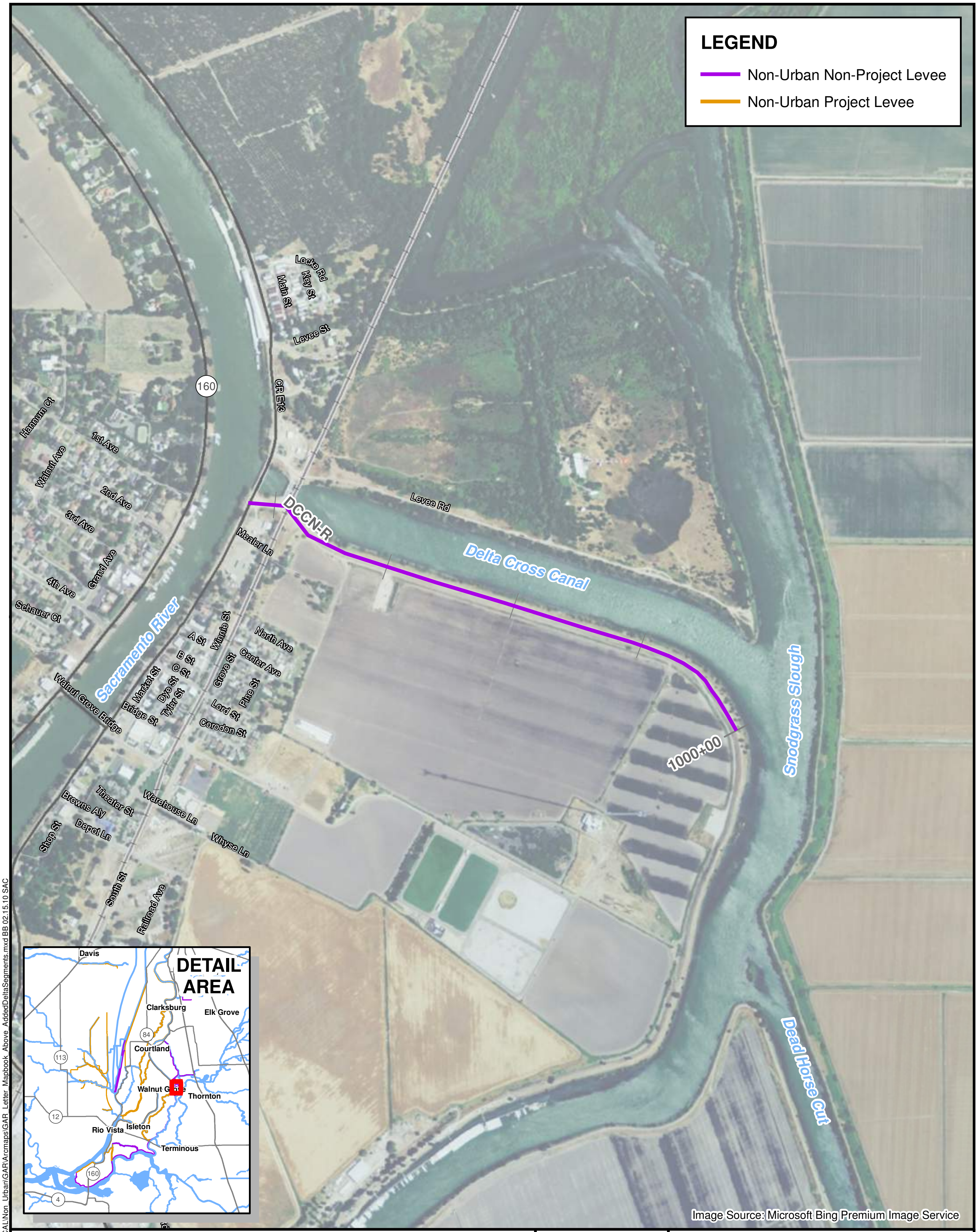
Using LiDAR data, Segment 1052 levee geometry was compared to a standard levee prism as defined by the 1953 MOU. This comparison assessed whether the levee, indicated by topography developed from LiDAR data, was larger than or equal to the standard levee prism at any given cross-section. Wide levees could meet this requirement even where levee slopes are steeper than those described in the 1953 MOU. For Segment 1052, approximately 35 percent of the levee is smaller than the standard levee prism.

Segment 1052: Hazard Mitigation

The following table identifies hazards for the levee segment and the estimated extent of the hazard. Comments are provided to assist with identifying potential remedial requirements.

Segment 1052 Hazards

Hazard	Extent (percent)	Comments
Underseepage	100	Based on Level 2-II Geomorphic Assessment and boring data, the levee has high potential for underseepage.
Stability	30	Based on available boring data and Level 2-II Geomorphic Assessment, levees on eastern end of the segment may be underlain by organic material.
Erosion	10	Based on the LiDAR data, erosion of the waterside slope may be occurring along about 10 percent of the segment.



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Feet

N

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Segment 1052

Geotechnical Assessment Report

NORTH NON-URBAN LEVEE EVALUATIONS

L:\Projects\DWR\GEOTECHNICAL\Non_Urban\GAR\Arcmaps\GAR_Letter_Mapbook_Above_AddedDeltaSegments.mxd BB 02.15.10 SAC

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

Levee Segment Name:	Delta Cross Canal south bank levee - Levee adjacent to Segment 128	
Levee Segment Number:	1052	
Brief Description of Segment/Reach:	Delta Cross Canal south bank levee - Levee adjacent to Segment 128	
Local Maintenance Authority:	USBR	
Freeboard Evaluation Criterion (ft):	Not Applicable	
Water Side Slope Design Criterion:	3H : 1V	Enter Other Criterion
Land Side Slope Design Criterion:	2H : 1V	Enter Other Criterion
North or South NULE?	North	

	Begin	End
NULE Station (ft):	1000+00	1042+00
Levee Mile:	Enter	Enter
Segment/Reach Length:	0.8 (miles)	4200 (feet)
Crest Width Design Criterion (ft):	20	
Design Guidance Document:	1953 MOU	
Project or Non-Project Levee?	Non-Project	

LEVEE CONSTRUCTION

Describe what is known about construction of this levee segment:	The Delta Cross Canal is a controlled diversion canal between the Sacramento River and Snodgrass Slough. This canal was constructed in 1949 by USBR as part of Central Valley Project. Based on the specifications the suitable material from the canal excavation were used for the construction of the levee. Based on the construction drawings and specifications it was noted that the waterside portion of the embankment was compacted and the landside portions were not compacted. According to a Reclamation staff, the embankment material consists of sand, gravel, and clay. A dirt service road is present on the embankment and at the embankment toe. According to a Reclamation staff, the embankment material consists of sand, gravel, and clay. The waterside and landside slopes of the canal embankment were designed as 3H:1V and 2H:1V respectively. No major rehabilitations have been performed on the canal embankment (Doc-8711).

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		*Heavy seepage*	*Minor seepage*	*Heavy seepage*	No reported past performance data
Landside slope stability		*None documented*	*None documented*	*None documented*	The segment has no documented slope instability.
Through seepage		*None documented*	*None documented*	*None documented*	Seepage in 2006 was reported as "The line of seeps was only a foot above the ditch water level, with the wet spot extending 2 or more feet above the ditch water level. There was a slight flow but nothing boiling." (USBR Documentation)

In addition to Ayres 2008/DWR 2009 studies, are there erosion occurrences identified in this study?	Yes	**If yes, please describe:**	Segment has multiple reported erosion sites between NULE Stations 1015+00 and 1042+00. None of the sites were described as affecting the levee crown (Doc - 8711)				
North NULE	**Erosion sites from the Ayres 2008 study**	**Ayres Methodology 2**			**Ayres Methodology 4**		
		Rating (1 to 72)	**Ranking (out of 117)**		**Rating (1 to 47)**	**Ranking (out of 117)**	
Are there erosion occurrences compiled in the Ayres study?	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**					
		Rating (1 to 100)	**Ranking (out of 67)**				
Are there erosion occurrences compiled in the DWR study?							
	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
I- LEVEE COMPOSITION - *at selected cross section* - Interpreted from Borings, Test Pits, field reconnaissance, NRCS maps, and analyst's interpretation of this assemblage of information					
Composition of levee material *for through seepage assessment*		*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*	*2 - SC, CL-ML, CL (LL<35); (non dispersive);soils are generally somewhat clayey with relatively low permeability such as clayey sand or clayey silt, lean sandy clay or lean clay with liquid limits less than 35.*	*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*	Based on available construction information (Doc- 8711).
Composition of levee material *for stability assessment*		*2 - SM, ML, clean gravels; soils are silty sands or sandy silts*	*2 - SM, ML, clean gravels; soils are silty sands or sandy silts*	*3- soils are more clayey than category 1 soils, with liquid limits greater than 35 and less than 50*	Based on available construction information (Doc- 8711).
II- GEOLOGY - *at selected cross section*	**(Scale of mapping)**				
Underseepage susceptibility *for underseepage assessment*	1:24,000	*5 - Very high*	*4 - High*	*5 - Very high*	Based on Level 2-II Geomorphic Assessment, the assessment section overlies overbank deposits; Boring data also shows thin blanket conditions.
Dispersive soils *for stability assessment*	1:24,000	*1 - Not dispersive*	*1 - Not dispersive*	*1 - Not dispersive*	SAR map shows soils are not likely dispersive.
Piping potential *for underseepage assessment*	1:24,000	*4 - High*	*2 - Low*	*5 - Very high*	Based on Level 2-II Geomorphic Assessment, and available boring data.
Piping potential *for through-seepage assessment*	1:24,000	*4 - High*	*2 - Low*	*5 - Very high*	Based on Level 2-II Geomorphic Assessment, and available boring data.
Soft soils *for stability assessment*	1:24,000	*5 - Present*	*1 - Not present*	*5 - Present*	Based on available boring data and Level 2-II Geomorphic Assessment.
III- OTHER INDICATORS - *at selected cross section*					
Animal persistence/burrows? *for through-seepage assessment*		*3 - Medium*	*3 - Medium*	*4 - High*	Animal burrows were observed during the field reconnaissance performed in December 2010 (Doc 8711).
Is a landside ditch or borrow pit present within 200 ft of toe? *for underseepage assessment*	No ditch	1			0
Is a landside ditch or borrow pit present within 200 ft of toe? *for stability assessment*	Ditch within 50 ft of toe	4			A ditch located within 50 ft from the landside levee toe.
Is waterside blanket present? *for underseepage assessment*	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:	1 - None documented	**Notes:**	Information regarding penetrations through the levee segment was not available.		
DWR's LMA maintenance rating from Maintenance Deficiency Summary Report:	LMA Not rated by DWR	**Notes:**	Non-project levee, not rated by DWR		

Segment 1052 LAT Results
Geotechnical Assessment Report

IV- TOPOGRAPHIC & ELEVATION INFORMATION *- at selected cross section(s)*

	Default cross section (used for Underseepage assessment)		Would you like to evaluate a different cross-section for **Stability**?	Yes	Would you like to evaluate a different cross-section for **Through Seepage**?	No
	Cross-section Station	1035+00	**Cross-section Station**	1000+00	**Cross-section Station**	1000+00
	Underseepage		**Stability**		**Through Seepage**	
Report elevations in NAVD 88	**Value** (where applicable)	**Rating** [1 (good) to 5 (bad)]	**Value** (where applicable)	**Rating** [1 (good) to 5 (bad)]	**Value** (where applicable)	**Rating** [1 (good) to 5 (bad)]
Levee crest elevation (ft)	22		20			
Levee toe elevation (landside) (ft)	6		2			
Levee crest width (ft)	17	2	17	2		
Evaluation water elevation (ft)	20.5		18.5			
Levee slope - landside (xH : 1V); **Enter x**	2	3	1.8	4		
Levee slope - waterside (xH : 1V); **Enter x**	2.8					
Freeboard above evaluation flood elevation (ft) (= levee crest elevation - evaluation water elevation)	1.5					
Levee height (ft) (= levee crest elevation - landside toe elevation)	16.0	4	18.0	4		
Levee prism base width (ft)	93.8					
Head (ft) (= evaluation water level - landside toe elevation)	14.5	3	16.5	4		
Head-to-base-width ratio (= head / base width)	0.155	4				
Base-width to head ratio (= base width / head)	6					

V- ANOMALIES

	Anomalies?	Description	Effect on Performance
Underseepage	Yes	The segment has one ditch that is at an angle to the levee that is, and located near NULE Station 1007+00.	Potential location for underseepage
Stability	No	NA	NA
Through Seepage	No	NA	NA
Erosion	No	NA	NA

MITIGATION AND PAST BREACHES

Existing constructed mitigation (List all)	Based on available documents, a rock slope revetment was placed between NULE Station 1015+00 and 1020+00 in 2004 (Doc 8711) and erosion repairs were performed as part of the 1985 Levee Erosion Control Plan approximately between NULE Stations 1005+00 and1010+00 and approximately between NULE Stations 1025+00 and 1030+00.
Has there been a past breach?	None Identified
If yes, describe nature of the breach and how it has been mitigated?	

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	**78**	65	79	Heavy seepage	Yes	***Hazard Level B***
Justification:	The segment has one reported underseepage. The high WHIS is consistent with reported past performance.					
Suggested additional data:	N/A					
Stability	**60**	40	65	None documented	No	***Hazard Level LD***
Justification:	The segment has no documented slope instability occurrences in the past. However, the estimated WHIS is relatively high. Given the hazard indicators, and if additional data were obtained to resolve the LD, it is very unlikely the additional data would result in a re-categorization to Hazard Level C.					
Suggested additional data:	Field investigation to better characterize levee and foundation materials.					
Through Seepage	**55**	43	63	None documented	Yes	***Hazard Level A***
Justification:	The estimated WHIS is consistent with the past performance data of no reported through seepage.					
Suggested additional data:	N/A					
Erosion				Yes		***Hazard Level B***
Justification:	The segment has multiple reported erosion events reported in 1985, 2004 and 2010. However, none of the erosion events were described as affecting the levee crown.					
Suggested additional data:	N/A					

Freeboard Check	Does levee pass freeboard check?	**Not Applicable**	
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?	**No**	
Provide details about where along segment (and by how much) levee does not pass geometry check:	35% of the segment did not pass the geometry check. The locations where the segment did not pass the geometry check are NULE Stations 1002+50 to 1007+50, and 1022+50 to 1037+50.		
Are there anomalies along the segment with respect to geometry?	No	Describe anomalies:	0
Summary Characterization of Levee Segment	Hazard Level B	**Comment / Justification:**	For this segment, the potential failure mode categorization for underseepage and erosion were Hazard Level B. The categorization for stability and through seepage are Hazard Level A and LD (A or B), respectively. This results in an overall categorization of Hazard Level B. If additional data were obtained, it is very unlikely that the LD for stability would be categorized as Hazard Level C. Because at least one of the segment's other failure modes is already categorized as Hazard Level B, and the LD failure mode would not be categorized as Hazard Level C, the overall categorization for the segment is Hazard Level B.

Evaluator:	Kanax	Evaluation Date:	2/9/2011
Checked By:	Sathish	Check Date:	2/9/2011
Senior Reviewer:	SP, DM, RC	Review Date:	2/10/2011

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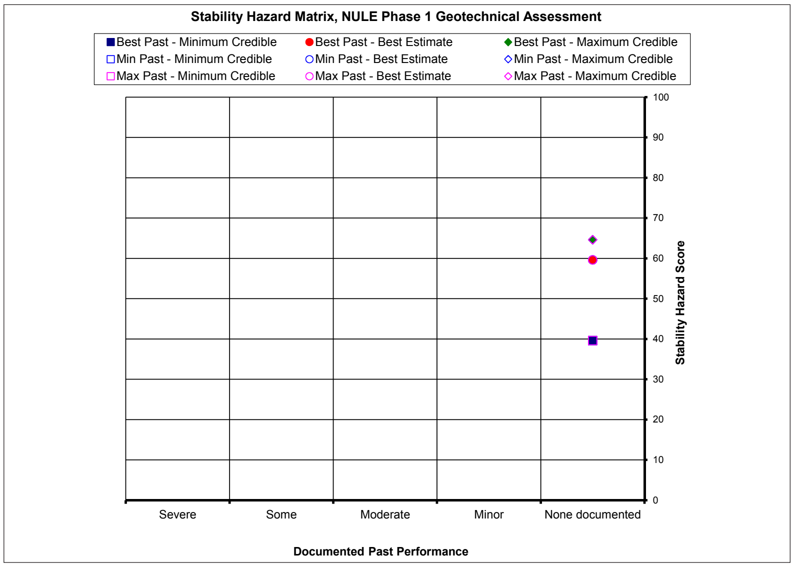
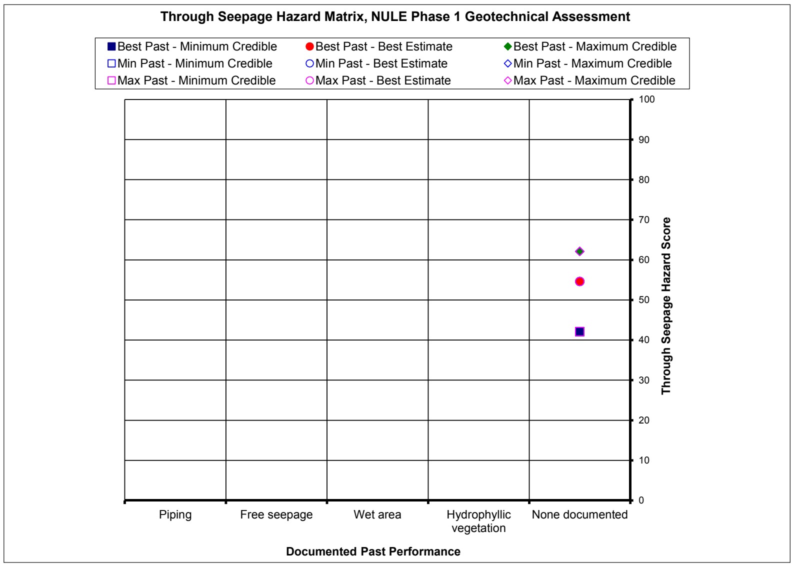
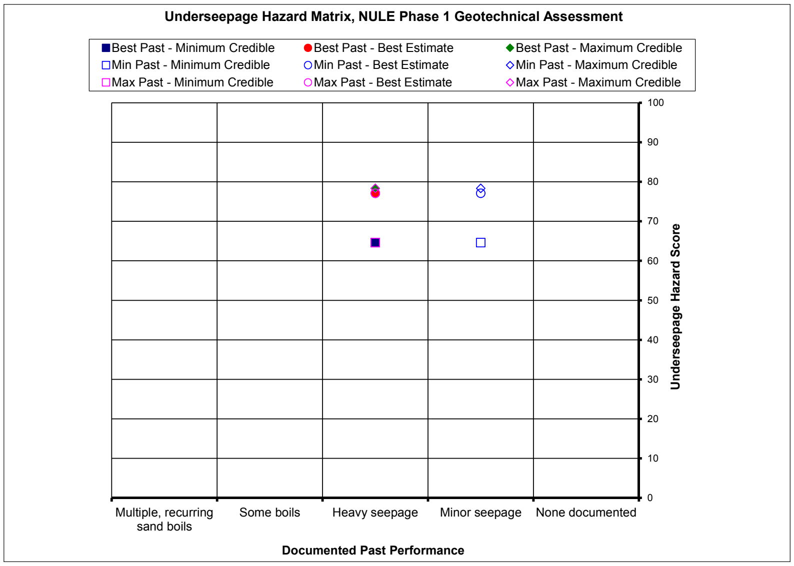
Segment 1052 LAT Results
Geotechnical Assessment Report

NORTH NON-URBAN LEVEE EVALUATIONS







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Segment 1052 LAT Results
Geotechnical Assessment Report

NORTH NON-URBAN LEVEE EVALUATIONS

UPDATED EXISTING GEOTECHNICAL DATA

TECHNICAL MEMORANDUM

Community of East Walnut Grove, California

California Department of Water Resources
Small Community Flood Risk Reduction Program

APPENDIX B

Geomorphology Technical Memorandum

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
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Acronyms and Abbreviations

Term	**Description**
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

Term	Description
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 then 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 (Helley 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; Helley 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 (Helley 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 (Helley 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 (Helley 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 (SNFy, 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 (Helley 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 SNFy 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 (Helley 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; Ql 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 Ql 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 (Helley 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 Helley 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 Helley 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 Helley 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 though 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 though 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 is 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 Helley 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 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, 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 Helley, 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 Helley 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 interfingers 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:

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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

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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)[1]		Department of Water Resources (1994)[2]		Atwater (1982)[3]		WLA Urban Levee Mapping (2007, 2008)[4]	
	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)[5]			Rch	Historical channel deposits
			SRm	Sacramento River meander belt (pre-1896)[6]			Rb	Historical channel bar deposits
							Hch	Holocene channel deposits
	Qa	Alluvium					Rch	Historical channel deposits
					Ql	Natural levee 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
							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
					Ql	Natural levee deposits	Ha	Holocene alluvial deposits, undifferentiated
							Ha(Agr)	Holocene alluvial deposits, cultivated in 1937
							Hdf	Holocene distributary fan deposits
							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
	Qb	Undivided basin deposits			Qyp	Younger alluvium of Putah Creek	Hffy	Late Holocene fine-grained alluvial fan deposits
							Hff	Holocene fine-grained alluvial fan deposits
							Hn	Holocene basin deposits
							Hn(Agr)	Holocene basin deposits, cultivated in 1937
							Hs	Holocene marsh deposits
							Hn/Qm	Holocene basin deposits overlying shallow Modesto Fm
	Qp	Peat deposits			Qpm	Peat and mud		
Middle to late Pleistocene	Qmu	Modesto Formation, Upper Member			Qom	Older alluvium of Montezuma Hills	Qmu	Modesto Formation, Upper Member
							Pf	Pleistocene alluvial fan deposits
	Qml	Modesto Formation, Lower Member			Qop	Older alluviium of Putah Creek	Qml	Modesto Formation, Lower Member
							Pf	Pleistocene alluvial fan deposits
	Qru	Riverbank Formation, Upper Member					Qru	Riverbank Formation, Upper Member
	Qrl	Riverbank Formation, Lower 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.

[1] 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.

[2] 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.sacramentoriver.org/website/recwebims/viewer.htm; Red Bluff to Colusa. This data source replaces Helley and Harwood (1985) along the Sacramento River north of Colusa.

[3] 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.

[4] Geologic mapping by WLA in 2007 and 2008 as part of the Urban Levee Evaluation Project.

[5] 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.

[6] 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, Ql	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

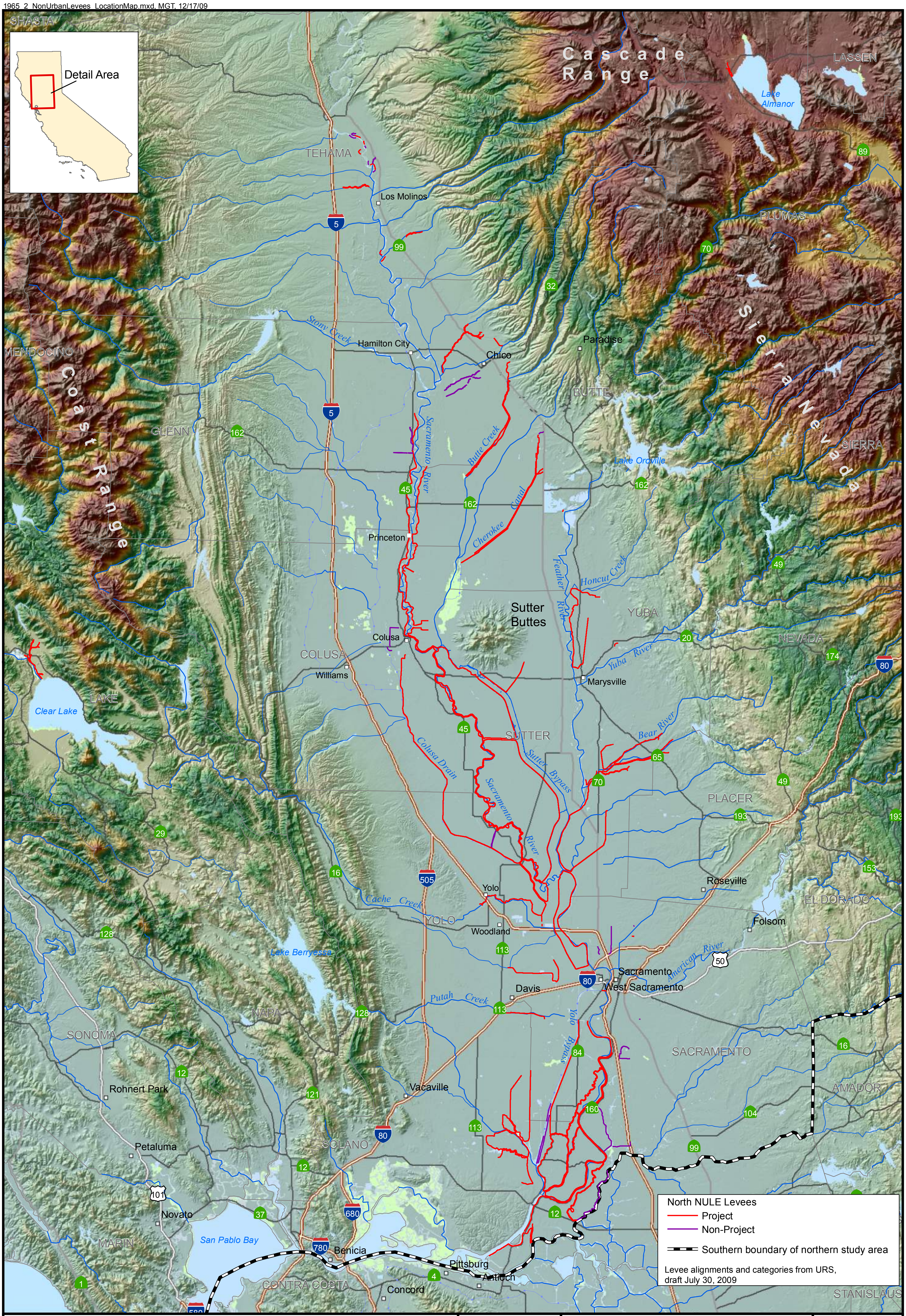
Performance Problem	Susceptibility Class	Miles Affected Levee	Percent Total Miles Affected	Affected Miles per Levee Mile (%)
Failure	VH	0.67	36	0.61
	H	0.64	35	0.15
	M	0.14	8	0.19
	L	0.39	21	0.20
	All classes	1.85	100	0.22
Seepage/Boils	VH	6.82	13	6.20
	H	40.84	76	9.27
	M	3.70	7	4.95
	L	2.20	4	1.11
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

1965_2_NonUrbanLevees_LocationMap.mxd, MGT, 12/17/09



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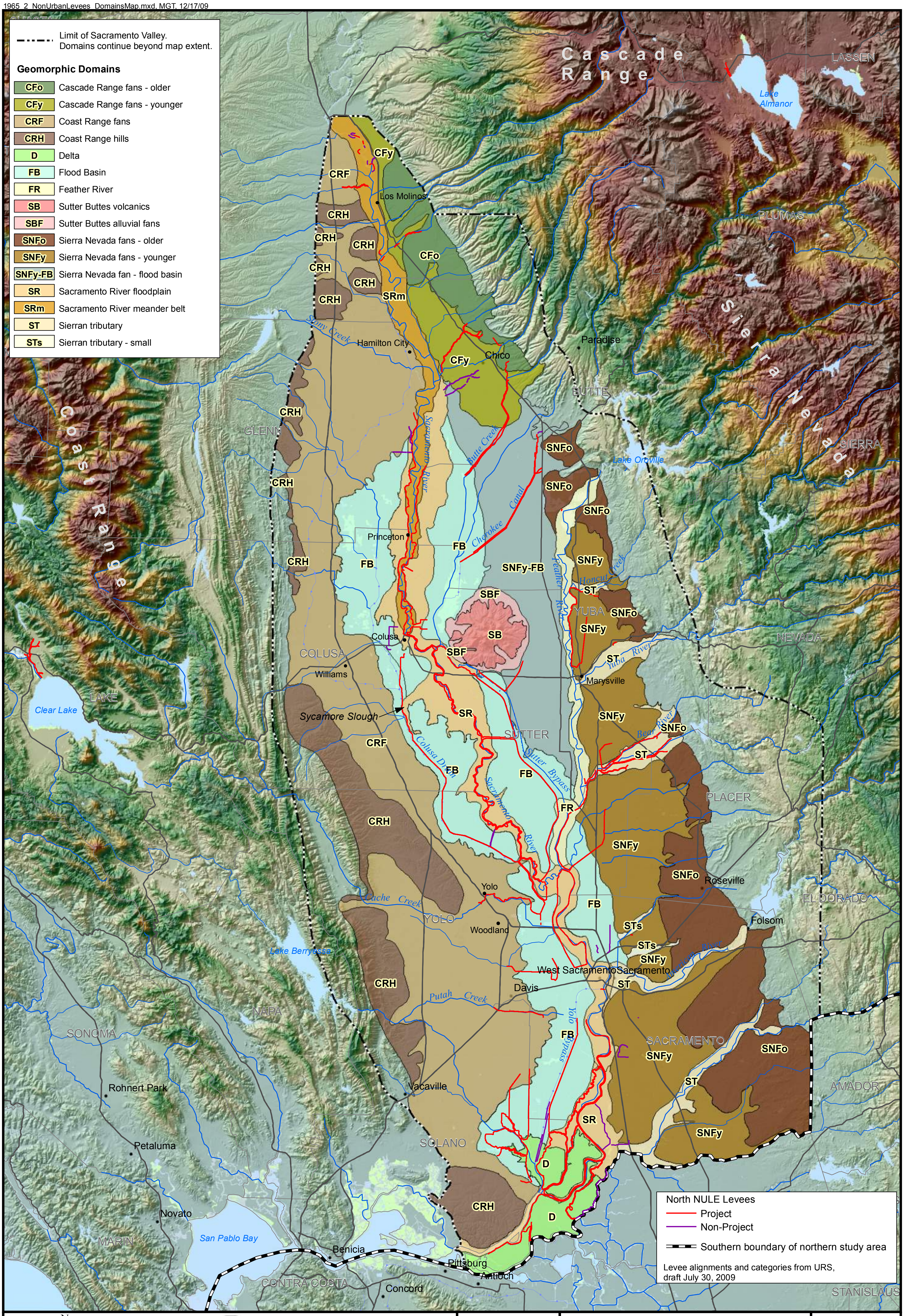
North NULE Levees

North Non-Urban Levee Evaluations

Figure 1



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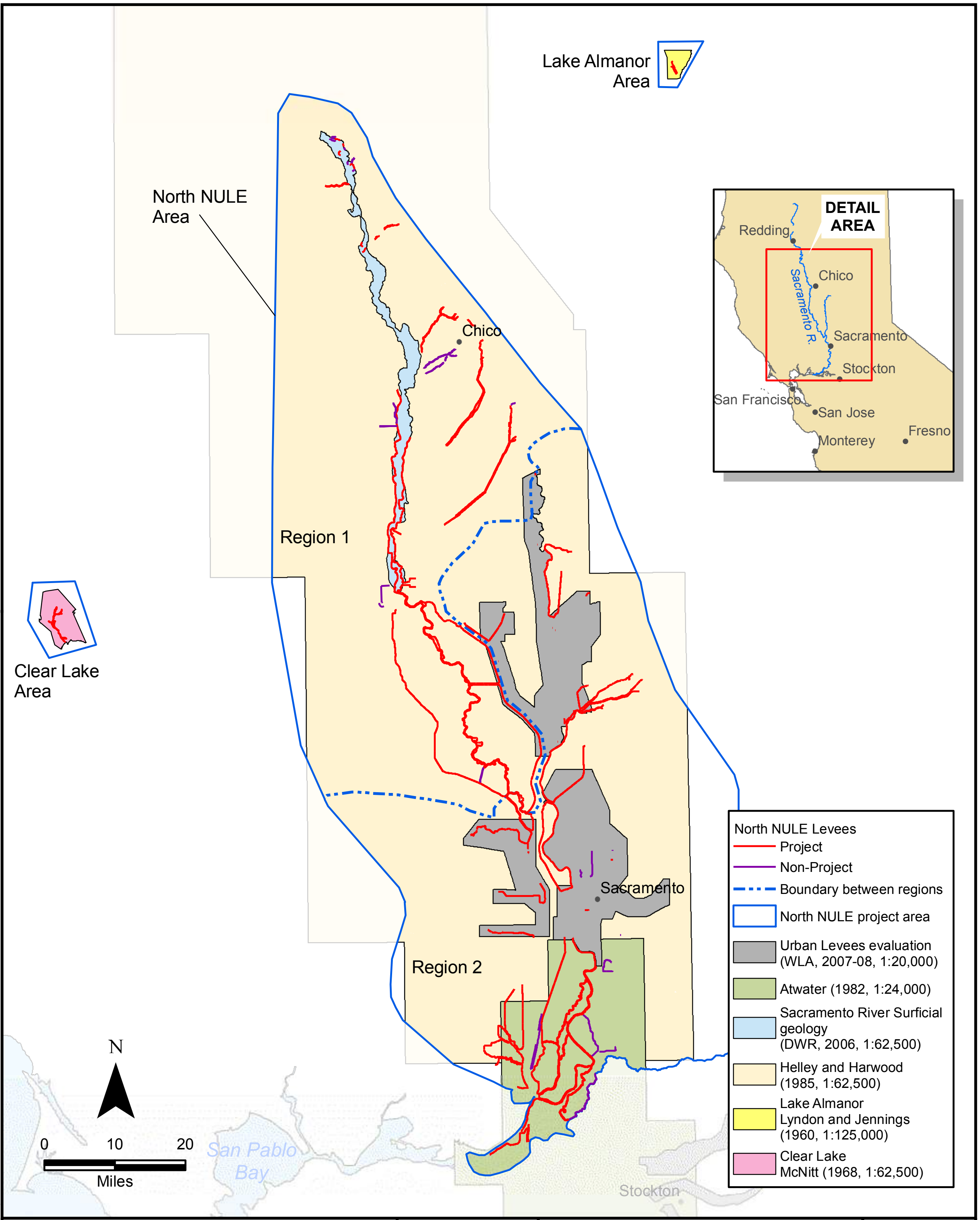
North NULE Geomorphic Domains

North Non-Urban Levee Evaluations

Figure 2



1965_NULE_2_GeologySources_Fig.mxd, MGT, 12/17/09

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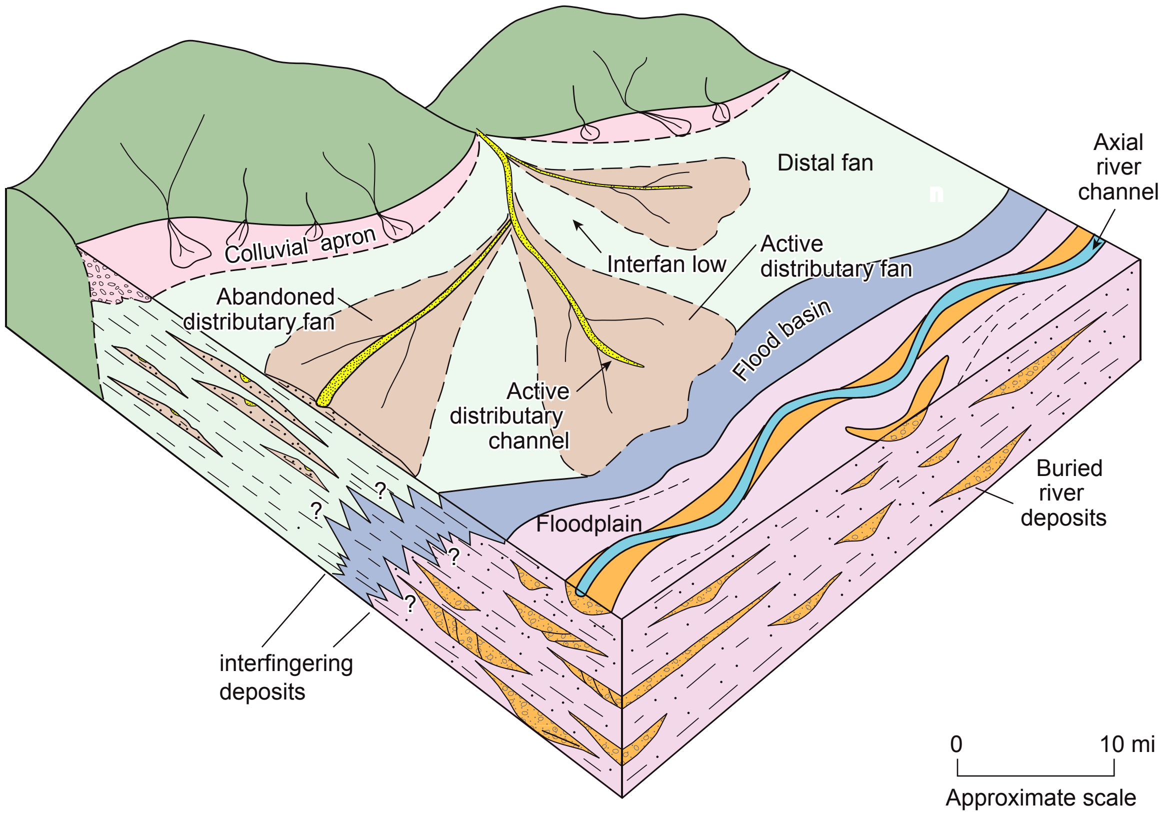
Index of Geologic Source Data

NORTH NON-URBAN LEVEE EVALUATIONS

**Figure
3**



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

1965_NULEF5 -block ai jlp.Modified 07.08.09

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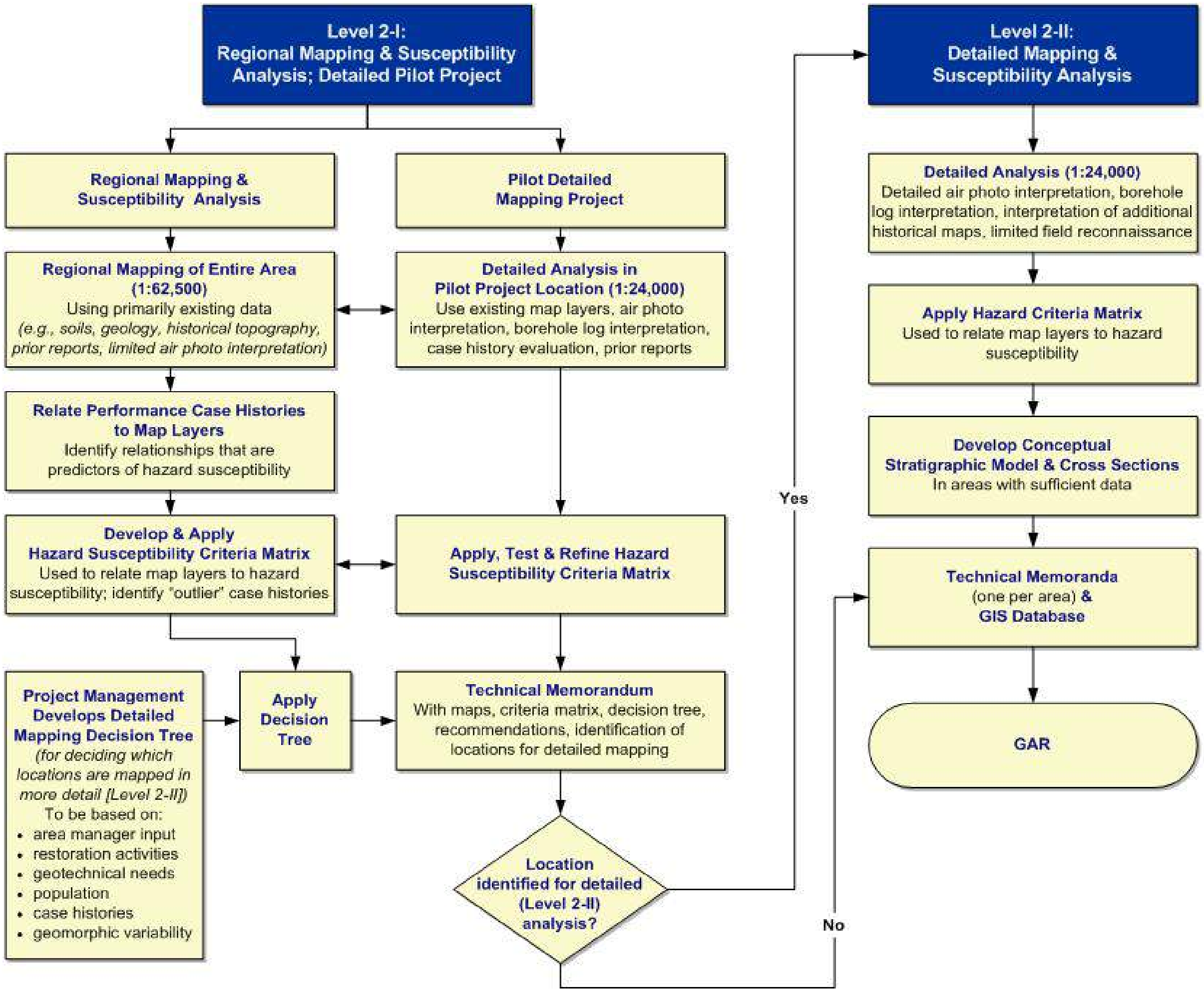
Conceptual Block Diagram

NORTH NON-URBAN LEVEE EVALUATIONS

Figure 4



1965_NULE-workflow_Fig.5.Modified 07.08.09

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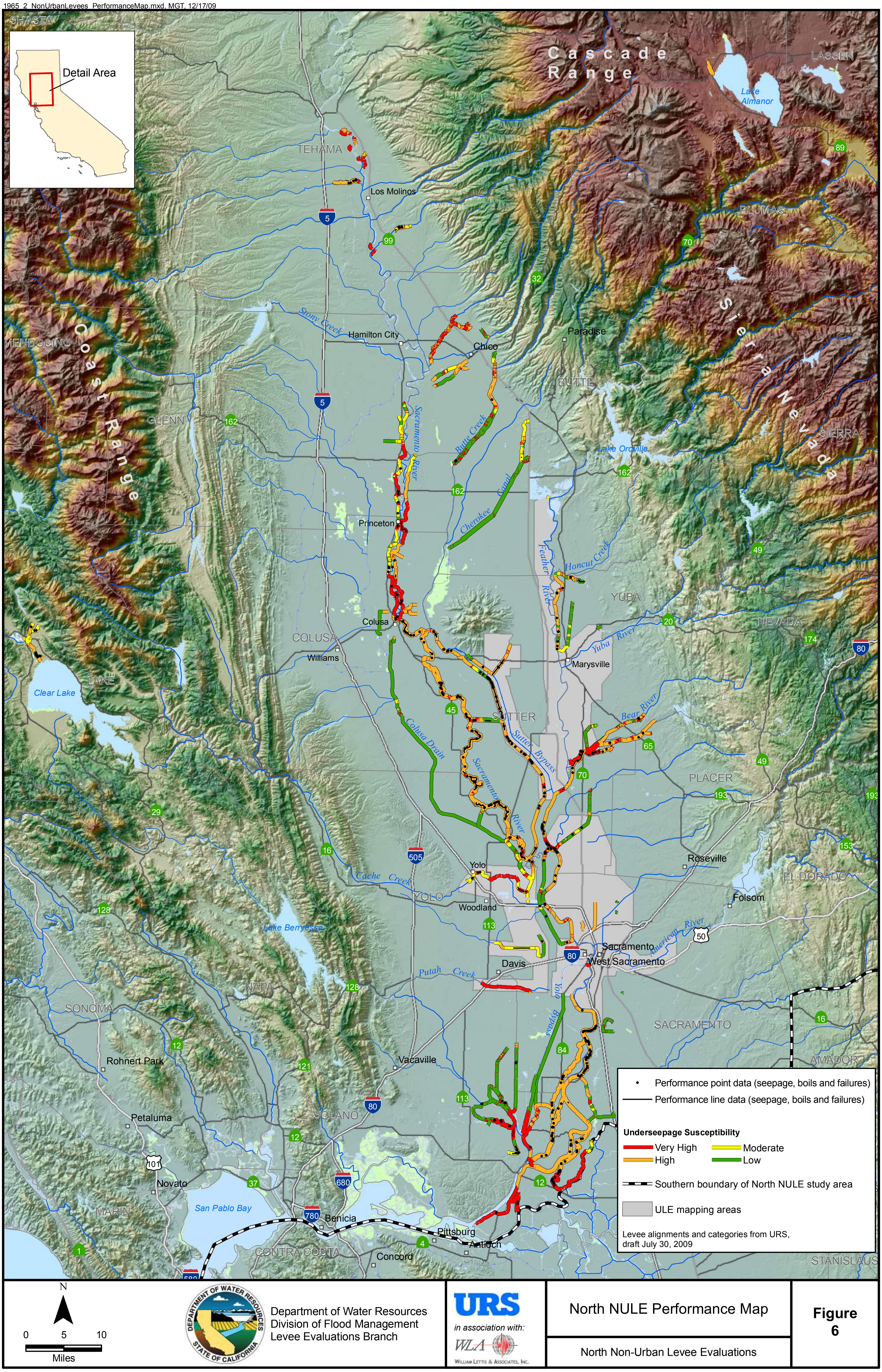
Workflow Diagram

NORTH NON-URBAN LEVEE EVALUATIONS

Figure 5



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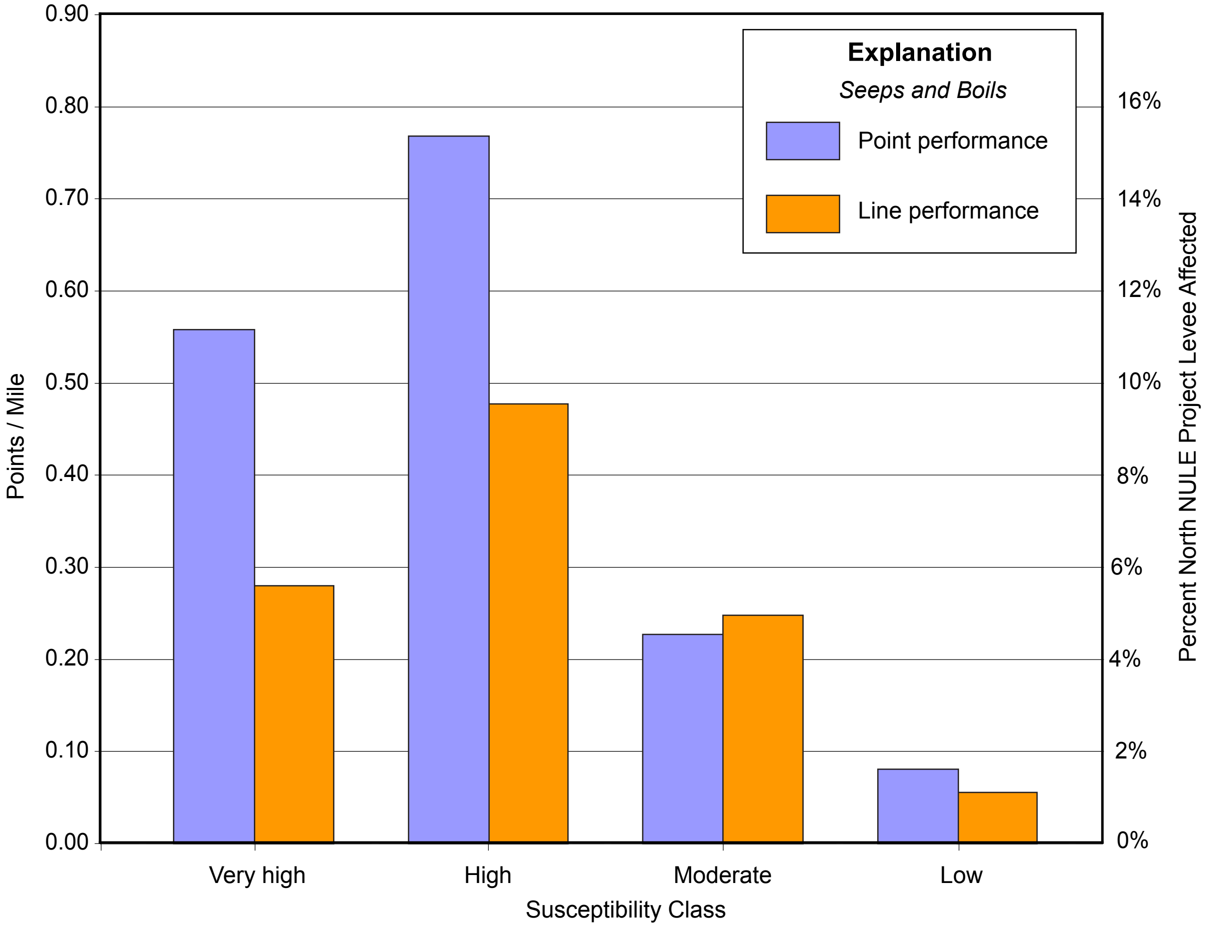
North NULE Performance Map

North Non-Urban Levee Evaluations

Figure 6



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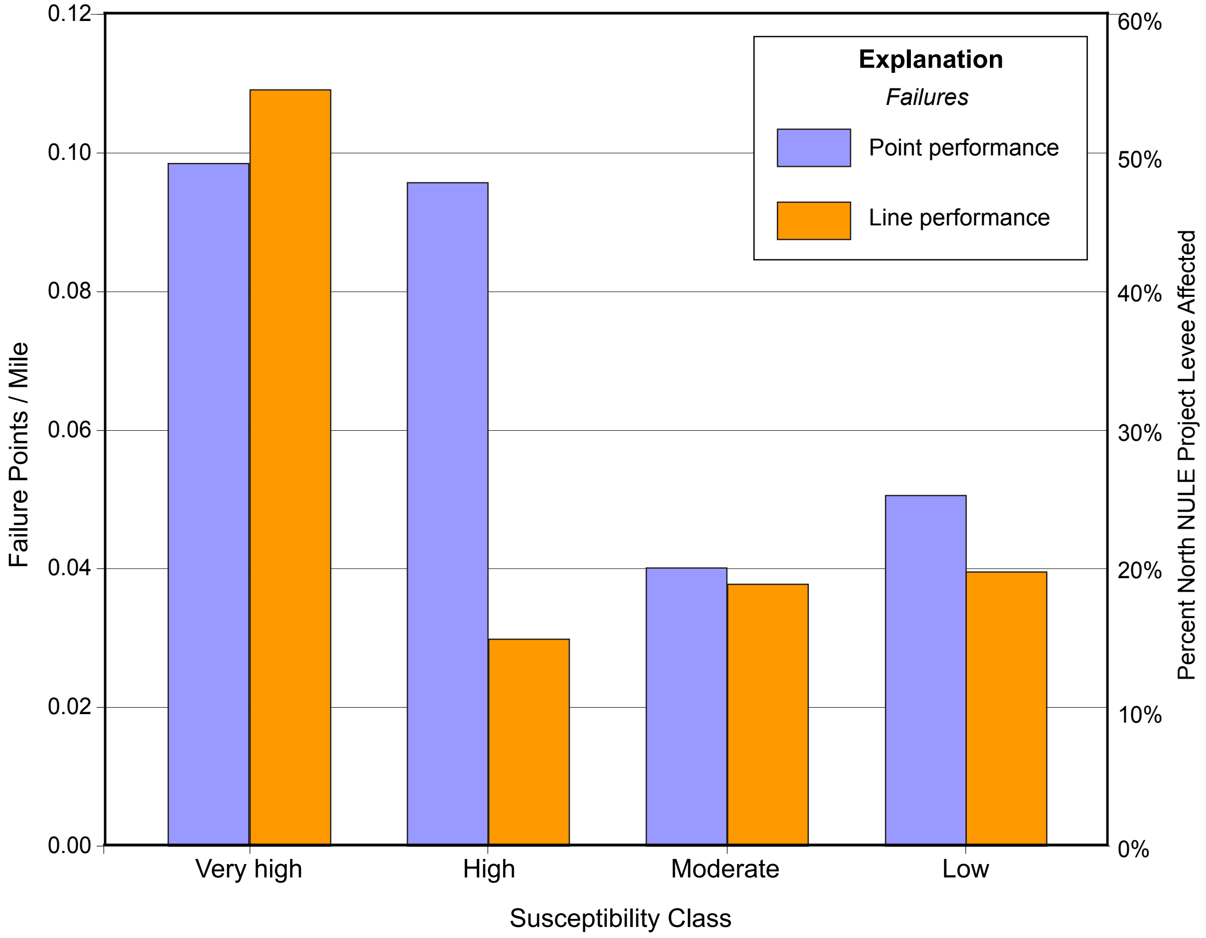
Plot of Seepage and Boil Frequency by Susceptibility Class

NORTH NON-URBAN LEVEE EVALUATIONS

Figure 7

1965_NULE_7_Plot Seepage and Boil Frequency_Fig.7.Modified 121709



1965_NULE_7_Plot Seepage and Boil Frequency_Fig.8,Modified 121709

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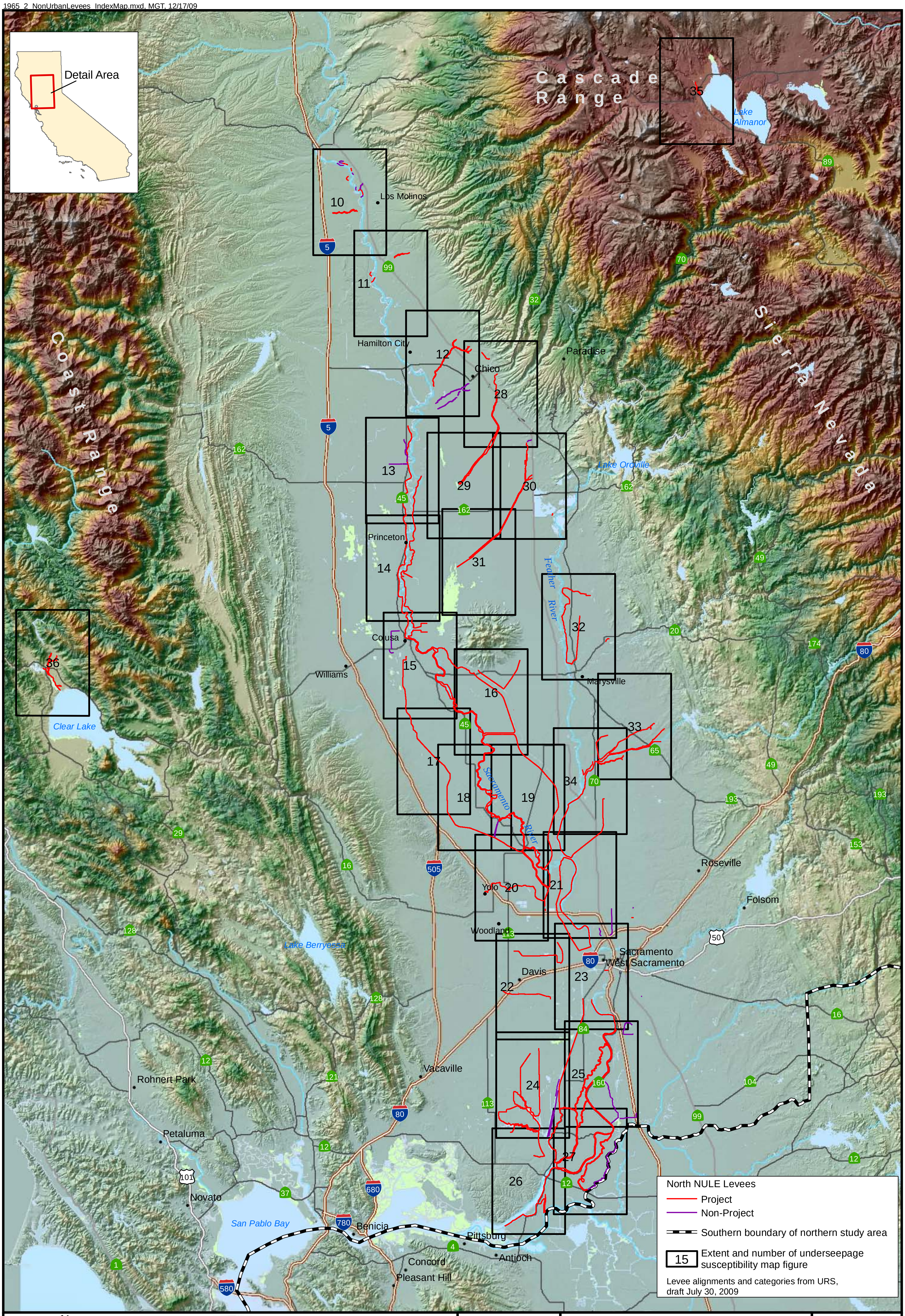
Plot of Failures
by Susceptibility Class

NORTH NON-URBAN LEVEE EVALUATIONS

Figure
8

1965_2_NonUrbanLevees_IndexMap.mxd, MGT, 12/17/09



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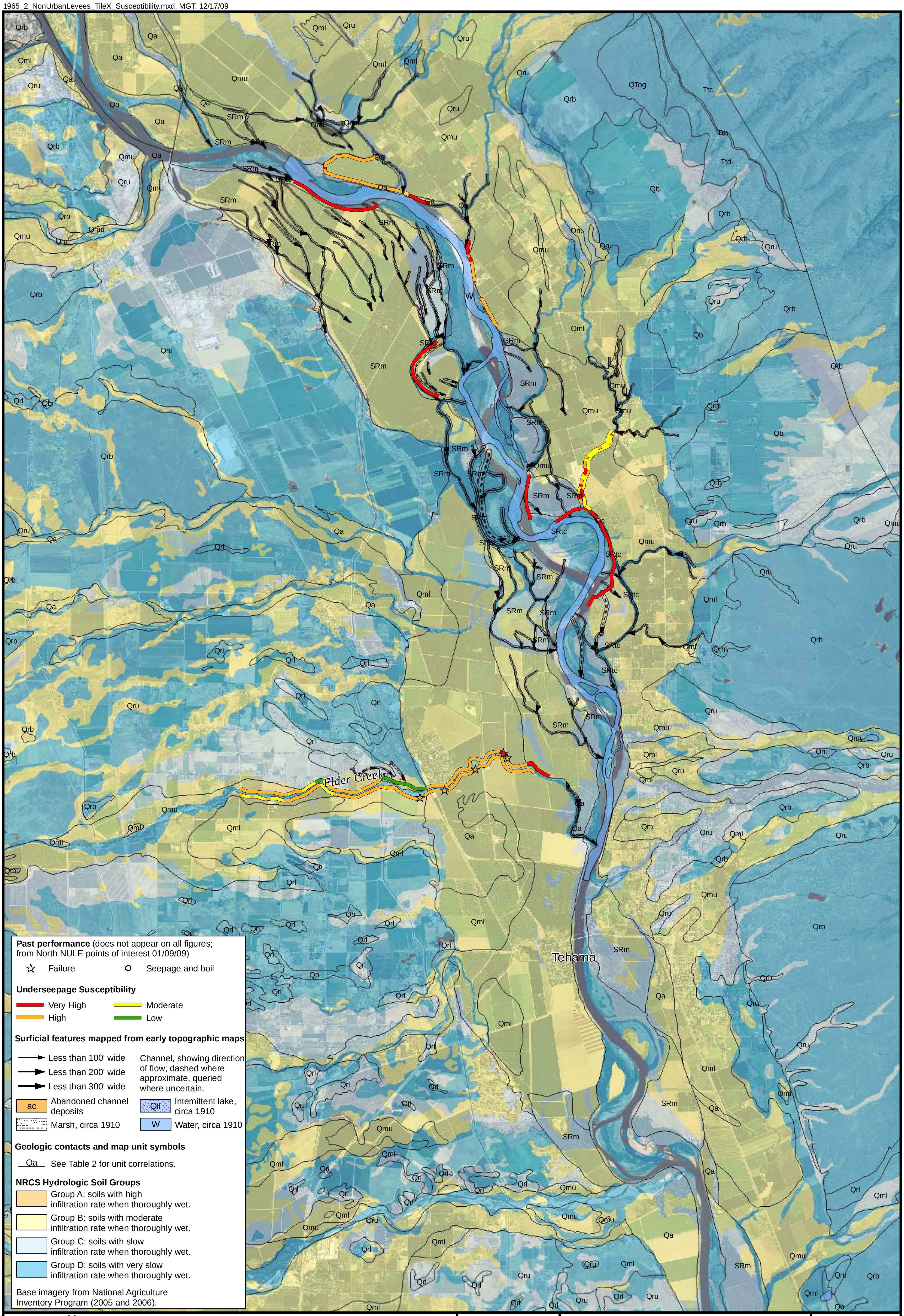
North NULE Index Map

North Non-Urban Levee Evaluations

Figure
9

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



N

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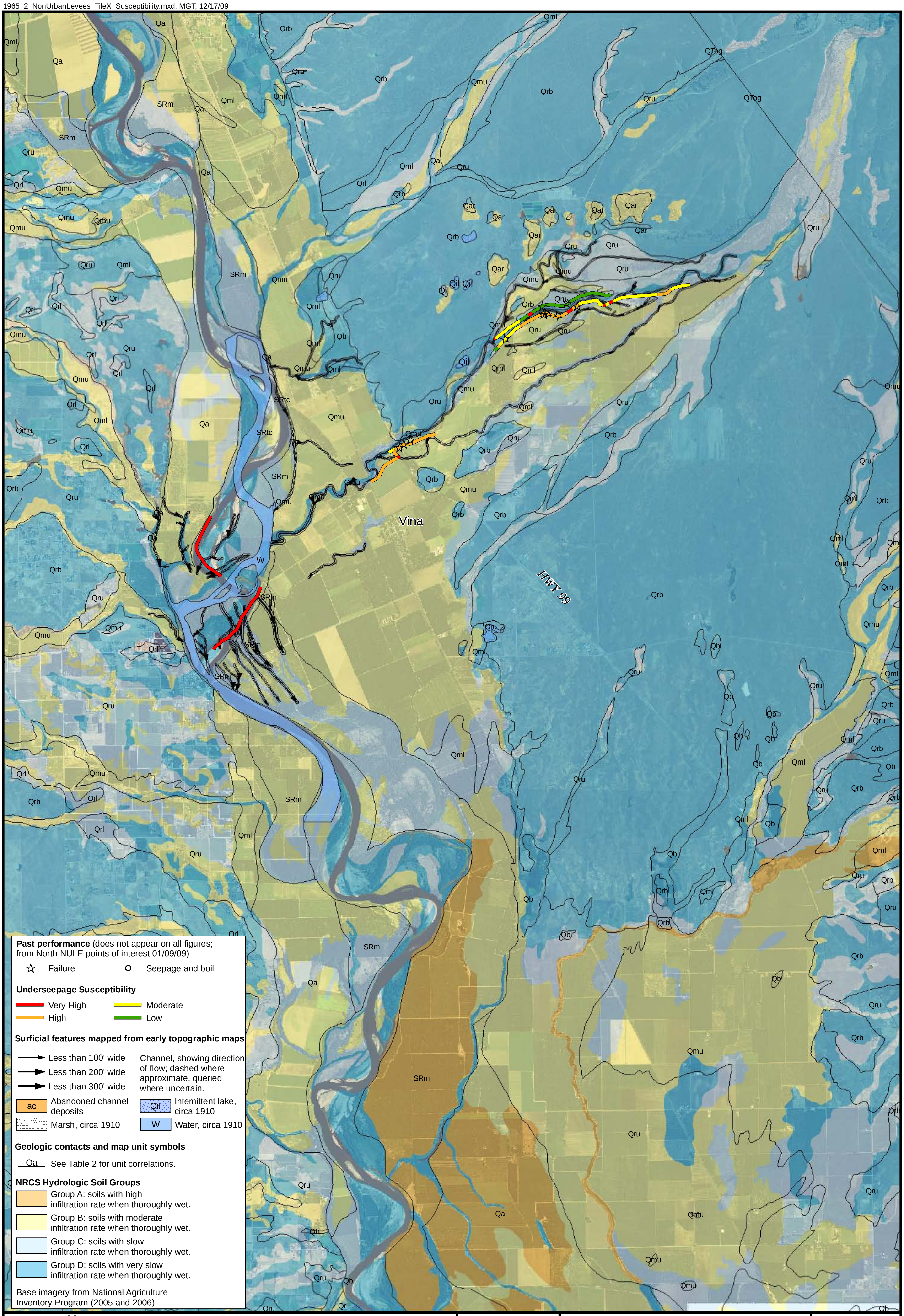
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 10

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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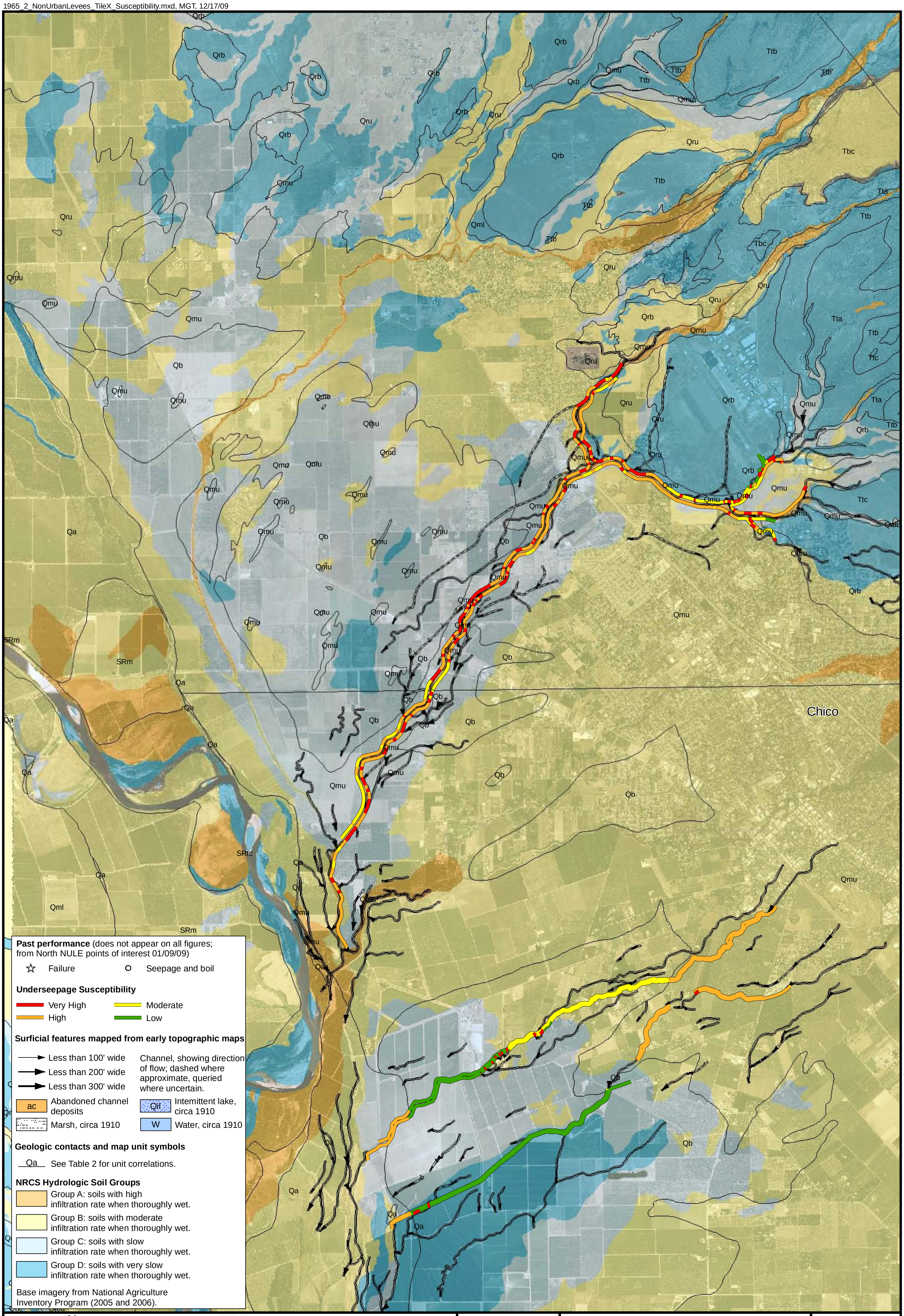
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure
11

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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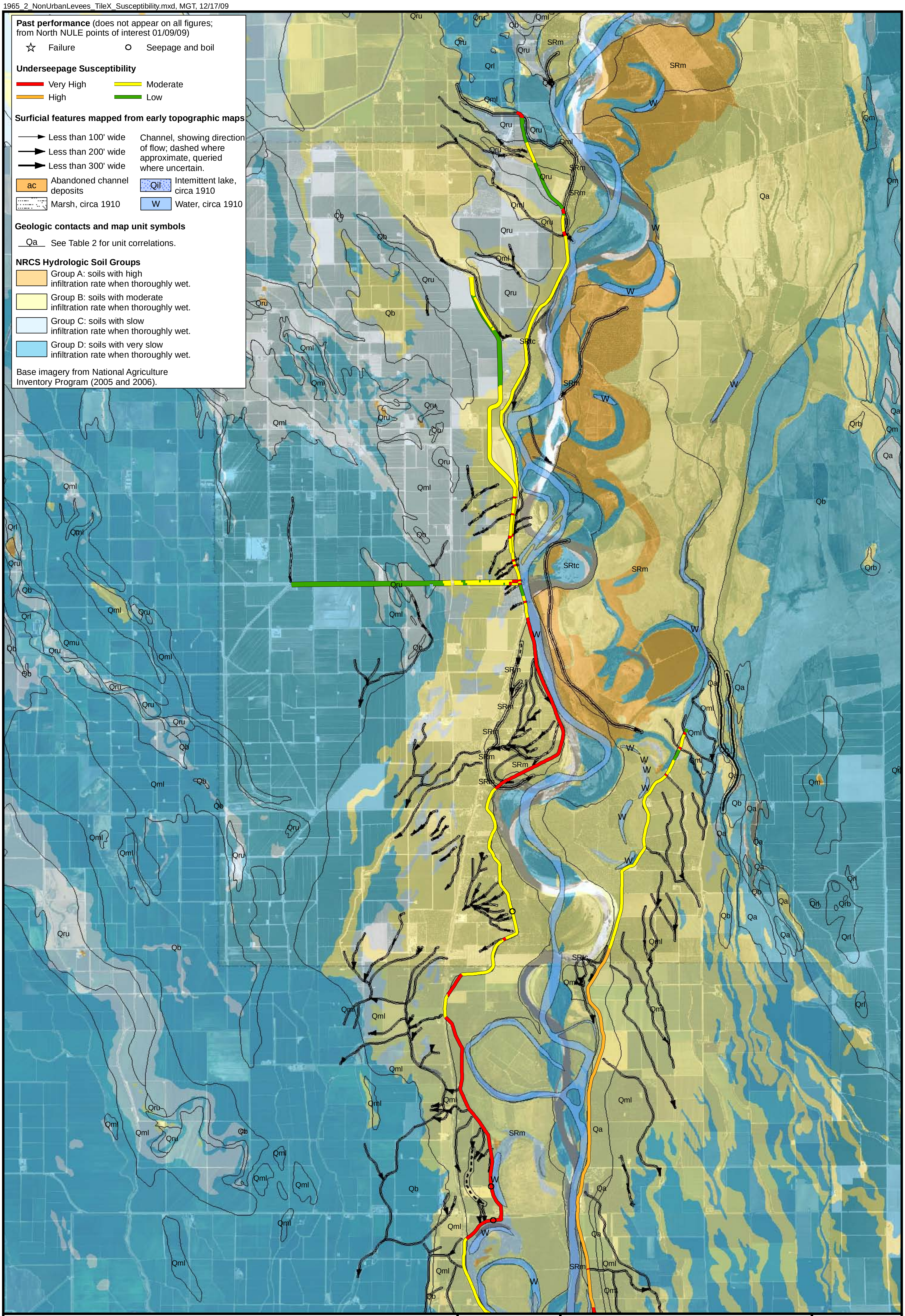
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 12

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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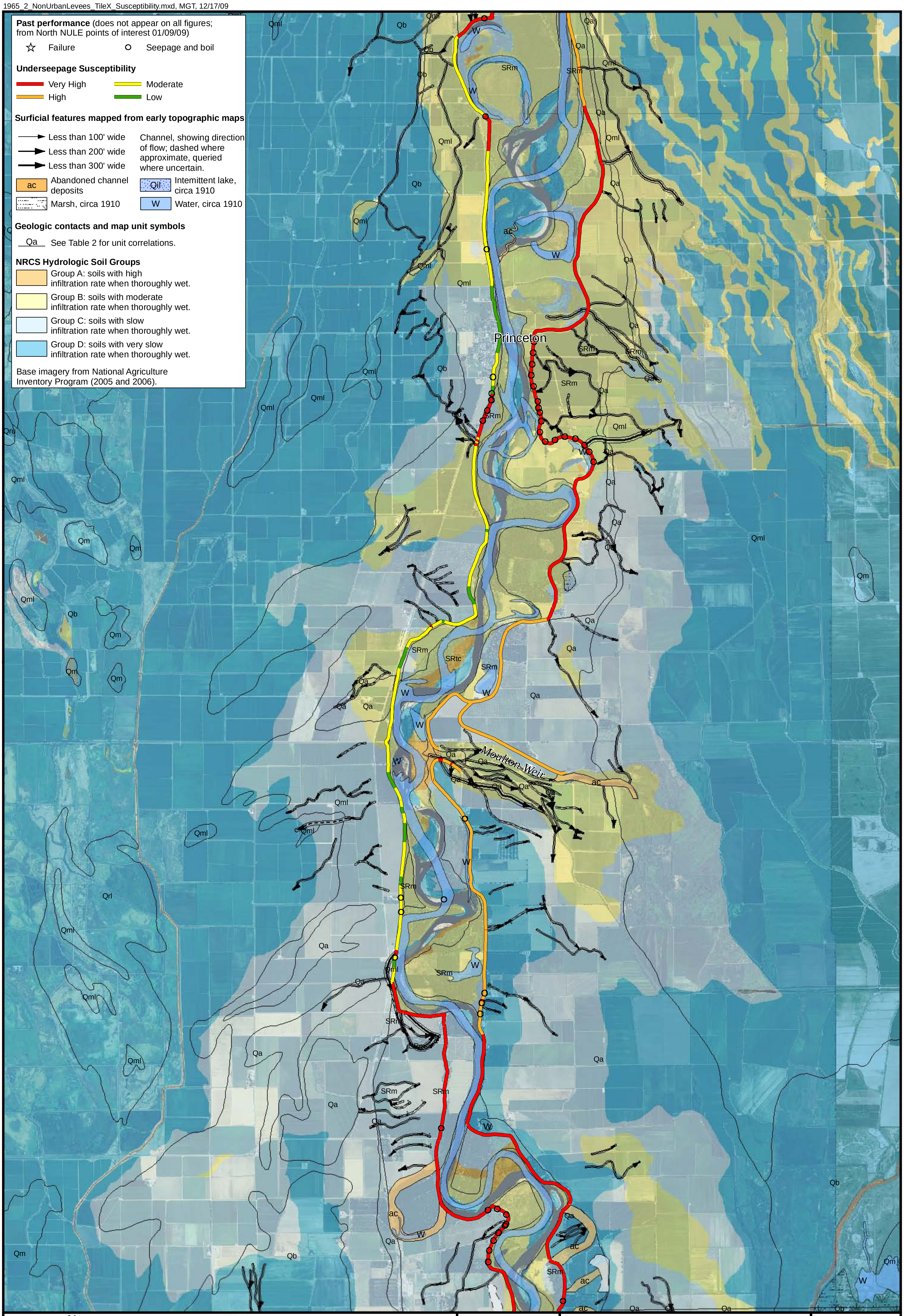
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure
13

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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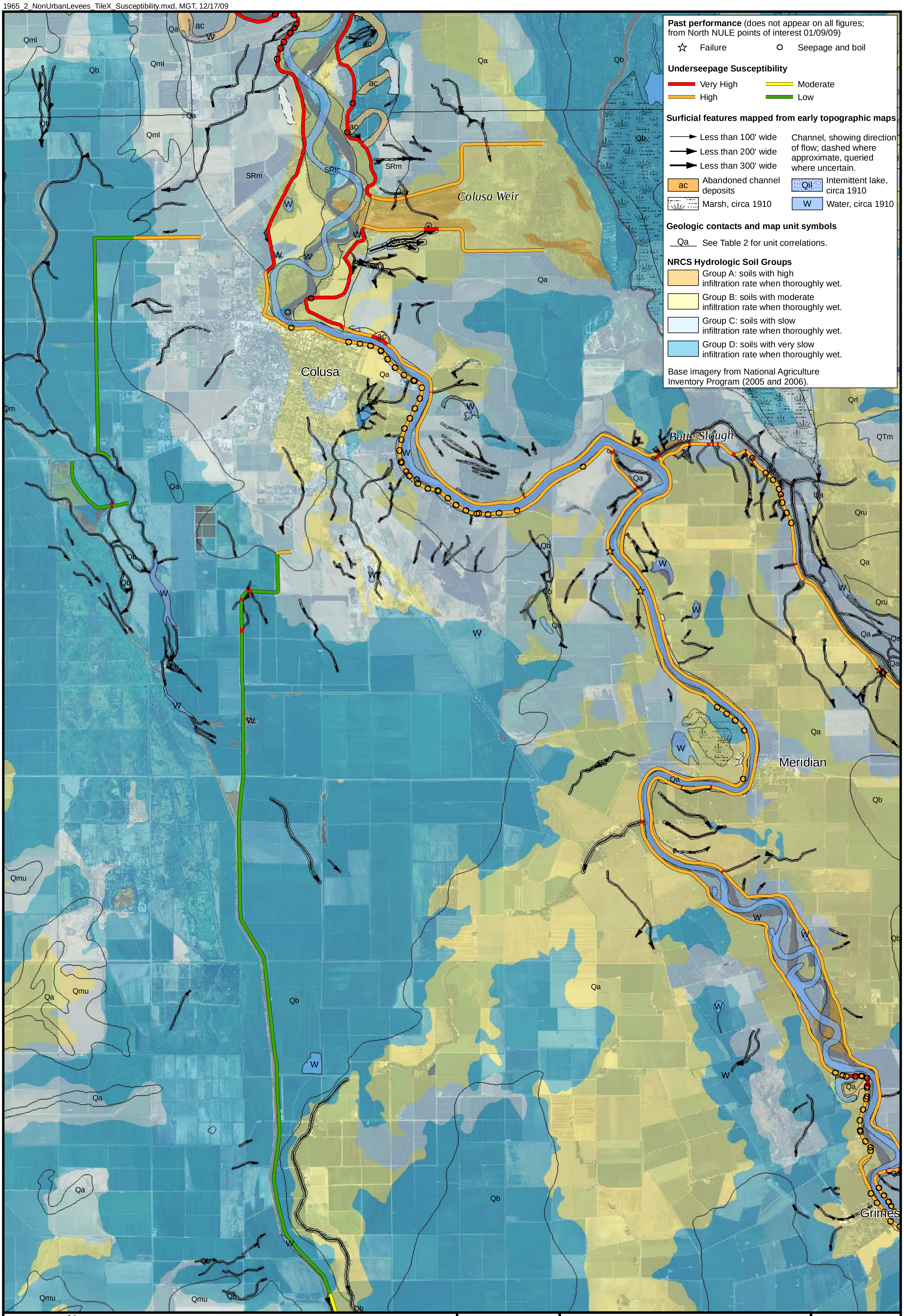
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure
14

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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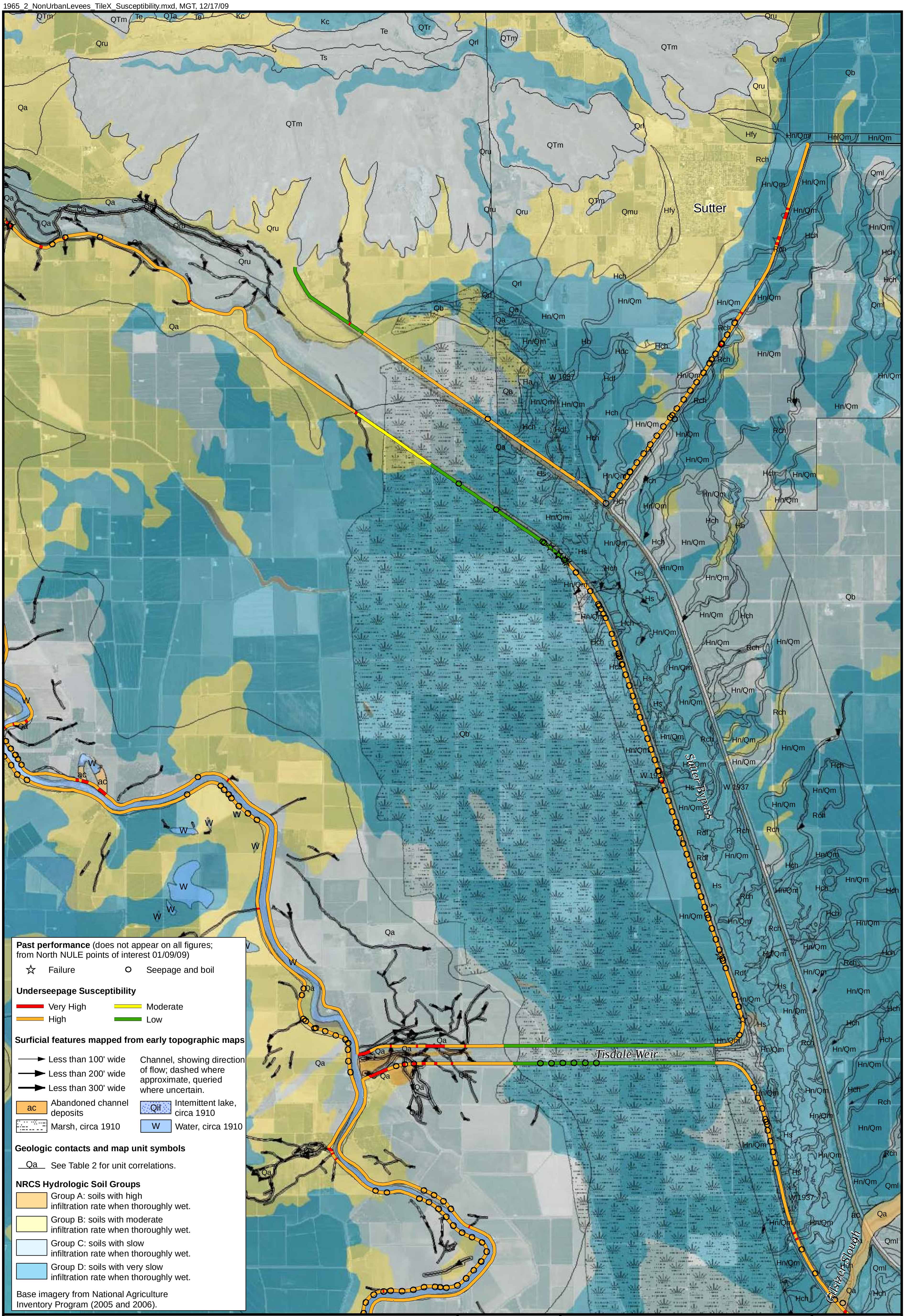
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 15

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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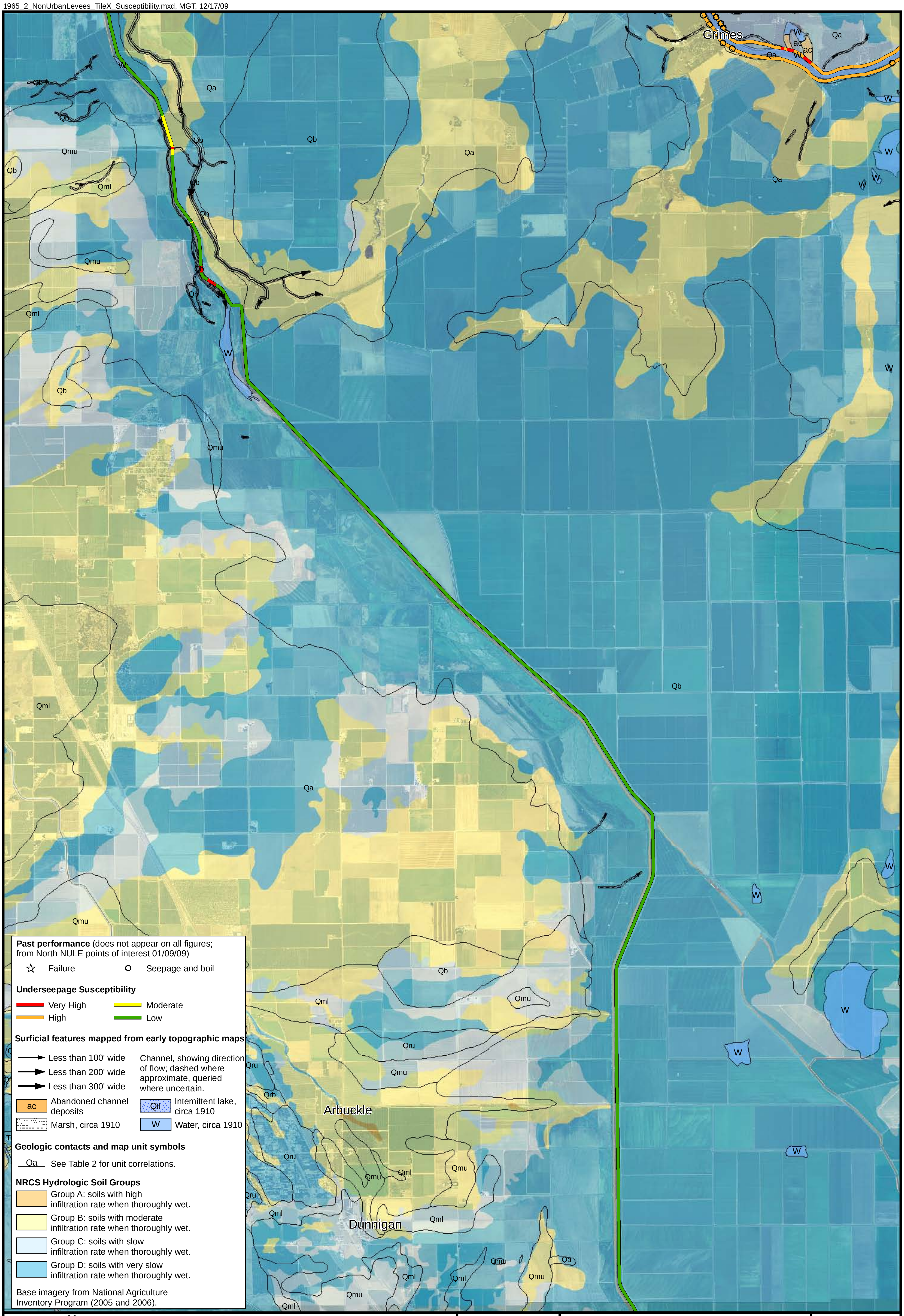
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 16

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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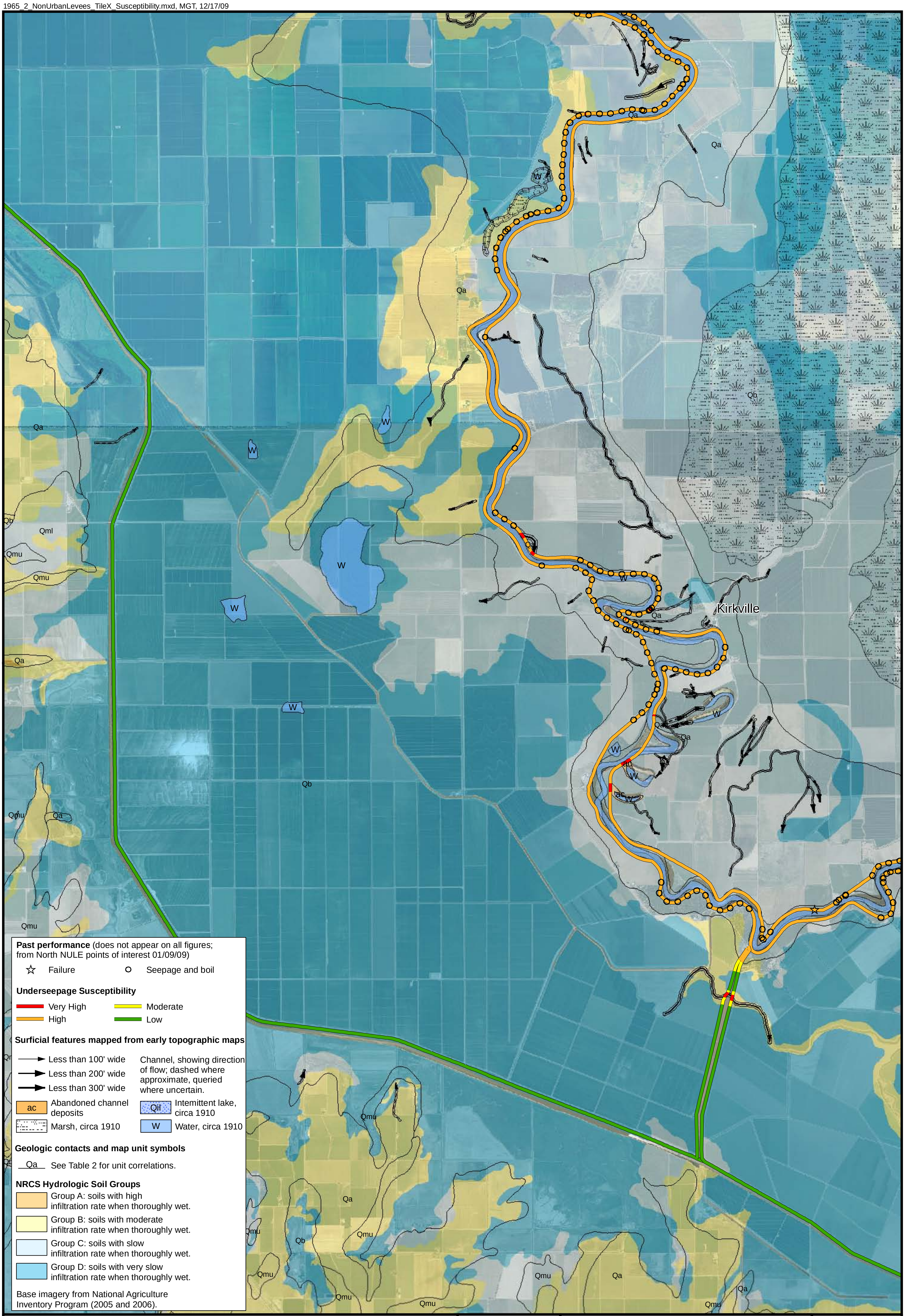
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 17

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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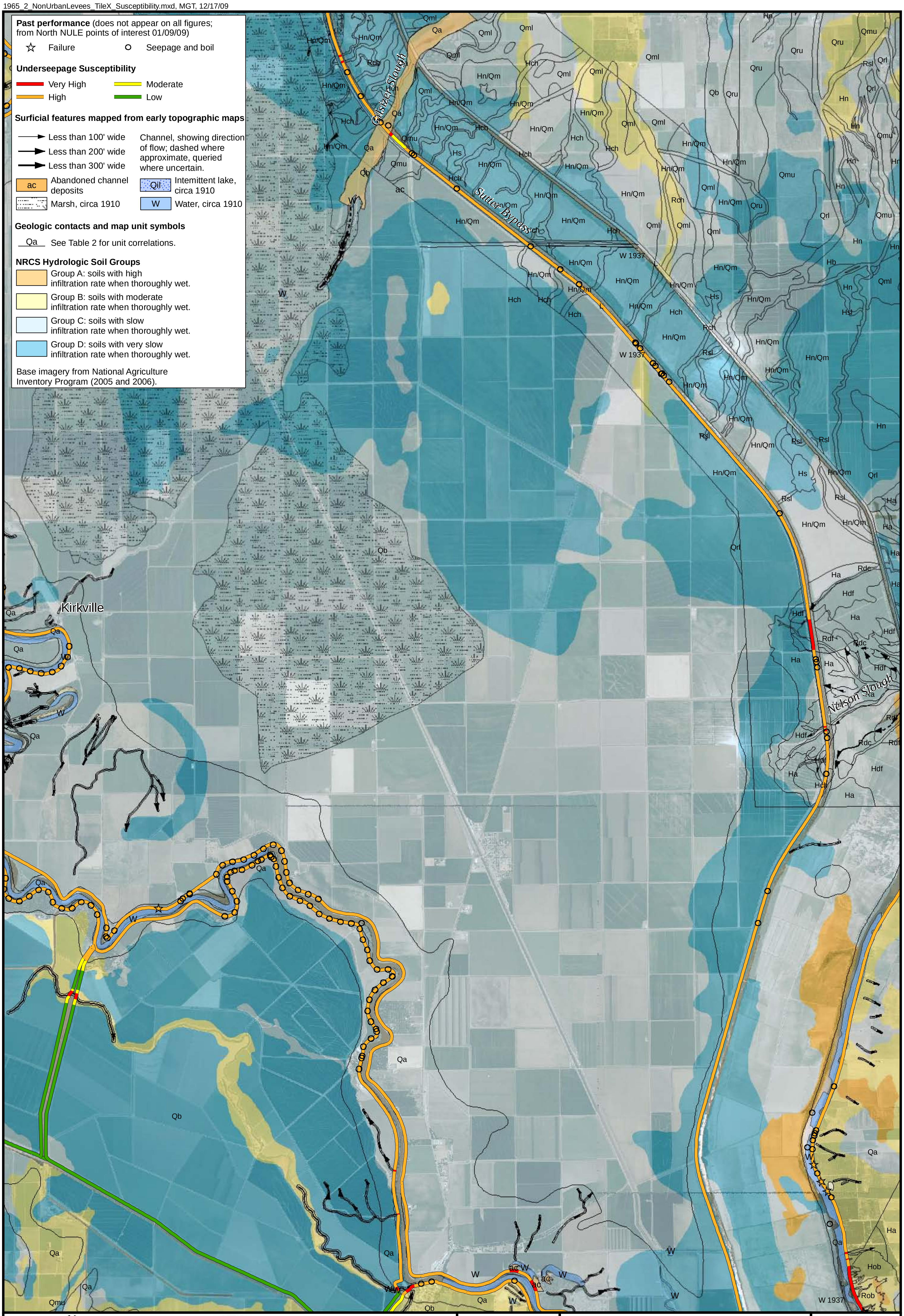
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure
18

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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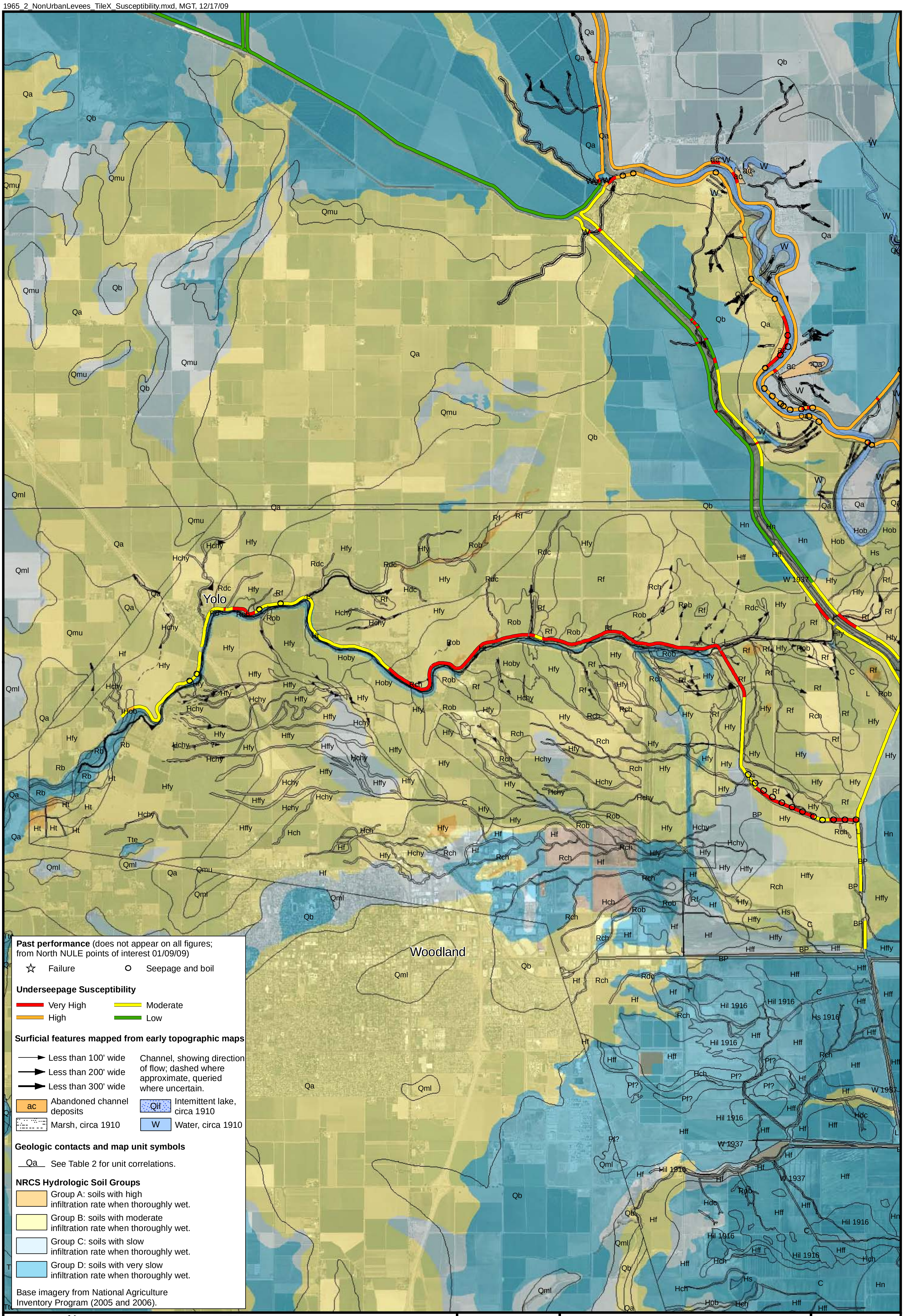
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 19

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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Levee Evaluations Branch

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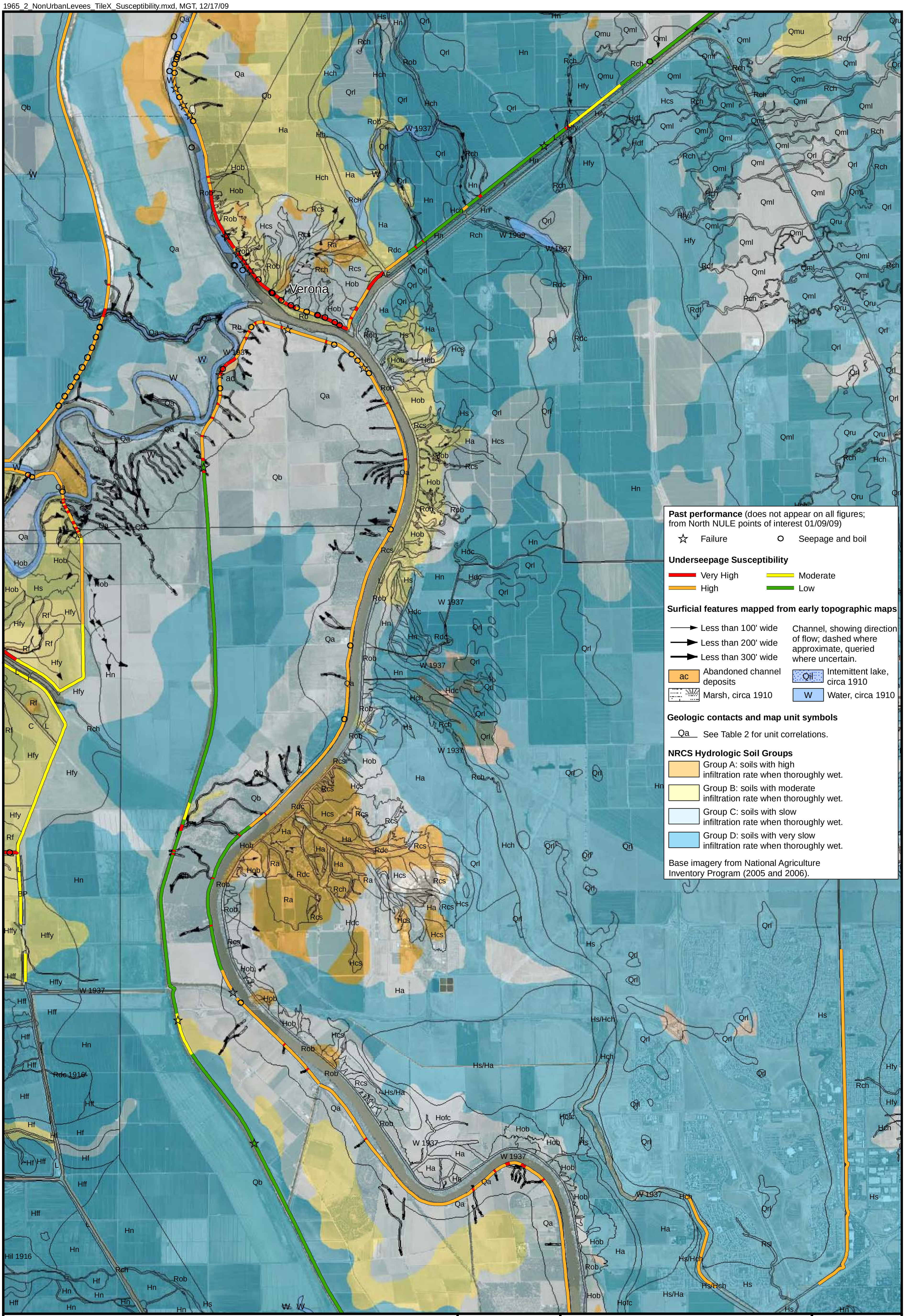
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 20

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



N

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mi
1:62,500

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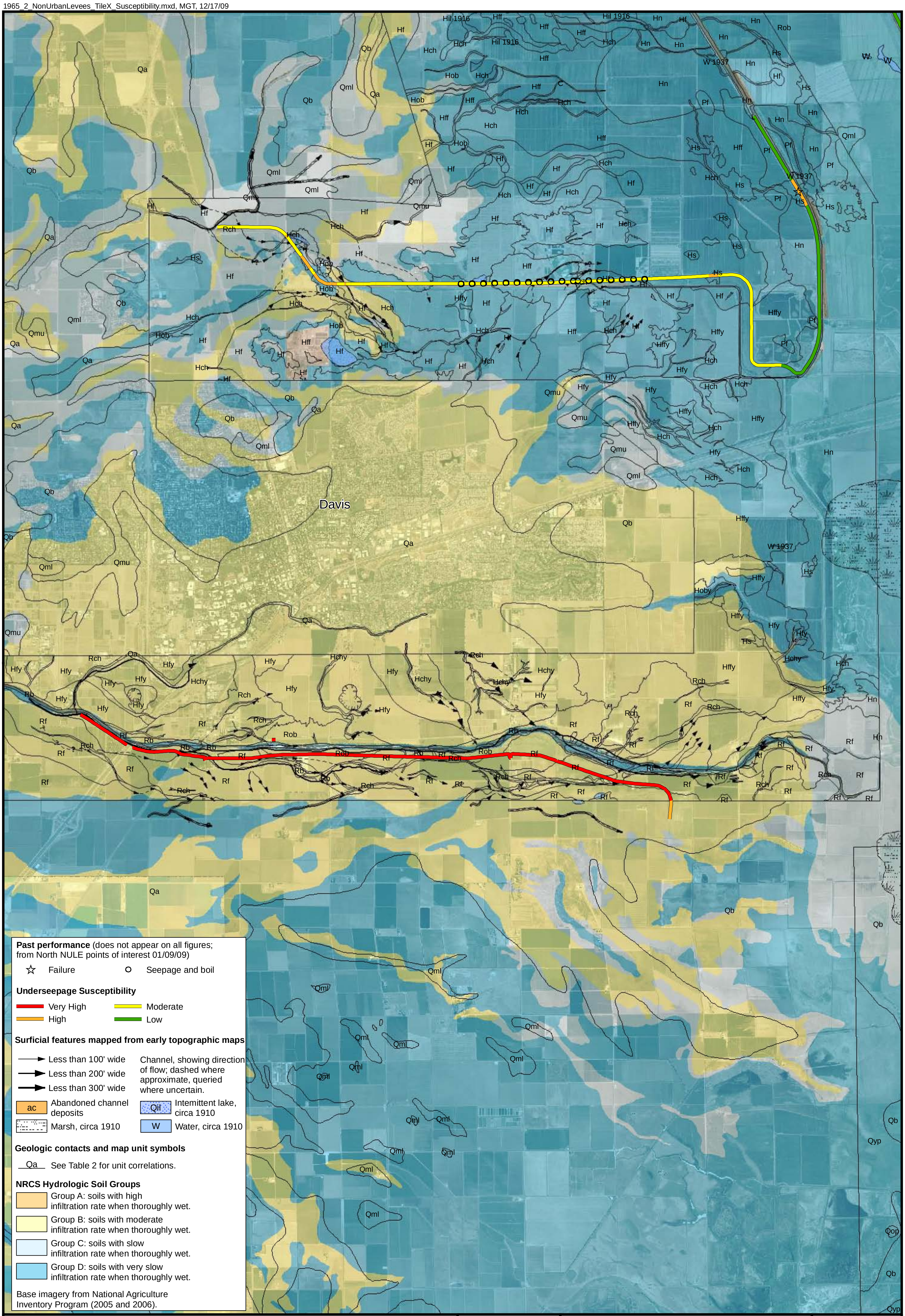
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 21



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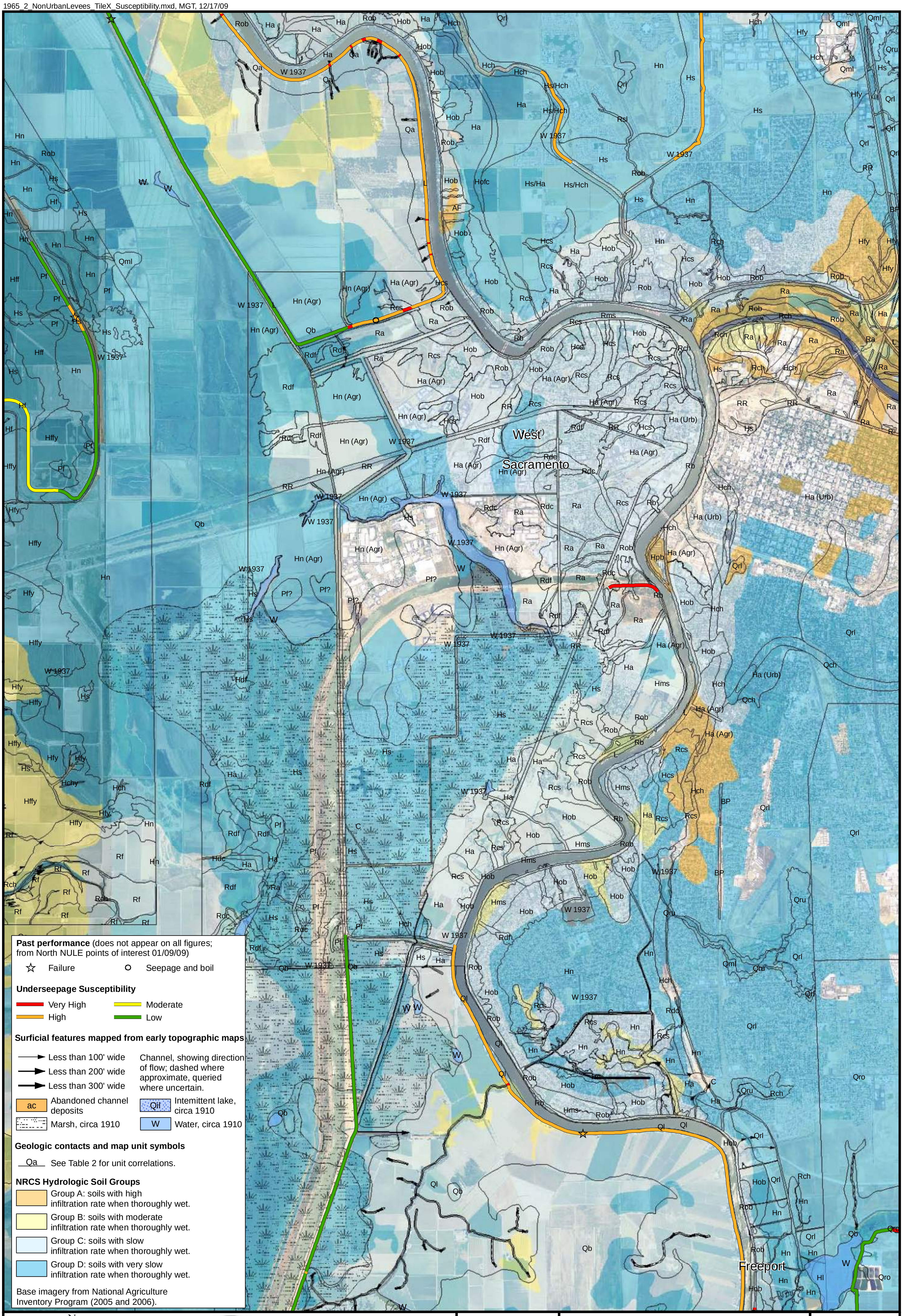
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 22

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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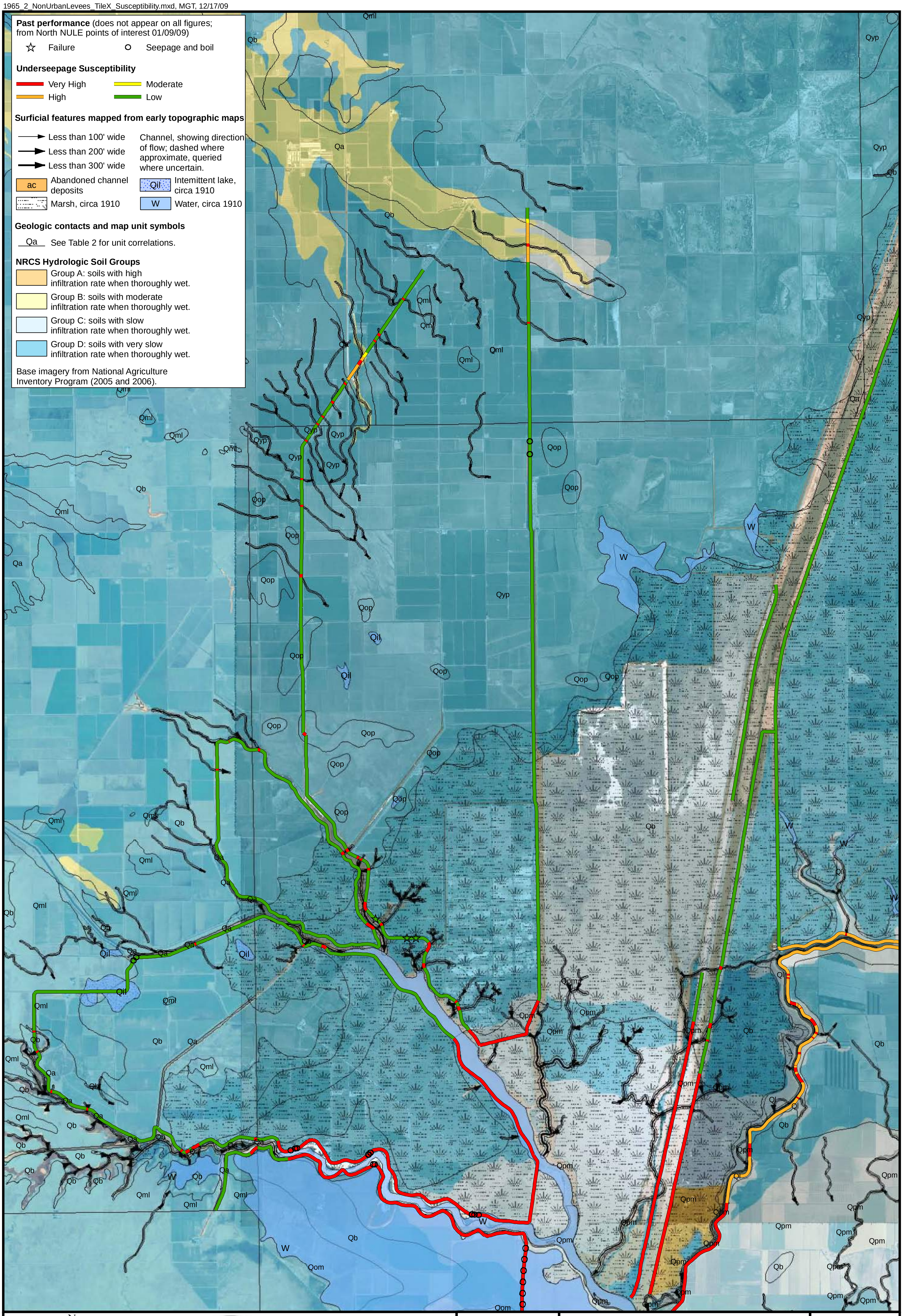
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 23



Past performance (does not appear on all figures; from North NULE points of interest 01/09/09)

- ☆ Failure
- ○ Seepage and boil

Underseepage Susceptibility

🟥 Very High	🟨 Moderate
🟧 High	🟩 Low

Surficial features mapped from early topographic maps

- → Less than 100' wide
- → Less than 200' wide
- → Less than 300' wide

Channel, showing direction of flow; dashed where approximate, queried where uncertain.

ac Abandoned channel deposits	Qil Intemittent lake, circa 1910
▨ Marsh, circa 1910	W Water, circa 1910

Geologic contacts and map unit symbols

Qa See Table 2 for unit correlations.

NRCS Hydrologic Soil Groups

- Group A: soils with high infiltration rate when thoroughly wet.
- Group B: soils with moderate infiltration rate when thoroughly wet.
- Group C: soils with slow infiltration rate when thoroughly wet.
- Group D: soils with very slow infiltration rate when thoroughly wet.

Base imagery from National Agriculture Inventory Program (2005 and 2006).

N

0 0.5 1
mi

1:62,500

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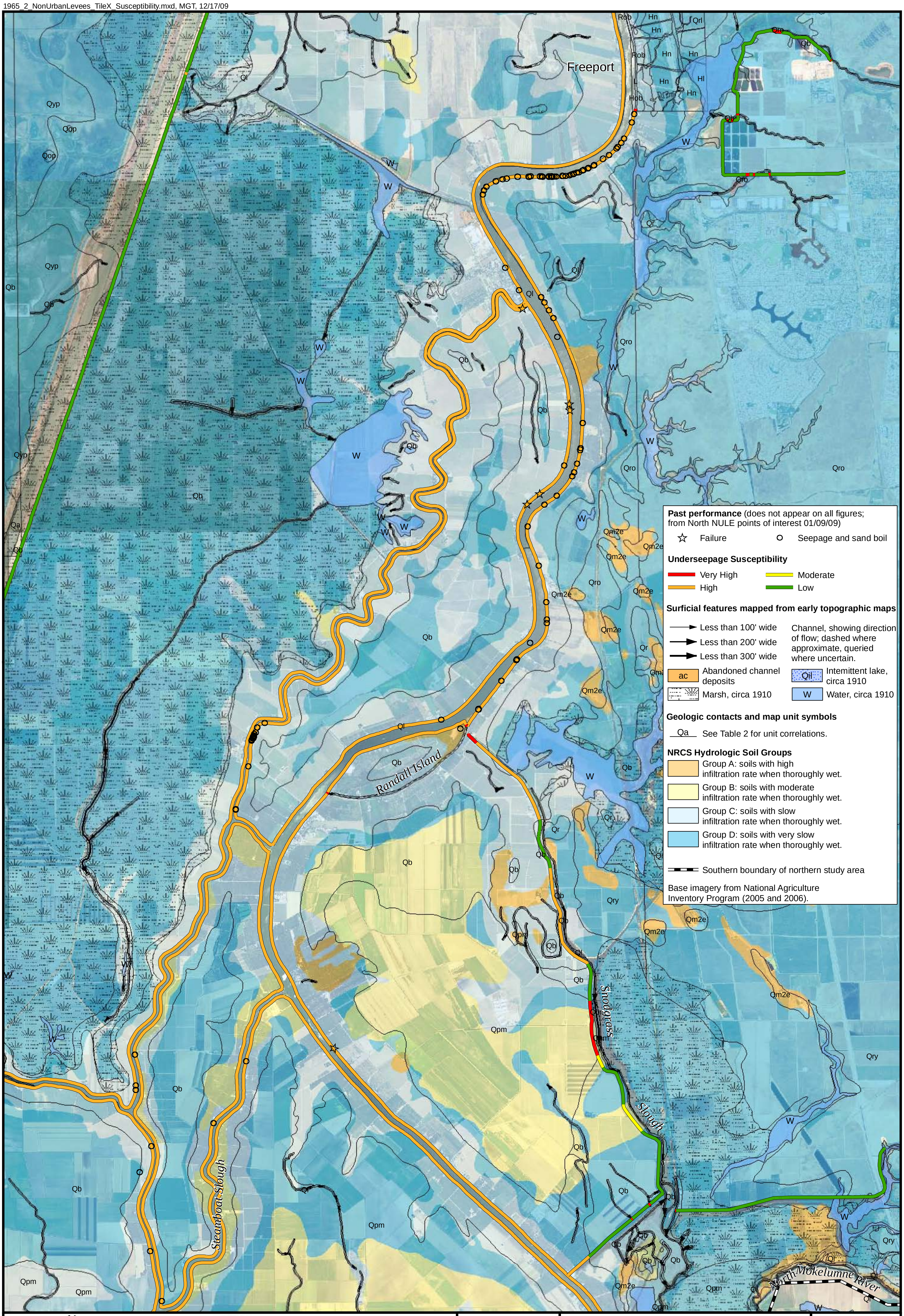
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 24

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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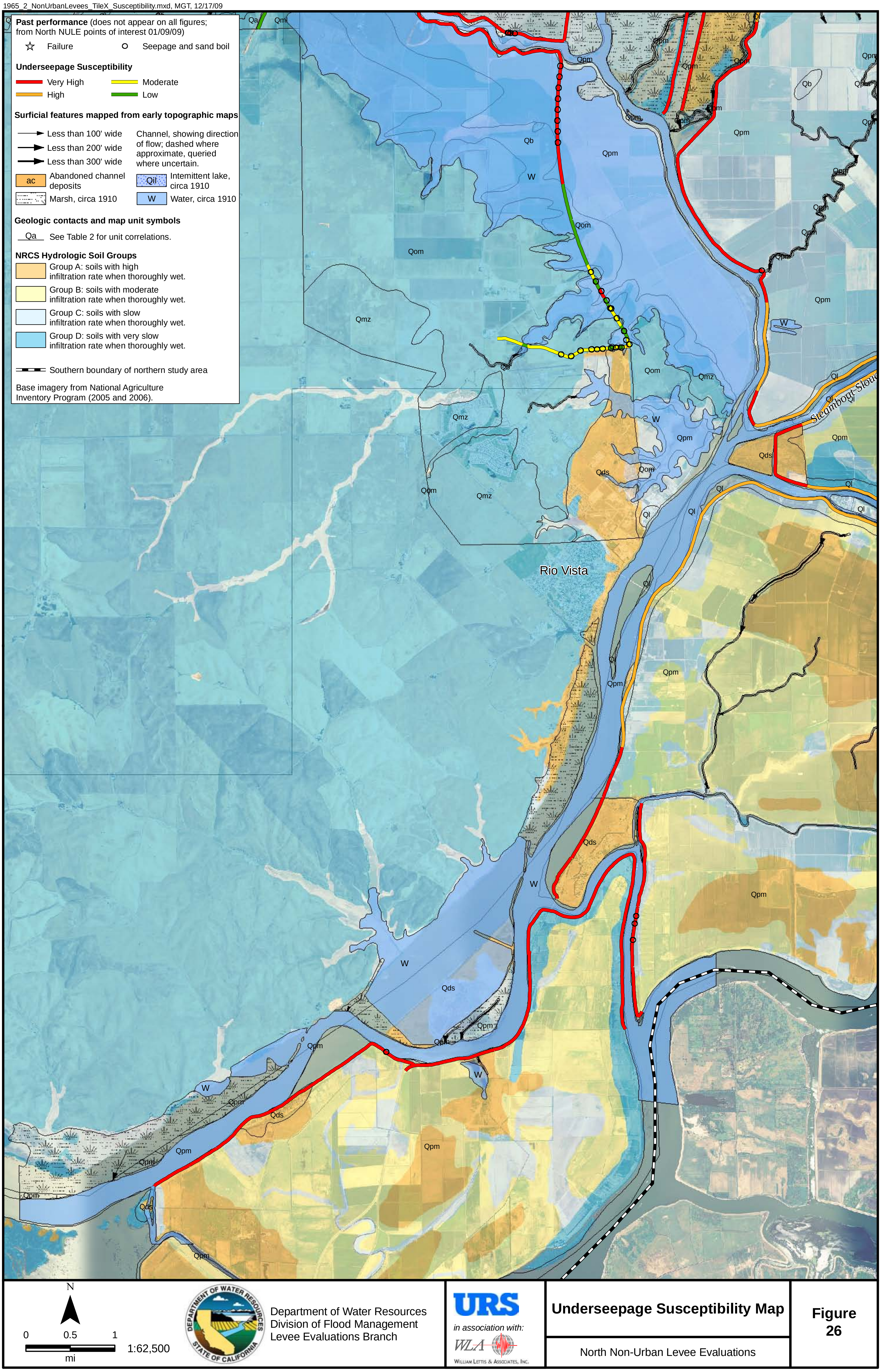
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 25



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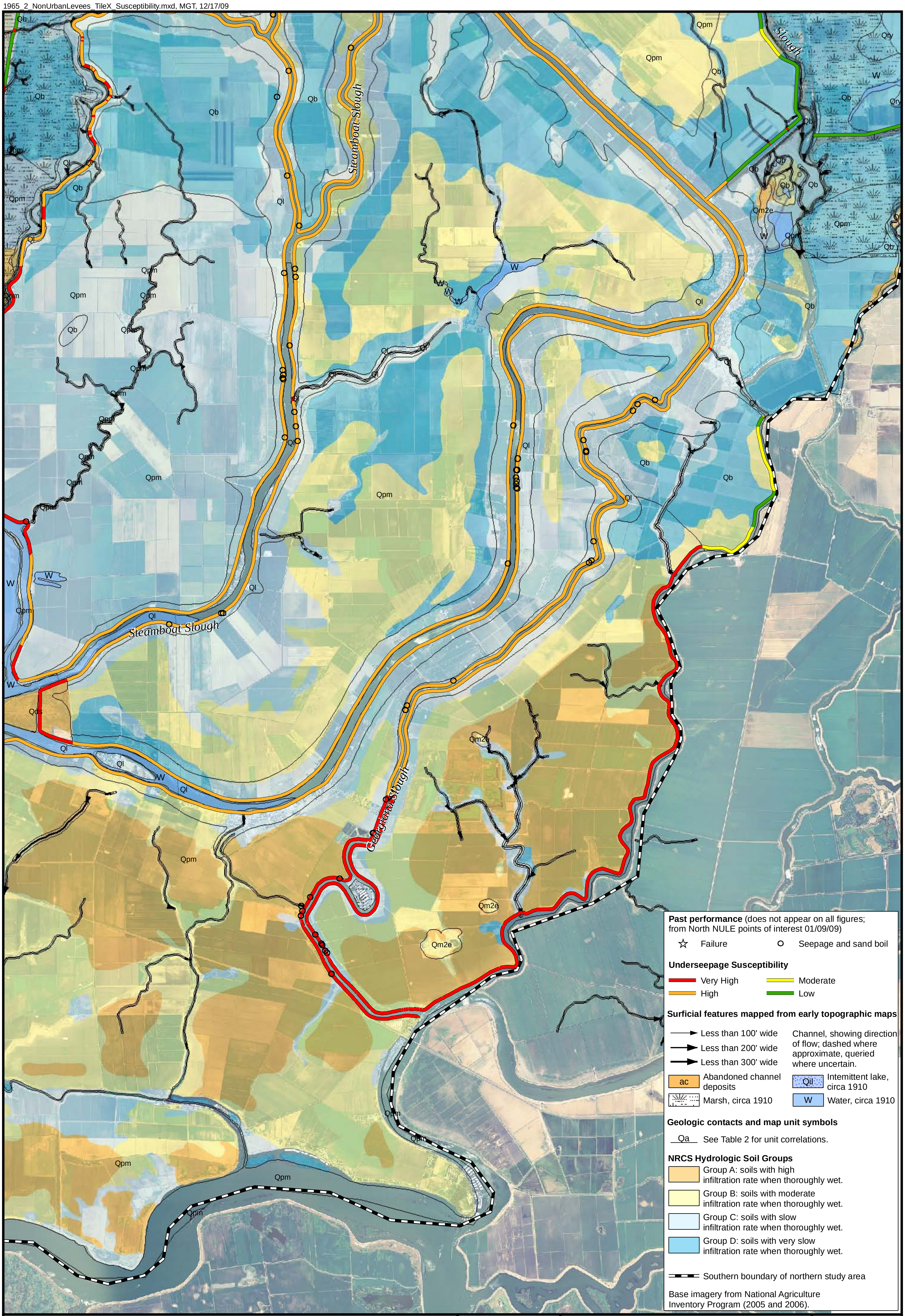
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 26

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



N

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1:62,500

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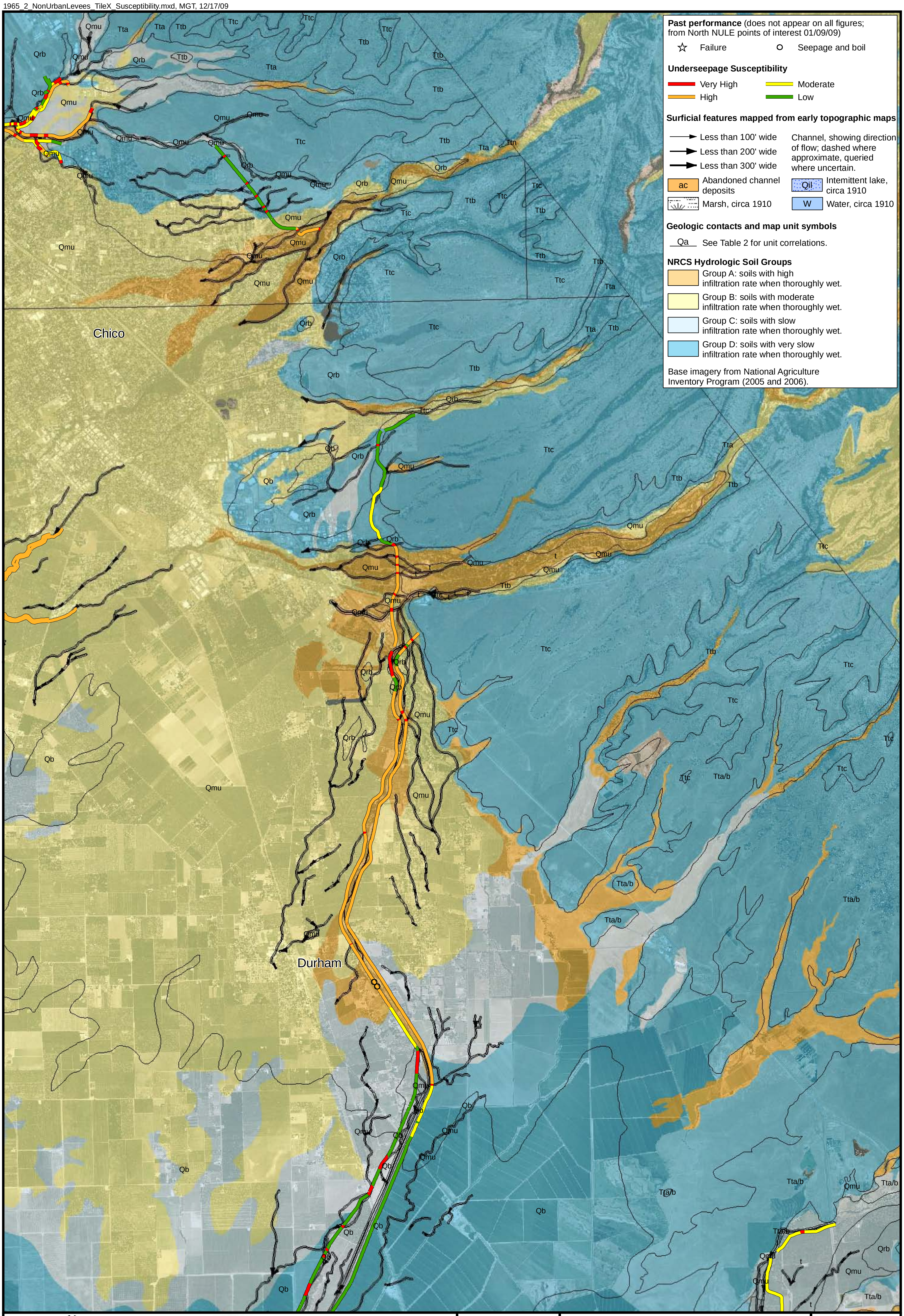
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 27

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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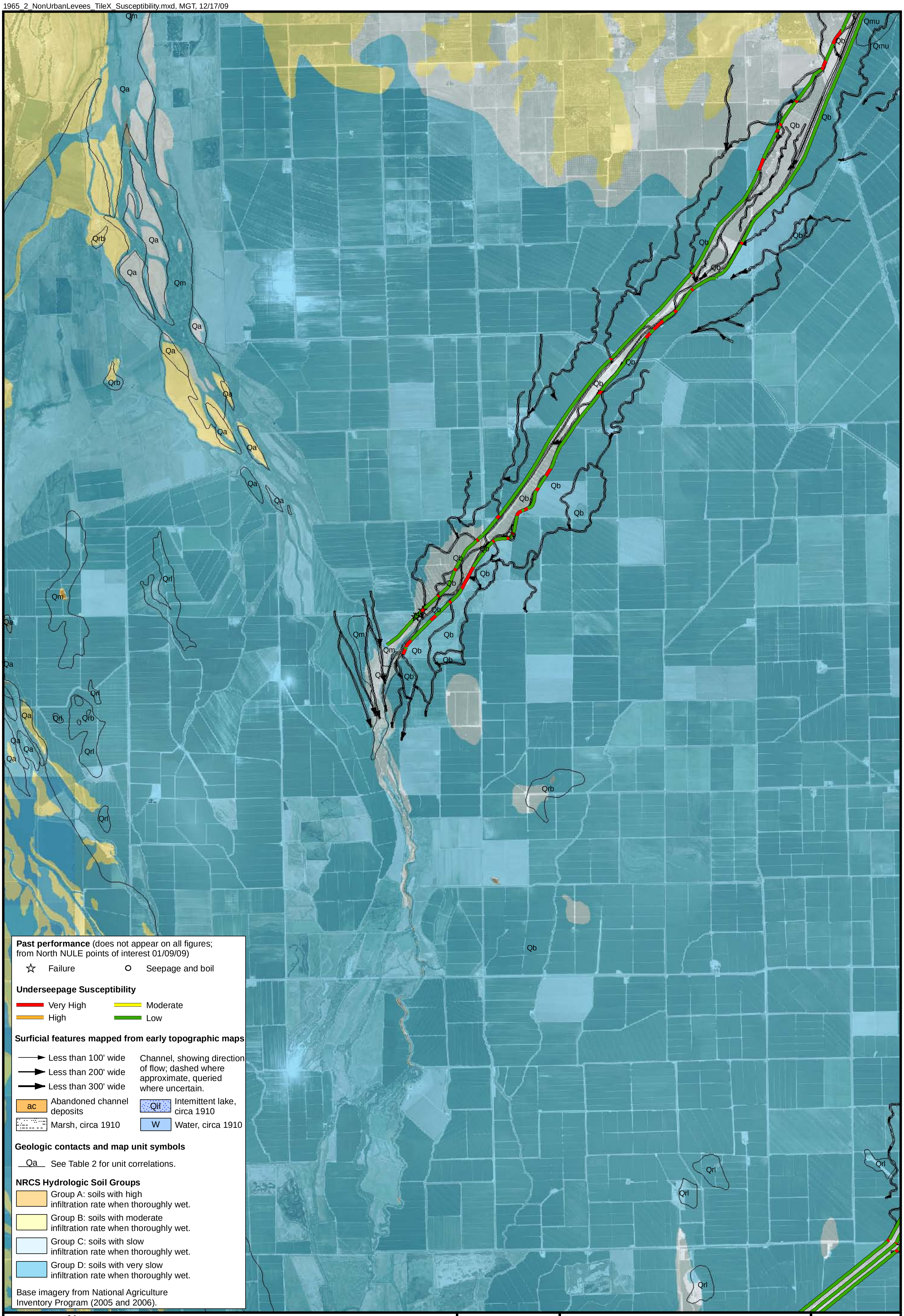
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 28

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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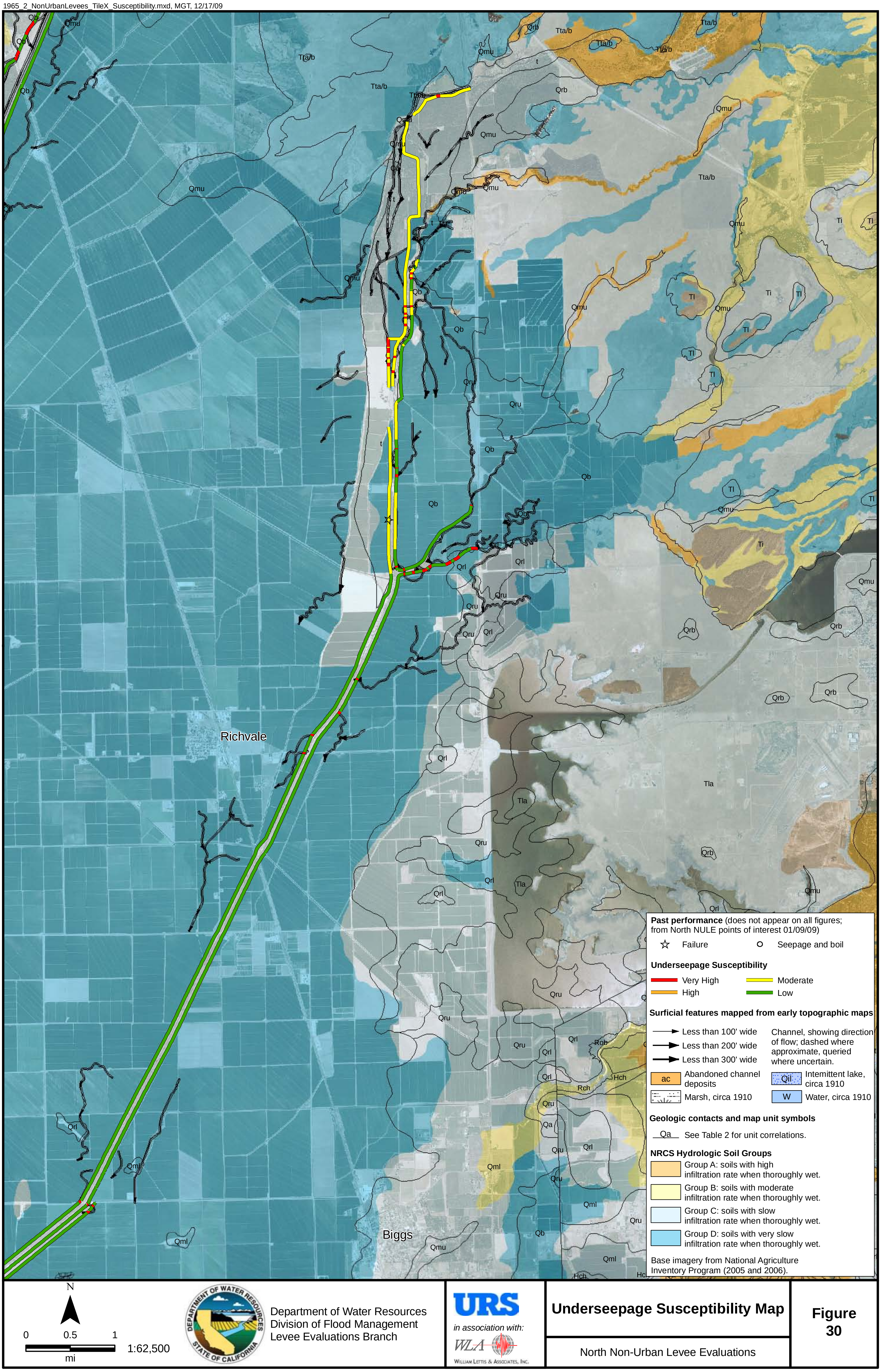
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure
29

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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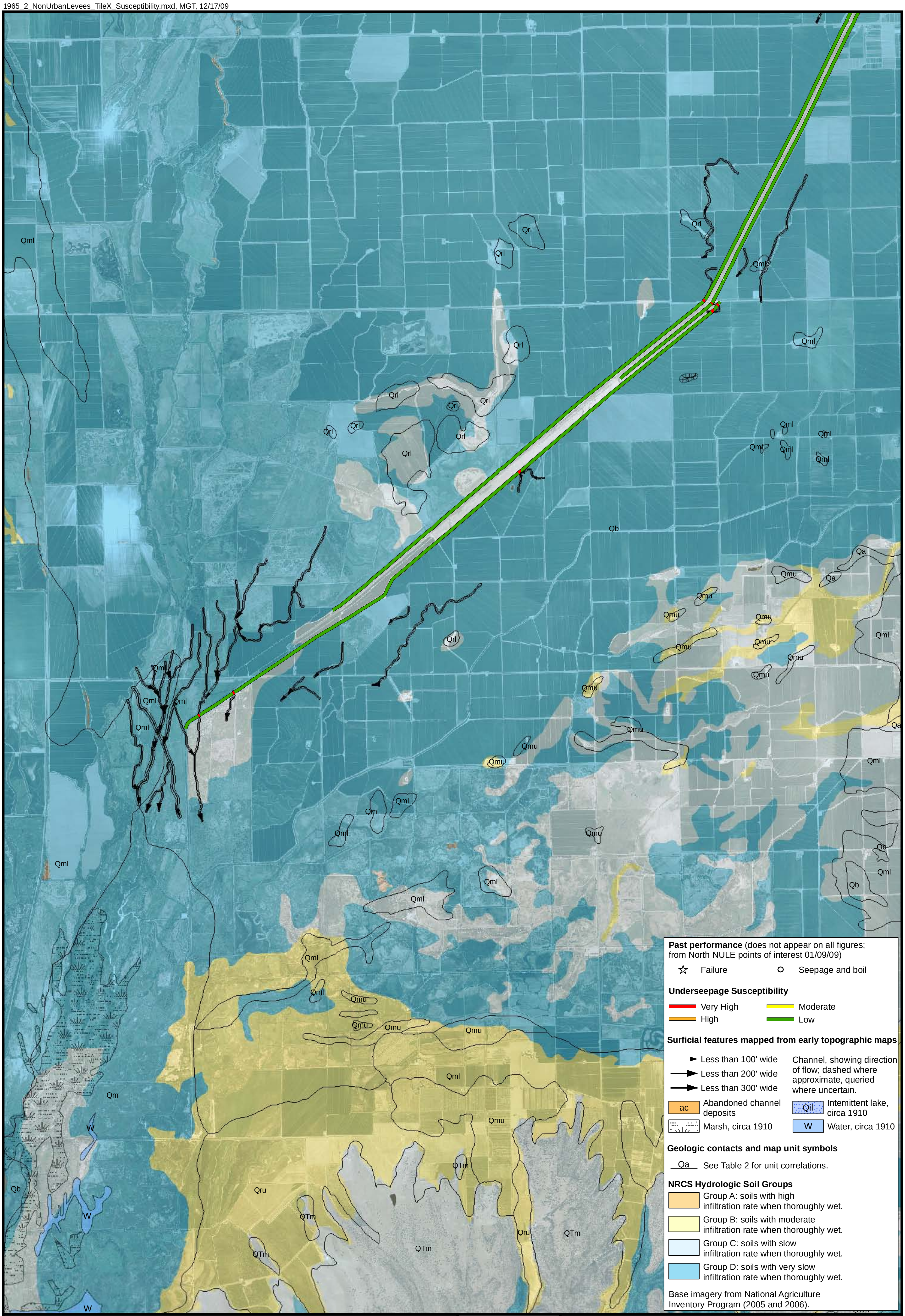
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 30

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



Past performance (does not appear on all figures; from North NULE points of interest 01/09/09)

☆ Failure

○ Seepage and boil

Underseepage Susceptibility

🟥 Very High

🟨 Moderate

🟧 High

🟩 Low

Surficial features mapped from early topographic maps

→ Less than 100' wide

→ Less than 200' wide

→ Less than 300' wide

Channel, showing direction of flow; dashed where approximate, queried where uncertain.

ac Abandoned channel deposits

Qil Intemittent lake, circa 1910

Marsh, circa 1910

W Water, circa 1910

Geologic contacts and map unit symbols

Qa See Table 2 for unit correlations.

NRCS Hydrologic Soil Groups

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Group B: soils with moderate infiltration rate when thoroughly wet.

Group C: soils with slow infiltration rate when thoroughly wet.

Group D: soils with very slow infiltration rate when thoroughly wet.

Base imagery from National Agriculture Inventory Program (2005 and 2006).

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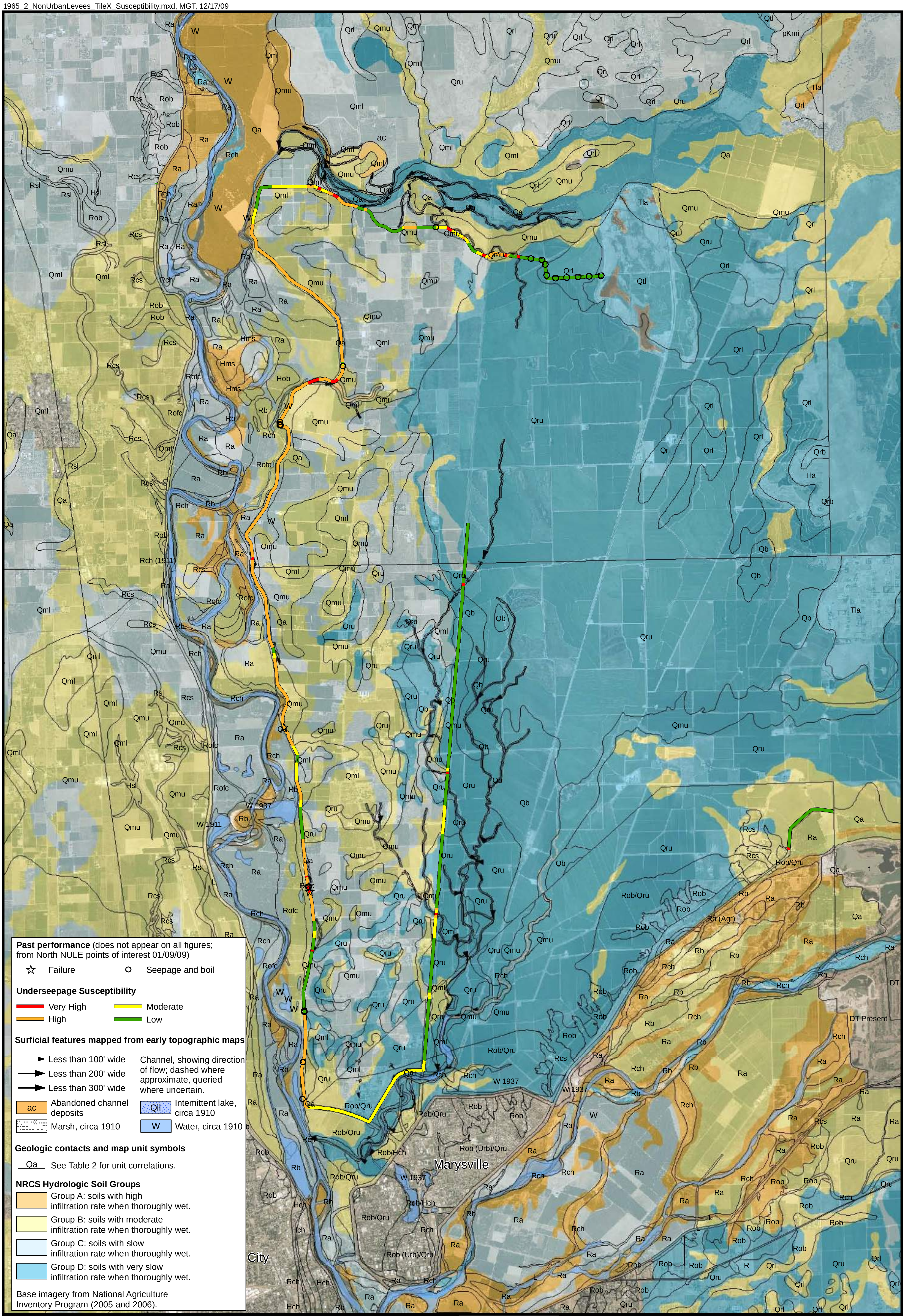
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 31

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



Past performance (does not appear on all figures; from North NULE points of interest 01/09/09)

☆ Failure　　○ Seepage and boil

Underseepage Susceptibility

🟥	Very High	🟨	Moderate
🟧	High	🟩	Low

Surficial features mapped from early topographic maps

→ Less than 100' wide
→ Less than 200' wide
→ Less than 300' wide

Channel, showing direction of flow; dashed where approximate, queried where uncertain.

ac	Abandoned channel deposits	Qil	Intemittent lake, circa 1910
▨	Marsh, circa 1910	W	Water, circa 1910

Geologic contacts and map unit symbols

Qa　See Table 2 for unit correlations.

NRCS Hydrologic Soil Groups

🟧	Group A: soils with high infiltration rate when thoroughly wet.
🟨	Group B: soils with moderate infiltration rate when thoroughly wet.
⬜	Group C: soils with slow infiltration rate when thoroughly wet.
🟦	Group D: soils with very slow infiltration rate when thoroughly wet.

Base imagery from National Agriculture Inventory Program (2005 and 2006).

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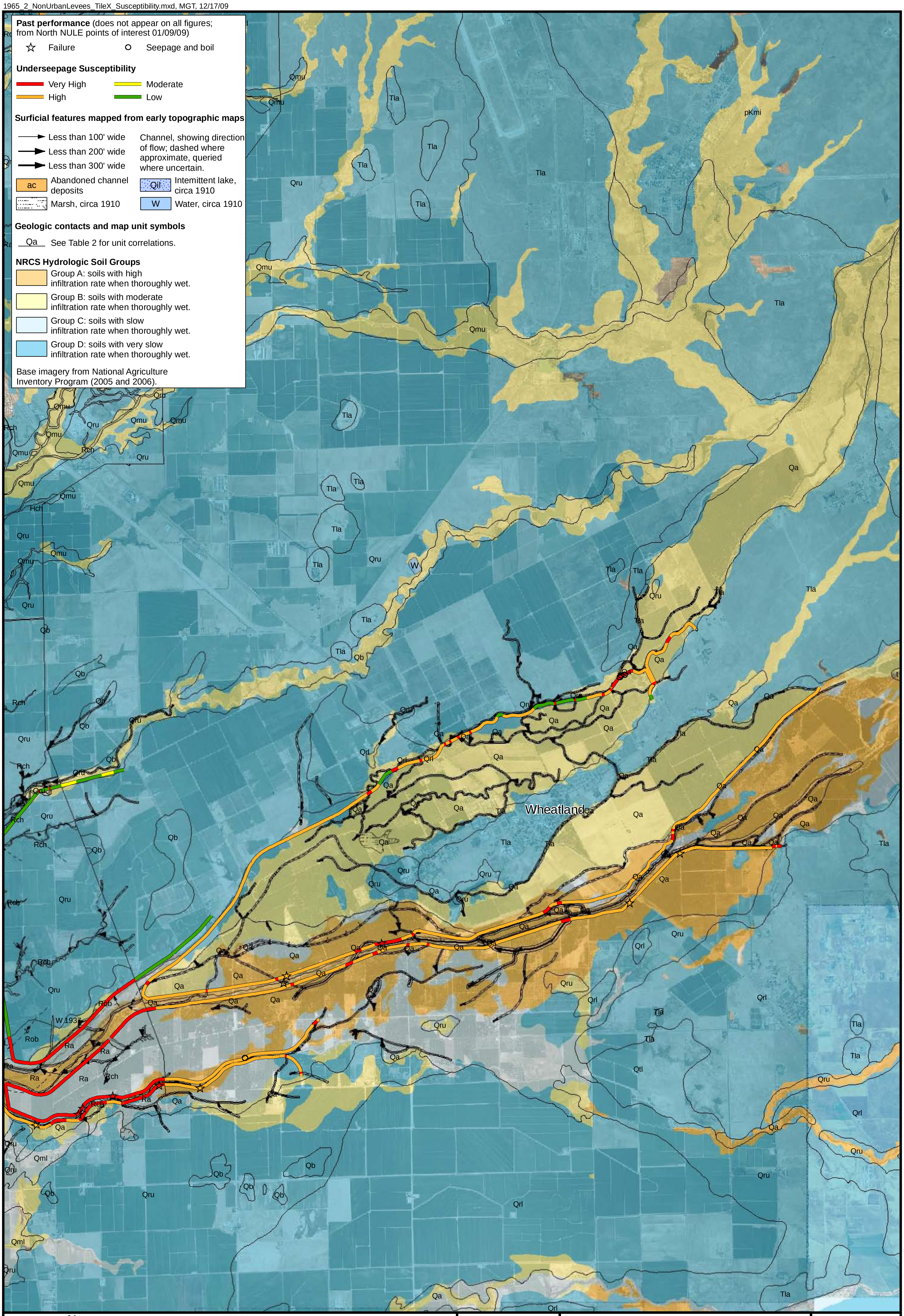
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 32

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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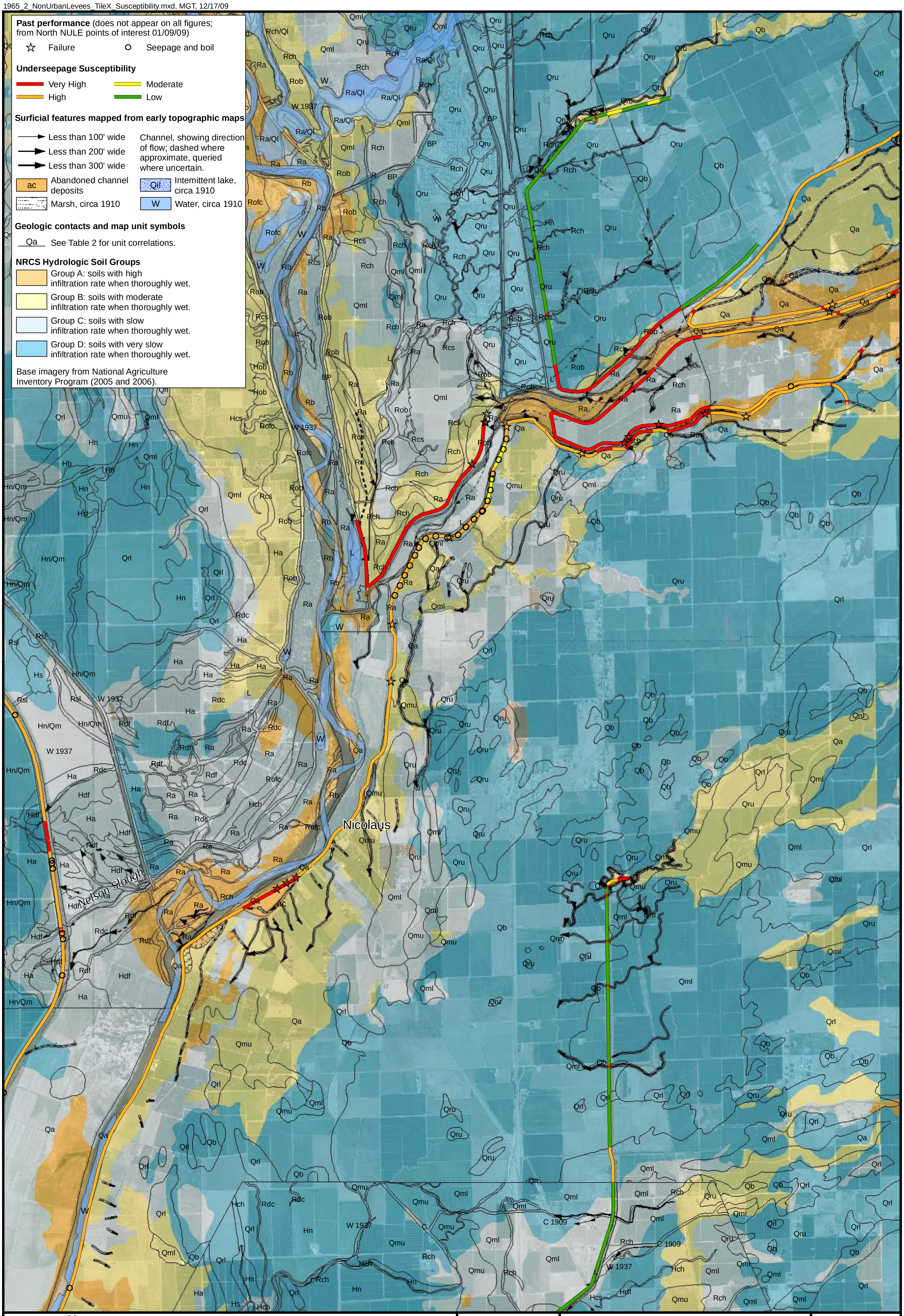
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 33

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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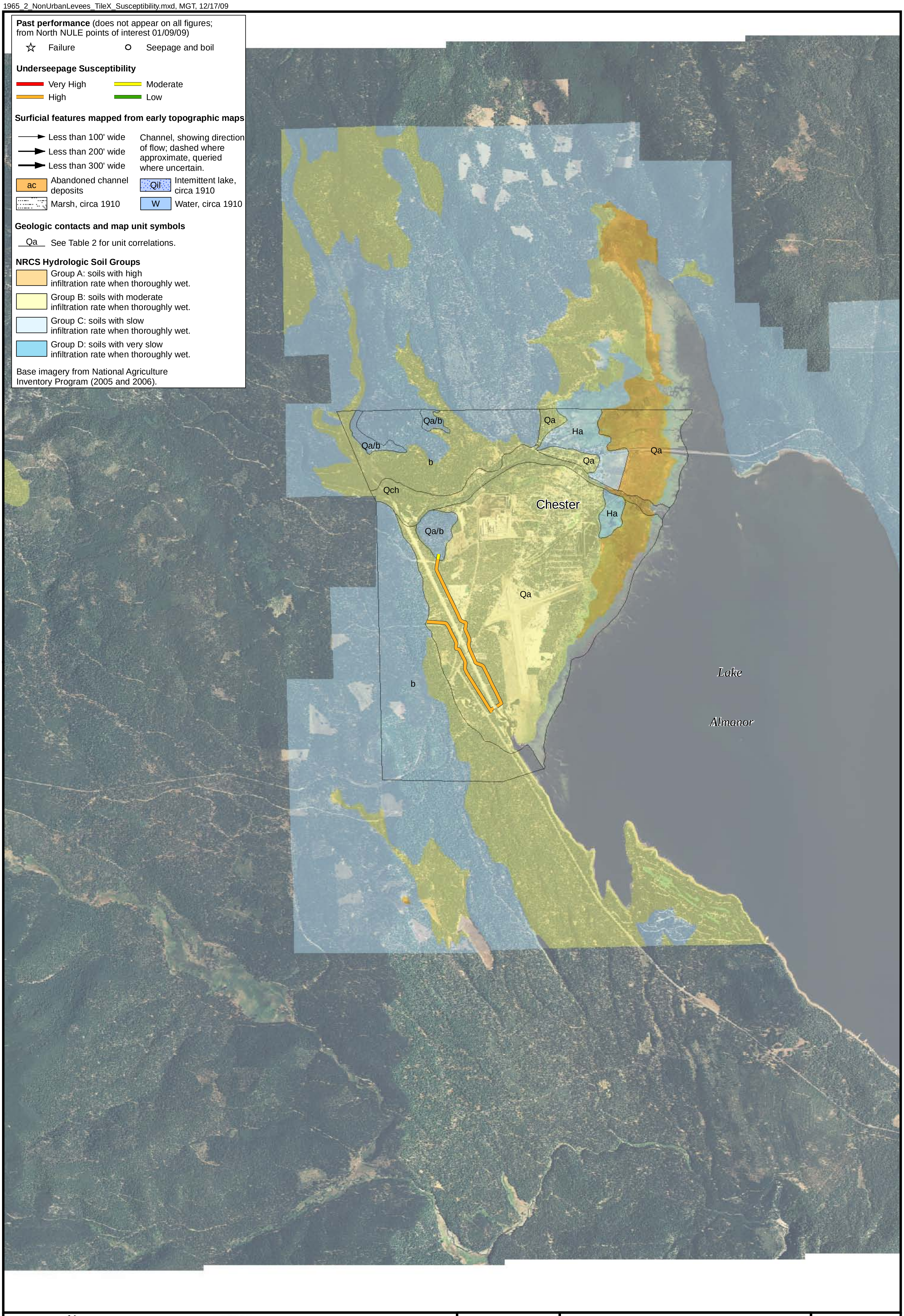
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 34

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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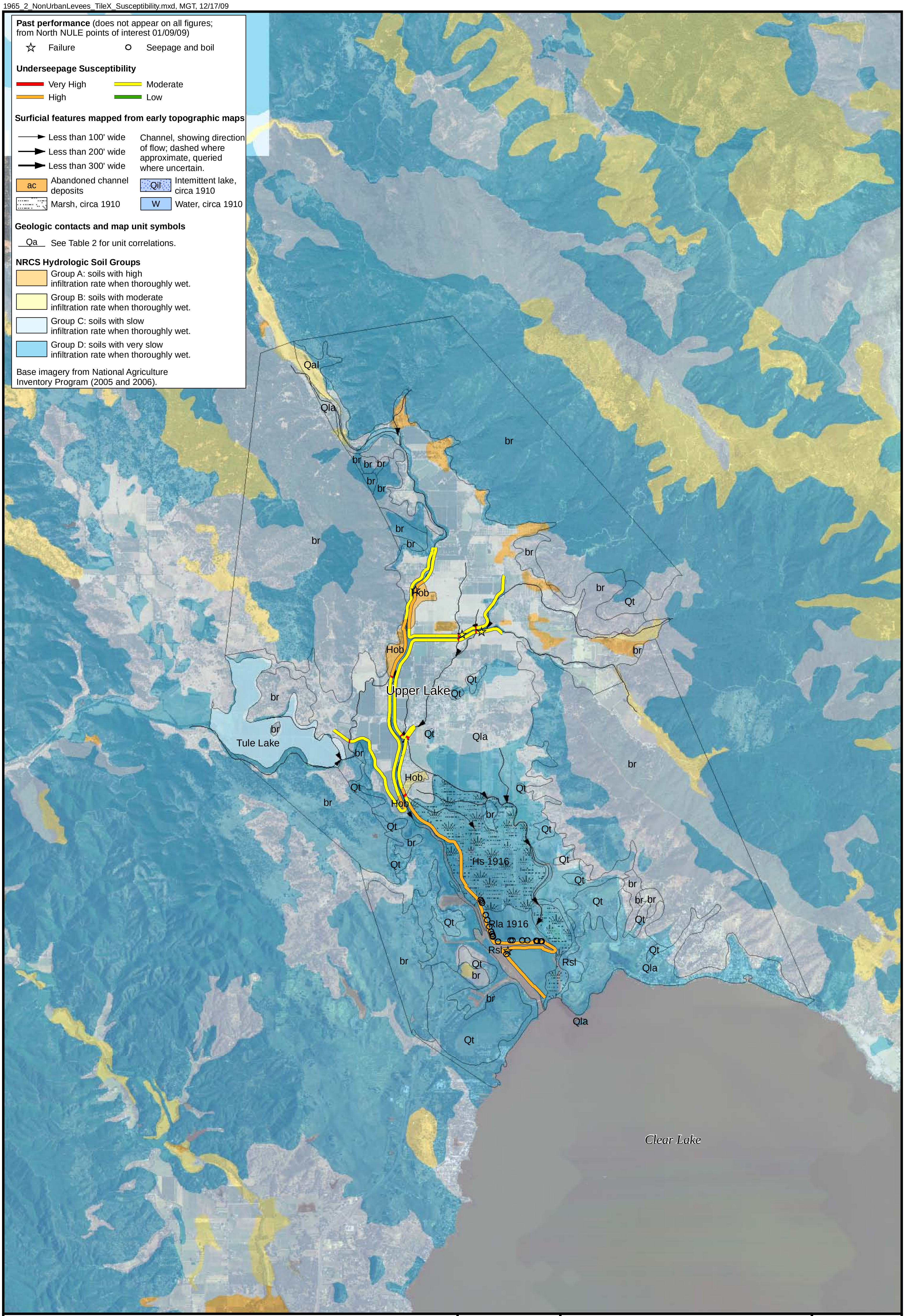
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 35

1965_2_NonUrbanLevees_TileX_Susceptibility.mxd, MGT, 12/17/09



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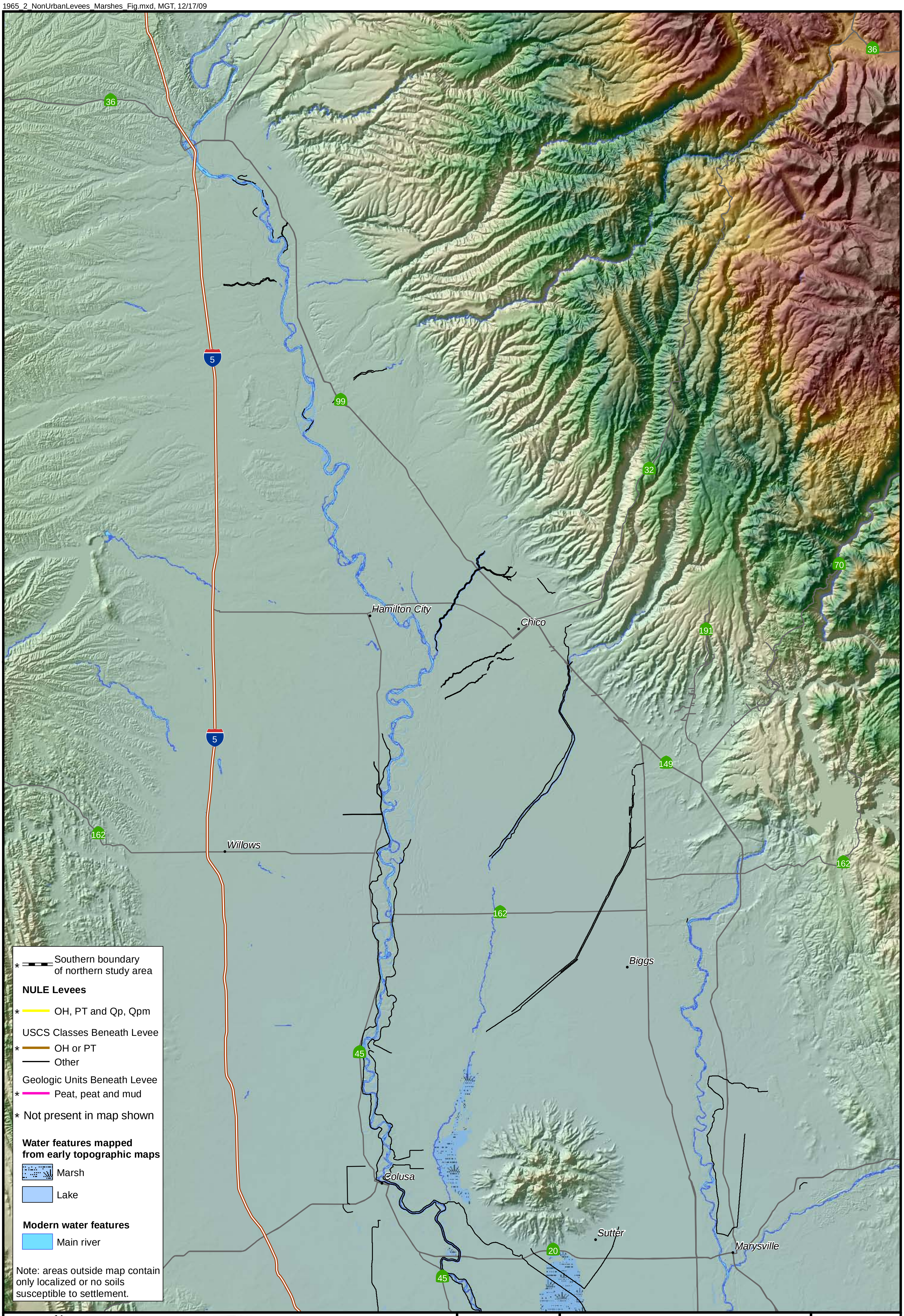
Underseepage Susceptibility Map

North Non-Urban Levee Evaluations

Figure 36

1965_2_NonUrbanLevees_Marshes_Fig.mxd, MGT, 12/17/09



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Miles

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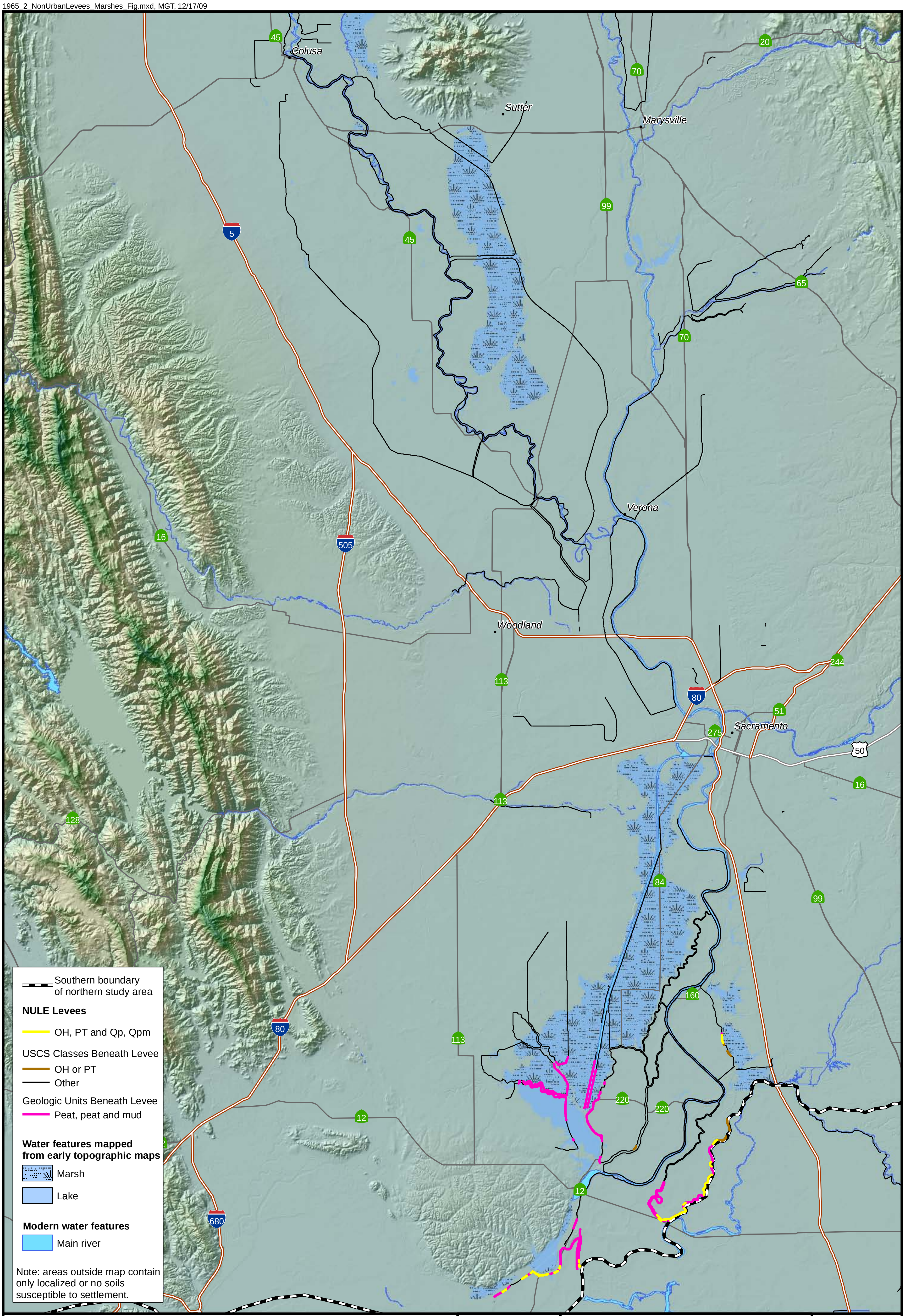
Map of Peat Deposits, Organic Soils, Historical Marshes and Wetlands

North Non-Urban Levee Evaluations

Figure 37a

1965_2_NonUrbanLevees_Marshes_Fig.mxd, MGT, 12/17/09



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Miles

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Division of Flood Management
Levee Evaluations Branch

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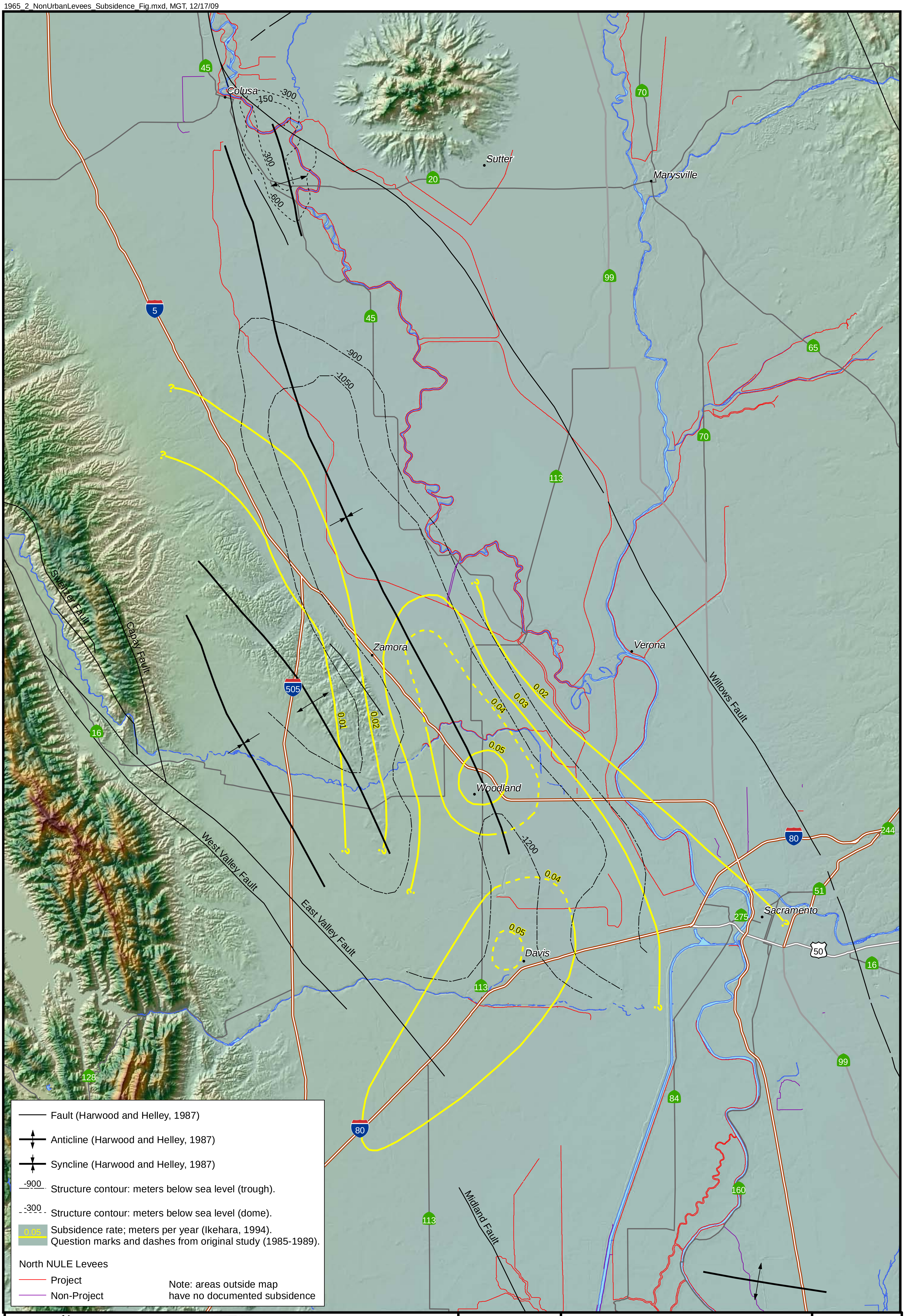
Map of Peat Deposits, Organic Soils, Historical Marshes and Wetlands

North Non-Urban Levee Evaluations

Figure 37b

1965_2_NonUrbanLevees_Subsidence_Fig.mxd, MGT, 12/17/09



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Miles

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Map of Subsidence with
Structural Geologic Features

North Non-Urban Levee Evaluations

Figure 38

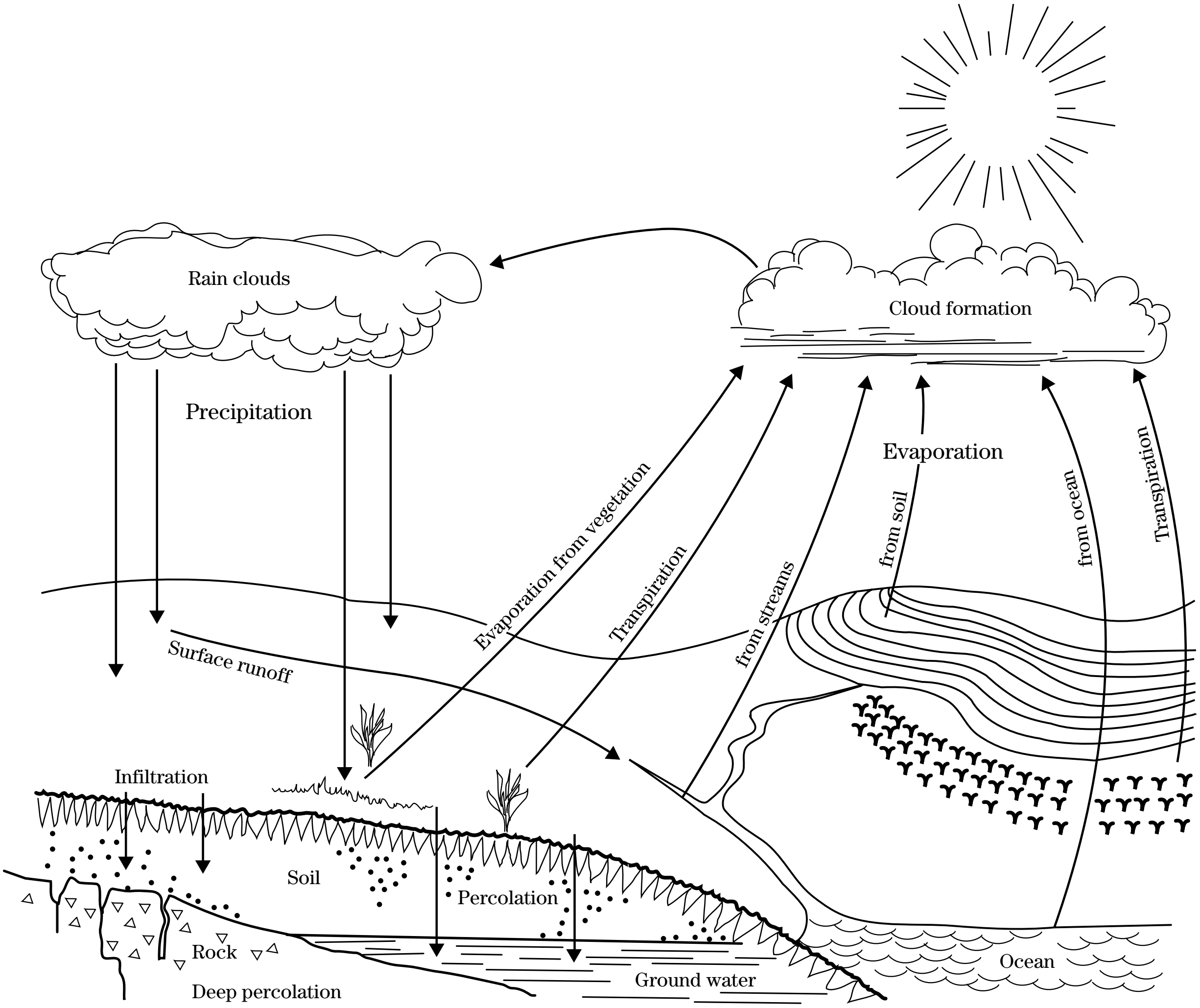
APPENDIX A

United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

Part 630 Hydrology
National Engineering Handbook

Chapter 7 Hydrologic Soil Groups



Issued 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.

Chapter 7 Hydrologic Soil Groups

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Chapter 7 Hydrologic Soil Groups

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 µm/s (>5.67 in/h)	≤40.0 to >10.0 µm/s (≤5.67 to >1.42 in/h)	≤10.0 to >1.0 µm/s (≤1.42 to >0.14 in/h)	≤1.0 µm/s (≤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 µm/s (>1.42 in/h)	≤10.0 to >4.0 µm/s (≤1.42 to >57 in/h)	≤4.0 to >0.40 µm/s (≤0.57 to >0.06 in/h)	≤0.40 µm/s (≤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

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Prepared By	Justin Pearce, Fugro William Lettis & Associates (FWLA), April 2010
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INTRODUCTION

This technical memorandum presents the results of surficial geologic mapping and geomorphic assessment in the North Non-Urban Levee Evaluations (NULE) Project's Study Area along a portion of the Sacramento River and three sloughs south of Courtland, California (Figure 1). Surficial geologic mapping and geomorphic assessment were completed by NULE Project team member Fugro William Lettis & Associates, Inc.

North NULE's South of Courtland Study Area (Study Area) includes approximately 100 miles of non-urban Project levees along Sacramento River, Georgiana Slough, Steamboat Slough, and Sutter Slough (Figure 1) in parts of Solano and Sacramento Counties, California. The river and sloughs in the Study Area are the lowest reaches of the Sacramento Valley fluvial network and extend into the tidally influenced Sacramento–San Joaquin Delta (Bryan, 1923).

The primary goal of this study is assessment of levee foundation underseepage susceptibility hazard through characterization of the type and distribution of surficial and near-surface geologic deposits that underlie the Non-Urban Project levees. Secondarily, this study develops an initial conceptual model that describes the primary geomorphic processes in the Study Area that, in turn, facilitates process-based stratigraphic interpretations. Plate 1, Sheet 1 (northern portion) and Plate 1, Sheet 2 (southern portion) present the surficial geologic map and levee foundation underseepage susceptibility results.

TECHNICAL APPROACH

The geomorphic assessment involved the integration and analysis of aerial photography, topographic maps, geologic maps, soil maps, historical documents, and field reconnaissance. Synthesis of these data informed the development of a detailed surficial geologic map, assessment of the primary geomorphic processes responsible for distributing or modifying surficial deposits in the Study Area, and creation of levee underseepage susceptibility hazard maps.

The Project team analyzed the following data:

- 1937 aerial photography (Table 1a)

Table 1a. Aerial Photography.

County Code	Roll Number	Frame Numbers
ABC	49	1 through 4
ABC	49	33 through 45
ABC	50	1 through 15
ABB	112	72 through 87
ABC	53	30 through 36
ABO	53	72 through 79

- Early and modern topographic maps (Table 1b)
- Published surficial geologic maps (Atwater, 1979, 1982; Helley and Harwood, 1985)
- Early and modern soil survey maps (Holmes et al., 1913; Carpenter and Cosby, 1930; Tugel et al., 1992)

Table 1b. USGS Topographic Maps.

Quadrangle Name	Publication Date	Photo Revision Date	Series	Scale	Survey Date
Courtland	1908	N/A	15-Minute	1:62,500	N/A
Isleton	1910	N/A	7.5-Minute	1:31,680	N/A
Rio Vista	1910	N/A	7.5-Minute	1:31,680	N/A
Jersey Island	1910	N/A	7.5-Minute	1:31,680	N/A
Courtland	1978	1993	7.5-Minute	1:24,000	N/A
Isleton	1978	1993	7.5-Minute	1:24,000	N/A
Rio Vista	1978	1993	7.5-Minute	1:24,000	N/A
Jersey Island	1978	1993	7.5-Minute	1:31,680	N/A

Through surficial geologic mapping, primary geomorphic features and associated surficial geologic deposits such as distributary channels, former tidal marsh sediments (peat and mud), and Holocene through historical flood deposits are identified.

WLA conducted field reconnaissance to confirm the nature of the geologic units and their geomorphic relationships. Areas of close inspection included the natural levee landforms and deposits along the Sacramento River, Georgiana Slough, and Steamboat Slough, peat and muck deposits in the island interiors, and slough deposits in the island interiors including Beaver Slough and Jackson Slough. General geomorphic features and relationships were reviewed for the larger study area from Highway 12 to the Paintersville bridge over the Sacramento River, near Courtland, California.

The Study Area's surficial geologic map (Plate 1 (Sheets 1 and 2)) was developed at the nominal scale of 1937 aerial photography (approximately 1:20,000) and is presented at 1:24,000-scale. The map should not be used or displayed at scales greater than 1:24,000. Solid map unit boundaries shown on the surficial geologic map should be considered approximate, and are accurate to within about 100 feet on either side of the line shown on the map; dashed contacts are accurate to within about 250 feet on either side of the line. Contacts that occur within the same geologic unit delineate allostratigraphic units. Allostratigraphic units are mappable layers or bodies identified on the basis of bounding discontinuities (Boggs, 1995). This approach is used to provide insight on surficial depositional history and activity within age categories.

Mapping shown on Plate 1 (Sheets 1 and 2) is based on analysis of 1937 aerial photography, along with early and modern soil surveys, and early topographic maps. A site visit was conducted to field check the office-based mapping. The 1937 aerial photographs are the primary data set for interpreting surficial geologic deposits because they are the oldest available high-quality images pre-dating much of the cultivation and landscape alteration in present-day Solano and Sacramento Counties. Therefore, the map depicts geologic deposits laid down before 1937. When synthesized, the map and photographic data provide key insights to the characteristics of deposits beneath the levees and serve as a technical framework for assessing underseepage susceptibility in the South of Courtland Study Area.

Levee foundation underseepage hazard analysis involves the spatial intersection of surficial geologic map data with NULE Project levee lines. Underseepage susceptibility category assignments (Table 2) are based on geologic age and depositional environment, as well as inferred relative permeability. The hazard assignments were tested during the Level 2-I geomorphology work phase by analyzing levee past performance data as an indicator of future underseepage susceptibility.

GEOLOGIC SETTING

The Study Area lies near the downstream end of the Sacramento River where the river flows through the Sacramento-San Joaquin River Delta. Fluvial and deltaic processes interact to produce the characteristic deposits of this area. Although the entire Study Area lies within the boundary of the Delta as established by the California State Lands Commission (Section 12220 of the Water Code) (Figure 1), surficial deposits and geomorphic processes grade from those characteristic of a more fluvial environment in the northern part of the Study Area to those characteristic of a more deltaic environment in the southern part of the Study Area.

This Study Area includes about 24 miles of the lower-most Sacramento River and sloughs, between Courtland and Rio Vista (Figure 1). Within this Study Area, the Sacramento River flows into and through the legal and physiographic Sacramento–San Joaquin Delta (the Delta). The Delta is aptly named because when inundated by floods, the rivers, tributary creeks and slough channels discharged into a wide body of relatively motionless water (Vaught, 2006).

The Delta has been the subject of many scientific, engineering, and policy studies over the last several decades. The intent of the following paragraphs is to summarize the primary geologic and geomorphic aspects of the Delta to provide general context for the physical setting. This section therefore provides an overview of the Delta's geologic evolution, a description of the natural Delta island and tidal marsh environment, and summarizes the ways in which hydraulic gold mining, reclamation of marshes, and construction of levees have contributed to present-day conditions within the Delta.

Geologic Evolution

The San Francisco Bay and Sacramento–San Joaquin Delta developed over the past 1 million years (Helley et al., 1979), shaped by active tectonic and geologic processes. The present configuration of the Delta is an inland tidal marsh that drains to the ocean through a series of bays and straits. Because the area is very near sea level, major changes in sea level and shoreline caused by global climactic fluctuations over the Quaternary (past approximately 2 million years) have left their geologic imprint on the Bay and Delta (Atwater et al., 1977). Under glacial conditions sea level was at a low-stand, alluvial plains were exposed, wind-blown sand dunes accumulated, and rivers incised to grade to an ocean level 300 to 400 feet below present elevations and a coastline several miles west of its present day position (Shlemon, 1967). During climactic warm periods (i.e. Holocene), sea levels achieved high-stands that filled or partially filled the Bay and Delta, with consequent deposition of alluvial, deltaic, and estuarine sediments.

About 15,000 years ago at the close of the last glacial period, sea level began to rise as glaciers in the higher latitudes began to melt. Subsequent vertical changes and eastward-transgression in sea level in the San Francisco Bay area are recorded by tidal-marsh deposits located at the base of Holocene estuarine sediments (Atwater et al., 1977; Atwater, 1980). The local geologic record of Holocene sea-level changes indicates that the rising sea entered the Golden Gate 10,000-11,000 years ago (Helley et al., 1979). The then newly formed bay spread across land areas as rapidly as 100 feet (30 m) per year. The ocean reached its present level at about 6,000 year ago (Helley et al., 1979). As sea level rose throughout the early Holocene, the base levels of the streams in the bay region were raised slightly, the younger alluvial sediments were deposited on the supratidal flood plains around the growing bay, and the younger bay mud was deposited beneath the rising water. Delta inundation rates decreased substantially since about 6,000 years ago (Malamud-Roam et al., 2007) such that the pace of sea level rise was slow enough to allow tidal marshes and ecosystems to form in close connection with sea level position (URS, 2007). The geologic evolution of the Delta thus results in Holocene (interglacial) peat and mud that have spread across and over coarser-grained latest Pleistocene alluvium. Another result of sea-level rise is silty and clayey Holocene river alluvium that extends into and overrides the Delta peat and mud as natural levees (Atwater, 1982). The height and breadth of the natural levee landforms decreases in the downstream direction in the Study Area (W.E.T., 1990).

Delta Islands and Tidal Marsh Environment

Prior to 1850, the Delta included landforms that are typical of many classic deltas – distributary channels bordered by natural levees and separated by tidal marshes and wetland islands (Atwater, 1980). The center of each Delta island was nearly flat to gently saucer-shaped, and at a few feet above or below sea level. The saucer-like island interiors were covered with thickets of tules that high tides inundated with 6 to 12 inches of water for 1/2 to 2 hours, twice a day (Thompson, 2006). Under natural conditions these islands were covered with water throughout a large part of the year and were always flooded at river high stage.

Tules, reeds, and other fibrous aquatic plants growing at water level were preserved as peat beds when sea levels slowly rose and inundated the present Delta. Organic material in the Delta accumulated faster than it could decay, allowing peat deposits to persist (Atwater and Belknap, 1979). The high groundwater table and standing surface water kept the peat wet and supported the marsh plants and shrubs. The water and plant life protected the peat from wasting by oxidation, shrinkage and deflation. The Delta's tidal wetlands were rooted in beds of fibrous plant material that graded downward into peat, deposits of which are thickest under the Delta's west-central islands (USACE, 1987). Along the upland margin of the Delta, freshwater marshes merged with flood basin marshes of slightly higher elevations. Although the wetland vegetation species in freshwater marshes were similar to those in flood basin marshes, the underlying soils are different because the flood basins dried out every summer, preventing peat accumulation (URS, 2007). The deepest known peat in the Delta underlies Sherman Island and extends 60 feet below sea level (USACE, 1987).

Mining Debris Sedimentation

Significant alteration of the Sacramento River and its watershed began in the mid-to-late 1800s with the onset of gold mining. Gold-rich gravel deposits underlie watersheds of the Sacramento River basin including the Mokelumne, American, Bear, Yuba, and Feather Rivers, as well as Butte and Cherokee Creek watersheds in the Redding area (Domagalski et al., 2000). Hydraulic mining activity in the watersheds draining the Sierra Nevada began with earnest in 1852-3 with the development of high-pressure water hoses and nozzles also called "monitors" (Gilbert, 1917). The detrital material, initially fines with sand (called slickens), and later gravel and larger clasts, was washed from the hillsides and into the river valleys. This, in combination with large flood events (e.g.,1862, 1867-8, 1881 floods) transported the mining debris downstream and supplied a substantial amount of sediment to many rivers draining into the lower Sacramento River, and the Sacramento River itself, in a very short period of time. The excessive sediment supplied resulted in aggradation (i.e. backfilling) of the channel and consequent decrease in channel cross section area that exacerbated flooding and deposition of mining debris (James, 1999). The discharging or dumping of hydraulic mining debris and tailings into rivers drainages was "enjoined" or halted in 1884 by a lawsuit decision from Judge Lorenzo Sawyer (Ellis, 1939). Further legal decisions in 1893 (i.e. the Caminetti Act) created the California Debris Commission (CDC), under which hydraulic mining was regulated in such a way as to prevent "injury" to the navigable waters of the Sacramento River. In short, hydraulic mining was allowed when licensed by the CDC which required the impoundment of the mine tailings (e.g. debris dams).

Gilbert (1917) estimated 1,400,000,000 cubic yards of sediment were delivered by the tributaries to the Sacramento River over a 65-year period from 1850 to 1915. Some of this material was washed to the San Francisco Bay, some of the material was deposited in stream valleys, some on the floodplains and flood basins, some within the river and slough channels, and some in the Delta marshes and islands. Gilbert (1917) estimated the volume of mining sediment deposits on "inundated lands, including tidal marshes" at about 294,000,000 cubic yards as of 1914.

The influx of mining detritus also filled the Study Area sloughs and channels such that mechanized dredging was required to maintain channel cross-section area for navigation and flood conveyance (Thompson, 2006). Commonly, the dredge spoils taken from the river were used as material to construct or augment flood control levees in the Study Area (DWR, 1995). Dredging technology and efficiency dramatically improved with the advent of hydraulic dredges in 1879, but clam-shell and bucket dredgers also were used to dredge channels. As the reach of the long-boom clamshell dredge increased, so did the ability to dredge from the river and build the artificial levee. Long-boom clamshell dredges performed much of the levee building in the formerly swampy bottomlands (Thompson and Dutra, 1983). Furthermore, it was common practice to mantle or "top dress" the fragile levee systems with fresh dredged material at intervals of 1 to 3 years (Thompson, 2006). The frequency and extent of levee dressing dropped in the 1930s and 1940s.

The transport and deposition of mining debris sediment within major and tributary channels and on floodplains had three results: (1) early complaints, and ultimately legal action, from valley farmers that the deposition of mining debris sediment (slickens) destroyed or impaired agriculture; (2) the construction of levees very close to river banks in order to protect arable land and also to encourage fluvial scour of the aggraded channel material; (3) dredging and widening of channels and sloughs in the Delta to remove accumulated sediment, build up levee prisms (top dressing), and improve navigation (Gilbert, 1917; James, 1999; Thompson, 2006; James et al., 2009).

Delta Reclamation, Levees, and Subsidence

While an exhaustive description of detailed levee construction history is beyond of the scope of this study, a brief qualitative synopsis of key events is important in understanding the surface evolution and foundation deposits laid down prior to the construction of the levees. Within the Study Area, levee construction is closely tied to "reclamation" of the tule swamps that covered the Delta's islands. Under the Swamp and Overflowed Land Act of 1850, marshland was converted to agricultural land through burning of tule vegetation, construction of drainage ditches, and construction of levees and drainage pumps. The government-sanctioned "reclamation" destroyed the original depositional environment and arrested natural geomorphic processes. The Swamp and Overflowed Land Act of 1850 allowed the State to sell land cheaply, which it did so with the caveat that it be reclaimed for cultivation. Land owners quickly realized that drainage and artificial levees would need to be constructed to make and keep the reclaimed land viable for cultivation.

Early levee systems in the Delta were made from blocks of peat during the 1860s (DWR, 1995), and were very short and the materials very weak. These discontinuous levees were easily eroded or destroyed by the tides and waves. A major flood occurred in 1862 that inundated nearly all of the Delta area, as described in Vaught (2006): *"From east to west, the waters of the Sacramento River spread well beyond the Tule, drowning the region in a torrent twelve miles wide and ten feet deep."* Another major flood also occurred in 1867; both floods transported and deposited sediment on the land surface, including upstream-sourced mining debris.

In 1868, the State legislature removed limitations on acreage of swamp and overflowed land that an individual could hold and there after the process of reclaiming the land (i.e., leveeing, burning tules) progressed with earnest. Sherman Island levees, the first to completely enclose an island, were constructed by 1869 and averaged 12 feet wide at the base and 3 to 4 feet tall (Thompson and Dutra, 1983). Levees along other Delta islands were also constructed soon afterwards, with Twitchell Island levees completed 1870-71. Steamboat Slough levees were still under construction by steam-powered dredges during the large flood of the Sacramento River in 1889[1].

Therefore, there was a period of about 16 years (between about 1852-3 and 1869) wherein mining debris likely was emplaced over the streams and sloughs natural levees. This period corresponds to the dramatic increase in hydraulic mining efficiency and massive sediment delivery to channels coupled with extremely large flood events prior to systematic leveeing.

Because of soil draining, conversion to farming, and construction of levees, most islands in the Study Area (and greater Delta) lie well below sea level (Figures 2 and 3). This land subsidence[2] primarily is the result of the loss of organic soil (peat) (Ingebritson et al., 2000). When peat soils are drained, outside air fills the pore spaces and the organic materials aerobically decompose, oxidize, lose volume and compact. In addition, intentional burning of the fields causes loss of peat through combustion, and agricultural tilling of organic and peaty soils exposes these light-weight organic materials to wind erosion resulting in deflation of the land surface (Mount and Twiss, 2005). Much of the enclosed areas of the central islands now are 10 or 15 feet below sea level; some places are closer to 20 feet below sea level (Figure 3). The shallow-saucer shaped islands of 150 years ago have become deep bowls. Much of the elevation loss occurred between 1897 and1918, when tracts and islands were first enclosed with levees built by dredges and kept free of water by use of pumps. Since then, the island floors have continued to subside (Figures 2 and 3). The elevation difference between the river or slough on one side of the levee and the lower island surface on the other side of the levee has resulted in increased hydrostatic pressure against the levees and underlying porous peat (Mount and Twiss, 2005).

SURFICIAL GEOLOGIC MAPPING

Previous Quaternary geologic mapping in the North NULE Delta Study Area includes 1:250,000-scale mapping by Strand and Koening (1965) and Wagner et al., (1981), 1:62,500-scale mapping by Helley and Harwood (1985), and Atwater's mapping (Atwater, 1979; 1982) at 1:24,000-scale. These data are used as an overall framework for more detailed mapping of surficial geologic deposits at a scale of 1:24,000 (Plate 1 (Sheets 1 and 2)). This study synthesizes Atwater's (1982) seminal

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[1] Sacramento Daily Record-Union newspaper, December 14, 1889, page 5 column 4.

[2] The American Geological Institute's Glossary of Geology defines the term subsidence as: "A local mass movement that involves principally the gradual downward settling or sinking of the solid Earth's surface with little or no horizontal motion and that dos not occur along a free surface (such as landslide). The movement is not restricted in rate, magnitude, or area involved. Subsidence may be due to: natural geologic processes such as solution, erosion, oxidation, thawing, lateral flow, or compaction of subsurface materials; earthquakes, slow crustal warping, and volcanism; or man's activity such as removal of subsurface solids, liquids, or gasses and wetting of some types of moisture-deficient loose or porous deposits."

mapping and delineates additional individual deposits based on relative age and depositional process or environment. The mapping depicted on Plate 1 (Sheets 1 and 2) are based on synthesis of existing mapping, detailed analysis of 1937 aerial photography, and early soil survey and topographic maps, and limited field reconnaissance. The mapping, therefore, is essentially a snapshot of geologic conditions circa 1937. The following paragraphs describe the mapping shown on Plate 1 (Sheets 1 and 2) including the general distribution of units, mapping criteria, characteristic soil relationships and geologic observations based on the mapping.

River, flood basin, and tidal marsh processes are not entirely separate. Rather, the processes represent a continuum across which the depositional environments are hydrologically and geomorphically linked. Because there is a continuum between river, flood basin, and tidal marsh depositional processes, the geologic contacts between the two deposits (or environments) often is gradational (transitional) rather than discrete.

Distribution of units

The deposits within the Study Area are from floodwaters of the Sacramento River and its distributaries, and were modified in low-lying areas by deltaic and estuarine processes. Micro-depositional environments within this setting have produced mappable deposits that differ from one another in grain size, sorting, or organic content. Channel natural levees, flood basins, and fresh water marshes are all components of the floodplain that itself is traversed by distributary, slough, and abandoned channels. Natural levees flank the margins of many active channels and sloughs. Associated overbank and crevasse splay deposits are present along the natural levee and extend toward the adjacent Delta. The overbank and crevasse splay deposits vary in lateral extent. Freshwater marsh deposits are present northwest of Sutter Island and northeast of Walnut Grove. Flood basin deposits are within Sutter Island and directly west of Sutter Island (Plate 1, Sheet 1).

Within the margins of the Delta the natural levee deposits grade laterally into peat and muck deposits of the tidal marsh islands (Plate 1 (Sheets 1 and 2); Ryer, Grand, Andrus, Brannan, and Twitchell Islands). Peat and muck deposits locally are crossed by river distributary and tidal slough channel deposits (Plate 1 (Sheets 1 and 2)).

Unit descriptions and mapping criteria

Map unit descriptions and criteria for mapping surficial deposits shown on Plate 1 (Sheets 1 and 2) are described herein, in order of oldest to youngest. Deposits of the same relative age are described based on depositional environment or process.

The oldest unit present in the Study Area is wind-deposited (eolian) sediment (map unit Qe) that may span from latest Pleistocene to Holocene in age (Atwater, 1982). It is present as relatively small local bodies, thought to have been derived from wind transport of fluvial sediments near the end of the Pleistocene. Mapping of eolian sediments is adapted from Atwater (1982) with map refinements and additions based on analysis of 1937 aerial photos and the mapped extent of Tyndall soils of Tugel et al., (1992). The eolian deposits likely consist of poorly to moderately cemented fine sand.

Eolian deposits do not directly underlie the levees in the Study Area, but should be expected in the subsurface as laterally discontinuous well-sorted (poorly graded) sandy lenses.

Surficial deposits mapped in the Study Area primarily are Holocene to historical in age. Holocene deposits underlie the modern floodplain and Delta island surfaces. Freshwater marsh, flood basin, and tidal marsh deposits are similar and grade laterally into one another, but with increasing organic content from basin to marsh to tidal mud and peat. In this study these deposits are categorized as Holocene because deposition in these environments was active up until the mid 1800s.

Holocene deposits

Fresh water marsh deposits (map unit Hs) consist of silt and clay with occasional thin organic lenses. Marsh deposits were perennially or seasonally submerged, and host Sacramento clay loam soils that contain near-surface lenses of partly decayed organic matter (Carpenter and Cosby, 1930). Marsh deposits are similar in texture to basin deposits, but are mapped based on bush-like symbols depicted on early U.S. Geological Survey topographic maps indicating marsh environments. Marsh deposits also are mapped based on the presence of standing water bodies surrounded by dark tones on 1937 aerial photographs.

Flood basin deposits (map unit Hn) consist of soft to stiff silt and clay laid down by slow-moving water in a relatively low-energy depositional environment. The deposit usually does not contain substantial organic material (Helley and Harwood, 1985), and fine-grained materials present in this map unit may have high plasticity. Criteria for mapping flood basin deposits include depression topography, relatively featureless surface morphology on topographic maps and aerial photos, and fine-grained inorganic soils. In this Study Area, flood basin deposits host Egbert clay loam soils (Tugel et al., 1992).

Tidal marsh deposits (map units Htm and Hpm) are Holocene peat and muck deposits consisting of beds of organic matter (plant remains) interbedded with alluvial silt and clay, that accumulated in the freshwater tidal marsh of the Sacramento-San Joaquin Delta. Organic material comprises at least 50 percent of the deposit. Tidal marsh deposits are encountered at or below present-day sea level. Most of these deposits pre-date the reclamation projects of the late 1800s and early 1900s when the extensive tidal freshwater marsh of the Delta was drained for agriculture.

Peat typically accumulates in fresh or brackish water swamps, marshes, or bogs where stagnant, anaerobic conditions prevent oxidation and bacterial decay of organic matter (Boggs, 1995). True peat generally has greater than 75 percent moisture content, visible vegetal matter (e.g, roots, leaf veins), and when dried will burn freely (Bates and Jackson, 1984). Just as common in the Study Area are beds of silt and clay with 10 to 50 percent organic matter (peaty mud). The term “muck” is applied to mixed mineral and organic deposits where the plant parts are not recognizable. The amount and thickness of organic matter varies across the Study Area, and generally increases to the south (DWR, 1995).

Historical tidal marsh deposits (Rpm) are mapped in active estuarine environments near sea level where accumulation of marsh vegetation, silt, and clay continued to take place at least as late as

1937. Some of these areas of tidal marsh persist today, including a large area along Snodgrass Slough near the town of Locke (Plate 1, Sheet 1).

Holocene peat and muck deposits (Hpm) are those tidal marsh deposits that were enclosed by levees and drained for farming before 1937 (Figure 3). In the island interiors they have been highly impacted by aeration, decomposition, compaction, burning, and erosion. Because of the extensive draining and plowing of the surficial peaty deposits for cultivation, as well as subsequent farming uses, much of the original surficial geologic and geomorphic character of the former tidal wetland was destroyed as of 1937. Therefore, mapping of Hpm for this study draws heavily from Atwater (1982), whose mapping estimated 1850 tide line extent and data included shallow cores augered for stratigraphic analysis. This study also uses early and modern soil maps, and review of aerial photographs to refine the delineation of unit Hpm and Htm on Plate 1 (Sheets 1 and 2). Peat and muck deposits usually bear the Egbert mucky loam soil or muck and peat of Carpenter and Cosby (1930), and the Gazwell mucky clay or peat and muck of Tugel et al. (1992).

Four categories of Holocene channels are mapped: sloughs (Hsl), distributary (Hdc), overflow (Hofc), and undifferentiated (Hch). Deposits within these channels may be similar texturally, but bear differences based on process. Criteria for differentiating among channel categories are based on map pattern, channel extent, and inter-connectivity with other channels.

Sloughs within the Delta islands were tidally-influenced features, and usually are channels that may or may not have “arms.” Slough channels commonly connect, or would have connected, two different channels during high-stage flows. Beaver Slough (Plate 1, Sheet 1) and Tomato Slough (Plate 1, Sheet 2) are examples of now-abandoned tidal slough channels. Deposits within these now abandoned or drained slough channels (Hsl) likely are relatively fine-grained, silt and clay with lesser fine sand, and are associated with the Scribner clay loam soil (Tugel et al., 1992). Sedimentary structures consistent with bi-directional tidal water flow may be present within the deposit.

Distributary channel deposits (Hdc) are floodplain channels that emanate from a main channel commonly at a sub-perpendicular trend, and traverse the floodplain for some distance before ending. Distributary channels may or may not deposit significant sediment as distributary fans (map unit Hdf), depending on the ratio of sediment to water and flow velocity within a given channel. It is inferred that the deposits within a distributary channel are made of similar textures as the sediment provided by the main channel, that is, likely silt, clay and lesser fine sand.

Overflow channels traverse the floodplain on the inside of a river bend, and were active during high-stage flow events. Overflow channels collect and direct water downstream over the floodplain for some distance before re-entering the channel of origin. Based on this hydrologic connectivity, it is inferred that overflow channel deposits (Hofc) are similar in texture to the sediments in the originating channel; that is, likely sand, silt, and clay, with possible traces of fine gravel.

Undifferentiated Holocene channel deposits (map unit Hch) in the Study Area likely consist of soft to stiff clayey silt, silty clay, with silty and clayey sand. This map unit is not extensive in the Study Area, and the map designation is used for channel deposits that cannot easily be placed into the aforementioned categories.

Holocene crevasse splay deposits (map unit Hcs) and overbank deposits (map unit Hob) together make up the natural levee landform that flanks the Sacramento River and its sloughs. These deposits likely consist of mixtures of silt, clay, and fine sand; the relative proportion of each texture varies across the Study Area, as well as within any individual deposit. Because of hydraulic sorting processes, floodplain deposits grade laterally into the adjacent lowland deposit and the geologic contacts between floodplain and lowland deposits are also gradational, as indicated by the dashed contact line. Crevasse splay deposits form from breaching of a river bank levee (natural or artificial) during high stages and deposition on the floodplain via narrow channels. Crevasse splay deposits commonly are lobate, fan-shaped, or birds-foot shaped in plan view. Overbank deposits are formed from the localized overtopping of channel banks or natural levees, and deposition from shallow sheet flow. Soils developed on the natural levees include Columbia silty clay loam (Carpenter and Cosby, 1930), Scribner clay loam, and the Sailboat silty loam (Tugel et al., 1992). The natural levees in the Study Area generally consist of interbedded and laterally discontinuous lenses of silt or clay, and silty or sandy clay.

Historical deposits

Historical deposits mapped in the Study Area include channel and floodplain deposits, as well as artificial fill deposits (Plate 1 (Sheets 1 and 2)). The term “historical” denotes deposits laid down since about 1849; these deposits are indicated with an “R” in the map unit symbol. These sediments were deposited by the same geomorphic processes as their Holocene counterparts. Many of the historical deposits are derived, at least in part, from re-working, transport, and deposition of hydraulic mining detritus (Gilbert, 1917; Bryan, 1923; James, 1999).

Historical deposits are differentiated from older deposits based on several criteria: (1) presence of bare soil or soil with sparse vegetation, shown as bright tones on 1937 aerial photographs, indicating the deposit has had insufficient time for substantial vegetation colonization, (2) tonal brightness and contrast patterns on 1937 aerial photos within orchards planted along natural levees that suggests post-orchard deposition, (3) stippled patterns on early topographic maps that are inferred to represent historical sand deposition on the floodplain; (4) association with soils having very little horizon development suggesting youthful deposition (e.g. Columbia fine sand; Homes et al., 1913); (5) anecdotal descriptions of historical flood events (e.g. early newspaper accounts), and (6) fresh or sharp geomorphic expression on aerial photographs, for example: sharply-defined distributary channel margins that suggest recency of scouring flow or lack of substantial modification from cultivation processes. Historical deposits are mapped where inferred to be about 3 feet thick or greater. Historical deposits include crevasse splay and overbank deposits along the Sacramento River and sloughs, and distributary channel and fan deposits that extend onto the floodplain, away from the river (Plate 1 (Sheets 1 and 2)).

Historical artificial fills are man-made heterogeneous deposits, with varying amounts of clay, silt, sand, and gravel from local borrow or source areas. These deposits include levee structures and canal levee systems (map unit L) as well as dredge spoils (map unit DS), which is material dredged from nearby channels and emplaced on the land surface.

Site-specific geologic observations

The following paragraphs summarize site-specific geologic observations based on the mapping of surficial deposits. This section does not include a point-by-point account of all of the important surficial and near-surface deposits and features, but rather summarizes key observations that warrant additional description that may not be gleaned from reviewing Plate 1 (Sheets 1 and 2).

Directly east of the head of Steamboat Slough[3], at the toe of the Holocene crevasse splay deposit on the eastern flank of the Sacramento River (Plate 1, Sheet 1, star symbol), a radiocarbon age of peat taken directly beneath a 5-foot-thick Holocene crevasse splay deposit (Hcs) yielded an age (in 14C years) of 1,910 +/-55 years before A.D. 1950 (Atwater, 1982). This suggests that the Sacramento River natural levee building process (vertical accretion) was active at least about 2,000 years ago. If this age is correct, Holocene crevasse splay and overbank deposits mapped in the Study Area are on the order of about 2,000 years old.

An abandoned channel (Hch) is mapped downstream from Isleton, north of the present-day Sacramento River (Plate 1, Sheet 2). The channel, not shown on Atwater (1982), is mapped based on 1937 aerial photographs (Figure 4). The gently arcuate map pattern of the abandoned channel suggests that it may be a former natural meander of the river; diverging from the present river directly upstream of Ida Island (Figure 4). Soils that are spatially associated with the channel deposit are recognized by Carpenter and Cosby (1930), but do not appear to be differentiated by Tugel et al. (1992) perhaps due to plowing of the surface layer over time. The soil type recognized on the abandoned channel deposit is the Sacramento mucky loam and consists of two main layers: an upper layer of fine-textured mucky material of high organic content, and a lower layer with lacustrine-like sediment and little organic material (Carpenter and Cosby, 1930). This stratigraphy suggests erosion of a fluvial channel, abandonment and subsequent development of an oxbow lake environment, followed by change to marsh environment. This also suggests that channel fill predominantly is fine-grained material from post-abandonment infilling in the upper several feet of the deposit; however, it is also possible that the soil survey pits did not explore deep enough to assess the texture of channel bottom deposits.

Also shown on Figure 4 are tidal marsh deposits and in-channel bar sediment that were present in 1910, but gone by 1937. These areas are shown with a diagonal hatch pattern on Figure 4. The change was identified by comparison of 1910 topographic maps (Table 1) against 1937 aerial

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[3] Steamboat Slough in 1848 was referred to as the "Middle Fork" or branch of the Sacramento River (Ringgold, 1948). Other records show Steamboat Slough was preferred over the "old river" Sacramento River route because it was more than 8 miles shorter and several hours less travel by steamship. Due to hydraulic mining, by the late 1850's Steamboat Slough was less traveled by the larger steamers, yet still the preferred route for flat bottomed boats that would stop at the landings.

photographs. It is likely that the sediments accumulated as a response to the influx and downstream transport of hydraulic mining debris. It is also likely that the in-channel sediment was subsequently removed from the channel by mechanical dredging of the river for navigation purposes (e.g., Thompson, 2006).

CONCEPTUAL GEOMORPHIC MODEL

Based on a synthesis of surficial geologic mapping, early topographic maps, soil surveys, and geologic maps, a preliminary conceptual model has been developed to describe dominant geomorphic processes that controlled surface and subsurface geologic deposits in the Delta Study Area (Figure 1). This conceptual model provides a consistent basis for understanding the types and distribution of surficial geologic deposits, primary geomorphic processes, and the shallow subsurface stratigraphy in the Study Area.

The Study Area includes Project levees along four waterways: the lower Sacramento River, Sutter Slough, Steamboat Slough, and Georgiana Slough. The lower Sacramento River is the master stream in the Study Area; however, flows through the Delta naturally were distributed among a network of channels and sloughs including the river. Near Clarksburg, the Sacramento River spawns a number of lesser distributary channels that flow independently for a short distance and then join with other channels, sloughs or with the main river. Fresh and salty estuarine waters mix through complex hydrologic interaction of the tidal prism. Channels currently are scoured and channel form maintained by tidal currents, but less dynamically as compared to “pristine” Delta conditions.

As described by Atwater (1982), the Delta during the late Quaternary can be likened to a stage on which two related and cyclical plays are presented simultaneously. In one play, wetlands, tidal marshes, and supratidal floodplains appear and grow as sea level encroaches from the west, then become areas of erosion and dissection upon sea level retreat and subaerial exposure. In the other play, sediment eroded from the Sierra Nevada originally by glaciers accumulates to build alluvial fans and when re-worked by wind-driven (eolian) process creates extensive sand dunes. Other lesser actors contribute to occupying or modifying the landscape, such as fluvial processes constructing terraces along streams or steady growth of tule swamps.

The Study Area is geomorphically distinct from other North NULE areas because the depositional history includes deltaic / tidal marsh processes in addition to fluvial processes. From these combined processes, the margins of the islands are slightly elevated rims made of overbank and splay deposits; whereas the slightly lower center of the islands were covered by peat formed by decaying tidal marsh vegetation. The beds of peat laterally merge with inorganic soils toward the Delta’s periphery at the regional scale, as well as towards the alluvial bank margins along islands at the local scale (Thompson, 2006).

As described in previous section, the Study Area reach of the Sacramento River, the river’s banks and adjoining land areas were impacted by the upstream hydraulic gold mining activities. In the mid to late 1800s, much of the Study Area was covered in fine-grained sediment with sand (slickens) derived from upstream mining activities and downstream fluvial transport and deposition of detritus. The influx of mining detritus also filled the Study Area sloughs and channels such that mechanized dredging was required to maintain channel cross-section area (Thompson, 2006). Commonly, the dredge spoils from the river were used as material to construct or augment flood control levees in the Study Area (DWR, 1995). Steamboat Slough levees were still under construction by steam-powered dredges during the large flood of the Sacramento River in 1889[4]. Therefore, based on the history of mining, reclamation, and flooding, historical deposition of mining debris sediment on the river's banks overprints and buries most of the Holocene natural levee deposits, and the present-day levees thus sit atop the historical mining debris that overlies Holocene alluvium, which in some places overlies peat.

Generalized subsurface stratigraphy

Synthesis of surficial mapping, the conceptual geomorphic model, and readily available geotechnical exploration data allow development of generalized geologic cross sections that depict likely subsurface distributions of deposits. Subsurface data were compiled from Atwater (1982) and USACE (1987). The conceptual cross sections are not intended to represent site-specific subsurface conditions. Plate 1 (Sheets 1 and 2) and Figure 2 show where two schematic cross sections were developed in the Study Area; the illustrations are shown on Figures 5 and 6. The cross section locations illustrate the inferred stratigraphy in the northern non-tidal part of the Study Area and the stratigraphy in the southern former tidal marsh part of the Study Area.

Figure 5 illustrates the inferred stratigraphy across Sutter Slough, Steamboat Slough, and the Sacramento River in the northern part of the Study Area. The generalized cross section shows the interfingering of Holocene basin and tidal marsh deposits in the subsurface, with tapering blankets of Holocene and historical natural levee deposits present adjacent to the channels. Historical and Holocene natural levee deposits are encountered directly beneath the Non-Urban levees. The lateral extent of the surficial deposits may be estimated from Plate 1 (Sheets 1 and 2), and the thickness of the historical and Holocene overbank and crevasse splay deposits decreases with distance away from the river or slough (Figure 5). By extension, this lateral pinching and interfingering geometry likely is present between the Holocene subsurface deposits (e.g., Hob-Hpm). In addition, relatively coarser-grained buried channels schematically shown on Figure 5 likely have limited lateral extent, but may be more continuous in the river-parallel direction. Late Pleistocene fluvial or alluvial fan deposits are interpreted to underlie the Holocene deposits based on the presence of relatively sandy and dense sediments at depth in boreholes. The thick beds of peat seen in cross section B-B' (Figure 6), located closer to the center of the Delta, are not encountered in this area. Unit Hpm here is relatively rich in silt and clay.

Figure 6 presents inferred subsurface stratigraphy along the southern portions of Grand Island (see Figure 2 for location). In contrast to the northern portions of Grand Island, a thick (up to 25 feet) bed of peat is present in the subsurface and is schematically shown as laterally extensive, but the layer may also be less extensive. Additional subsurface data may constrain the actual extents and continuity of the peat layer. The peat bed probably thins and is interpreted to laterally pinch out

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[4] Sacramento Daily Record-Union newspaper, December 14, 1889, page 5 column 4.

toward the Sacramento River at the margin of the island (Figure 6). In contrast, the peat bed is relatively thick beneath and adjacent to Steamboat Slough (Figure 6). Localized sand-rich deposits interpreted as buried channels are encountered in bore holes adjacent to Steamboat Slough (USACE, 1993). Surficial and near-surface deposits are likely similarly distributed laterally and vertically as described for Figure 5, having limited extents with thinning and interfingering boundaries.

APPLICATIONS TO STUDY AREA LEVEES

The preceding sections summarize the major map units constituting levee foundations and the shallow stratigraphic relationships in the Study Area. These factors (sediment texture, permeability, and shallow stratigraphic relationships) exert controls on underseepage processes and are incorporated into the underseepage susceptibility analysis.

Underseepage susceptibility analysis 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. The underseepage susceptibility classes listed in Table 2 were assigned based on geologic age, depositional environment, stratigraphic relationships, and inferred relative soil permeability. Table 3 lists the units present beneath Study Area levees; underseepage assignments are not listed for deposits present elsewhere in the North NULE Study Area. The susceptibility assignments are shown graphically on Plate 1 (Sheets 1 and 2).

Almost all levee foundations in the Study Area (96.5 percent) are judged to have very high susceptibility to underseepage (97.3 miles). These foundations consist of historical overbank deposits (Rob) derived from upstream gold mining activities, and to a lesser extent dredge spoils derived from adjacent channels (DS) or Holocene peat and mud deposits (Hpm) (Table 2).

Historical overbank deposits laid down by large floods on the Sacramento River before levee construction (e.g., 1862, 1881, 1889) blanket older sediments and therefore directly underlie much of the present-day levees. Dredge spoils underlie the Non-Urban levee at the southern end of the map area at the confluence of Steamboat Slough and the Sacramento River (Plate 1, Sheet 2). Peat and muck deposits directly underlie only 1.4 miles of levee foundations (Table 2), however, peat and muck likely are present in the subsurface (Figures 5 and 6).

Table 2. Underseepage Susceptibility Summary.

Unit Symbol	Unit Name	Susceptibility Rating	Mileage	Percent
Rob	Historical overbank deposits	Very High	87.6	87.6
Rcs	Historical crevasse splay deposits	Very High	6.0	6.0
Hpm	Holocene peat and mud	Very High	1.4	1.4
DS	Dredge spoils derived from channel	Very High	1.3	1.3
Rdc	Historical distributary channel deposits	Very High	0.8	0.8
Rofc	Historical overflow channel deposit	Very High	0.2	0.2

Table 2. Underseepage Susceptibility Summary.

Unit Symbol	Unit Name	Susceptibility Rating	Mileage	Percent
Hob	Holocene overbank deposits	High	2.6	2.6
Hch	Holocene channel deposits	High	0.6	0.6
Rsl	Historical slough deposits	High	0.2	0.2
Hsl	Holocene slough deposits	Moderate	0.1	0.1
Rch	Historical channel deposits	Very High	0.0	0.0
Rdf	Historical distributary fan deposits	Very High	0.0	0.0
Rpm	Historical peat and mud	Very High	0.0	0.0
Ra	Historical alluvium (undifferentiated)	Very High	0.0	0.0
Rb	Historical channel bar deposits	Very High	0.0	0.0
Hcs	Holocene crevasse splay deposits	High	0.0	0.0
Hs	Holocene marsh deposits	Moderate	0.0	0.0
Qe	Quaternary eolian deposits	Moderate	0.0	0.0
Hn	Holocene basin deposits	Low	0.0	0.0

Existing geomorphic studies indicate that bank stratigraphy in the Study Area generally consists of a cohesive (fine-grained) tidal mud / flood basin overlain by relatively more granular natural levee deposits that, in turn, are overlain by the artificial levee (W.E.T., 1990). There is, therefore, a likely permeability contrast occurs between the lower cohesive layers at the channel bank toe and the overlying relatively sandier natural levee layers (e.g., Sutter Slough, Figure 6). This model indicates that bank stratigraphy and property contrasts at geologic contacts may influence foundation underseepage pathways (i.e., flow at the contact between the layers).

Performance data for the Study Area levees (URS, 2009) show a record of underseepage-related problems generally consistent with the assigned levee foundation underseepage susceptibility. Documented levee performance problems include foundation seepage, boils, sand boils, and levee failure. Performance points (seeps, boils) are present along both banks of Sutter Slough, Steamboat Slough, Georgiana Slough, and the Sacramento River. Several documented performance problems are clustered along the lower third of Georgiana Slough levees and along Steamboat Slough at and near the junction with Miner’s Slough.

SUMMARY

The Study Area includes levees along four waterways in the Sacramento–San Joaquin Delta: the lower Sacramento River, Sutter Slough, Steamboat Slough, and Georgiana Slough. The surficial geologic mapping and levee underseepage susceptibility assessment is based on the analysis of early aerial photography, topographic maps, existing Quaternary geologic mapping, soil maps, limited subsurface data, and historical documents. These data have been used to construct a conceptual model that describes the dominant late Quaternary and historical geomorphic processes in the Study Area and their influence on near-surface and shallow subsurface stratigraphic relationships.

This Study Area is distinct from other North NULE levee areas in that the geologic evolution over the late Quaternary involves both fluvial and deltaic (tidal marsh) processes. The result of these combined processes is the construction of Delta islands separated by tidal channels. The islands, formerly at sea level, hosted freshwater tidal marsh environments that produced beds of organic-rich sediment and peat material. Reclamation of the Delta islands and the construction of artificial levees has altered the natural processes, and promoted the decay and compaction of the organic-rich material resulting in island subsidence. Transport and deposition of sediment derived from upstream gold mining activities occurred just before, or during, the initial construction of the Non-Urban levees in the Study Area. As a result of large floods in the late 1800s, historical overbank sediments blanketed the older deposits, and therefore directly underlie most of the present-day levees in the Study Area.

The presence of historical overbank and crevasse splay deposits beneath the levees has resulted in a very high susceptibility to underseepage along 93 percent of the levee mileage within the Study Area. In addition to the presence of these young, unconsolidated deposits, bank stratigraphy and property contrasts at geologic contacts may influence foundation underseepage pathways (i.e., flow at the contact between the layers). Performance data for the Study Area levees (URS, 2009) show a record of underseepage-related problems consistent with the assigned underseepage susceptibility.

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 shallow subsurface conditions 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 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.

Fugro 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. Fugro 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 that were identified 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.

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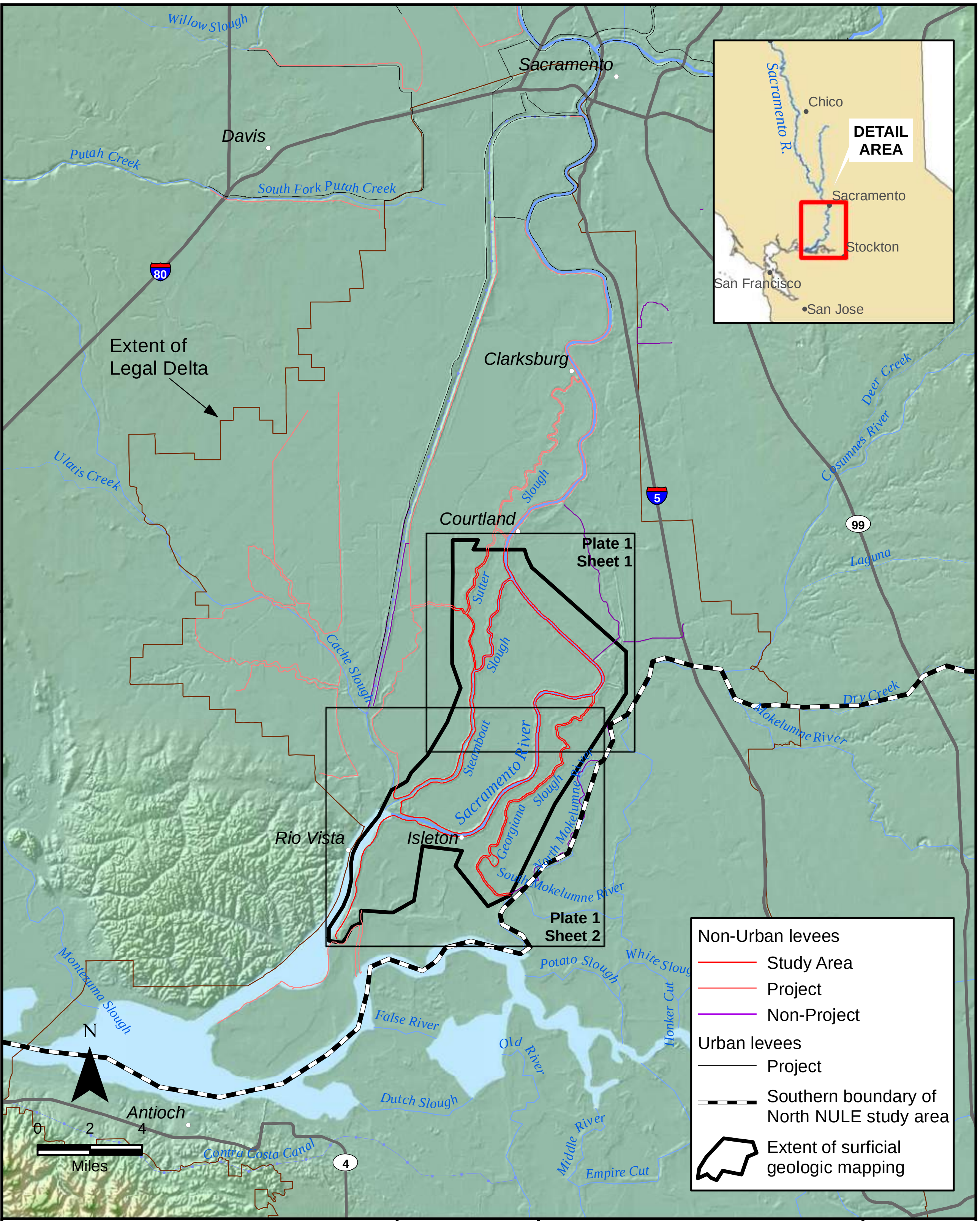

1965_2_NULE_GroupB_LocationMap.mxd, MGT, 12/21/10

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Levee Evaluations Branch

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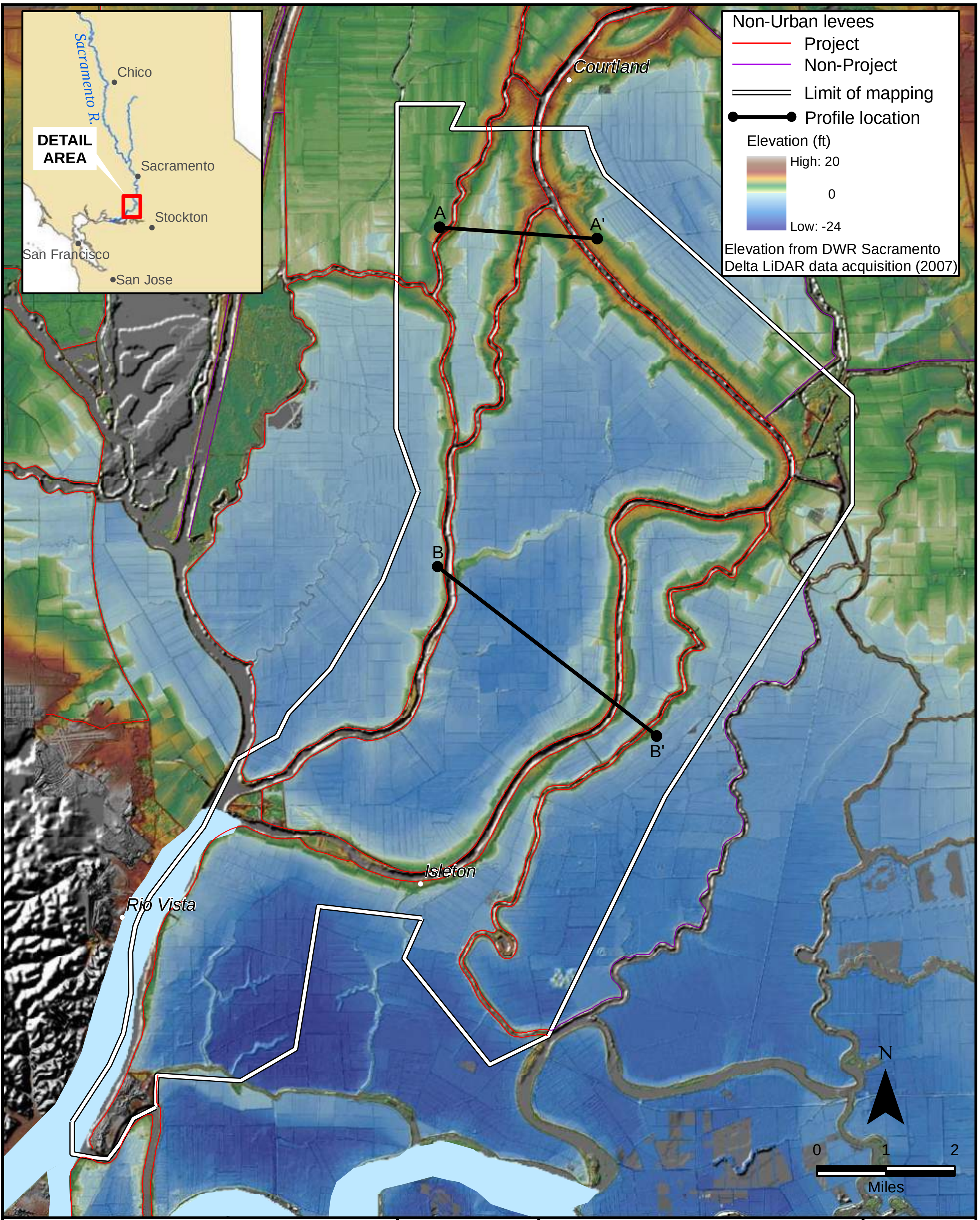
Location Map

NORTH NON-URBAN LEVEE EVALUATIONS

Figure
1



1965_2_NULE_GroupB_DEM_Subzero.mxd, MGT, 12/21/10

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Levee Evaluations Branch

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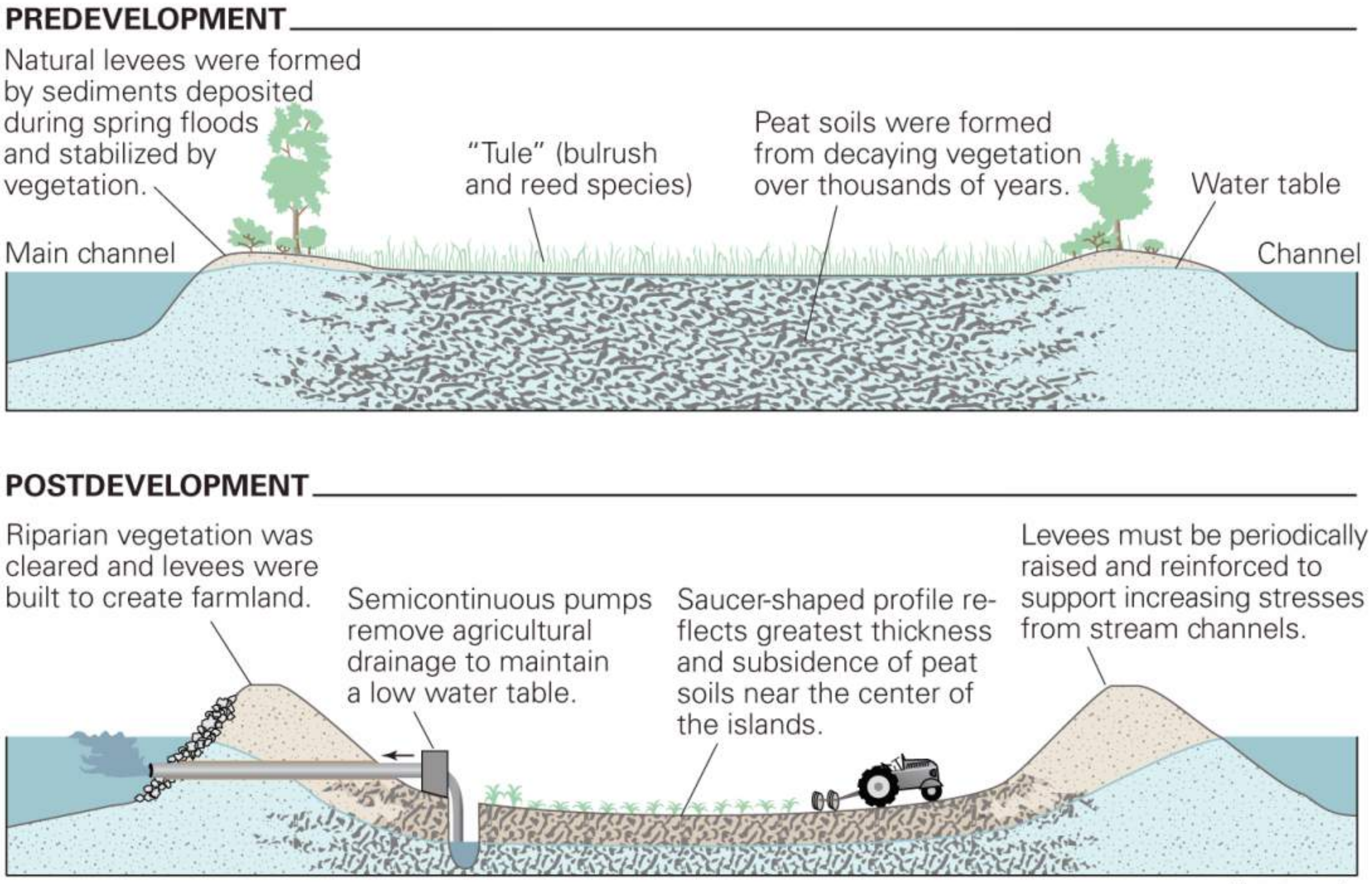
DEM of South of Courtland Study Area
Colored to Illustrate Sub-zero Elevation Area

NORTH NON-URBAN LEVEE EVALUATIONS

Figure 2



From: Ingebritson et al. (2000); U.S. Geological Survey Fact Sheet 00-500.

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WLA
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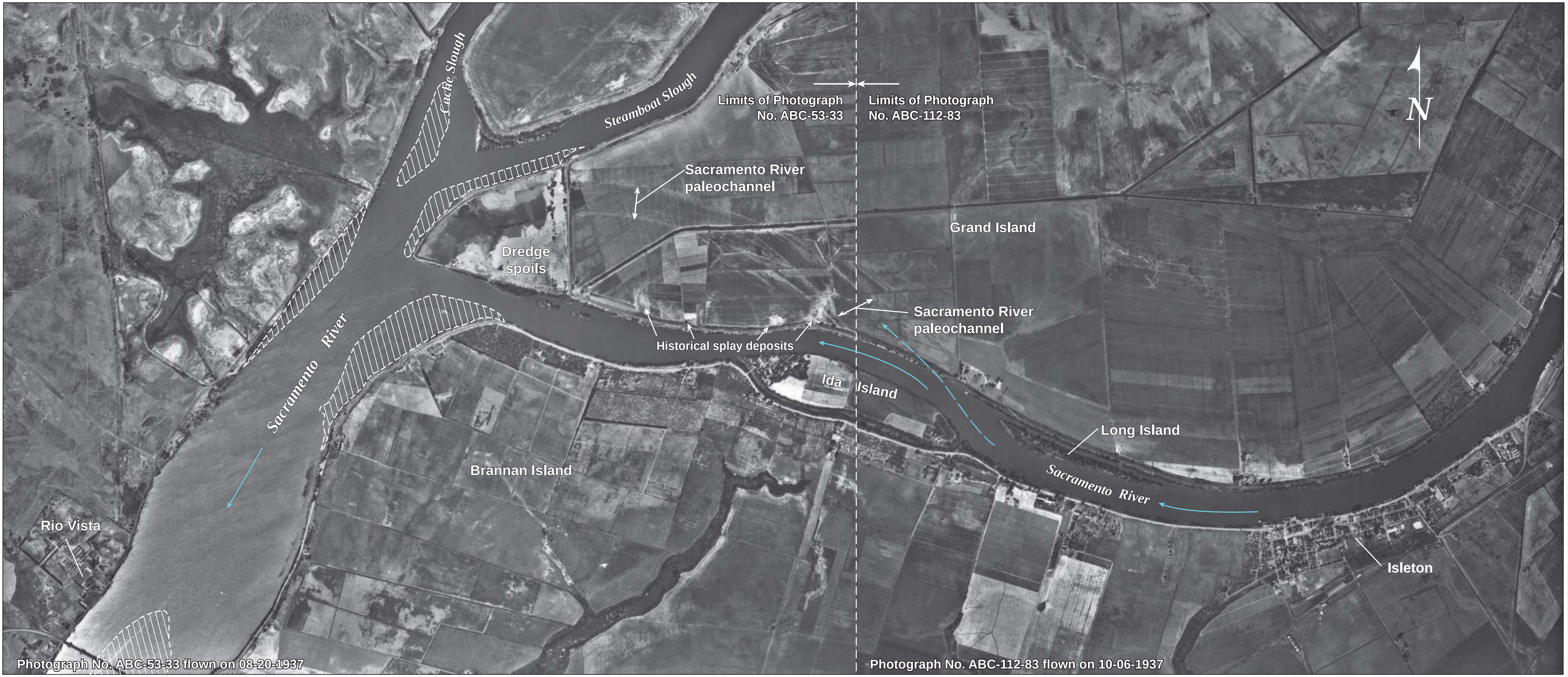
Delta Island, Peat, and Subsidence

NORTH NON-URBAN LEVEE EVALUATIONS

Figure 3



Explanation

▨ Land shown on 1910 (surveyed 1906 - 1908)
Rio Vista historical topographic map; not present in 1937

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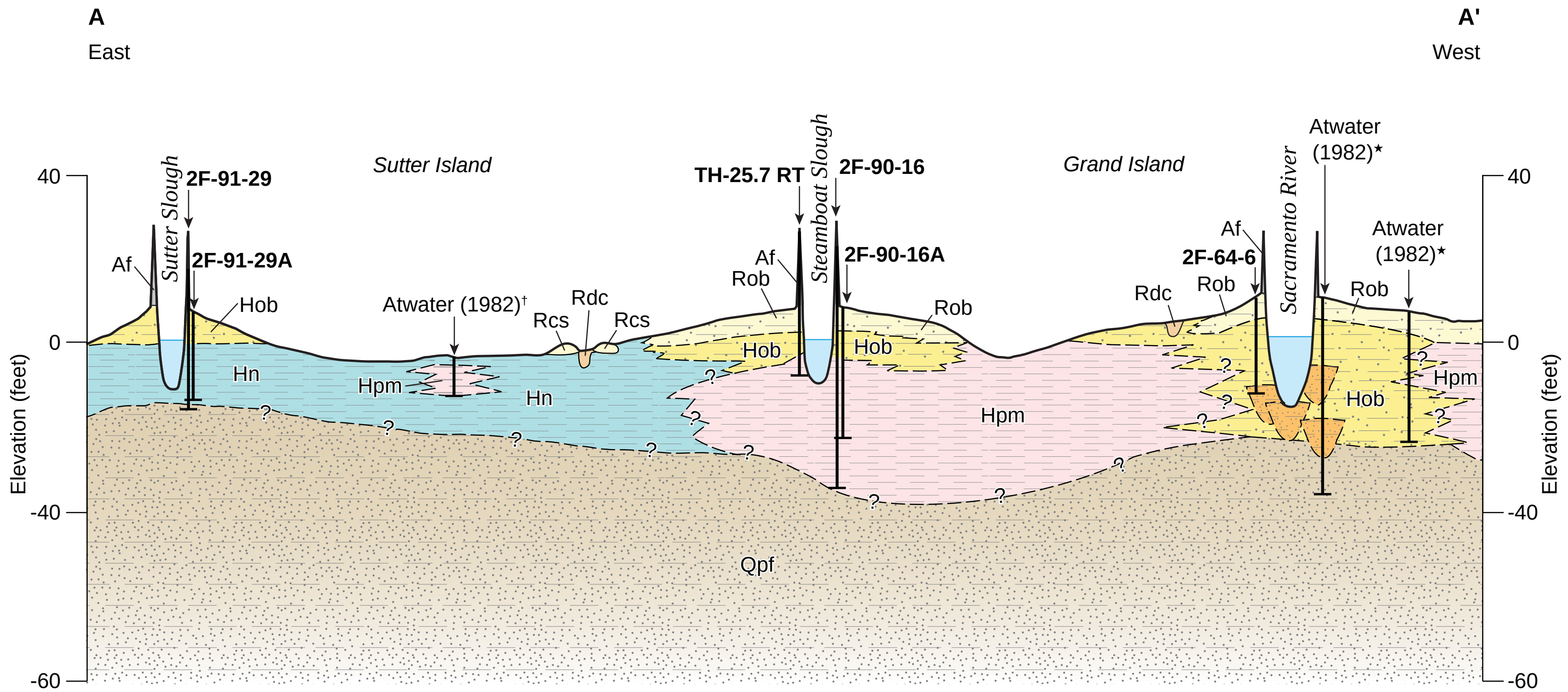
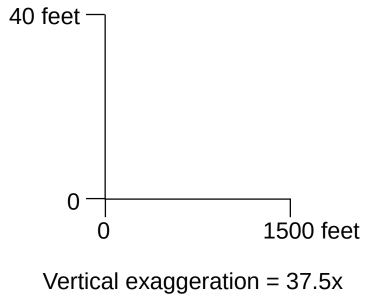
1937 Aerial Photograph of the
Sacramento River near Isleton

NORTH NON-URBAN LEVEE EVALUATIONS

Figure 4





Explanation

Af	Artificial fill
Rob	Historical overbank deposits (fine sand, silt, and clay)
Hob	Holocene overbank deposits (fine sand, silt, and clay)
Hpm	Holocene peat and mud of tidal wetlands (interbedded organic-rich soft silt and clay)
▽	Buried channel (sandy silt and silty sand)
Hn	Holocene basin deposits (fine sand, silt, and clay)
Qpf	Late Pleistocene alluvial fan deposits (poorly graded dense sand and silty sand)
Rcs	Historical crevasse splay deposits (fine sand and silt)
Rdc	Historical distributary channel deposits (sand, silt, and clay)

Atwater (1982)†	Soil core by Atwater (1982)
Atwater (1982)*	Subsurface data from other sources, presented in Atwater (1982)
TH-25.7 RT **2F-90-16**	Borehole data, USACE (1993)
– – – – – – –	Contact, approximately located
– –?– – –?– –	Contact, location uncertain

Notes: 1. Topography from USGS 7.5' topographic maps, 5-foot contour interval.
2. Lithologic information shown has been generalized and simplified and may not necessarily represent actual ground conditions at the site-specific level.

Graphics, Projects, 1965 North Urban Levees, 8_ Group B Levees Delta, modified 10.20.10

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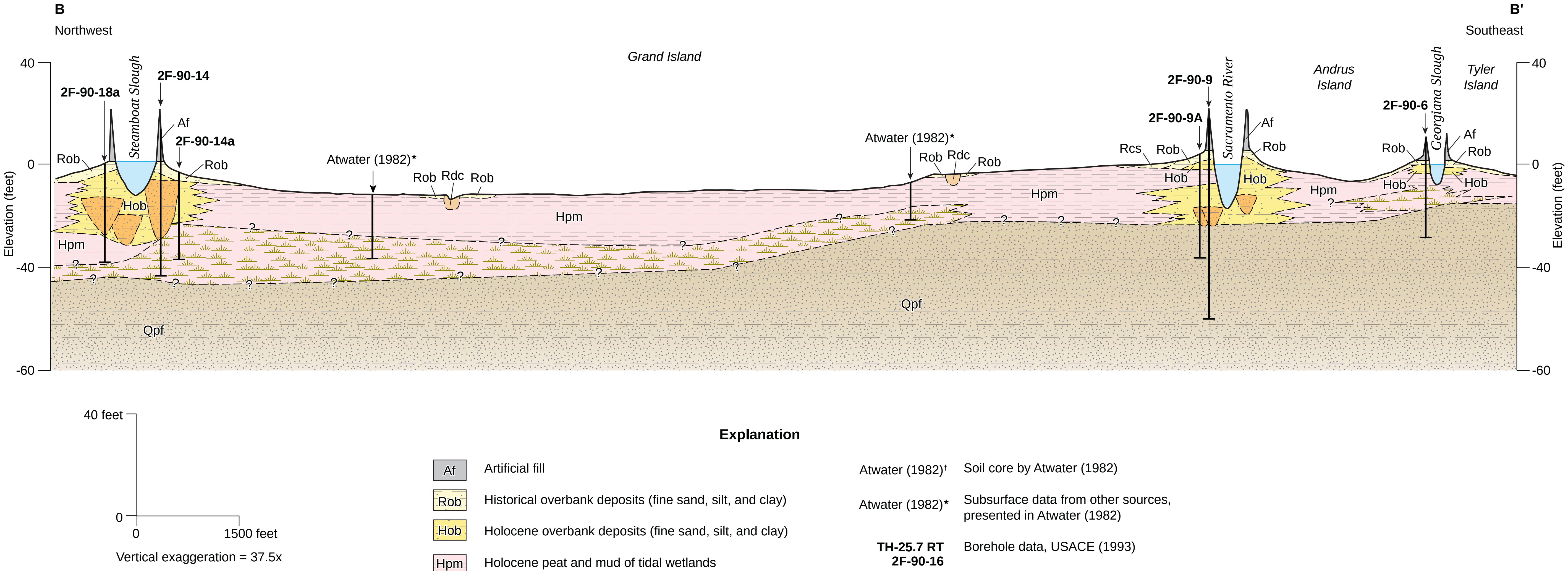
Conceptual Geologic Cross Section A - A'

NORTH NON-URBAN LEVEE EVALUATIONS

Figure 5



Explanation

Af	Artificial fill
Rob	Historical overbank deposits (fine sand, silt, and clay)
Hob	Holocene overbank deposits (fine sand, silt, and clay)
Hpm	Holocene peat and mud of tidal wetlands (interbedded organic-rich soft silt and clay)
▨	Thick peat bed
Qpf	Pleistocene alluvial fan deposits (poorly graded dense sand and silty sand)
▼	Buried channel (sandy silt and silty sand)
Rdc	Crevasse splay deposits (fine sand and silt)

Atwater (1982)†	Soil core by Atwater (1982)
Atwater (1982)*	Subsurface data from other sources, presented in Atwater (1982)
TH-25.7 RT **2F-90-16**	Borehole data, USACE (1993)
– – – – – – –	Contact, approximately located
– –?– – –?– –	Contact, location uncertain

Graphics, Projects, 1965 North Urban Levees, 8_ Group B Levees Delta, modified 10.20.10

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Division of Flood Management
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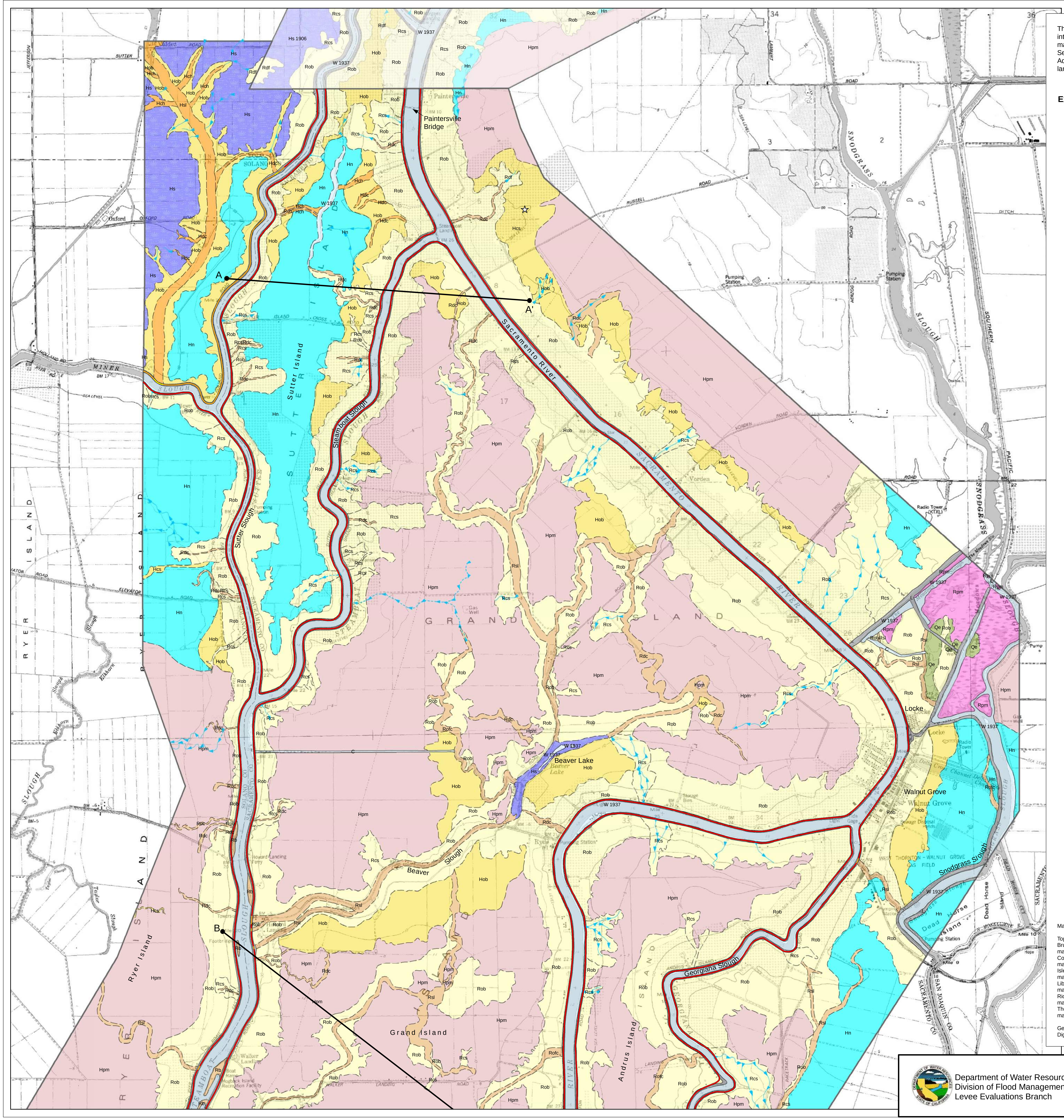
Conceptual Geologic Cross Section B - B'

NORTH NON-URBAN LEVEE EVALUATIONS

Figure 6



This map shows surficial geologic deposits and levees as they existed in 1937. Map units and boundaries are drawn by interpretation of historical aerial photography supplemented by data from historical maps and surveys. For reference, the mapping is superimposed on modern U.S. Geological Survey 7.5' topographic base maps (individual maps referenced below). See accompanying technical memorandum for complete descriptions of map units, process descriptions and methodology. Adjacent polygons that have identical map unit symbols are employed to delineate sequences of sedimentation and landscape evolution.

Explanation

Underseepage Susceptibility Along Non-Urban Levee Alignment

🟥 Very High	🟧 High	🟨 Moderate	🟩 Low (not present in this study area)

Geologic contact; dashed where approximate, dotted where concealed, queried where uncertain; solid contacts accurate to within about 100' on either side of line shown on map. Dashed contacts are accurate to within about 250', and are generally gradational.

Narrow channel, generally <100 ft in width; dashed where approximate.

A A' Cross section location

☆ Location of radiocarbon age date reported in Atwater (1982).

W 1937	Water; date indicates year of historical dataset.
C	Canal, circa 1937.

Geologic Units

	L	Levee (made of artificial fill), circa 1937.
HISTORICAL	Rob	Overbank deposits; silt, clay, and lesser sand; deposited during high-stage water flow, overtopping channel banks.
	Rcs	Crevasse splay deposits; fine sand and silt with clay deposited from breaching of natural or artificial levees.
	Rdf	Distributary fan deposits; sand, silt and clay laid by distributary channels.
	Rch	Channel deposits; well-sorted sand, silt, clay, and trace scattered fine gravel.
	Rb	Channel bar deposits; fine gravel, sand, and silt deposited in or along channel lateral margins.
	Rdc	Distributary channel deposits, sand, silt, and clay; channelized flow conducting sediment to floodplain.
	Rofc	Overflow channel deposits; sand, silt, and clay deposited in floodplain channels occupied primarily when high-stage water overtops channel banks and returns to river.
	Rsl	Slough deposits; silt, clay, and sand, fining upward facies, low-energy channel deposits.
	Rpm	Tidal marsh deposits; peat and muck, interbedded peat and organic-rich silt and clay.
HOLOCENE	Hob	Overbank deposits; silt, clay, and lesser sand; deposited during high-stage water flow, overtopping channel banks.
	Hcs	Crevasse splay deposits; fine sand and silt with clay deposited from breaching of natural levees.
	Hch	Channel deposits; poorly graded sand and trace fine gravel.
	Hdc	Distributary channel deposits, sand, silt, and clay; channelized flow conducting sediment to floodplain.
	Hsl	Slough deposits; silt, clay, and trace fine sand, fining upward facies, low-energy tidally or formerly tidally influenced channel deposits.
	Hpm	Peat and muck; interbedded peat and organic-rich silt and clay, former tidal marsh deposits, now drained and farmed.
	Hn	Basin deposits; fine sand, silt and clay.
	Hs	Marsh deposits; silt and clay, possibly with organic-rich beds; perennially or seasonally submerged, as shown by bush symbols on early USGS topographic maps, or where appear inundated or saturated on 1937 photos.
PLEISTOCENE	Qe	Eolian deposits; poorly to moderately cemented sand and silt.

Stratigraphic Correlation Chart

Time	Depositional Environment								
Epoch	Channel deposits			Floodplain and alluvial-fan deposits			Flood basin deposits			Cultural deposits
Historical	Rch	Rb Rofc	Rdc Rsl	Ra	Rob Rcs	 Rdf	Hn	Hs	Rpm	L
Holocene	Hch	Hsl Hdc		Ha	Hob Hcs				Hpm	
Pleistocene				Qe						

Map projection: UTM NAD83 Zone 10N

Topographic base USGS 7.5' quadrangles:
Bruceville (ID: 38121-C4), published 1968, revised 1980;
map scale 1:24,000, five foot contour interval.
Courtland (ID: 38121-C5), published 1978, revised 1993;
map scale 1:24,000, five foot contour interval.
Isleton (ID: 38121-B5), published 1978, revised 1993;
map scale 1:24,000, five foot contour interval.
Liberty Island (ID: 38121-C6), published 1978, revised 1993;
map scale 1:24,000, five foot contour interval.
Rio Vista (ID: 38121-B6), published 1978, revised 1993;
map scale 1:24,000, five foot contour interval.
Thornton (ID: 38121-B4), published 1978;
map scale 1:24,000, five foot contour interval.

Geologic Mapping by S. Dee, G. Van Etten, A. Wade
Digital Cartography by M. Ticci and J. Finley

N

0 2,000 ft
0 1 km
1:24,000

Scale is 1 in = 2,000 ft when printed at 23 inch by 30 inch page size

Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

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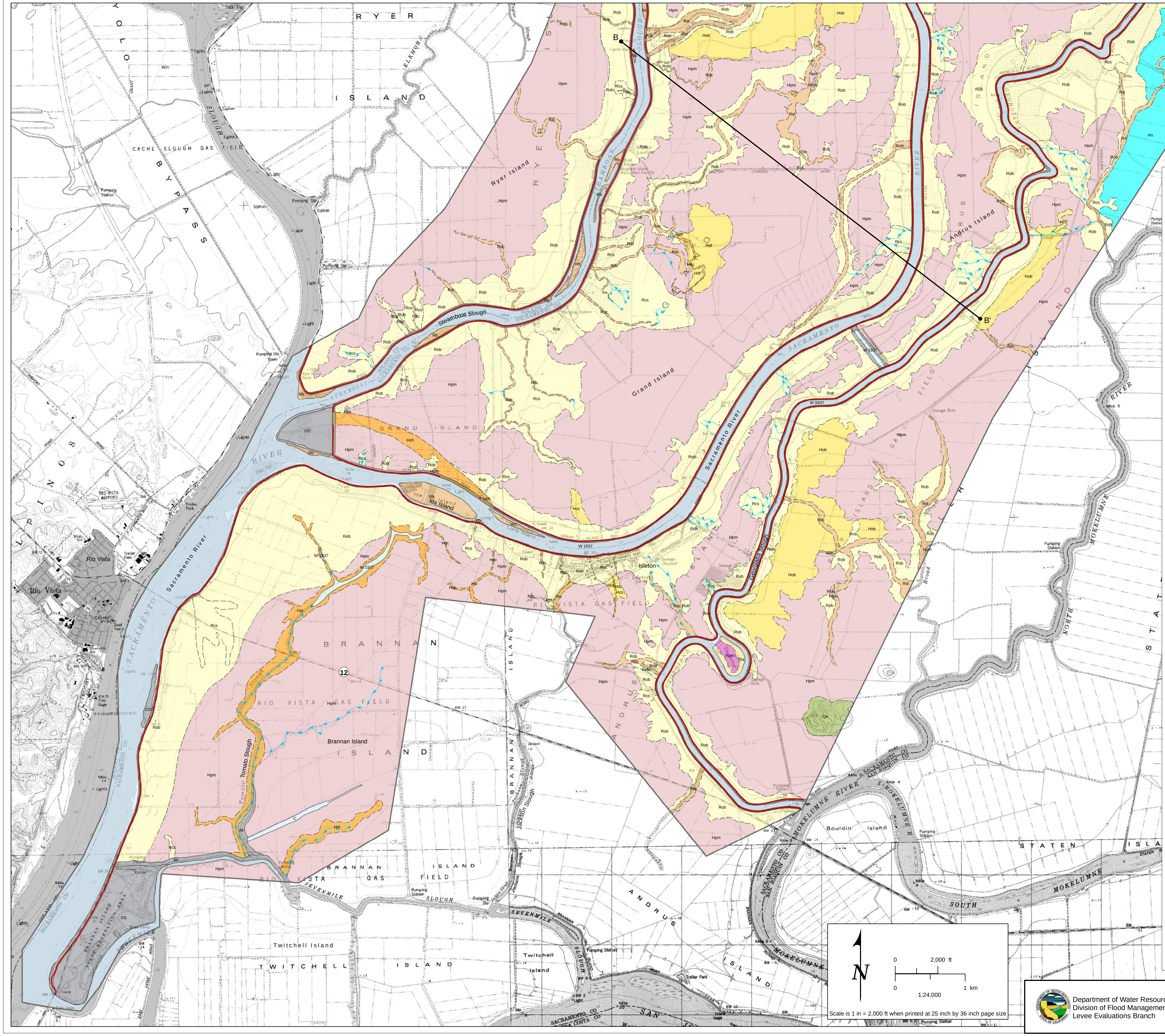
Surficial Geologic Map of South of Courtland Study Area

NORTH NON-URBAN LEVEE EVALUATIONS

Plate 1

Sheet 1

1965_2_NULE_GroupB_Plate_North.mxd MGT 12/21/10



N

0 2,000 ft

0 1 km

1:24,000

Scale is 1 in = 2,000 ft when printed at 25 inch by 36 inch page size

This map shows surficial geologic deposits and levees as they existed in 1937. Map units and boundaries are drawn by interpretation of historical aerial photography supplemented by data from historical maps and surveys. For reference, the mapping is superimposed on modern U.S. Geological Survey 7.5' topographic base maps (individual maps referenced below). See accompanying technical memorandum for complete descriptions of map units, process descriptions and methodology. Adjacent polygons that have identical map unit symbols are employed to delineate sequences of sedimentation and landscape evolution.

Explanation

Underseepage Susceptibility Along Non-Urban Levee Alignment

🟥	🟧	🟨	🟩
Very High	High	Moderate (not present in Plate 2)	Low (not present in this Study Area)

——— – – –? ········	Geologic contact; dashed where approximate, dotted where concealed, queried where uncertain; solid contacts accurate to within about 100' on either side of line shown on map. Dashed contacts accurate to within about 250', and are generally gradational.
►——► – ►	Narrow channel, generally <100 ft in width; dashed where approximate.
B ●——● B'	Cross section location
W 1937	Water; date indicates year of historical dataset.
C	Canal, circa 1937.

Geologic Units

	AF	Artificial fill, circa 1937.
	L	Levee (made of artificial fill), circa 1937.
	DS	Dredge spoils; material from channel dredging and typically hydraulically emplaced.
HISTORICAL	Rob	Overbank deposits; silt, clay, and lesser sand; deposited during high-stage water flow, overtopping channel banks.
	Rcs	Crevasse splay deposits; fine sand and silt with clay deposited from breaching of natural or artificial levees.
	Rb	Channel bar deposits; fine gravel, sand, and silt deposited in or along channel lateral margins.
	Rdc	Distributary channel deposits, sand, silt, and clay; channelized flow conducting sediment to floodplain.
	Rofc	Overflow channel deposits; sand, silt, and clay deposited in floodplain channels occupied primarily when high-stage water overtops channel banks and returns to river.
	Rsl	Slough deposits; silt, clay, and sand, fining upward facies, low-energy channel deposits.
	Ra	Alluvial deposits undifferentiated; sand, silt, and minor lenses of fine gravel.
	Rpm	Tidal marsh deposits; peat and muck, interbedded peat and organic-rich silt and clay.
HOLOCENE	Hob	Overbank deposits; silt, clay, and lesser sand; deposited during high-stage water flow, overtopping channel banks.
	Hcs	Crevasse splay deposits; fine sand and silt with clay deposited from breaching of natural levees.
	Hdf	Distributary fan deposits; sand, silt and clay.
	Hch	Channel deposits; poorly graded sand and trace fine gravel.
	Hdc	Distributary channel deposits, sand, silt, and clay; channelized flow conducting sediment to floodplain.
	Hsl	Slough deposits; silt, clay, and trace fine sand, fining upward facies, low-energy tidally or formerly tidally influenced channel deposits.
	Hpm	Peat and muck; interbedded peat and organic-rich silt and clay, former tidal marsh deposits, now drained and farmed.
	Hn	Basin deposits; fine sand, silt and clay.
PLEISTOCENE	Qe	Eolian deposits; poorly to moderately cemented sand and silt.

Stratigraphic Correlation Chart

Time	Depositional Environment									
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		Rofc	Rsl		Rcs						
Holocene	Hch	Hsl		Ha	Hob			Hpm			
		Hdc			Hcs	Hdf					
Pleistocene				Qe							

Map projection: UTM NAD83 Zone 10N

Topographic base USGS 7.5' quadrangles:
Bouldin Island (ID: 38121-A5), published 1997; map scale 1:24,000, five foot contour interval.
Isleton (ID: 38121-B5), published 1978, revised 1993; map scale 1:24,000, five foot contour interval.
Jersey Island (ID: 38121-A6), published 1978; map scale 1:24,000, five foot contour interval.
Rio Vista (ID: 38121-B6), published 1978, revised 1993; map scale 1:24,000, five foot contour interval.

Geologic Mapping by S. Dee, G. Van Etten, A. Wade
Digital Cartography by M. Ticci and J. Finley

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Division of Flood Management
Levee Evaluations Branch

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Surficial Geologic Map of South of Courtland Study Area

NORTH NON-URBAN LEVEE EVALUATIONS

Plate
1

Sheet 2

UPDATED EXISTING GEOTECHNICAL DATA

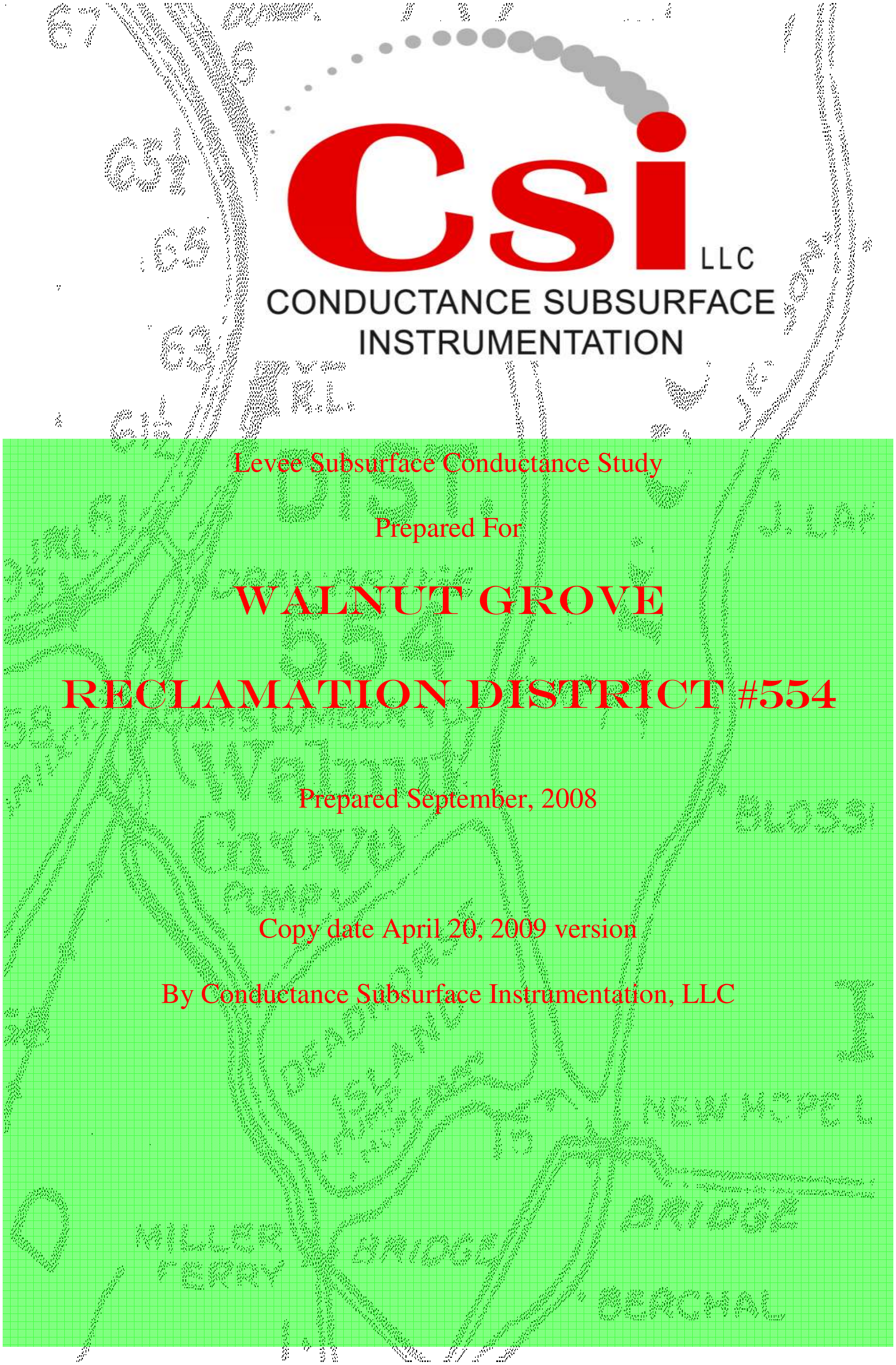
TECHNICAL MEMORANDUM

Community of East Walnut Grove, California

California Department of Water Resources
Small Community Flood Risk Reduction Program

APPENDIX C

Electromagnetic Survey



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

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INTRODUCTION TO CONDUCTANCE STUDIES 8

FACTORS AFFECTING SUBSURFACE TERRAIN CONDUCTIVITY 9

THE STUDY 10

EXPLANATION OF PROCEDURES USED IN CONDUCTANCE STUDY 12

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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

Michael L Stefani

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 15th and* completed on *October 15th, 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*.

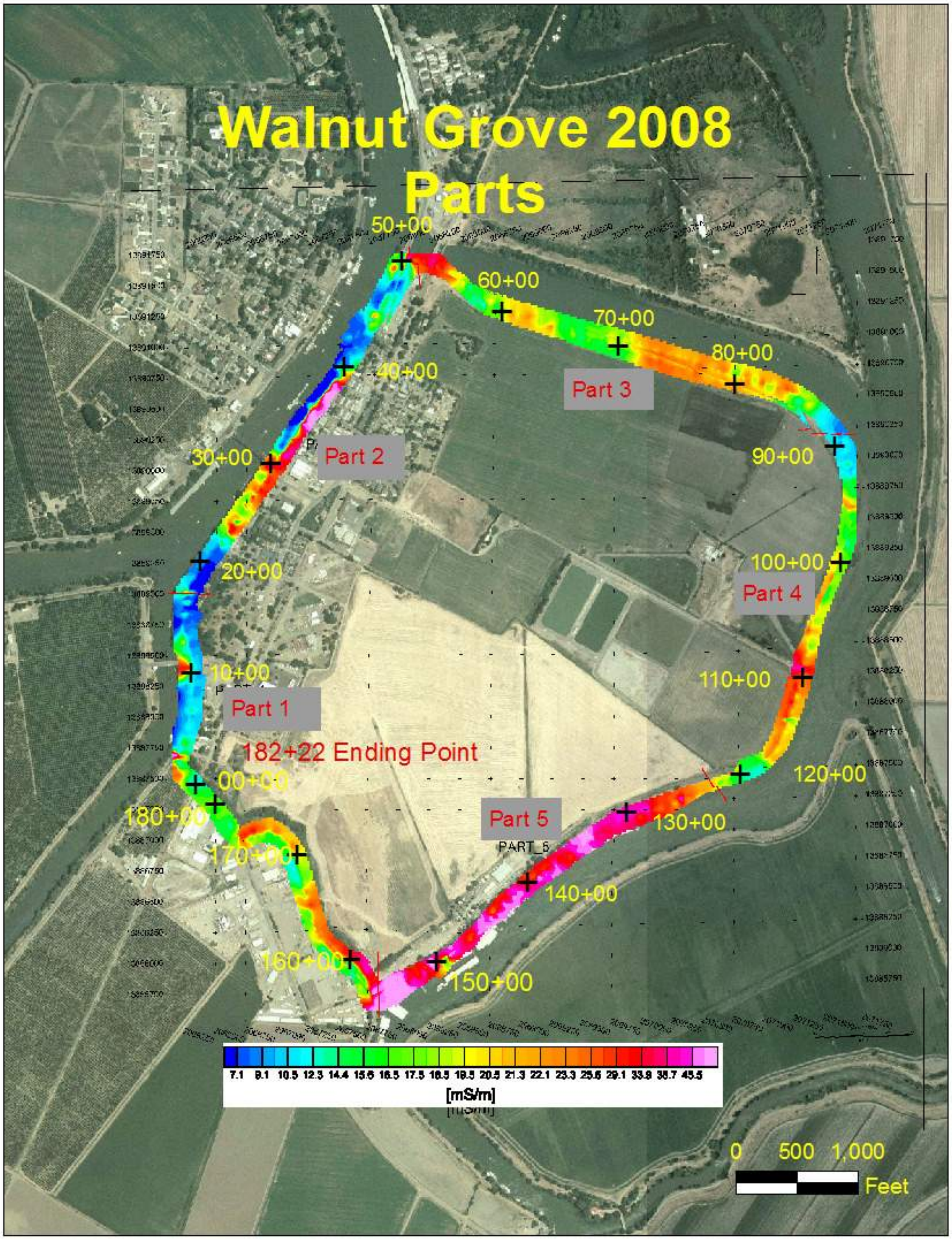
The Walnut Grove project an excellent example of how environmental conditions can hamper a project. The west side of the project went through the commercial section of Walnut grove. Traffic was halted for the duration of the three traverses but there were many parked vehicles still present. The effect 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

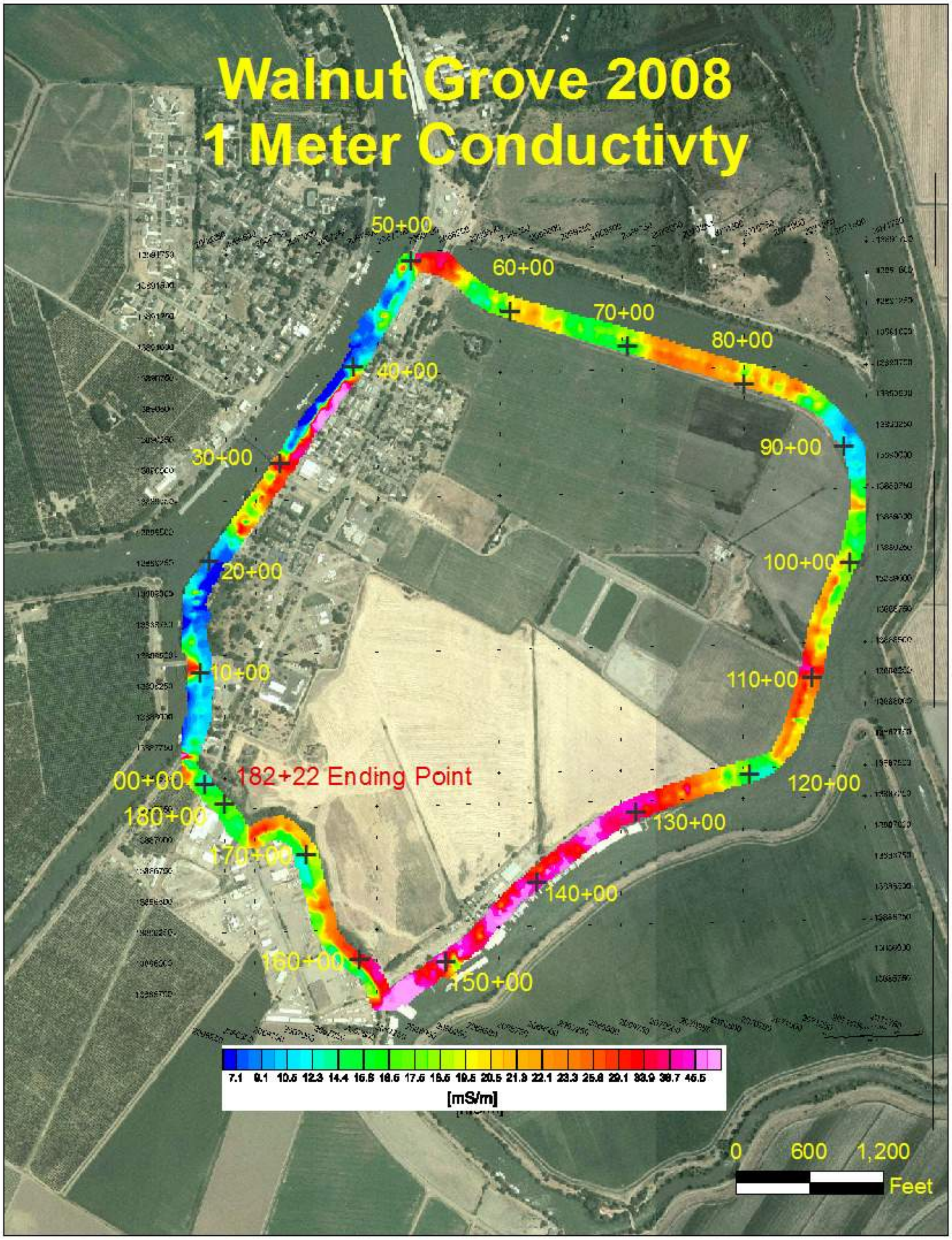
Explanation of Procedures Used in Conductance Study

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.

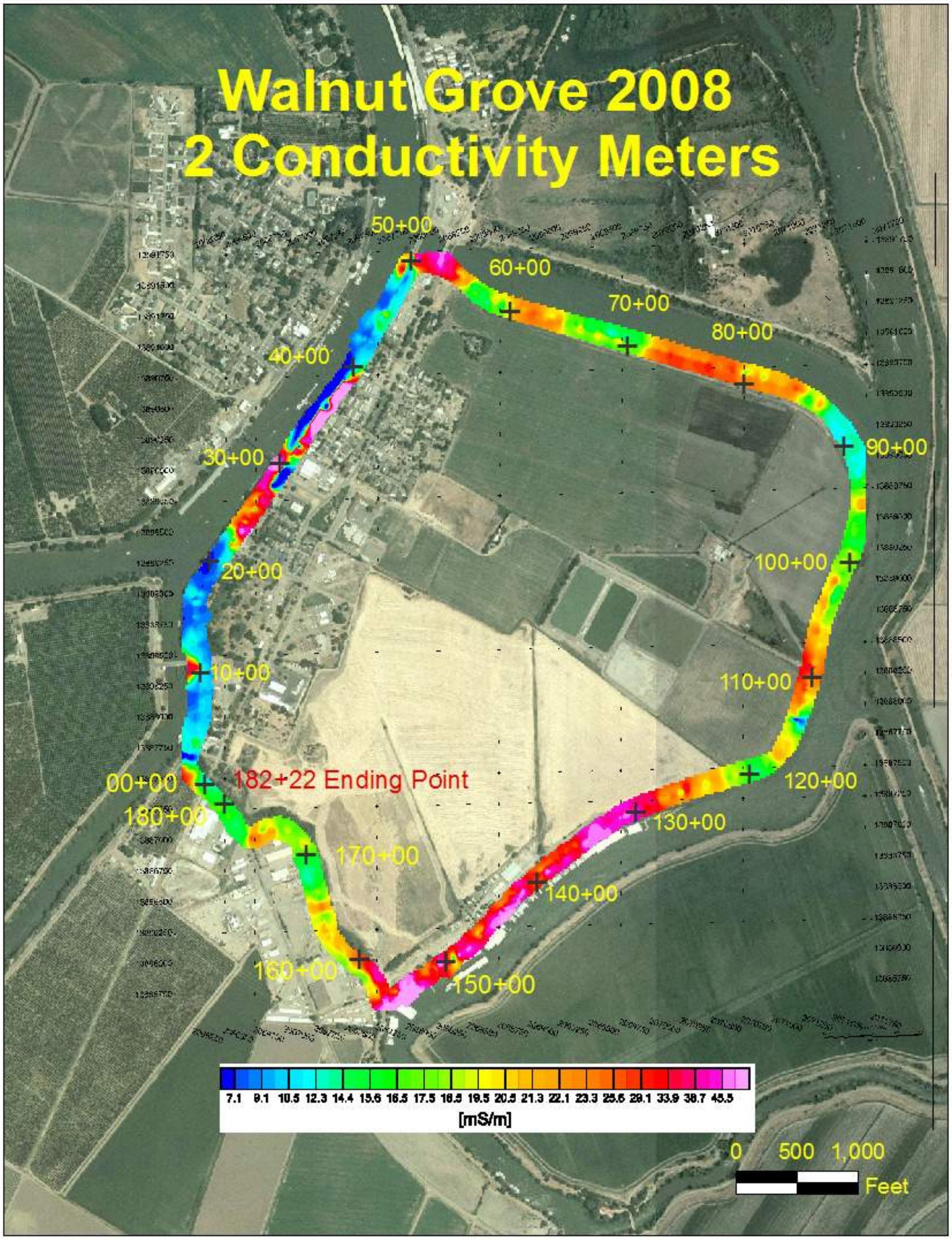
Walnut Grove Parts



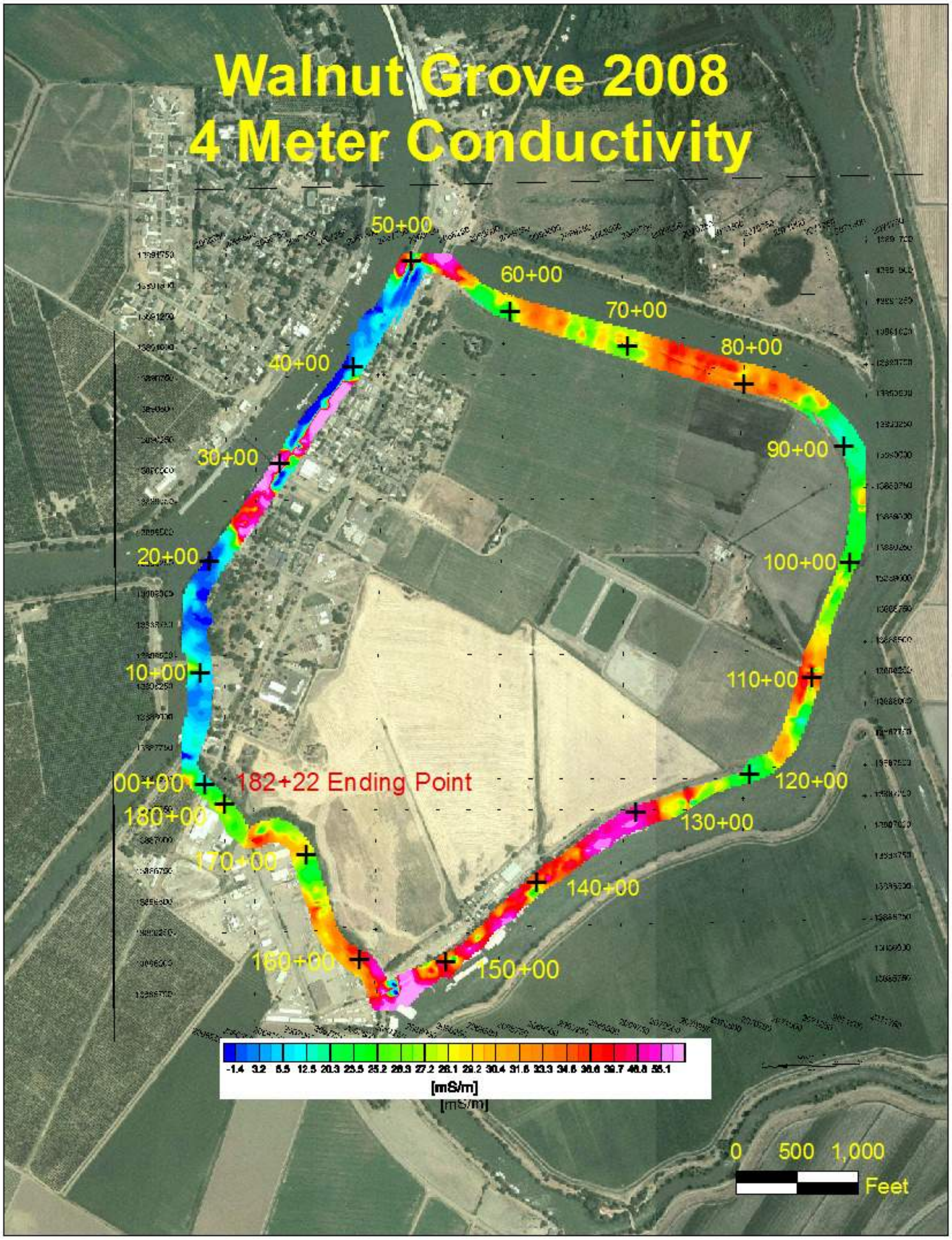
Walnut Grove 1 Meter Conductivity



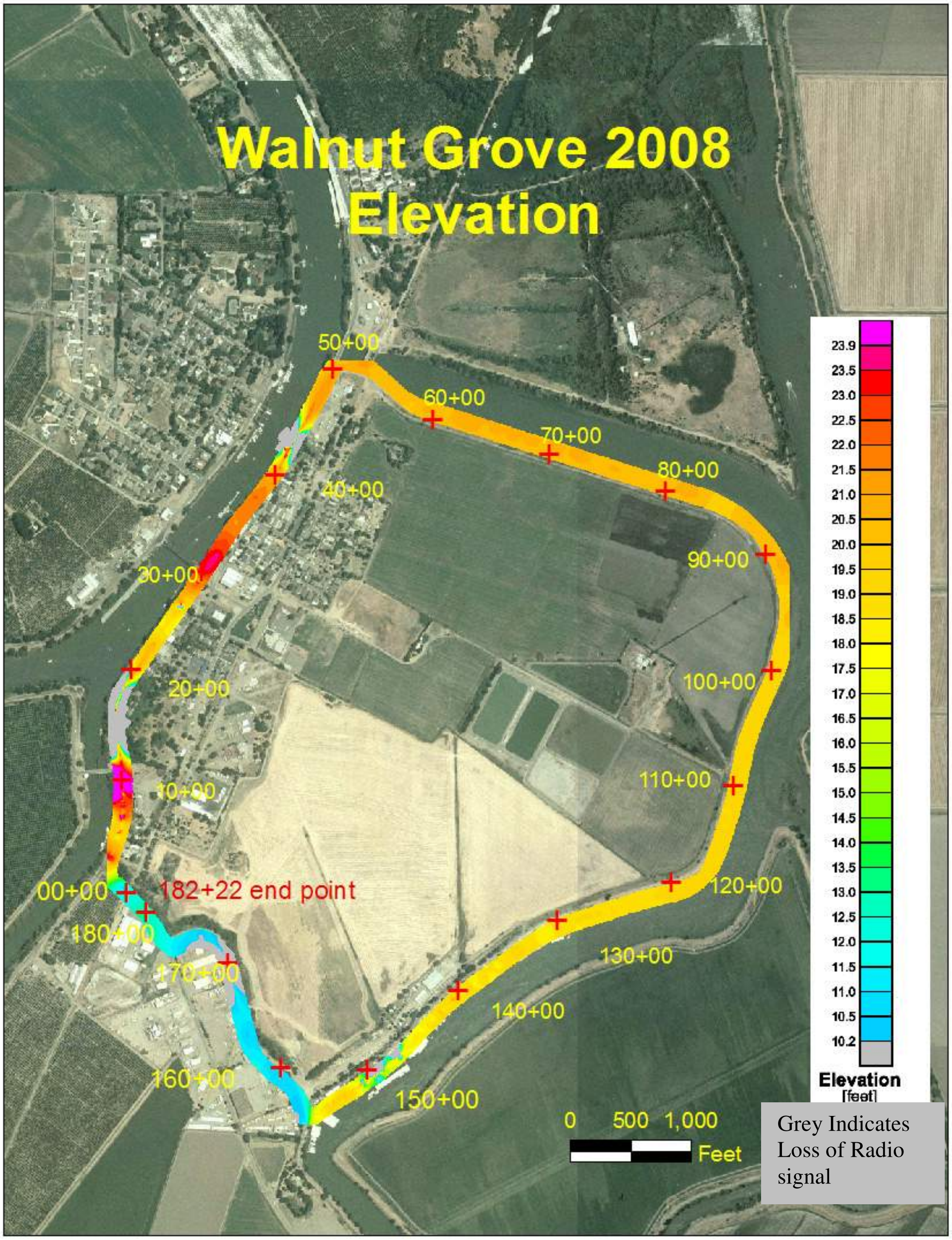
Walnut Grove 2 Meter Conductivity



Walnut Grove 4 Meter Conductivity



Elevations



Grey Indicates Loss of Radio signal

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

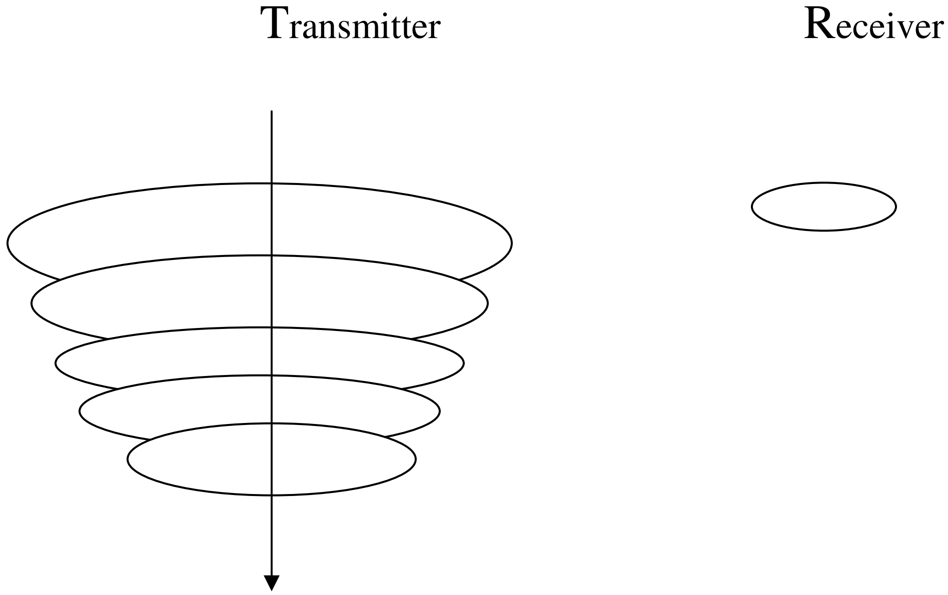


Figure 1 Induced Current Flow in Ground

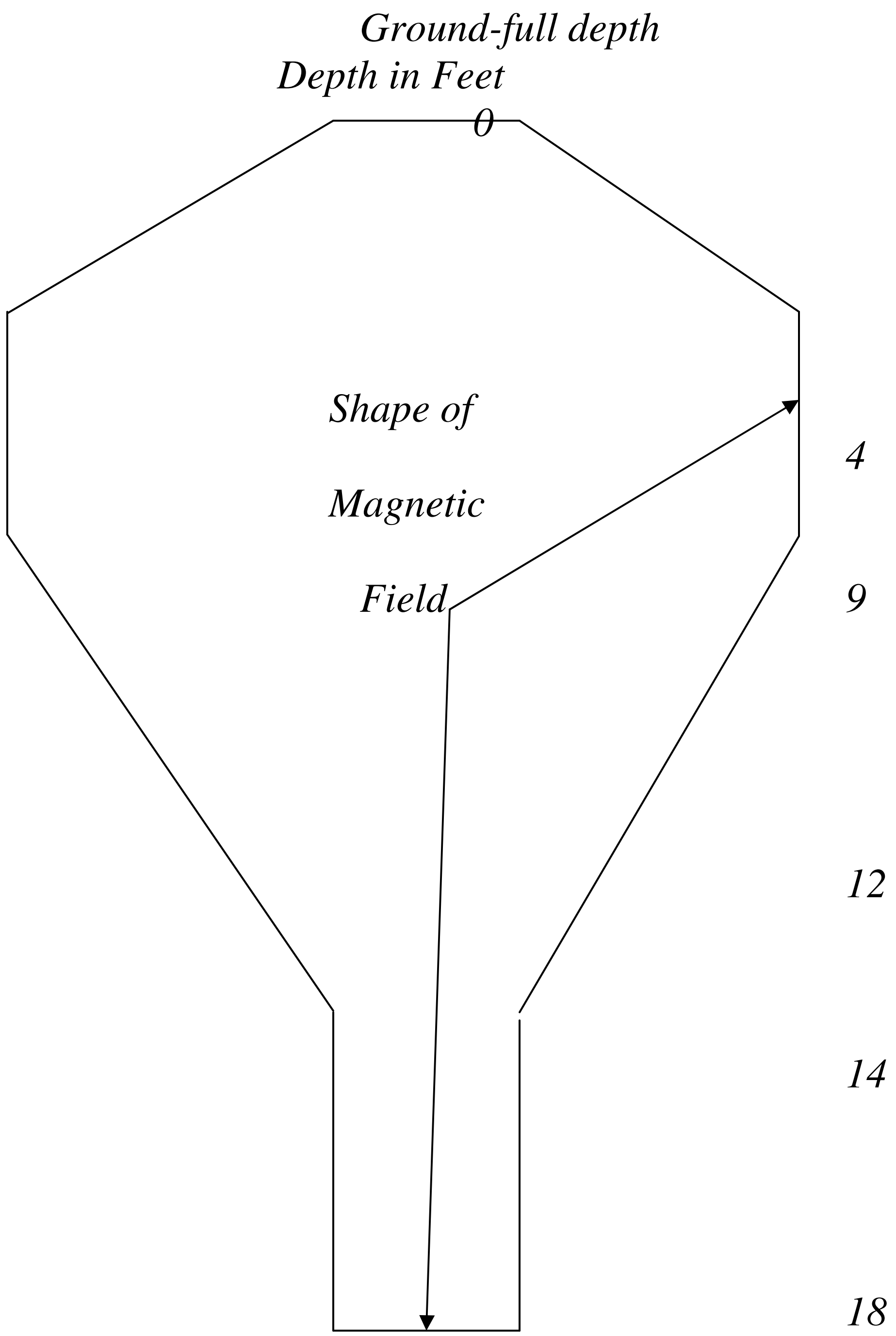


Figure 2 Instrument at 4 meter spacing. – Deep Depth

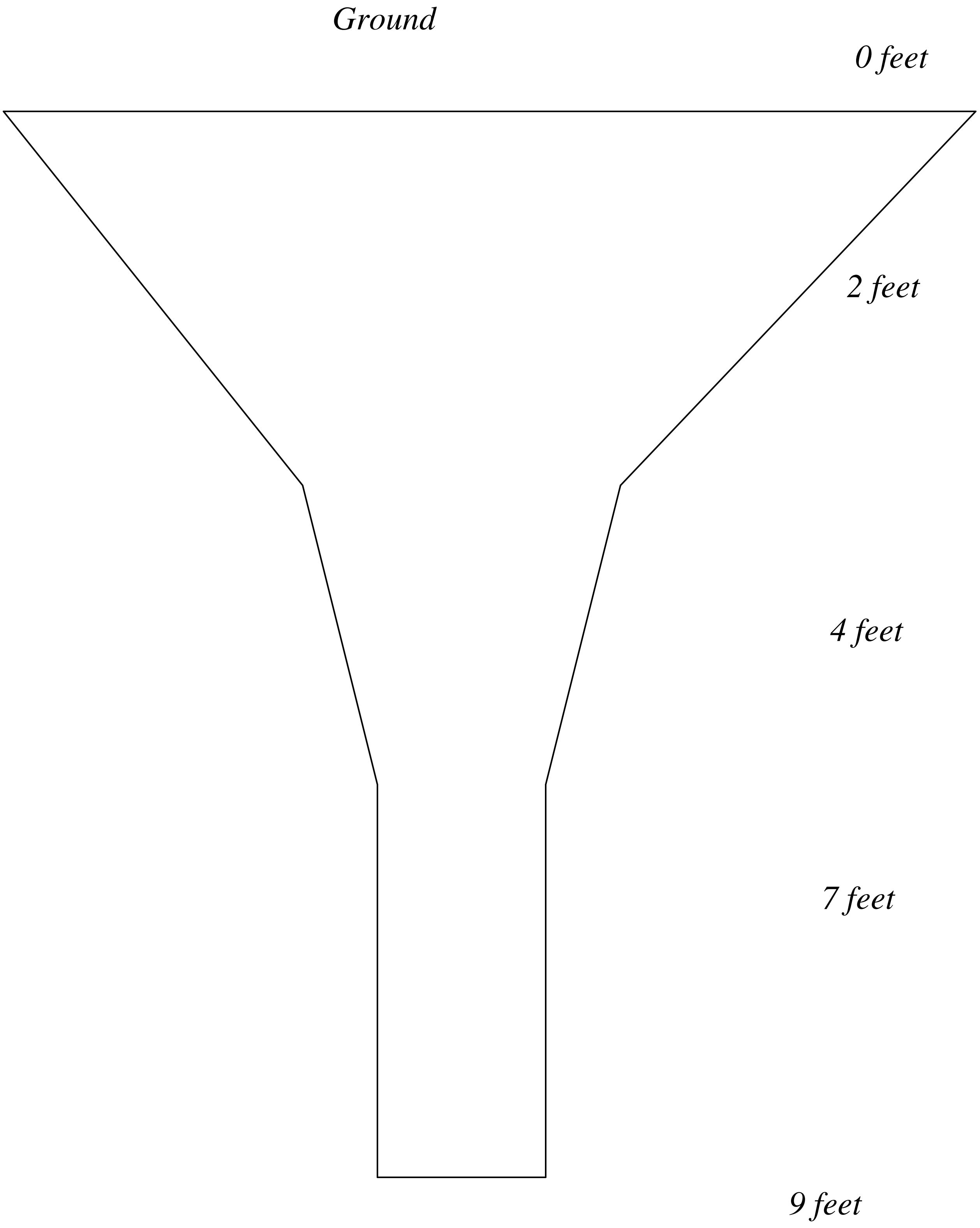


Figure 3 Instrument at 2 meter spacing.

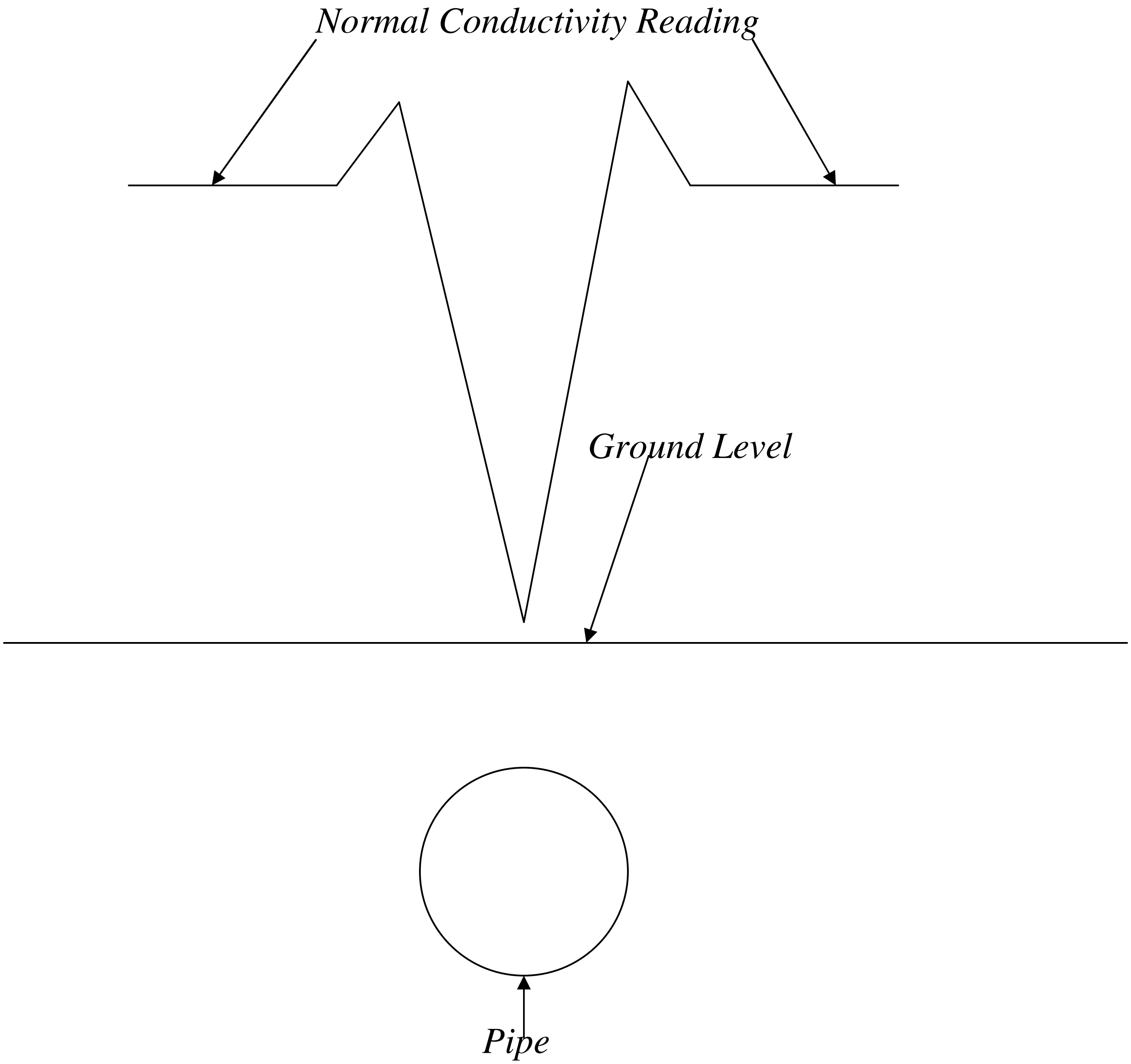


Figure 4 Typical Response over a Pipe

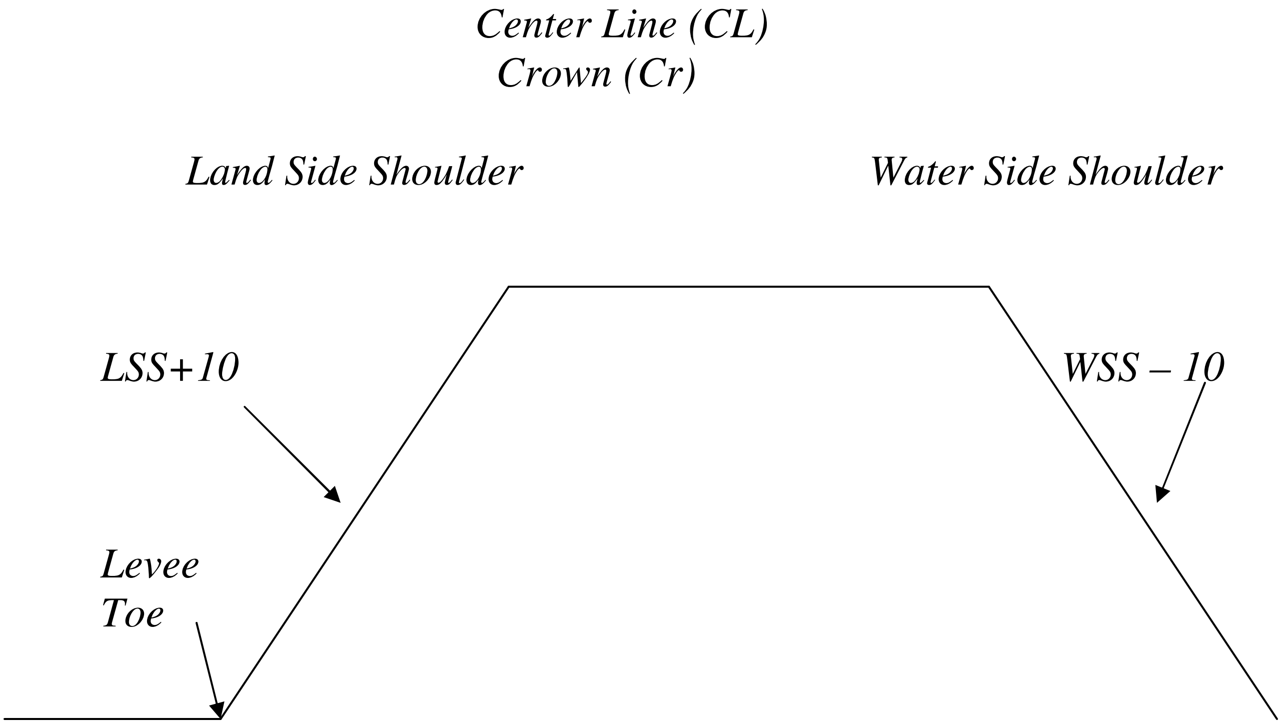


Figure 5 Levee Cross Section

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.

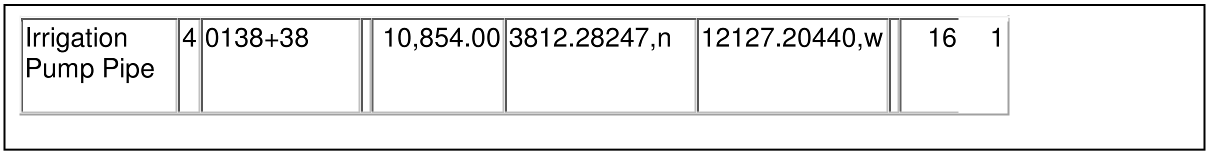
Events are different categories of objects or occasions in the levee.

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 pages13 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 to possible to better define the locations. Phase two should consists 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

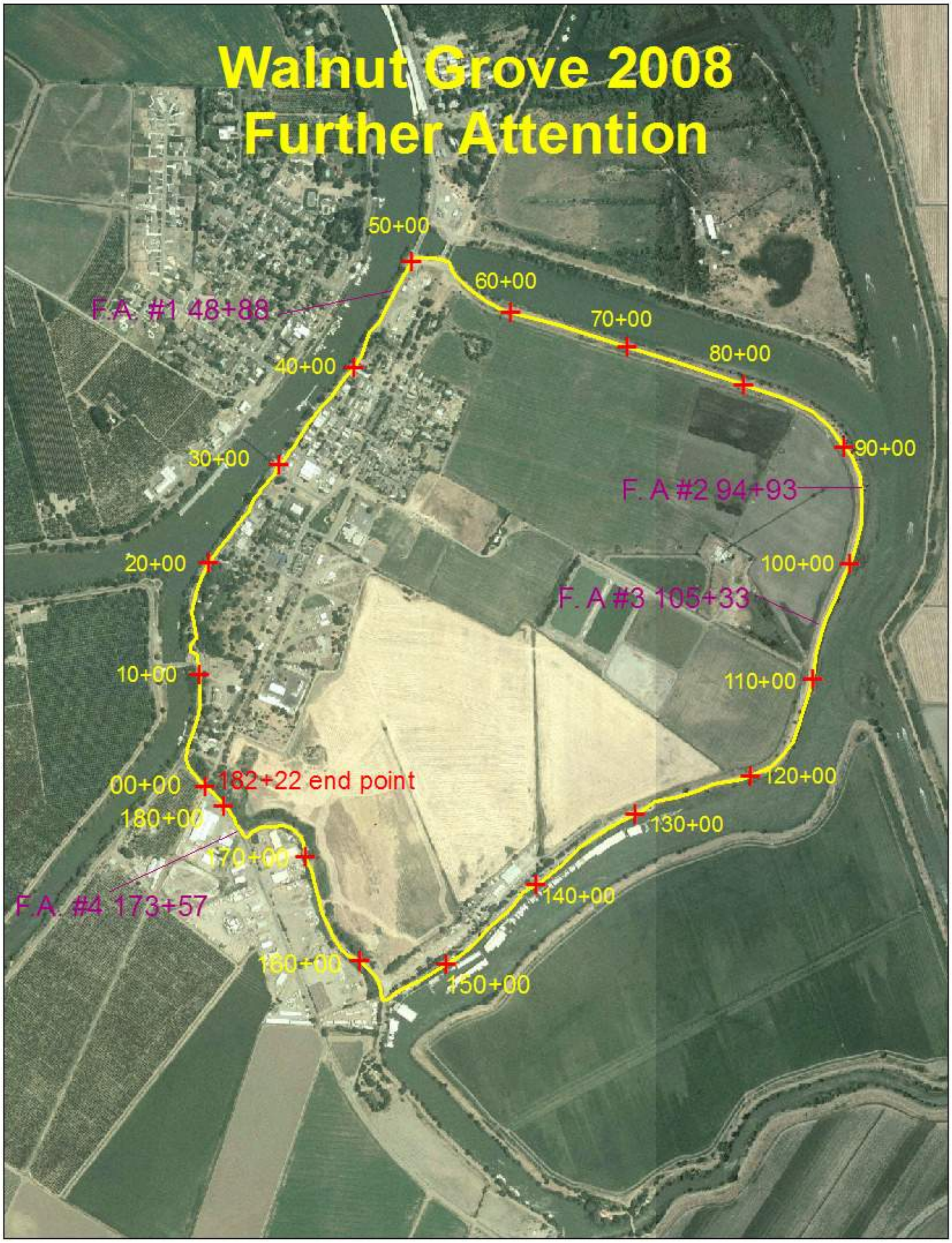
All the above areas are located in the table labeled Areas for Further Attention starting on page 31 followed by maps on page 34

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 CONDUCTIVTY IS NOT A PANACEA

Subsurface conductivity studies have some limits imposed by various physical laws and should not 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 in not the only answer to these problems but one of the most important when analyses data in 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.

DEVLOPMENT OF SUBSURFACE CONDUCTIVTY 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.

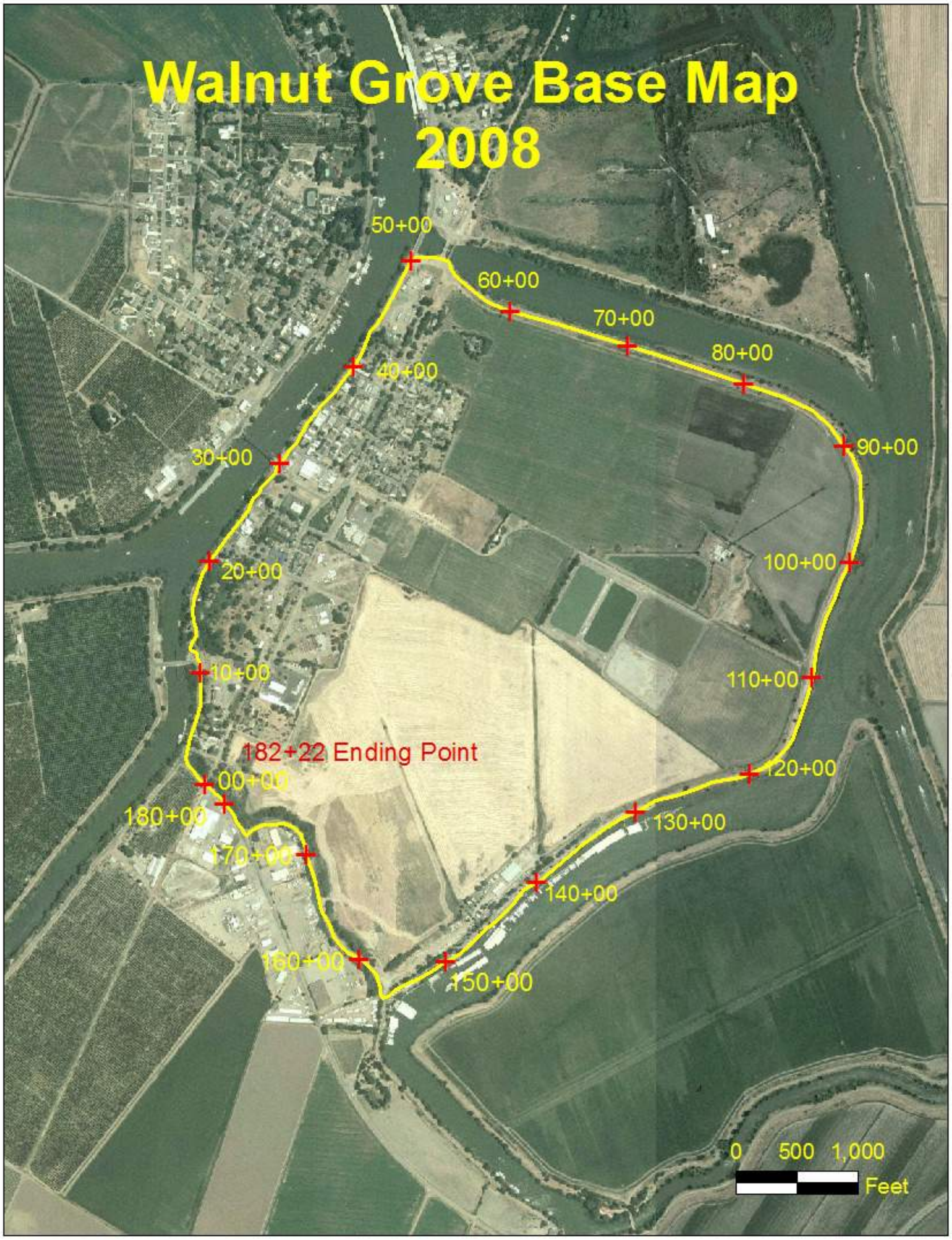
The most obvious event that occurred were unknowns, defined by CSI (as explained earlier) as metallic signals perpendicular to direction of travel and with no visible source. In over 80 percent of the cases these unknowns, when excavated, turned to be abandoned pipes that ranged in with diameter from 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 diploes carried in horizontal position. By comparing the two profiles more analysis was able to be performed over the entire length of the study areas.

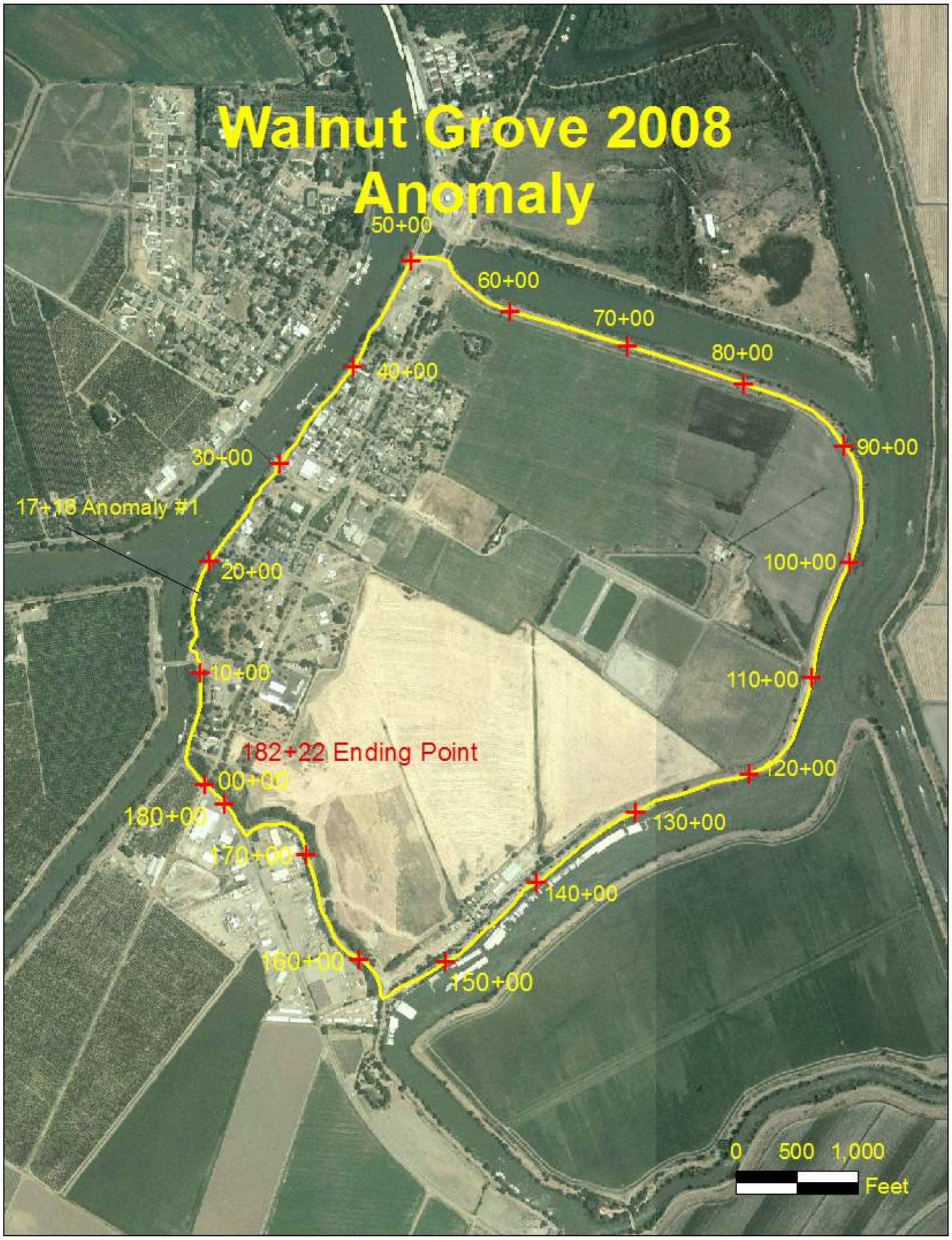
After several years Geonics' converted the Em31 (and developed the Em31-3 that allowed information to be derived from 3 depths at the same time) into a digital device and along with other developers, engineered software that allowed even greater interpretation of the conductivity signals. Software allowing 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.

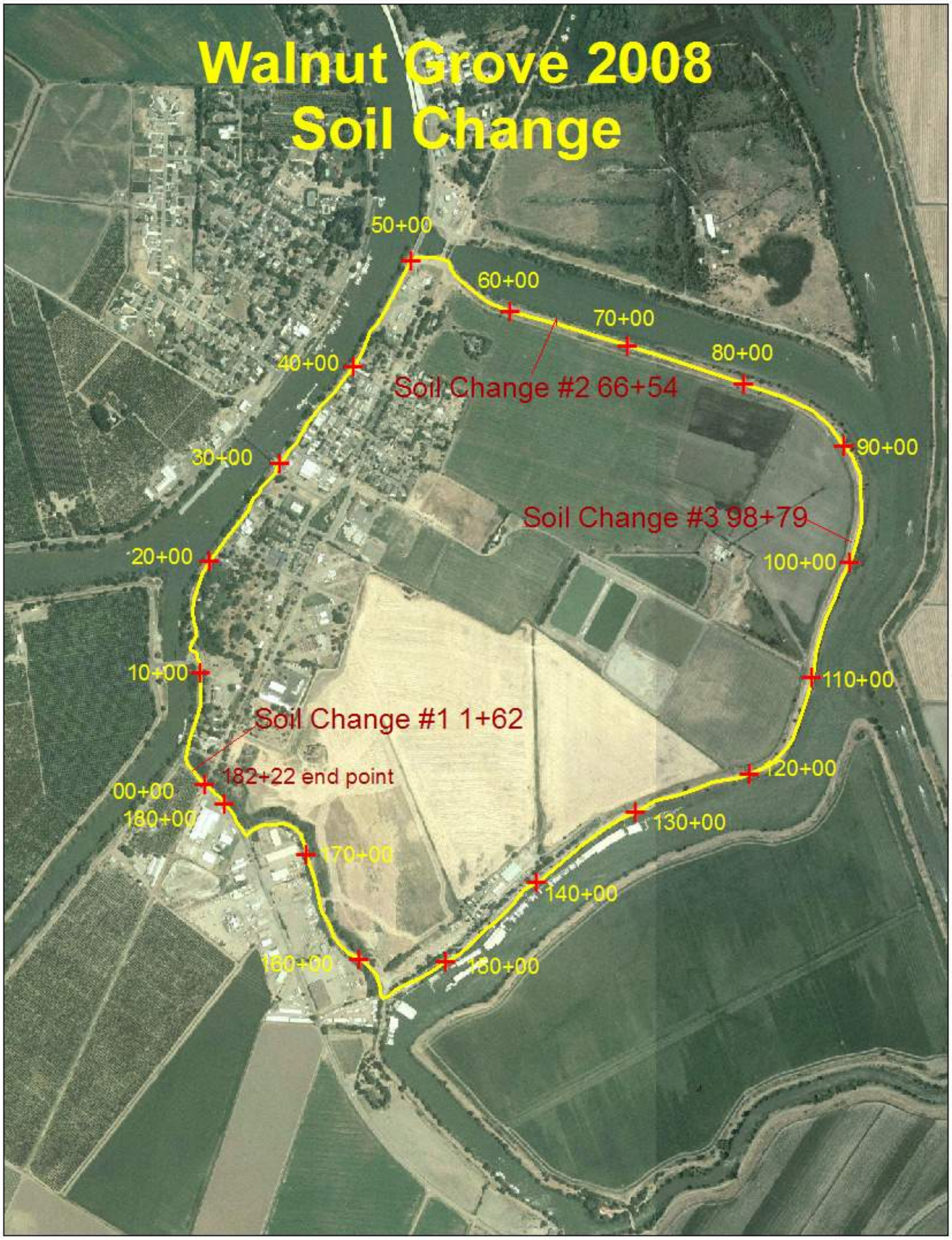
Walnut Grove Base Map



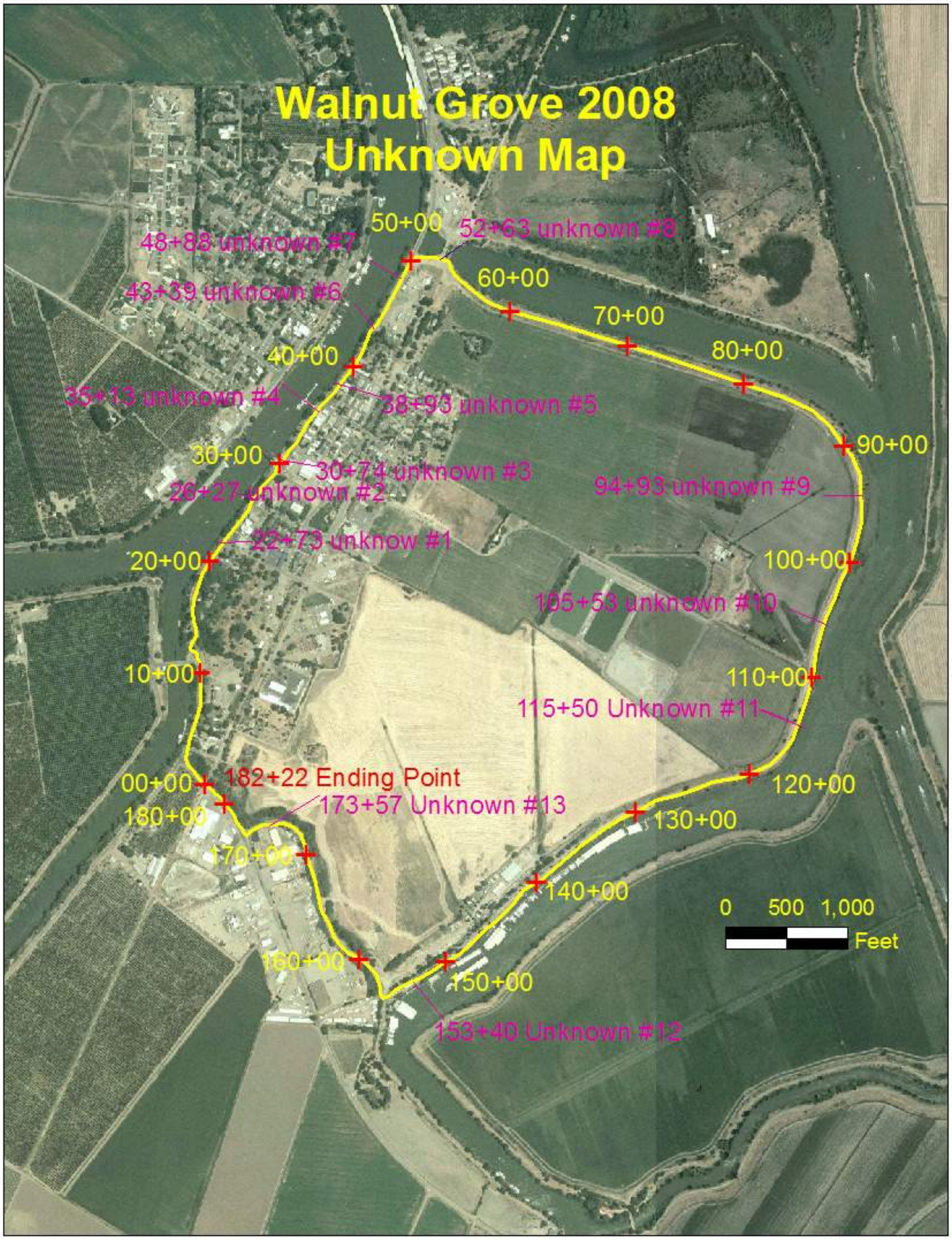
Walnut Grove Anomaly Map



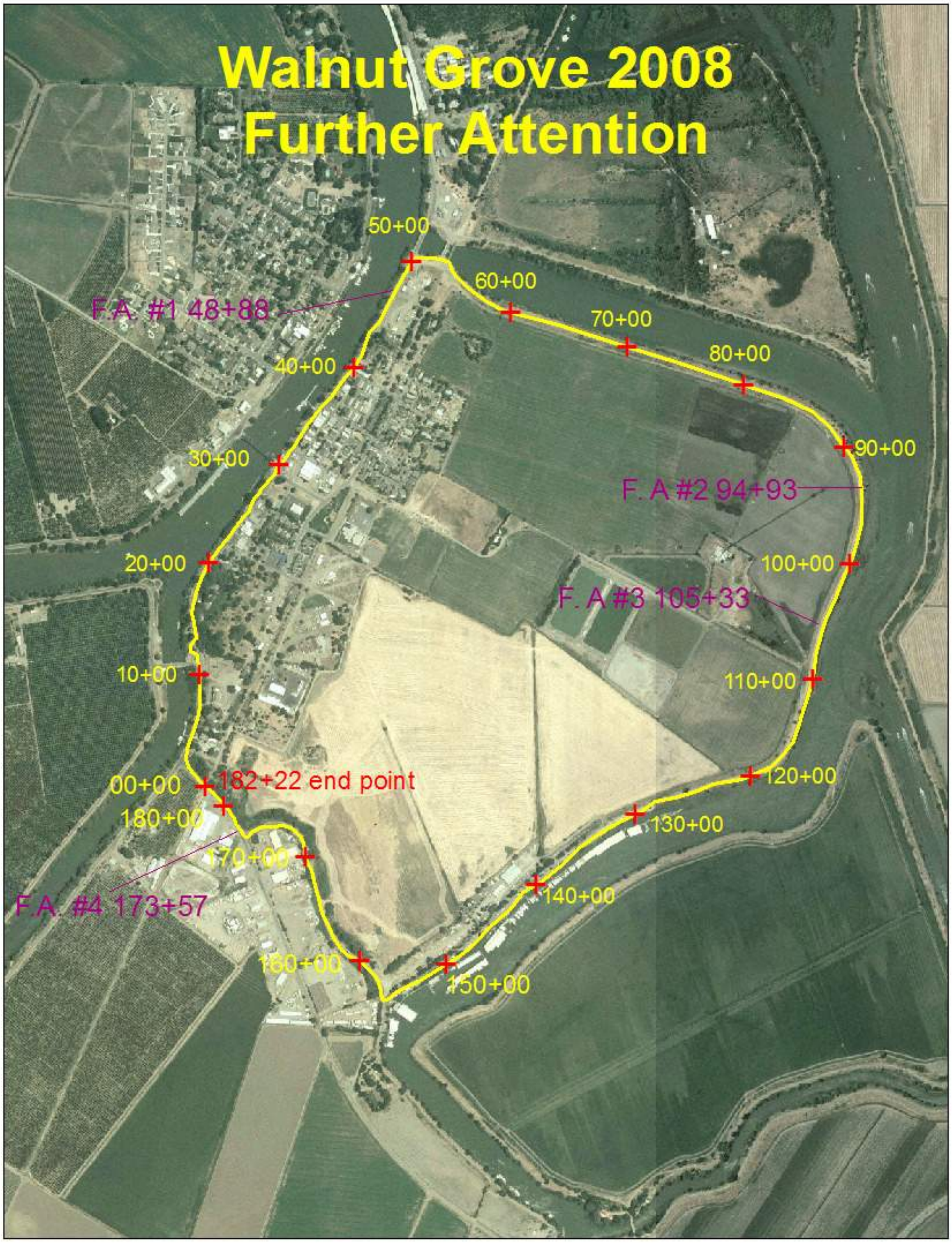
Walnut Grove Soil Change Map



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.

UPDATED EXISTING GEOTECHNICAL DATA

TECHNICAL MEMORANDUM

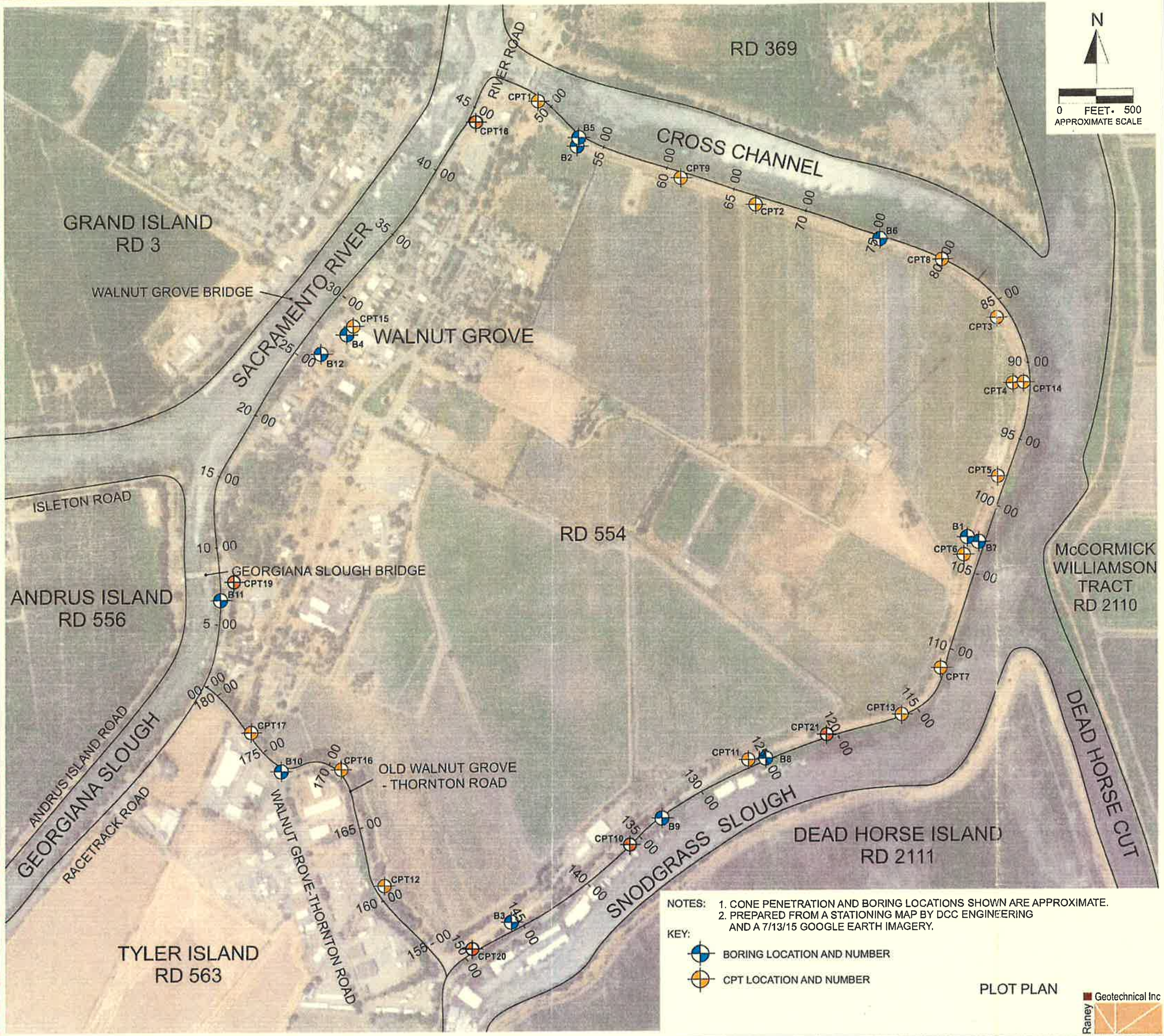
Community of East Walnut Grove, California

California Department of Water Resources
Small Community Flood Risk Reduction Program

APPENDIX D

Raney Plan and Profile
Historic Boring Logs and Cone Penetrometer Tests

PROJECT NUMBER: 1135-021



NOTES:
1. CONE PENETRATION AND BORING LOCATIONS SHOWN ARE APPROXIMATE.
2. PREPARED FROM A STATIONING MAP BY DCC ENGINEERING AND A 7/13/15 GOOGLE EARTH IMAGERY.

KEY:

⊕	BORING LOCATION AND NUMBER
⊕	CPT LOCATION AND NUMBER

PLOT PLAN

Raney Geotechnical Inc

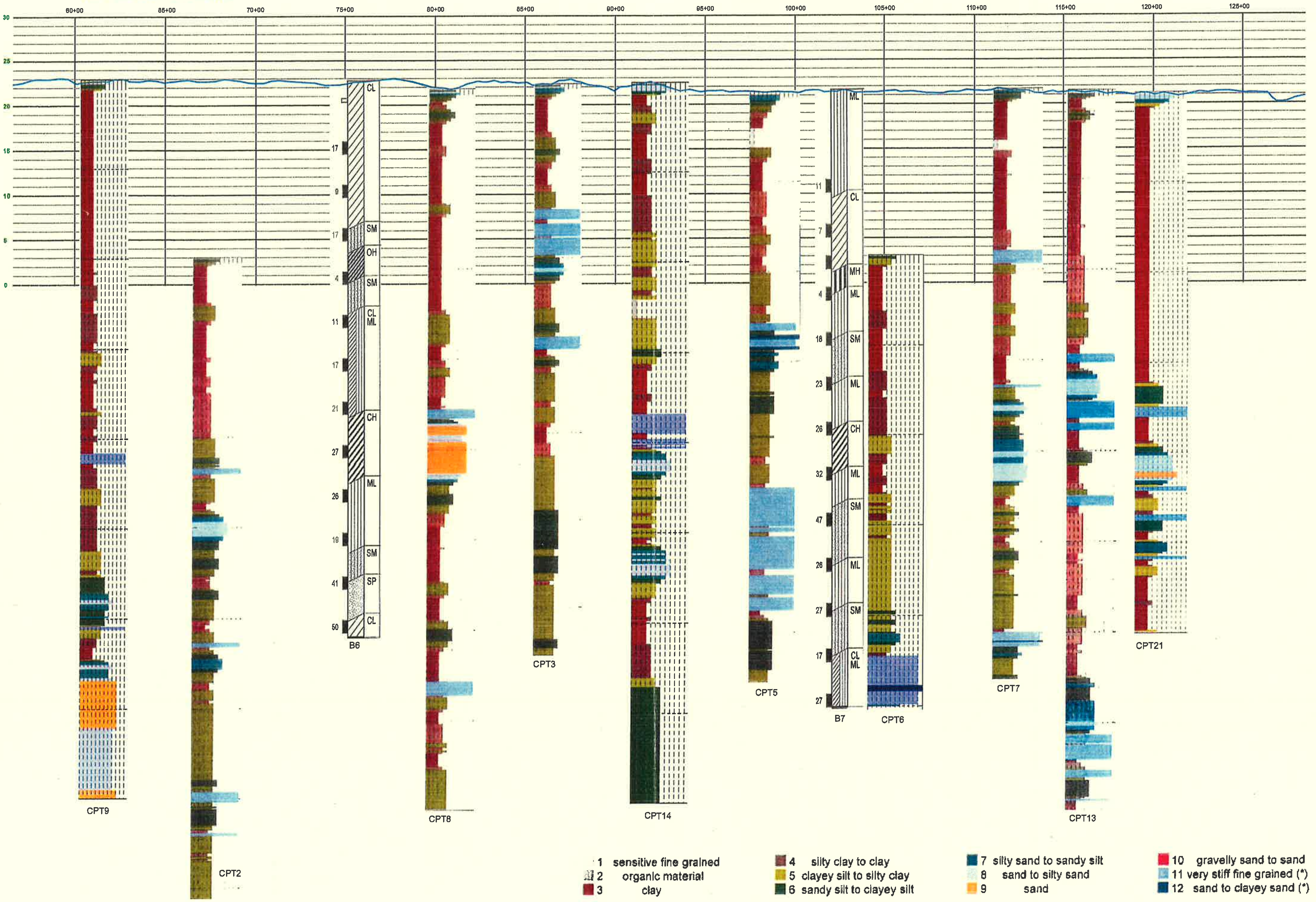
PLATE 1

CROSS CHANNEL

DELTA CROSS CHANNEL
LEVEE CENTERLINE PROFILE

SNOD GRASS

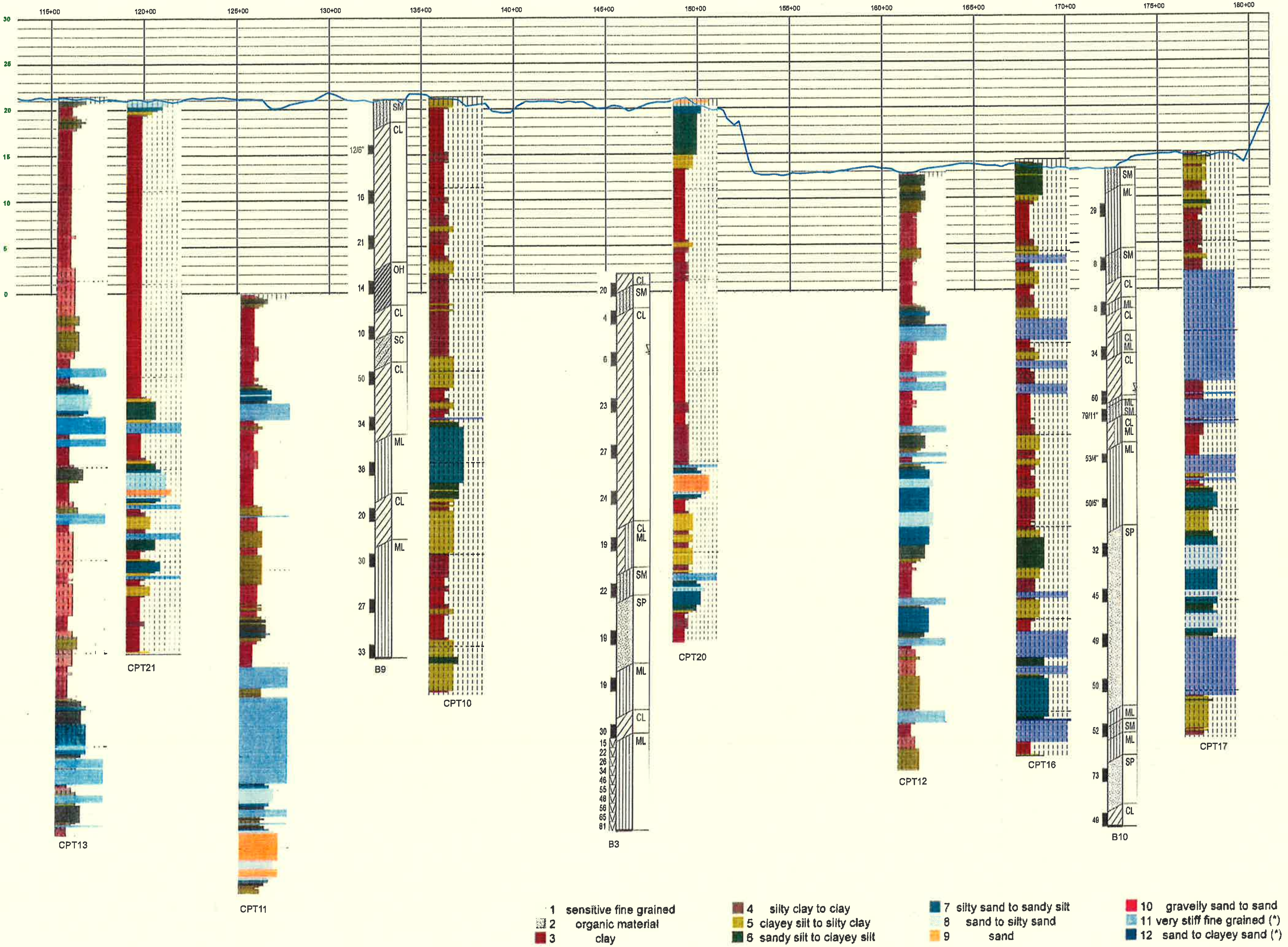
SNODGRASS SLOUGH
LEVEE CENTERLINE PROFILE

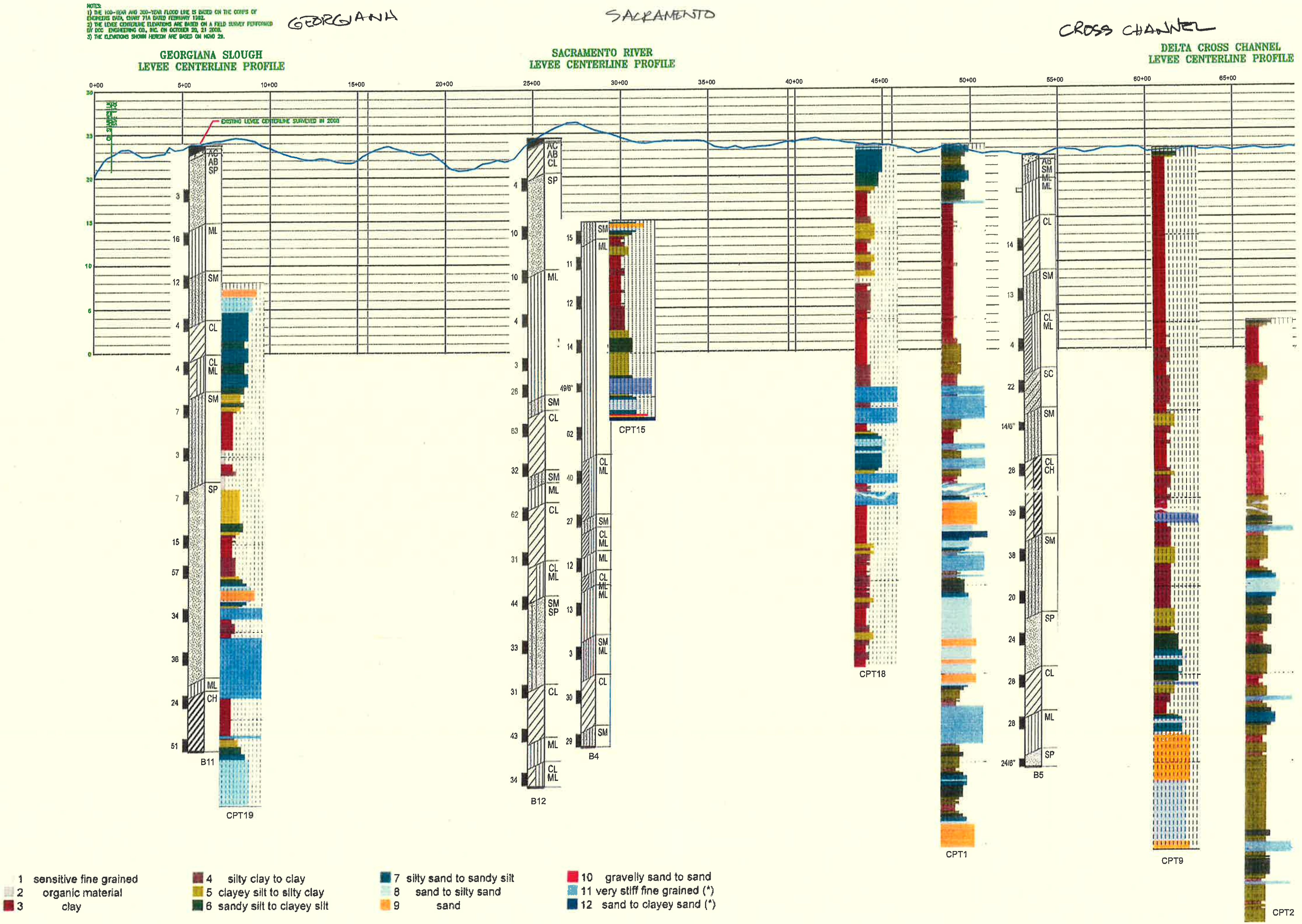


SNODGRASS

TYLER CROSS LEVEE
LEVEE CENTERLINE PROFILE

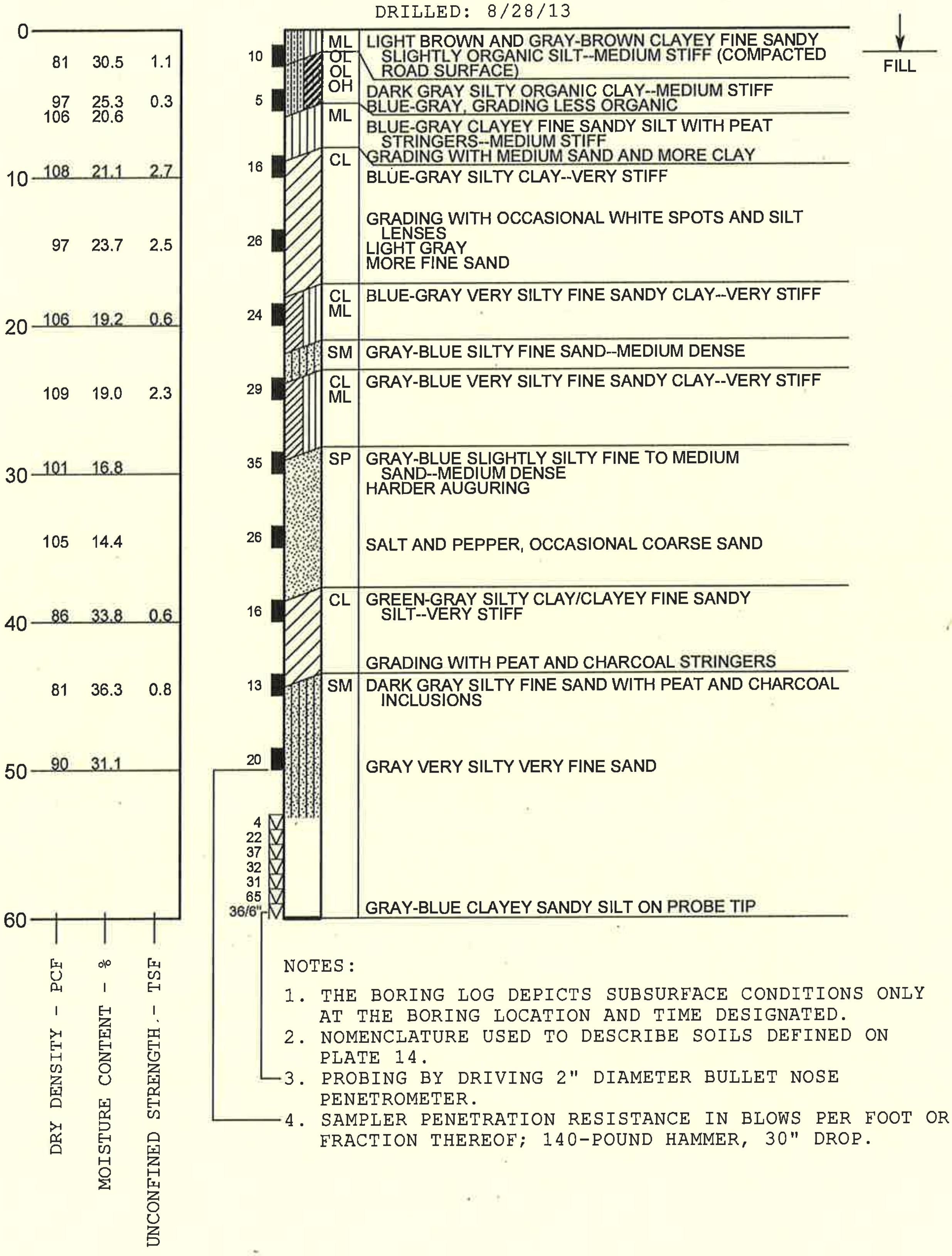
TYLER




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 2008.
3) THE ELEVATIONS SHOWN HEREON ARE BASED ON NGVD 29.

BORING 1

DRILLED: 8/28/13



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. PROBING BY DRIVING 2" DIAMETER BULLET NOSE PENETROMETER.
4. SAMPLER PENETRATION RESISTANCE IN BLOWS PER FOOT OR FRACTION THEREOF; 140-POUND HAMMER, 30" DROP.

PROJECT NUMBER: 1135-021
PLATE NUMBER: 2

DRAWN BY: FM
DATE: 5/19/15

LOG OF BORING

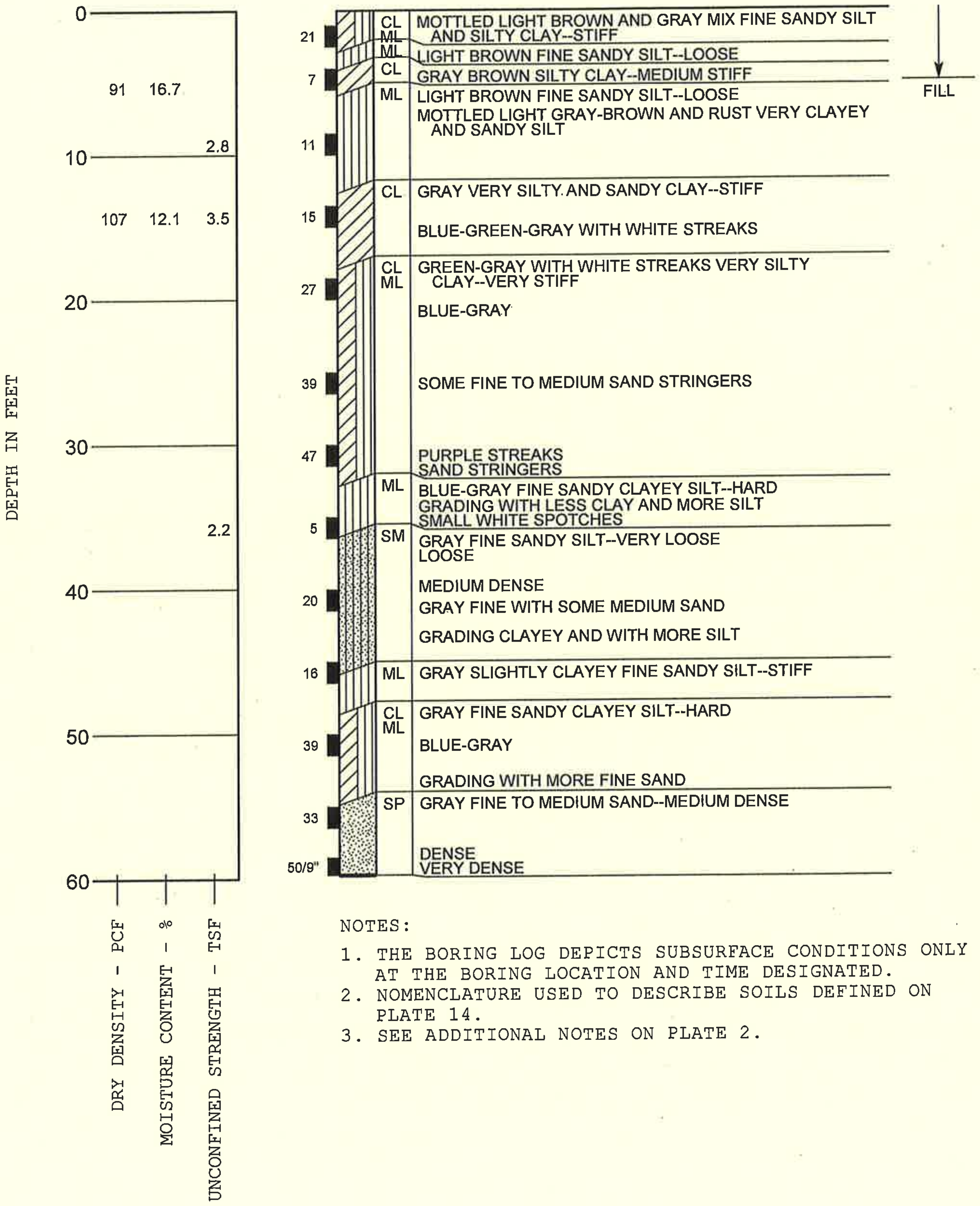
PLATE 2

PROJECT NUMBER: 1135-021
PLATE NUMBER: 3

DRAWN BY: TL
DATE: 3/2/16

BORING 2

DRILLED: 8/28/13



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.

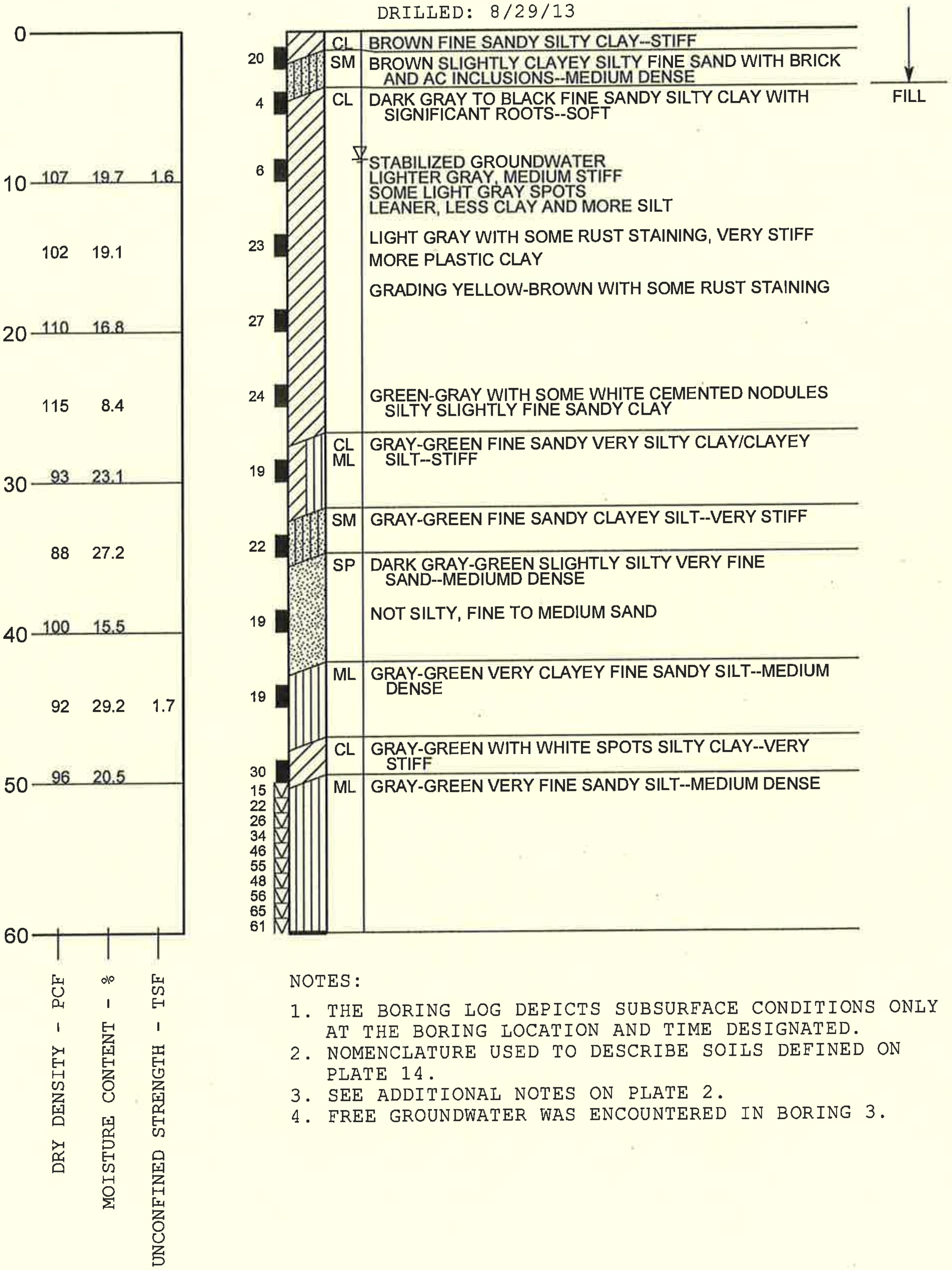
LOG OF BORING

PROJECT NUMBER: 1135-021
PLATE NUMBER: 4

DRAWN BY: TL
DATE: 3/2/16

BORING 3

DRILLED: 8/29/13



CL BROWN FINE SANDY SILTY CLAY--STIFF

SM BROWN SLIGHTLY CLAYEY SILTY FINE SAND WITH BRICK AND AC INCLUSIONS--MEDIUM DENSE

CL DARK GRAY TO BLACK FINE SANDY SILTY CLAY WITH SIGNIFICANT ROOTS--SOFT

∇ STABILIZED GROUNDWATER
LIGHTER GRAY, MEDIUM STIFF
SOME LIGHT GRAY SPOTS
LEANER, LESS CLAY AND MORE SILT

LIGHT GRAY WITH SOME RUST STAINING, VERY STIFF
MORE PLASTIC CLAY

GRADING YELLOW-BROWN WITH SOME RUST STAINING

GREEN-GRAY WITH SOME WHITE CEMENTED NODULES SILTY SLIGHTLY FINE SANDY CLAY

CL ML GRAY-GREEN FINE SANDY VERY SILTY CLAY/CLAYEY SILT--STIFF

SM GRAY-GREEN FINE SANDY CLAYEY SILT--VERY STIFF

SP DARK GRAY-GREEN SLIGHTLY SILTY VERY FINE SAND--MEDIUMD DENSE

NOT SILTY, FINE TO MEDIUM SAND

ML GRAY-GREEN VERY CLAYEY FINE SANDY SILT--MEDIUM DENSE

CL GRAY-GREEN WITH WHITE SPOTS SILTY CLAY--VERY STIFF

ML GRAY-GREEN VERY FINE SANDY SILT--MEDIUM DENSE

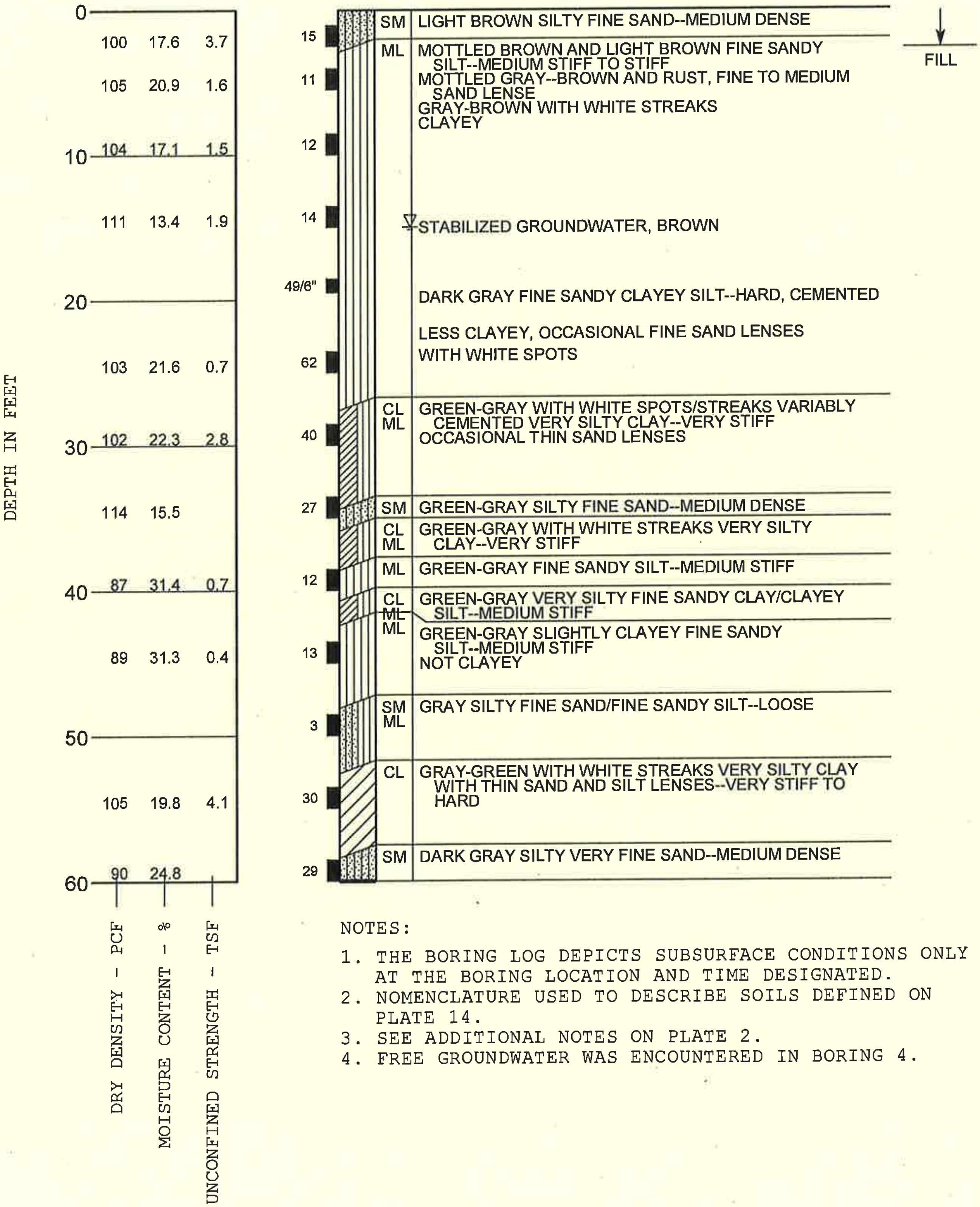
NOTES:

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.
4. FREE GROUNDWATER WAS ENCOUNTERED IN BORING 3.

LOG OF BORING

BORING 4

DRILLED: 9/5/13



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.
4. FREE GROUNDWATER WAS ENCOUNTERED IN BORING 4.

PROJECT NUMBER: 1135-021
PLATE NUMBER: 5

DRAWN BY: EM
DATE: 5/19/15

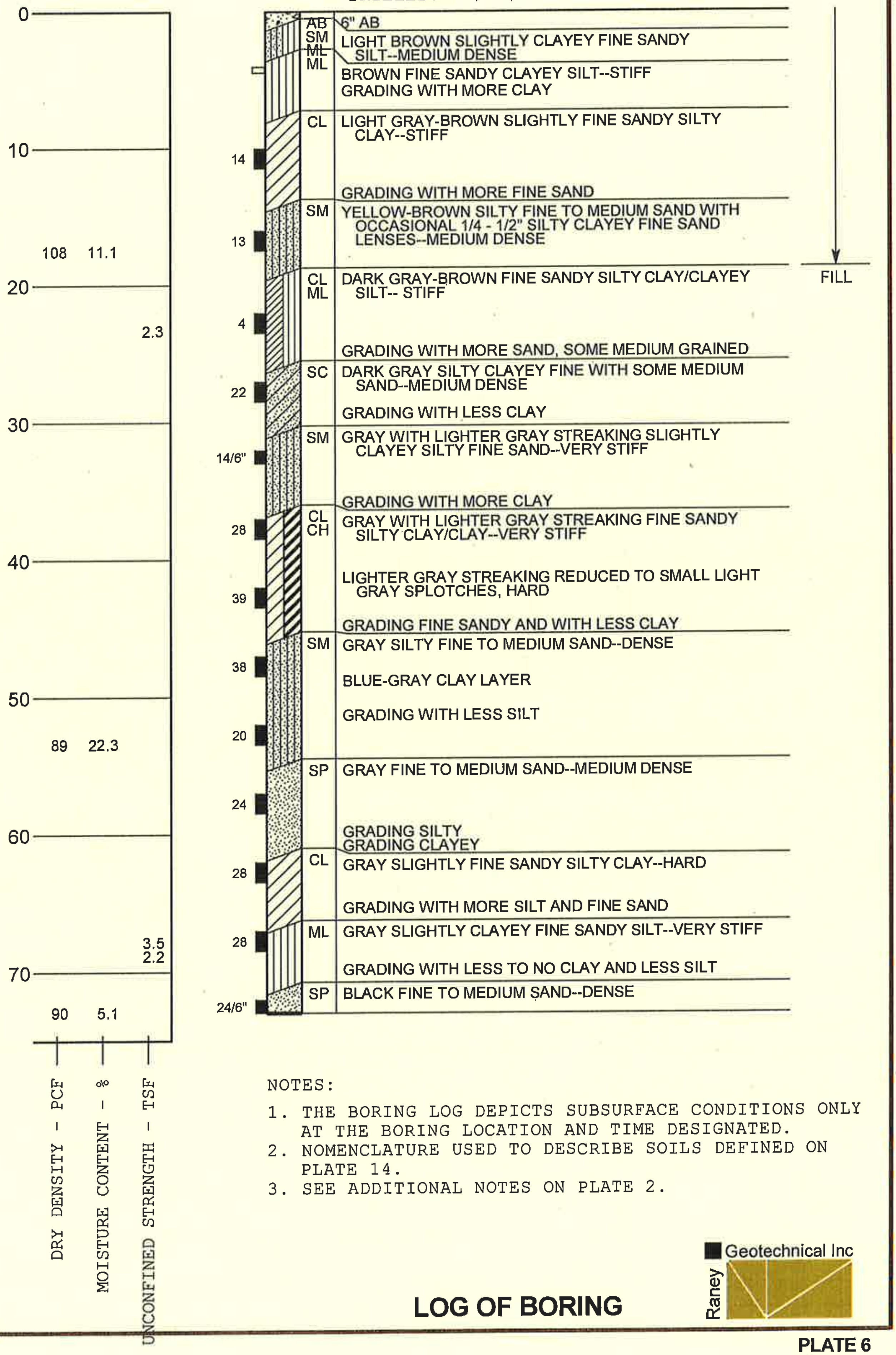
LOG OF BORING

PROJECT NUMBER: 1135-021
PLATE NUMBER: 6

DRAWN BY: TL
DATE: 3/4/16

BORING 5

DRILLED: 10/16/13



AB 6" AB

SM ML LIGHT BROWN SLIGHTLY CLAYEY FINE SANDY SILT--MEDIUM DENSE

ML BROWN FINE SANDY CLAYEY SILT--STIFF
GRADING WITH MORE CLAY

CL LIGHT GRAY-BROWN SLIGHTLY FINE SANDY SILTY CLAY--STIFF
GRADING WITH MORE FINE SAND

SM YELLOW-BROWN SILTY FINE TO MEDIUM SAND WITH OCCASIONAL 1/4 - 1/2" SILTY CLAYEY FINE SAND LENSES--MEDIUM DENSE

CL ML DARK GRAY-BROWN FINE SANDY SILTY CLAY/CLAYEY SILT-- STIFF
GRADING WITH MORE SAND, SOME MEDIUM GRAINED

SC DARK GRAY SILTY CLAYEY FINE WITH SOME MEDIUM SAND--MEDIUM DENSE
GRADING WITH LESS CLAY

SM GRAY WITH LIGHTER GRAY STREAKING SLIGHTLY CLAYEY SILTY FINE SAND--VERY STIFF
GRADING WITH MORE CLAY

CL CH GRAY WITH LIGHTER GRAY STREAKING FINE SANDY SILTY CLAY/CLAY--VERY STIFF
LIGHTER GRAY STREAKING REDUCED TO SMALL LIGHT GRAY SPLOTCHES, HARD
GRADING FINE SANDY AND WITH LESS CLAY

SM GRAY SILTY FINE TO MEDIUM SAND--DENSE
BLUE-GRAY CLAY LAYER
GRADING WITH LESS SILT

SP GRAY FINE TO MEDIUM SAND--MEDIUM DENSE
GRADING SILTY
GRADING CLAYEY

CL GRAY SLIGHTLY FINE SANDY SILTY CLAY--HARD
GRADING WITH MORE SILT AND FINE SAND

ML GRAY SLIGHTLY CLAYEY FINE SANDY SILT--VERY STIFF
GRADING WITH LESS TO NO CLAY AND LESS SILT

SP BLACK FINE TO MEDIUM SAND--DENSE

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.

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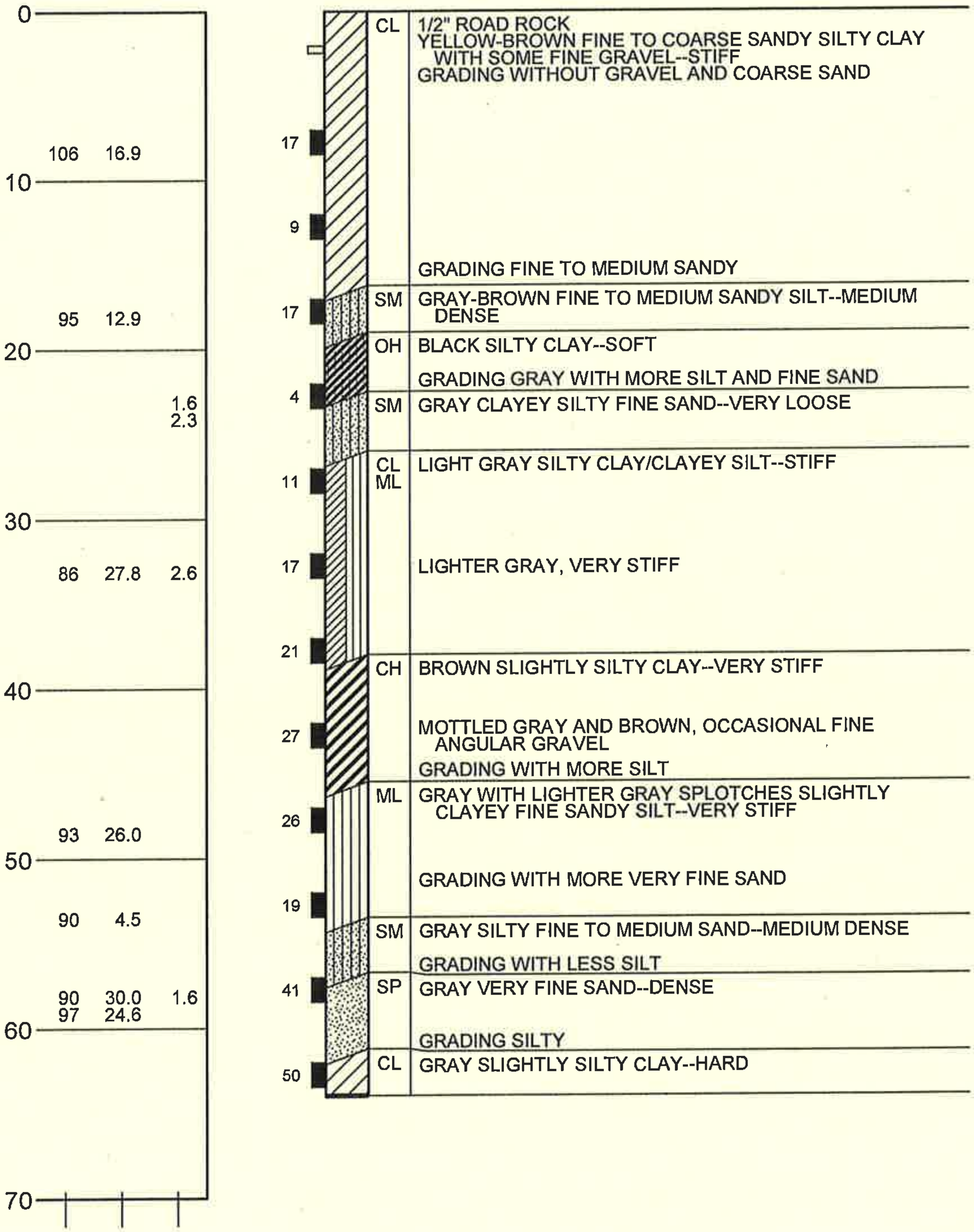
LOG OF BORING

BORING 6

DRILLED: 10/17/13



CL 1/2" ROAD ROCK
YELLOW-BROWN FINE TO COARSE SANDY SILTY CLAY WITH SOME FINE GRAVEL--STIFF
GRADING WITHOUT GRAVEL AND COARSE SAND
GRADING FINE TO MEDIUM SANDY

SM GRAY-BROWN FINE TO MEDIUM SANDY SILT--MEDIUM DENSE

OH BLACK SILTY CLAY--SOFT
GRADING GRAY WITH MORE SILT AND FINE SAND

SM GRAY CLAYEY SILTY FINE SAND--VERY LOOSE

CL ML LIGHT GRAY SILTY CLAY/CLAYEY SILT--STIFF
LIGHTER GRAY, VERY STIFF

CH BROWN SLIGHTLY SILTY CLAY--VERY STIFF
MOTTLED GRAY AND BROWN, OCCASIONAL FINE ANGULAR GRAVEL
GRADING WITH MORE SILT

ML GRAY WITH LIGHTER GRAY SPLOTCHES SLIGHTLY CLAYEY FINE SANDY SILT--VERY STIFF
GRADING WITH MORE VERY FINE SAND

SM GRAY SILTY FINE TO MEDIUM SAND--MEDIUM DENSE
GRADING WITH LESS SILT

SP GRAY VERY FINE SAND--DENSE
GRADING SILTY

CL GRAY SLIGHTLY SILTY CLAY--HARD

DEPTH IN FEET

DRY DENSITY - PCF

MOISTURE CONTENT - %

UNCONFINED STRENGTH - TSF

PROJECT NUMBER: 1135-021
PLATE NUMBER: 7

DRAWN BY: TL
DATE: 3/4/16

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.

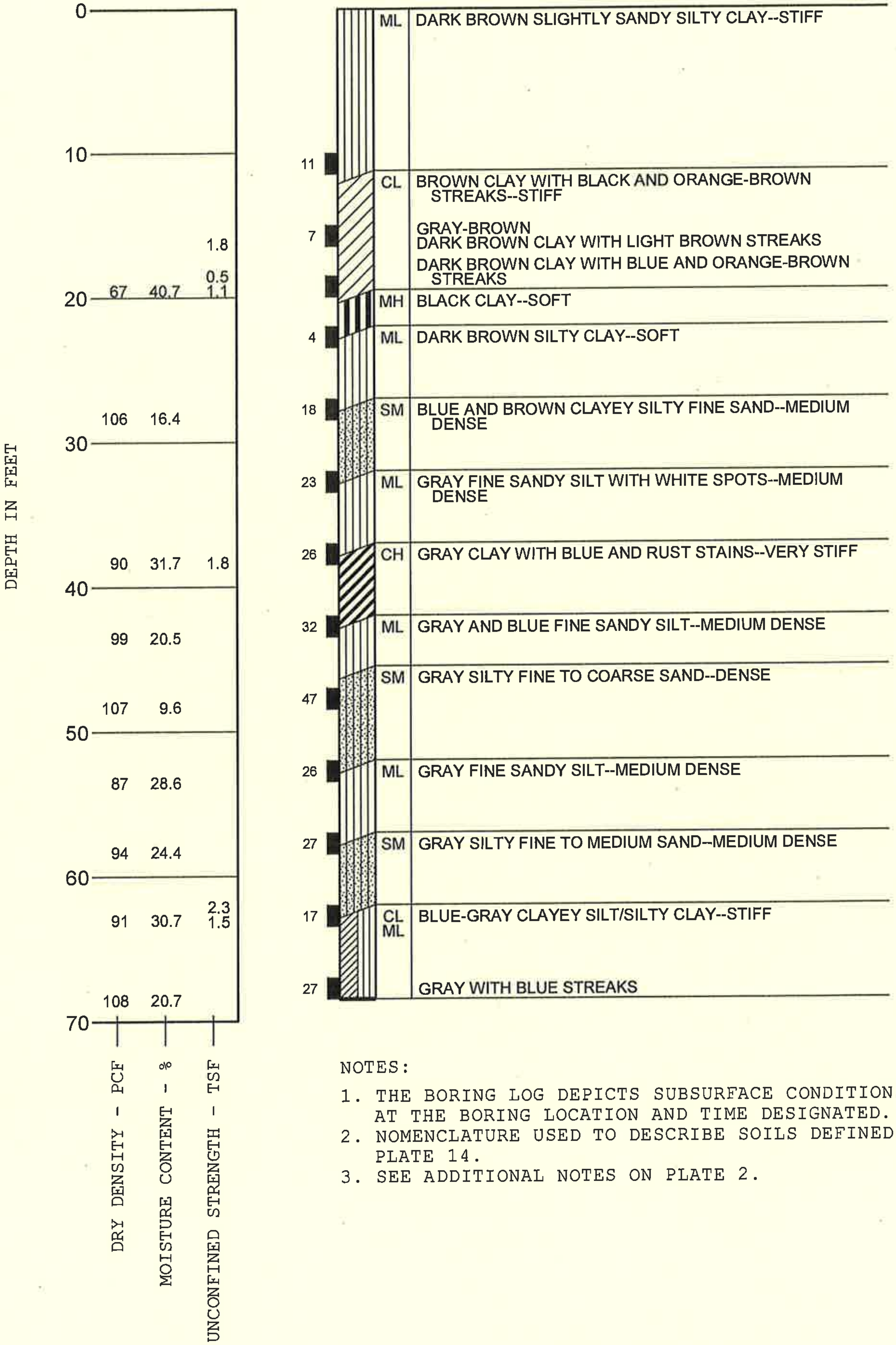
LOG OF BORING

PROJECT NUMBER: 1135-021
PLATE NUMBER: 8

DRAWN BY: TL
DATE: 3/4/16

BORING 7

DRILLED: 10/18/13



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.

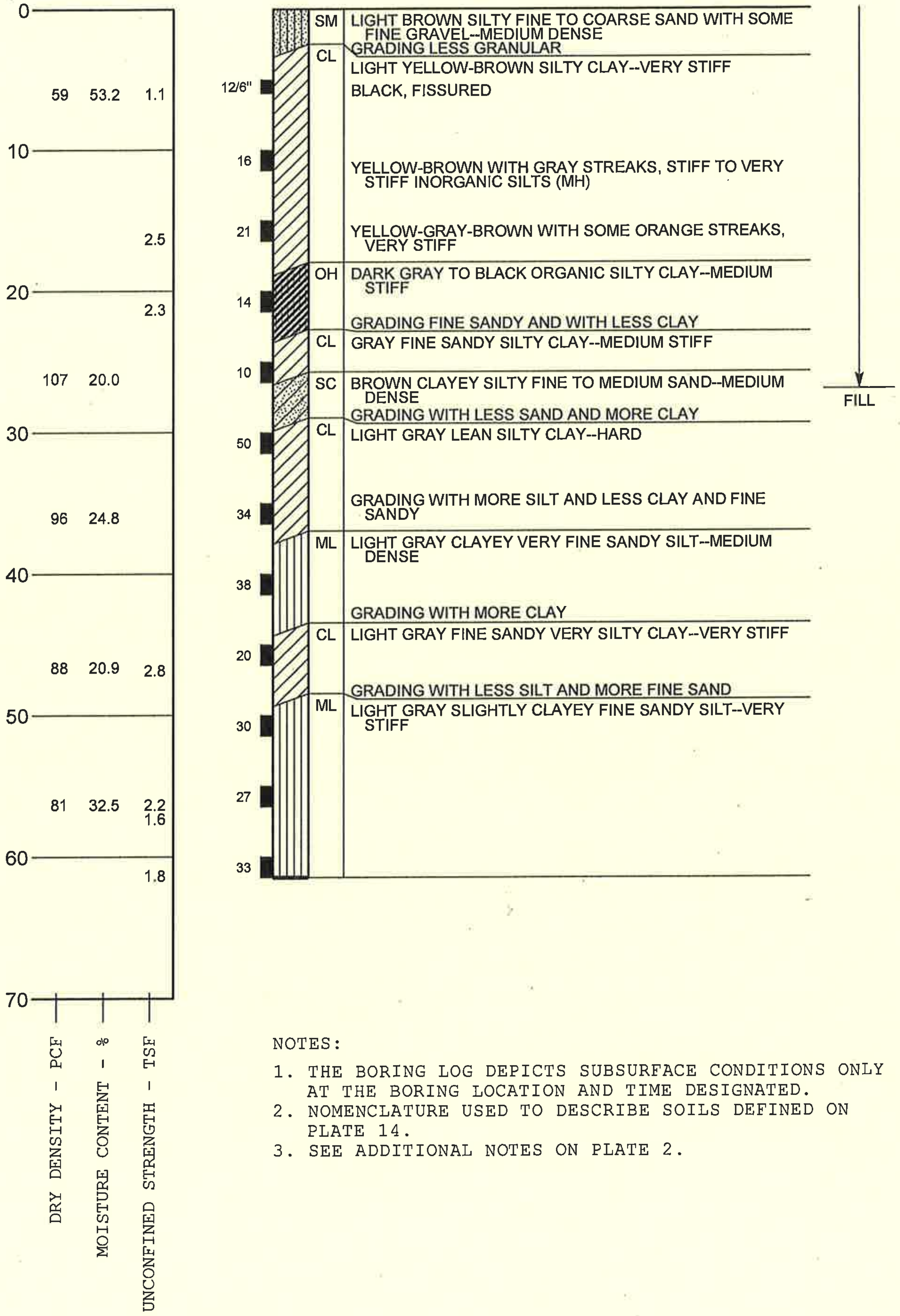
LOG OF BORING

PROJECT NUMBER: 1135-021
PLATE NUMBER: 10

DRAWN BY: TL
DATE: 3/4/16

BORING 9

DRILLED: 11/4/13



SM LIGHT BROWN SILTY FINE TO COARSE SAND WITH SOME FINE GRAVEL--MEDIUM DENSE
GRADING LESS GRANULAR

CL LIGHT YELLOW-BROWN SILTY CLAY--VERY STIFF
BLACK, FISSURED
YELLOW-BROWN WITH GRAY STREAKS, STIFF TO VERY STIFF INORGANIC SILTS (MH)
YELLOW-GRAY-BROWN WITH SOME ORANGE STREAKS, VERY STIFF

OH DARK GRAY TO BLACK ORGANIC SILTY CLAY--MEDIUM STIFF
GRADING FINE SANDY AND WITH LESS CLAY

CL GRAY FINE SANDY SILTY CLAY--MEDIUM STIFF

SC BROWN CLAYEY SILTY FINE TO MEDIUM SAND--MEDIUM DENSE
GRADING WITH LESS SAND AND MORE CLAY

CL LIGHT GRAY LEAN SILTY CLAY--HARD
GRADING WITH MORE SILT AND LESS CLAY AND FINE SANDY

ML LIGHT GRAY CLAYEY VERY FINE SANDY SILT--MEDIUM DENSE
GRADING WITH MORE CLAY

CL LIGHT GRAY FINE SANDY VERY SILTY CLAY--VERY STIFF
GRADING WITH LESS SILT AND MORE FINE SAND

ML LIGHT GRAY SLIGHTLY CLAYEY FINE SANDY SILT--VERY STIFF

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.

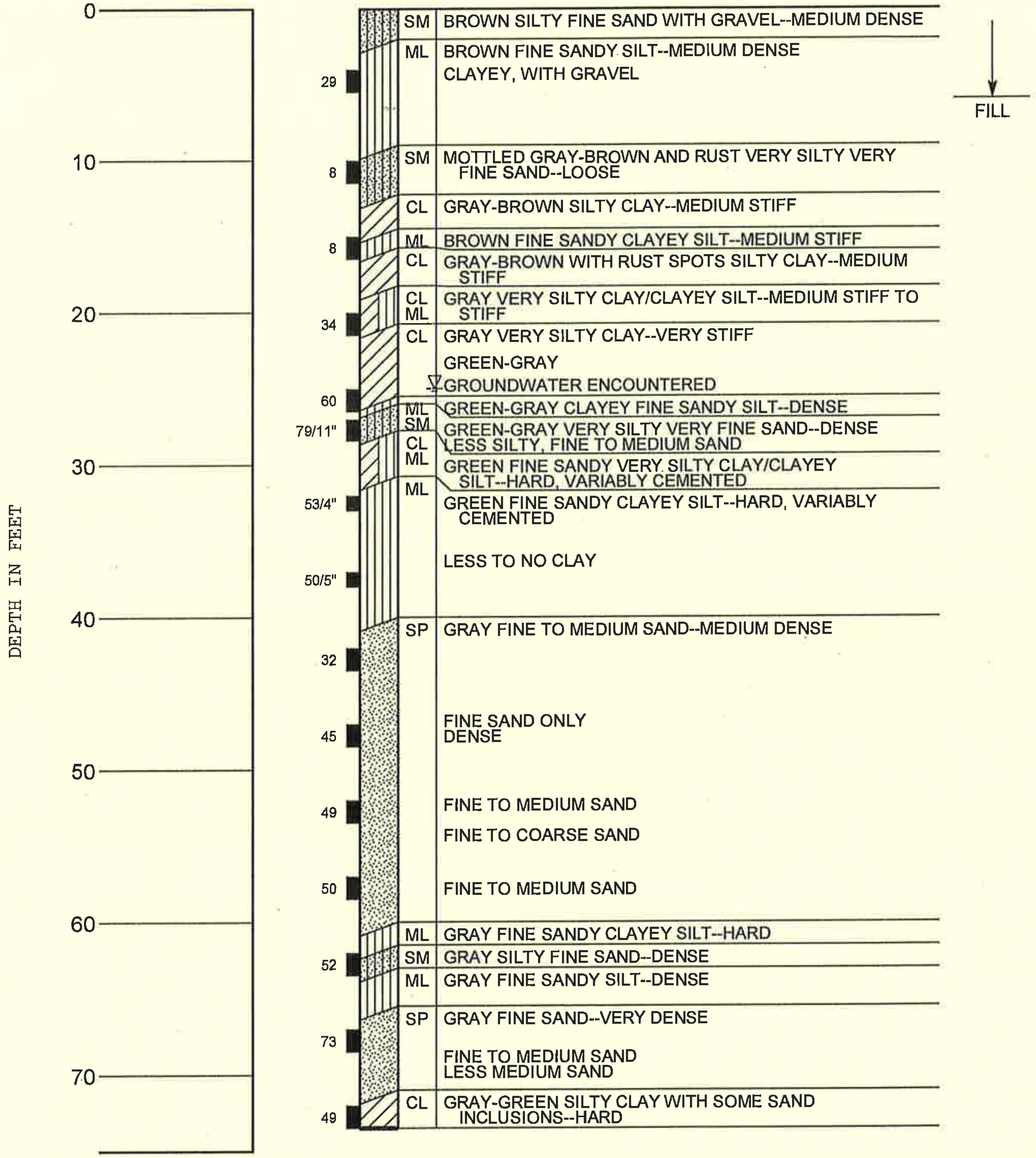
LOG OF BORING

PROJECT NUMBER: 1135-021
PLATE NUMBER: 11

DRAWN BY: TL
DATE: 3/10/16

BORING 10

DRILLED: 11/7/13



SM BROWN SILTY FINE SAND WITH GRAVEL--MEDIUM DENSE
ML BROWN FINE SANDY SILT--MEDIUM DENSE
CLAYEY, WITH GRAVEL
SM MOTTLED GRAY-BROWN AND RUST VERY SILTY VERY FINE SAND--LOOSE
CL GRAY-BROWN SILTY CLAY--MEDIUM STIFF
ML BROWN FINE SANDY CLAYEY SILT--MEDIUM STIFF
CL GRAY-BROWN WITH RUST SPOTS SILTY CLAY--MEDIUM STIFF
CL ML GRAY VERY SILTY CLAY/CLAYEY SILT--MEDIUM STIFF TO STIFF
CL GRAY VERY SILTY CLAY--VERY STIFF
GREEN-GRAY
∇ GROUNDWATER ENCOUNTERED
ML GREEN-GRAY CLAYEY FINE SANDY SILT--DENSE
SM GREEN-GRAY VERY SILTY VERY FINE SAND--DENSE
LESS SILTY, FINE TO MEDIUM SAND
CL ML GREEN FINE SANDY VERY SILTY CLAY/CLAYEY SILT--HARD, VARIABLY CEMENTED
ML GREEN FINE SANDY CLAYEY SILT--HARD, VARIABLY CEMENTED
LESS TO NO CLAY
SP GRAY FINE TO MEDIUM SAND--MEDIUM DENSE
FINE SAND ONLY
DENSE
FINE TO MEDIUM SAND
FINE TO COARSE SAND
FINE TO MEDIUM SAND
ML GRAY FINE SANDY CLAYEY SILT--HARD
SM GRAY SILTY FINE SAND--DENSE
ML GRAY FINE SANDY SILT--DENSE
SP GRAY FINE SAND--VERY DENSE
FINE TO MEDIUM SAND
LESS MEDIUM SAND
CL GRAY-GREEN SILTY CLAY WITH SOME SAND INCLUSIONS--HARD

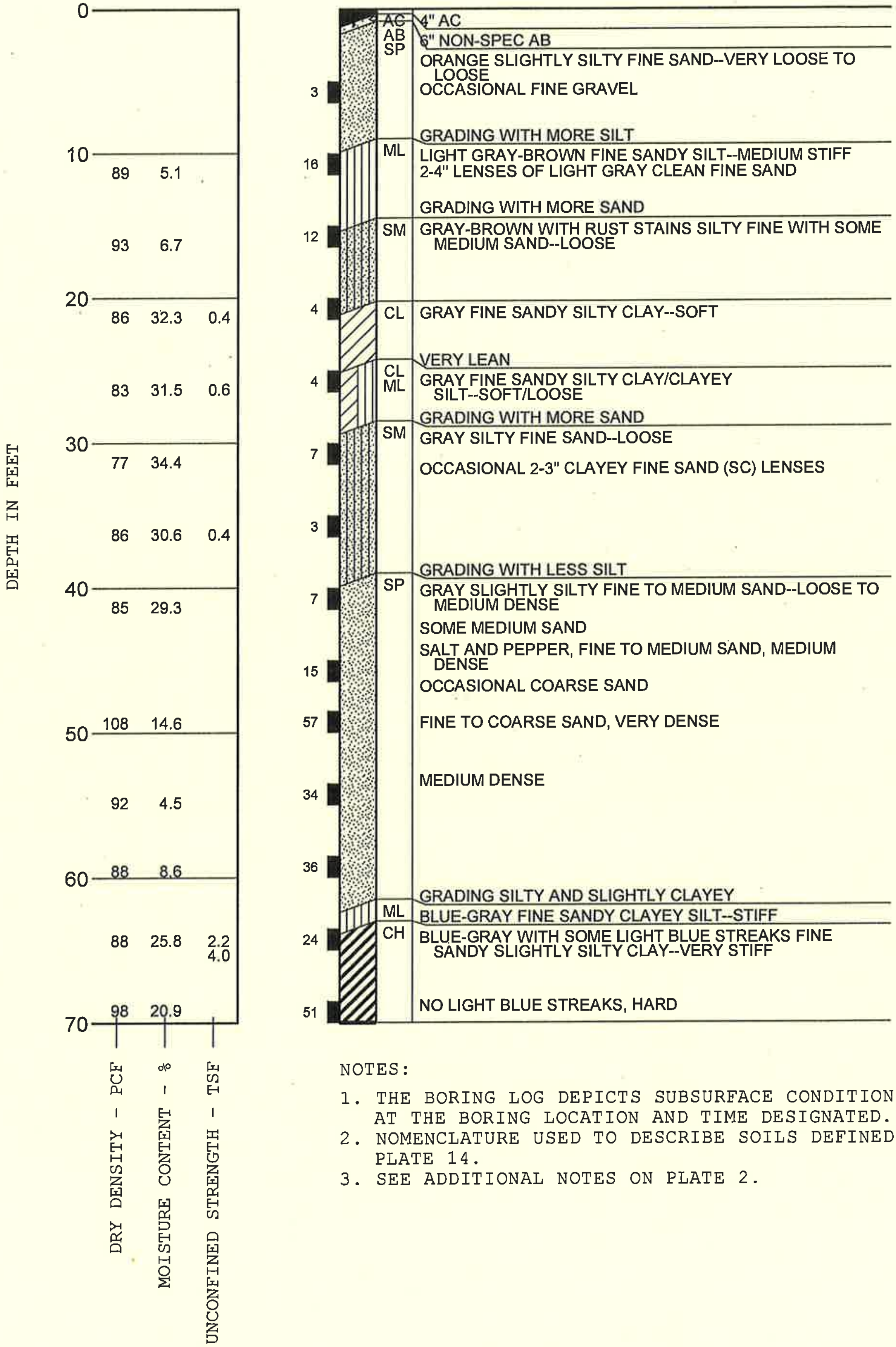
NOTES:
1. THE BORING LOG DEPICTS SUBSURFACE CONDITIONS ONLY AT THE BORING LOCATION AND TIME DESIGNATED.
2. NOMENCLATURE USED TO DESCRIBE SOILS DEFINED ON PLATE 14.
3. SEE ADDITIONAL NOTES ON PLATE 2.
4. FREE GROUNDWATER WAS ENCOUNTERED IN BORING 10.

LOG OF BORING

Raney Geotechnical Inc

BORING 11

DRILLED: 11/12/13



DRAWN BY: TL
DATE: 3/10/16

PROJECT NUMBER: 1135-021
PLATE NUMBER: 12

NOTES:

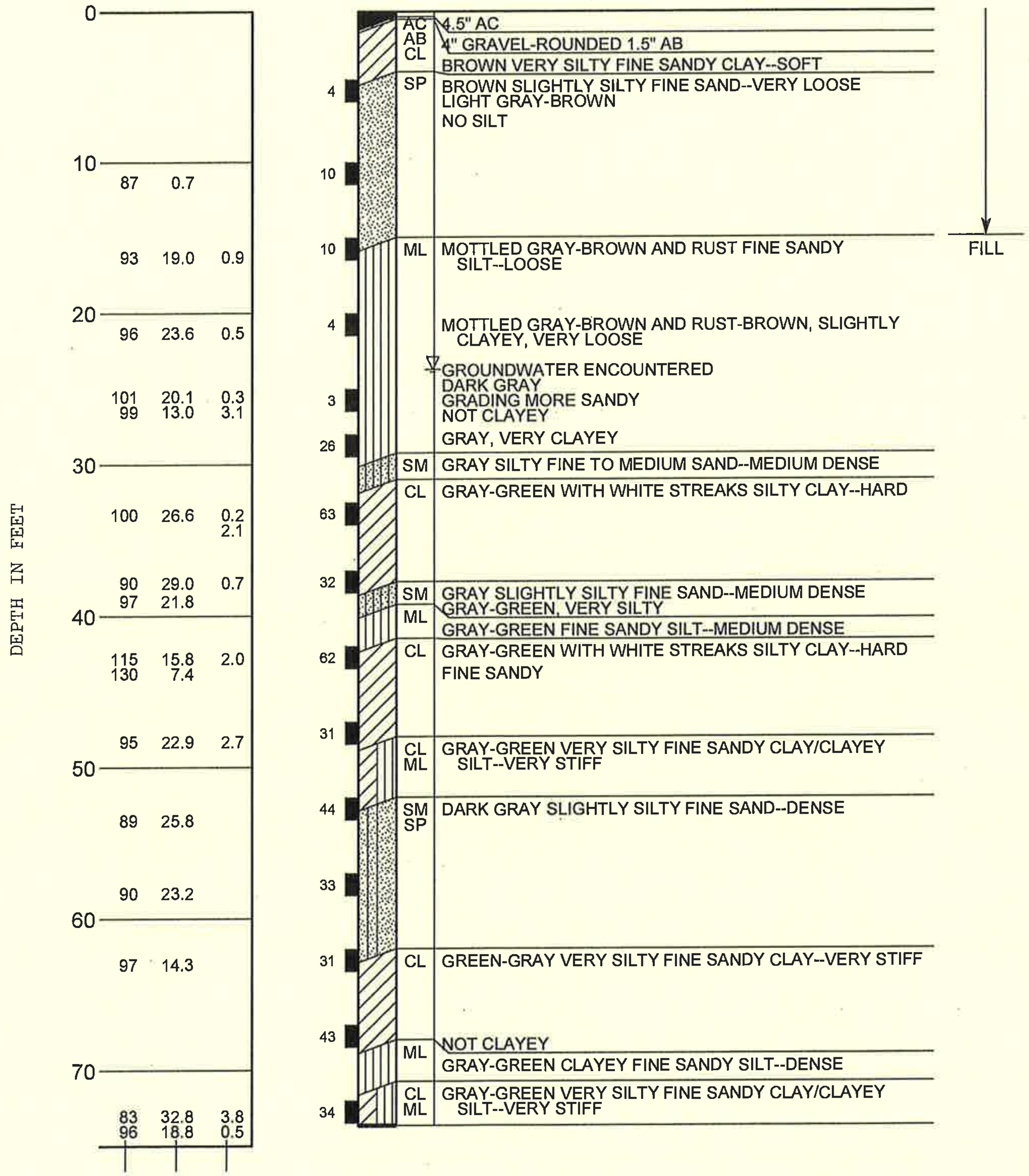
1. THE BORING LOG DEPICTS SUBSURFACE CONDITIONS ONLY AT THE BORING LOCATION AND TIME DESIGNATED.
2. NOMENCLATURE USED TO DESCRIBE SOILS DEFINED ON PLATE 14.
3. SEE ADDITIONAL NOTES ON PLATE 2.

LOG OF BORING

PROJECT NUMBER: 1135-021
PLATE NUMBER: 13
DRAWN BY: TL
DATE: 3/10/16

BORING 12

DRILLED: 11/14/13



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.
4. FREE GROUNDWATER WAS ENCOUNTERED IN BORING 12.

Raney Geotechnical Inc

LOG OF BORING

PLATE 13

PROJECT NUMBER: 1135-021
PLATE NUMBER: 14

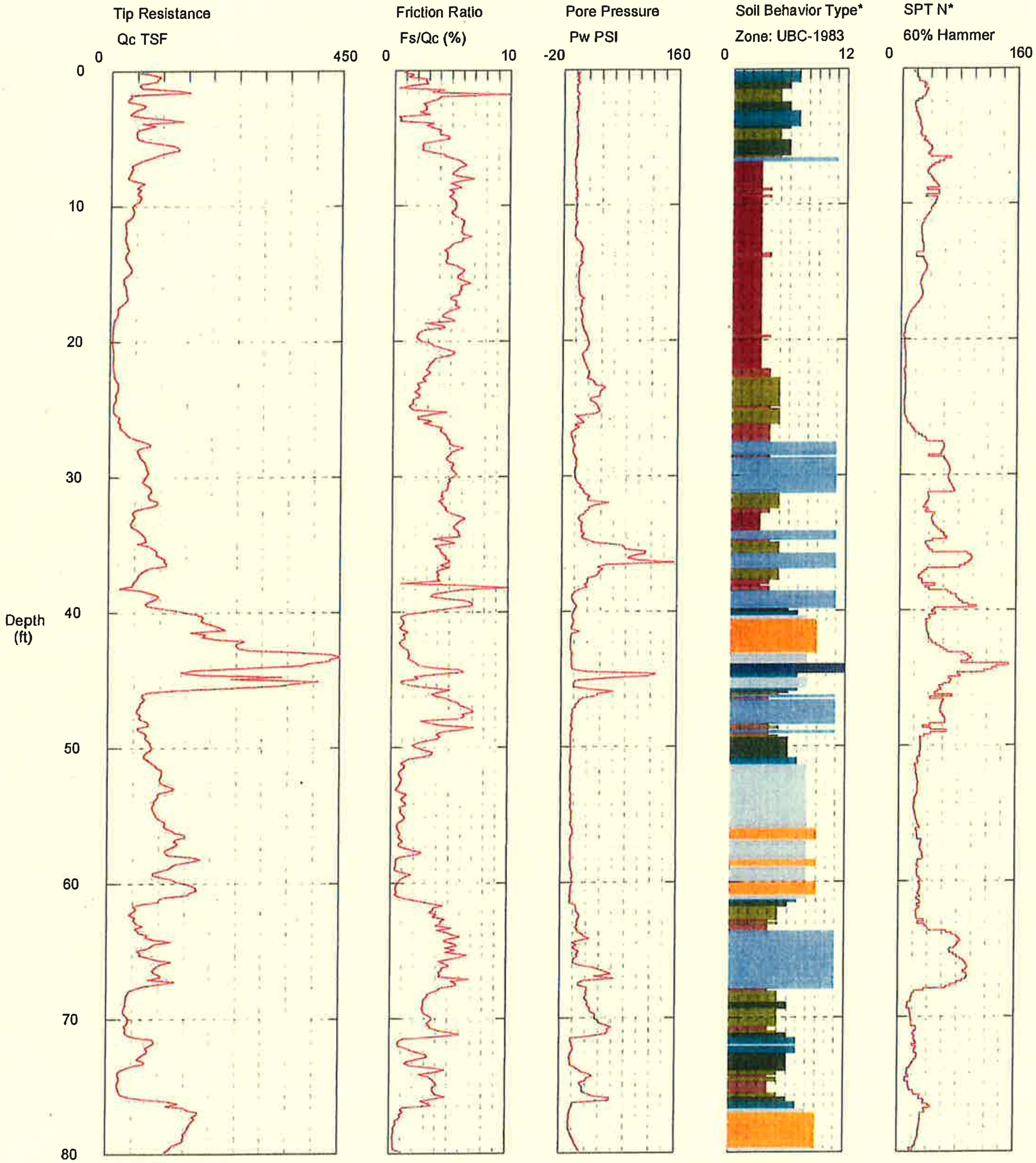
GRAPH	SYMBOL	DESCRIPTION	MAJOR DIVISIONS		
○	GW	WELL GRADED GRAVELS, GRAVEL-SAND MIXTURES	CLEAN GRAVELS WITH LESS THAN 5% FINES	GRAVEL AND GRAVELLY SOILS MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	COARSE GRAINED SOILS MORE THAN 50% LARGER THAN NO. 200 SIEVE
○	GP	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES			
▥	GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES	GRAVELS WITH MORE THAN 12% FINES		
▨	GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES			
░	SW	WELL GRADED SANDS, GRAVELLY SANDS	CLEAN SANDS WITH LESS THAN 5% FINES	SANDS AND SANDY SOILS MORE THAN 50% OF COARSE FRACTION PASSING NO. 4 SIEVE	
░	SP	POORLY GRADED SANDS, GRAVELLY SANDS			
▥	SM	SILTY SANDS, SAND-SILT MIXTURES	SANDS WITH MORE THAN 12% FINES		
▨	SC	CLAYEY SANDS, SAND-CLAY MIXTURES			
▥	ML	INORGANIC SILTS, ROCK FLOUR, OR CLAYEY SILTS WITH SLIGHT PLASTICITY	LIQUID LIMIT LESS THAN 50	SILTS AND CLAYS	FINE GRAINED SOILS MORE THAN 50% SMALLER THAN NO. 200 SIEVE
▧	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			
▥	MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS SILTS, ELASTIC SILTS	LIQUID LIMIT GREATER THAN 50	SILTS AND CLAYS	
▨	CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS			
▩	OH	ORGANIC CLAYS AND ORGANIC SILTS OF MEDIUM TO HIGH PLASTICITY			
▦	PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENT	HIGHLY ORGANIC SOILS		

UNIFIED SOIL CLASSIFICATION SYSTEM

Raney Geotechnical

Operator: Rocco
Sounding: CPT-1Sta.49+10
Cone Used: DSG1111

CPT Date/Time: 1/29/2014 9:51:51 AM
Location: Walnut Grove
Job Number: RNY-464-1135-021



Maximum Depth = 80.38 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 (*)

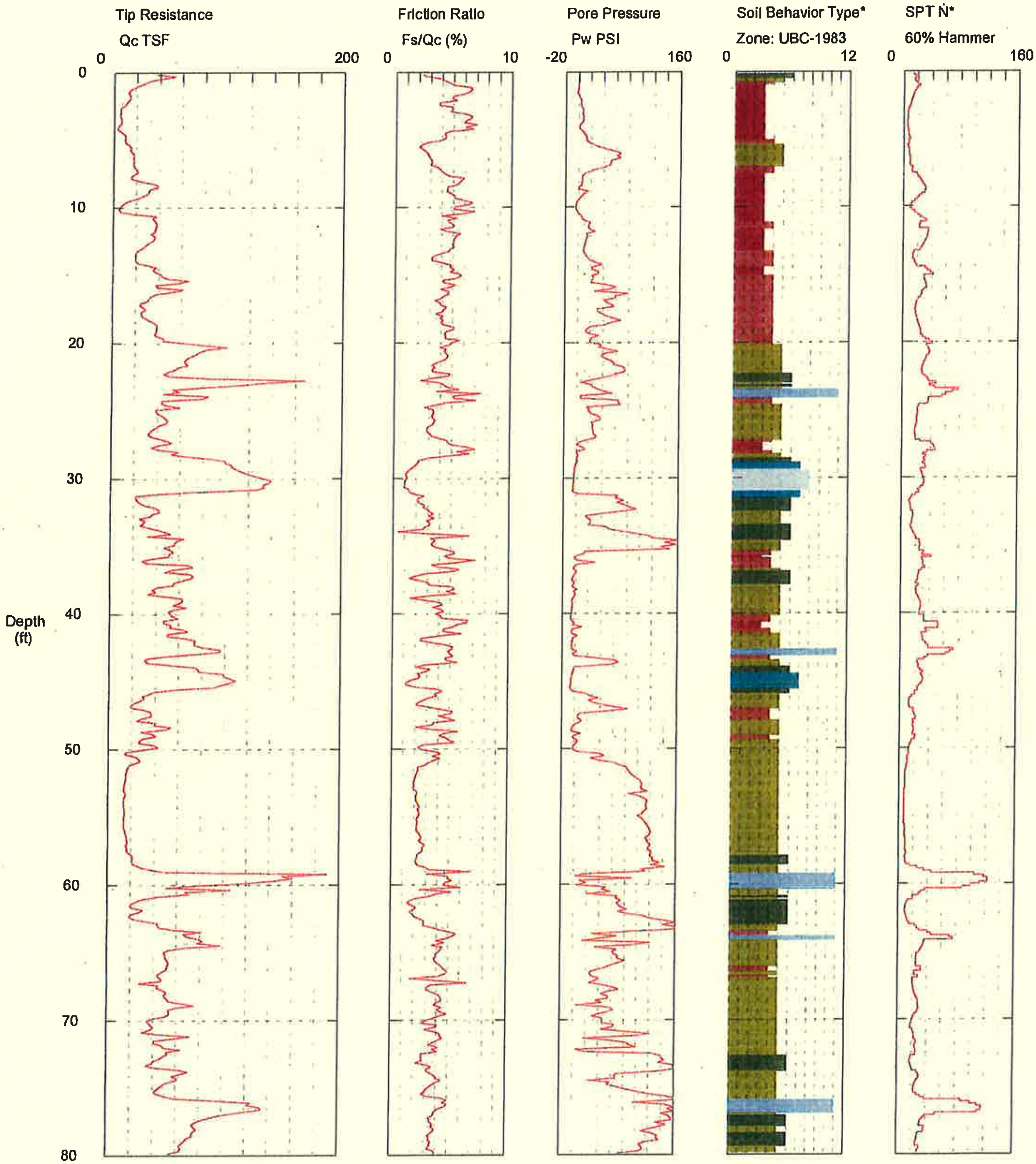
Soil behavior type and SPT based on data from UBC-1983

PLATE 15

Raney Geotechnical

Operator: Rocco
Sounding: CPT-2Sta.67+00
Cone Used: DSG1111

CPT Date/Time: 1/29/2014 11:01:24 AM
Location: Walnut Grove
Job Number: RNY-464-1135-021



Maximum Depth = 80.38 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 (*)

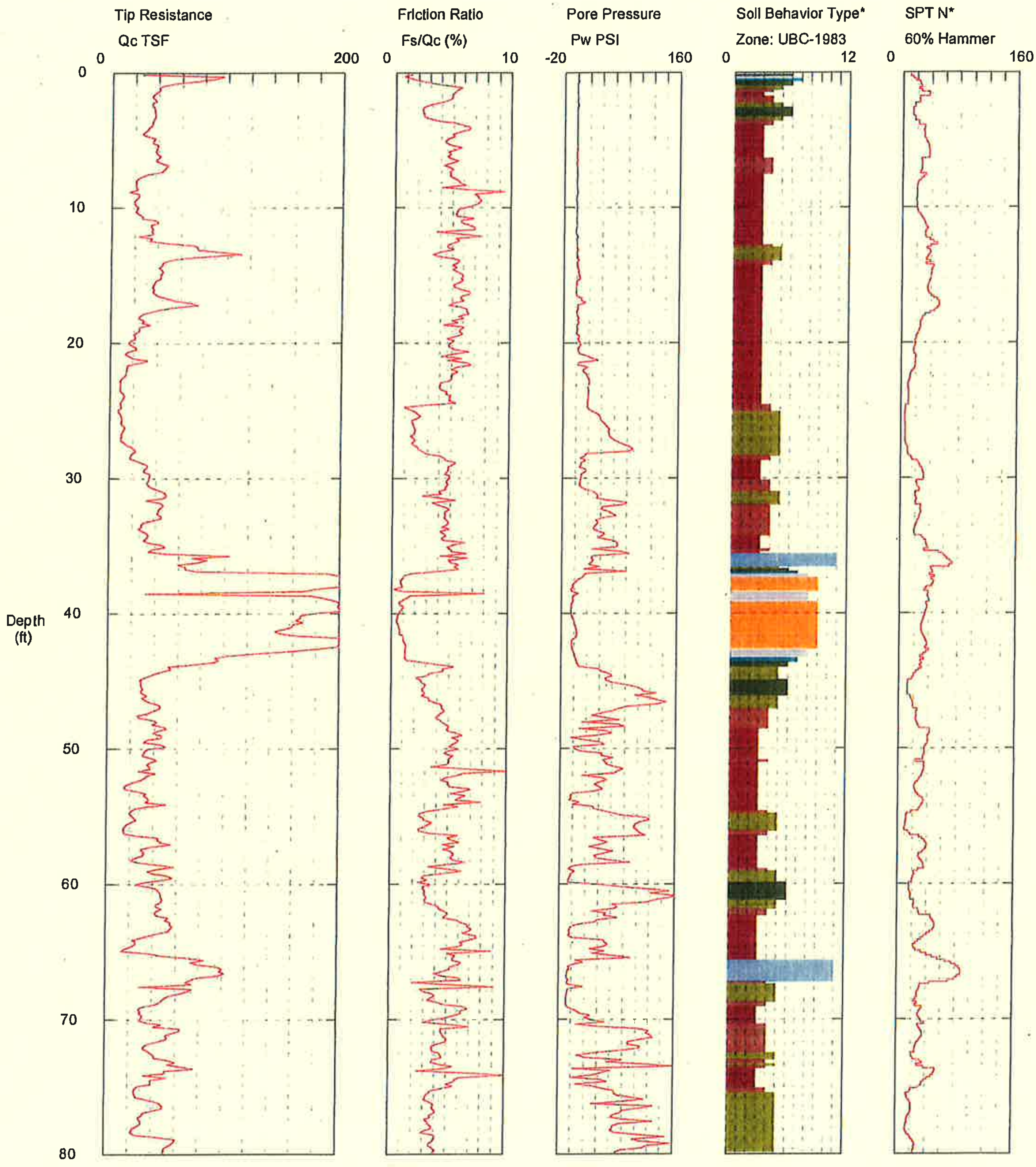
Soil behavior type and SPT based on data from UBC-1983

PLATE 16

Raney Geotechnical

Operator: Rocco
Sounding: CPT-8Sta.80+00
Cone Used: DSG1111

CPT Date/Time: 1/29/2014 4:53:01 PM
Location: Walnut Grove
Job Number: RNY-464-1135-021



Maximum Depth = 80.05 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 (*)

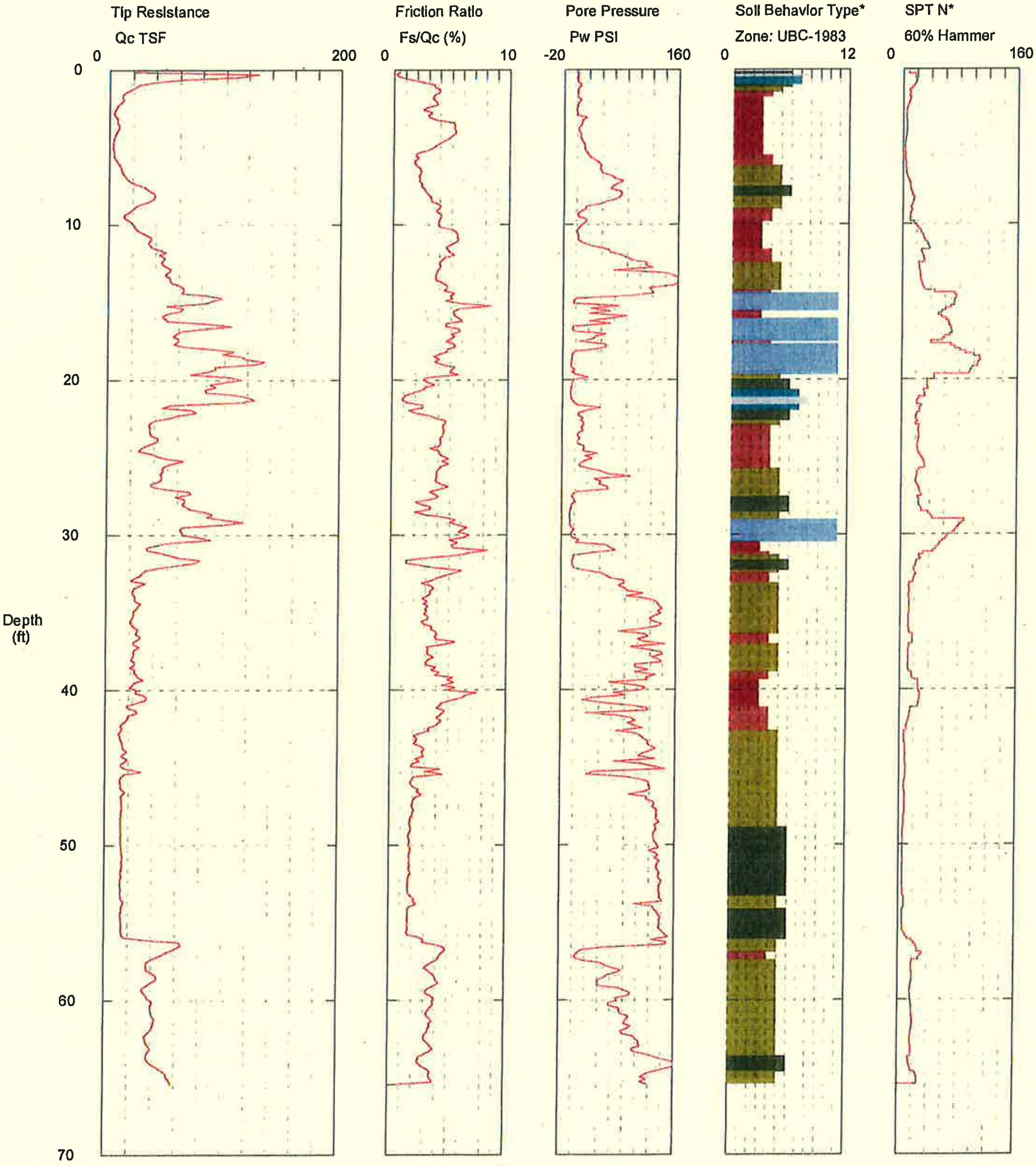
oil behavior type and SPT based on data from UBC-1983

PLATE 17

Raney Geotechnical

Operator: Rocco
Sounding: CPT-3Sta.86+00
Cone Used: DSG1111

CPT Date/Time: 1/29/2014 12:18:49 PM
Location: Walnut Grove
Job Number: RNY-464-1135-021



Maximum Depth = 65.45 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 (*)

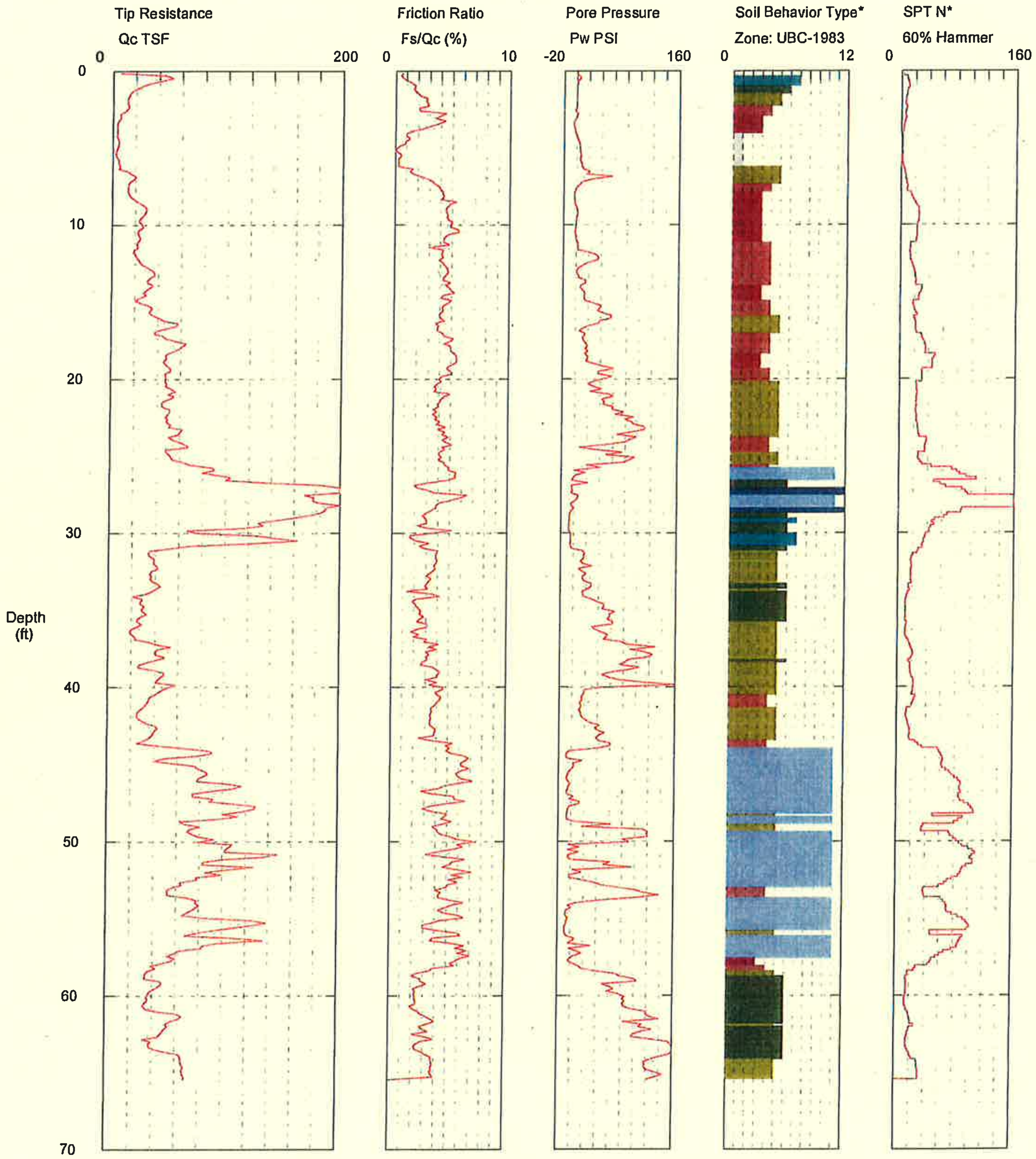
Soil behavior type and SPT based on data from UBC-1983

PLATE 18

Raney Geotechnical

Operator: Rocco
Sounding: CPT-5Sta.98+00
Cone Used: DSG1111

CPT Date/Time: 1/29/2014 2:11:56 PM
Location: Walnut Grove
Job Number: RNY-464-1135-021



Maximum Depth = 65.45 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 (*)

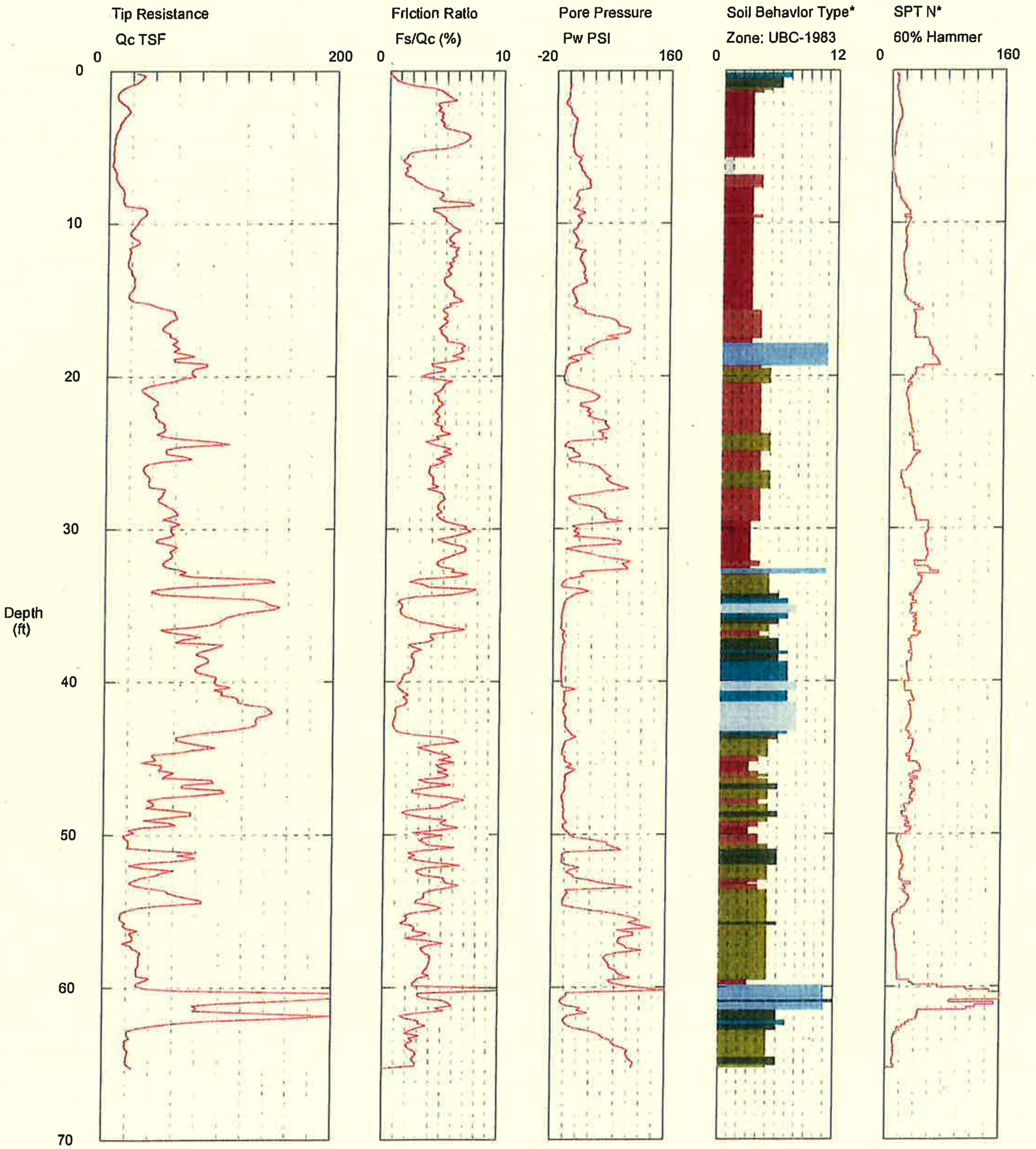
Soil behavior type and SPT based on data from UBC-1983

PLATE 19

Raney Geotechnical

Operator: Rocco
Sounding: CPT-7Sta.112+00
Cone Used: DSG1111

CPT Date/Time: 1/29/2014 3:52:41 PM
Location: Walnut Grove
Job Number: RNY-464-1135-021



Maximum Depth = 65.29 feet

Depth Increment = 0.164 feet

▨ 1 sensitive fine grained	🟥 4 silty clay to clay	🟦 7 silty sand to sandy silt	🟥 10 gravelly sand to sand
▨ 2 organic material	🟨 5 clayey silt to silty clay	▨ 8 sand to silty sand	🟦 11 very stiff fine grained (*)
🟥 3 clay	■ 6 sandy silt to clayey silt	🟧 9 sand	■ 12 sand to clayey sand (*)

Soil behavior type and SPT based on data from UBC-1983

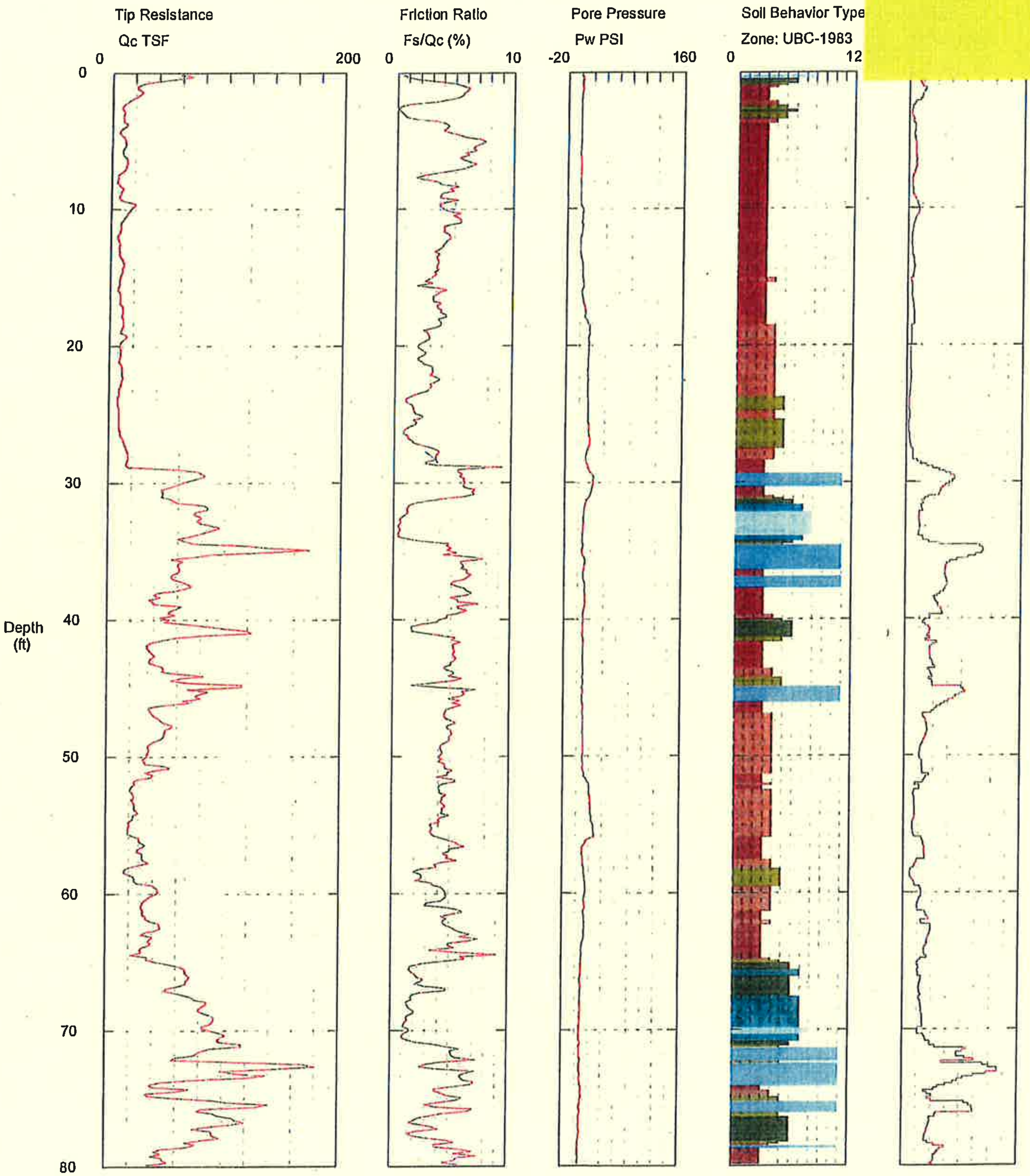
PLATE 20

Raney Geotechnical

Operator: Rocco
Sounding: Sta.116+86
Cone Used: DSG1111

CPT Date/Time: 1/31/2014 10
Location: Walnut Grove
Job Number: RNY-464-1135-(

CPT 13



Maximum Depth = 80.05 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 (*)

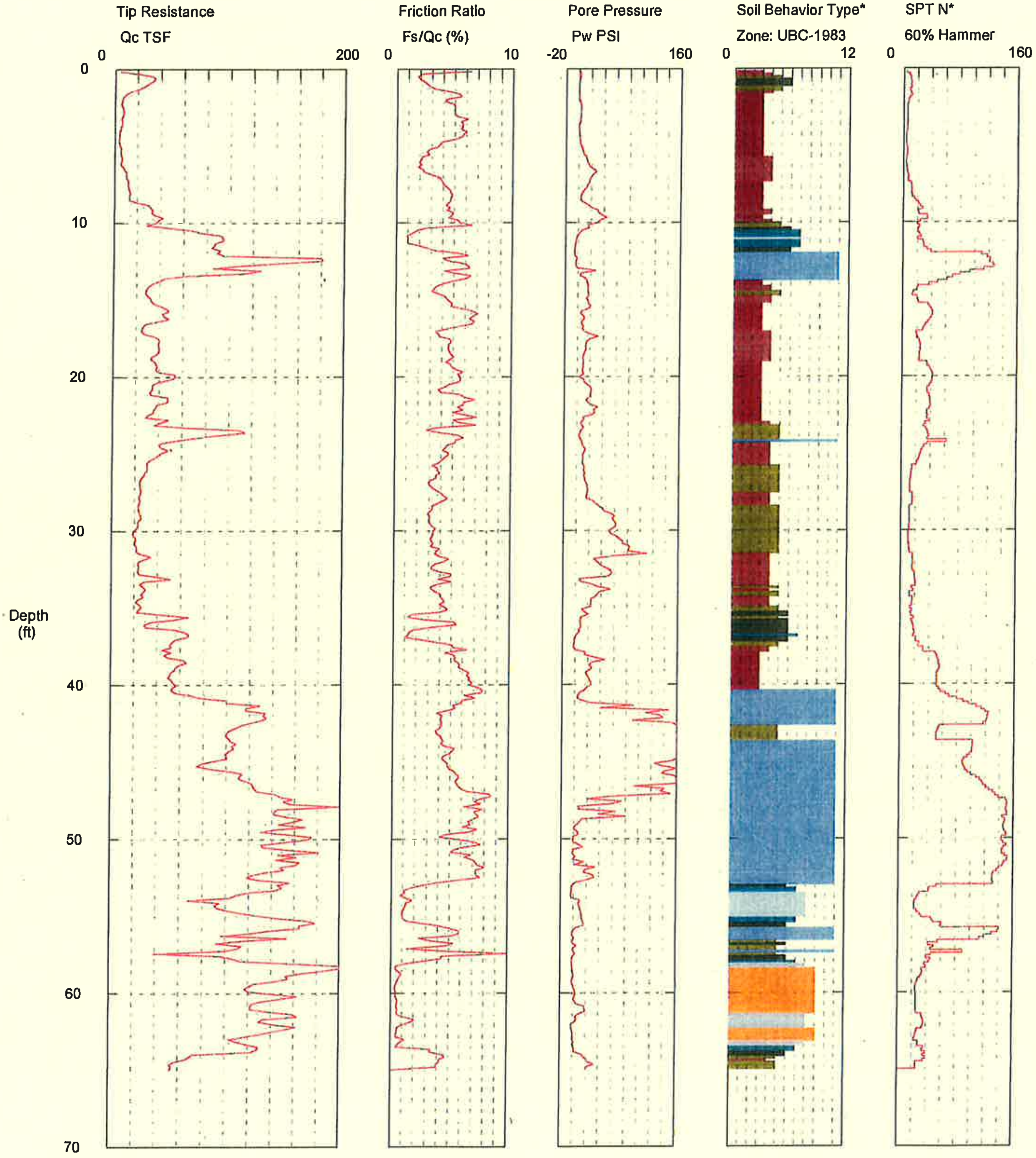
oil behavior type and SPT based on data from UBC-1983

PLATE 21

Raney Geotechnical

Operator: Rocco
Sounding: CPT-11Sta.126+50
Cone Used: DSG1111

CPT Date/Time: 1/31/2014 8:12:13 AM
Location: Walnut Grove
Job Number: RNY-464-1135-021



Maximum Depth = 64.96 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 (*)

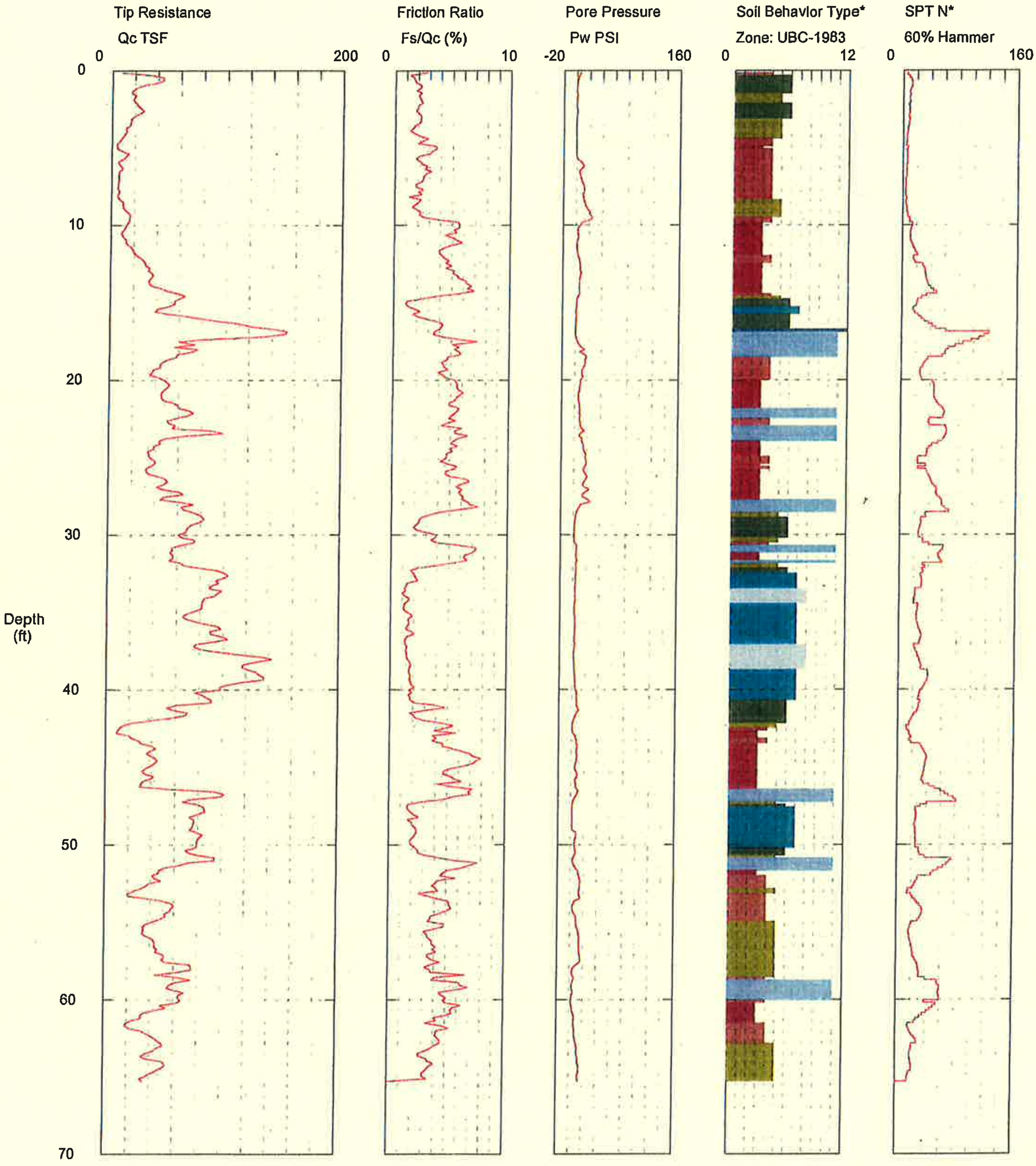
Soil behavior type and SPT based on data from UBC-1983

PLATE 22

Raney Geotechnical

Operator: Rocco
Sounding: CPT-12Sta.160+40
Cone Used: DSG1111

CPT Date/Time: 1/31/2014 9:36:14 AM
Location: Walnut Grove
Job Number: RNY-464-1135-021



Maximum Depth = 65.29 feet

Depth Increment = 0.164 feet

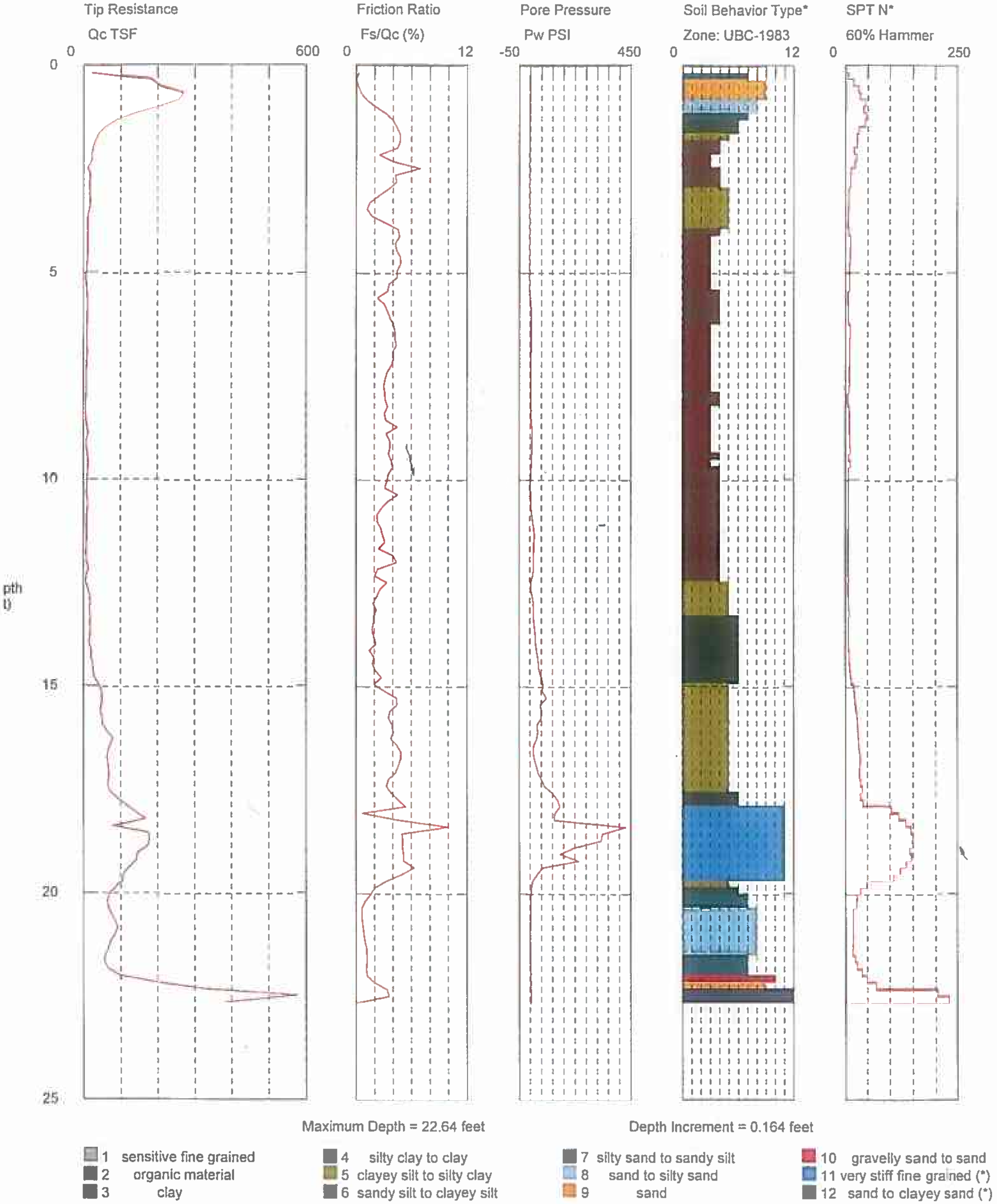
⬜ 1 sensitive fine grained
▨ 2 organic material
🟥 3 clay
🟥 4 silty clay to clay
🟨 5 clayey silt to silty clay
🟩 6 sandy silt to clayey silt
🟦 7 silty sand to sandy silt
⬜ 8 sand to silty sand
🟧 9 sand
🟥 10 gravelly sand to sand
🟦 11 very stiff fine grained (*)
🟦 12 sand to clayey sand (*)

Soil behavior type and SPT based on data from UBC-1983

Raney Geotechnical

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

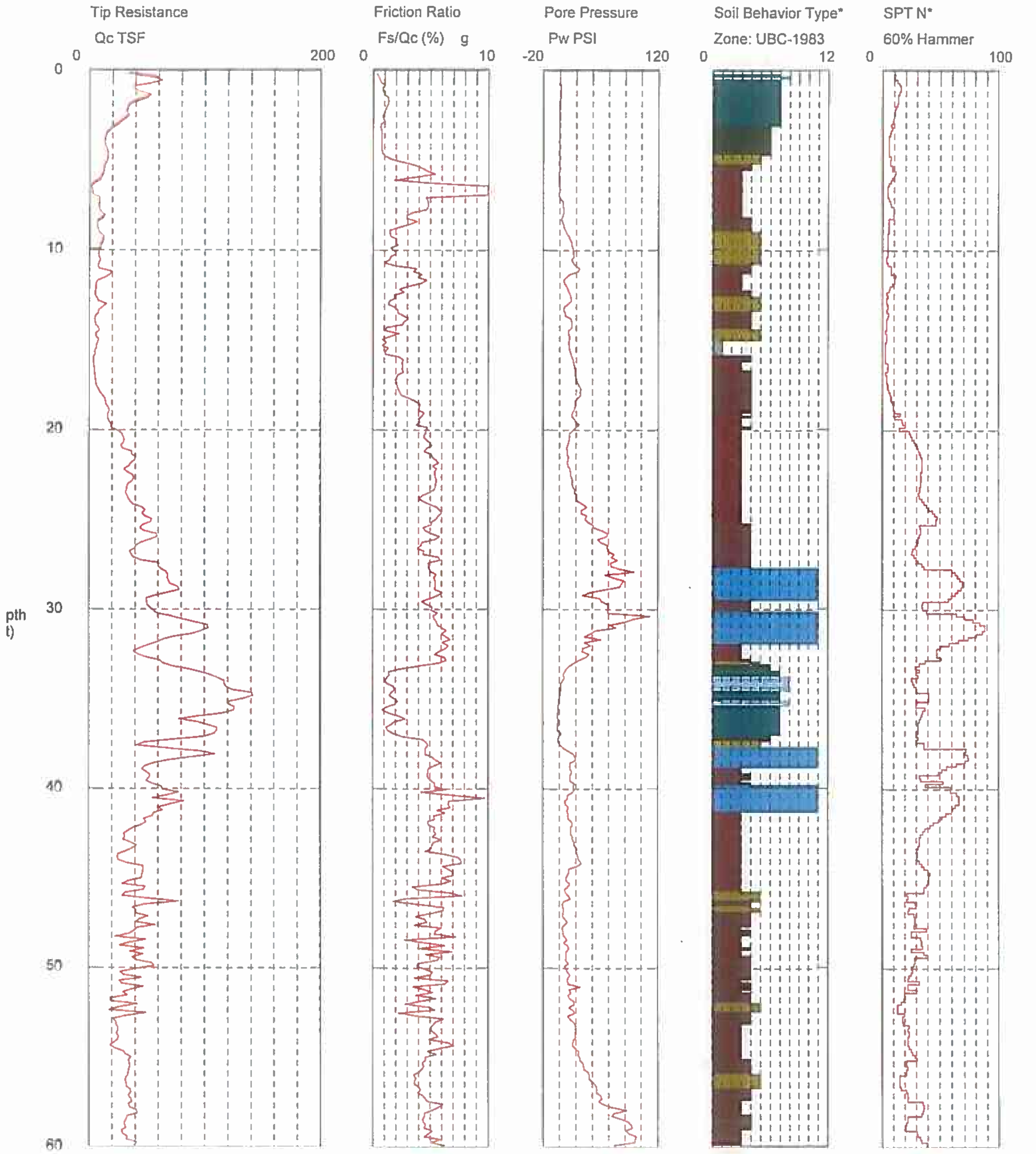
CPT Date/Time: 1/31/2014 12:29:29 PM
Location: Walnut Grove
Job Number: RNY-464-1135-021



Raney Geotechnical

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

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



Maximum Depth = 60.37 feet

Depth Increment = 0.164 feet

▨ 1 sensitive fine grained	■ 4 silty clay to clay	■ 7 silty sand to sandy silt	🟥 10 gravelly sand to sand
■ 2 organic material	🟩 5 clayey silt to silty clay	■ 8 sand to silty sand	🟦 11 very stiff fine grained (*)
🟫 3 clay	■ 6 sandy silt to clayey silt	🟧 9 sand	■ 12 sand to clayey sand (*)

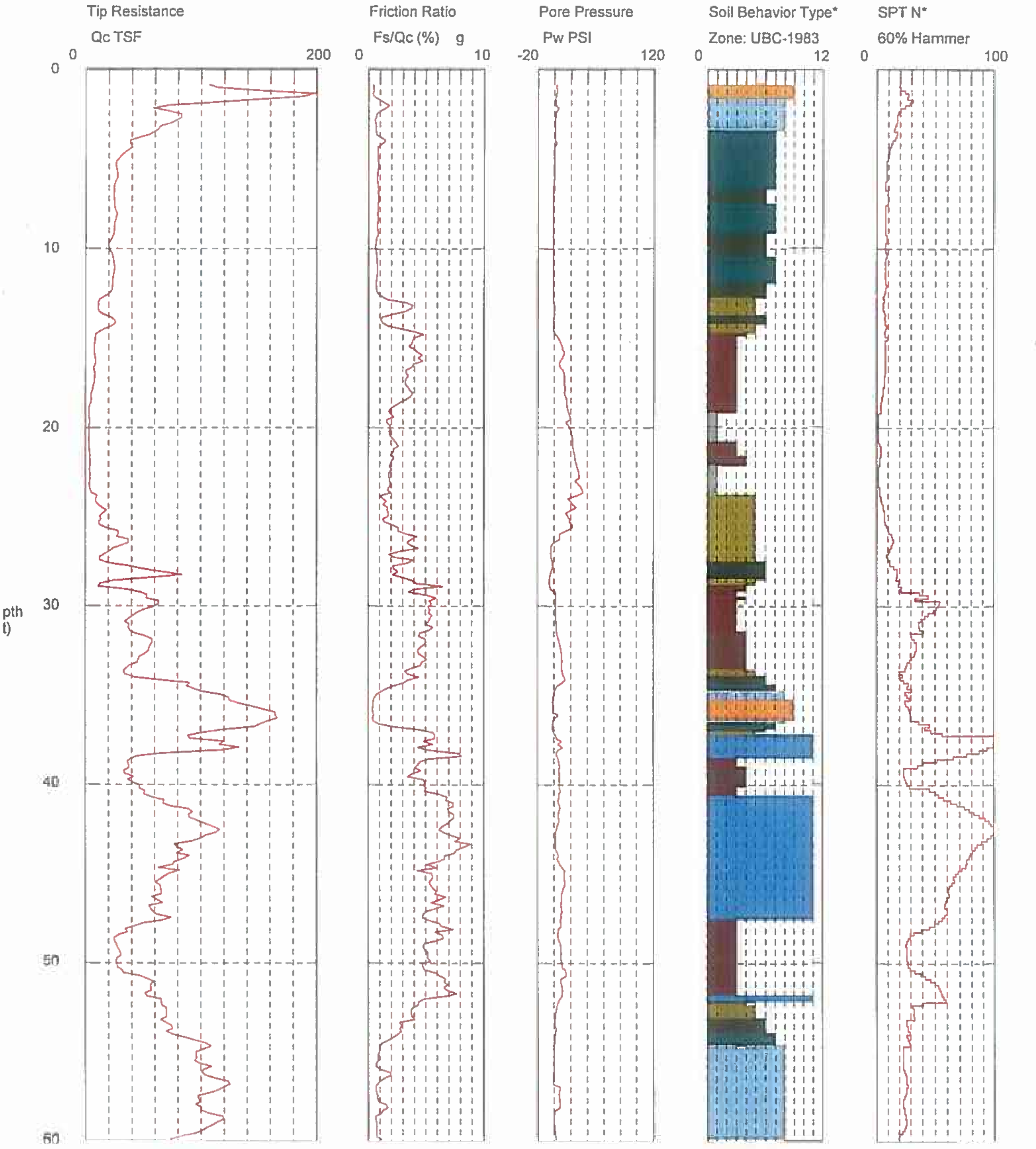
Auto Enhance On

Filter On

Raney Geotechnical

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

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



Maximum Depth = 60.20 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 (*)

Auto Enhance On

Filter On

DIST.	COUNTY	ROUTE	POST MILES TOTAL PROJECT	SHEET NO.	TOTAL SHEETS
3	Sac				

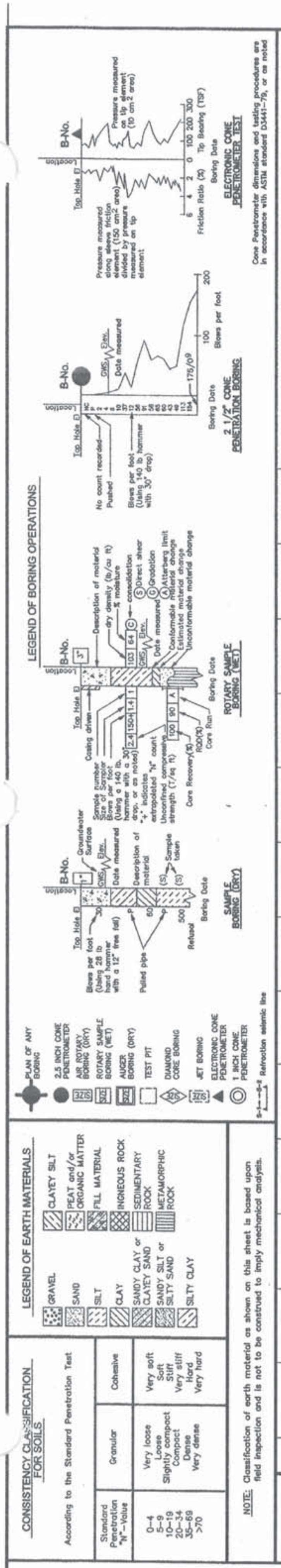
F. P. Taber 7-2-98
REGISTERED GEOTECHNICAL ENGINEER

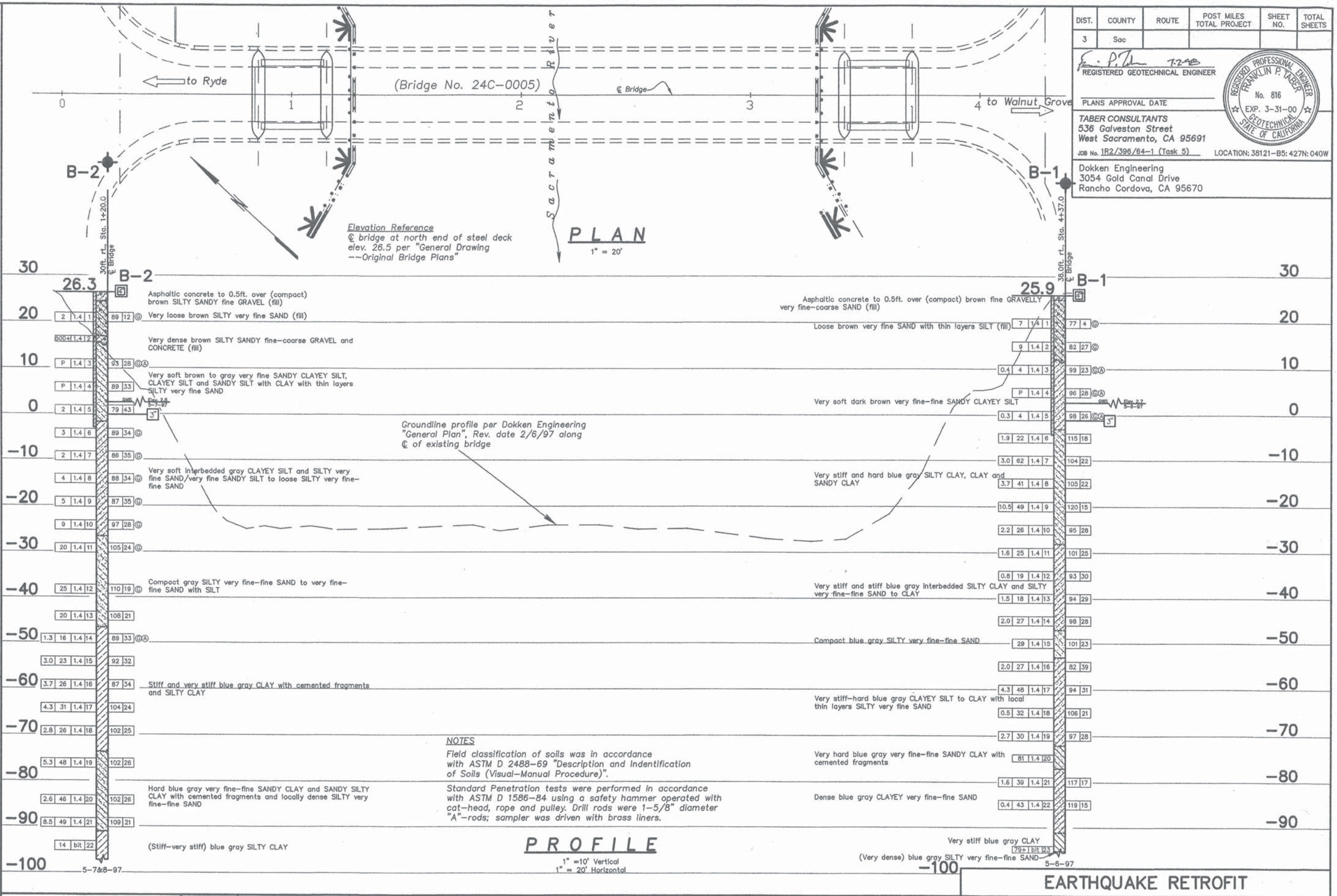
No. 816
EXP. 3-31-00

PLANS APPROVAL DATE

TABER CONSULTANTS
536 Galveston Street
West Sacramento, CA 95691
JOB No. 1R2/396/64-1 (Task 5)
LOCATION: 38121-B5: 427N: 040W

Dokken Engineering
3054 Gold Canal Drive
Rancho Cordova, CA 95670





Elevation Reference
℄ bridge at north end of steel deck elev. 26.5 per "General Drawing --Original Bridge Plans"

NOTES

Field classification of soils was in accordance with ASTM D 2488-69 "Description and Indentification of Soils (Visual-Manual Procedure)".

Standard Penetration tests were performed in accordance with ASTM D 1586-84 using a safety hammer operated with cat-head, rope and pulley. Drill rods were 1-5/8" diameter "A"-rods; sampler was driven with brass liners.

Carl Huang
DESIGN OVERSIGHT
Carl Huang 11/19/98
SIGN OFF DATE

DRAWN BY	M. D. Robertson
CHECKED BY	T. A. Krause

T. A. Krause
FIELD INVESTIGATOR
DATE May 1997

PREPARED FOR
SACRAMENTO COUNTY

John Maniscalco
PROJECT ENGINEER

BRIDGE NO.
24C-0005
POST MILE

EARTHQUAKE RETROFIT
WALNUT GROVE BRIDGE OVER SACRAMENTO RIVER
LOG OF TEST BORINGS

ORIGINAL SCALE IN INCHES FOR REDUCED PLANS 0 1 2 3

CU 03
EA L21708

DISREGARD PRINTS BEARING EARLIER REVISION DATES → 6/16/98
REVISION DATES (PRELIMINARY STAGE ONLY)
SHEET 33 OF 33

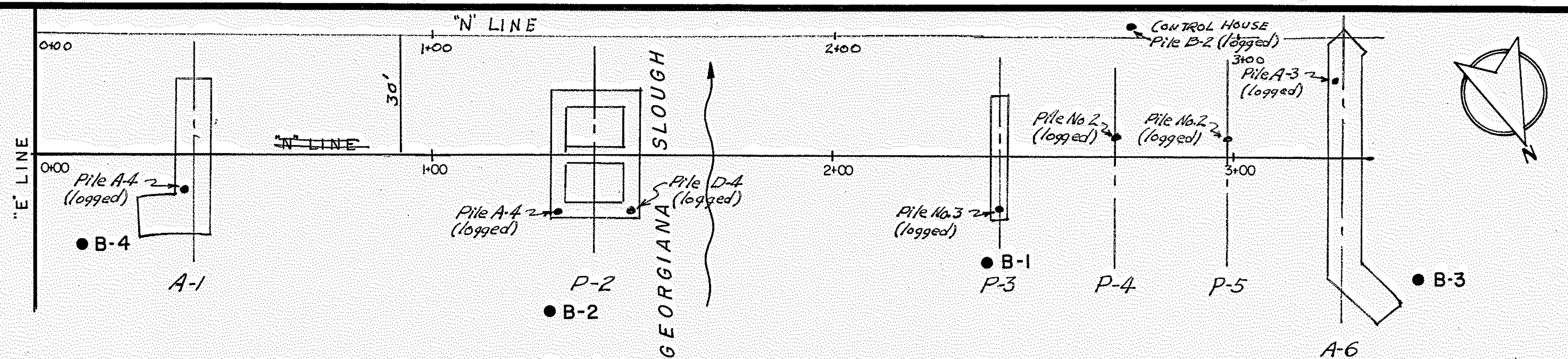
6/98 1R239664-1.dwg 1=1

S-1260(1) 22 of 43

DIST	COUNTY	ROUTE	SECTION	SHEET NO.	TOTAL SHEETS
III	SAC	1260		13	34

W. J. Pond
BRIDGE ENGINEER – C.E. License No. 4779

Approved February 2, 1961



PLAN

NOTE

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

Design Pile Loading: 24" ⌀ Steel Pipe 75T
16" ⌀ Concrete 45T
Timber 30T

Type Pile: Conc. Filled Steel Pipe
Concrete
Treated Timber

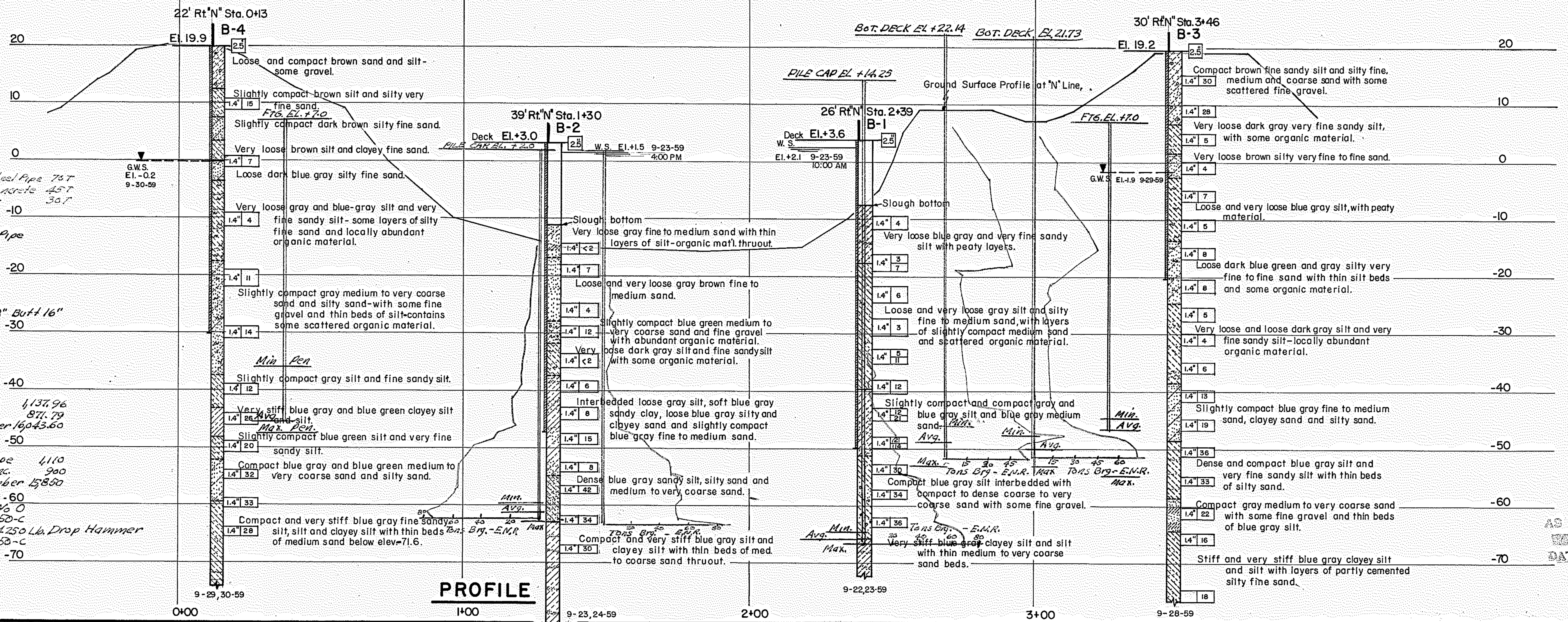
Diameters: Pipe 24"
Concrete 16"
Timber (Avg) Tip 8" Butt 16"

Total No Piles: Pipe 17
Conc. 12
Timber 249

Lin Ft. Piles, "As Built": Pipe 1,137.96
Conc. 871.79
Timber 16,043.60

Lin. Ft. Piles As Per Plans: Pipe 1,110
Conc. 900
Timber 15,850

Hammers: Pipe - Vulcan No 0
Conc. - Vulcan 50-C
Timber - Vulcan 4250 Lb. Drop Hammer
Vulcan 50-C



PROFILE

AS BUILT A.F.B.
F.T.W.
DATE 6-15-1962

a.l.s.

LEGEND OF EARTH MATERIALS

SIZE CLASSIFICATION

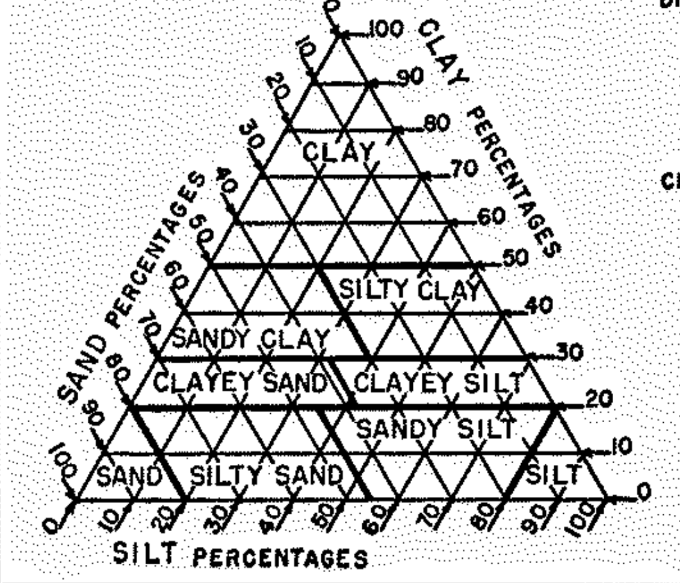


Diagram showing the basis of grainsize distribution used in determination of class names. Size classification is based on the Wentworth grade scale in field classification or the A.S.T.M. grade scale in the laboratory sieve analysis.

Classification of earth material shown on this sheet is based on field inspection and should not be construed to imply mechanical analysis unless so stated.

MATERIAL SYMBOLS

- ▨ Gravel
- ▨ Sand
- ▨ Silt
- ▨ Clay
- ▨ Sandy clay or clayey sand
- ▨ Sandy silt or silty sand
- ▨ Silty clay or clayey silt
- ▨ Peat or organic matter
- ▨ Fill material
- ▨ Shale
- ▨ Sandstone
- ▨ Limestone
- ▨ Metamorphic rock
- ▨ Igneous rock

CONSISTENCY CLASSIFICATION

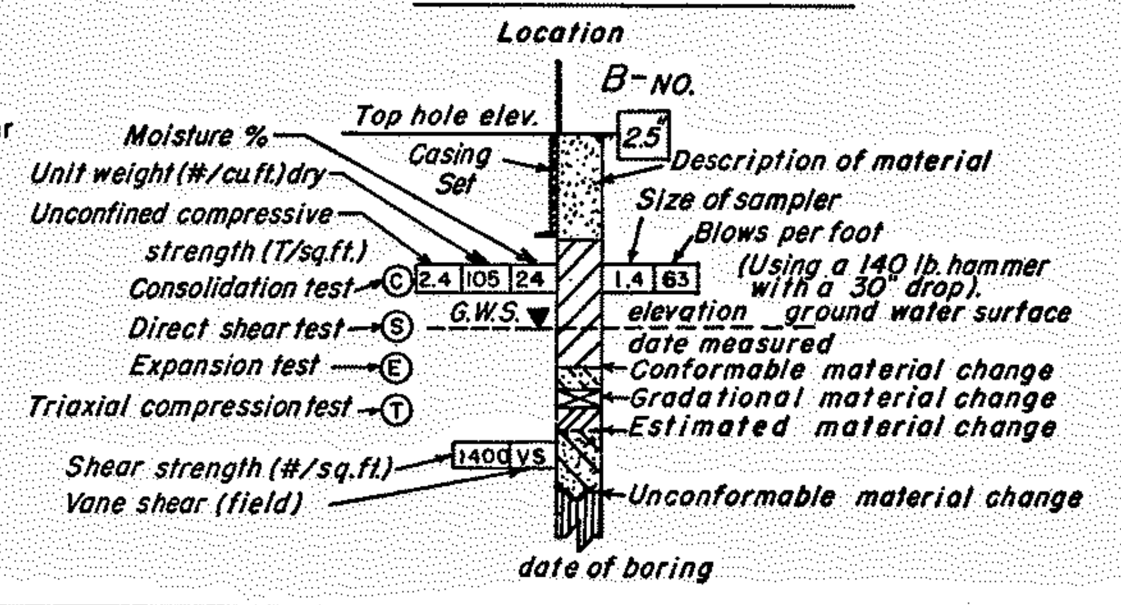
According to the Standard Penetration Test.

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

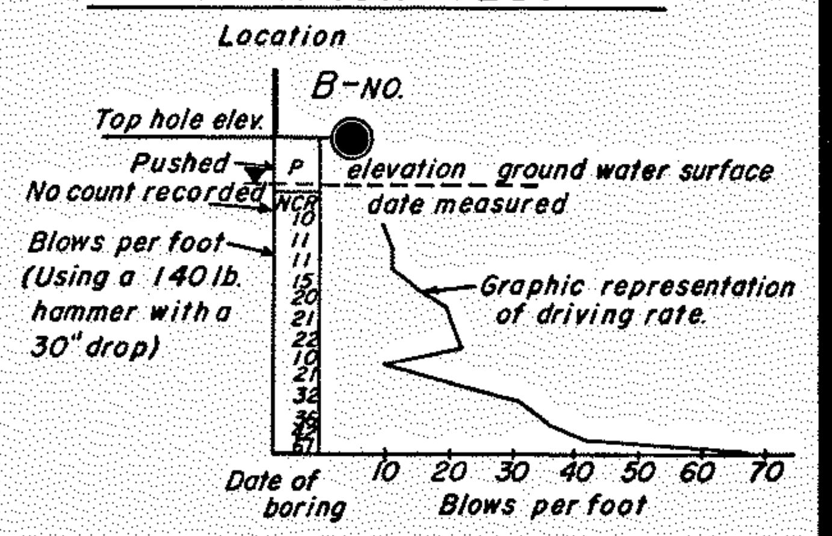
LEGEND OF BORING OPERATIONS

- ● Plan of any boring
- Size Flush penetrometer
- ● 2.5" Cone penetrometer
- Size Rotary boring
- Size Auger boring
- Size Sample boring
- Size Jet boring
- Size Diamond core boring
- Test pit

ROTARY BORING



PENETRATION TEST



MOORE and TABER
Engineers — Geologists

Job No 3926F APPROVED H.R. Taber 10-12-59
LICENSED CIVIL ENGINEER No 9165

SACRAMENTO COUNTY

BRIDGE ACROSS GEORGIANA SLOUGH

LOG OF TEST BORINGS

Scale H-1"=20 V-1"=10'	Date Oct. 6, 1959 Nov. 3, 1960	File	Drawing

VERNLITE CLEARPRINT 1000H

22

13-2-2 23

T16 30

BR# 4F7006

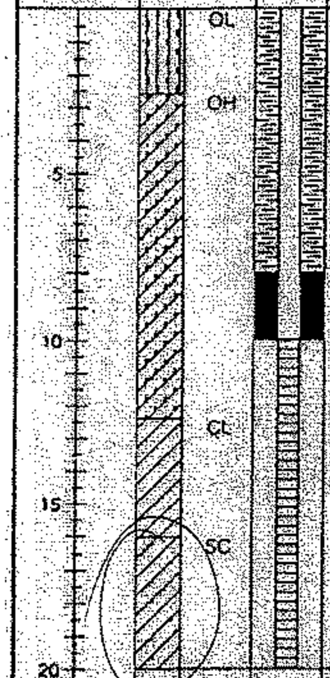
State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

DRILL HOLE LOG

SHEET 1 of 1
HOLE NO ND-11
ELEV ________ FEET
DEPTH 20.0 FEET

PROJECT 1992 North Delta Seepage Monitoring
FEATURE Tyler Island
LOCATION Levee toe, south of Delta Cross Channel
CONTR. PC Exploration DRILL RIG Mobile Drill, B-61
DATE DRILLED 6/14/93-6/14/93
ATTITUDE Vertical
LOGGED BY G. Newmarch
DEPTH TO WATER ∇ Not Determined

AD = Hole drilled with 8" hollow-stem auger



ELEV. DEPTH	LOG	WELL CONS	FIELD CLASSIFICATION AND DESCRIPTION	MODE	REMARKS
	OL		0.0 - 2.5' ORGANIC CLAY: Dark yellowish brown (10YR 4/2). Very silty. Contains about 15% organics. Low to medium plasticity. Soft. Moderately moist.	AD	Soft materials, rapid drilling rate 0 to 12.5 feet.
	OH		2.5 - 12.5' ORGANIC CLAY: Olive gray (5Y 3/2). Silty and clayey. Medium to high plasticity. Soft. Moist to 6 feet and then saturated. Organic clay becomes moderately stiff at 8 feet.		
	CL		12.5 - 16.0' INORGANIC CLAY: Pale yellowish brown (10YR 6/2) to moderate yellowish brown (10YR 5/4). Silty. Contains less than 5% organics. Low to medium plasticity. Very stiff. Saturated.		Slightly firmer materials 12.5 to 15 feet.
	SC		16.0 - 20.0' SAND: Light olive brown (5Y 5/6). Fine-grained. Very clayey. Silty. Grains subangular to subround. Predominately quartz. Saturated.		Soft materials, faster drilling rate 16 to 20 feet. Produced about 0.75 GPM while developing.
					Total Depth = 20 feet

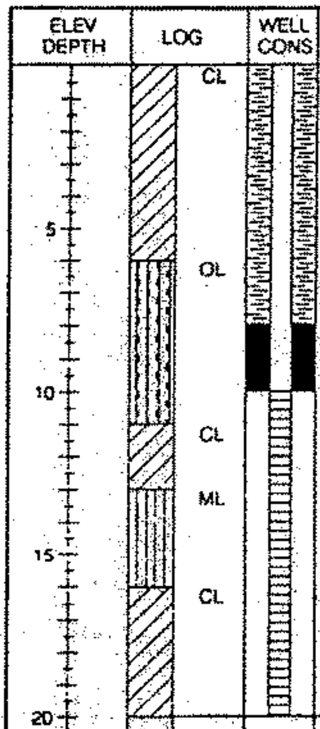
State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

DRILL HOLE LOG

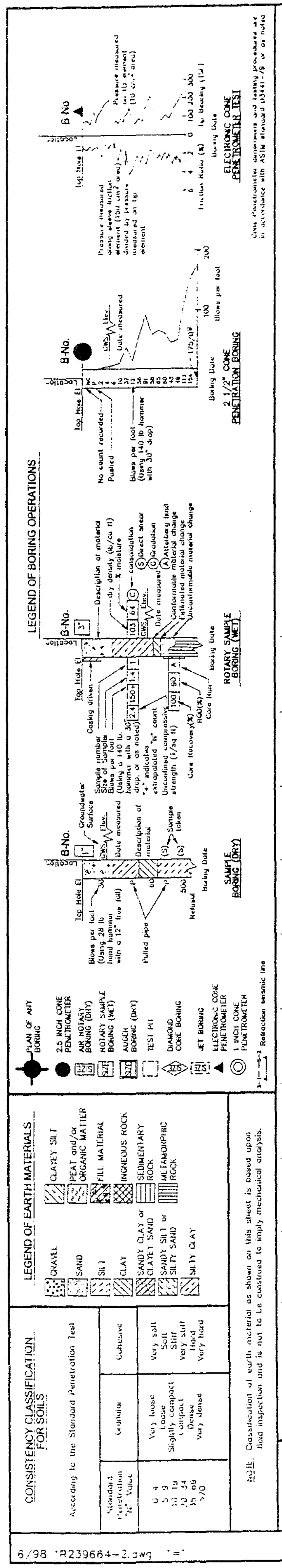
SHEET 1 of 1
HOLE NO. ND-34
ELEV. ______ FEET
DEPTH 20.0 FEET

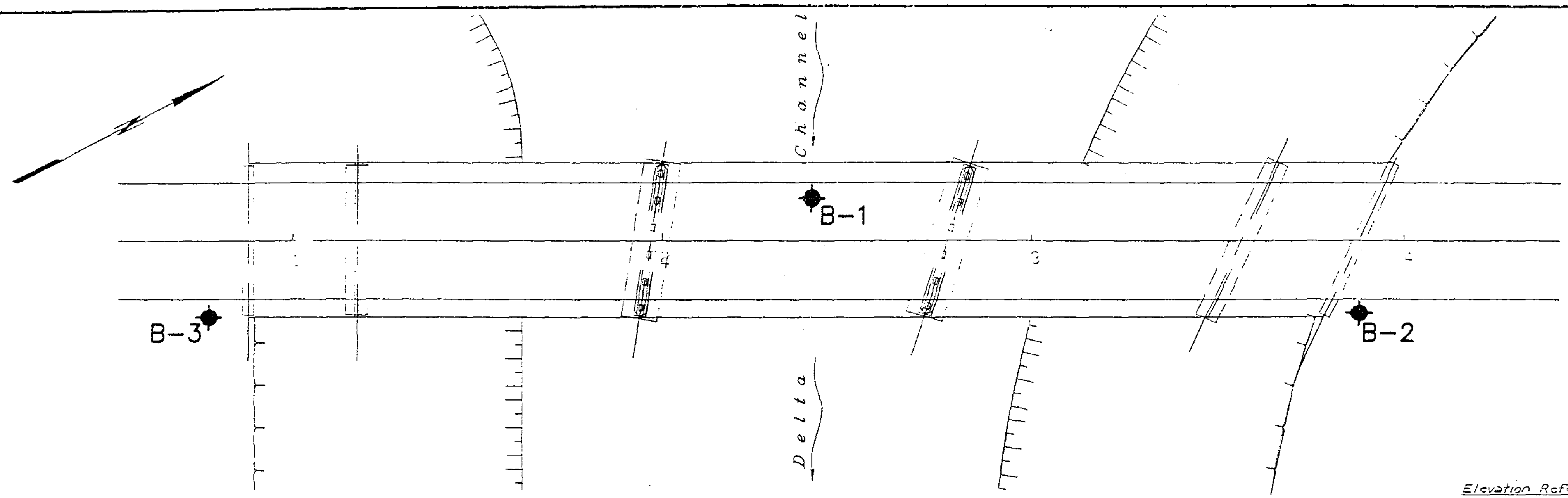
PROJECT 1992 North Delta Seepage Monitoring
FEATURE Tyler Island/Walnut Grove
LOCATION Levee toe
CONTR. PC Exploration
DRILL RIG Mobile Drill B-61
DATE DRILLED 12/11/92-12/11/92
ATTITUDE Vertical
LOGGED BY G. Newmarch
DEPTH TO WATER ⊻ Not Determined

AD = Hole drilled with 8" hollow-stem auger



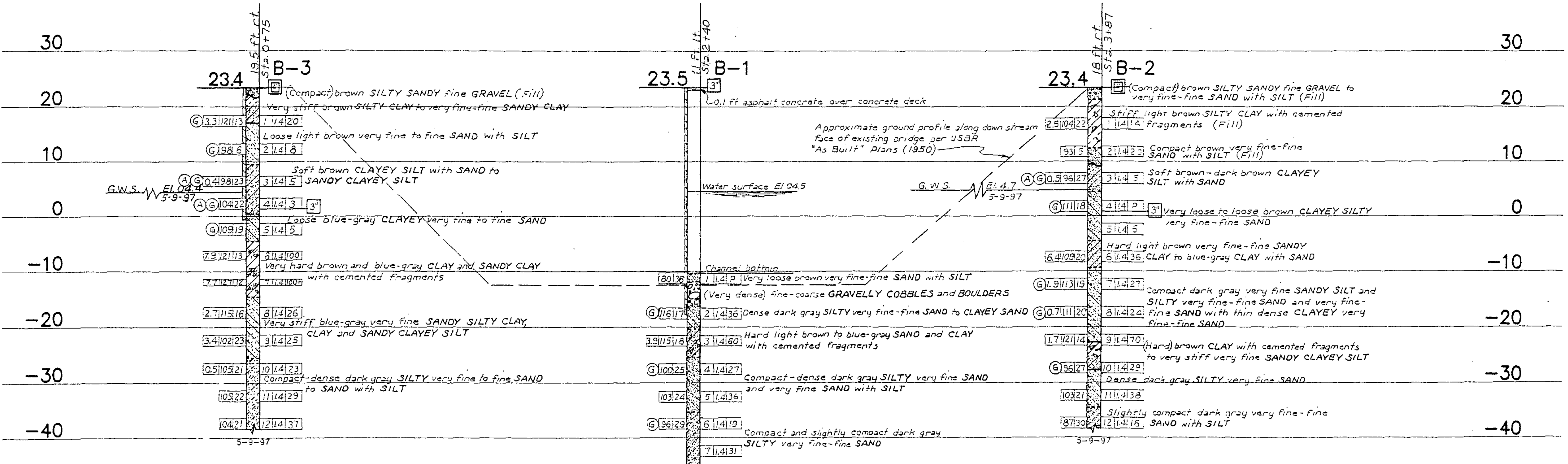
FIELD CLASSIFICATION AND DESCRIPTION	MODE	REMARKS
0.0 - 6.0' CLAY: Moderate yellowish brown (10YR 5\4). Silty. Low to medium plasticity. Soft. Saturated.	AD	
		No drilling cuttings being returned at 5 feet.
6.0 - 11.0' ORGANIC CLAY: Dark greenish gray (5G 4/1). Low to medium plasticity. Moderately stiff. Saturated.		Firm material and slower rate of drilling 6 - 11 feet.
11.0 - 13.0' CLAY: Moderate yellowish brown (10YR 5/4). Silty. Low to medium plasticity. Very stiff. Saturated.		Very firm material and slower rate of drilling 11 - 13 feet.
13.0 - 16.0' SILT: Greenish gray (5G 6/1). Clayey and sandy (fine-grained sand). Saturated.		Softer material 13 - 16 feet Water flowed from hole at 14 feet.
16.0 - 20.0' CLAY: Greenish gray (5G 6/1). Silty. Low to medium plasticity. Very stiff. Saturated.		Firm material and slower rate of drilling 16 - 20 feet.
		Total Depth = 20 feet





PLAN
1" = 20'

Elevation Reference
Centerline North abutment at edge of deck-
Elev. 23.50
Per US Department of the Interior, Bureau of
Reclamation "As Built" plans, 1950



NOTES

Field classification of soils was in accordance with ASTM D 2488-69 "Description and Indentification of Soils (Visual-Manual Procedure)".

Standard Penetration tests were performed in accordance with ASTM D 1586-84 using a safety hammer operated with cat-head, rope and pulley. Drill rods were 1-5/8" diameter "A"-rods; sampler was driven with brass liners.

PROFILE
1" = 10' Vertical
1" = 20' Horizontal

DIST.	COUNTY	ROUTE	POST MILES TOTAL PROJECT	SHEET NO.	TOTAL SHEETS
3	Sac				

F. P. Taber 6-17-98
REGISTERED GEOTECHNICAL ENGINEER

PLANS APPROVAL DATE

FRANKLIN P. TABER
No. 816
EXP. 3-31-00

TABER CONSULTANTS
536 Galveston Street
West Sacramento, CA 95691
JOB No. 1R2/396/64-2 (Task 5)
LOCATION: 38121-85: 444N: 026W

Dokken Engineering
3054 Gold Canal Drive
Rancho Cordova, CA 95670

LOCATION: 38121-85 N444: W026

Note: Classification of earth material as shown on this sheet is based upon field inspection and is not to be construed to imply mechanical analysis.

DESIGN OVERSIGHT
SIGN OFF DATE
DRAWN BY J. O. Darr
CHECKED BY T. A. Krause
T. A. Krause
FIELD INVESTIGATOR
DATE May 1997

PREPARED FOR
SACRAMENTO
COUNTY

John Maniscalco
PROJECT ENGINEER

BRIDGE NO. 24C-0167
POST MILE

EARTHQUAKE RETROFIT
DELTA CROSS CHANNEL BRIDGE
LOG OF TEST BORINGS

ORIGINAL SCALE IN INCHES FOR REDUCED PLANS 0 1 2 3

CU 03
EA 21703

DISREGARD PRINTS BEARING EARLIER REVISION DATES
REVISION DATES (PRELIMINARY STAGE ONLY)
SHEET 13 OF 13

6/98 R239664-2.dwg

UPDATED EXISTING GEOTECHNICAL DATA

TECHNICAL MEMORANDUM

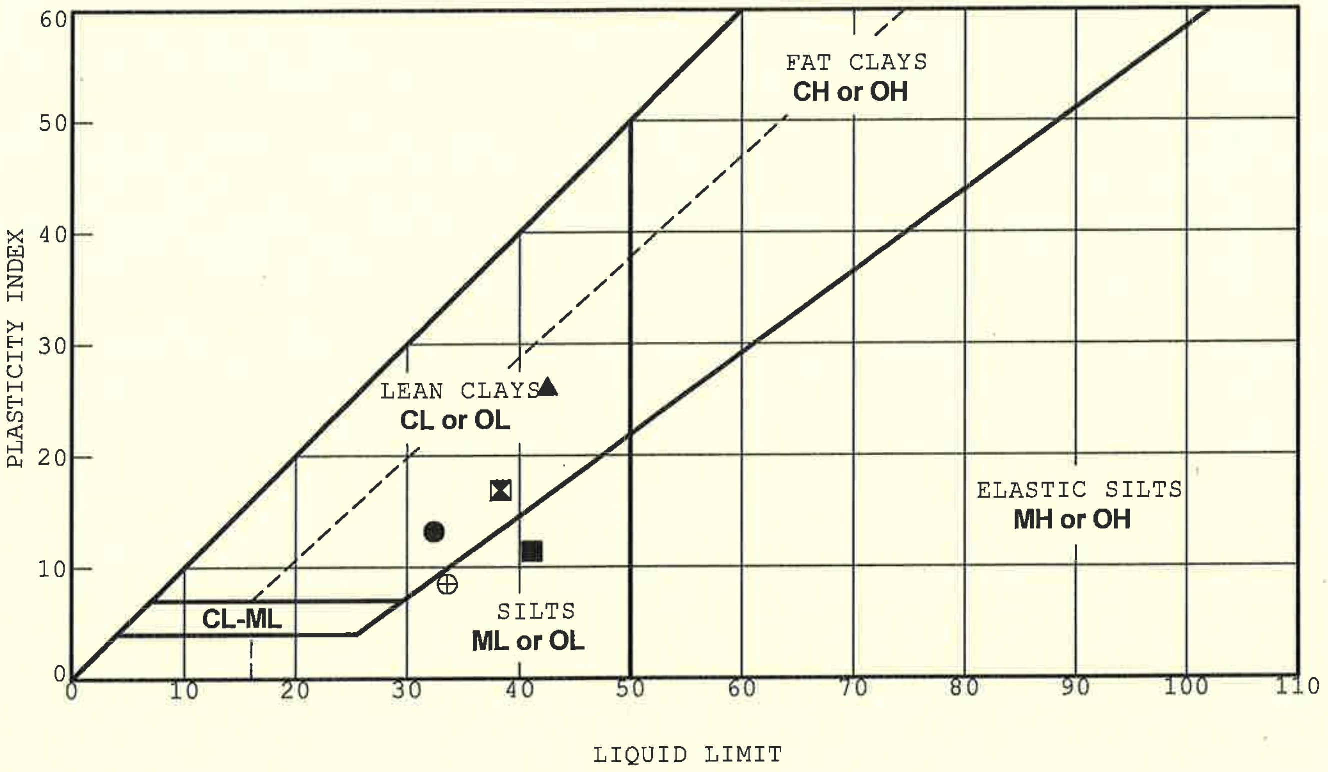
Community of East Walnut Grove, California

California Department of Water Resources
Small Community Flood Risk Reduction Program

APPENDIX E

Raney Laboratory

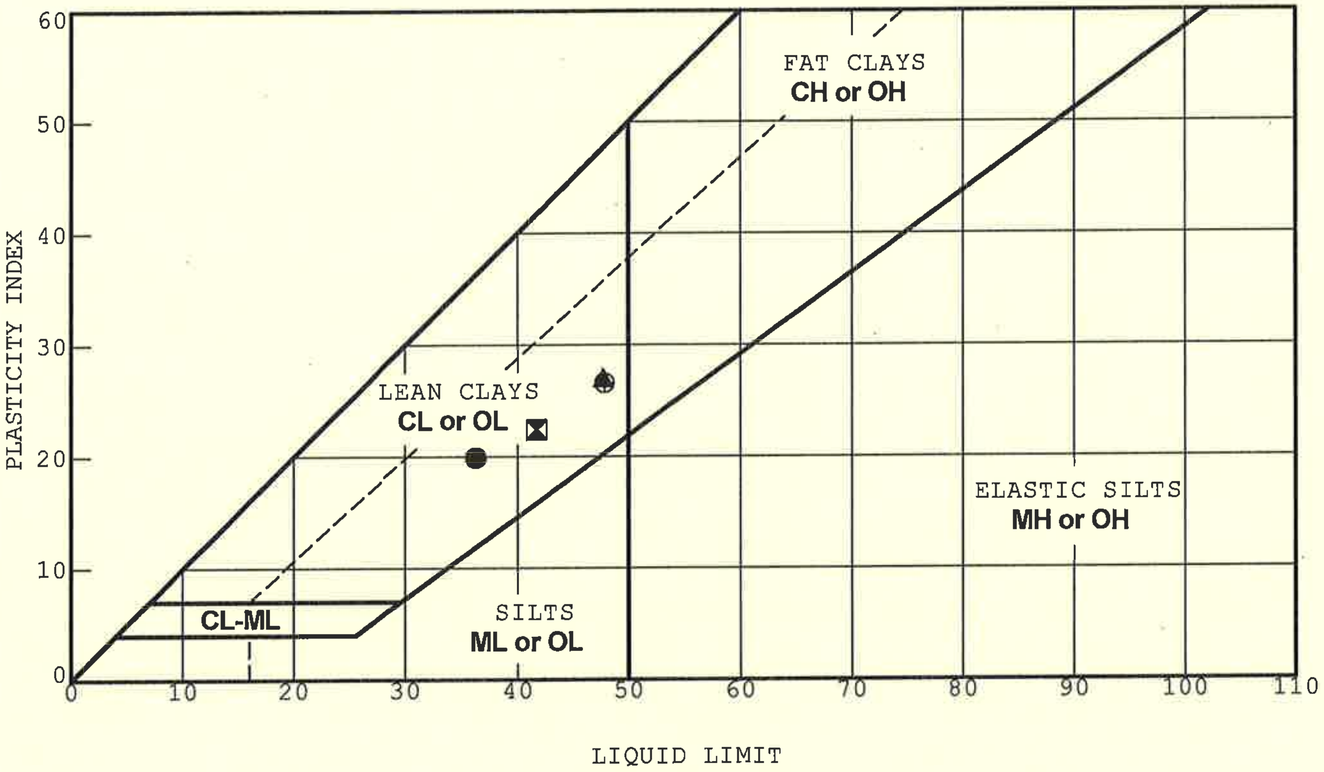
PROJECT NUMBER: 1135-021
PLATE NUMBER: 24A



CLASSIFICATION TEST RESULTS						
SYMBOL	SAMPLE LOCATION	DEPTH FEET	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL CLASSIFICATION
●	BORING 2	2.0	32	19	13	CL
☒	BORING 2	9.5	38	21	17	CL
▲	BORING 2	14.5	43	16	26	CL
⊕	BORING 2	19.5	34	25	9	ML
■	BORING 2	51.0	41	30	11	ML

ATTERBERG LIMIT DATA

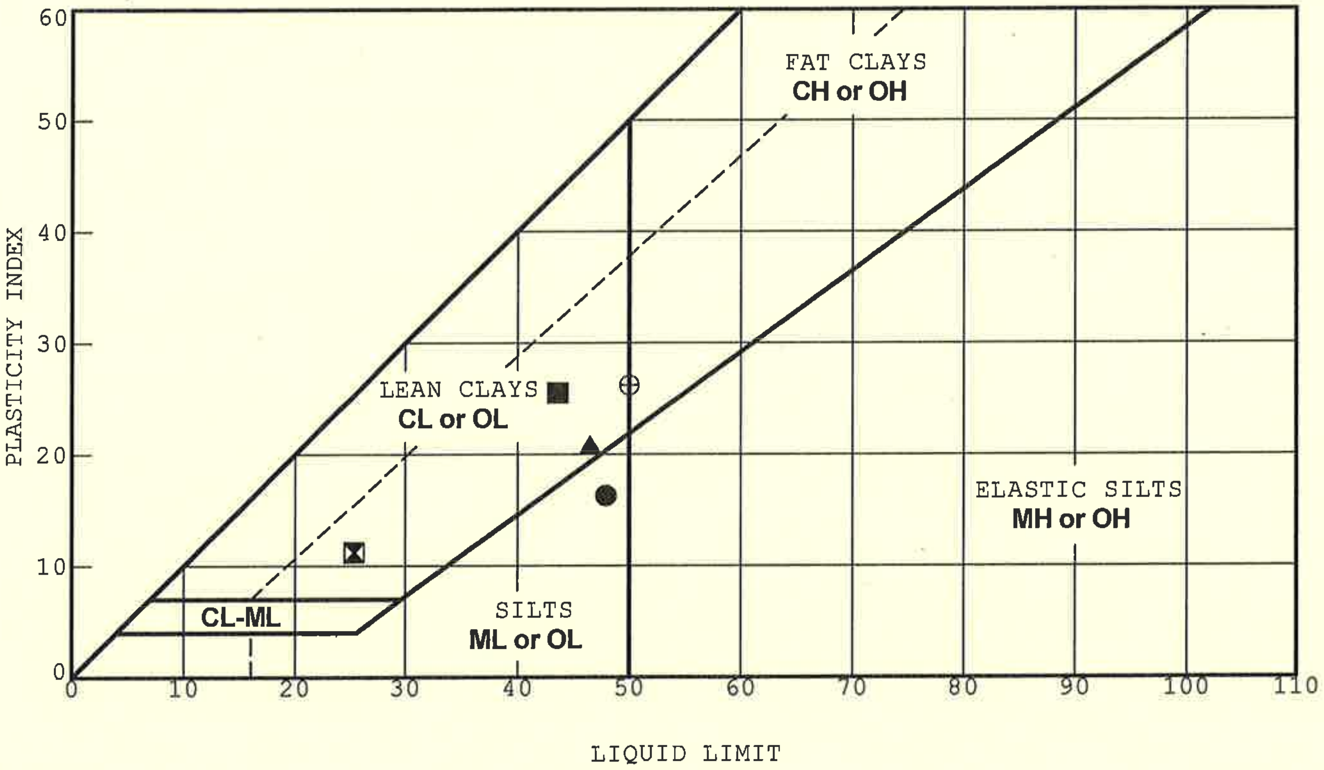
PROJECT NUMBER: 1135-021
PLATE NUMBER: 24B



CLASSIFICATION TEST RESULTS						
SYMBOL	SAMPLE LOCATION	DEPTH FEET	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL CLASSIFICATION
●	BORING 3	9.0	36	16	20	CL
⊠	BORING 3	14.5	42	19	22	CL
▲	BORING 3	24.5	48	21	27	CL
⊕	BORING 3	49.0	48	21	27	CL

ATTERBERG LIMIT DATA

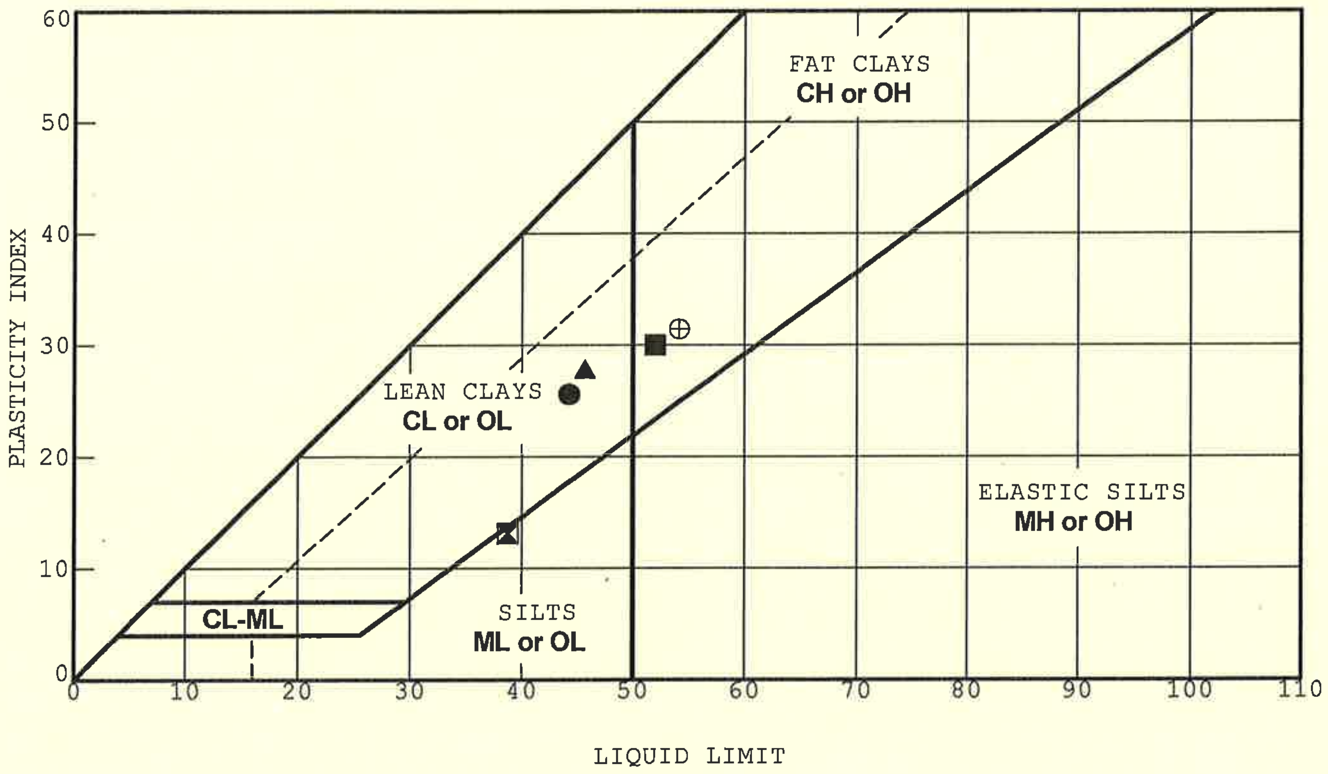
PROJECT NUMBER: 1135-021
PLATE NUMBER: 24C



CLASSIFICATION TEST RESULTS						
SYMBOL	SAMPLE LOCATION	DEPTH FEET	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL CLASSIFICATION
●	BORING 5	22.5	48	32	16	ML
⊠	BORING 5	28.0	25	14	11	CL
▲	BORING 5	38.0	47	26	21	CL
⊕	BORING 5	42.0	50	24	26	CH
■	BORING 5	63.0	44	18	26	CL

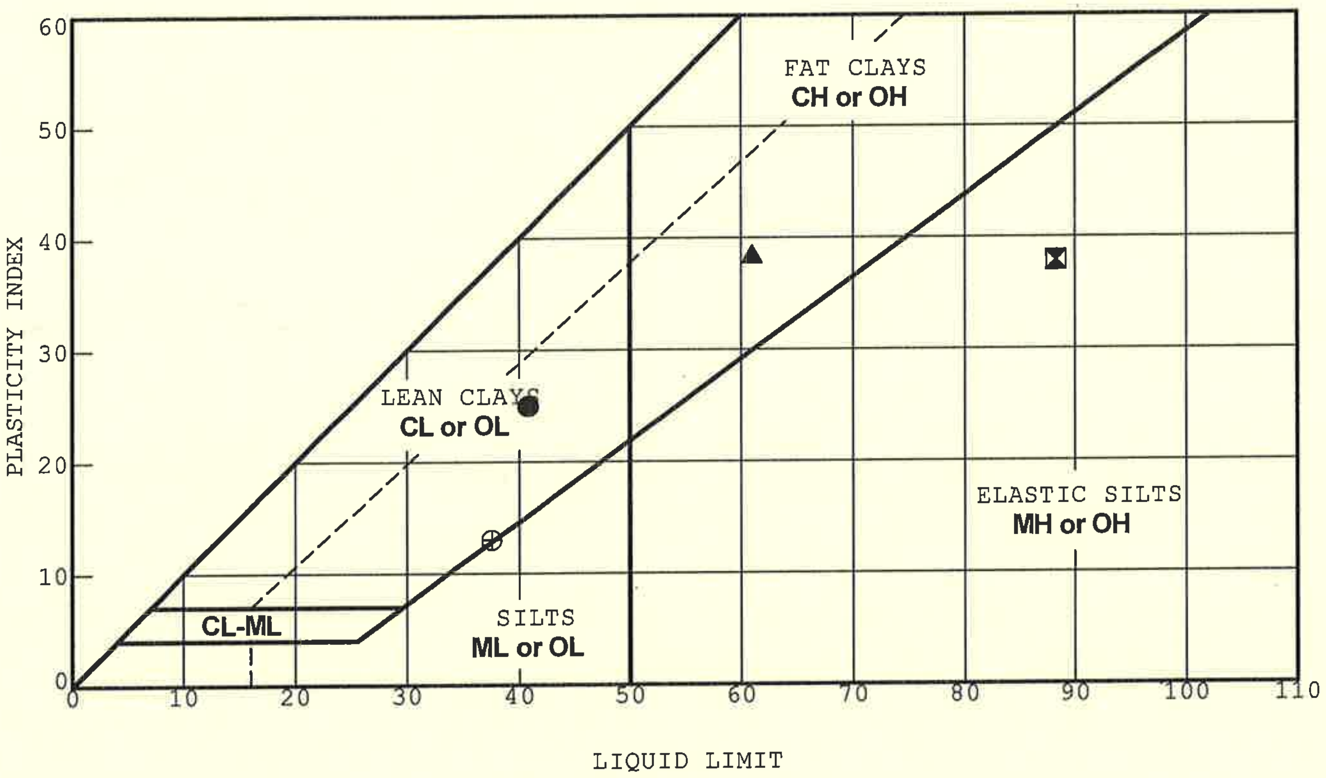
ATTERBERG LIMIT DATA

PROJECT NUMBER: 1135-021
PLATE NUMBER: 24D



CLASSIFICATION TEST RESULTS						
SYMBOL	SAMPLE LOCATION	DEPTH FEET	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL CLASSIFICATION
●	BORING 6	28.0	44	19	26	CL
⊠	BORING 6	33.0	39	26	13	ML
▲	BORING 6	38.0	46	18	28	CL
⊕	BORING 6	43.0	54	23	31	CH
■	BORING 6	63.0	52	22	30	CH

ATTERBERG LIMIT DATA

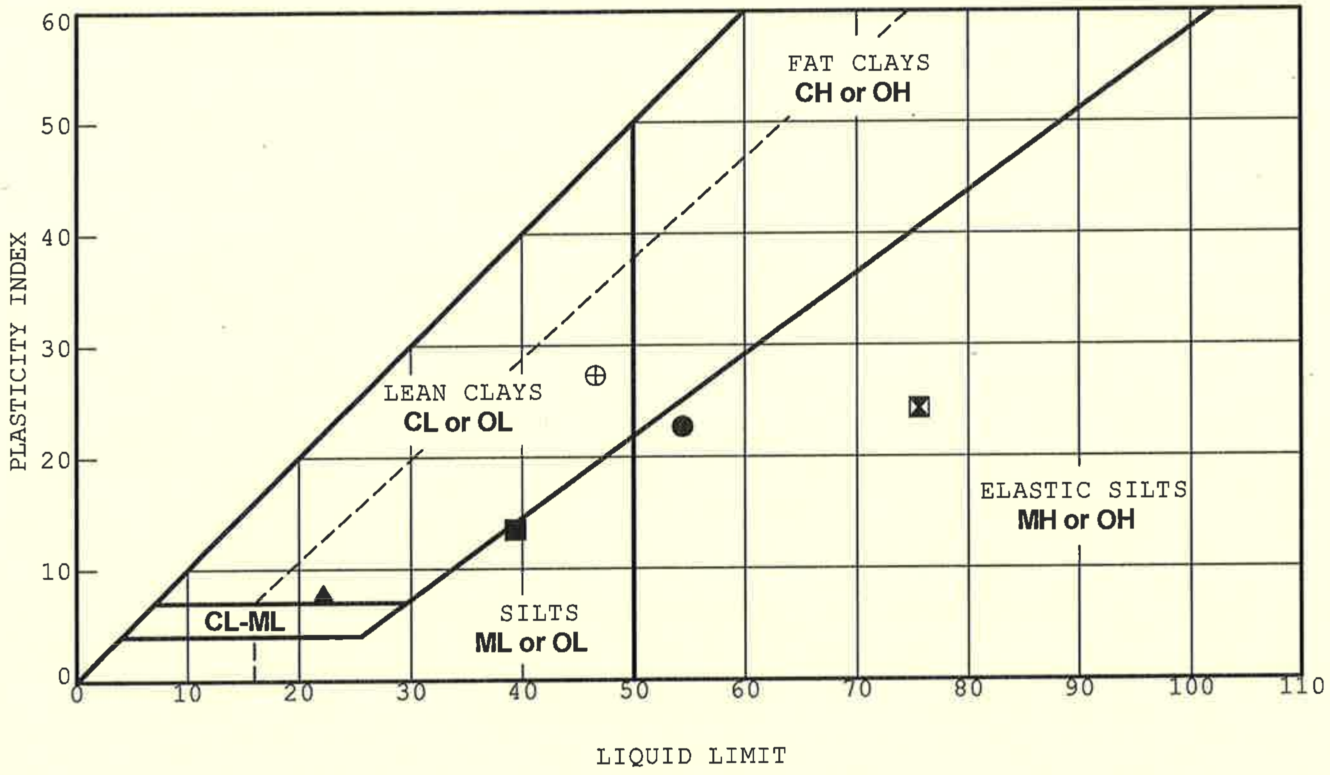


PROJECT NUMBER: 1135-021
PLATE NUMBER: 24E

CLASSIFICATION TEST RESULTS						
SYMBOL	SAMPLE LOCATION	DEPTH FEET	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL CLASSIFICATION
●	BORING 7	11.0	41	16	25	CL
⊠	BORING 7	19.0	88	50	38	MH
▲	BORING 7	38.0	61	23	39	CH
⊕	BORING 7	63.0	38	25	13	ML

ATTERBERG LIMIT DATA

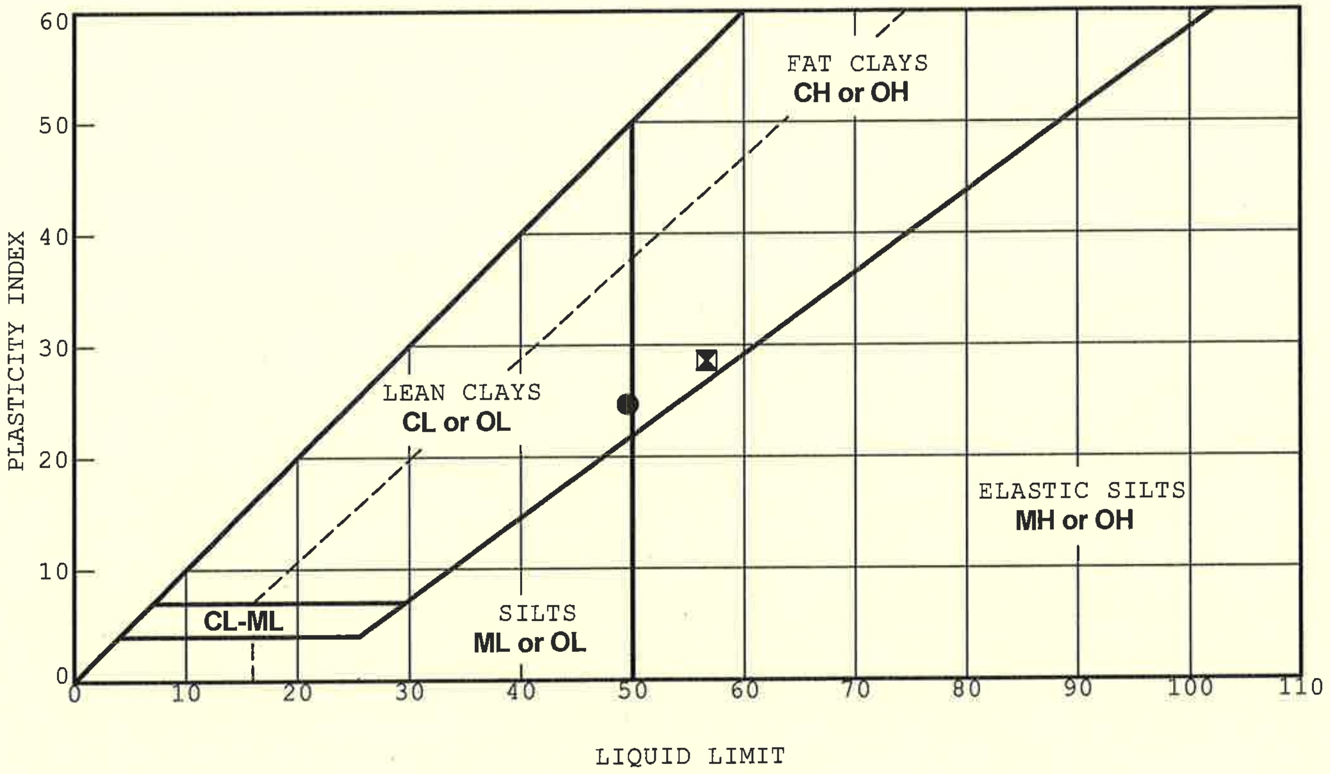
PROJECT NUMBER: 1135-021
PLATE NUMBER: 24F



CLASSIFICATION TEST RESULTS						
SYMBOL	SAMPLE LOCATION	DEPTH FEET	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL CLASSIFICATION
●	BORING 9	16.0	54	32	23	MH
☒	BORING 9	20.5	76	51	24	MH
▲	BORING 9	26.0	22	14	8	CL
⊕	BORING 9	45.5	47	19	27	CL
■	BORING 9	55.5	39	26	14	ML

ATTERBERG LIMIT DATA

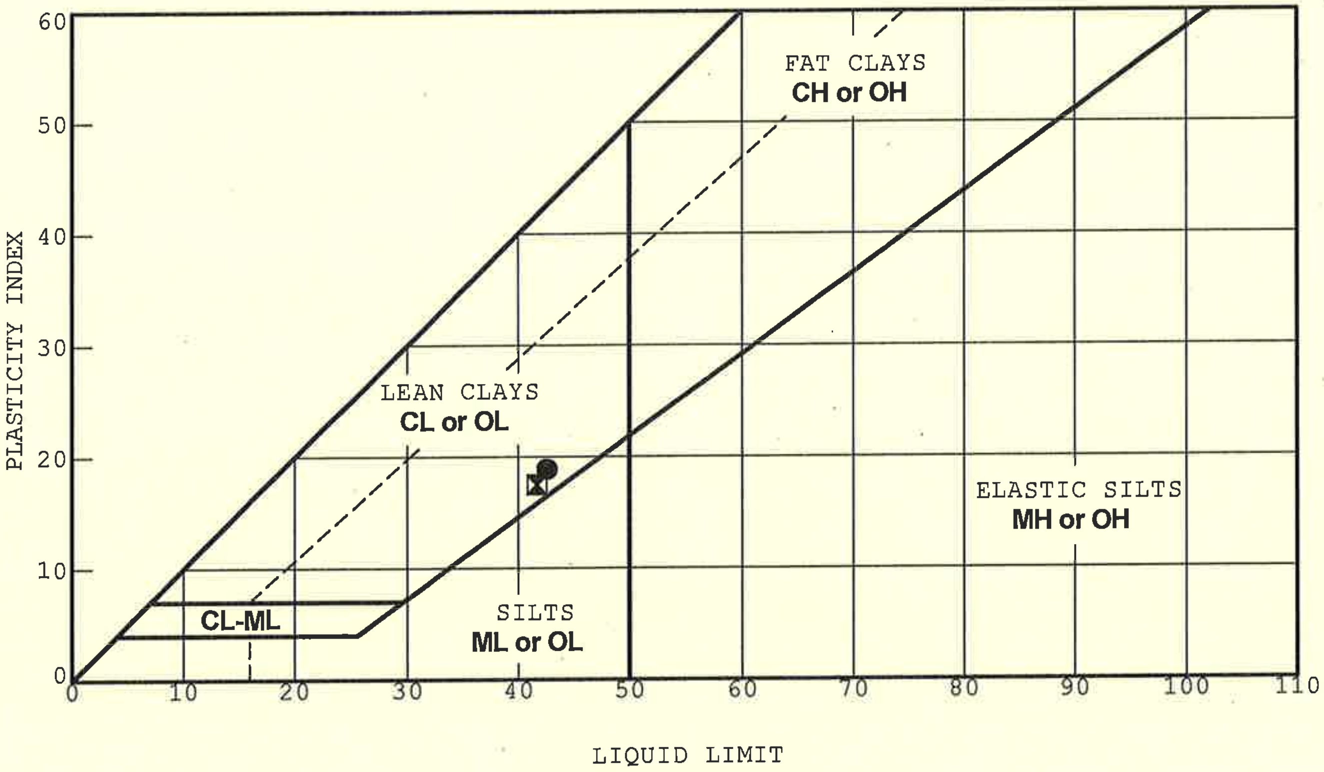
PROJECT NUMBER: 1135-021
PLATE NUMBER: 24G



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

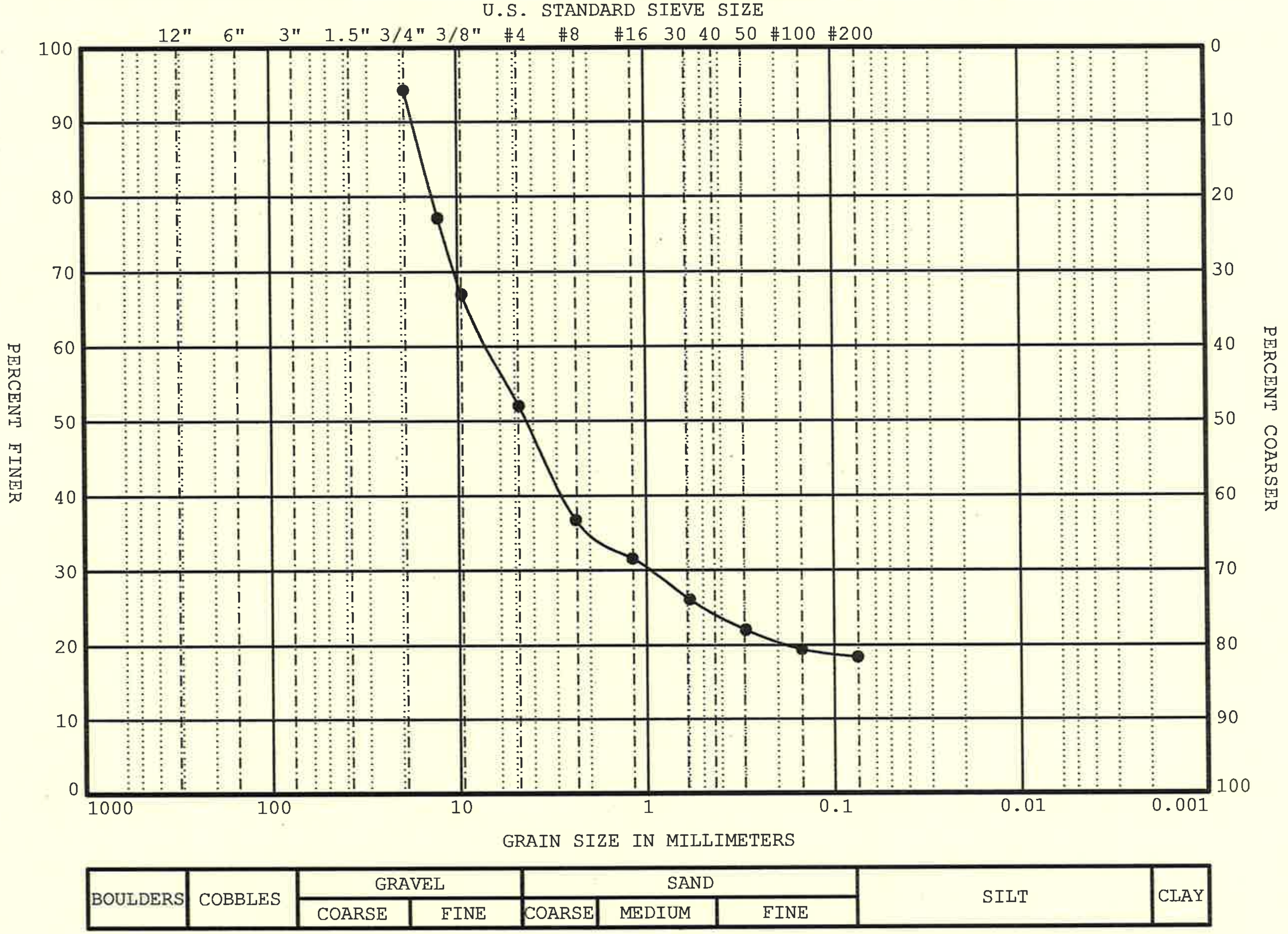


CLASSIFICATION TEST RESULTS						
SYMBOL	SAMPLE LOCATION	DEPTH FEET	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	SOIL CLASSIFICATION
●	BORING 12	34.5	43	24	19	CL
☒	BORING 12	47.5	42	24	18	CL

ATTERBERG LIMIT DATA

PROJECT NUMBER: 1135-021
PLATE NUMBER: 25A

SYMBOL	LOCATION	DEPTH	UNIFIED CLASSIFICATION	DESCRIPTION
●	BORING 1	2.0'	GM	FILL



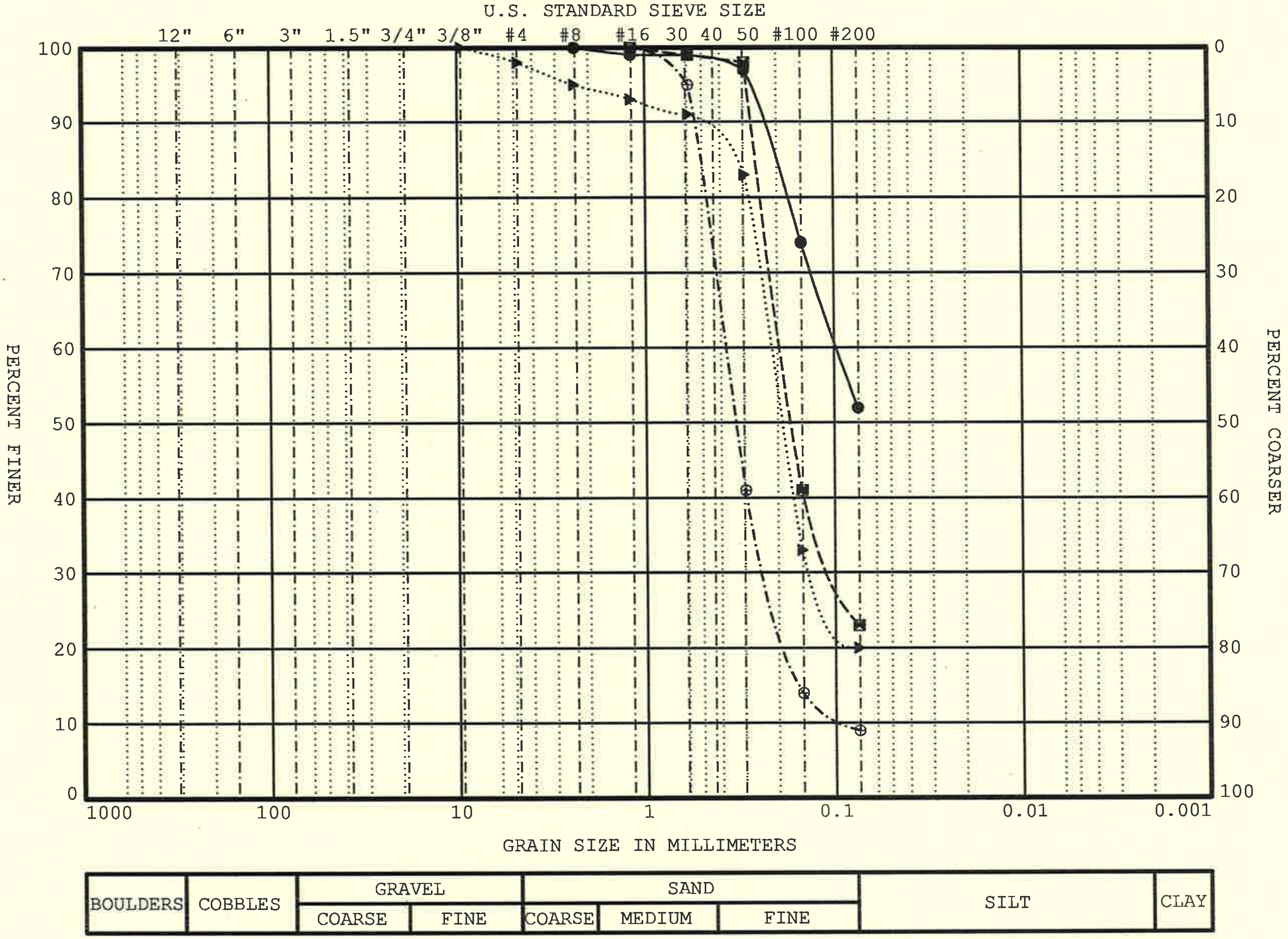
GRAIN SIZE DISTRIBUTION

Raney Geotechnical Inc

PLATE 25A

PROJECT NUMBER: 1135-021
PLATE NUMBER: 25B

SYMBOL	LOCATION	DEPTH	UNIFIED CLASSIFICATION	DESCRIPTION
●	BORING 2	31.0'	ML	BLUE GRAY VERY SILTY CLAY WITH SAND STRINGERS
☒	BORING 2	36.0'	SM	GRAY FINE SANDY SILT
▲	BORING 2	41.0'	SM	GRAY FINE TO MEDIUM SANDY SILT
⊕	BORING 2	59.5'	SP-SM	GRAY FINE TO MEDIUM SAND



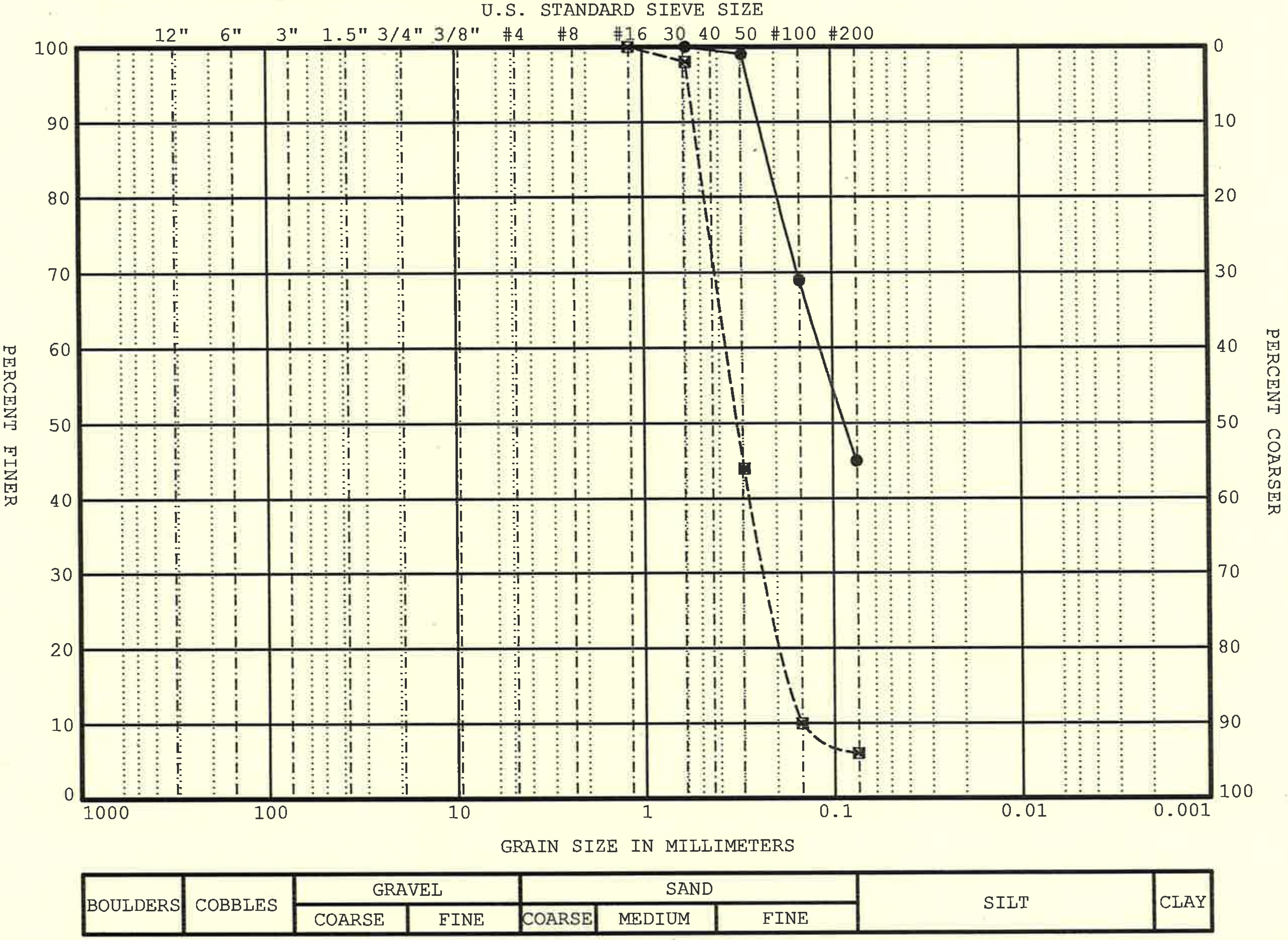
GRAIN SIZE DISTRIBUTION

Raney Geotechnical Inc

PLATE 25B

PROJECT NUMBER: 1135-021
PLATE NUMBER: 25C

SYMBOL	LOCATION	DEPTH	UNIFIED CLASSIFICATION	DESCRIPTION
●	BORING 3	34.5'	SM	GRAY-GREEN FINE SANDY CLAYEY SILT
☒	BORING 3	39.5'	SP-SM	DARK GRAY-GREEN SLIGHTLY SILTY VERY FINE TO MEDIUM SAND



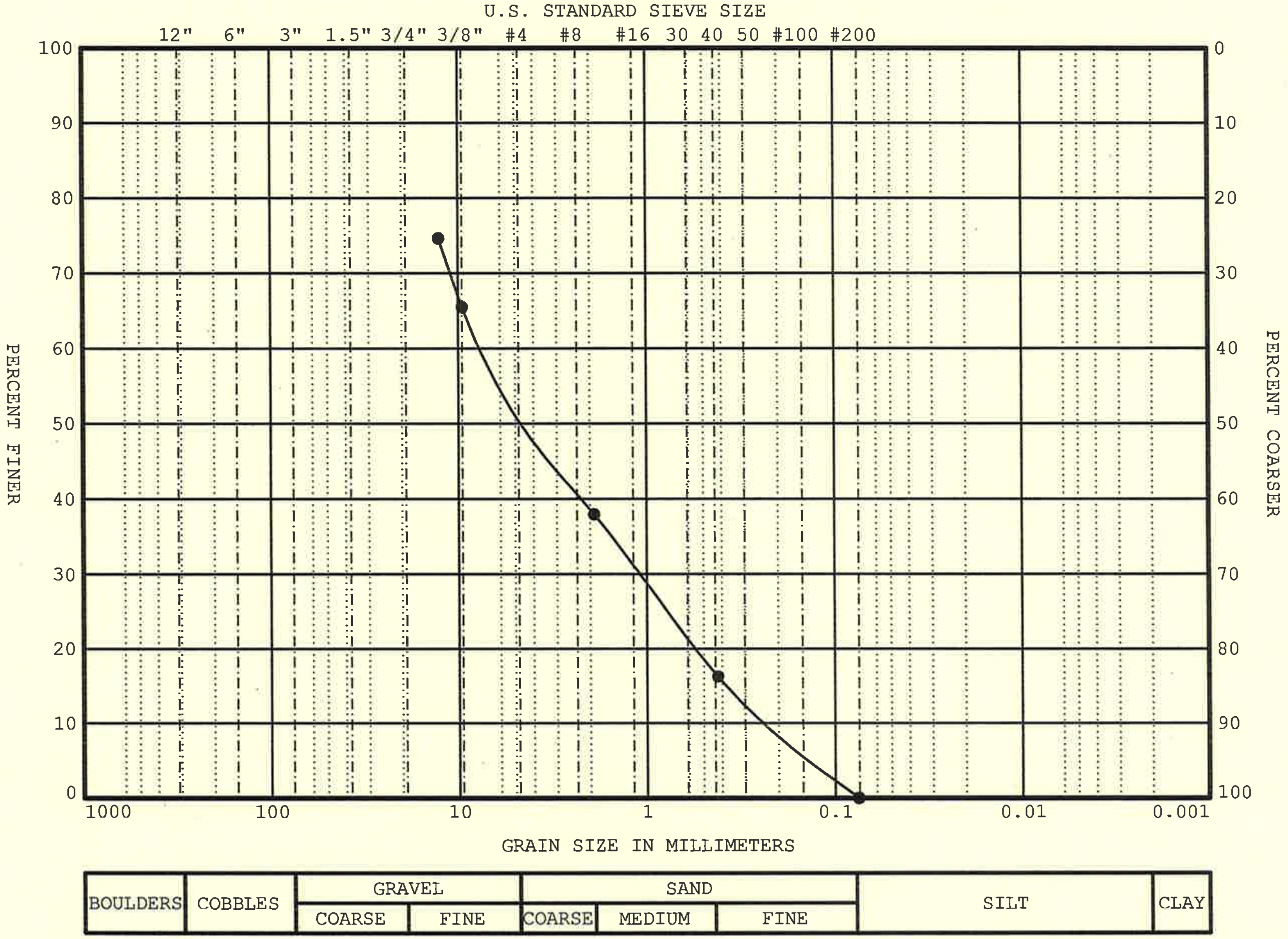
GRAIN SIZE DISTRIBUTION

Raney Geotechnical Inc

PLATE 25C

PROJECT NUMBER: 1135-021
PLATE NUMBER: 25D

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



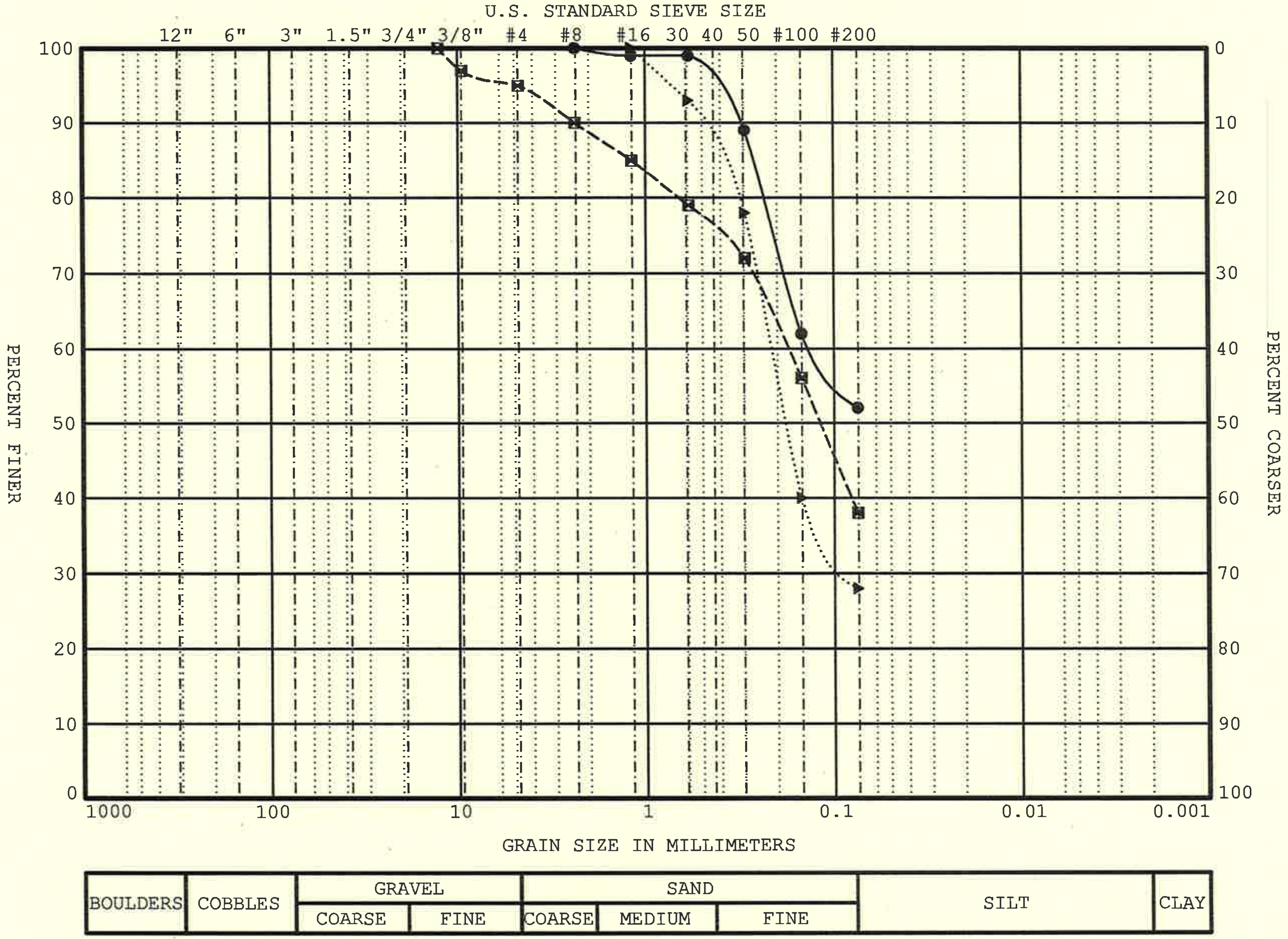
GRAIN SIZE DISTRIBUTION

Raney Geotechnical Inc

PLATE 25D

PROJECT NUMBER: 1135-021
PLATE NUMBER: 25E

SYMBOL	LOCATION	DEPTH	UNIFIED CLASSIFICATION	DESCRIPTION
●	BORING 5	17.0'	ML	YELLOW-BROWN FINE TO MEDIUM SANDY CLAYEY SILT
☒	BORING 5	32.5'	SM	GRAY SLIGHTLY CLAYEY SILTY FINE SAND
▲	BORING 5	47.5'	SM	GRAY SILTY FINE TO MEDIUM SAND



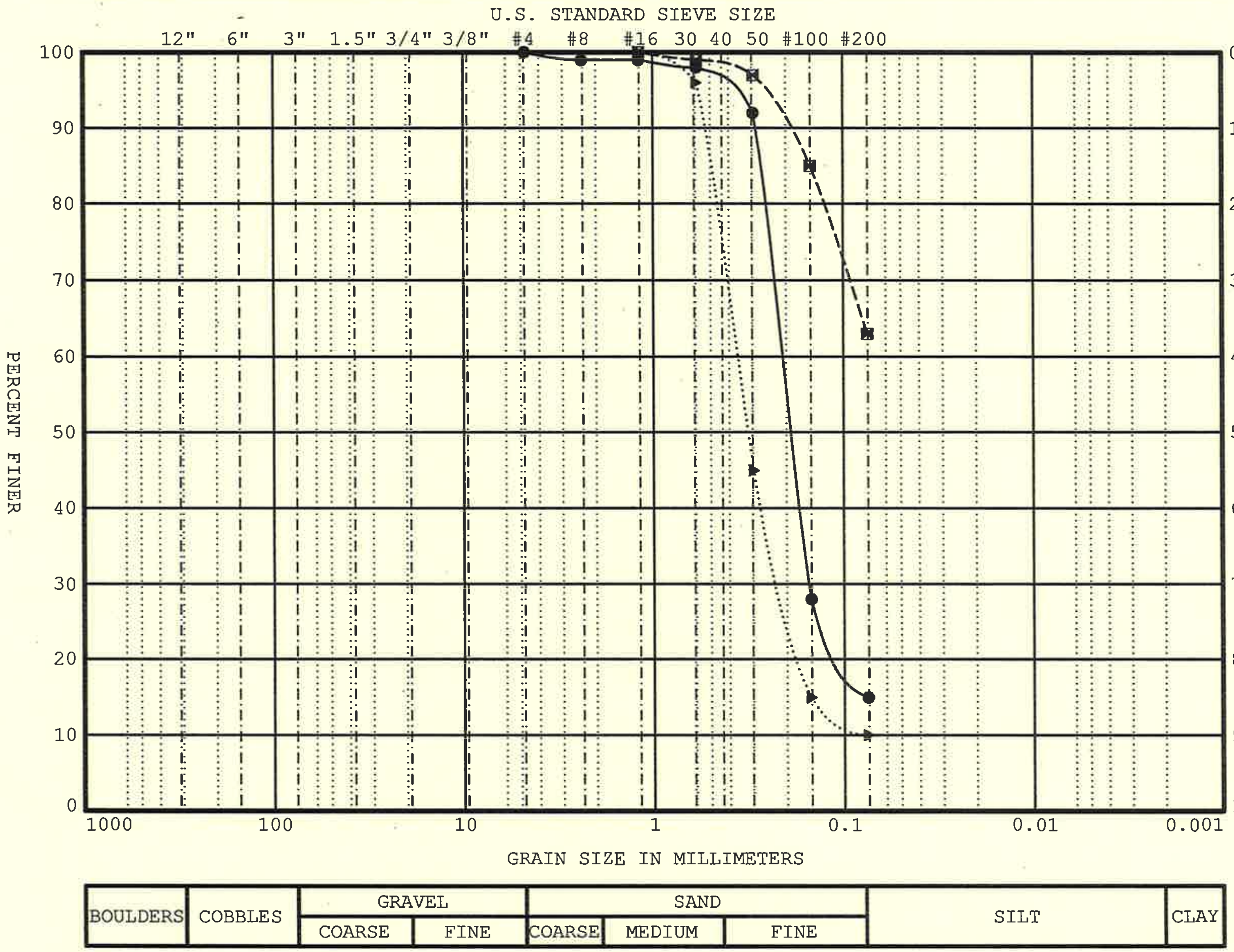
GRAIN SIZE DISTRIBUTION

Raney Geotechnical Inc

PLATE 25E

PROJECT NUMBER: 1135-021
PLATE NUMBER: 25F

SYMBOL	LOCATION	DEPTH	UNIFIED CLASSIFICATION	DESCRIPTION
●	BORING 5	53.0'	SM	GRAY SILTY FINE TO MEDIUM SAND
⊠	BORING 5	68.0'	ML	GRAY SLIGHTLY CLAYEY FINE SANDY SILT
▲	BORING 5	72.5'	SP-SM	BLACK FINE TO MEDIUM SAND



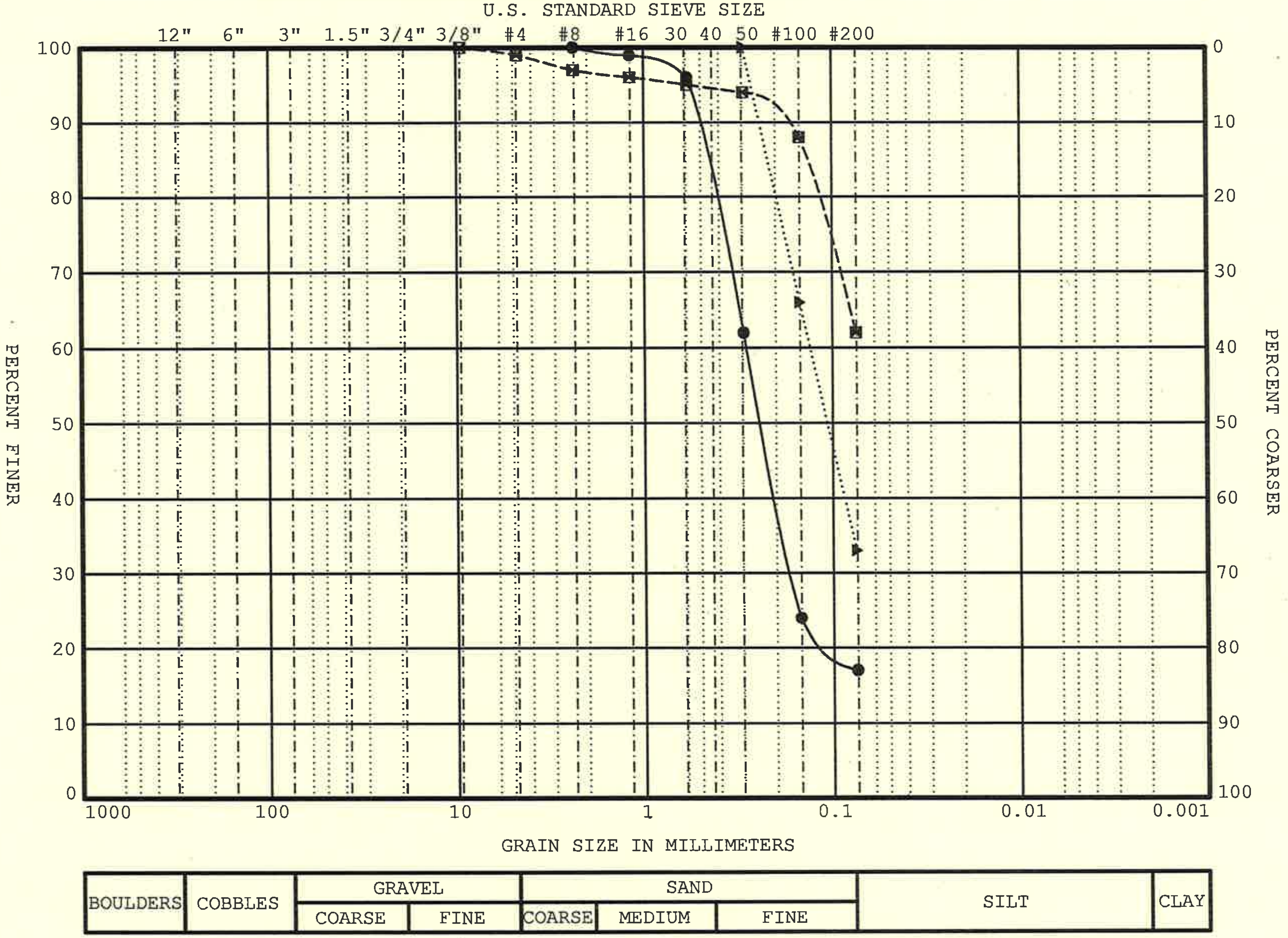
GRAIN SIZE DISTRIBUTION

Raney Geotechnical Inc

PLATE 25F

PROJECT NUMBER: 1135-021
PLATE NUMBER: 25G

SYMBOL	LOCATION	DEPTH	UNIFIED CLASSIFICATION	DESCRIPTION
●	BORING 6	18.0'	SM	GRAY-BROWN FINE TO MEDIUM SANDY SILT
☒	BORING 6	48.0'	ML	GRAY CLAYEY FINE SANDY SILT
▲	BORING 6	58.0'	SM	GRAY SILTY FINE TO MEDIUM SAND



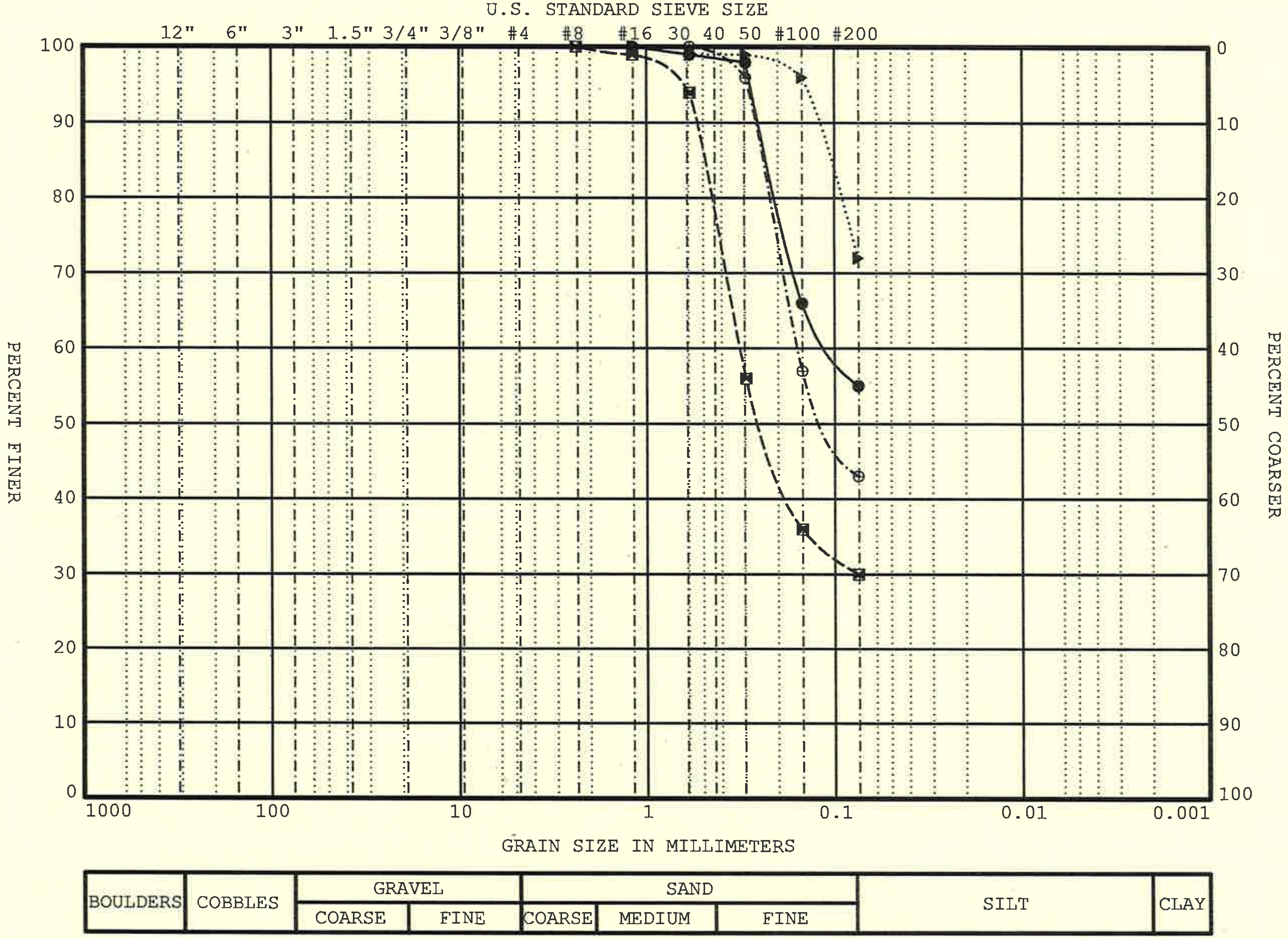
GRAIN SIZE DISTRIBUTION

Raney Geotechnical Inc

PLATE 25G

PROJECT NUMBER: 1135-021
PLATE NUMBER: 25H

SYMBOL	LOCATION	DEPTH	UNIFIED CLASSIFICATION	DESCRIPTION
●	BORING 7	43.0'	ML	GRAY AND BLUE FINE SANDY SILT
☒	BORING 7	48.0'	SM	GRAY SILTY FINE TO COARSE SAND
▲	BORING 7	53.0'	ML	GRAY FINE SANDY SILT
⊕	BORING 7	58.0'	SM	GRAY SILTY FINE TO MEDIUM SAND



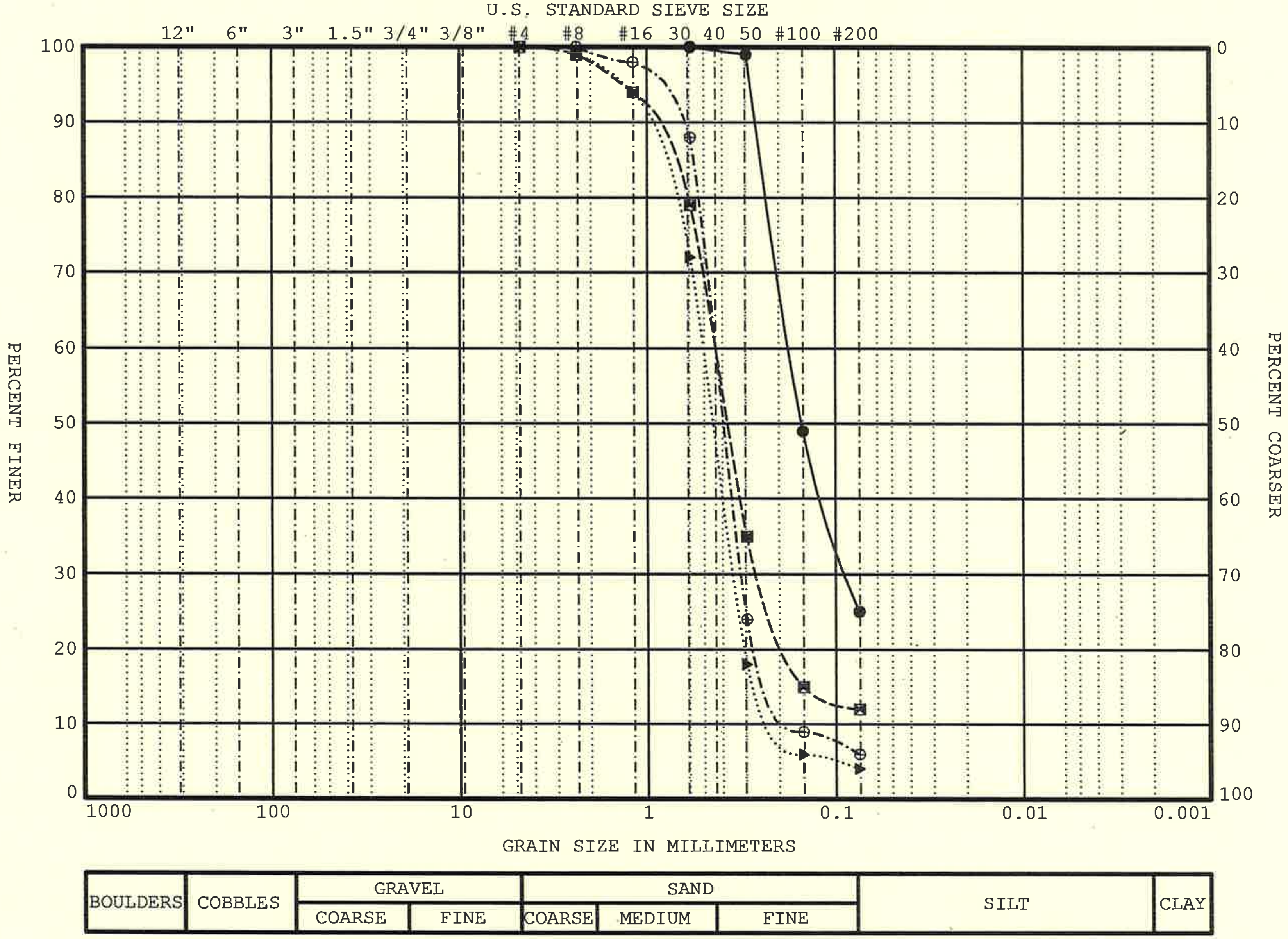
GRAIN SIZE DISTRIBUTION

Raney Geotechnical Inc

PLATE 25H

PROJECT NUMBER: 1135-021
PLATE NUMBER: 25I

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



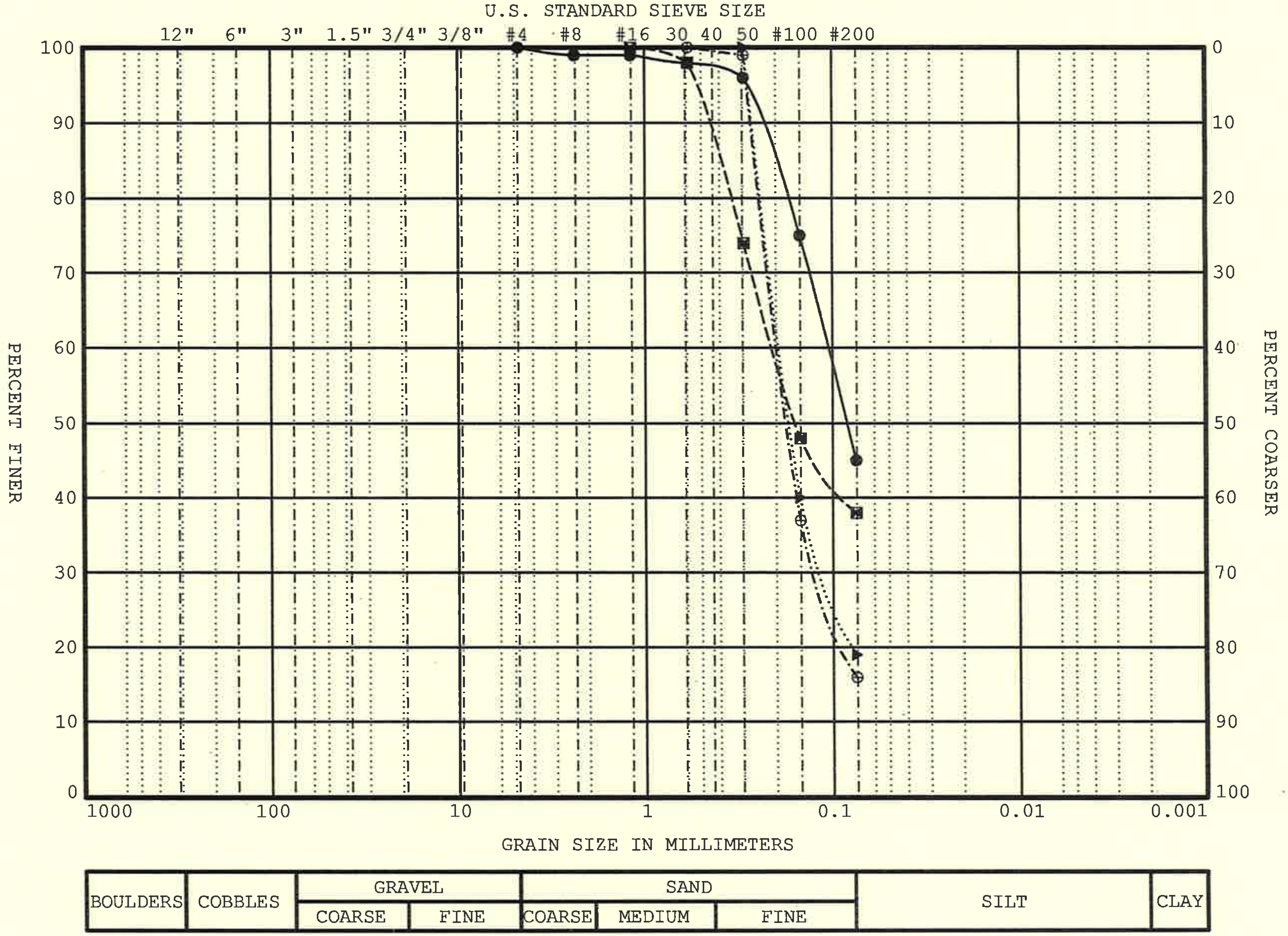
GRAIN SIZE DISTRIBUTION

Raney Geotechnical Inc

PLATE 25I

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

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PLATE 25J