Technical Memorandum

To: George Booth and Shayan Rehman, Sacramento County - Department of Water Resources

From: Graham Bradner and Jeff Twitchell, GEI Consultants, Inc.

Date: October 2018

Re: Existing Geotechnical Data Technical Memorandum
SCFRR - Community of Locke in Sacramento County

Introduction

The purpose of this memorandum is to summarize existing geotechnical information and past performance for the levees protecting the community of Locke in Sacramento County and identify recommendations for further subsurface investigation. The Reclamation District (RD) 369 basin levees protecting this community are constructed along the left bank of the Sacramento River (California Department of Water Resources [DWR] Non-Urban Levee Evaluation [NULE] Segment 121), and the right banks of Meadows Slough (NULE Segment 1040), Meadows Cross Slough (NULE Segment 1054), and Snodgrass Slough (NULE Segment 1054), as shown on Figure 1 and discussed in more detailed below. The ring levee system protecting the community of Locke is completed by the RD 554 levee along the left bank of the Sacramento River from the Delta Cross Channel to the southern limit of RD 369 (NULE Segment 127) and high ground provided by the former railroad embankment that extends along the southeast edge of Locke. The railroad embankment runs along the full southeast extent of the basin, the portion along Snodgrass Slough is included in Segment 1054, the remaining approximately 0.25-miles is not classified as a levee.

Existing conditions information for these levees is primarily available from the DWR Division of Flood Management's NULE project which addressed 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.

Sacramento River Levee

The Sacramento River left bank levees near Locke (NULE Segments 121 and 127) extends approximately 1.0 mile along Sacramento River from the western extension of Meadows Slough at the upstream end to the confluence of the Sacramento River and the Delta Cross Channel at the southern, downstream end. These NULE levee segments are SPFC levees. The northern, upstream 0.8 miles (NULE Segment 121) are part of the RD 369 levee system, and the remaining 0.2 miles (NULE Segment 127) are part of the RD 554 levee system. Along this Sacramento River extent, flow is from north to south. The approximate upstream water surface elevation (WSE) near river mile (RM) 28.1 for the 100-year WSE is 18.3 feet and the downstream 100-year WSE near RM 27.3 is approximately 17.7 feet (GEI, 2016). The United States Army Corps of Engineers (USACE) 1955/57 design profile WSE as provided by DWR (1955/57 design profile) is 17.5 feet at the upstream end of the Sacramento River portion of the levee and 16.9 feet at the downstream end. These WSEs are in reference to the North American Vertical Datum of 1988 (NAVD88).

Meadows Slough Levee

The Meadows Slough right bank levee (NULE Segment 1040) is a Non-SPFC levee that is a part of the RD 551 levee system. It is approximately 1.4 miles long, extending from the confluence of Snodgrass Slough and Meadows Slough westward towards the Sacramento River. The westerly 0.6 miles of this NULE segment are common to the RD 369 basin parameter, with Meadow Slough within the RD 369 basin, as shown on Figure 1. The levee helps protect Locke from flooding of the Sacramento River and Snodgrass Slough. The western end of Meadows Slough does not connect to the Sacramento River and is affected by the backwater conditions. 100-year and 1955/57 design profile WSEs are not available for the Meadow Slough levee.

Meadows Cross Slough Levee

The Meadows Cross Slough right bank levee (portion of NULE Segment 1054) is a Non-SPFC levee that is a part of the RD 369 levee system. It is approximately 0.6 miles long, extending from the Meadow Slough Levee southeast to the Snodgrass Slough Levee portion of NULE Segment 1054, see Figure 1. Meadow Slough is located to the east of the levee for approximately half of the extent and the other half does not have an adjacent waterway but protects Locke from flooding when nearby sloughs overtop their banks. 100-year and 1955/57 design profile WSEs are not available for the Meadow Cross Slough levee.

Snodgrass Slough Levee

The Snodgrass Slough right bank levee protecting Locke (portion of NULE Segment 1054) is a Non-SPFC levee that is a part of the RD 369 levee system. This portion of ring levee system surrounding Locke is about 0.6 miles long and extends along a former railroad embankment from the Meadow Cross Slough Levee southwesterly to the boundary with RD 554. (The NULE Segment 1054 levee continues approximately 0.9 miles along the right bank of Snodgrass slough through RD 554.) 100-year and 1955/57 design profile WSEs are not available for the Snodgrass Slough levee.

Levee Construction History and Improvements

Most of the levees surrounding the community of Locke were initially constructed prior to 1906 by local interests and generally built using materials dredged from the adjacent rivers and sloughs and placed without compaction. The RD 369 levee along Snodgrass Slough was constructed prior to 1937 as part of a railroad embankment.

Between 1941 and 1955, USACE improved portions of the levees along the Sacramento River (NULE Segments 121 and 127) that did not meet USACE standards. Improvements consisted of levee reconstruction and bank protection work at multiple locations. Additional riverbank protection work was performed from 1965 to 1967, 1972 to 1974, and 1981 as part of the Sacramento River Bank Protection Project.

Levee Past Performance

Past performance is based primarily on the DWR NULE project information which was gathered through review of available documents and interviews with levee maintenance personnel. Reported past performance for the RD 369 and RD 554 Sacramento River levees protecting Locke is limited to records of erosion including slope caving, wavewash erosion, scouring, embankment slope failure, and toe failure of rock revetment. For the remainder of the RD 369 basin, the Non-SPFC levees along Meadows Slough and Meadows Cross Slough have reports of past seepage between 1949 and 1954.

2868 Prospect Park Drive, Suite 310
Rancho Cordova, CA 95670
916.631.4500 fax 916.631.4501

The report of seepage observed by landowners between 1949-1953 along the Meadows Slough levee (NULE Segment 1040, levee common with RD 551) was for seepage mapped on the Locke side of the levee, no other information is available. There were no identified records of past performance for the portion of the Snodgrass Slough levee protecting the community of Locke. Past performance is summarized in Table 1 and shown on Figure 2.

In 2012, DWR's Flood System Repair Project (FSRP) evaluated past performance records for non-urban SPFC levees through existing documentation and field reconnaissance and identified *critical* and *serious* sites for repair. The FSRP was designed to be consistent with the state system-wide investment approach of the Central Valley Flood Protection Plan (CVFPP), and the SPFC. The FSRP goal was to help prioritize funded system repair projects to focus on repair of damage or deficiencies that are critical, that have a potential to become critical, or that may impede flood fight capabilities. For the FSRP *critical* and *serious* past performance problems were generally defined as follows:

- *Critical* Past Performance Problem: If not repaired, the site presents a significant risk of failure or would impede flood control function or flood fight activities during the next highwater event.
- *Serious* Past Performance Problem: If not repaired in a timely manner, the site has the potential to become critical during the next high-water event.

The FSRP identified no sites along the levees surrounding Locke.

Most recently, a July 2018 DWR report titled "2017 Storm Damage – DWR Emergency Rehabilitation" (IFC, 2018) summarized DWR rehabilitation sites and USACE PL 84-99 sites resulting from 2017 storm damage. For DWR's review of the 2017 damage sites, they followed FSRP guidelines to identify sites as *critical* or *serious*. No *critical* or *serious* 2017 storm damage sites were identified along the levees surrounding the community of Locke. The report also notes identification of "area of concern" sites that did not rise to the level of *critical* or *serious*. Location information for these sites was not available from DWR at the time of this Memorandum. No USACE PL 84-99 sites from the 2017 storm damage were identified along the Locke levees.

Levee Freeboard and Geometry

The DWR NULE project freeboard review measured available freeboard against the 1955/57 design water surface profile for SPFC levees. For the Sacramento River levees protecting the community of Locke (NULE Segments 121 and 127) the NULE review found that a minimum of 3 feet of freeboard above the 1955/57 design profile was available throughout both segments. The levees along Meadow Slough, Meadows Cross Slough, and Snodgrass Slough (NULE Segments 1040 and 1054) do not have a 1955/57 design profile as they are Non-SPFC levees, and a freeboard review was not completed.

The DWR NULE project also reviewed and summarized NULE segment geometry based on Light Detection and Ranging (LiDAR) topography collected for DWR's Central Valley Floodplain Evaluation and Delineation (CVFED) between October 2008 and February 2009. Documented geometry information for the levees surrounding the community of Locke are summarized in Table 2.

Available Geotechnical Information

The DWR NULE project included an assessment (Phase 1 only) of the levees protecting the community of Locke. The NULE Phase 1 study included all the levees protecting Locke, but was based on non-intrusive studies and readily available data. No subsurface explorations were completed as a part of the NULE Phase 1 study. Assessment data such as historical reports, interviews with personnel, construction records, levee performance records, existing exploration records, and other data provided by relevant agencies was collected and reviewed for the study. Geomorphic studies and topographical surveys were also completed. This collection of information was used to characterize the existing condition of the Non-Urban levees in the NULE Geotechnical Assessment Report (GAR). NULE GAR segment specific write-ups for each of the segments protecting the community of Locke (NULE Segments 121, 127, 1040, and 1054) are attached in Appendix A.

More recently than the NULE data collection and review, DWR has conducted geotechnical borings in the Delta to obtain information for the proposed alignment of the water conveyance facilities associated with the Bay Delta Conservation Plan (BDCP), also referred to as California WaterFix. Data available for review is limited at this time and available subsurface information (log or profile data) did not include any explorations along the levees surrounding the community of Locke.

The available exploration data from the NULE document review is described below.

Geomorphic Setting

Geomorphology mapping developed for the DWR NULE project indicates the levees protecting the community of Locke primarily overlie recent overbank deposits (Rob) likely consisting of interbedded sand, silt, and clay deposited during high-stage flow, overtopping channel banks. A few localized areas of historical slough deposits (Rsl) are also present. The slough deposits are likely to consist of silt, clay, and trace sand, fining upward from low-energy tidally or formally tidally influenced channel deposits. Parts of the Meadows Cross Slough levee and the Snodgrass Slough levee in RD 369 are mapped over pleistocene eolian deposits (Qe) which are likely to contain poorly to moderately cemented sand and silt. Historical tidal marsh deposits (Rpm) are mapped on the waterside of the Meadow Cross Slough and Snodgrass Slough levees. For mapping and additional information, the technical memorandum for the geomorphology effort that cover this area is included in Appendix B.

Existing Subsurface Explorations

Based on review of existing subsurface data, there was one existing exploration identified along the approximately three miles of levee surrounding the community of Locke. The exploration was performed by Caltrans for the Delta Cross Channel Bridge seismic retrofit in 1997. The bridge extends from Locke at the southern end of NULE Segment 127 to West Walnut Grove. Three borings were completed along the bridge, one on each abutment and one at the channel center. The boring near Locke was approximately 60 feet deep and shows an embankment composed of silty clay to sand with silt and a foundation composed of a clayey blanket about 10 feet thick underlain by a sandy aquifer. The boring was not deep enough to identify the depth to a deeper aquiclude layer. Other existing exploration information may also be available near this southern end of the NULE Segment 127 levee from known explorations completed for the construction of the Delta Cross Channel, but exploration location information and logs were not located at this time.

Additionally, one landside toe boring was completed as part of the DWR's 1958 Salinity Control Barrier investigations in the northern corner of the NULE Segment 1040 Meadows Slough levee (that is common to RD 551 perimeter) and the RD 551 Sacramento River left bank levee, see Figure 2. The boring was approximately 40 feet deep and shows a silty blanket layer to approximately 20 feet below the landside ground surface underlain by a sandy aquifer. The boring was not deep enough to identify the depth to a deeper aquiclude layer. Available log information for both borings is limited stick profiles without detailed material descriptions. These available stick log profiles are included in Appendix C.

Understanding of Existing Geotechnical Conditions

The NULE GAR assessments were based on non-intrusive studies and readily available data as discussed above. More specifically, hazard indicators and levee performance history identified during the data review process were used as the basis for categorizing each levee segment. For each levee segment, hazard indicators were assessed for four potential failure mechanisms: underseepage, slope stability, through seepage, and erosion. Assessments were made based on information about levee and foundation composition, levee geometry, hydraulic head at the assessment WSE, and the presence of penetrations, ditches, and burrowing animal activity. These hazard indicators were then compared to a levee's performance history to categorize each geotechnical potential failure mode. The NULE GAR assessments were performed at a single WSE (assessment WSE). The assessment WSE was the 1955/57 design profile, where available. Otherwise assessments were performed for a water surface at 1.5 to 6 feet below the levee crest, depending on the levee location. For Delta levees where a 1955/57 design profile was not available, the assessment WSE was set at 1.5 feet below the levee crest.

Hazard categories were assigned for each of the four potential failure mechanisms (underseepage, slope stability, through seepage, and erosion) and then were evaluated collectively to assign an overall hazard level category to each NULE segment. The NULE GAR found NULE Segment 121 (RD 369) and NULE Segment 127 (RD 554) along Sacramento River, adjacent to Locke and north to Meadow Slough, to have a *low* likelihood of levee failure at the 1955/57 design WSE. Along the northern edge of the RD 369 basin the levee common with RD 551, NULE Segment 1040, was assessed to have a *moderate* likelihood of levee failure at the assessed WSE (assigned as 1.5 feet below levee crest) based on potential vulnerability to underseepage and stability. For the rest of the basin, the non-project levees along Meadows Cross Slough and Snodgrass Slough, NULE Segment 1054, were identified to be lacking sufficient data to fully assess the likelihood of levee failure at the assessed WSE (assigned as 1.5 feet below levee crest). Based on available site condition information, moderate to high underseepage, through seepage, and stability potential was identified for Segment 1054 but past performance documentation was not available to correlate these risks. Individual results for the four potential failure mechanisms are summarized in Table 3. More discussion of these results can be found in the GAR segment write-ups included in Appendix A. The railroad embankment beyond Snodgrass Slough (NULE Segment 1054), to the southeast of Locke was not evaluated in the NULE study.

Conclusions and Recommendations

Geotechnical understanding of the embankment and foundation will be critical to the evaluation of structural alternatives for the community of Locke. As discussed above, limited existing geotechnical information is available for the levees protecting this community. Further understanding of the subsurface conditions including the depth of the aquiclude layer will be critical in preventing conservative assumptions during evaluation of potential structural improvements. Therefore, additional subsurface explorations are recommended to complete the feasibility study. Site-specific geotechnical explorations will be outlined in a separate geotechnical investigation plan. The investigation program will include collection of soil samples and in-situ data, detailed descriptions of embankment and foundation conditions, and laboratory testing to support geotechnical evaluation and development of feasibility-level repair recommendations.

2868 Prospect Park Drive, Suite 310
Rancho Cordova, CA 95670
916.631.4500 fax 916.631.4501

References

California Department of Water Resources, 2017. *2017 Storm Damage Emergency Rehabilitation Program Summary (DWR Rehabilitation and USACE PL 84-99 Information).* July 26.

ICF International, 2016. *Final Environmental Impact Report/Environmental Impact Statement for the Bay Delta Conservation Plan/California WaterFix, Volume 1 Final EIR/EIS for the BDCP/California WaterFix, Chapter 9 – Geology and Seismicity.* Prepared by IFC International for California Department of Water Resources and U.S. Bureau of Reclamation. December. Accessed online: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/exhibit102/docs/vol1/

GEI Consultants, Inc. 2016. *Sacramento River Basin Channel Capacity Atlas.* Prepared by GEI Consultants for California Department of Water Resources (DWR). December.

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

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

URS Corporation. 2013. *2012 Levee Performance Problems Evaluation for Sacramento River Basin.* Flood Systems Repair Project. Prepared by URS for Department of Water Resources (DWR) Division of Flood Management. February.

2868 Prospect Park Drive, Suite 310
Rancho Cordova, CA 95670
916.631.4500 fax 916.631.4501

Tables

Figures

Appendices

Acronyms

BDCP	Bay Delta Conservation Plan
CVFED	Central Valley Floodplain Evaluation and Delineation
CVFPP	Central Valley Flood Protection Plan
DWR	California Department of Water Resources
FSRP	DWR's Flood System Repair Project
GAR	Geotechnical Assessment Report
LiDAR	Light Detection and Ranging
NAVD88	North American Vertical Datum of 1988
NULE	Non-Urban Levee Evaluation
RD	Reclamation District
RM	River Mile
SPFC	State Plan of Flood Control
USACE	United States Army Corps of Engineers
WSE	Water Surface Elevation

2868 Prospect Park Drive, Suite 310
Rancho Cordova, CA 95670
916.631.4500 fax 916.631.4501

Tables

2868 Prospect Park Drive, Suite 310
Rancho Cordova, CA 95670
916.631.4500 fax 916.631.4501

Table 1. Summary of Reported Past Performance - Levees Surrounding the Community of Locke

NULE Segment and Location	Flood Season	Reported Performance Description	Approximate Location (Levee Mile when available)	Mitigation
121 Left Bank Sacramento River RD 369 (SPFC levee)	1957	Slope caved: 6 to 24 feet above water surface. Caving to shoulder of levee at LM 0.52.	Locations between LM 0.09 - 0.12 and LM 0.53 - 0.59	None documented
	1957	Slope eroded to 3 feet high above water surface	LM 0.24 - 0.52	None documented
	1969	Erosion and sloughing along 1300 feet. Identified as area where the levee was in critical condition due to erosion.	LM 0.0 - 0.25	Recommended for Repair
	1969	Dormant bank caving over 400 feet	LM 0.3 - 0.38	Recommended for Repair
	1969	Active caving over 500 feet (continues into Segment 127)	LM 0.72 - 0.8	Recommended for Repair
	1991	Wavewash erosion along waterside slope above rock reventment	LM 0.24 - 0.52	None documented
	1997	Erosion along levee toe 100 feet in length with 3 foot vertical face. Flood Damage Inspection Report indicates a beaver hole in the bank at the downstream end of the eroded area.	LM 0.40 - 0.43	None documented
	1998	Toe failure of the rock revetment with a 2 to 3 foot vertical face above water surface.	LM 0.32 - 0.36	None documented
127 Left Bank Sacramento River RD 554 (SPFC levee)	1969	Active caving over 500 feet (primarily in Segment 121)	LM 0.0 - 0.05	Recommended for Repair
	1997	Erosion - Scouring, embankment slope failure	LM 0.1	None documented

Table 1. Summary of Reported Past Performance - Levees Surrounding the Community of Locke

NULE Segment and Location	Flood Season	Reported Performance Description	Approximate Location (Levee Mile when available)	Mitigation
1040 Right Bank Meadows Slough RD 551/369 (Non-SPFC levee)	1949-1953	Seepage observed by landowners	Reported on RD 369 basin side along easterly 0.6 miles of segment	None documented
1054 Right Bank Meadows Cross Slough and Right Bank Snodgrass Slough RD 369 & RD 554 (Non-SPFC levee)	1954	Seepage indicated on aerial photographs	Reported within RD 369 extents along approximately northerly 0.4 miles of segment	None documented

Table 2. Summary of Levee Geometry[1] - Levees Surrounding the Community of Locke

NULE Segment	Segment Location	Approximate Levee Height	Approximate Crest Width	Approximate Landside Slopes	Approximate Waterside Slopes
121	Left Bank Sacramento River - RD 369 (SPFC levee)	12 to 13 feet above the landside toe	40 to 55 feet	1.8H:1V to 2.7H:1V	1.6H:1V to 2.5H:1V
127	Left Bank Sacramento River - RD 554 (SPFC levee)	12 to 14 feet above the landside toe	80 to greater than 100 feet	1.8H:1V to 3H:1V	1.3H:1V to 2.3H:1V
1040[2]	Right Bank Meadows Slough RD 551/RD 369 (Non-SPFC levee)	16 to 27 feet above the landside toe	10 to 15 feet	4.5H:1V to 6H:1V	3H:1V to 4H:1V
1054[2]	Right Bank Meadows Cross Slough and Right Bank Snodgrass Slough RD 369 & RD 554 (Non-SPFC levee)	14 to 19 feet above the landside toe, though some locations range from 7 to 14 feet	15 to 40 feet	1.7H:1V to 4H:1V	2.5H:1V to 3H:1V

[1] Based on summaries provided in NULE Geotechnical Assessment Report

Table 3. Summary of NULE GAR Assessment Results - Levees Surrounding the Community of Locke

NULE Segment	Segment Location	Assessment WSE	Overall Segment Categorization[1]	Results by Individual Failure Mechanism			
				Underseepage[2]	Slope Stability[2]	Through Seepage[2]	Erosion[2]
121	Left Bank Sacramento River - RD 369 (SPFC levee)	1957 Design WSE	Low	Low	Low	Low	Low
127	Left Bank Sacramento River - RD 554 (SPFC levee)	1957 Design WSE	Low	Low	Low	Low	Low
1040[4]	Right Bank Meadows Slough RD 551/RD 369 (Non-SPFC levee)	1.5 feet below levee crest	Moderate	Moderate	Lacking Sufficient Data (Low to Moderate)[3]	Low	Low
1054[4]	Right Bank Meadows Cross Slough and Right Bank Snodgrass Slough RD 369 & RD 554 (Non-SPFC levee)	1.5 feet below levee crest	Lacking Sufficient Data (Moderate to High)[3]	Lacking Sufficient Data (Moderate to High)[3]	Lacking Sufficient Data (Moderate to High)[3]	Lacking Sufficient Data (Moderate to High)[3]	Low

[1] As part of the NULE GAR, hazard categories for each of the four potential failure mechanisms were evaluated collectively to assign an overall hazard level category to each segment.

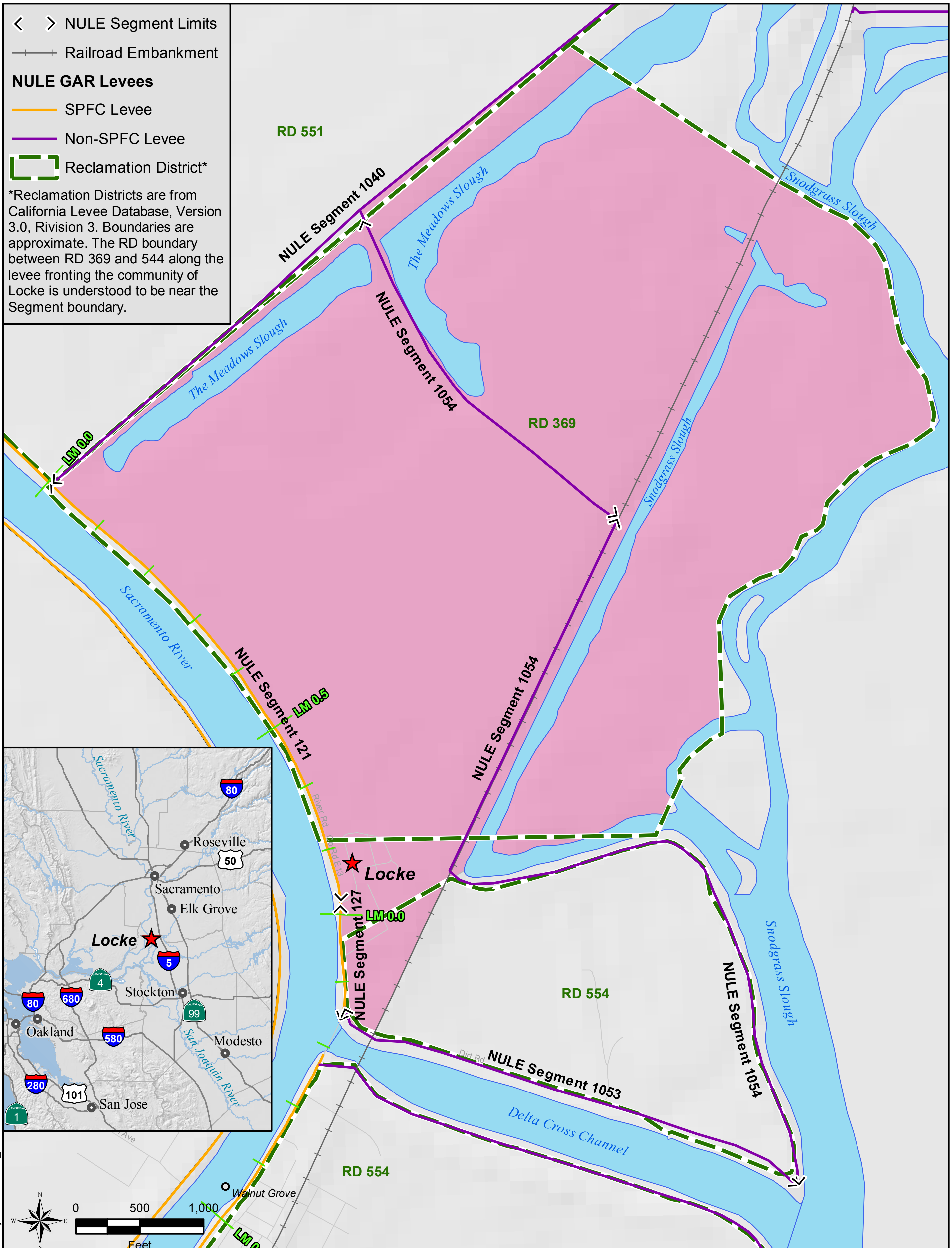
[2] Likelihood of either levee failure or the need to flood-fight to prevent levee failure when the water reaches the assessment WSE.

[3] The segment was lacking sufficient data about past performance or hazard indicators to assign a hazard level, or there was poor correlation between past performance and hazard indicator scores.

[4] NULE segment extends beyond RD 369, NULE assessment for segment as a whole

Figures

2868 Prospect Park Drive, Suite 310
Rancho Cordova, CA 95670
916.631.4500 fax 916.631.4501



Small Communities
Flood Risk Reduction Program

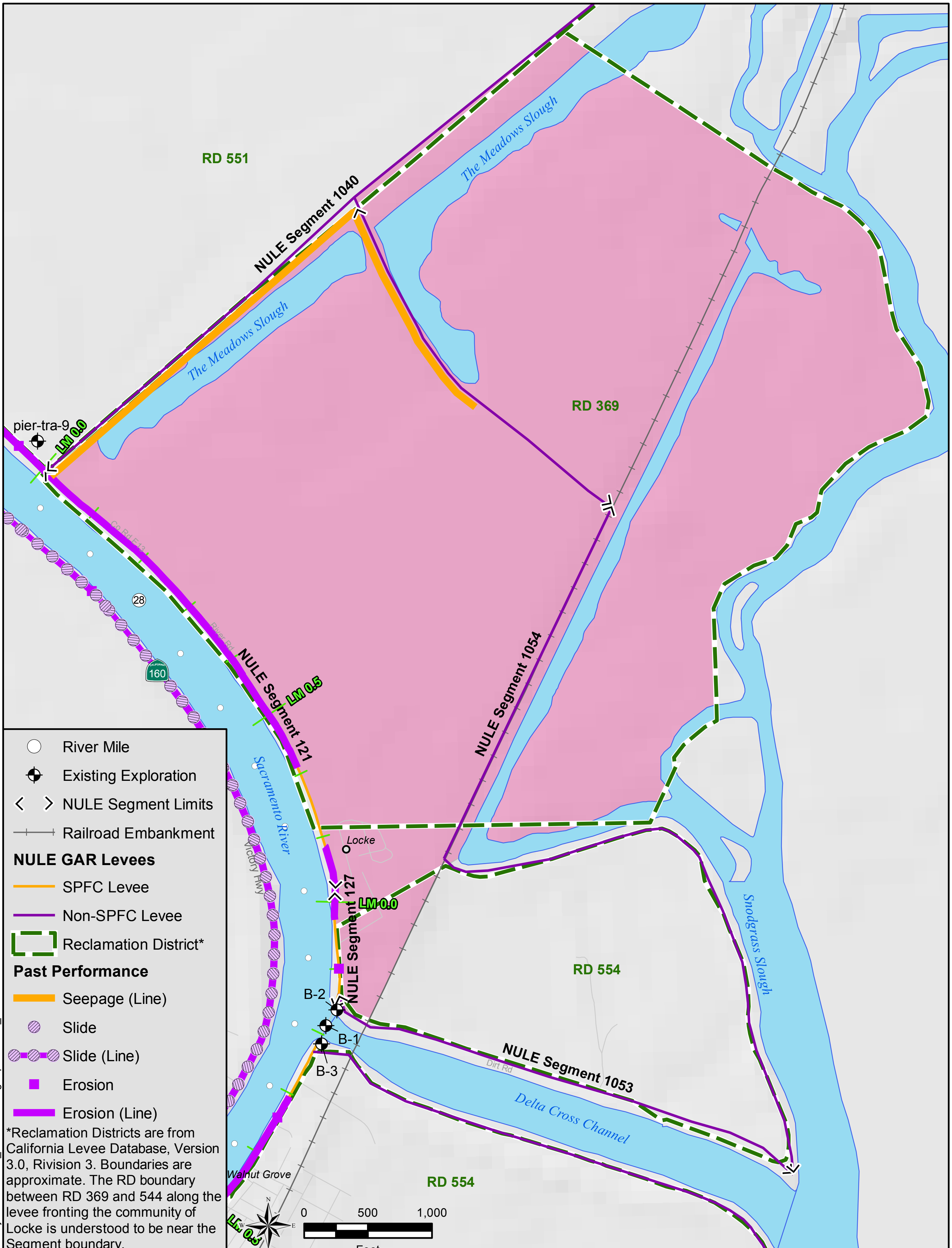
County of Sacramento

GEI Consultants

COMMUNITY OF LOCKE

MAY 2018

FIGURE 1



15-May-2018 Z:\Projects\1800778_Locke\ExistingExplorations_PastPerformance.mxd KLM

Small Communities Flood Risk Reduction Program	GEI Consultants	EXISTING EXPLORATIONS AND PAST PERFORMANCE
County of Sacramento		MAY 2018 — FIGURE 2

Appendix A

NULE GAR Segment Write-Ups

2868 Prospect Park Drive, Suite 310
Rancho Cordova, CA 95670
916.631.4500 fax 916.631.4501

RD 0369, UNIT 1, SEGMENT 121 SUMMARY

This segment summary presents collected information and the assessment results for Segment 121. 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 121: Segment Description and Assessment Summary

Segment 121 is a non-urban Project levee located on the right (east) bank of the Sacramento River in Sacramento County, California. The segment extends from the Meadows Slough southward to Levee Road, which is located 0.2 miles north of the Delta Cross Canal. The following table summarizes information for Segment 121.

Segment 121 Information

Maintenance Authority	Unit	Levee Miles*	NULE Stationing*
RD 0369	1	0 to 0.8	Sacramento River Left Bank 2515+49 to 2556+52

* 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 categorizations for each potential failure mode for Segment 121.

Segment 121 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 121 is Hazard Level A.

Segment 121: 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 historic topographic maps (Courtland, 1:62,500), the Segment 121 levee was 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 in 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 121.

Segment 121 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 121 include erosion reported in 1997 and 1998. There are no documented reports of underseepage, through seepage, or slope instability. The following table summarizes reported performance events.

Segment 121 Reported Levee Performance Events

Flood Season	Reported Performance Event	Approximate Location (Levee Mile)	Mitigation
1955	Wave wash erosion (Doc-3113)	0.24 – 0.52	Mitigated with revetment (Doc-3113).
1997	Erosion along levee toe (Doc-256)	0.40 – 0.43	Mitigation not documented.
1998	Toe failure of the rock revetment on the waterside (Doc-1540)	0.32 – 0.36	Mitigation not documented.

Underseepage

Although documented seepage events were not found for Segment 121, the CLD lists a relief well at LM 0.08. Relief wells are typically installed in areas of underseepage. Details of the relief well were not found.

Improvements

Improvements include riverbank protection work performed under the Sacramento River Bank Protection Project Phase 1 (SRBPP) from 1965 to 1967 and from 1972 to 1974, and during Phase 2 in 1981 (Doc-8587). The completed riverbank protection work included placement of revetment at multiple locations along the segment.

Planned Improvements

Based on the documents reviewed, no improvements to Segment 121 are currently planned.

Segment 121: 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 121 levee heights range from approximately 12 to 13 feet above the landside toe. Including the rounded shoulders, the crest width ranges from approximately 40 to 55 feet. LiDAR survey data indicate the landside slopes are approximately 1.8H:1V to 2.7H:1V. The waterside slopes are approximately 1.6H:1V to 2.5H:1V.

Penetrations

According to the DWR Pipe Inventory, 6 pipes penetrate the levee segment. Pipe diameters range from 4 to 12 inches. The pipes are approximately 4 to 8 feet below the levee crown.

Animal Activity

A beaver hole was documented downstream of an erosion site at LM 0.43 in 1997 (Doc-256). Animal persistence based on data from DWR is “none documented.”

Maintenance

The DWR assessments performed in the fall of 2008 on Segment 121 indicate that DWR rates levee maintenance as unacceptable (U).

Other Features

Buildings on the outskirts of Walnut Grove are located at the landside slope of Segment 121 between LM 0.0 to LM 0.1 and between LM 0.65 to LM 0.8.

Segment 121: 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 121.

In Segment 121, the levee foundations consist of silt and clay with interbedded layers of sand and gravel, and the levees consist of sand and some silt.

Geomorphic Setting

Segment 121 is in the Sacramento Valley flood basin. Geomorphology Level 2-II mapping indicates the Segment 121 levee overlies recent overbank deposits 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. The Level 2-II mapping also indicates that recent slough deposits (silt, clay, and sand) underlie the segment at LM 0.25.

Geotechnical Investigations

Geotechnical investigations for Segment 121 previously performed by others were not found. There are seven borings located along adjacent levee segments within the same geomorphic setting that may be indicative of the levee and foundation conditions for Segment 121. 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, and the other five were drilled near the landside levee toe. These borings range in depth from 14 to 80 feet. The stick logs of these borings indicate that the soil encountered in the levee prism consists mostly of sand and some silt, and that the soil in the foundation consists of 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 that are indicated 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 121: Geotechnical Assessment Results

The overall categorization for Segment 121 is Hazard Level A. As discussed in Volume 1, Section 2 of this report, this 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 is 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 121 Underseepage Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	Minimum Credible	Maximum Credible	Best Estimate	Minimum Credible	Maximum Credible	
56	55	56	None documented	None documented	None documented	Hazard Level A

Although the levee foundation materials (overbank deposits of silt, sand and clay) with high to very high underseepage susceptibility suggest that underseepage could occur the levee section is wide for the differential head between the assessment water surface elevation and the levee toe making underseepage less likely to occur. Segment 121 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 121 Stability Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	Minimum Credible	Maximum Credible	Best Estimate	Minimum Credible	Maximum Credible	
36	26	36	None documented	None documented	None documented	Hazard Level A

Hazard indicators that suggest that levee instability is less likely to occur include moderate levee height of 12 to 13 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 121 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 121 Through Seepage Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	Minimum Credible	Maximum Credible	Best Estimate	Minimum Credible	Maximum Credible	
50	30	50	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 121 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 121 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 wide.

Segment 121: Other Levee Assessments

Freeboard

Data from the LiDAR survey indicate that the levee crest for Segment 121 is above the 1955/57 WSE. A minimum freeboard of 3 feet is present throughout the segment.

Overtopping

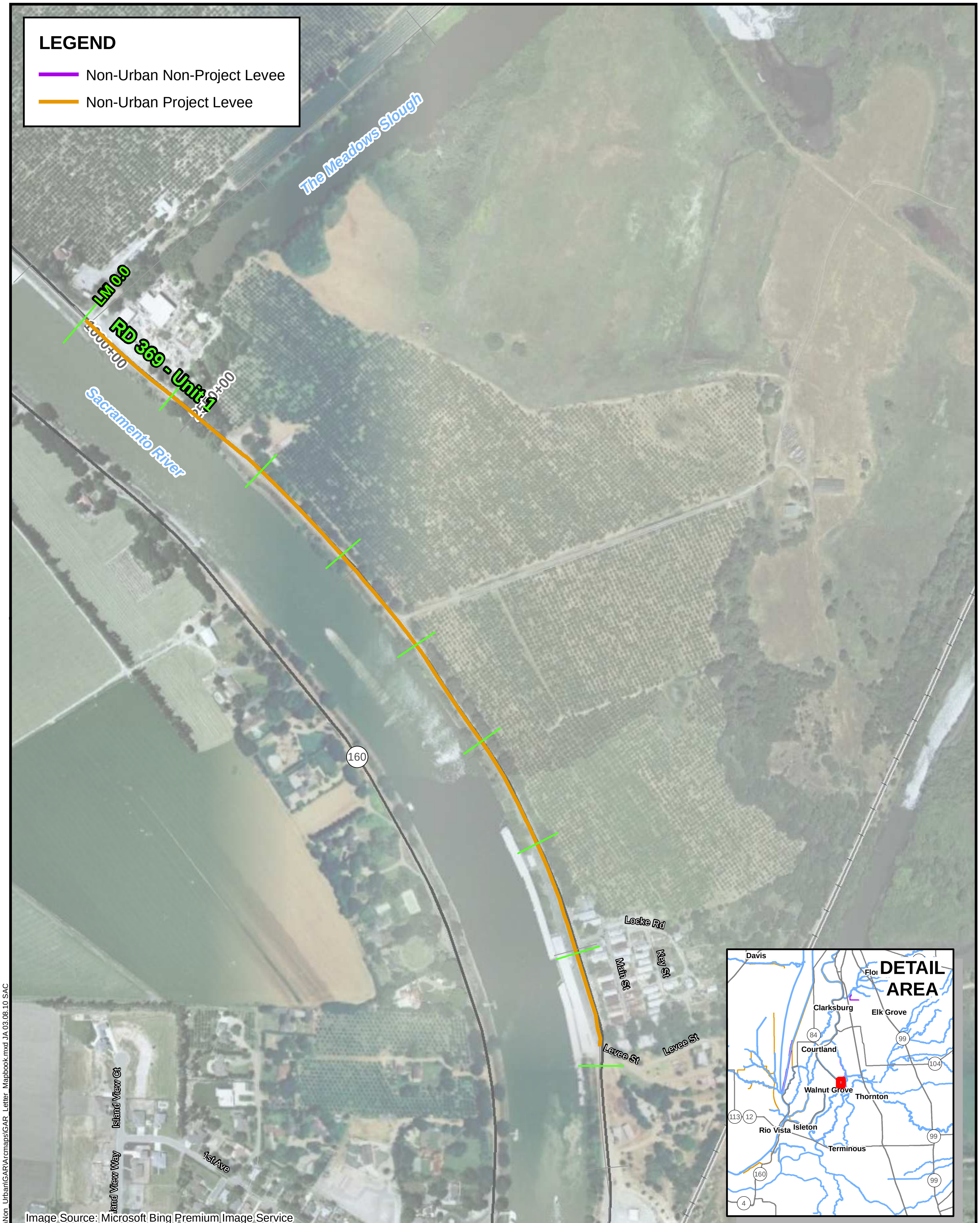
Overtopping was considered based only on past performance. Evaluation of flood flows, flood elevations, channel capacities, and other factors influencing overtopping risk is beyond the scope of the NULE Project. These factors should be studied by others to evaluate the overtopping risk to the NULE levees.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

Geometry

Using the LiDAR data, the levee geometry was compared with a standard levee prism defined by the Segment 121 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 121, 100 percent of the levee meets the standard levee prism.

Segment 121: Hazard Mitigation

No hazards were identified for Segment 121.



0 300 600

Feet

N

Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

URS

Segment 121

RD 0369

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)

				Begin	End
Levee Segment Name:	RD 0369		NULE Station (ft):	2515+49	2556+52
Levee Segment Number:	121		Levee Mile:	0	0.8
Brief Description of Segment/Reach:	RD 0369 - Libby - McNeil		Segment/Reach Length:	0.8 (miles)	4103 (feet)
			Crest Width Design Criterion (ft):	20	
Local Maintenance Authority:	RD 0369		Design Guidance Document:	1953 MOU	
Freeboard Evaluation Criterion (ft):	3				
Water Side Slope Design Criterion:	3H : 1V	Enter Other Criterion	Project or Non-Project Levee?	Project	
Land Side Slope Design Criterion:	2H : 1V	Enter Other Criterion			
North or South NULE?	North				

LEVEE CONSTRUCTION

Describe what is known about construction of this levee segment:	Based on historic topographic maps (Courtland, 1:62,500), the Segment 121 levee was 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 in 1954 and 1955 (Doc-2116). The improvements included levee construction and bank protection. The locations of the improvements 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*	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 1955, 1997, 1998 and 2009.					
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*		*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	*5 - Very high*	*4 - High*	*5 - Very 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 ; A beaver hole was documented at the downstream of an erosion site at LM 0.43 in 1997 (Doc-256).
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:**	6 pipes ranging in size from 4 to 12 inches in diameter and between 4 and 8 feet below the levee crest. 5 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	2540+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)	22.5					
Levee toe elevation (landside) (ft)	10					
Levee crest width (ft)	43	1				
Evaluation water elevation (ft)	17.4					
Levee slope - landside (xH : 1V); **Enter x**	2	3				
Levee slope - waterside (xH : 1V); **Enter x**	1.63					
Freeboard above evaluation flood elevation (ft) (= levee crest elevation - evaluation water elevation)	5.1					
Levee height (ft) (= levee crest elevation - landside toe elevation)	12.5	3				
Levee prism base width (ft)	88.4					
Head (ft) (= evaluation water level - landside toe elevation)	7.4	2				
Head-to-base-width ratio (= head / base width)	0.084	2				
Base-width to head ratio (= base width / head)	12					

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

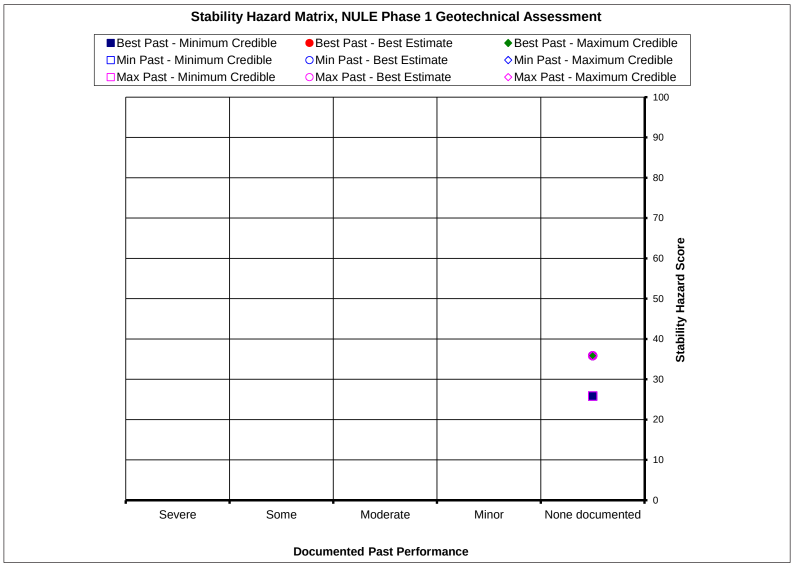
Existing constructed mitigation (List all)	Improvements include riverbank protection work performed under the Sacramento River Bank Protection Project (SRBPP). Under the SRBPP, the levee was resloped and revetment was placed from LM 0.24 to LM 0.52 in 1955 (Doc-3113), revetment was placed along approximately 930 feet at LM 0.12 (RM 28.1) in 1976 (Doc-4529) and along approximately 890 feet at LM 0.15 (RM 27.8) 1981.
Has there been a past breach?	None Identified
If yes, describe nature of the breach and how it has been mitigated?	

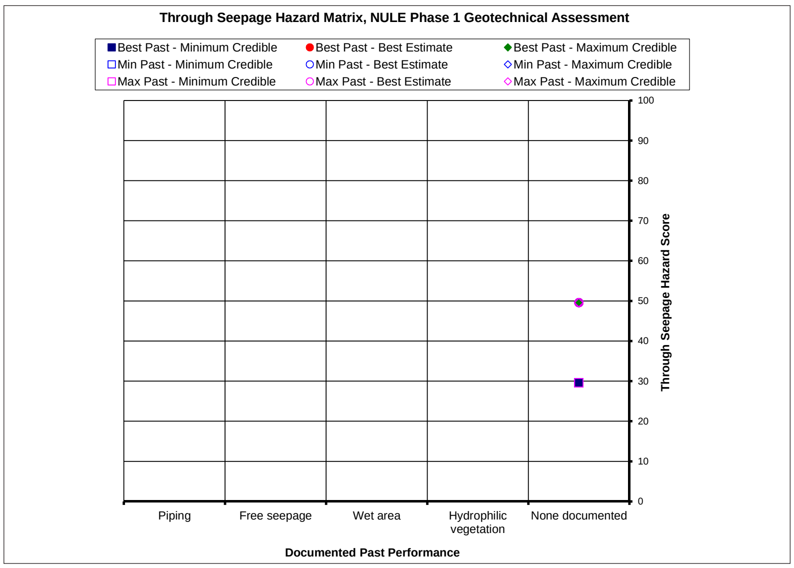
SUMMARY

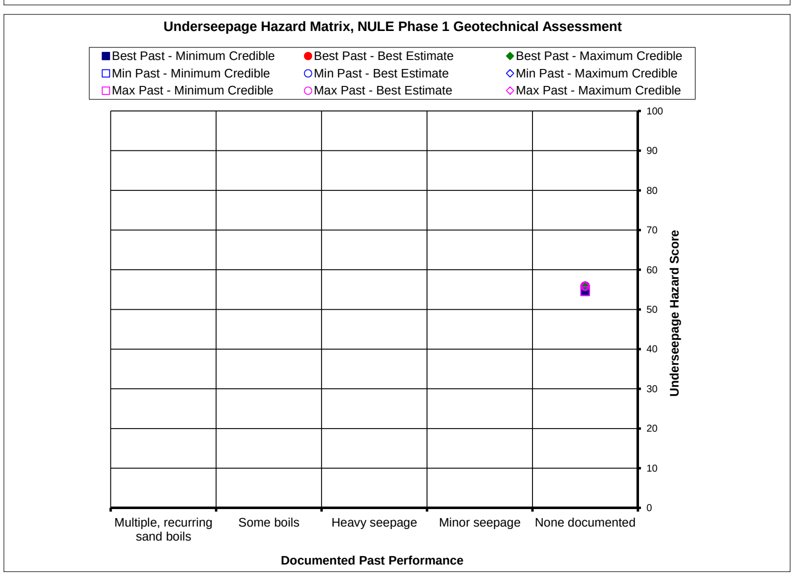
Failure Mode	Weighted Hazard Indicator Score (Best)	Weighted Hazard Indicator Score (Minimum Credible)	Weighted Hazard Indicator Score (Maximum Credible)	Past performance issues?	Are past performance and Weighted Hazard Indicator Score consistent?	Levee categorization
Underseepage	**56**	55	56	None documented	Yes	***Hazard Level A***
Justification:	Segment 121 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:	Confirm presence, purpose and condition of relief well within the segment with RD.					
Stability	**36**	26	36	None documented	Yes	***Hazard Level A***
Justification:	Segment 121 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	**50**	30	50	None documented	Yes	***Hazard Level A***
Justification:	Segment 121 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 121 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 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
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
100
90
80
70
60
50
40
30
20
10
0
Stability Hazard Score
Severe
Some
Moderate
Minor
None documented
Documented Past Performance


Through Seepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
100
90
80
70
60
50
40
30
20
10
0
Through Seepage Hazard Score
Piping
Free seepage
Wet area
Hydrophilic vegetation
None documented
Documented Past Performance


Underseepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
100
90
80
70
60
50
40
30
20
10
0
Underseepage Hazard Score
Multiple, recurring sand boils
Some boils
Heavy seepage
Minor seepage
None documented
Documented Past Performance

RD 0554, UNIT 1, SEGMENT 127 SUMMARY

This segment summary presents collected information and the assessment results for Segment 127. 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 127: Segment Description and Assessment Summary

Segment 127 is a non-urban Project levee located on the left (east) bank of the Sacramento River in Sacramento County, California (see attached map). The segment extends from Levee Road 0.2 miles north of the Delta Cross Canal southward to the confluence of the Delta Cross Canal and the Sacramento River. The following table summarizes information for Segment 127.

Segment 127 Information

Maintenance Authority	Unit	Levee Miles*	NULE Stationing*
RD 0554	1	0 to 0.2	Sacramento River Left Bank 2506+08 to 2515+48

* 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 127 categorizations for each potential failure mode.

Segment 127 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 127 is Hazard Level A.

Segment 127: 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 127 levees were initially constructed prior to 1906 by local interests. Specific documentation of the construction methods for the levees were not available. Portions of the levee that did not meet Project standards were improved by the USACE to Project standards in 1941 and between 1954 and 1955 (Doc-2116). The improvements included levee construction and bank protection. The location of the improvements was not available. The following table presents the 1953 MOU geometric criteria for Segment 127.

Segment 127 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 127 include a single erosion site reported during the 1997 flood season, but no documented reports of underseepage, through seepage, or slope instability. The following table summarizes reported performance events.

Segment 127 Reported Levee Performance Events

Flood Season	Reported Performance Event	Approximate Location (Levee Mile)	Mitigation
1997	Erosion - Scouring, embankment slope failure (Doc-256)	0.10	Mitigation not documented.

Improvements

Improvements to Segment 127 include placement of revetment along the entire length of the segment (Doc-4261). The placement of revetment between LM 0.00 to LM 0.09 was completed in 1976 by the USACE (Doc-4261).

Planned Improvements

Based on the documents reviewed, no improvements to Segment 127 are currently planned.

Segment 127: 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 127 levee heights range from approximately 12 to 14 feet above the landside toe. Including the rounded shoulders, crest widths range from approximately 80 to greater than 100 feet. LiDAR survey data indicate that the landside slopes are approximately 1.8H:1V to greater than 3H:1V. The waterside slopes are approximately 1.3H:1V to 2.3H:1V.

Penetrations

According to the DWR Pipe Inventory, one pipe penetrates the levee segment at an unknown depth below the levee crown. The pipe diameter is 4 inches.

Animal Activity

No animal activity was 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 Segment 127.

Other Features

The Delta Cross Canal Bridge is at the south end of the segment. Two buildings in Segment 127 are located on the levee crest.

Segment 127: Levee Composition and Foundation Conditions

The NULE team established an understanding of the 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 127.

In Segment 127, the levee foundations consist of silt and clay with interbedded layers of sand and gravel, and the levees consist of sand and some silt.

Geomorphic Setting

Segment 127 is in the Sacramento Valley flood basin. Geomorphology Level 2-II mapping indicates the Segment 127 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 127 were not found. Seven borings located along adjacent levee segments within the same geomorphic setting may be indicative of the levee and foundation conditions for Segment 127. 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, while the other five were drilled near the landside levee toe. The seven borings range in depth from 14 to 80 feet. The stick logs of these borings indicate that the soil in the levee prism consists mostly of sand and some silt, and that the soil in the foundation consists of 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 127: Geotechnical Assessment Results

The overall Segment 127 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 127 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 127 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 127 Stability Assessment Results*

WHIS			Performance Summary			Categorization
Best Estimate	**Minimum Credible**	**Maximum Credible**	**Best Estimate**	**Minimum Credible**	**Maximum Credible**	
41	31	41	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 12 to 14 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 127 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 127 Through Seepage Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	**Minimum Credible**	**Maximum Credible**	**Best Estimate**	**Minimum Credible**	**Maximum Credible**	
40	20	40	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 low number of levee penetrations. Segment 127 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 127 is categorized as Hazard Level A for erosion because the single erosion event in the segment during the 1997 flood season was minor and did not impact the levee crown and there were no erosion events documented during the 1998 flood season. In addition, the levee section is very wide.

Segment 127: Other Levee Assessments

Freeboard

Data from the LiDAR survey indicate that the levee crest for Segment 127 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 127 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 127, 100 percent of the levee meets the standard levee prism.

Segment 127: Hazard Mitigation

No hazards were identified for this segment.

0 150 300
Feet

N

Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

URS

Segment 127

RD 0554 - North 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)

			Begin	End
Levee Segment Name:	RD 0554 - north portion	NULE Station (ft):	2506+08	2515+48
Levee Segment Number:	127	Levee Mile:	0	0.2
Brief Description of Segment/Reach:	RD 0554 - Walnut Grove - north of Delta Cross Channel	Segment/Reach Length:	0.2 (miles)	940 (feet)
		Crest Width Design Criterion (ft):	20	
Local Maintenance Authority:	RD 0554	Design Guidance Document:	1953 MOU	
Freeboard Evaluation Criterion (ft):	3			
Water Side Slope Design Criterion:	3H : 1V	Enter Other Criterion	Project or Non-Project Levee?	Project
Land Side Slope Design Criterion:	2H : 1V	Enter Other Criterion		
North or South NULE?	North			

LEVEE CONSTRUCTION

Describe what is known about construction of this levee segment:	Based on historical topographic maps (Isleton, 1:31,680), the Segment 127 levees were initially constructed prior to 1906 by local interests. Specific documentation of the construction methods for the levees were not available. Portions of the levee that did not meet Project standards were improved by the USACE to Project standards in 1941 and 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:**	One rotational embankment failure probably on the waterside occurred in 1997 (CLD)

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:	2 - Fewer than 5	**Notes:**	1 pipe 4 inches in diameter and an unknown distance below the levee crest. The pipe is assumed to be 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	2510+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)	24					
Levee toe elevation (landside) (ft)	11					
Levee crest width (ft)	102	1				
Evaluation water elevation (ft)	17					
Levee slope - landside (xH : 1V); **Enter x**	1.7	4				
Levee slope - waterside (xH : 1V); **Enter x**	1.33					
Freeboard above evaluation flood elevation (ft) (= levee crest elevation - evaluation water elevation)	7.0					
Levee height (ft) (= levee crest elevation - landside toe elevation)	13.0	3				
Levee prism base width (ft)	141.4					
Head (ft) (= evaluation water level - landside toe elevation)	6.0	2				
Head-to-base-width ratio (= head / base width)	0.042	1				
Base-width to head ratio (= base width / head)	24					

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

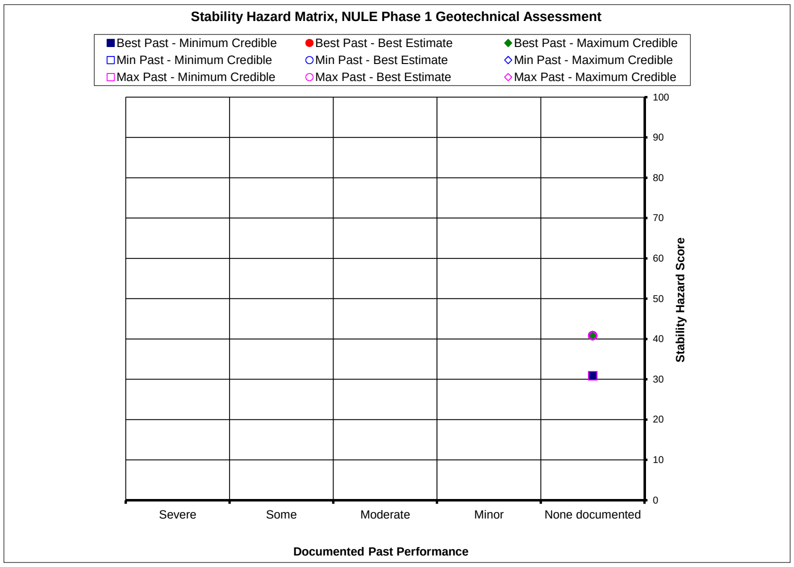
Existing constructed mitigation (List all)	Placement of revetment along the entire length of the segment (Doc-4261); The placement of revetment between LM 0.00 to LM 0.09 was completed in 1976 by USACE (Doc-4261).
Has there been a past breach?	None Identified
If yes, describe nature of the breach and how it has been mitigated?	

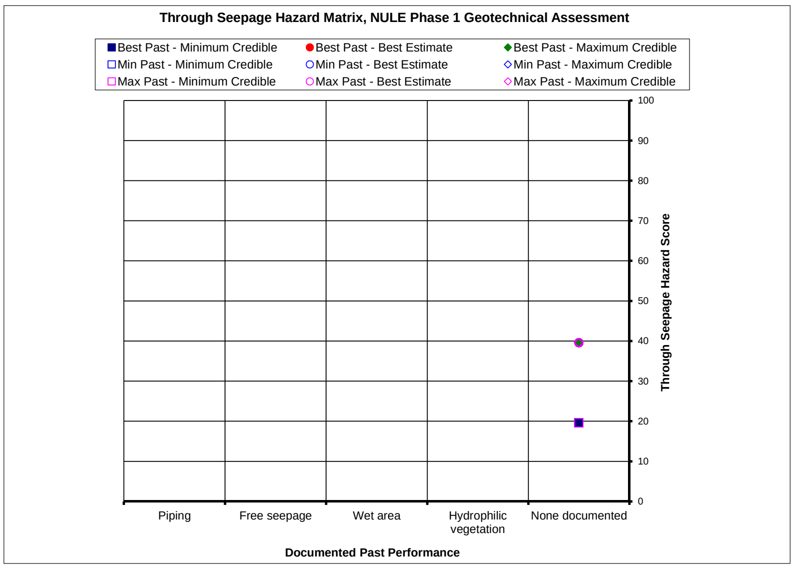
SUMMARY

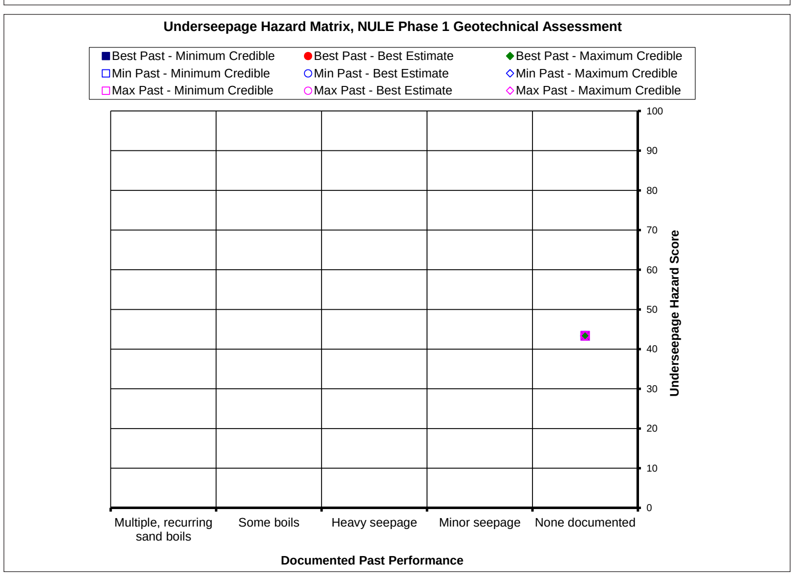
Failure Mode	Weighted Hazard Indicator Score (Best)	Weighted Hazard Indicator Score (Minimum Credible)	Weighted Hazard Indicator Score (Maximum Credible)	Past performance issues?	Are past performance and Weighted Hazard Indicator Score consistent?	Levee categorization
Underseepage	**44**	44	44	None documented	Yes	***Hazard Level A***
Justification:	Segment 127 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:	Confirm presence, purpose and condition of relief well at LM 0.12 with RD.					
Stability	**41**	31	41	None documented	Yes	***Hazard Level A***
Justification:	Segment 127 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	**40**	20	40	None documented	Yes	***Hazard Level A***
Justification:	Segment 127 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 127 is categorized as Hazard Level A for erosion because the single erosion event in the segment during the 1997 flood season was minor and did not impact the levee crown and there were no erosion events documented during the 1998 flood season. 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
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
100
90
80
70
60
50
40
30
20
10
0
Stability Hazard Score
Severe
Some
Moderate
Minor
None documented
Documented Past Performance


Through Seepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
100
90
80
70
60
50
40
30
20
10
0
Through Seepage Hazard Score
Piping
Free seepage
Wet area
Hydrophilic vegetation
None documented
Documented Past Performance


Underseepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
100
90
80
70
60
50
40
30
20
10
0
Underseepage Hazard Score
Multiple, recurring sand boils
Some boils
Heavy seepage
Minor seepage
None documented
Documented Past Performance

RD 0551, SEGMENT 1040 SUMMARY

This segment summary presents collected information and the assessment results for Segment 1040. The summary is based on data that were readily available 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 1040: Segment Description and Assessment Summary

Segment 1040 is a non-urban, non-Project levee located on the right (north) bank of the Meadows Slough in Sacramento County, California (see attached map). The segment extends from the intersection of the Snodgrass Slough and the Meadows Slough westward to the intersection of the Meadows Slough and the Sacramento River. The following table summarizes segment information.

Segment 1040 Information

Maintenance Authority	Unit	Levee Miles*	NULE Stationing*
RD 0551	—	0 to 1.4	The Meadows Slough Right Bank 1000+00 to 1073+00

* The levee mile and stationing alignments differ.

As directed by DWR, the segment was assessed for each potential failure mode with water at an elevation 1.5 feet below the levee crest. It is our understanding from interviews with the RD (Doc-8314 and locals meeting held on April 14, 2010) that the levee is significantly higher than flood levels and as such the water surface elevation used in the assessment may be overstated. The following table presents the Segment 1040 categorizations for each potential failure mode.

Segment 1040 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 A

Based on these NULE Phase 1 levee assessments for Segment 309, through seepage and erosion are categorized as Hazard Level A, underseepage is categorized as Hazard Level B, and stability is categorized as Hazard Level LD. 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 1040: 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 historic topographic maps (Courtland, 1:62,500) (Doc-8590), the Segment 1040 levee was initially constructed prior to 1906 by local interests. The RD 0551 1919 Plan of Reclamation indicates that Segment 1040 was likely constructed using materials dredged from the adjacent Meadows Slough, and presents the plan for raising and enlarging the levee using similar methods (Doc-5232). The plan indicated the levee was to be constructed with a crest width of 9 feet, a waterside slope of 3H:1V and a landside slope of 5H:1V. The following table presents the 1953 MOU geometric criteria for Segment 1040.

Segment 1040 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 RD 0551 maintenance personnel (Doc-8314). Based on the available information, performance events in Segment 1040 include underseepage. The following table summarizes reported performance events.

Segment 1040 Reported Levee Performance Events

Flood Season	Reported Performance Event	Approximate Location (Station)	Mitigation
1949–1953	Seepage observed by landowners (Doc-914).	1055+00 to 1073+00	Mitigation not indicated.

Improvements

Documentation of improvements to the levee since initial construction were not available.

Planned Improvements

Based on the URS review, no improvements to Segment 1040 are currently planned.

Segment 1040: 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 1040 levee heights range from approximately 16 to 27 feet above the landside toe. The height gradually increases from about 16 feet near Station 1000+00 to about 27 feet near Station 1055+00 and then decreases to 24 feet near the end at Snodgrass Slough. Including the rounded shoulders, crest width ranges from approximately 10 to 15 feet. LiDAR survey data indicate the landside slopes are approximately 4.5H:1V to 6H:1V. The waterside slopes are approximately 3H:1V to 4H:1V.

Penetrations

Information regarding penetrations through the levee segment was not available.

Animal Activity

Animal activity was not reported in the reviewed documents. Animal persistence based on data from DWR is not available for Segment 1040.

Maintenance

DWR assessments were not available for Segment 1040.

Other Features

Segment 1040 has four ditches that do not run parallel to the levee. The ditches are located near NULE Stations 1025+50, 1032+50, 1038+50 and 1058+00.

Segment 1040: 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 1040.

In Segment 1040, the levee foundation consists of silt underlain by sand in the western half and is underlain by clay and possibly peat in the eastern half. The levee may be primarily silt with some sand at the west end, becoming more clayey to possibly peaty towards the east.

Geomorphic Setting

According to the Level 2-I mapping, Segment 1040 is in the Sacramento River floodplain and natural levees domain (SR). The natural levee deposits that underlie the western end of the segment are interbedded sand, silt, and clay and may have layers from 2 to 5 feet thick that are probably laterally discontinuous along the levee. The sediments comprising the floodplain deposits underlying the eastern end of the segment consist of clay, silt, and possibly peat. Recent, more detailed Level 2-II mapping is generally consistent with Level 2-I mapping along Segment 1040 except that the Level 2-II mapping indicates that Segment 1040 foundation soils are recent overbank deposits (silt, clay, and lesser sand) that may overlie the flood basin deposits. A recent crevasse splay deposit (fine sand with silt and clay) is mapped from Station 1014+00 to 1030+00. Marsh deposits are mapped on the waterside of the segment from Station 1032+00 to the end of the Level 2-II mapping area near Station 1058+00.

Geotechnical Investigations

Geotechnical investigations for Segment 1040 performed by others include one boring in the DWR Salinity Control Barrier Study (1958) (Doc-8306). This boring was drilled near the landside levee toe to a depth of about 40 feet at the western end of the segment. The boring's stick log indicates that the soil encountered in the foundation consists of silt underlain by sand.

Other Subsurface Information

The NRCS USCS soil map indicates the existing levee overlies fine-grained (CH) surface soils. The NRCS USCS map does not indicate the variation of soil types that is indicated in the Level 2-II mapping or that was found in the borings.

Levee Composition

The available data indicate that the Segment 1040 levee may be primarily silt with some sand at the west end, becoming more clayey to possibly peaty towards the east.

Segment 1040: Geotechnical Assessment Results

The overall Segment 1040 categorization is Hazard Level B. As discussed in Volume 1, Section 2 of this report, the overall assessment is based on the individual potential failure mode categorizations. For this segment, through seepage and erosion are categorized as Hazard Level A, underseepage is categorized as Hazard Level B, and stability is categorized as Hazard Level LD. 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 summary of the LAT results and the matrix plots are attached.

A Weighted Hazard Indicator Score was calculated for each potential failure mode at the assessment water surface elevation, the top of levee less 1.5 feet. It is our understanding from interviews with the RD (Doc-8314 and locals meeting held on April 14, 2010) that the levee is significantly higher than flood levels and as such the water surface elevation used in the assessment may be overstated. The assessment is 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 1040 Underseepage Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	Minimum Credible	Maximum Credible	Best Estimate	Minimum Credible	Maximum Credible	
66	53	68	Minor seepage	Minor seepage	Heavy seepage	Hazard Level B

Hazard indicators suggesting that underseepage could occur include levee foundation materials (silt and sand in the west and possibly peat in the east) that have high to very high underseepage susceptibility and a levee section that is moderate for the differential head between the assessment water surface elevation and the levee toe. Segment 1040 is categorized as Hazard Level B based on the consistency between the hazard indicators that suggest that underseepage may occur and the past performance data of minor seepage in the segment.

Stability

Segment 1040 Stability Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	**Minimum Credible**	**Maximum Credible**	**Best Estimate**	**Minimum Credible**	**Maximum Credible**	
61	36	66	None documented	None documented	None documented	LD (A and B)

Hazard indicators suggesting that levee instability could occur include the levee composition of weak, clayey soil in the eastern portion of the segment, a levee height of up to 27 feet above the levee toe, the high differential head between the assessment water surface elevation and the levee toe, and soft soils in the foundation. Given the inconsistency between the hazard indicators, which suggest that levee instability may occur, and the lack of a past performance history of levee instability in the segment, Segment 1040 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 1040 Through Seepage Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	**Minimum Credible**	**Maximum Credible**	**Best Estimate**	**Minimum Credible**	**Maximum Credible**	
38	30	55	None documented	None documented	None documented	Hazard Level A

Hazard indicators suggesting that through seepage is less likely to occur include the levee composition of silt and sand in the west and clayey soil in the east, no documented penetrations, no documented animal persistence and a levee section that is moderate for the differential head between the assessment water surface elevation and the levee toe. Given the consistency between the best estimate hazard indicators, which suggests a low likelihood of through seepage, and the lack of a past performance history of through seepage in the segment, Segment 1040 is categorized as Hazard Level A for the through seepage potential failure mode.

Erosion

Segment 1040 is categorized as Hazard Level A for erosion. Erosion features were not identified in the available documents. Based on the LiDAR data, minor erosion of the waterside levee toe may be occurring along about 30 percent of the segment.

Segment 1040: Other Levee Assessments

Freeboard

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

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. The documents reviewed do not indicate this levee segment has been overtopped.

Geometry

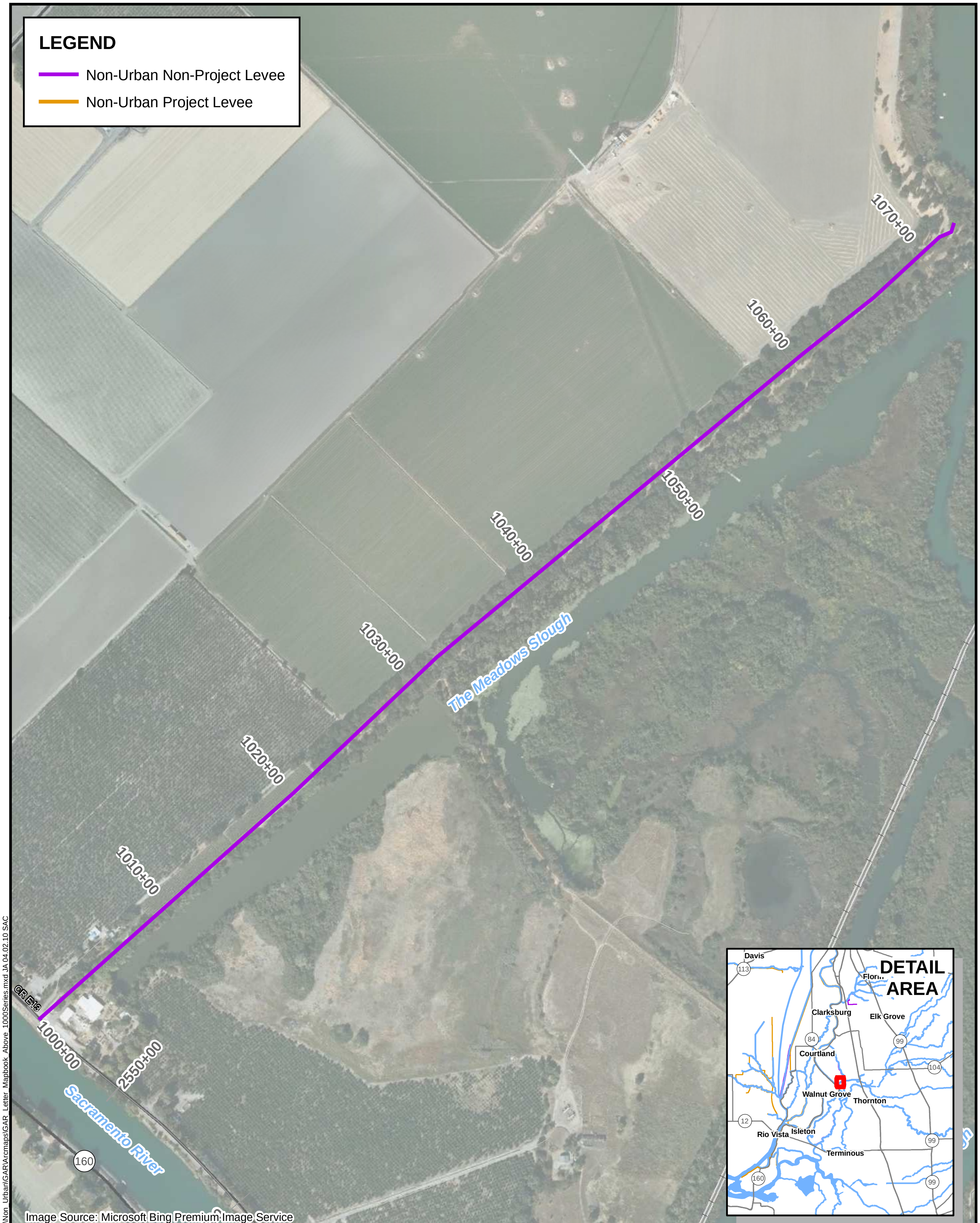
Using the LiDAR data, the levee geometry was compared with a standard levee prism defined by the Segment 1040 1953 MOU geometric criteria. This check was performed by assessing whether the levee indicated by topography developed from the LiDAR data was larger than or equal to the standard levee prism 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 1040, approximately 65 percent of the levee is smaller than the standard levee prism due to a narrow crest width.

Segment 1040: Hazard Mitigation

The following table presents identified hazards for Segment 1040 and the estimated extent of the hazard. Comments are provided to assist with identifying potential remedial requirements.

Segment 1040 Hazards

Hazard	Extent (percent)	Comments
Underseepage	70	Extent is the western end of the segment where the segment ties into the levees along the Sacramento River; a portion of the segment overlies a recent crevasse splay, as shown on Level 2-II mapping (sand layers underlying the levee may extend to 40 feet below the levee toe); at the eastern end of segment, soft soils (possibly peat) are the likely source of underseepage past performance.
Stability	30	Extent is the eastern end of segment where soft soils are likely.



0 400 800
Feet

N

Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

URS

Segment 1040
Geotechnical Assessment Report

NORTH NON-URBAN LEVEE EVALUATIONS

L:\Projects\DWR\GEOTECHNICAL\Non Urban\GAR\Arcmaps\GAR_Letter_Mapbook_Above_1000Series.mxd JA 04.02.10 SAC

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

Levee Segment Name:	TMSS-L 1000+00-1073+00		Begin	End
Levee Segment Number:	1040	NULE Station (ft):	1000+00	1073+00
Brief Description of Segment/Reach:	Right bank of The Meadows Slough	Levee Mile:	0	1.4
		Segment/Reach Length:	1.4 (miles)	7300 (feet)
		Crest Width Design Criterion (ft):	20	
Local Maintenance Authority:	RD 0551	Design Guidance Document:	Plan of Reclamation - RD 0551 (Doc-5232)	
Freeboard Evaluation Criterion (ft):	Not Applicable			
Water Side Slope Design Criterion:	3H : 1V (Enter Other Criterion)	Project or Non-Project Levee?	Non-Project	
Land Side Slope Design Criterion:	2H : 1V (Enter Other Criterion)			
North or South NULE?	North			

LEVEE CONSTRUCTION

Describe what is known about construction of this levee segment: The Segment 1040 levee was initially constructed by local interests. Based on an early topographic map (Courtland, 1:62,500), initial construction occurred prior to 1906. The RD 0551 1919 Plan of Reclamation indicates that Segment 1040 was likely initially constructed using materials dredged from the adjacent Meadows Slough and presented the plan for raising and enlarging the levee using similar methods (Doc-5232).

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		*Minor seepage*	*Minor seepage*	*Heavy seepage*	Seepage in the eastern end (1055+00 to 1073+00) of the segment as reported by landowners between 1949 to 1954 (Doc-914).
Landside slope stability		*None documented*	*None documented*	*None documented*	None indicated in interview with RD.
Through seepage		*None documented*	*None documented*	*None documented*	None indicated in interview with RD.

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?:	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*	*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
Composition of levee material *for stability assessment*		*4 - CH, MH; moderately dispersive soils; loose sand, sand with silt, or non-plastic silt*	*3- soils are more clayey than category 1 soils, with liquid limits greater than 35 and less than 50*	*5 - OL, OH, Peat, dispersive soil*	Based on NULE Level 2-II mapping

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*	Recent overbank and crevasse splay deposits were mapped in 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*	*1 - None or no data*	*5 - Very high*	Mapped as none in piping potential map; Available boring information shows possible presence of silt in foundation.
Piping potential *for through seepage assessment*	1:24,000	*4 - High*	*1 - None or no data*	*5 - Very high*	Based on NULE Level 2-II mapping.
Soft soils *for stability assessment*	1:24,000	*5 - Present*	*1 - Not present*	*5 - 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*	Animal activity was not indicated in the reviewed documents or RD 0551 interview. DWR data is not available for this 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*	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:	1 - None documented	**Notes:**	No penetrations were documented during the site reconnaissance; The DWR penetration inventory does not cover Segment 1040.		
DWR's LMA maintenance rating from Maintenance Deficiency Summary Report:	LMA Not rated by DWR	**Notes:**	N/A		

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	1010+00	**Cross-section Station**	1050+00	**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)	27.5		29			
Levee toe elevation (landside) (ft)	6.5		3			
Levee crest width (ft)	12	4	18	2		
Evaluation water elevation (ft)	26		27.5			
Levee slope - landside (xH : 1V); **Enter x**	5	1	4.5	1		
Levee slope - waterside (xH : 1V); **Enter x**	3.1		3.5			
Freeboard above evaluation flood elevation (ft) (= levee crest elevation - evaluation water elevation)	1.5					
Levee height (ft) (= levee crest elevation - landside toe elevation)	21.0	5	26.0	5		
Levee prism base width (ft)	182.1					
Head (ft) (= evaluation water level - landside toe elevation)	19.5	4	24.5	5		
Head-to-base-width ratio (= head / base width)	0.107	3				
Base-width to head ratio (= base width / head)	9					

V- ANOMALIES

	Anomalies?	Description	Effect on Performance
Underseepage	Yes	Segment 1040 has four ditches that do not run parallel to the levee. The ditches are located near NULE Station 1025+50, 1032+50, 1038+50 and 1058+00.	Potential location for seepage and boils.
Stability	Yes	Encroachment of agricultural fields into levee prism.	Potential levee instability.
Through Seepage	No	N/A	N/A
Erosion	No	N/A	N/A

MITIGATION AND PAST BREACHES

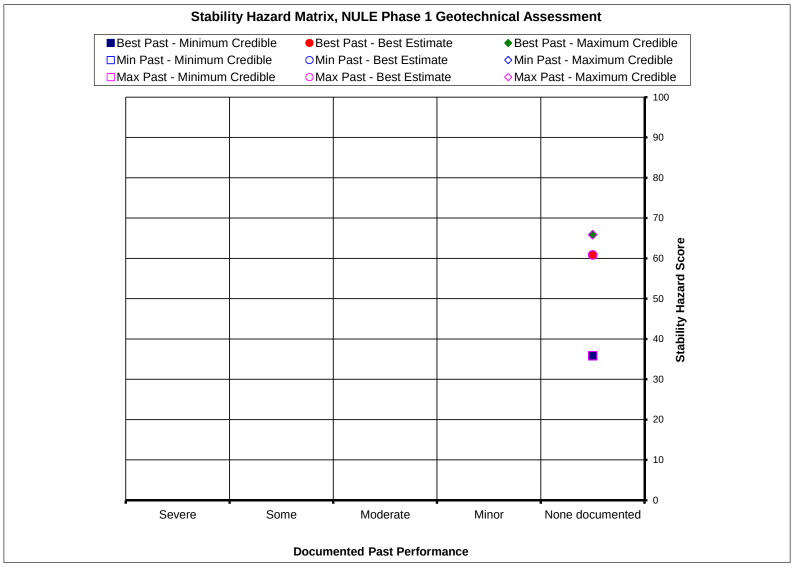
Existing constructed mitigation (List all)	Existing constructed mitigation was not found in the available documents.	
Has there been a past breach?	None Identified	
If yes, describe nature of the breach and how it has been mitigated?		

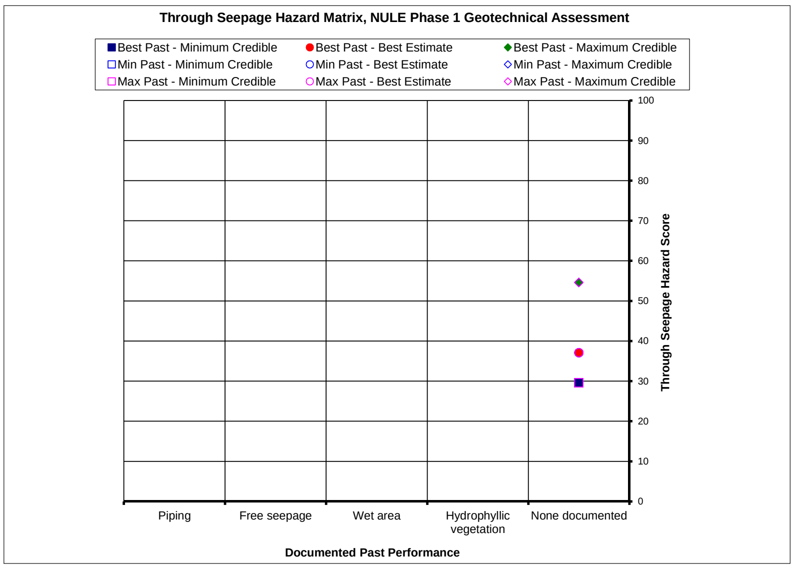
SUMMARY

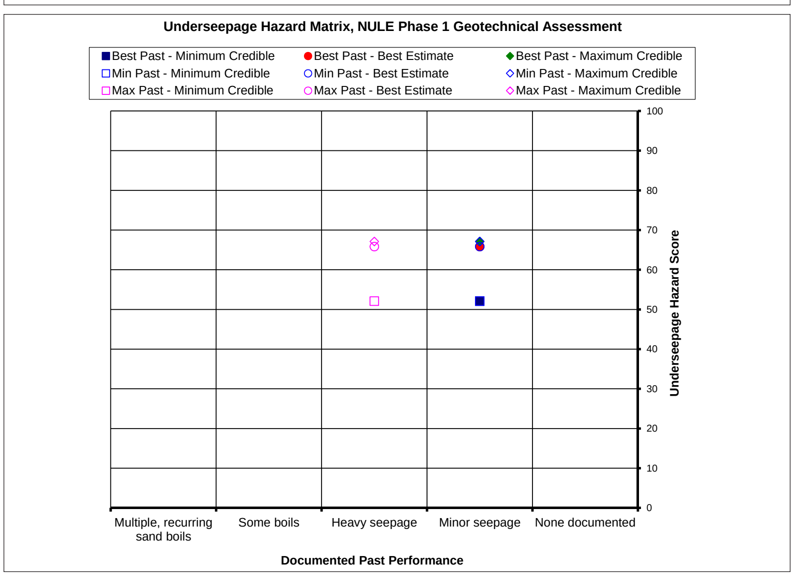
Failure Mode	**Weighted Hazard Indicator Score (Best)**	**Weighted Hazard Indicator Score (Minimum Credible)**	**Weighted Hazard Indicator Score (Maximum Credible)**	**Past performance issues?**	**Are past performance and Weighted Hazard Indicator Score consistent?**	**Levee categorization**
Underseepage	**66**	53	68	Minor seepage	Yes	***Hazard Level B***
Justification:	Segment 1040 is categorized as Hazard Level B due to the consistency between the hazard indicators that suggests that underseepage may occur and the past performance data of minor seepage within the segment.					
Suggested additional data:	Confirm underseepage past performance with RD; field investigations to confirm foundation material type.					
Stability	**61**	36	66	None documented	No	***Hazard Level LD***
Justification:	Segment 1040 is categorized as Lacking Sufficient Data due to the inconsistency between the hazard indicators that suggests that levee instability may occur and the past performance data of no documented levee instability within the segment. 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:	Confirm past performance data with RD. Borings to characterize foundation and levee.					
Through Seepage	**38**	30	55	None documented	Yes	***Hazard Level A***
Justification:	Segment 1040 is categorized as Hazard Level A due to the consistency between the Best Estimate WHIS that suggests a low likelihood of through-seepage and the past performance data of no documented through-seepage within the segment.					
Suggested additional data:	Borings to confirm levee materials.					
Erosion				No		***Hazard Level A***
Justification:	Erosion features were not identified in the available documents. Based on the LIDAR data, minor erosion of the waterside levee toe may be occurring along about 30 percent of the segment.					
Suggested additional data:	Confirm with RD that past performance erosion events have not occurred.					

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:	The freeboard check was not performed as a water surface elevation was not available for the check.		
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:	65% of segment does not meet geometry criteria due to narrow crest width.		
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 categorization for stability is Lacking Sufficient Data. Underseepage is categorized as 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:	TK	Evaluation Date:	3/16/2010
Checked By:	JWR	Check Date:	3/16/2010
Senior Reviewer:	Review Team	Review Date:	3/17/2010


Stability Hazard Matrix, NULE Phase 1 Geotechnical Assessment
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
0
10
20
30
40
50
60
70
80
90
100
Stability Hazard Score
Severe
Some
Moderate
Minor
None documented
Documented Past Performance


Through Seepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
0
10
20
30
40
50
60
70
80
90
100
Through Seepage Hazard Score
Piping
Free seepage
Wet area
Hydrophyllic vegetation
None documented
Documented Past Performance


Underseepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
0
10
20
30
40
50
60
70
80
90
100
Underseepage Hazard Score
Multiple, recurring sand boils
Some boils
Heavy seepage
Minor seepage
None documented
Documented Past Performance

UNITED STATES BUREAU OF RECLAMATION/STATE PARKS, SEGMENT 1054 SUMMARY

This segment summary presents collected information and the assessment results for Segment 1054. The summary is based on readily-available data at the time of assessment of this segment. 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 1054: Segment Description and Assessment Summary

Segment 1054 is a non-urban Non-Project levee on the right bank of Snodgrass Slough and right bank of the Meadows Slough in Sacramento County, California. The segment extends from the confluence of the Delta Cross Canal and Snodgrass Slough northward to the confluence of Snodgrass Slough and Locke Slough, then continues westward and northward along Locke Slough to a cross levee extending northwest to Meadows Slough. The following table summarizes segment information.

Segment 1054 Information

Maintenance Authority	Unit	Levee Miles	NULE Stationing
USBR	-	0 to 0.71	Snodgrass Slough Right Bank (SDSS-R) 1096+75 to 1134+50
California State Parks	-	0 to 0.77	Snodgrass Slough Right Bank (SDSS-R) 1134+50 to 1175+11
California State Parks	-	0 to 0.60	The Meadows Cross Slough Right Bank (TMXS-R) 1000+00 to 1031+43

Since the 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 Segment 1054 categorizations for each potential failure mode.

Segment 1054 Potential Failure Mode Assessment Summary

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

Based on these NULE Phase 1 levee assessments for Segment 1054, erosion is categorized as Hazard Level A, and underseepage, through seepage and stability are categorized as Lacking Sufficient Data. If additional data were obtained, it is very unlikely that the LD for the underseepage, through seepage or stability failure modes would be categorized as Hazard Level A. Therefore, the overall categorization for the segment is LD (B or C). The overall categorization of LD (B or C) means that, if additional data were obtained to resolve the LD, the overall categorization for this segment would be either Hazard Level B or Hazard Level C.

Segment 1054: 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), portions of Segment 1054 (between NULE Stations SDSS-R 1096+75 and 1144+50, and Stations TMXS-R 1015+00 and 1031+43) were initially constructed by local interests prior to 1906. According to the *Level 2-II Geomorphic Assessment*, the rest of the levee was constructed prior to 1937. The levee between NULE Stations SDSS-R 1144+50 and 1175+11 is part of a railway embankment. Specific documentation of the construction methods for the levee were not available.

The following table presents the 1953 MOU geometric criteria for Segment 1054.

Segment 1054 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, Segment 1054 experienced erosion that was reported in 1985. There are no documented reports of overtopping, underseepage, through seepage or slope instability. The following table summarizes reported performance events.

Segment 1054 Reported Levee Performance Events

Flood Season	Reported Performance Event	Approximate Location (NULE Station)	Mitigation
1984 or before	Erosion (USBR Documentation)	SDSS-R 1096+75 to 1123+75	Riprap placed

Improvements

Erosion repairs were performed as part of the 1984 Levee Erosion Control Plan approximately between NULE Stations SDSS-R 1096+75 and 1123+75.

Planned Improvements

According to available documents, no improvements to Segment 1054 are currently scheduled. The USBR is developing concepts to control vegetation (Doc-8805).

Segment 1054: 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 1054 levee heights range from about 14 to 19 feet above the landside toe. At some locations the levees are shorter, and heights range from 7 to 14 feet. Including rounded shoulders, crest width is approximately 15 to 40 feet and LiDAR survey data indicate the landside slopes are about 1.7H:1V to 4H:1V. The waterside slopes are approximately 2.5H:1V to 3H:1V. Ditches are present near the landside toe of portions of the segment:

- From about NULE SDSS-R Station 1116+50 to 1151+00; it may be unlined and is about 10 to 20 feet wide and ranges from about 2 to 3 feet deep.
- From about NULE SDSS-R Station 1157+50 to 1167+00; it may be unlined and is about 10 to 15 feet wide and ranges from about 2 to 4 feet deep.
- From about NULE TMXS-R Station 1021+00 to 1031+00; it may be unlined and is about 10 to 20 feet wide and varies from about 2 to 4 feet deep.

Penetrations

A complete inventory of penetrations through the levee segment was not available.

Animal Activity

Animal activity was not reported in reviewed documents. However, animal activity was noted during an interview (Doc-8805). Animal persistence based on data from DWR is not available for Segment 1054.

Maintenance

DWR assessments were not available for Segment 1054. Levee between NULE Stations SDSS-R 1096+75 and 1134+50 is under the jurisdiction of the USBR. Levee between NULE Stations SDSS-R 1134+50 and 1175+11 and between NULE Stations TMXS-R 1000+00 and 1031+43 is under the jurisdiction of the state parks. During data collection, there were no maintenance programs identified for these levees.

Other Features

A pump station is near NULE Station SDSS-R 1134+00. Overflow culverts were located near NULE Station SDSS-R 1123+00. These culverts were plugged in 1985 (USBR documentation). Segment 1054 has ditches that are at an angle to the levee NULE SDSS-R Stations 1134+00, 1151+00, 1157+50, and near TMXS-R Station 1029+00.

Segment 1054: 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 1054.

In Segment 1054, the levee foundation may consist of sand, clay, silt, and loam and the levees may consist of sand, gravel, and clay.

Geomorphic Setting

According to the *Level 2-II Geomorphic Assessment*, Segment 1054 levee between NULE Stations SDSS-R 1096+75 and 1134+50 predominantly overlies basin deposits (fine sand, silt, and clay). The levee between NULE Stations SDSS-R 1134+50 and 1144+50 predominantly overlies Overbank deposits (silt, clay, and lesser sand). Overbank deposits (silt, clay, and lesser sand) are mapped between NULE Stations SDSS-R 1144+50 and 1151+00, NULE Stations SDSS-R 1157+00 to 1174+00 and NULE Stations TMXS-R 1008+00 to 1010+00 and 1017+00 to 1028+00. Eolian deposits (poorly consolidated sandy windblown material) are mapped between NULE Stations SDSS-R 1153+00 to 1157+00 and 1174+00 to 1175+11 and in NULE Stations TMXS-R 1000+00 to1008+00 and 1010+00 to

1016+00. Slough deposits and marsh deposits are also mapped in some isolated areas of the segment.

Geotechnical Investigations

Seventeen borings were drilled by USBR as part of the Delta Cross Canal construction. One of these borings was drilled at the toe of the south east end of the segment. The boring is 33 feet deep. Six of seventeen borings were drilled along the proposed centerline of the adjacent levee segment (Segment 1053). The borings range in depth from 15 to 100 feet. According to the stick logs for the borings near this segment, soil in the foundation consisted of 3-foot-thick clayey loam and a 3- to 5-foot-thick clay layer overlying a sand layer extending to the maximum explored depth of about 30 feet.

Other Subsurface Information

The USCS soil map indicates that the existing levee in Segment 1054 mostly overlies fine-grained materials (CL-ML, CH, SM, OH and CL). The NRCS USCS map does not indicate the variation of soil types shown in level 2-II mapping, nor the variation found in borings.

Levee Composition

Available data indicate that Segment 1054 levee between NULE Station SDSS-R 1096+75 to 1134+50 may consist of sand, gravel, and clay (Doc-8805). Data about the composition of other levee portions in this segment were not found in available documents.

Segment 1054: Geotechnical Assessment Results

The overall Segment 1054 categorization is Lacking Sufficient Data (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, erosion is categorized as Hazard Level A, and underseepage, through seepage and stability are categorized as Lacking Sufficient Data. If additional data were obtained, it is very unlikely that the LD for the underseepage, through seepage or stability failure modes would be categorized as Hazard Level A. Therefore, the overall categorization for the segment is LD (B or C). A summary of the LAT results and the matrix plots are attached.

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 1054 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 (B or C)

The levees in Segment 1054 are generally 14 to 19 feet high, resulting in relatively high differential water head. The levee overlies overbank and basin deposits that are highly susceptible to underseepage. The segment has no reported underseepage. Given the inconsistency between the WHIS, which suggests that underseepage is likely to occur, and the absence of past reported underseepage, Segment 1054 is categorized as Lacking Sufficient Data for the underseepage 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 re-categorize the segment to Hazard Level A.

Stability

Segment 1054 Stability Assessment Results*

WHIS			Performance Summary			Categorization
Best Estimate	**Minimum Credible**	**Maximum Credible**	**Best Estimate**	**Minimum Credible**	**Maximum Credible**	
74	44	74	None Documented	None Documented	None Documented	LD (B or C)*

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

Portions of Segment 1054 levees may overlie organic soils that have high potential for slope instability. The levee height is up to 19 feet above the levee toe. However, the segment has no reported slope instability. Given the inconsistency between the WHIS, which suggests that instability is likely to occur, and the absence of past performance data, Segment 1054 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 t hat the additional data would re-categorize the segment to Hazard Level A.

Through Seepage

Segment 1054 Through Seepage Assessment Results

WHIS			Performance Summary			Categorization
Best Estimate	Minimum Credible	Maximum Credible	Best Estimate	Minimum Credible	Maximum Credible	
70	45	70	None Documented	None Documented	None Documented	LD (B or C)

Segment 1054 may consist of sand, gravel and clay. The levees are generally 14 to 19 feet high, resulting in relatively high differential water head between the assessment water surface elevation and the levee toe. However, the segment has no reported through seepage. Given the inconsistency between the WHIS, which suggests that through seepage is likely to occur, and the absence of past through seepage, Segment 1054 is categorized as Lacking Sufficient Data for the through seepage 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 re-categorize the segment to Hazard Level A.

Erosion

Segment 1054 is categorized as Hazard Level A for erosion. The segment has only one reported waterside erosion event, and the site was reported in the 1984 *Levee Erosion Control Plan* (USBR Documentation). According to LiDAR data, minor erosion of the waterside slope may be occurring along about 10 percent of the segment.

Segment 1054: 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 that this levee segment has no reported overtopping in the past 20 years.

Geometry

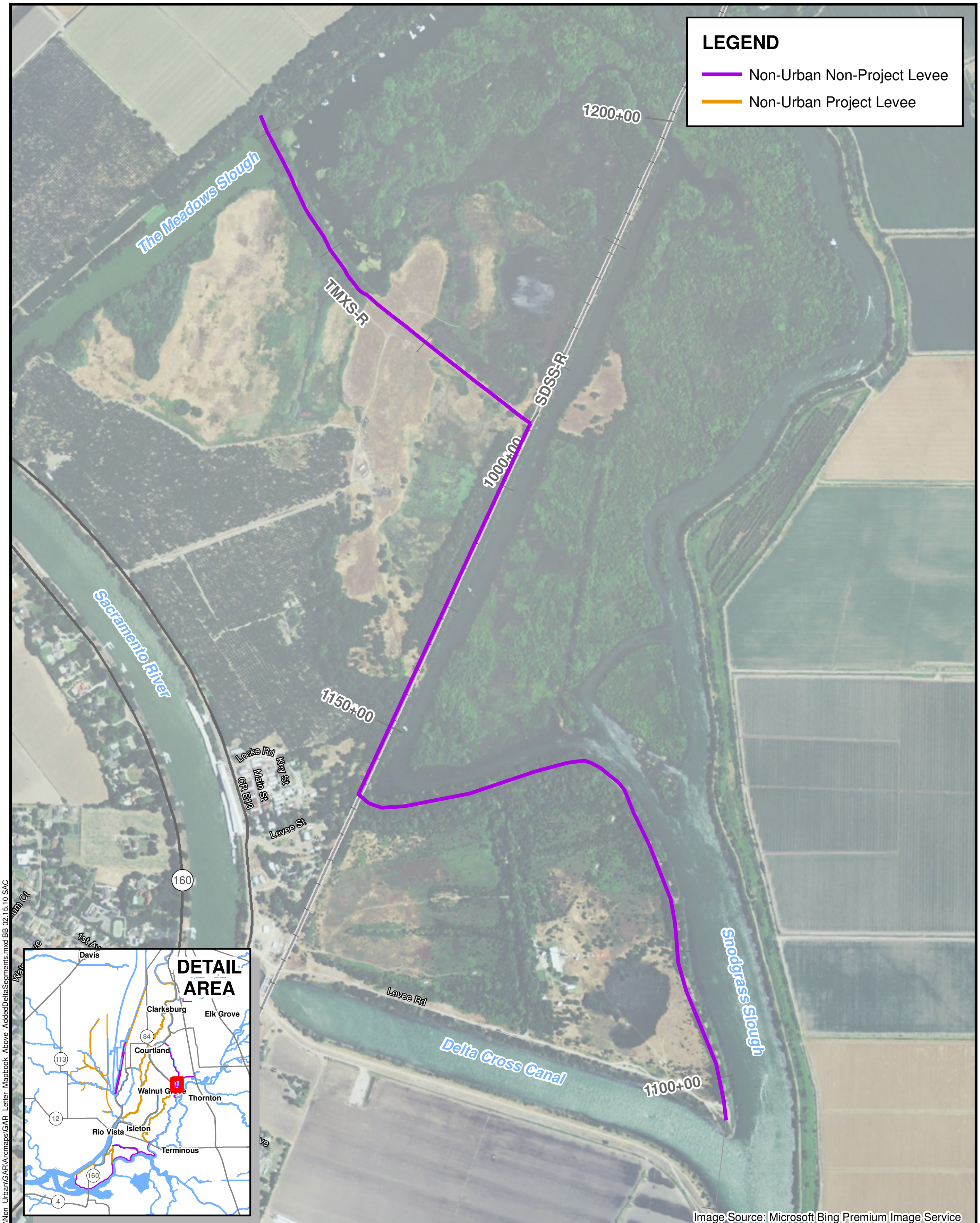
Using LiDAR data, Segment 1054 levee geometry was compared to a standard levee prism as defined by the 1953 MOU. This comparison assessed whether the levee, indicated by topography developed from LiDAR data, was larger than or equal to the standard levee prism at any given cross-section. Wide levees could meet this requirement even where levee slopes are steeper than those described in the 1953 MOU. For Segment 1054, approximately 35 percent of the levee is smaller than the standard levee prism.

Segment 1054: 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 1054 Hazards

Hazard	Extent (percent)	Comments
Underseepage	50	The extent of mitigation was estimated based on the landside levee slopes that are steeper than 4H:1V and the levees with wider crest, as indicated by LiDAR data.
Stability	30	Based on available boring data and Level 2-II Geomorphic Assessment, southern portion of Segment 1054 levees may be underlain by organic material .
Through-Seepage	50	The extent of mitigation was estimated based on the landside levee slopes that are steeper than 4H:1V and the levees with wider crest, as indicated by LiDAR data.



0 500 1,000
Feet

N

Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

URS

Segment 1054
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)

					Begin	End
Levee Segment Name:	Snodgrass Slough west bank levee north of Delta Cross Canal - Levee adjacent to			NULE Station (ft):	1096+75	1175+11
Levee Segment Number:	1054			Levee Mile:	Enter	Enter
Brief Description of Segment/Reach:	Snodgrass Slough west bank levee north of Delta Cross Canal - Levee adjacent to Segment 121			Segment/Reach Length:	1.5 (miles)	7836 (feet)
				Crest Width Design Criterion (ft):	20	
Local Maintenance Authority:	USBR and California State Parks			Design Guidance Document:	1953 MOU	
Freeboard Evaluation Criterion (ft):	Not Applicable					
Water Side Slope Design Criterion:	3H : 1V	Enter Other Criterion		Project or Non-Project Levee?	Non-Project	
Land Side Slope Design Criterion:	2H : 1V	Enter Other Criterion				
North or South NULE?	North					

LEVEE CONSTRUCTION

Describe what is known about construction of this levee segment:	Based on historical topographic maps (Isleton, 1:31,680), portions of the Segment 1054 levees (Between NULE Station SDSS-R 1096+75 to 1144+50 and TMXS-R 1015+00 to 1031+43 were initially constructed by local interests prior to 1906. According to the Level 2-II Geomorphic Assessment, the rest of the levee were constructed prior to 1937. 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?	Yes	If yes, please describe:	One erosion event reported USBR Documentation. The site was repaired under 1984 Levee Erosion Control Plan.				
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*		*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*	The available data indicate that the Segment 1054 levee may consist of sand, gravel, and clay (Doc-8805).
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*	The available data indicate that the Segment 1054 levee may consist of sand, gravel, and clay (Doc-8805).
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 (Rob).
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*	*4 - High*	The available data indicate that the Segment 1054 levee may consist of sand, gravel, and clay (Doc-8805).
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*	*2 -Low*	*3 - Medium*	Animal activity was noted during an interview (Doc-8805). Animal persistence based on data from DWR is not available for Segment 1054.
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:	1 - None documented	Notes:	A complete inventory of 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		

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	SDSS-R 1170+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)	24		22			
Levee toe elevation (landside) (ft)	6		1			
Levee crest width (ft)	29	1	20	1		
Evaluation water elevation (ft)	22.5		20.5			
Levee slope - landside (xH : 1V); **Enter x**	2.5	3	1.8	4		
Levee slope - waterside (xH : 1V); **Enter x**	2.7					
Freeboard above evaluation flood elevation (ft) (= levee crest elevation - evaluation water elevation)	1.5					
Levee height (ft) (= levee crest elevation - landside toe elevation)	18.0	4	21.0	5		
Levee prism base width (ft)	122.6					
Head (ft) (= evaluation water level - landside toe elevation)	16.5	4	19.5	4		
Head-to-base-width ratio (= head / base width)	0.135	4				
Base-width to head ratio (= base width / head)	7					

V- ANOMALIES

	Anomalies?	Description	Effect on Performance
Underseepage	Yes	Segment has ditches that are at an angle to the levee located near NULE SDSS-R Station 1134+00, 1151+00, 1157+50, and TMXS-R Station 1029+00; A pump station is located near NULE Station SDSS-R 1134+00.	Potential locations for underseepage
Stability	No	NA	NA
Through Seepage	No	NA	NA
Erosion	No	NA	NA

MITIGATION AND PAST BREACHES

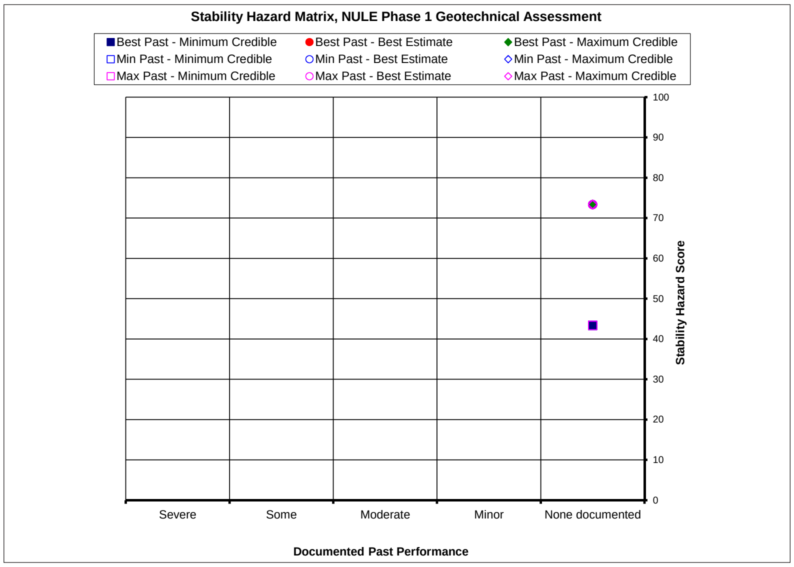
Existing constructed mitigation (List all)	Erosion repairs were performed as part of the 1984 Levee Erosion Control Plan approximately between NULE Stations SDSS-R 1096+75 and1123+75.
Has there been a past breach?	None Identified
If yes, describe nature of the breach and how it has been mitigated?	

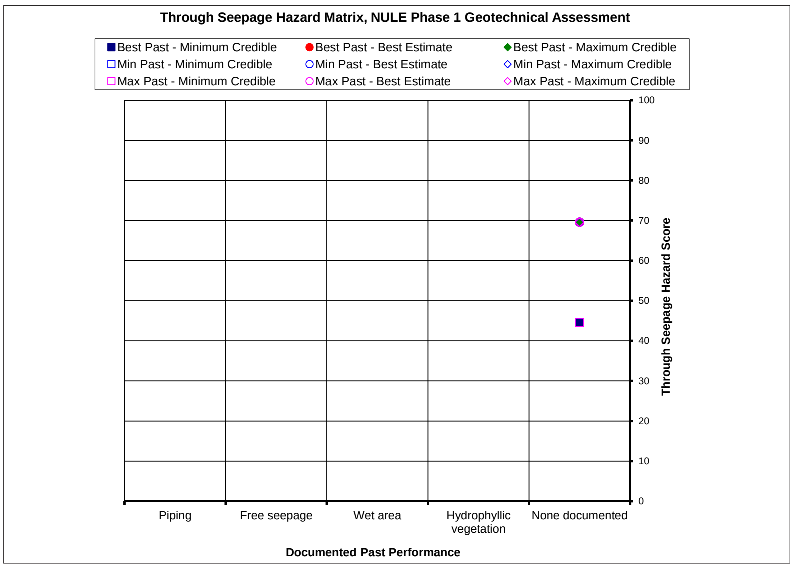
SUMMARY

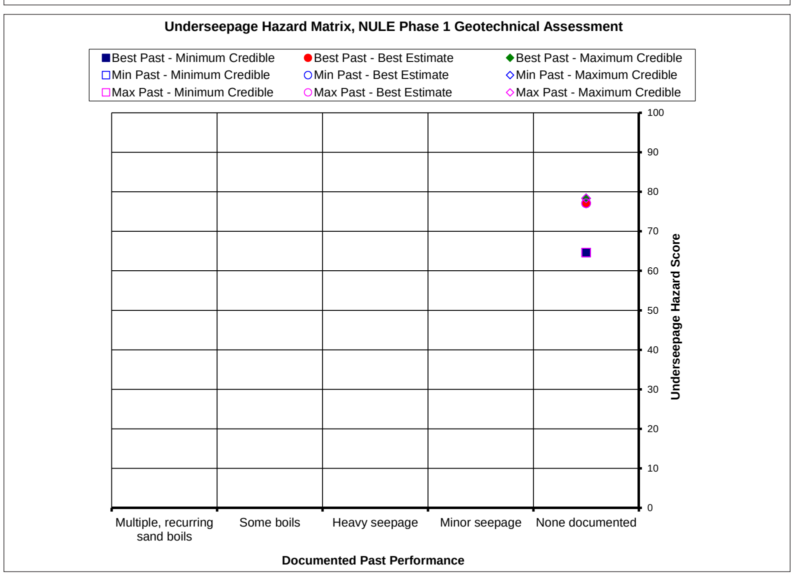
Failure Mode	Weighted Hazard Indicator Score (Best)	Weighted Hazard Indicator Score (Minimum Credible)	Weighted Hazard Indicator Score (Maximum Credible)	Past performance issues?	Are past performance and Weighted Hazard Indicator Score consistent?	Levee categorization
Underseepage	**78**	65	79	None documented	No	***Hazard Level LD***
Justification:	The segment has no reported underseepage. The high WHIS is inconsistent with past performance. Given the hazard indicators, and if additional data were obtained to resolve the LD, it is very unlikely that the additional data would re-categorize the segment to Hazard Level A.					
Suggested additional data:	Need to check and confirm with the RDs for past performance data					
Stability	**74**	44	74	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 is very unlikely that the additional data would re-categorize the segment to Hazard Level A.					
Suggested additional data:	Need to check and confirm with the RDs for past performance data					
Through Seepage	**70**	45	70	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 is very unlikely that the additional data would re-categorize the segment to Hazard Level A.					
Suggested additional data:	Need to confirm that the RD has no other reported past performance; do geotechnical investigation.					
Erosion				Yes		***Hazard Level A***
Justification:	The segment has only one reported past performance data available for erosion. Based on LiDAR data, about 10% 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:	35% of the segment did not pass the geometry check. The locations where the segment did not pass the geometry check are NULE TMXS-R Stations 1012+50 to 1017+50 and SDSS-R Stations 1142+50 to 1147+50, 1098+00 to 1117+50.		
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 all LD (B or C). The categorization for erosion is Hazard Level A. If additional data were obtained, it is very unlikely that the LD for underseepage, stability and through-seepage would be categorized as Hazard Level A. Therefore, the overall categorization for the segment is LD (B or C). The overall categorization of LD (B or C) means that, if additional data were obtained to resolve the LD, the overall categorization for this segment would be either Hazard Level B or Hazard Level C.

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


Stability Hazard Matrix, NULE Phase 1 Geotechnical Assessment
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
100
90
80
70
60
50
40
30
20
10
0
Stability Hazard Score
Severe
Some
Moderate
Minor
None documented
Documented Past Performance


Through Seepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
100
90
80
70
60
50
40
30
20
10
0
Through Seepage Hazard Score
Piping
Free seepage
Wet area
Hydrophyllic vegetation
None documented
Documented Past Performance


Underseepage Hazard Matrix, NULE Phase 1 Geotechnical Assessment
Best Past - Minimum Credible
Best Past - Best Estimate
Best Past - Maximum Credible
Min Past - Minimum Credible
Min Past - Best Estimate
Min Past - Maximum Credible
Max Past - Minimum Credible
Max Past - Best Estimate
Max Past - Maximum Credible
100
90
80
70
60
50
40
30
20
10
0
Underseepage Hazard Score
Multiple, recurring sand boils
Some boils
Heavy seepage
Minor seepage
None documented
Documented Past Performance

Appendix B

Geomorphology Technical Memorandum

2868 Prospect Park Drive, Suite 310
Rancho Cordova, CA 95670
916.631.4500 fax 916.631.4501

2870 Gateway Oaks Drive, Suite 150
Sacramento, CA 95833
Tel: 916.679.2000 Fax: 916.679.2900

In association with:
William Lettis & Associates, Inc.

Prepared For	Department of Water Resources Division of Flood Management
Project	Non-Urban Levee Evaluations Project Task Order U-103
Date	December 22, 2010
Subject	Level 2-II Geomorphic Assessment and Surficial Mapping Along a Portion of the Sacramento River and Three Sloughs South of Courtland Study Area
Prepared By	Justin Pearce, Fugro William Lettis & Associates (FWLA), April 2010
Reviewed By	Janet Sowers, FWLA, March 2010; Keith Knudsen, Jennifer Mendonca, URS, April, 2010; Steve Belluomini, Keith Millard, DWR, 2010

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

---

[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.

<u>Historical deposits</u>

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

---

[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

2870 Gateway Oaks Drive, Suite 150
Sacramento, CA 95833
Tel: 916.679.2000 Fax: 916.679.2900

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

---

[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.

REFERENCES

Atwater, B.F., Hedel, C.W., Helley, E.J., 1977. *Late Quaternary Depositional History, Holocene Sea-level Changes, and Vertical Crustal Movement, Southern San Francisco Bay, California.* U.S. Geological Survey Professional Paper 1014, 15 p.

Atwater, B.F., 1979. *Generalized Geologic Map of the Rio Vista 15-minute Quadrangle, California*. U.S. Geological Survey Open-File Report 79-833.

Atwater, B.F., and Belknap, D.F., 1979. "Tidal Wetland Deposits of the Sacramento-San Joaquin Delta, California", In: *Proceedings, Quaternary Depositional Environments of the Pacific Coast, Pacific Coast Paleogeography Symposium 4*, Pacific Section of the Society of Economic Paleontologists and Mineralogists, p. 89-103.

Atwater, B.F., 1980. *Attempts to Correlate Late Quaternary Climatic Records between San Francisco Bay, the Sacramento-San Joaquin Delta, and the Mokelumne River California*, Ph.D dissertation: Newark, The University of Delaware, 214 p.

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.

Bates, J.L., and Jackson, J.A., editors, 1984. *Dictionary of Geologic Terms 3rd ed*.. New York, Doubleday, 571 p.

Boggs, S., Jr., 1995. *Principles of Sedimentology and Stratigraphy, 2d ed*., Upper Saddle River, Englewood Cliffs, NJ: Prentice-Hall, 774 p.

Bryan, K., 1923, *Geology and Groundwater Resources of Sacramento Valley, California*, U.S. Geological Survey Water-Supply Paper 495, 285 p.

Carpenter, E.J. and Cosby, S.w., 1930. *Soil Survey of the Suisun Area, California*. US Department of Agriculture, Bureau of Chemistry and Soils.

Domagalski, J.L., Knifong, D.L., Dileanis, P.D., Brown, L.R., May, J.T., Connor, Valerie, and Alpers, C.N., 2000. *Water Quality in the Sacramento River Basin, California,1994–98*: U.S. Geological Survey Circular 1215, 36 p., on-line at http://pubs.water.usgs.gov/circ1215/.

DWR (California Department of Water Resources). 1995. Sacramento-San Joaquin Delta Atlas. California Department of Water Resources; Available at: http://baydeltaoffice.water.ca.gov/DeltaAtals/index.cfm

Ellis, W.T., 1939, <u>Memories; my seventy-two years in the romantic county of Yuba, California</u>, Published by The University of Oregon, Library of Congress call number F869.M39 E6, 308 p.

Gilbert, G. K., 1917, *Hydraulic-Mining Debris in the Sierra Nevada*. U.S. Geological Survey Professional Paper 105, 154 p.

Helley, E.J., and Harwood, D.S., 1985, *Geologic map of the late Cenozoic deposits of the Sacramento Valley and Northern Sierran foothills, California*. Scale 1:62,500, USGS Map File MF-1790.

Helley, E.J., Lajoie, K.R., Spangle, W.E., Blair, M.L., 1979. *Flatland Deposits of the San Francisco Bay Region, California – Their Geology and Engineering Properties, and Their Importance to Comprehensive Planning*. USGS Professional Paper 943. 88 p.

Holmes, L.C., Watson, E.B., Harrington, G.L., Nelson, J., Guernsey, J.E., and Zinn, C.J., 1913. "Soil map, California: reconnaissance survey, Sacramento Valley sheet: In *Reconnaissance soil survey of Sacramento Valley, California*. Scale 1:250,000.

Ingebritson, S. E., Ikehara, M. E., Galloway, D. L., and Jones, D. R., 2000. *Delta subsidence in California*: U. S. Geological Survey Fact Sheet 00-500, 4 p.

James, L.A., 1999. "Time and the persistence of alluvium: River engineering, fluvial geomorphology, and mining sediment in California." *Geomorphology*, v. 31, p 265 – 290.

James, L.A., Singer, M.B., Ghoshal, S, and Megison, M., 2009. "Historical channel changes in the lower Yuba and Feather Rivers, California: Long-term effects of contrasting river-management strategies." *Geological Society of America Special Paper 451*, p 57 – 81.

Malamoud-Roam, F., Dettinger, M., Ingram, B.L., Hughes, M.K., Florsheim, J.L., 2007. "Holocene Climates and Connections between the San Francisco Bay Estuary and its Watershed." *San Francisco Estuary and Watershed Science*, 5(1), article 3 February 2007.

Mount, J., and Twiss, R. 2005. "Subsidence, Sea-level Rise, and Seismicity in the Sacramento-San Joaquin Delta." *San Francisco Estuary and Watershed Science*, 3(1), article 5.

Saucier, R.T., 1994. *Geomorphology and Quaternary Geologic History of the Lower Mississippi Valley*. Vol. I, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 414 p.

Shlemon, R.J., 1967. *Landform-Soil Relationships in northern Sacramento County, California*. [PhD. dissertation: University of California, Berkeley.

Strand, R.G. and Koenig, J.B., 1965. *Geologic map of California: Sacramento Sheet.* Scale 1:250,000: California Division of Mines and Geology,

Thompson, J. 2006. "Early Reclamation and Abandonment of the Central Sacramento-San Joaquin Delta:; *Sacramento History: Journal of the Sacramento County Historical Society*, VI(1-4)

Thompson, J. and Dutra, E. 1983. The Tule Breakers, a Story of the California Dredge. Published by Stockton Corral of Westerners Intermational, Universtiy of the Pacific, Stockton, California. 368 p.

Tugel, A.J., C.S., Beutler, W.T., Neikirk, W.R., Reed, W.B., Sheldon, T.D., Thorson, and J.M. Wright, 1992, *Soil Survey of Sacramento County, California*, 1:24,000, USDA Soil Conservation Service.

2870 Gateway Oaks Drive, Suite 150
Sacramento, CA 95833
Tel: 916.679.2000 Fax: 916.679.2900

In association with:
William Lettis & Associates, Inc.

URS Corporation, 2007. *Technical Memorandum: Delta Risk Management Strategy (DRMS) Phase I; Topical Area Delta Geomorphology Draft 2, July 31, 2007*. Prepared by URS Corporation/Jack R. Benjamin & Associates, Inc., prepared for the California Department of Water Resources (DWR), 39 p.

URS Corporation, 2009. Technical Memorandum: North NULE Level 2-I Geomorphic Assessment; Prepared by Fugro William Lettis & Associates, Inc.; Unpublished consultant report to DWR.

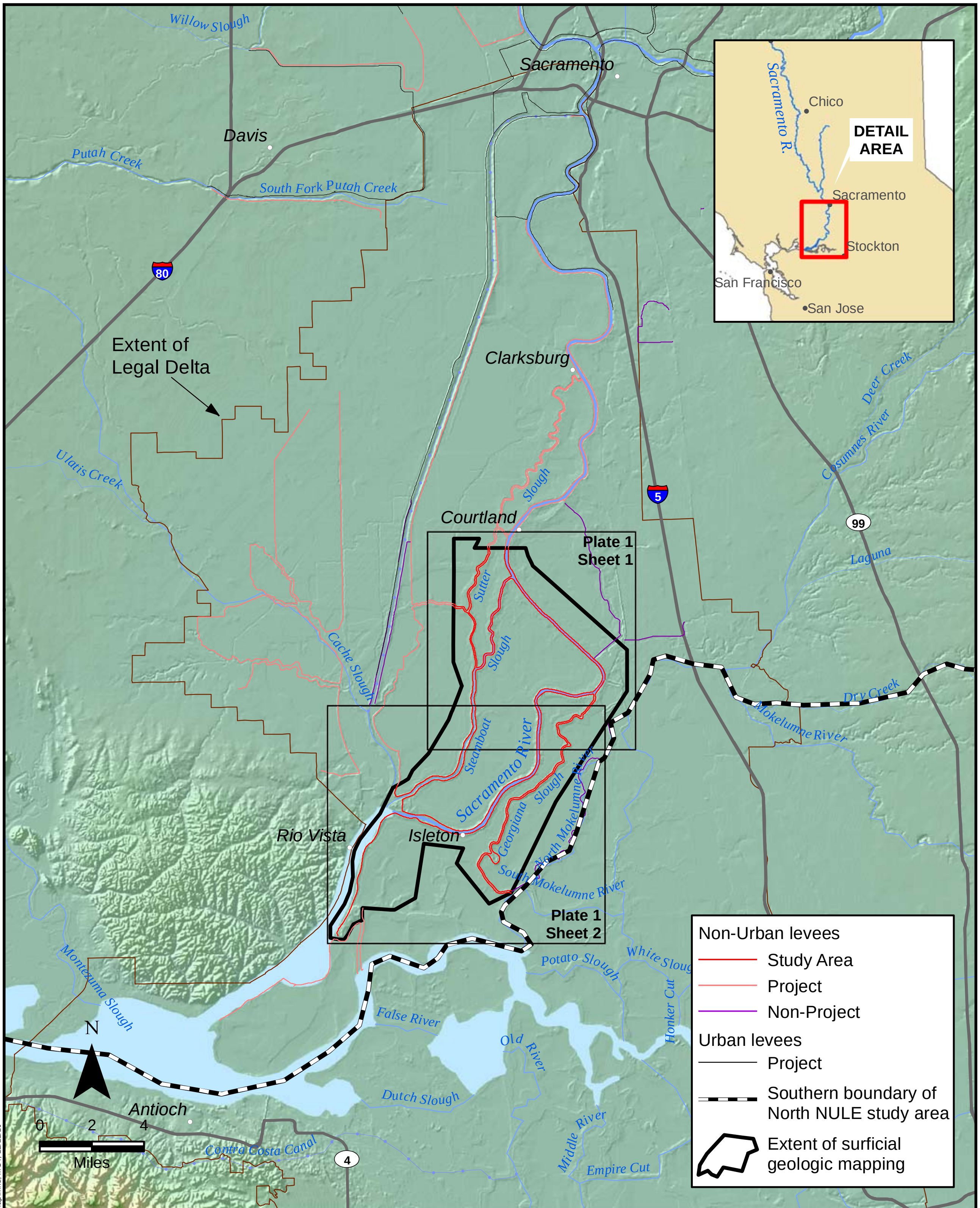
USACE (U.S. Army Corps of Engineers), 1987. *Liquefaction Potential of Levee Foundations: Implications for Catastrophic Levee Failure.* Prepared by Geotechnical Branch, US Army Engineer District, Sacramento Corps of Engineers.

USACE (U.S. Army Corps of Engineers), 1993. *Sacramento River Flood Control System Evaluation Initial Appraisal Report – Lower Sacramento Area; Attachment B: Basis of Design Geotechnical Evaluation of Levees, February 1993.* Prepared by Soil Design Section, Geotechnical Branch, Sacramento District.

Vaught, D. J., 2006. "A Swamplander's Vengeance: R.S. Carey and the Failure to Reclaim Putah Sink, 1855-1895," *Sacramento History Journal*, VI(1-4); 161-176

Wagner, D.L., Jennings, C.W., Bedrossian, T.L. and Bortugno, E.J., 1981. *Geologic map of the Sacramento quadrangle, California*, California Division of Mines and Geology, Regional Geologic Map 1A, Scale 1:250000.

W.E.T. (Water Engineering and Technology), 1990. *Geomorphic Analysis and Bank Protection Alternatives for Sacramento River (RM 0-78), Feather River (RM 28-61), Yuba River (RM 0-11), and Bear River (RM 0-17)*; Consultant report prepared for US Army Corps of Engineers, Sacramento District, Sacramento California. Draft Report. July 1990.



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

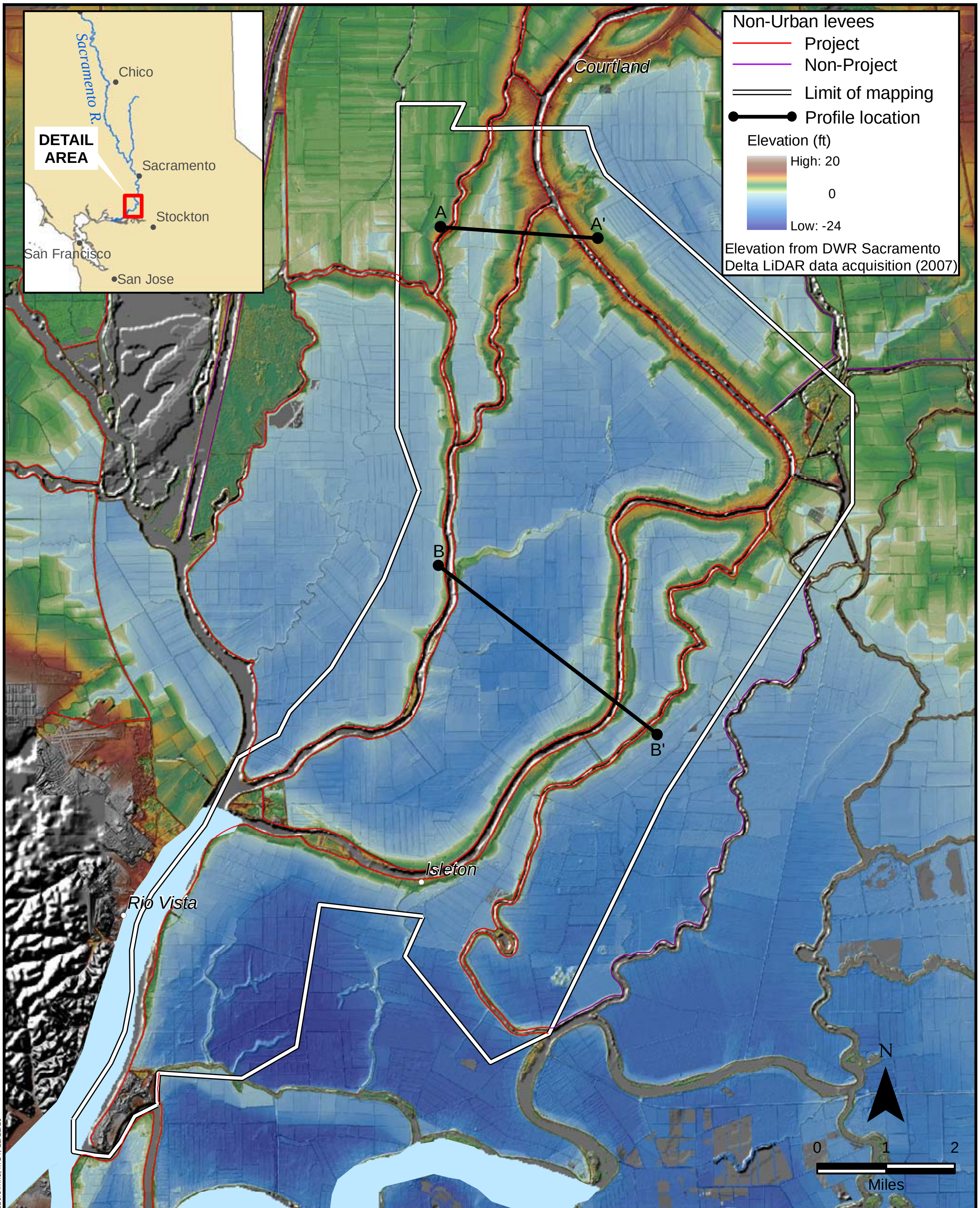
Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

URS
in association with:
Fugro WLA

Location Map

NORTH NON-URBAN LEVEE EVALUATIONS

Figure 1



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

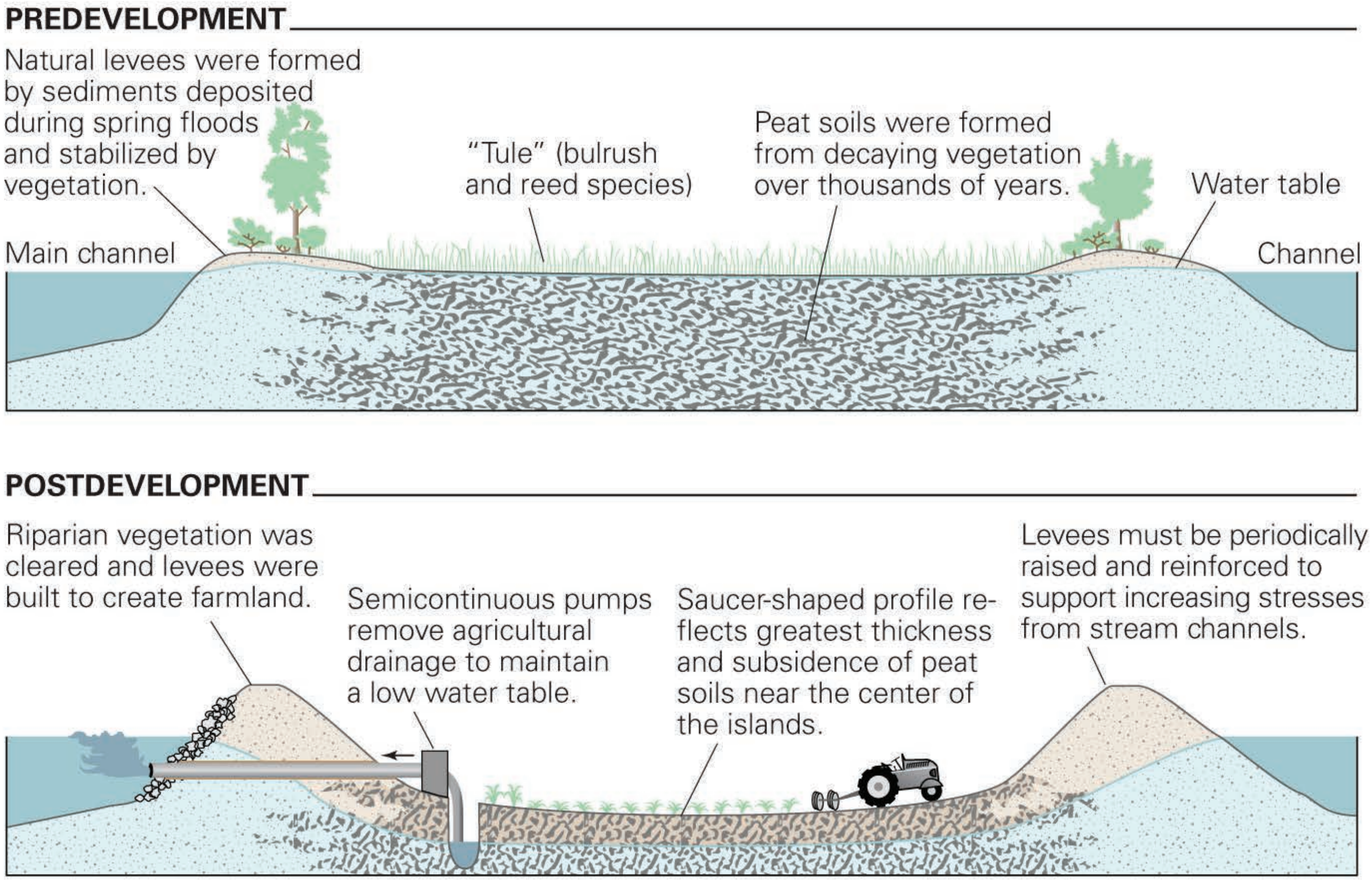
Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

URS
in association with:
Fugro WLA

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.

Not to scale

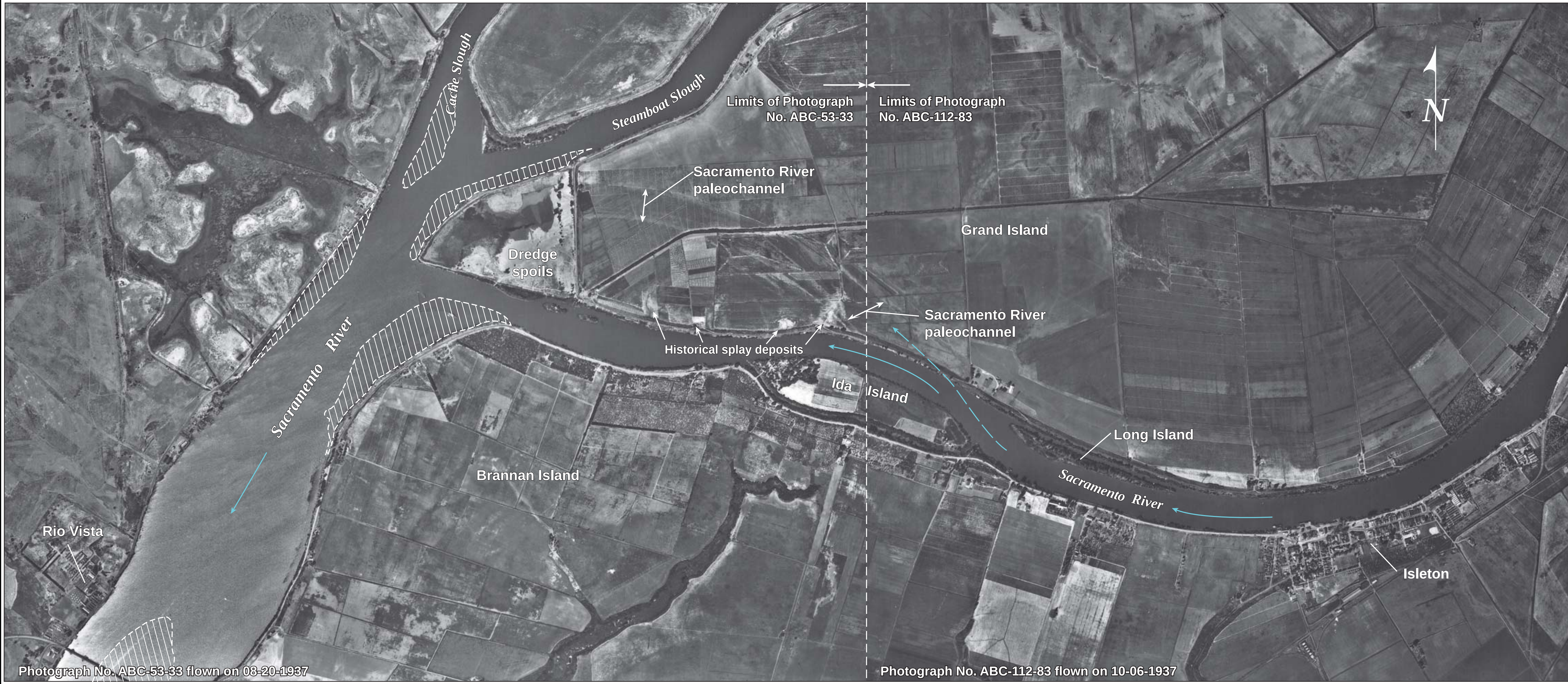
Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

URS in association with: WLA William Lettis & Associates, Inc.

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

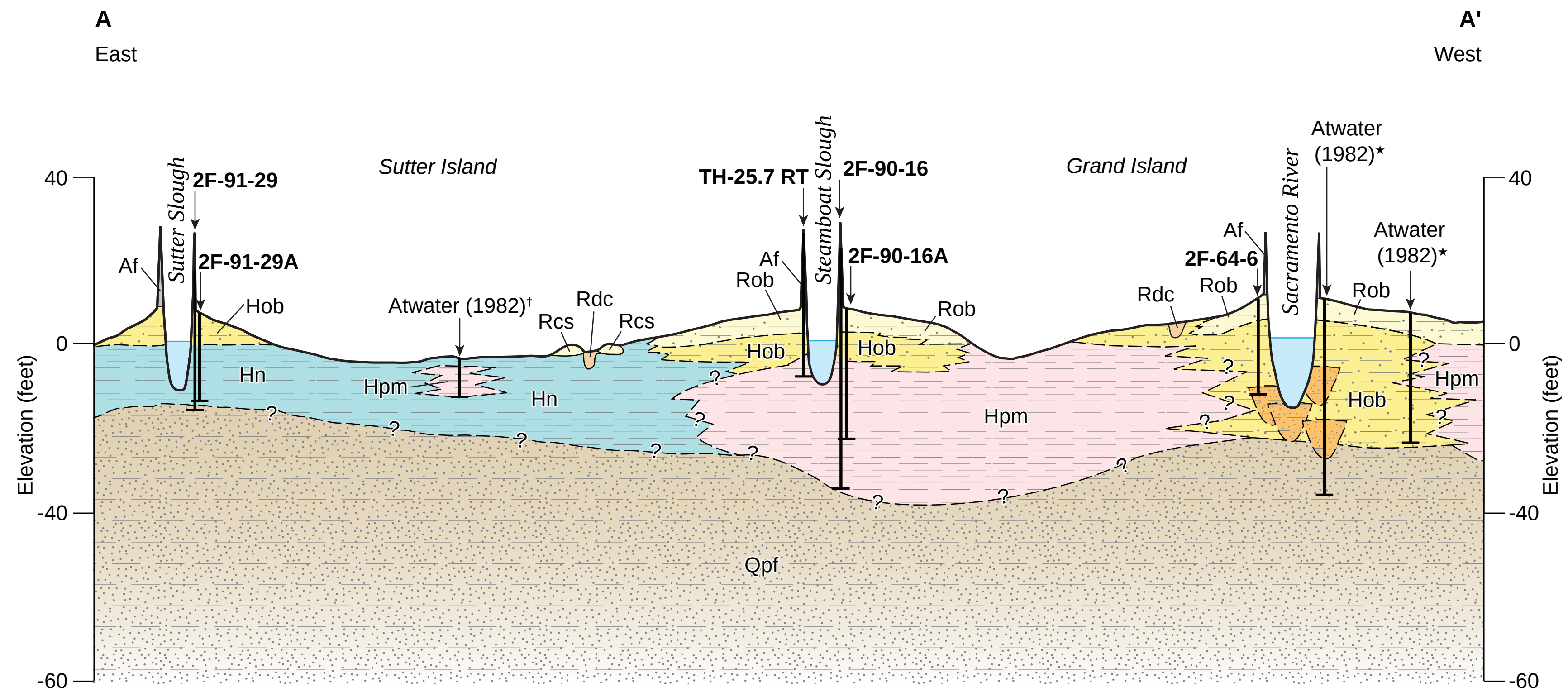
Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

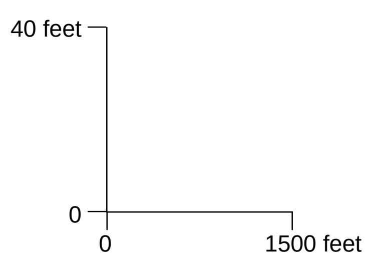
URS in association with: WLA William Lettis & Associates, Inc.

1937 Aerial Photograph of the Sacramento River near Isleton

NORTH NON-URBAN LEVEE EVALUATIONS

Figure 4





Vertical exaggeration = 37.5x

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.

Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

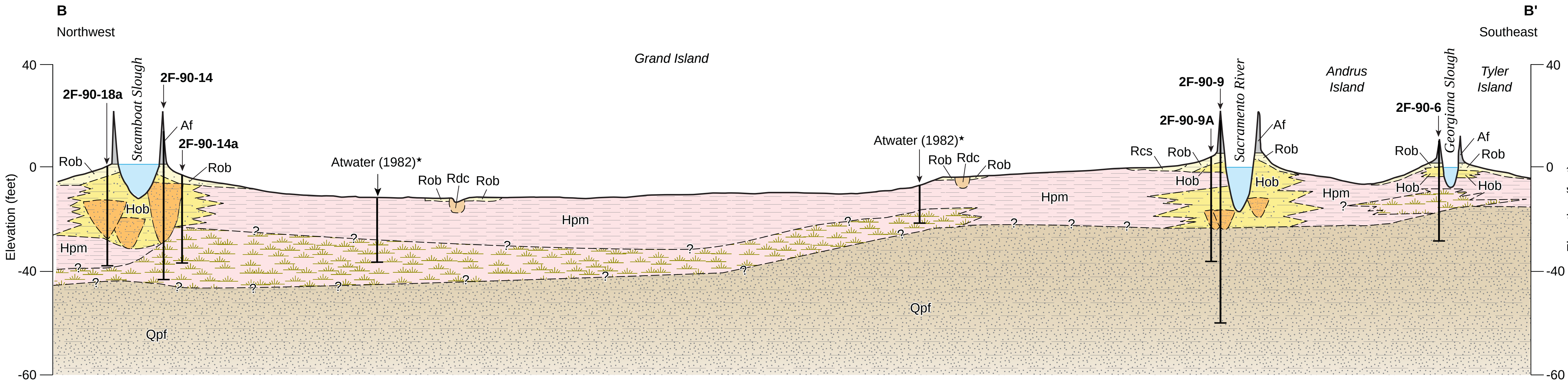
URS
in association with:
WLA
William Lettis & Associates, Inc.

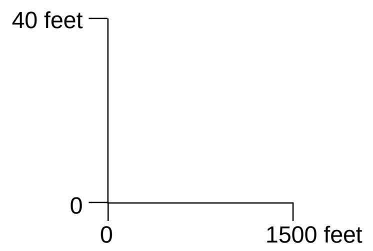
Conceptual Geologic Cross Section A - A'

NORTH NON-URBAN LEVEE EVALUATIONS

Figure 5

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





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

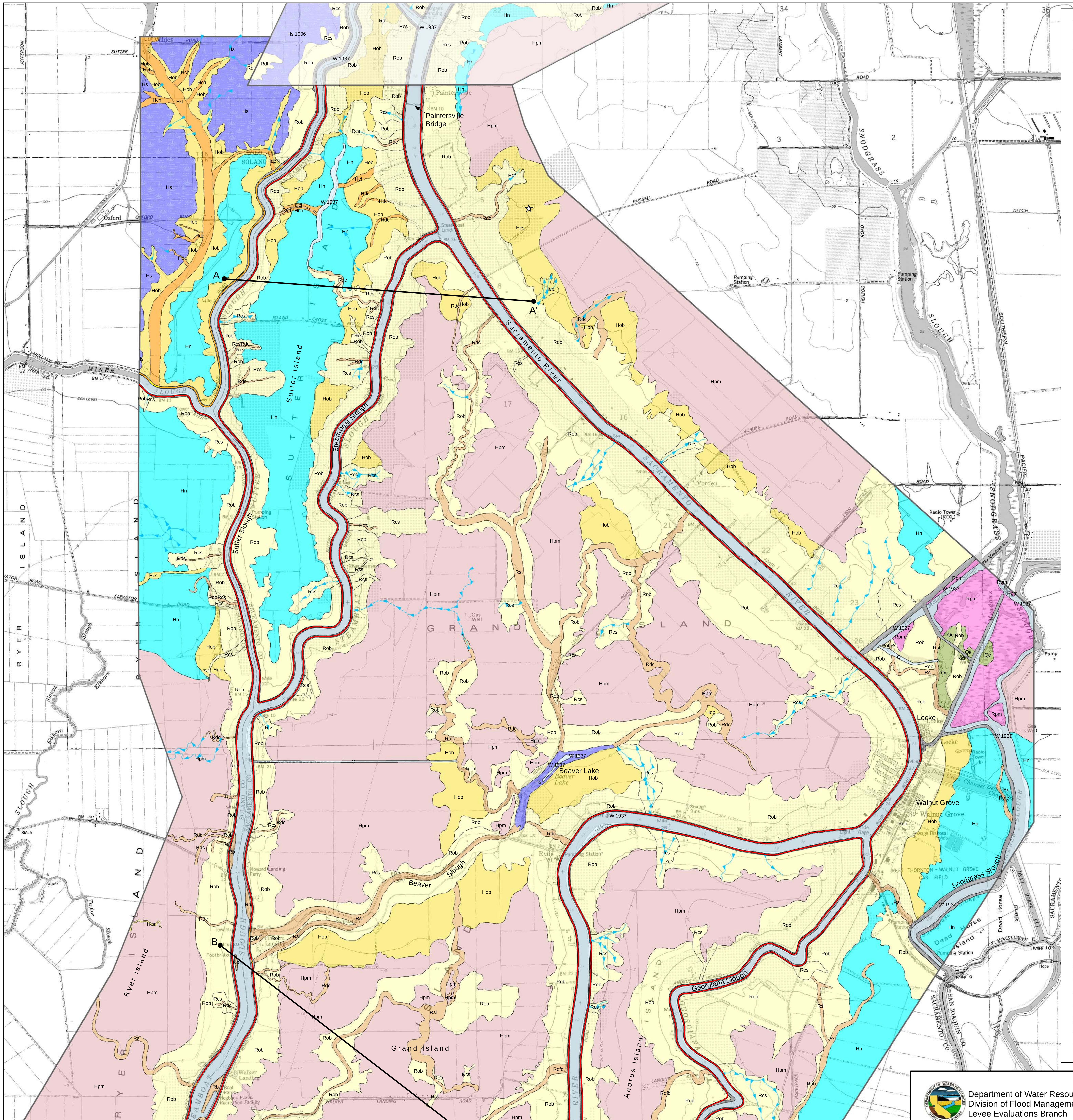
Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

URS in association with: WLA William Lettis & Associates, Inc.

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

URS in association with: Fugro William Lettis & Associates, Inc.

Surficial Geologic Map of South of Courtland Study Area

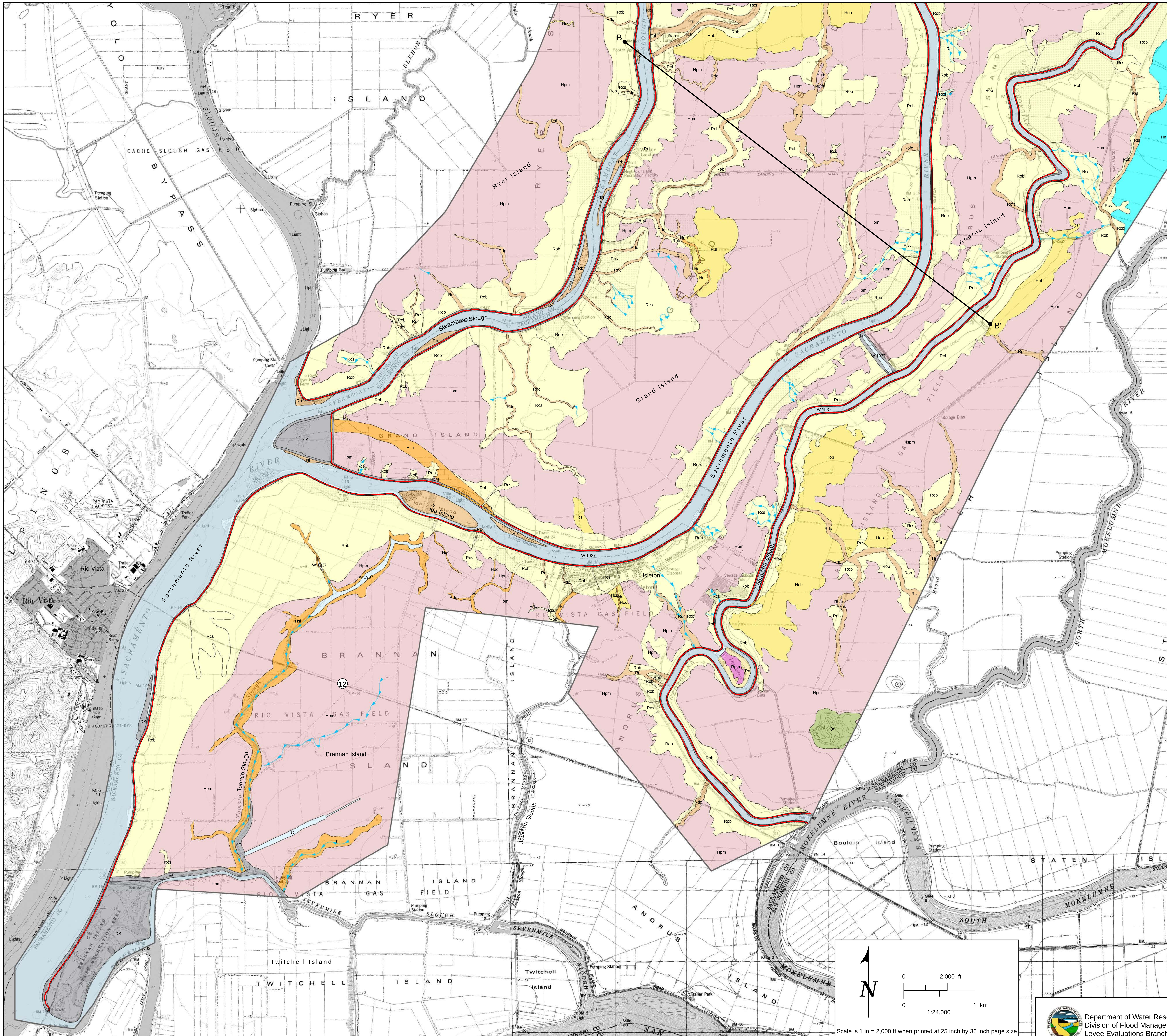
NORTH NON-URBAN LEVEE EVALUATIONS

Plate 1

Sheet 1

NULE Level 2-II: Group B Levees Geomorphic Assessment

1965_2_NULE_GroupB_Plate_North.mxd MGT 12/21/10



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

HISTORICAL

- AF — Artificial fill, circa 1937.
- L — Levee (made of artificial fill), circa 1937.
- DS — Dredge spoils; material from channel dredging and typically hydraulically emplaced.
- 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			
Epoch	Channel deposits	Floodplain and alluvial-fan deposits	Flood basin deposits		Cultural deposits
Historical	Rch; Rb, Rdc; Rofc, Rsl	Ra; Rob; Rcs	Hn	Rpm	L, AF, DS
Holocene	Hch; Hsl; Hdc	Ha; Hob; Hcs, Hdf	Hn	Hpm	
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

Department of Water Resources
Division of Flood Management
Levee Evaluations Branch

URS
in association with:
Fugro William Lettis & Associates, Inc.

Surficial Geologic Map of South of Courtland Study Area

NORTH NON-URBAN LEVEE EVALUATIONS

Plate 1

Sheet 2

NULE Level 2-II: Group B Levees Geomorphic Assessment

1965_2_NULE_GroupB_Plate_South.mxd MGT 12/21/10

Appendix C

Existing Exploration Logs

2868 Prospect Park Drive, Suite 310
Rancho Cordova, CA 95670
916.631.4500 fax 916.631.4501

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

6-17-98
REGISTERED GEOTECHNICAL ENGINEER

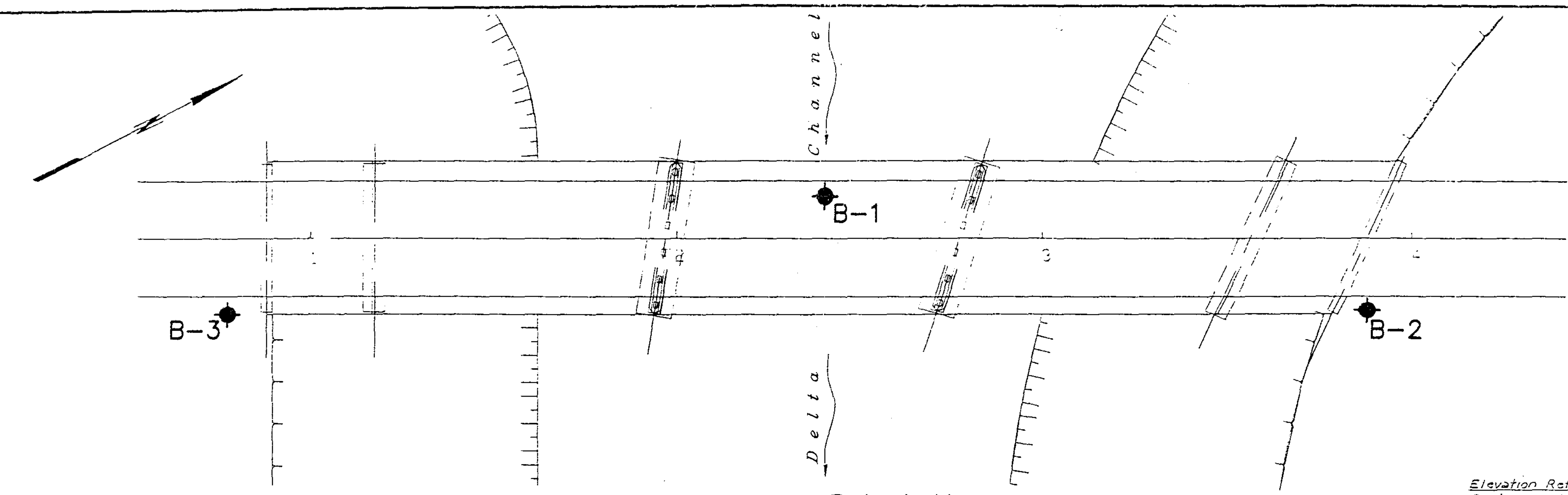
REGISTERED PROFESSIONAL ENGINEER FRANKLIN P. TABER No. 816 EXP. 3-31-00 GEOTECHNICAL STATE OF CALIFORNIA

PLANS APPROVAL DATE

TABER CONSULTANTS
536 Galveston Street
West Sacramento, CA 95691

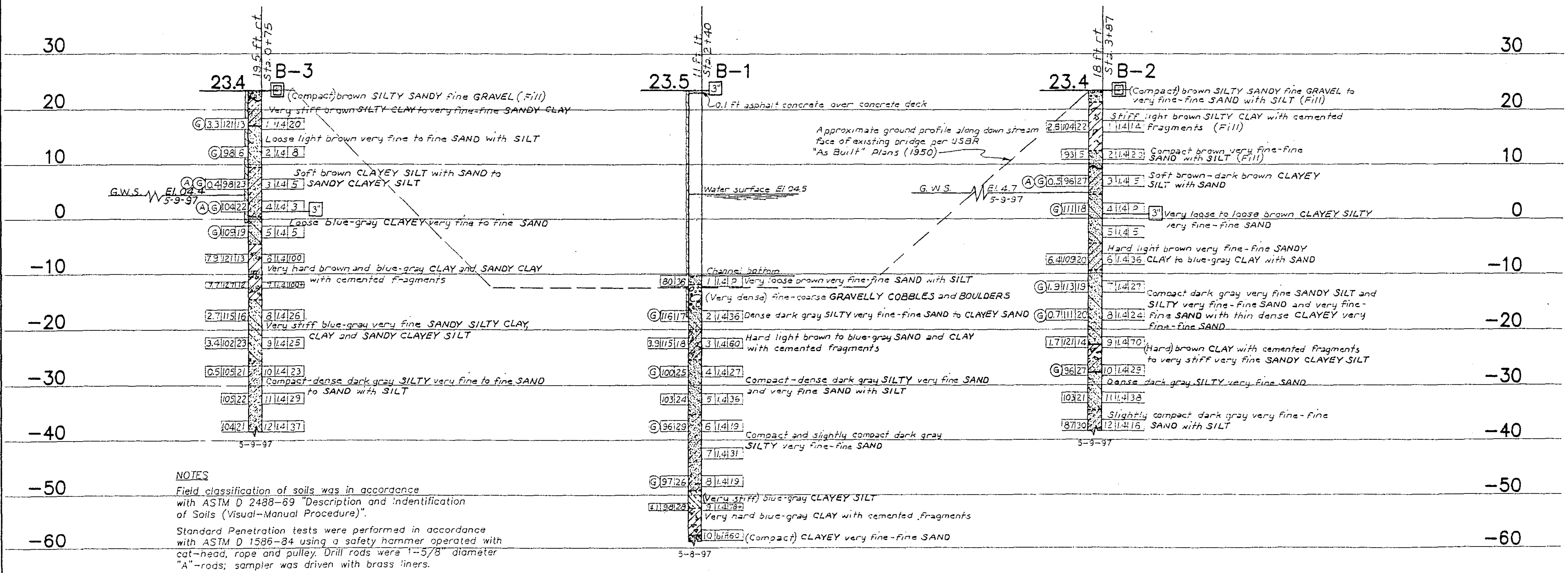
JOB No. 1R2/396/64-2 (Task 5) LOCATION: 38121-85: 444N: 026W

Dokken Engineering
3054 Gold Canal Drive
Rancho Cordova, CA 95670



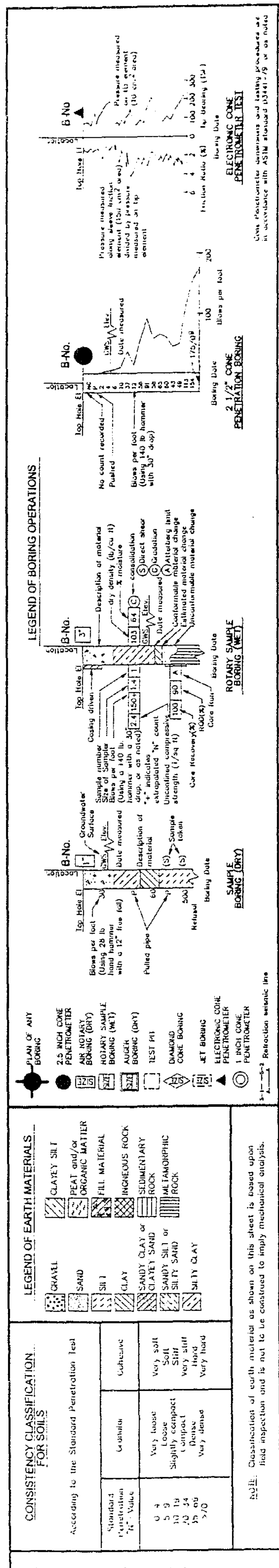
PLAN
1" = 20'

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 Identification 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



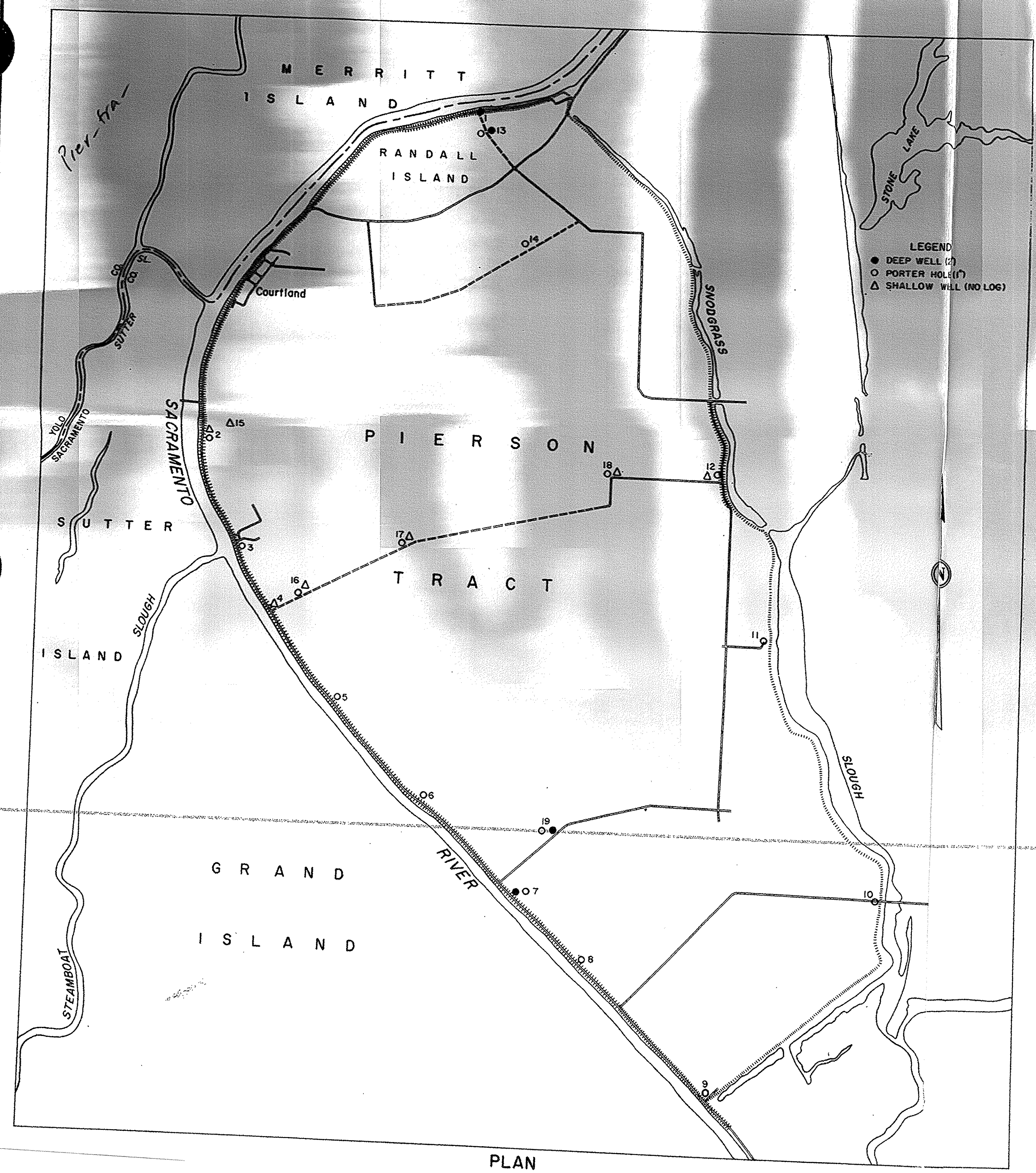
LOCATION: 38121-85 N444: W026

EARTHQUAKE RETROFIT
DELTA CROSS CHANNEL BRIDGE
LOG OF TEST BORINGS

DESIGN OVERSIGHT	DRAWN BY	J. O. Darr	T. A. Krause (FIELD INVESTIGATOR)	PREPARED FOR SACRAMENTO COUNTY	John Maniscalco (PROJECT ENGINEER)	BRIDGE NO. 24C-0167
SIGN OFF DATE	CHECKED BY	T. A. Krause	DATE May 1997			POST MILE

CU 03 EA 421703

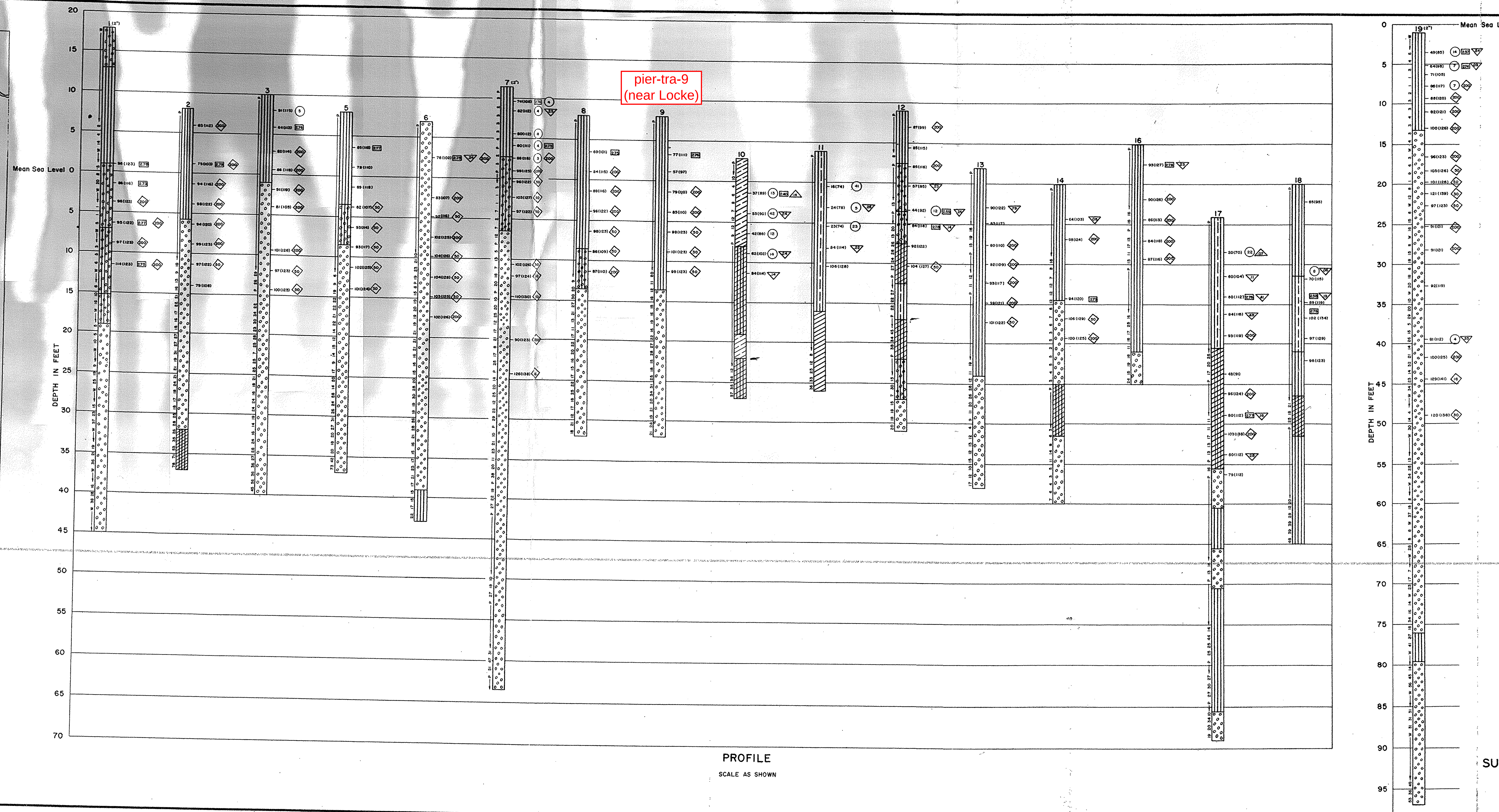
6/98 R239664-2.dwg



PLAN

SCALE IN FEET

2000 0 2000 4000 6000



PROFILE

SCALE AS SHOWN

NOTES:

GRAPHIC LOGS ARE BASED ON VISUAL CLASSIFICATION.
ALL BORINGS ARE ONE INCH DIAMETER, EXCEPT WHERE NOTED.
HAMMER WEIGHT - 1" HOLES 116 lbs., 2" HOLES 175 lbs.
DRILLING DATES:
1" HOLES — JAN. 31, 1958 TO MAY 14, 1958
2" HOLES — FEB. 11, 1958 TO APRIL 15, 1958

LEGEND

9(70) DRY (WET) DENSITY IN POUNDS PER CUBIC FOOT

UNCONFINED COMPRESSIVE STRENGTH, K_c Kg/cm^2

UNCONFINED COMPRESSIVE STRESS AT 10% STRAIN, S_{10} Kg/cm^2

LOSS ON IGNITION IN PERCENT

MAXIMUM SIEVE SIZE RETAINING 50% OF SAMPLE BY WEIGHT, D_{50}

SPECIFIC GRAVITY

SILT — ORGANIC CLAY

PEAT — SILTY PEAT

CLAY — SILTY CLAY

SAND — SILTY SAND

ORGANIC SILT — SAND, WITH SILT LENSES

STATE OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES
DIVISION OF RESOURCES PLANNING
SALINITY CONTROL BARRIER INVESTIGATION

SUBSURFACE EXPLORATION ON PIERSON TRACT

PLAN AND PROFILE OF BORINGS

SCALE AS SHOWN