Appendix F2. Levee Vulnerability Assessment (Final Draft)

1. Introduction and Purpose

The Delta Conveyance Project (Project) would include intakes C-E-3 and C-E-5 along the Sacramento River between the confluences with American River and Sutter Slough, the Bethany Reservoir Alignment tunnel to convey water from the intakes to the southern end of the Delta, and the Bethany Reservoir Pumping Plant with associated facilities to deliver water to the existing State Water Project.

The internal diameter of the tunnel would be 36-foot for the Project design capacity of 6,000 cubic feet per second (cfs). The tunnel would be located primarily within the Delta, which is a flood-prone area with many islands and tracts below sea level and protected by approximately 1,100 miles of earthen levees (Arcadis, 2017). In most cases, levees were constructed over many years to protect the island interiors from inundation and reduce flood risk to the residents and workers operating within the Delta (DWR, 1982). The ability for these levees to withstand hydraulic loading is critical to the success of the Project; many of the levees will be relied upon to provide flood protection during construction as well as protect permanent assets and infrastructure. Additionally, many levees within the Delta have roads constructed on their crowns which provide regional access within the Delta. It is an objective of the Project to avoid to the extent practical the use of existing levee crowns as haul routes, but existing roads are still critical for everyday traffic, levee maintenance and monitoring, as well as access to some Project locations. Conceptual development of Project options and features warrants consideration of the condition of existing levees given the importance of flood protection in the Delta and the significant role of levees in the Delta.

The purpose of this TM is to:

- Provide an overview of existing levee geometry standards
- Describe the approach and findings of a relative vulnerability assessment of levees within the Project

1.1 Organization

This TM is organized as follows:

- Introduction and Purpose
- Methodology
- Analysis and Results
- Observations and Conclusions
- References
- Attachment 1 – Levee Geometry Standards
- Attachment 2 – Figures

1.2 Summary of Results

A brief summary of the results from this study are presented below.

- Five criteria and corresponding numeric scoring system were developed to assess relative levee vulnerability which include:
  - Criterion 1 – Levees Meeting Levee Geometry Standards
  - Criterion 2 – Freeboard Against the 100-year Flood Elevation
  - Criterion 3 – Ditches Proximity (if present) to landside toe of levee or berm
  - Criterion 4 – Vulnerability to Sea Level Rise
  - Criterion 5 – Change in Levee Crest Elevation Between 2007 and 2017 LiDAR
- Each relative vulnerability criterion is evaluated by cross-section and is summarized as the percentage of levee cross-sections evaluated within a levee system meeting a specific standard established by the criterion. The individual vulnerability criteria are weighted and combined to provide a relative vulnerability score by cross-section. The vulnerability scores of all cross-sections are grouped and sorted into quartiles and assigned a levee rating of "Very Low," "Low," "Medium," or "High," relative vulnerability.
- A summary of key statistics that can be extracted from the vulnerability criteria when considering the entire data set used in this assessment includes:
  - Criterion 1 – 72% of levee cross-sections reviewed have geometry that meet or exceed the Public Law 84-99 (PL84-99) Delta-specific levee geometry
  - Criterion 2 – 86% of levee cross-sections reviewed have at least 1.5 feet of freeboard above the 100-year flood elevation level
  - Criterion 3 – 44% of levee cross-sections reviewed do not have a toe-ditch, or if a toe-ditch is present, it is beyond 4 levee heights from the landside levee toe or beyond 2 levee heights from the berm toe
  - Criterion 4 – 47% of levee cross-sections reviewed have at least 1.5 feet of freeboard above a 100-year flood elevation that considers potential Sea Level Rise (SLR)
  - Criterion 5 – 82% of levee cross-sections reviewed have a 2017 crest elevation that is within 0.5 feet of the 2007 crest elevation

2. Methodology

The levees in the Delta are exposed to many hazards that may damage or cause failure, resulting in flooding of the island interior. The most significant hazards are due to hydrologic, hydraulic, and seismic (earthquake) loading which can lead to seepage and stability-related failures. A variety of site-specific conditions can also contribute to a levee's vulnerability for failure when subjected to loading including poor/weak embankment or foundation soils, insufficient levee geometry (height, width, and slope inclination), and various types of particularly damaging animal activity or vegetation growth.

The goal of this assessment is to evaluate indicators of levee condition that are not heavily reliant on site-specific subsurface data while providing meaningful results to compare levee vulnerability. Existing levee geometry can provide an indication of how levee systems may perform during different loading conditions and can provide an even stronger indication of how levees might perform relative to one another. Larger levees that are tall with wide crests and shallow slopes will inherently be less vulnerable compared to smaller levees with similar composition, loading and foundation conditions. Important geometric considerations related to levee vulnerability which can be extracted from topographic data include:

- Overall levee cross-sectional geometry (levee height and slope inclinations) which inherently provide a metric of seepage and slope instability susceptibility
- Freeboard which provides a direct measure of the maximum flood level a levee can protect against which translates to a risk of overtopping
- Proximity of a toe-ditch to the levee toe (if present) which may thin or penetrate subsurface fine-grained blanket layers and increase underseepage and slope instability susceptibility
- Vulnerability to SLR which evaluates the current condition of levees under increasing future water levels.
- Past changes in levee crest elevation provides an indication of potential future levee settlement and, in turn, reflect areas that may require future levee modifications to maintain flood protection

Criterion specific to each of the above considerations was developed to evaluate levees within the Project vicinity. The evaluation was performed using cross-sections developed every 500 feet along the levee alignments using LiDAR data collected and provided by the Department of Water Resources (DWR). The geometric criteria developed for this study do not provide a comprehensive evaluation of a levee system or guarantee levee performance. The results provided herein are intended to help locate Project infrastructure and better understand potential flood risks within Bethany Reservoir Alignment Project area. This vulnerability assessment does not replace the need for site specific investigations, testing, and analyses. This initial screening-level levee relative vulnerability analysis involved three primary steps:

- Develop relative vulnerability criteria
- Apply criteria to levee cross-sections throughout the Project area
- Summarize frequency of vulnerability rankings by levee system

2.1 Information Sources

2.1.1 Background

Numerous programs and supporting studies have been performed to evaluate the conditions of existing levees in the Delta and potential vulnerabilities due to flooding and seismic events. The programs included assessments on the Delta's ecosystem and habitat, water quality, water availability, natural hazards impact, land use, economic impact, etc. The levee studies were performed with various objectives and levels of detail and culminated in providing a range of data compilations and levee performance evaluations with varying approaches and spatial distributions. Specific programs that contained information used to support the screening-level levee vulnerability assessment discussed herein include:

- **Delta Risk Management Strategy (DRMS) 2005-2008:** The intent of the program was to evaluate the performance of the levees under various stressors and hazards and assess the potential consequences (risks) for economic, public health, and safety in the event of levee failures. The DRMS study was performed in two phases, Phase 1-Risk Analysis, and Phase 2-Risk Reduction and Risk Management Strategies. The source information pulled from the Delta Risk Management Strategy (URS, 2008) used for this effort is presented in Section 2.1.2.

Other studies reviewed that contain pertinent site-specific information that could support design level engineering, but were not incorporated into this screening level assessment are:

- **Delta Levee Investment Strategy (DLIS) 2013-2017:** The DLIS study area included the Sacramento-San Joaquin Delta and the Suisun Marsh. The program applied a risk analysis methodology to identify an investment strategy for the State based on risks to the levee system by considering threats to the levees and the assets they protect. The DLIS study evaluated the probability of flooding for a given island/tract considering two hazards that could cause a levee to breach; hydraulic flooding from high water or seepage, and seismic activity. The vulnerability to each of these hazards was represented with a fragility curve and the condition of the levee.
- **Central Valley Flood Protection Plan (CVFPP) 2008-2012:** The intent of the CVFPP is to provide a systemwide plan to manage flood control facilities that are part of the State Plan of Flood Control (SPFC). SPFC includes projects and facilities that the Central Valley Flood Protection Board and DWR have provided assurance of cooperation to the federal government. Non-Project levees are not within the plan.
- **Urban Levee Evaluation Program (ULE) 2008-2014:** The purpose of the Urban Levee Evaluation (ULE) Program was to evaluate urban Project levees and appurtenant Non-Project levees and determine whether they meet established United States Army Corps of Engineers (USACE) levee design criteria for seepage and slope stability. The program also identified potential levee deficiencies with recommended improvements, repair alternatives, and associated costs. The evaluation process was performed in several steps, beginning with historical data collection and preparation of a Technical Review Memorandum (TRM). Additional subsurface geotechnical and laboratory testing was then performed and summarized in a Geotechnical Data Report (GDR). Based on the findings from the TRM and GDR, a Geotechnical Evaluation Report (GER) was prepared that presented seepage, slope stability, and seismic evaluations. The GER also included analyses and recommendations for remediation of those levee segments not meeting criteria. The ULE program divided the SPFC system into urban “Study Areas” for investigation, analysis, and reporting. Study Areas that have potential relevance to the Project include the Sacramento River, West Sacramento, and South West Sacramento Study Areas.
- **Non-Urban Levee Evaluation Program (NULE) 2008-2014:** The purpose of the Non-Urban Levee Evaluation (NULE) Program was to evaluate non-urban Project levees and appurtenant Non-Project levees and determine whether they meet a defined geotechnical design criteria. The program covered a large geographical area, and as such, was divided into two “basin” study areas; the North NULE study area encompasses the area within the Sacramento River Basin, and the South NULE study area encompasses the area with the San Joaquin River Basin. The evaluation of the levees within each study area was performed in two phases. Phase 1 evaluation entailed using non-intrusive studies using readily available information and preparing a Geotechnical Assessment Report (GAR). The GAR included an assessment of each levee segment and categorized the segment based on a determined hazard level. Phase 2 evaluation entailed performing field and laboratory testing, geotechnical analyses, and preparing a GDR and a corresponding Geotechnical Overview Report (GOR) for specific areas or segments.
- **California Bay-Delta Program (CALFED) 1994-2008:** The intent of the CALFED Program was to systematically address the concerns and reliability of the Delta water supply through the participation and coordination with federal, State, and local governments. There were four main areas that the CALFED Program focused on: Ecosystem Health, Water Quality, Water Supply Reliability, and Levee System Integrity. The intent of the Levee System Integrity focus area, or CALFED Levee Program, was to identify and reconstruct those levees not meeting USACE PL84-99

Delta Specific Standard. One of the premises is that the system-wide levee stability is improved if all levees meet this standard.

- **Available Reclamation Districts 5-year plans:** The purpose of the 5-year plans is for individual reclamation districts to summarize the engineering, construction and funding goals needed to meet or maintain a specific levee standard to increase flood protection to qualify for state and/or federal funding.

2.1.2 Data Sources

Data used for this levee vulnerability assessment includes:

- **Flood Elevation Data**: The 100-year flood elevations used for the assessment are based on geographic information system (GIS) data compiled by DWR for *Analysis of Delta Levees Compliance of HMP [Hazard Mitigation Plan] and PL 84-99 Design Geometry* (DWR, 2011) as described in the DLIS. The hydrologic inputs are largely based on previous hydrology studies prepared by USACE in 1976 and 1992 for the Sacramento – San Joaquin Delta (USACE, 1976; 1992). The Bulletin 192-82 theoretical prism check is the only component of this relative levee vulnerability evaluation that relies on the 300-year flood elevation data. The 300-year flood elevation was not available in GIS format from DWR, so the 300-year flood elevations by levee system were hand-estimated using the hydraulic profiles provided in the USACE 1992 study. Locations not included in the USACE 1992 study were assumed to have a 300-year flood elevation 0.5 feet above the 100-year values provided in the DWR GIS data based on the average difference observed on existing profiles throughout the Delta. These flood elevations are used for the freeboard requirements for Delta levee geometry Standards. 100-year flood elevations are used in Hazard Mitigation Plan (HMP), and Public Law (PL) 84-99 (PL 84-99) levee standards. 300-year flood elevations are used in the DWR Bulletin 192-82 (192-82) levee standard.
- **Levee Stationing**: Levee stationing and levee alignments within the study area are based on data accumulated by the DWR Delta Levees Program, which has been updated from time to time based on updated levee alignment information provided by local levee reclamation districts and maintenance agencies. The fundamental source of the levee stationing was provided as station points in the USACE 1992 study; however, these have been adjusted to new levee centerlines where levee alignments have been modified since the 1992 report.
- **Organics/Peat Thickness**: The thickness of organic material in the levee foundation as an input to define the required landside slope geometry to meet Delta levee geometry standards. Contours of organics/peat thickness were previously developed and digitized for the Delta Risk Management Strategy (URS, 2008) and were used in this levee vulnerability assessment.
- **LiDAR Survey Data**: The cross-sectional data used in this vulnerability assessment was developed using LiDAR data obtained by DWR in December 2017 and January 2018. The vulnerability assessment uses a simplified slope geometry defined by crest elevation, crest width, landside levee height, waterside and landside slope, landside berm height and slope, if present, and landside toe-ditch location, if present. The specified vertical accuracy of the 2017 LiDAR was reported as 0.65 feet, but with better vertical accuracy of 0.33 feet in non-vegetated areas (e.g., levee crown). 2007 LiDAR collected by DWR was the source of past geometry studies, such as the Delta Levee Investment Strategy (Arcadis, 2017). The 2007 LiDAR data was also incorporated into this levee vulnerability study by comparing changes in crest elevation between 2007 and 2017.

The levee vulnerability study was performed using 5,151 cross-sections developed along levee systems that fall within the alignment. The cross-sections are typically spaced every 500 feet along the levee centerline. Internal levees that are not intended to provide flood protection are typically not included in the data set. The study included levees throughout the Delta. A summary of the cross-sections for each levee system along the Bethany Reservoir Alignment and included in the data set is presented in this TM, including Table 1 below.

Table 1. Levee Systems Considered in Vulnerability Assessment

Number of analysis sections considered per levee system

Levee System	Analysis Sections[a]
Brack Tract	139
Byron Tract	138
Canal Ranch	102
Clifton Court Tract	52
Coney Island	59
South of Delta-Mendota Canal and Old River	51
Drexler[b]	117
DWR Maintenance Area 9	91
Ehrheardt Club	80
Fabian Tract	199
Glanville Tract	135
Honker Lake Tract[b]	63
King Island	96
Libby McNeil	49
Lower Jones Tract	96
Upper Jones Tract	100
Lower Roberts Island[b]	154
McCormack-Williamson Tract	92
Middle Roberts Island[b]	46
New Hope Tract	197
Randall Island	20
Rindge Tract	166
Terminous Tract	223
Union Island East	160
Union Island West	172
Victoria Island	159
Walnut Grove	30

[a] Analysis sections are typically taken every 500 lineal feet.

[b] Lower Roberts Island, Middle Roberts Island, Upper Roberts Island (No data available), Honker Lake Tract and Drexler are all located within the same levee system. The data extents do not cover the entire perimeter of the levee system

2.2 Levee Geometry and Freeboard Standards

Levee geometry standards and requirements in the Delta vary based on Project versus Non-Project levees, and Urban versus Non-Urban levees. Project levees are those levees that were either built, rebuilt, or adopted and maintained to USACE standards. Non-Project levees have been built and are maintained by private interests or local districts. Urban and Non-Urban levees are those that protect a population greater, or less than 10,000, respectively. The design standards that apply to the Delta levees are summarized below.

2.2.1 Flood Hazard Mitigation Plan (HMP)

The Flood Hazard Mitigation Plan (HMP) prepared by DWR in 1983 outlined a set of conditions including maintenance and rehabilitation that a reclamation district should demonstrate in order to receive federal disaster relief. The plan included a “Short-Term Rehabilitation Plan” to receive federal disaster aid until a “Comprehensive Long-Term Mitigation Plan” is implemented. Part of the plan included the local agencies or district to maintain a minimum levee geometry consisting of:

- Freeboard of 1 foot above the 100-year WSEL
- Crown width at least 16 feet
- Waterside slope inclinations of 1.5 horizontal to 1 vertical (H:V)
- Landside slope inclinations of 2H:1V
- Levees should have all-weather access roads

DWR and FEMA agreed to these design guidelines, and those reclamation districts that met the HMP qualified for FEMA disaster relief; however, this agreement is no longer in place.

2.2.2 Public Law 84-99

The Sacramento District of USACE established a Delta-specific standard for levees as part of PL 84-99, which defines the minimum levee configuration as:

- Freeboard of 1.5 feet over the 100-year WSEL
- Crown width of 16 feet
- Waterside slope of 2H:1V
- Landside slope that ranges from 3H:1V to 5H:1V depending on height of levee and thickness of peat (See Attachment 1)

The minimum geometry criteria (USACE, 1987) was not intended to become a “design standard” for the Non-Project levees, but rather a uniform procedure to establish eligibility for PL 84-99 aid; however, the criteria are widely used and applied to both Non-Urban and Urban levees in the Delta.

2.2.3 DWR Bulletin 192-82

A levee investigation program undertaken as a joint study between DWR and USACE resulted in Bulletin 192-82, Delta Levees Investigation, by DWR (DWR, 1982) with supplemental geometry criteria later provided by DWR (DWR, 1989). The objective of the study was to primarily identify a plan to improve Non-Project levees within the Delta. Separate geometry standards were developed for levees protecting Urban and Agricultural (Non-Urban) Tracts. The levees evaluated in this levee vulnerability assessment classify as agricultural (Non-Urban) levees. The plan resulted in a minimum design configuration consisting of:

- Freeboard using a 300-year WSEL should be 1.5 feet for agricultural (non-urban) areas and 3.0 feet for urban areas, respectively.
- Crown width at least 16 feet:
  – Waterside slope inclinations of 2H:1V (horizontal: vertical)
- Landside geometry varies based on height of levee, thickness of peat, and if a berm is present:
  – Landside slopes without a berm range from 3H:1H to 7H:1V (See Attachment 1)
  – Landside levee slopes with a berm are 3H:1V and include berms that are ½ the levee height with slopes that range from 3H:1V to 13H:1V (See Attachment 1)

The plan was intended to eventually have all levees within the Delta, regardless of being Urban or Non-Urban, upgraded to a minimum configuration and thus reducing the chances for failure. At the time of the Bulletin 192-82 report, this amounted to approximately 537 miles of Non-Project levees.

2.3 Relative Levee Vulnerability Criteria

The relative levee vulnerability criteria presented herein was developed internally by the DCA team and through feedback on the approach provided by the DCO. The criteria used in this TM to evaluate relative levee vulnerability are as follows:

- Criterion 1 – Levees meeting levee geometry standards
- Criterion 2 – Freeboard against the 100-year flood elevation
- Criterion 3 – Ditches Proximity of toe-ditch (if present) to landside toe of levee or berm
- Criterion 4 – Vulnerability to sea level rise
- Criterion 5 – Change in Levee Crest Elevation between 2007 and 2017 LiDAR

Each criterion was evaluated using a rating score that varied from 1 to 4 scale (1 being unfavorable, 4 being favorable) and was assigned an importance (weighting) factor ranging from 1 to 5 scale (1 being of little importance, 5 being very important). The rating scores and importance factors were multiplied together for each criterion and the cumulative sum of all criteria provides a levee vulnerability score. The vulnerability scores can then be grouped and compared to provide a relative levee vulnerability rating (Levee Vulnerability Rating). Further discussion of the rating score for each criterion, levee vulnerability score, and levee vulnerability rating are provided below. A summary of the criteria, rating scores, and importance factors used in the assessment is provided in Table 2.

Table 2. Levee Vulnerability Evaluation Criteria and Vulnerability Ratings

The criteria and rating scores used to evaluate levee cross-sections
Rating Score (Lower Numbers = Worse Conditions)

Criterion	Importance Factor	1	2	3	4
Levees Meeting Geometry Standards	5	Does Not Meet HMP	Meets HMP	Meets 84-99	Meets 192-82
Freeboard Against 100-year Flood Elevation	3	less than 0 feet	0 to less than 1 foot	1 to less than 1.5 feet	Greater than or equal to 1.5 feet

Criterion	Importance Factor	1	2	3	4
Toe Ditches	2	Ditch is present within 1 levee height from landside levee toe and no berm is present	Ditch is present within 1 to 2 levee heights from landside levee toe or 1 levee height from berm toe	Ditch is present within 2 to 4 levee heights from landside levee toe or 1 to 2 levee heights from berm toe	No ditch or ditch is present beyond 4 levee heights from landside levee toe and beyond 2 levee heights from berm toe
Vulnerability to Sea Level Rise	2	Freeboard less than 0 feet	Freeboard 0 to less than 1 foot	Freeboard 1 to less than 1.5 feet	Freeboard greater than or equal to 1.5 feet
Change in Levee Crest Elevation	2	>1.0 ft decrease in crest elevation from 2007 to 2017	0.75 to 1.0 ft decrease in crest elevation from 2007 to 2017	0.5 to 0.75 ft decrease in crest elevation from 2007 to 2017	Less than 0.5 ft decrease in crest elevation from 2007 to 2017

The vulnerability criteria used in these analyses are based on LiDAR data and are therefore limited by the level of accuracy associated with the source data set. Allowable tolerances in the assessment were incorporated so that small deficiencies that are within the vertical accuracy tolerance of the source data do not flag a levee section as deficient. Allowable tolerances used for the criteria are provided below.

2.3.1 Criterion 1 – Levees Meeting Geometry Standards

In general terms, levee geometries defined by the HMP, PL84-99, and Bulletin 192-82 result in increasingly robust cross-sections; meaning that levees meeting Bulletin 192-82 also meet PL84-99 and HMP. For this analysis, the existing levee geometry was compared to each geometry standard provided in the HMP, PL84-99, and Bulletin 192-82; and a rating score was assigned to that levee section based on the most stringent standard met. Rating score metrics for this category were assigned as follows:

- Rating Score 1: Section does not meet a theoretical levee prism defined by HMP
- Rating Score 2: Section meets a theoretical levee prism defined by HMP
- Rating Score 3: Section meets a theoretical levee prism defined by PL84-99
- Rating Score 4: Section meets a theoretical levee prism defined by Bulletin 192-82

An allowable tolerance of +/- 0.1 feet was applied to levee crown elevations based on greater accuracy of LiDAR obtained in unvegetated areas. An allowable tolerance of +/- 1.0 feet was applied to levee toe elevations since the vertical accuracy of LiDAR data in vegetated areas is lower and levee performance is not as sensitive to geometry discrepancies compared to the levee crest.

Levee geometry standards are well known in the Delta and are commonly used as a metric to assess the robustness of a levee and its ability to provide flood protection. The geometry standards incorporate various minimum levee configurations that provide a uniform landside slope stability factor of safety of 1.25 for PL84-99 (USACE, 1987) and a landside stability factor of safety of 1.3 for Bulletin 192-82 (DWR, 1982). Given the significance of levee geometry in evaluating the condition of Delta levees, an importance factor of 5 was selected for this criterion representing an overall weighting of approximately 36 percent of the levee vulnerability score.

2.3.2 Criterion 2 – Freeboard Against 100-year Flood Elevation

Freeboard is a metric that is embedded in geometry standards described above. Instances where levees meet PL84-99 or Bulletin 192-82 will also meet freeboard requirements. However, levees that meet freeboard requirements but do not meet a specific geometry standard still reduce flood potential relative to levees without adequate freeboard. Therefore, a freeboard assessment independent of meeting geometry standard is included in the relative vulnerability evaluation. The criterion scoring metrics were assigned as follows:

- Rating Score 1: Freeboard against the 100-year WSEL is less than 0 feet.
- Rating Score 2: Freeboard against the 100-year WSEL is greater than or equal to 0 feet but less than 1 foot.
- Rating Score 3: Freeboard against the 100-year WSEL is greater than or equal to 1 foot but less than 1.5 feet.
- Rating Score 4: Freeboard against the 100-year WSEL is greater than or equal to 1.5 feet.

Similar to Criterion 1, an allowable tolerance of +/- 0.1 feet was applied to levee crown elevations based on greater accuracy of LiDAR obtained in unvegetated areas.

Freeboard is directly linked to crest elevation, which represents the maximum flood elevation a levee can withstand prior to overtopping. Levees can be tall, but not meet a levee geometry standard due to slope inclinations, and still provide a higher level of flood protection compared to a levee with a lower crest elevation. An importance factor of 3 was selected for this criterion, which represents an overall weighting of approximately 22 percent of the levee vulnerability score.

2.3.3 Criterion 3 – Toe-Ditches

Ditches in the Delta are often required to manage ground water levels and distribute irrigation water within a reclamation district. However, a consequence of installing toe-ditches is they can reduce the overall stability of a levee and create potentially adverse seepage paths below the levee. The presence of a toe-ditch does not mean the levee is unstable or will fail due to seepage, but it does increase the levee vulnerability relative to levees that do not have a toe-ditch. The effect of a toe-ditch on a levee is influenced by the proximity of the toe-ditch to the levee and depth of the toe-ditch. The toe-ditch depths are not well defined by the existing data sources and were therefore not considered in this assessment. The toe-ditch location relative to the landside levee toe or berm toe was considered. Rating scores for this category were assigned as follows:

- Rating Score 1: Ditch is present within 1 levee height from the landside levee toe and no berm is present.
- Rating Score 2: Ditch is present within 1 to 2 levee heights from the landside levee toe or 1 levee height from the berm toe.
- Rating Score 3: Ditch is present within 2 to 4 levee heights from the landside levee toe or 1 to 2 levee height from the berm toe.
- Rating Score 4: No ditch is present, or the ditch is present beyond 4 levee heights from the landside levee toe, or beyond 2 levee heights from the berm toe.

The presence of a toe-ditch will typically have a negative impact on levee stability and protection against seepage and piping. However, they can also be necessary to manage groundwater and can be safely implemented if properly designed. An importance factor of 2 was selected for this criterion, which represents an overall weighting of approximately 14 percent of the levee vulnerability score.

2.3.4 Criterion 4 – Vulnerability to Sea Level Rise

The conceptual construction timeline for the Project will occur over a roughly 10-year span between about 2030 and 2040 and has potential to be impacted by SLR. A uniform increase of 1.5 feet was added to the 100-year WSEL for this levee vulnerability study as a proxy for site-specific hydraulic studies to capture potential SLR as well as changes in future hydraulic conditions and uncertainty. The 1.5-foot increase in WSEL was added uniformly to the 100-year WSEL and was redefined as 100-year SLR WSEL for this levee vulnerability study. Freeboard was then checked against the 100-year SLR WSEL. Rating scores for this category were assigned as follows:

- Rating Score 1: Freeboard against the 100-year SLR WSEL less than 0 feet.
- Rating Score 2: Freeboard against the 100-year SLR WSEL is greater than or equal to 0 feet but less than 1 foot.
- Rating Score 3: Freeboard against the 100-year SLR WSEL is greater than or equal to 1 foot but less than 1.5 feet.
- Rating Score 4: Freeboard against the 100-year SLR WSEL is greater than or equal to 1.5 feet.

Similar to Criterion 1 and 2, an allowable tolerance of +/- 0.1 feet was applied to levee crown elevations based on greater accuracy of LiDAR obtained in unvegetated areas.

The vulnerability to SLR criterion considers a levee system's resiliency to increasing flood elevations during future periods of potential Project construction. The uniform increase of 1.5 feet is not based on site-specific hydraulic analyses and would generally be considered conservative for most Delta levees during a likely period of construction through 2040, particularly those along the eastern margins of the Delta. An importance factor of 2 was selected for this criterion, which represents an overall weighting of approximately 14 percent of the levee vulnerability score.

2.3.5 Criterion 5 – Change in Levee Crest Elevation

Levees within the Delta are often underlain by thick deposits of highly compressible soils that are constantly settling due to consolidation. As a result, levees that currently meet a particular geometry standard may not meet standards in the future due to settlement in combination with rising water levels. Reclamation districts also implement periodic upgrades that may include levee crest raises or other modifications to the levee geometry to maintain compliance with levee standards. Changes in crest elevation may be influenced by both ongoing settlement and/or modifications to the levee cross-section. Crest elevation decreases between the 2007 and 2017 LiDAR would be most likely attributed to settlement and provide an indication of how the levee crest may change over time and in turn lead to future flood risks. Rating scores for this category were assigned as follows:

- Rating Score 1: Crest elevation decrease greater than 1.0 feet between the 2007 and 2017 LiDAR
- Rating Score 2: Crest elevation decrease equal to 0.75 feet to less than 1.0 feet between the 2007 and 2017 LiDAR
- Rating Score 3: Crest elevation decrease equal to 0.5 feet to less than 0.75 feet between the 2007 and 2017 LiDAR
- Rating Score 4: Crest elevation decrease less than 0.5 feet between the 2007 and 2017 LiDAR.

Decreases in levee crest elevation over time do not provide a direct metric of levee flood resilience but rather an indication of settlement that may be occurring. Ongoing settlement may be connected to soft compressible foundations as well as a lack of continual attention to maintain the levee geometry. In both cases, decreases in levee crest elevation reflect a condition that may increase flooding risk during a future construction period. An importance factor of 2 was selected for this criterion, which represents an overall weighting of approximately 14 percent of the levee vulnerability score.

2.3.6 Relative Levee Vulnerability Rating

The rating scores and importance factors for the relative levee vulnerability criteria were multiplied together and summed to provide a levee vulnerability score that ranged from 14 to 56 for each levee cross-section. The lowest possible vulnerability score (highest relative vulnerability) a cross-section could receive is 14 which results from receiving a rating score of one for each of the five criteria. Similarly, the highest possible vulnerability score (lowest relative vulnerability) a cross-section could receive is 56 which is obtained by receiving a rating score of four for each of the five criteria.

The levee vulnerability scores provide a single metric that can be used to compare the relative vulnerability of one levee cross-section to another. By combining the levee vulnerability scores for all cross-sections and binning the results into quartiles, relative vulnerability ratings (Levee Rating) were developed. Each data quartile contains about ¼ of the resulting levee vulnerability scores and were assigned a Levee Rating of “Very Low,” “Low,” “Medium,” or “High” relative vulnerability. The levee scores associated with each Levee Rating are:

- High relative vulnerability: levee vulnerability score range is from 14 to 38
- Medium relative vulnerability: levee vulnerability score range is from 39 to 47
- Low relative vulnerability: levee vulnerability score range is from 48 to 52
- Very Low relative vulnerability: levee vulnerability score range is from 53 to 56

2.4 Assumptions and Limitations

The levee vulnerability assessments provided herein are based on available topographic data, subsurface data (peat/organics thickness), and existing WSELs (100-yr and 300-yr). The results of the analyses are therefore influenced by the accuracy of available data as discussed above. Assumptions used to perform the relative vulnerability assessment include the following:

- The simplified cross-section consisting of points at the waterside contact between the slope and river level, levee crest hinges, levee toe, berm toe (if present), and ditch hinges (if present) adequately represents existing levee geometry for the purposes of this study.
- Source topography is based on LiDAR and does not include bathymetry. The LiDAR data set used for this vulnerability assessment does not define the waterside toe elevation or waterside slope below the waterline at the time of the survey. These unknowns are acknowledged and assumed to be negligible.
- Inaccuracies and uncertainty present within source data will affect sections similarly throughout the Delta.
- Seismic performance and deformation were not explicitly considered in the levee vulnerability evaluations. However, some factors considered in the levee geometry evaluations are applicable to seismic vulnerability, such as peat thickness as an input in determining levee slope targets.

3. Analysis and Results

The analyses were performed using the criteria and assumptions presented in Section 2 Methodology. Results are summarized in the following subsections.

3.1 Levee Geometry Standards

The results of the levee geometry standards evaluation are summarized as a percentage of cross-sections within a levee system that received a rating score of 1, 2, 3 or 4 as shown below in Table 3. A graphical presentation of the results is presented in Figures 3-1a and 3-1b (See Attachment 2).

Table 3. Levee Geometry Standards Summary of Results

Percentage of levee system sections resulting in each Standard Levee Geometry criterion rating[a]

Levee System	1[b]	2[c]	3[d]	4[e]
Brack Tract	17	58	21	4
Byron Tract	0	0	1	99
Canal Ranch	25	39	23	13
Clifton Court Tract	0	0	0	100
Coney Island	0	8	25	66
South of Delta-Mendota Canal and Old River	0	0	0	100
Drexler	54	0	4	42
DWR Maintenance Area 9	2	0	0	98
Ehrheardt Club	41	3	3	54
Fabian Tract	0	0	0	100
Glanville Tract	27	17	18	38
Honker Lake Tract	56	8	5	32
King Island	0	14	44	43
Libby McNeil	10	6	6	78
Lower Jones Tract	1	5	22	72
Upper Jones Tract	10	28	17	45
Lower Roberts Island	0	6	8	86
McCormack-Williamson Tract	90	7	2	1
Middle Roberts Island	87	0	0	13
New Hope Tract	12	18	23	47
Randall Island	0	0	0	100
Rindge Tract	1	11	43	46

Levee System	1[b]	2[c]	3[d]	4[e]
Terminous Tract	25	48	13	14
Union Island East	0	0	0	100
Union Island West	0	0	13	87
Victoria Island	0	1	22	77
Walnut Grove	0	47	17	37

[a] Results indicate the percentage of evaluated cross-sections that fall into each rating score bin. Due to rounding, total for each levee system may not add to 100 percent.
[b] Rating Score 1: Does not meet minimum Hazard Mitigation Plan (HMP) geometry
[c] Rating Score 2: Meets HMP geometry
[d] Rating Score 3: Meets PL84-99 geometry
[e] Rating Score 4: Meets Bulletin 192-82 geometry

3.2 Freeboard

The results of the freeboard evaluation are summarized as a percentage of cross-sections within a levee system that received a rating score of 1, 2, 3 or 4 as shown below in Table 4. A graphical presentation of the results is presented in Figures 3-2a and 3-2b (See Attachment 2).

Table 4. Freeboard Summary of Results

Percentage of levee system sections resulting in each Freeboard criterion rating[a]

Levee System	1[b]	2[c]	3[d]	4[e]
Brack Tract	2	6	8	84
Byron Tract	0	0	0	100
Canal Ranch	2	18	25	56
Clifton Court Tract	0	0	0	100
Coney Island	0	0	0	100
South of Delta-Mendota Canal and Old River	0	0	0	100
Drexler	40	6	0	54
DWR Maintenance Area 9	2	0	0	98
Ehrheardt Club	36	0	0	64
Fabian Tract	0	0	0	100
Glanville Tract	13	11	2	73
Honker Lake Tract	13	13	25	50
King Island	0	0	2	98
Libby McNeil	2	0	0	98
Lower Jones Tract	0	0	2	98
Upper Jones Tract	0	7	5	88
Lower Roberts Island	0	0	1	99

Levee System	1[b]	2[c]	3[d]	4[e]
McCormack-Williamson Tract	53	36	5	5
Middle Roberts Island	0	0	0	100
New Hope Tract	4	2	11	84
Randall Island	0	0	0	100
Rindge Tract	1	0	0	99
Terminous Tract	11	10	26	54
Union Island East	0	0	0	100
Union Island West	0	0	0	100
Victoria Island	0	0	0	100
Walnut Grove	0	0	0	100

[a] Results indicate the percentage of evaluated cross-sections that fall into each rating score bin. Due to rounding, total for each levee system may not add to 100 percent.

[b] Rating Score 1: Freeboard against the 100-year WSEL less than 0 feet

[c] Rating Score 2: Freeboard against the 100-year WSEL is greater than or equal to 0 feet but less than 1 foot

[d] Rating Score 3: Freeboard against the 100-year WSEL is greater than or equal to 1 foot but less than 1.5 feet

[e] Rating Score 4: Freeboard against the 100-year WSEL is greater than or equal to 1.5 feet

3.3 Toe Ditch Proximity

The results of the toe-ditch evaluation are summarized as a percentage of cross-sections within a levee system that received a rating score of 1, 2, 3 or 4 as shown below in Table 5. A graphical presentation of the results is presented in Figures 3-3a and 3-3b (See Attachment 2).

Table 5. Toe Ditch Proximity Summary of Results

Percentage of levee system sections resulting in each Landside Toe Ditch criterion rating[a]

Levee System	1[b]	2[c]	3[d]	4[e]
Brack Tract	12	67	1	21
Byron Tract	20	58	0	22
Canal Ranch	0	71	1	28
Clifton Court Tract	0	0	0	100
Coney Island	0	90	0	10
South of Delta-Mendota Canal and Old River	0	0	0	100
Drexler	51	25	0	24
DWR Maintenance Area 9	0	2	0	98
Ehrheardt Club	6	15	0	79
Fabian Tract	24	30	1	46
Glanville Tract	34	16	7	42
Honker Lake Tract	0	0	0	100

Levee System	1[b]	2[c]	3[d]	4[e]
King Island	0	51	0	49
Libby McNeil	0	4	4	92
Lower Jones Tract	0	69	0	31
Upper Jones Tract	2	59	1	38
Lower Roberts Island	0	0	0	100
McCormack-Williamson Tract	0	68	0	32
Middle Roberts Island	24	0	0	76
New Hope Tract	7	32	1	61
Randall Island	0	0	0	100
Rindge Tract	0	74	1	25
Terminous Tract	16	54	1	29
Union Island East	31	35	0	34
Union Island West	3	65	2	31
Upper Andrus Island	5	3	1	92
Venice Island	0	72	3	25
Victoria Island	2	87	1	11
Walnut Grove	0	50	0	50

[a] Results indicate the percentage of evaluated cross-sections that fall into each rating score bin. Due to rounding, total for each levee system may not add to 100 percent.

[b] Rating Score 1: Toe ditch is present within 1 levee height form the landside levee toe and no berm is present

[c] Rating Score 2: Toe ditch is present within 1 to 2 levee heights from the landside levee toe or 1 levee height from the berm toe

[d] Rating Score 3: Toe ditch is present within 2 to 4 levee heights from the landside levee toe or 1 to 2 levee height from the berm toe

[e] Rating Score 4: No toe-ditch is present, or the ditch is present beyond 4 levee heights from the landside levee toe and beyond 2 levee height from the berm toe

3.4 Vulnerability to Sea Level Rise

The results of the SLR evaluation are summarized as a percentage of cross-sections within a levee system that received a rating score of 1, 2, 3 or 4 as shown below in Table 6. A graphical presentation of the results is presented in Figures 3-4a and 3-4b (See Attachment 2).

Table 6. Sea Level Rise Freeboard Summary of Results

Percentage of levee system sections resulting in each Sea Level Rise criterion score[a]

Levee System	1[b]	2[c]	3[d]	4[e]
Brack Tract	16	81	1	2
Byron Tract	0	0	0	100
Canal Ranch	44	47	6	3
Clifton Court Tract	0	0	0	100

Levee System	1[b]	2[c]	3[d]	4[e]
Coney Island	0	36	8	56
South of Delta-Mendota Canal and Old River	0	0	0	100
Drexler	54	5	7	34
DWR Maintenance Area 9	2	0	0	98
Ehrheardt Club	36	10	0	54
Fabian Tract	0	0	0	100
Glanville Tract	27	30	10	34
Honker Lake Tract	62	11	2	25
King Island	2	91	5	2
Libby McNeil	2	4	4	90
Lower Jones Tract	2	52	28	18
Upper Jones Tract	12	50	20	18
Lower Roberts Island	1	7	17	75
McCormack-Williamson Tract	95	3	0	2
Middle Roberts Island	87	0	0	13
New Hope Tract	16	31	10	43
Randall Island	0	0	0	100
Rindge Tract	1	92	4	4
Terminous Tract	46	43	5	6
Tyler Island	17	34	22	27
Union Island East	0	0	0	100
Union Island West	0	0	0	100
Victoria Island	0	1	11	88
Walnut Grove	0	0	0	100

[a] Results indicate the percentage of evaluated cross-sections that fall into each rating score bin. Due to rounding, total for each levee system may not add to 100 percent.
[b] Rating Score 1: Freeboard against the 100-year SLR WSEL less than 0 feet
[c] Rating Score 2: Freeboard against the 100-year SLR WSEL is greater than or equal to 0 feet but less than 1 foot
[d] Rating Score 3: Freeboard against the 100-year SLR WSEL is greater than or equal to 1 foot but less than 1.5 feet
[e] Rating Score 4: Freeboard against the 100-year SLR WSEL is greater than or equal to 1.5 feet.

3.5 Change in Levee Crest Elevation from 2007 to 2017

The results of the change in levee crest elevation are summarized as a percentage of cross-sections within a levee system that received a rating score of 1, 2, 3 or 4 as shown below in Table 7. A graphical presentation of the results is presented in Figures 3-5a and 3-5b (See Attachment 2).

Table 7. Change in Crest Elevation from 2007 to 2017 Summary of Results

Percentage of levee system sections resulting in each crest elevation change criterion score[a]

Levee System	1[b]	2[c]	3[d]	4[e]
Brack Tract	2	4	12	83
Byron Tract	16	1	1	83
Canal Ranch	0	0	0	100
Clifton Court Tract	12	2	4	83
Coney Island	10	14	5	71
South of Delta-Mendota Canal and Old River	16	2	8	75
Drexler	15	2	4	79
DWR Maintenance Area 9	0	0	0	100
Ehrheardt Club	1	0	0	99
Fabian Tract	0	0	2	98
Glanville Tract	0	0	0	100
Honker Lake Tract	5	3	13	79
King Island	7	6	21	66
Libby McNeil	0	0	0	100
Lower Jones Tract	13	8	15	65
Upper Jones Tract	39	6	13	42
Lower Roberts Island	13	7	11	69
McCormack-Williamson Tract	0	0	0	100
Middle Roberts Island	7	0	4	89
New Hope Tract	3	5	11	82
Randall Island	0	0	0	100
Rindge Tract	8	17	31	43
Terminous Tract	21	6	9	64
Union Island East	0	0	1	99
Union Island West	0	1	3	96
Victoria Island	27	9	9	55
Walnut Grove	0	0	0	100

[a] Results indicate the percentage of evaluated cross-sections that fall into each rating score bin. Due to rounding, total for each levee system may not add to 100 percent.
[b] Rating Score 1: Crest elevation decrease greater than 1.0 feet between the 2007 and 2017 LiDAR
[c] Rating Score 2: Crest elevation decrease equal to 0.75 feet to less than 1.0 feet between the 2007 and 2017 LiDAR
[d] Rating Score 3: Crest elevation decrease equal to 0.5 feet to less than 0.75 feet between the 2007 and 2017 LiDAR
[e] Rating Score 4: Crest elevation decrease less than 0.5 feet between the 2007 and 2017 LiDAR

3.6 Relative Levee Vulnerability Rating

The results of the relative levee vulnerability rating evaluation are summarized as a percentage of cross-sections within a levee system that received a Levee Rating of Very Low, Low, Medium, or High relative vulnerability as shown below in Table 8. A graphical presentation of the results is presented in Figures 3-6a and 3-6b (See Attachment 2).

Table 8. Relative Levee Vulnerability Rating of Results

Percentage of levee system sections resulting in each Relative Vulnerability Rating[a]

Levee System	H[b]	M[c]	L[d]	VL[e]
Brack Tract	70	27	1	1
Byron Tract	0	14	67	19
Canal Ranch	63	24	10	4
Clifton Court Tract	0	0	13	87
Coney Island	12	29	54	5
South of Delta-Mendota Canal and Old River	0	0	18	82
Drexler	54	7	26	14
DWR Maintenance Area 9	2	0	2	96
Ehrheardt Club	43	4	16	38
Fabian Tract	0	0	54	46
Glanville Tract	31	31	20	18
Honker Lake Tract	62	10	25	3
King Island	5	71	21	3
Libby McNeil	2	16	8	73
Lower Jones Tract	6	33	49	11
Upper Jones Tract	41	18	34	7
Lower Roberts Island	3	11	18	68
McCormack-Williamson Tract	95	4	1	0
Middle Roberts Island	87	0	0	13
New Hope Tract	24	28	14	34
Randall Island	0	0	0	100
Rindge Tract	11	58	31	0
Terminous Tract	70	22	7	2
Union Island East	0	0	66	34
Union Island West	0	3	74	23
Victoria Island	1	33	58	8
Walnut Grove	0	60	3	37

[a] Results indicate the percentage of evaluated cross-sections that fall into each vulnerability score bin. Due to rounding, total for each levee system may not add to 100 percent.
[b] High relative vulnerability: vulnerability score range is from 14 to 38
[c] Medium relative vulnerability: vulnerability score range is from 39 to 47

[d] Low relative vulnerability: vulnerability score is from 48 to 52
[e] Very low relative vulnerability: vulnerability score range is from 53 to 56

4. Observations and Conclusions

This TM presents the results of a relative levee vulnerability assessment performed for the Project. The results of this TM are intended as a screening level assessment to identify potential vulnerabilities within the Delta levee systems, not to be interpreted as design-level analyses. However, it should also be noted that screening of existing levee geometry as a means for prioritizing levee upgrades is common practice within the Delta and supported by DWR Delta Special Projects program managed by the Delta Levees group within DWR. Key observations and conclusions from the assessment include:

- The relative vulnerability ratings of Very Low, Low, Medium or High relative vulnerability are a metric to compare one levee cross-section and system to another and the bins were assigned based on all of the analyses performed. Of the approximately 5,100 cross-sections evaluated, approximately one-fourth of the sections received the highest possible vulnerability score and half of the cross-sections received scores of over 48 or higher (Low vulnerability or better). As a result, levee cross-sections may meet relatively stringent current standards (i.e., PL 84-99 geometry and freeboard) but may still be characterized as having a “medium relative vulnerability” due to the presence of a toe-ditch or lack of future freeboard when considering potential impacts due to SLR.
- When siting Project infrastructure, consider the relative vulnerability ratings and levee geometry standards as part of the selection siting process. Levee locations with higher vulnerability rankings may require more robust mitigations and/or repair footprints.
- Lower Roberts Island, Middle Roberts Island, Upper Roberts Island, Honker Lake Tract, and Drexler are separated internally by low/smaller internal levees which are not designed or intended to provide flood protection against a 100-year WSEL assumed in this levee vulnerability study. These levee systems share a perimeter levee that provides flood protection. The LiDAR source data covers the western and northern extent of the shared perimeter levee but does not cover the eastern and southern extent. As a result, the assessment presented herein for this levee system is based on a partial data set within this portion of the Delta. It is also noted that Lower Roberts Island includes an interior levee along the southern boundary that separates it from the other levee systems and provides additional flood protection although not to a 100-year WSEL standard.
- The results provided herein should be used in conjunction with sound engineering judgement when selecting the locations of Project infrastructure. This analysis provides an indication of levee relative vulnerability at discrete cross-section locations. The higher relative vulnerability rankings serve as an indicator of levee locations within the Project area that may be deficient and require further evaluation and possible mitigation. Future repairs should consider type, magnitude and extents of deficiencies.
- As Project components progress from feasibility and planning level studies to design level studies, obtaining site-specific subsurface data and testing and conducting site-specific engineering analyses will be needed.
- The levees along the Clifton Court Tract and on the southern side of the Delta-Mendota Canal and Old River appear to be relatively robust compared to other Delta levees, based on the variables considered in this assessment. These levees would likely require few repairs if any to protect Project infrastructure.

5. References

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Attachment 1
Levee Geometry Standards

Attachment 1 Levee Geometry Standards

Presentation of levee geometry standards relating peat/organics thickness and levee height to allowable landside levee or berm slopes for Public Law 84-99 (USACE, 1987) and DWR Bulletin 192-82 (DWR, 1982) and (DWR, 1989). Content excerpted from these standards includes:

- Public Law 84-99 – Four charts showing the required landside height versus peat thickness for a specific landside levee slope (Figures A-D). Each chart is developed for a different landside slope which include 2H:1V, 3H:1V, 4H:1V, and 5H:1V. This geometry standards applies to both urban and non-urban levee systems.
- DWR Bulletin 192-82 – Four charts which present the minimum landside slope or berm slope based on levee height, presence of berm, contours of peat thickness and land use. Figures 1 and 3 are for urban tracts and presented for completeness. Figures 2 and 4 present the reference standards for agricultural (non-urban) tracts which were used for the geometry assessment in this TM.

PL 84-99

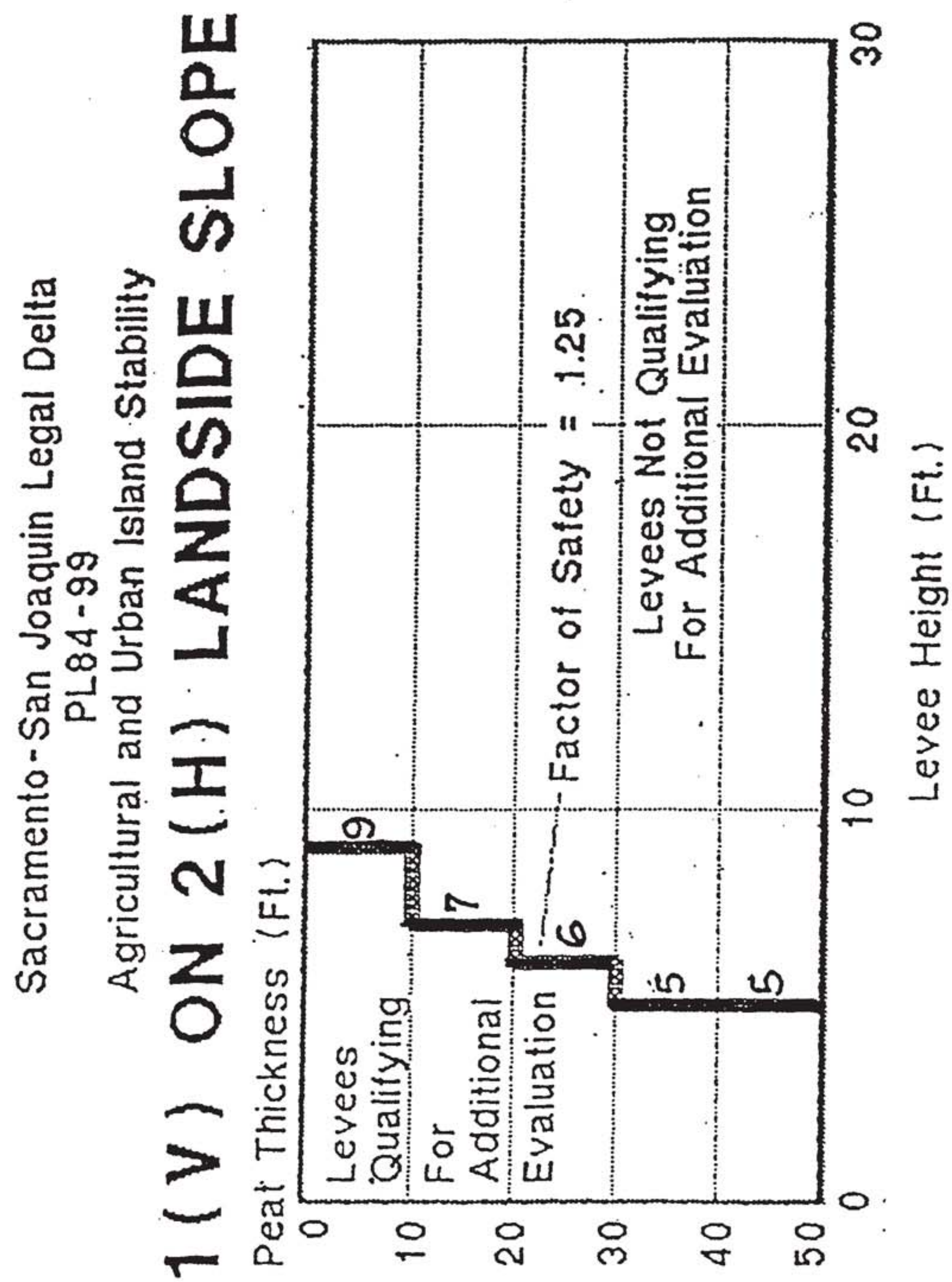


Figure A. Public Law 84-99, Landside Slope 2H:1V

D-031947

PL 84-99

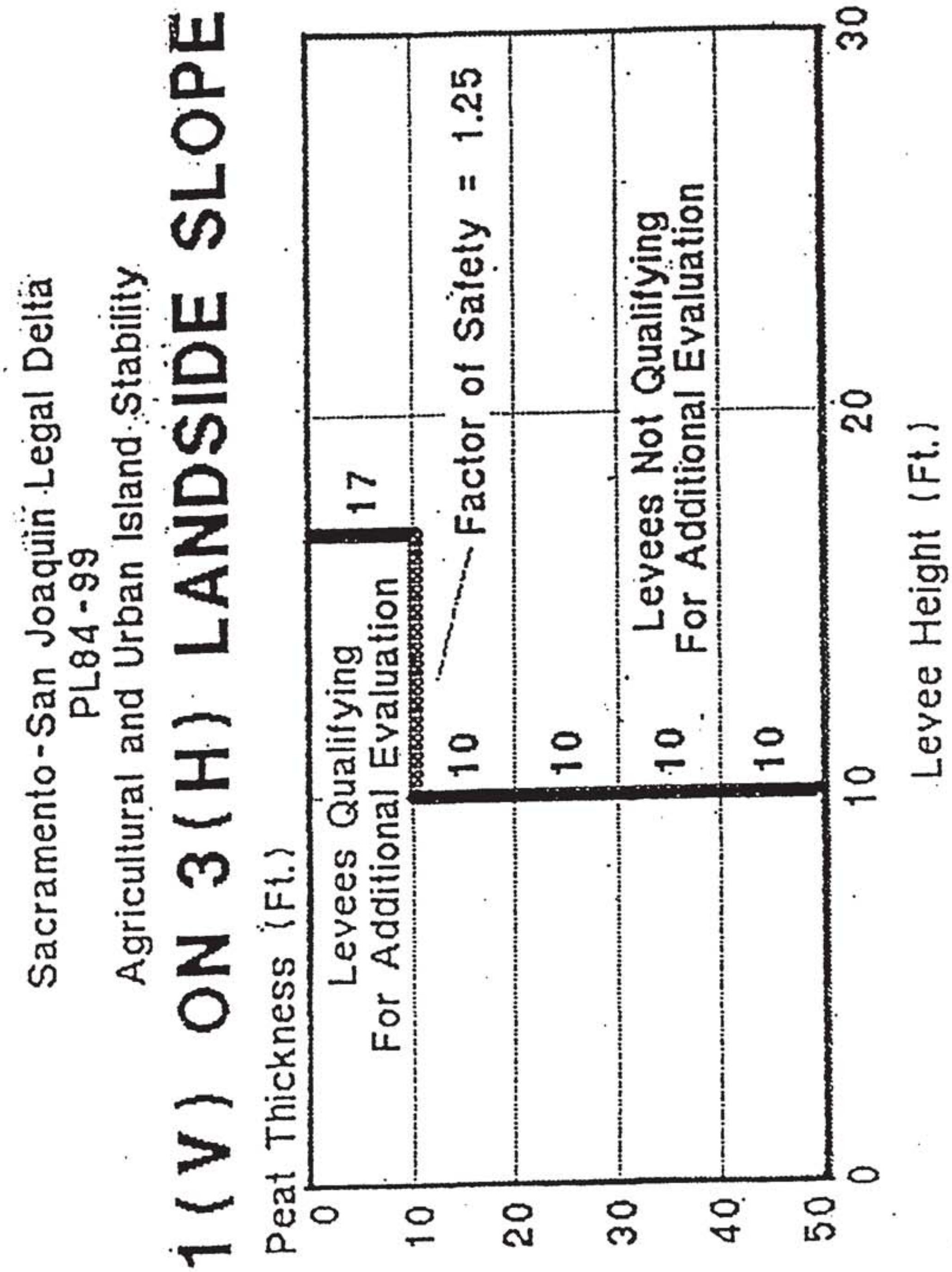


Figure B. Public Law 84-99, Landside Slope 3H:1V

PL 84-99

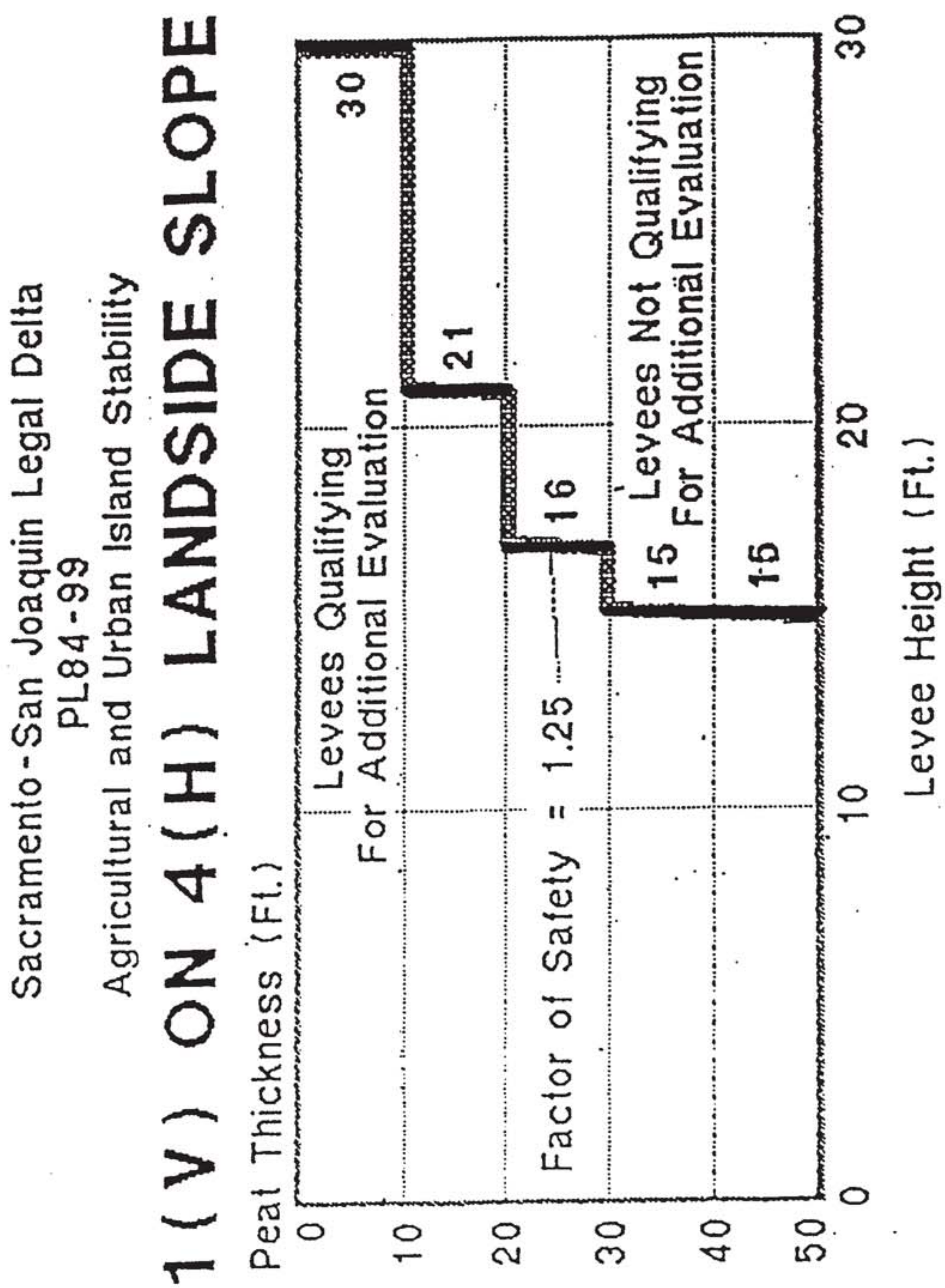


Figure C. Public Law 84-99, Landside Slope 4H:1V

PL 84-99

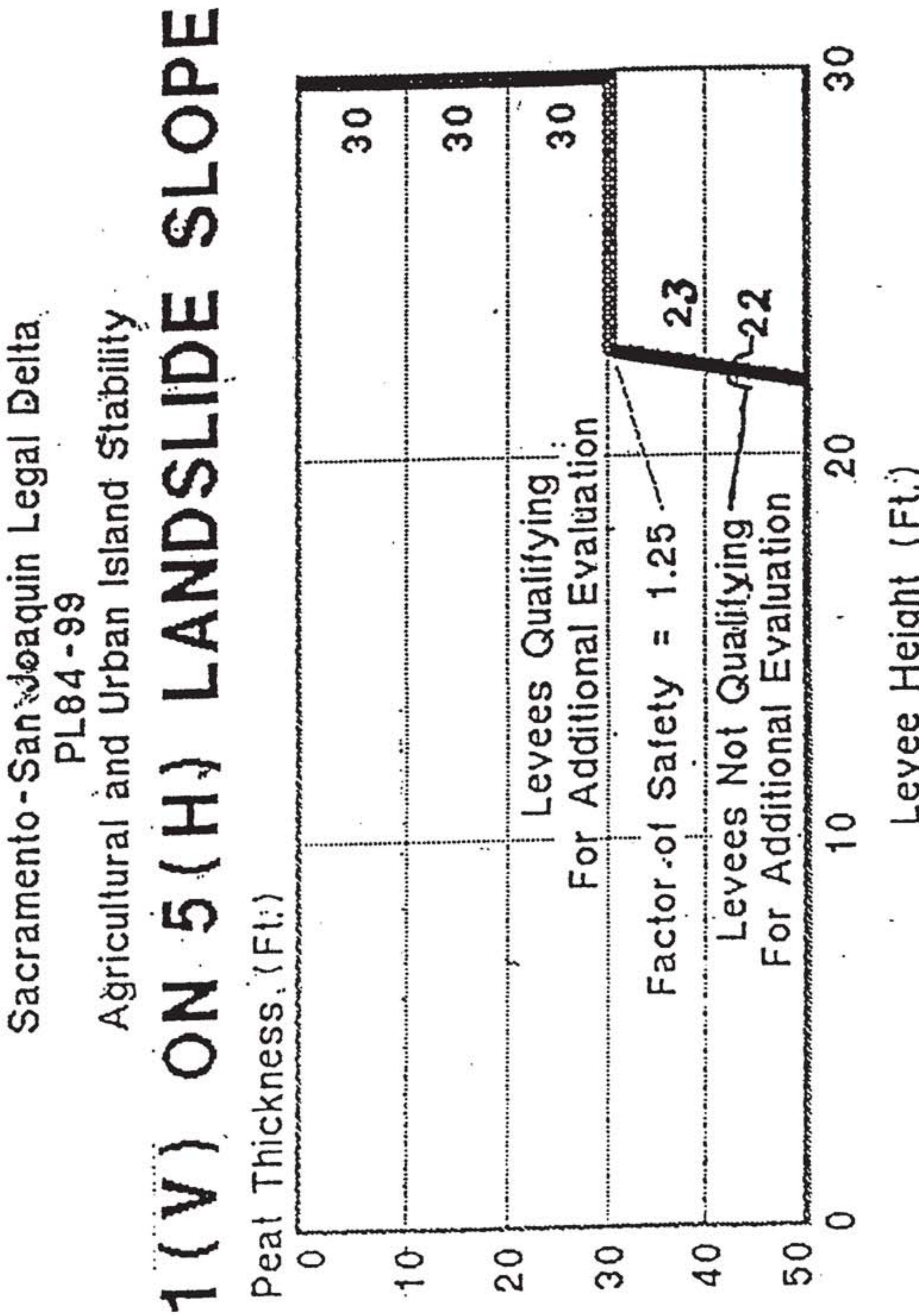


Figure D. Public Law 84-99, Landside Slope 5H:1V

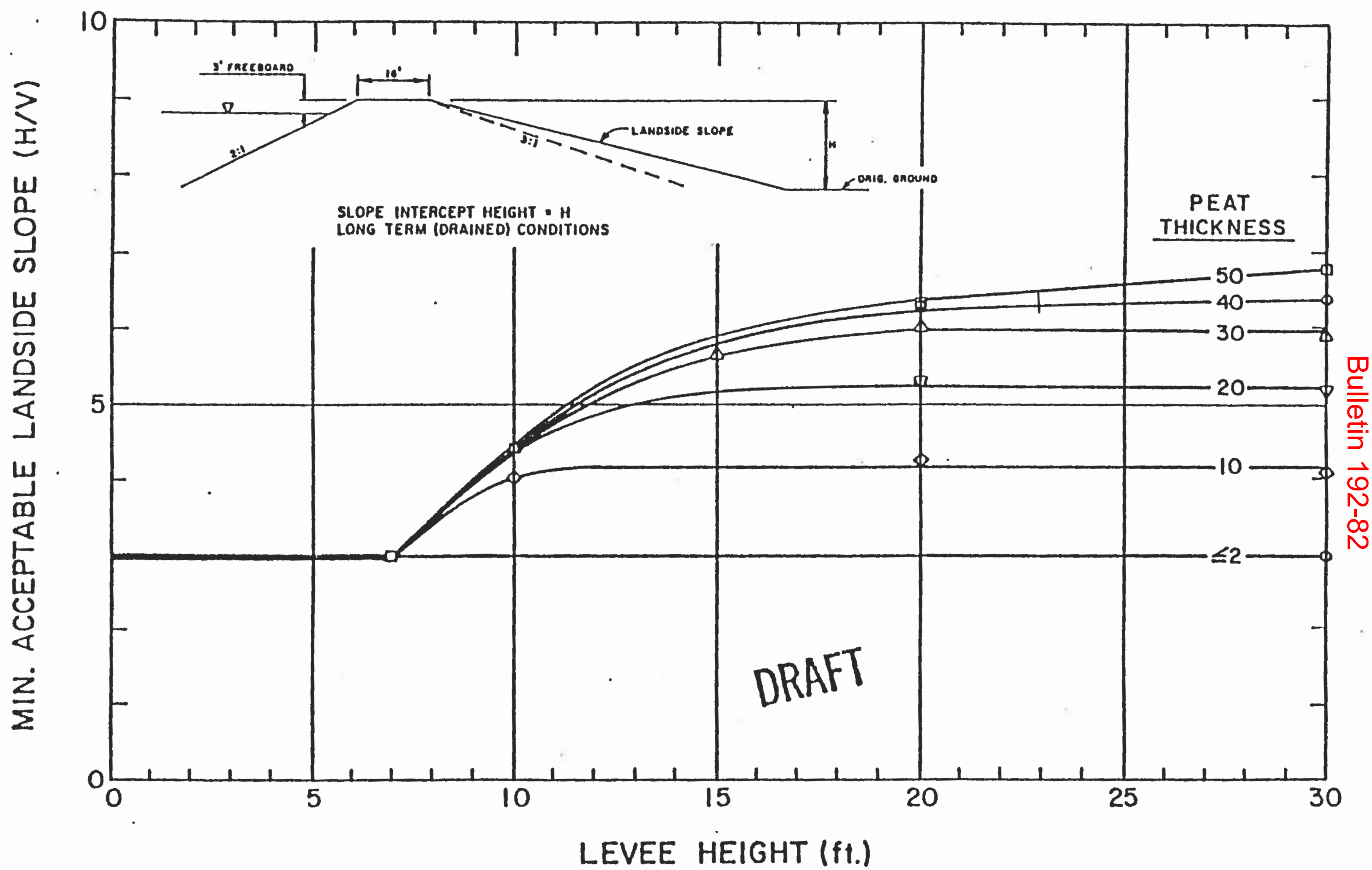


FIGURE 1: MINIMUM ACCEPTABLE LANDSIDE SLOPES FOR LEVEES PROTECTING URBAN TRACTS

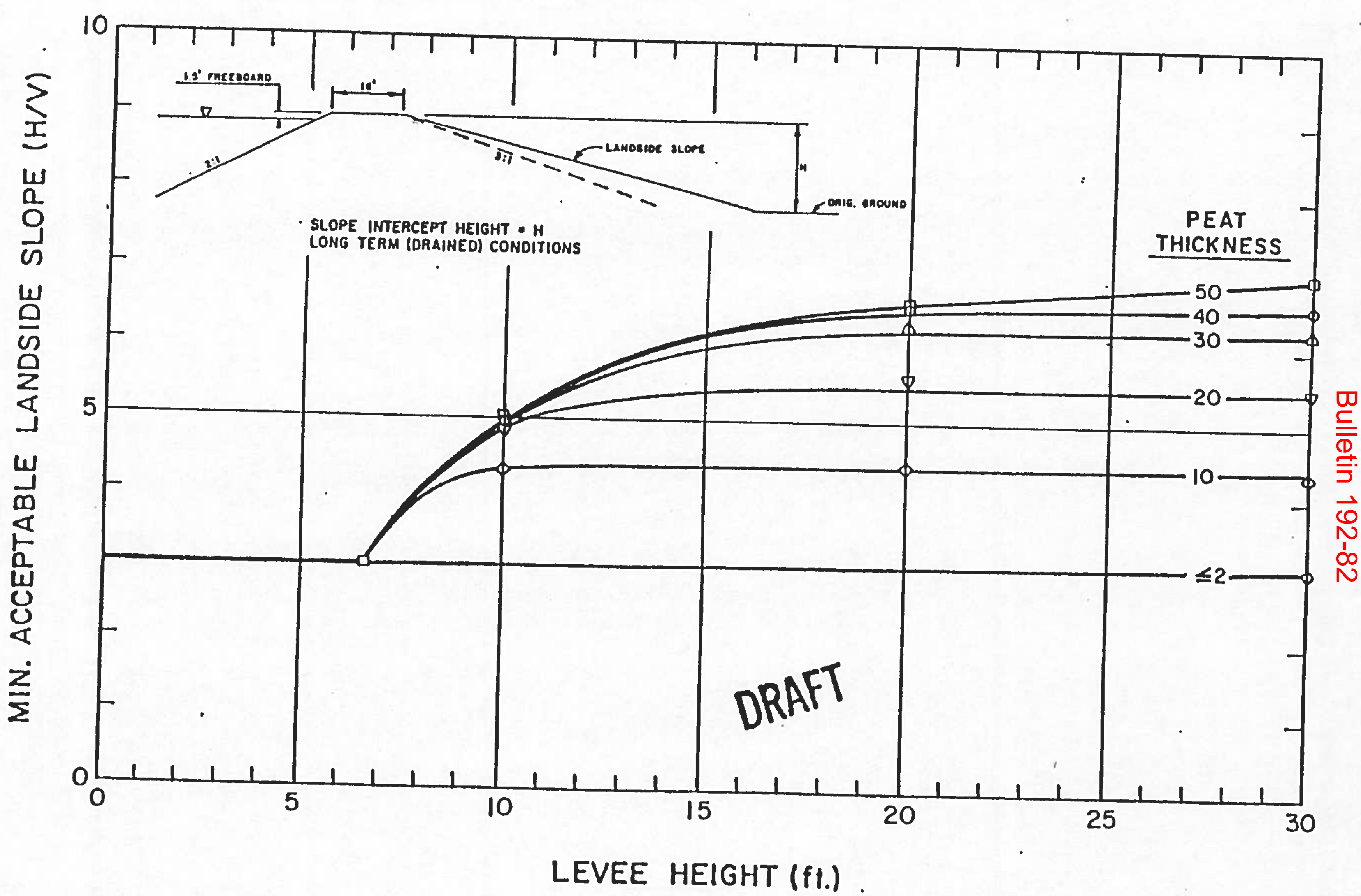


FIGURE 2: MINIMUM ACCEPTABLE LANDSIDE SLOPES FOR LEVEES PROTECTING AGRICULTURAL TRACTS

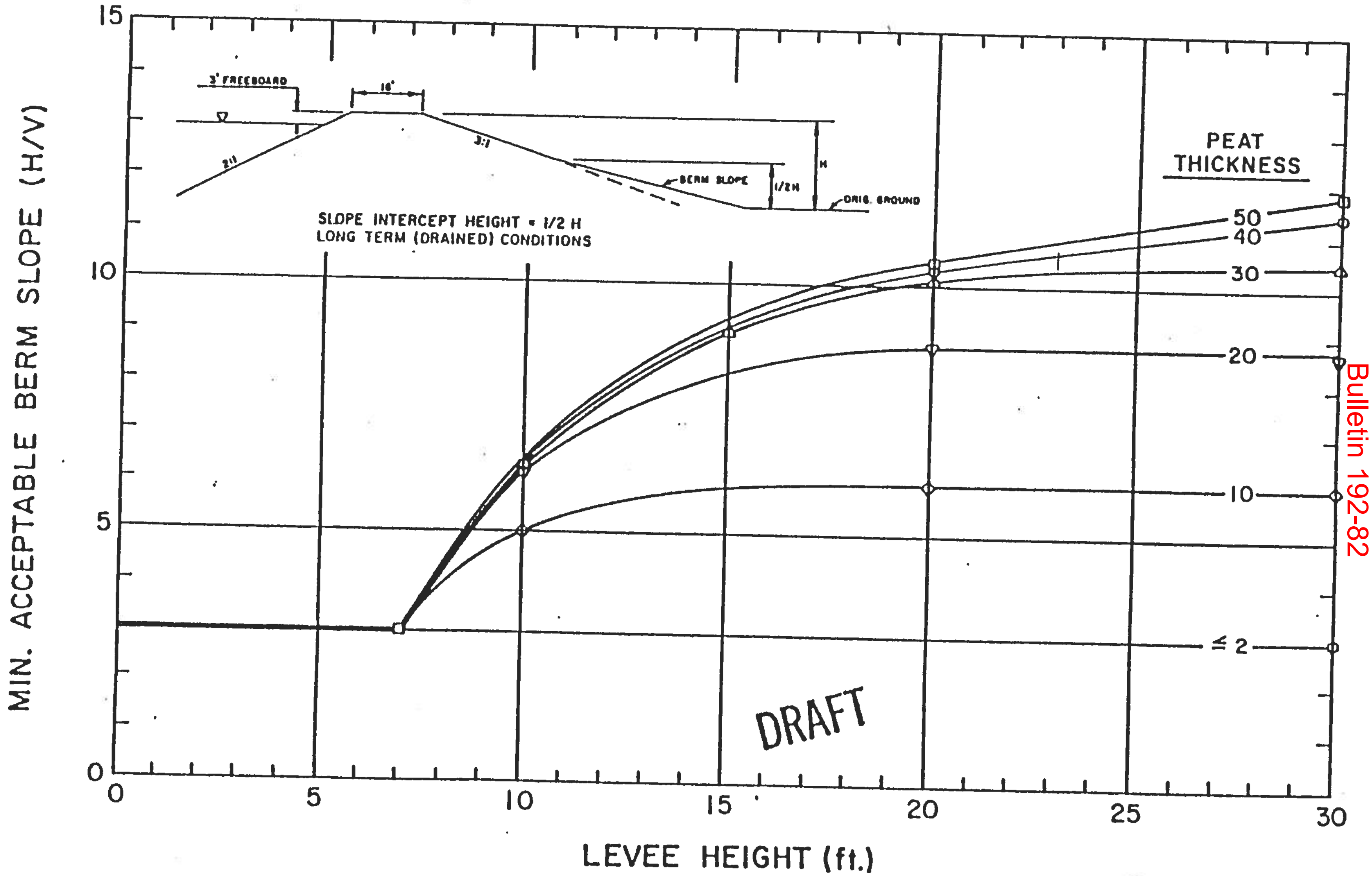


FIGURE 3: MINIMUM ACCEPTABLE BERM SLOPES FOR LEVEES PROTECTING URBAN TRACTS

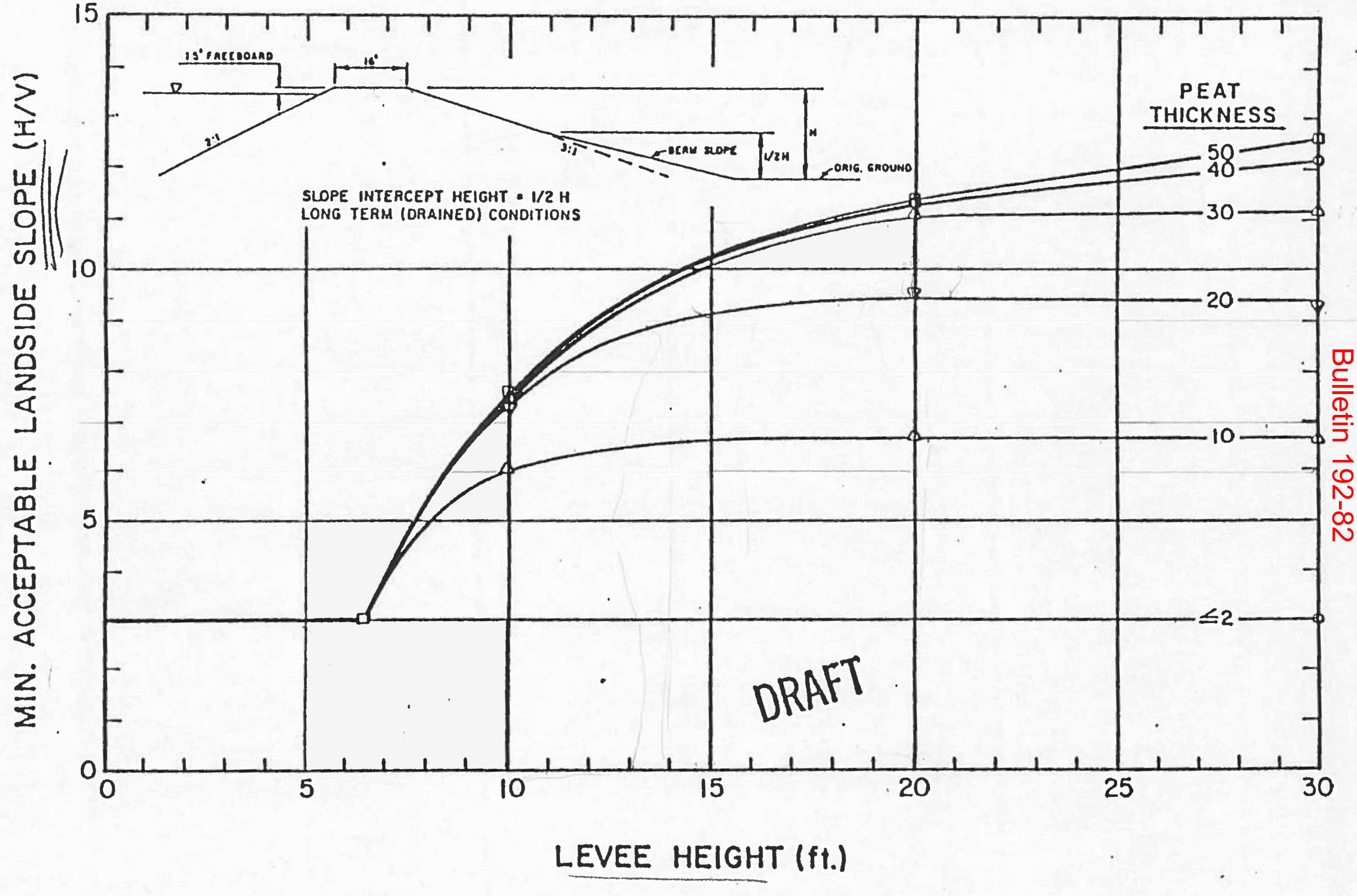
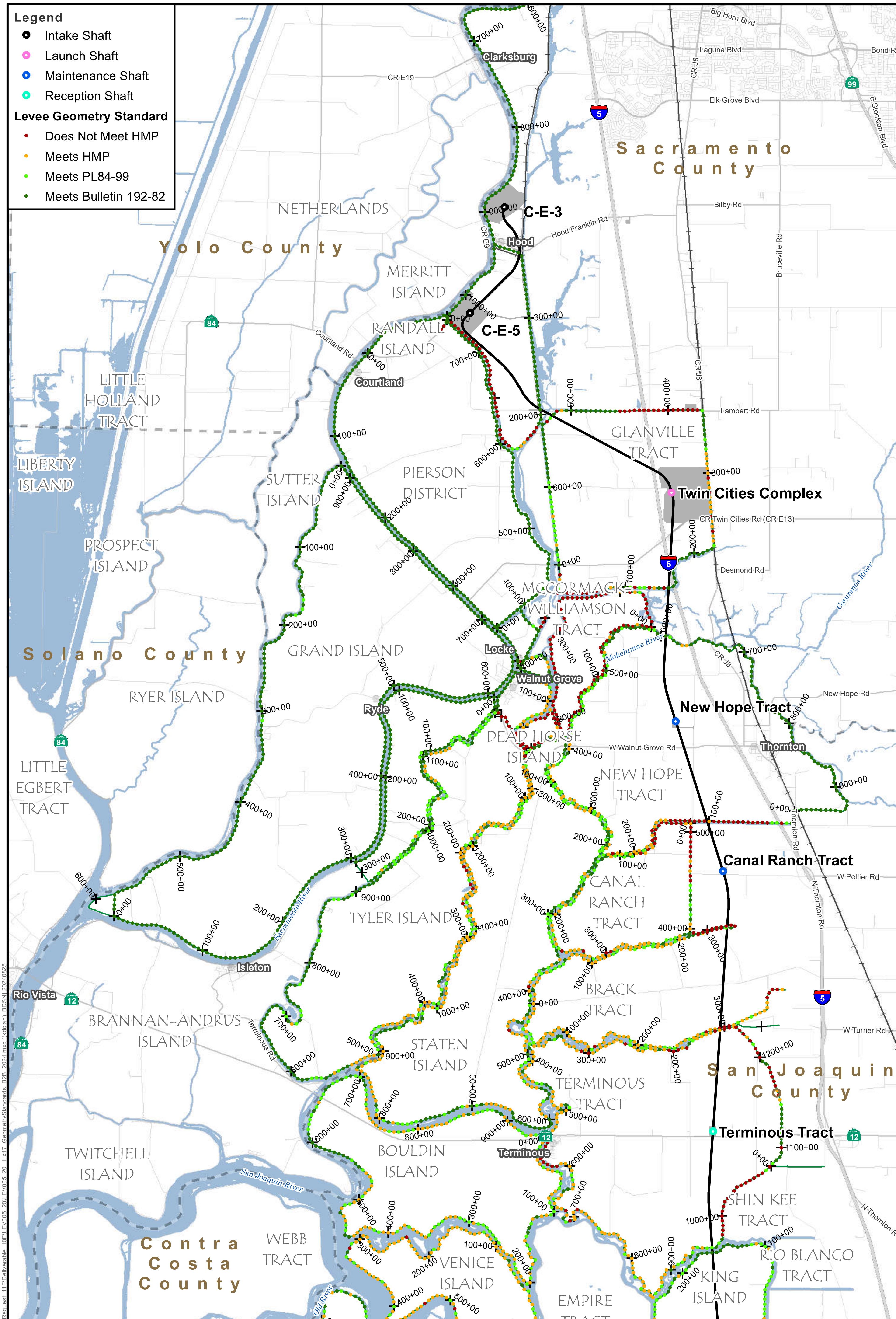


FIGURE 4: MINIMUM ACCEPTABLE BERM SLOPES FOR LEVEES PROTECTING AGRICULTURAL TRACTS

Attachment 2
Figures

Attachment 2 Figures

Graphical presentation of the relative levee vulnerability criteria and relative levee vulnerability results by cross-section location.



DCA DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

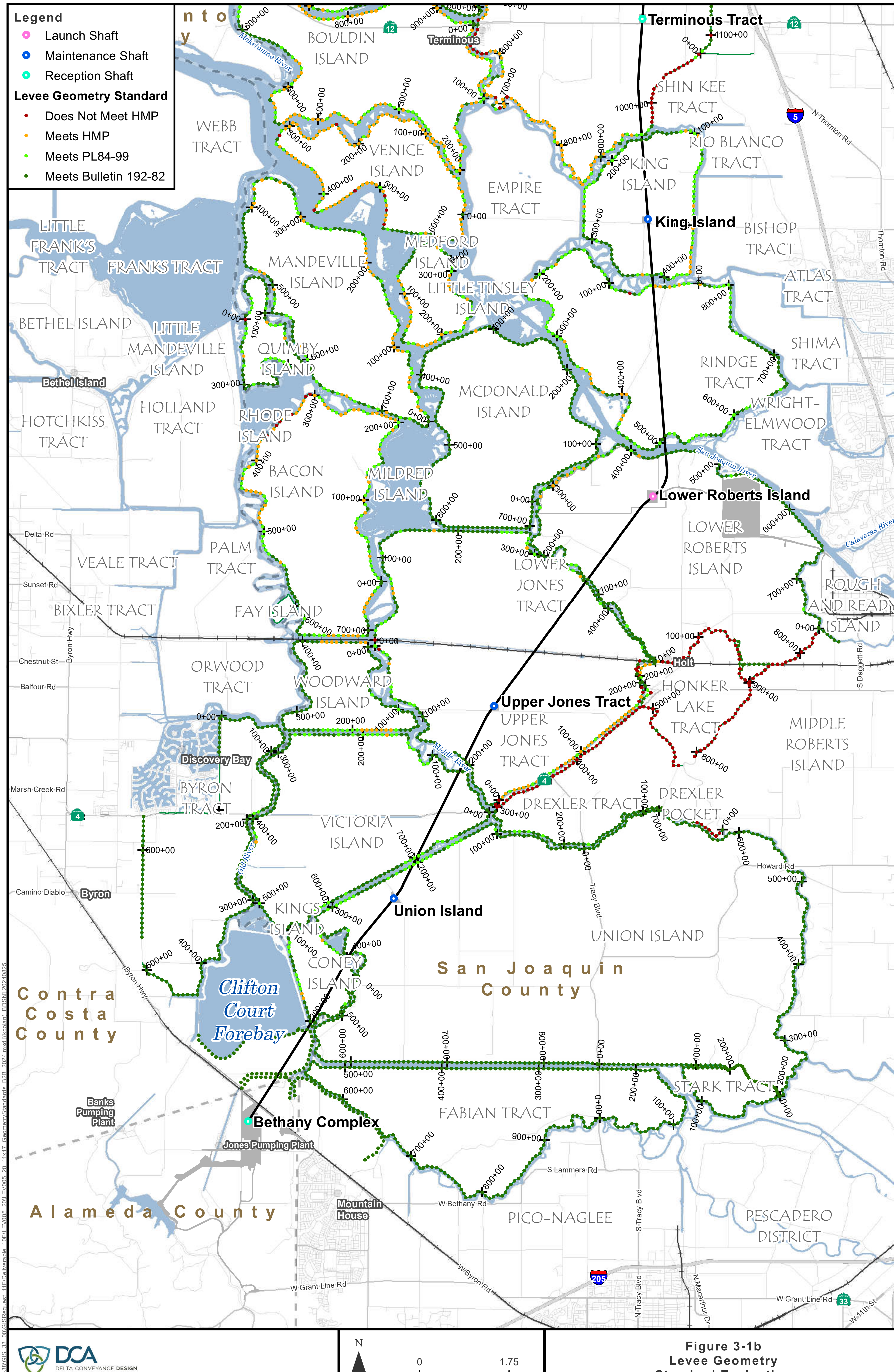
For Illustration Purposes Only

N

0 1.75 Miles

Figure 3-1a
Levee Geometry Standard Evaluation

Data Source: DCA, DWR



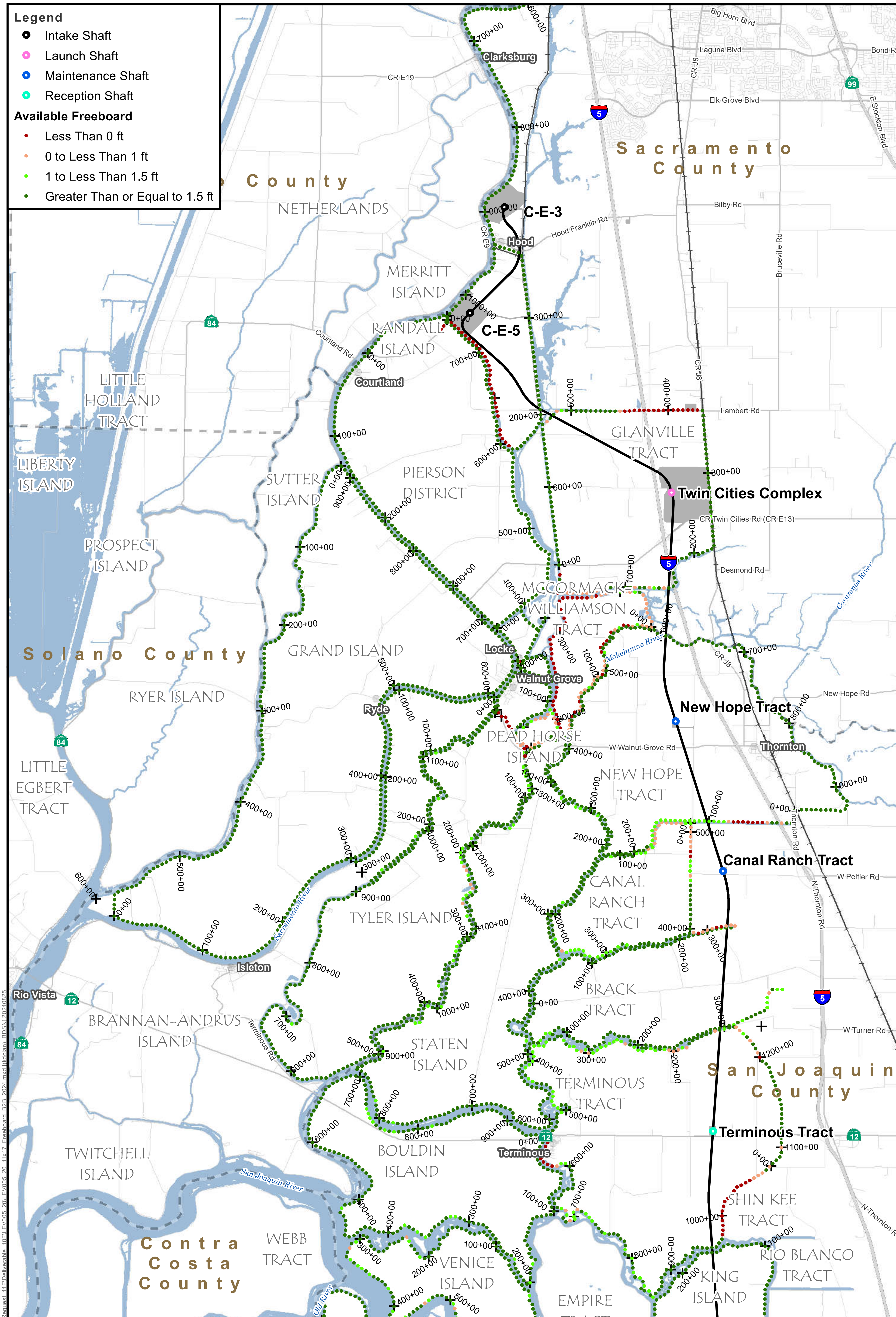
DCA DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

For Illustration Purposes Only

Figure 3-1b
Levee Geometry Standard Evaluation

Data Source: DCA, DWR

T:\WG_38\GIS_33_00\GISRequest_11\FileDeliverable_10\FILEV005_20\LEV005_20_11x17_GeometryStandards_B2B_2024.mxd (kdolan) BDSN 20240825



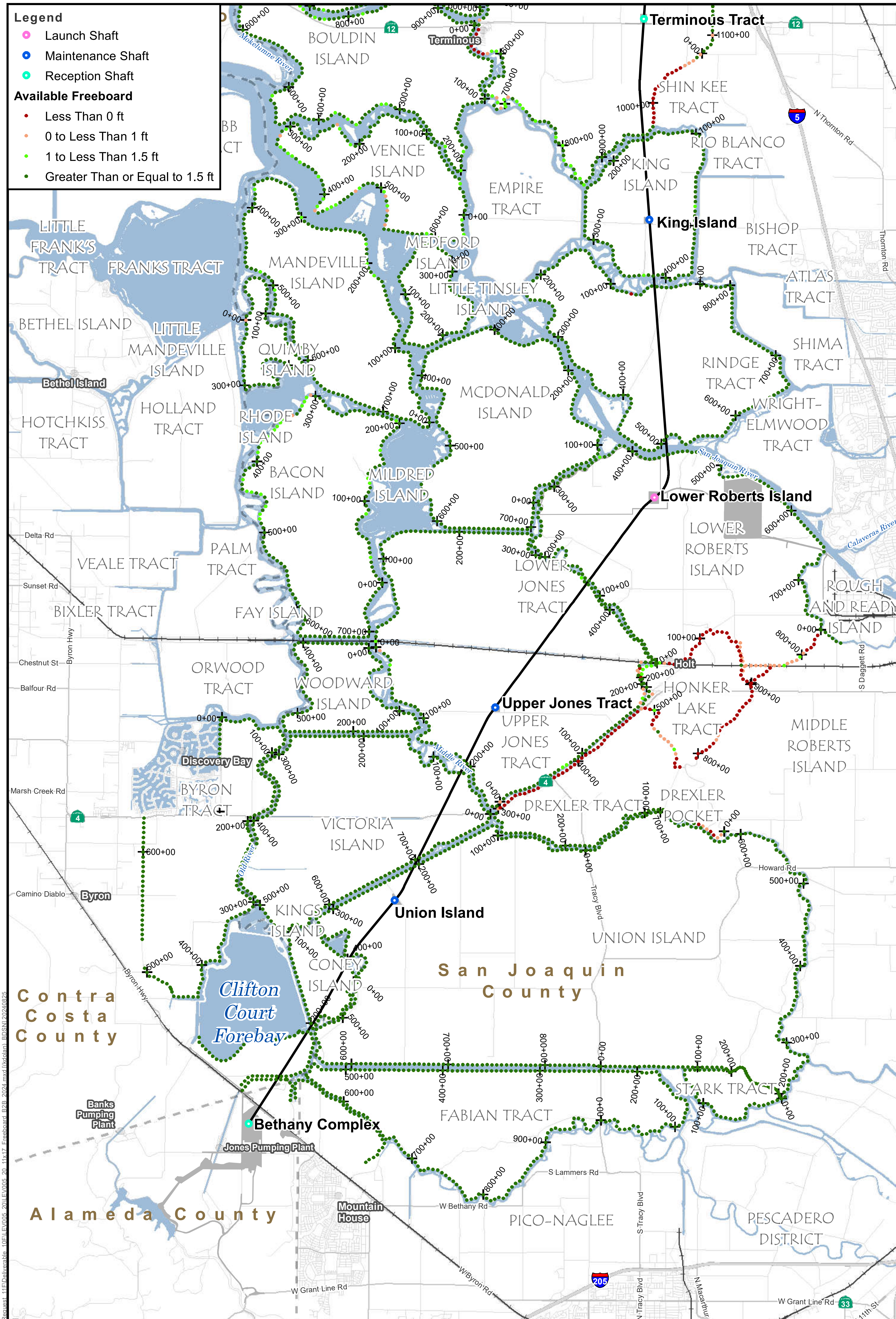
For Illustration Purposes Only

N

0 1.75 Miles

Figure 3-2a
Freeboard against 100-year Flood Elevation

Data Source: DCA, DWR



For Illustration Purposes Only

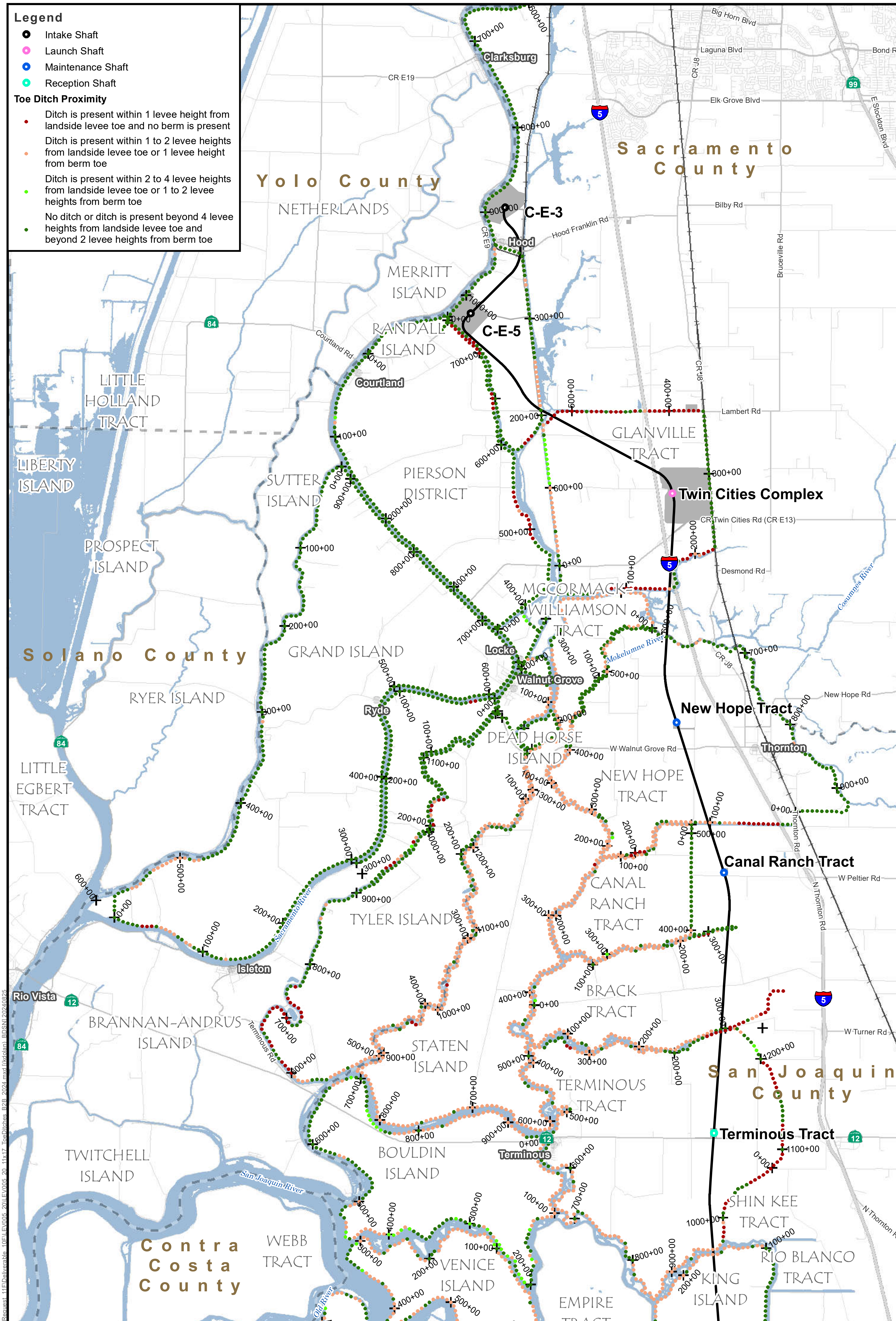
N

0 1.75 Miles

Figure 3-2b
Freeboard against 100-year Flood Elevation

DCA DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

Data Source: DCA, DWR

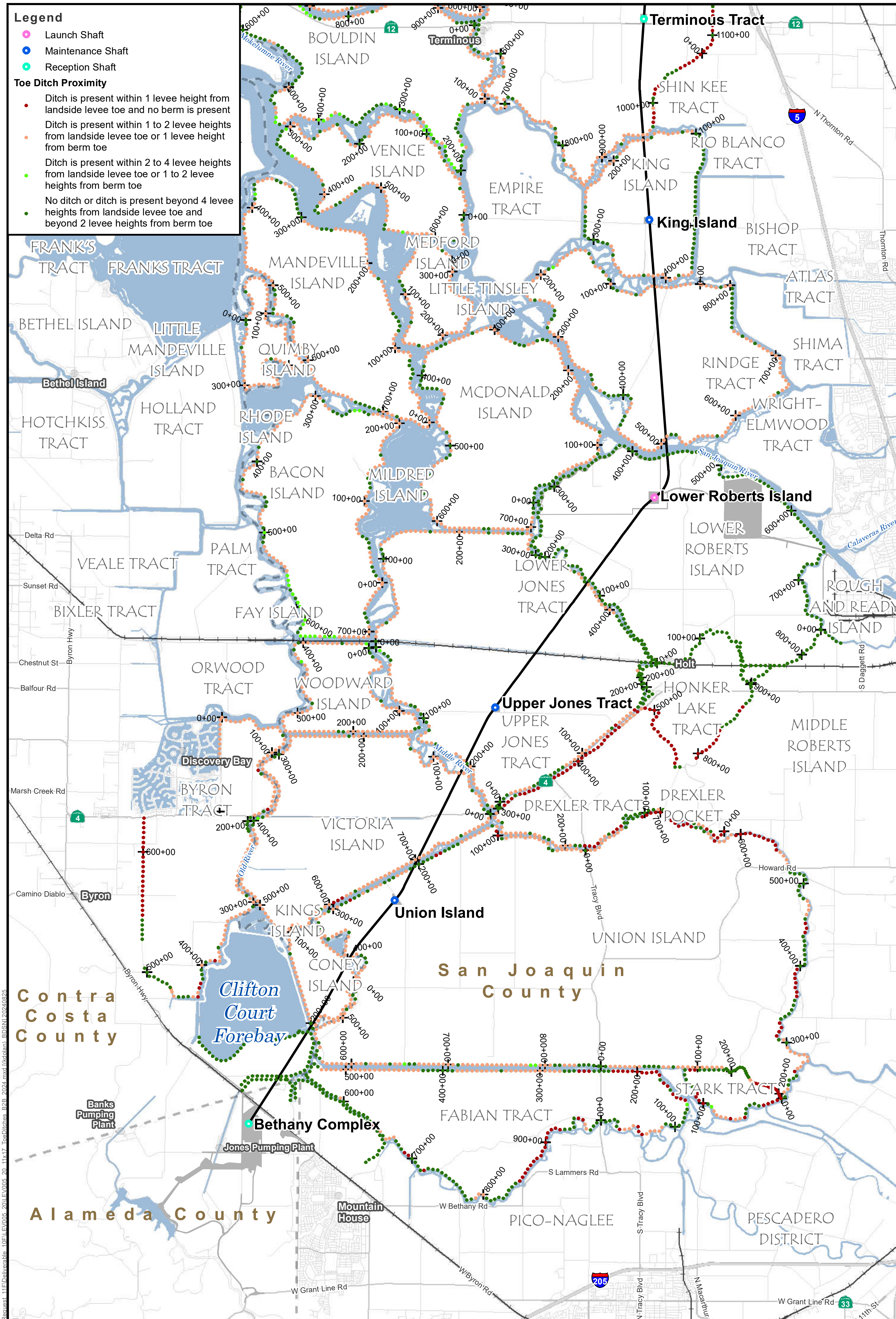


DCA DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

For Illustration Purposes Only

Figure 3-3a
Toe Ditch Proximity

Data Source: DCA, DWR



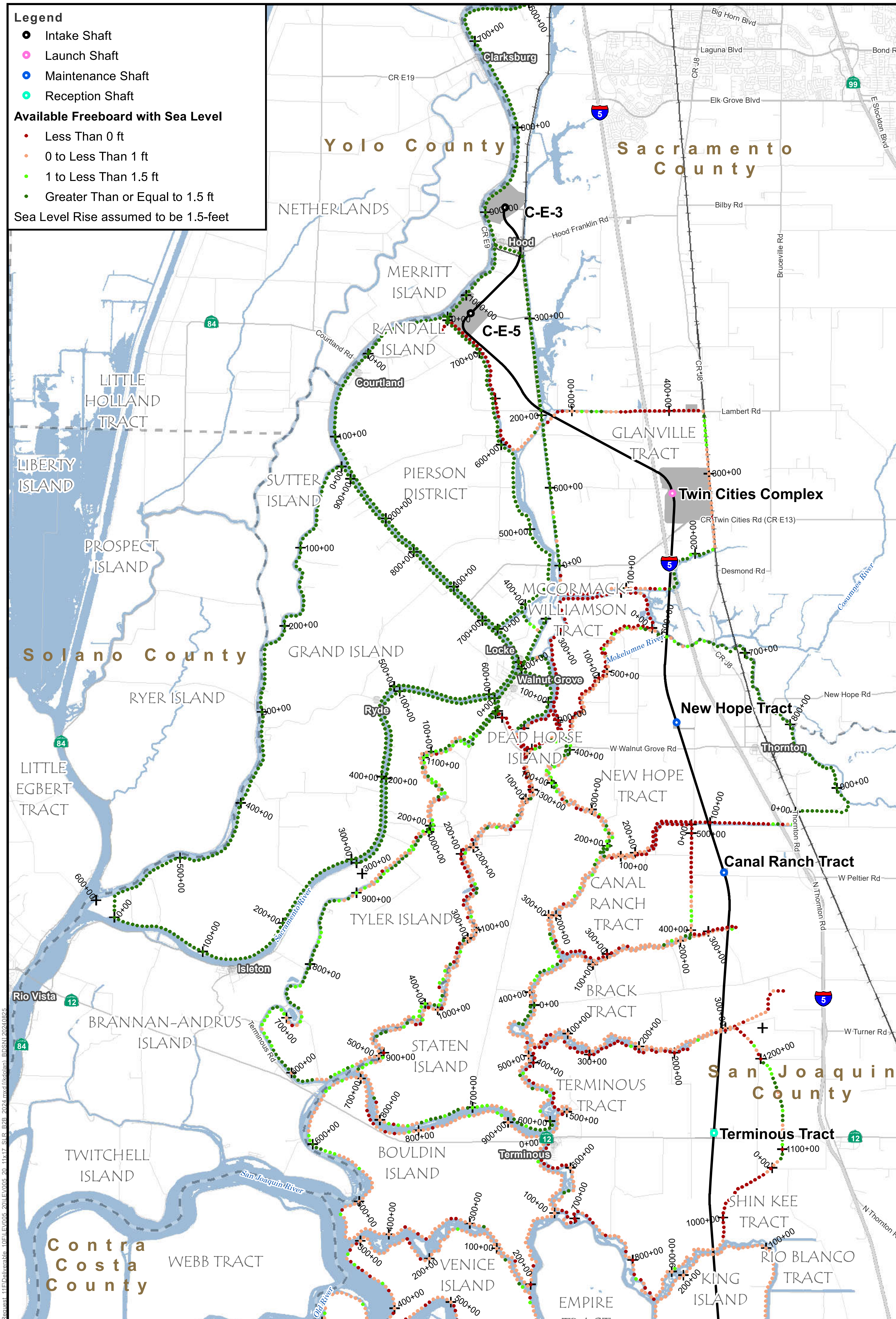
DCA DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

For Illustration Purposes Only

N
0 1.75 Miles

Figure 3-3b
Toe Ditch Proximity

Data Source: DCA, DWR



DCA DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

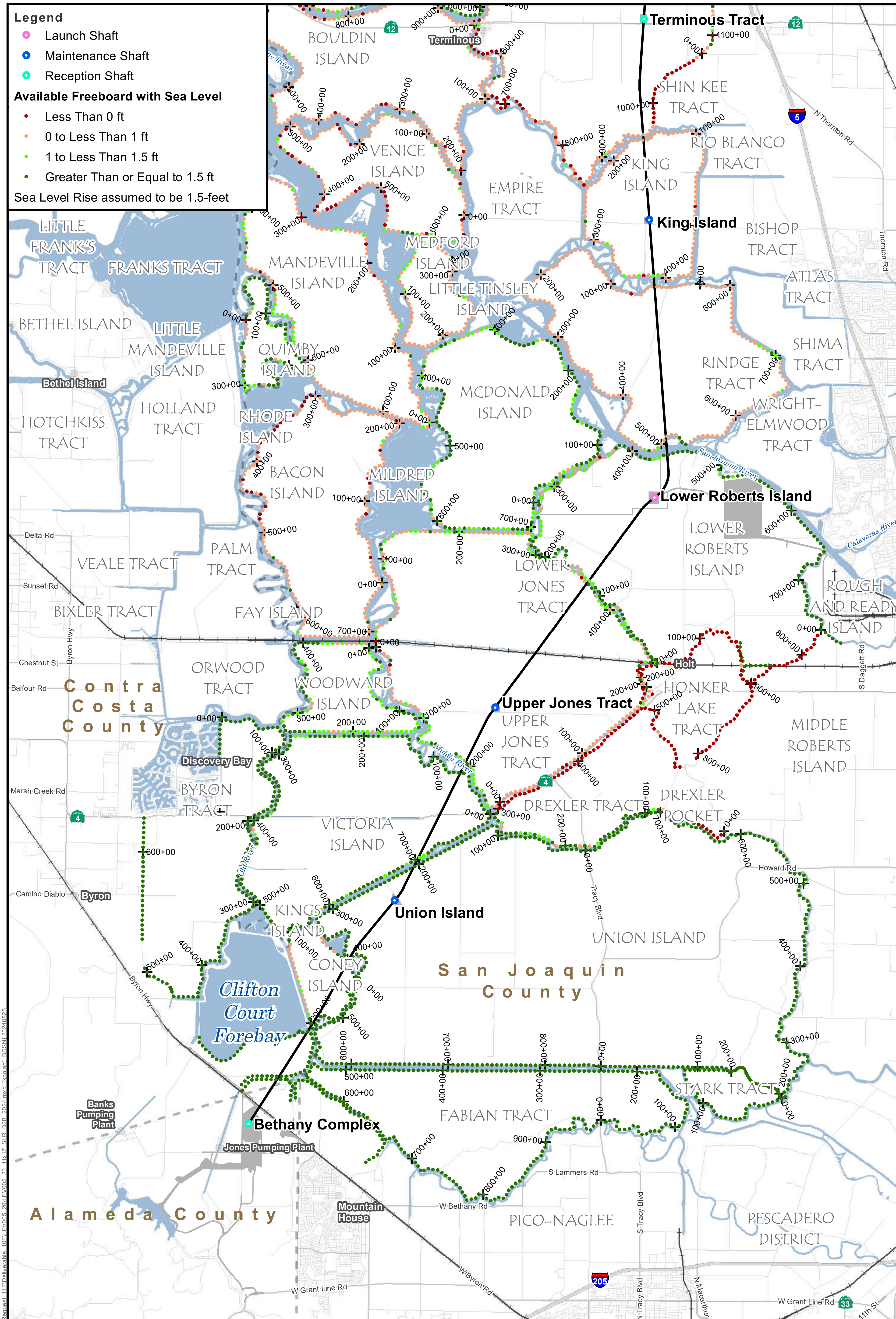
For Illustration Purposes Only

N

0 1.75 Miles

Figure 3-4a
Available Freeboard with Sea Level Rise

Data Source: DCA, DWR



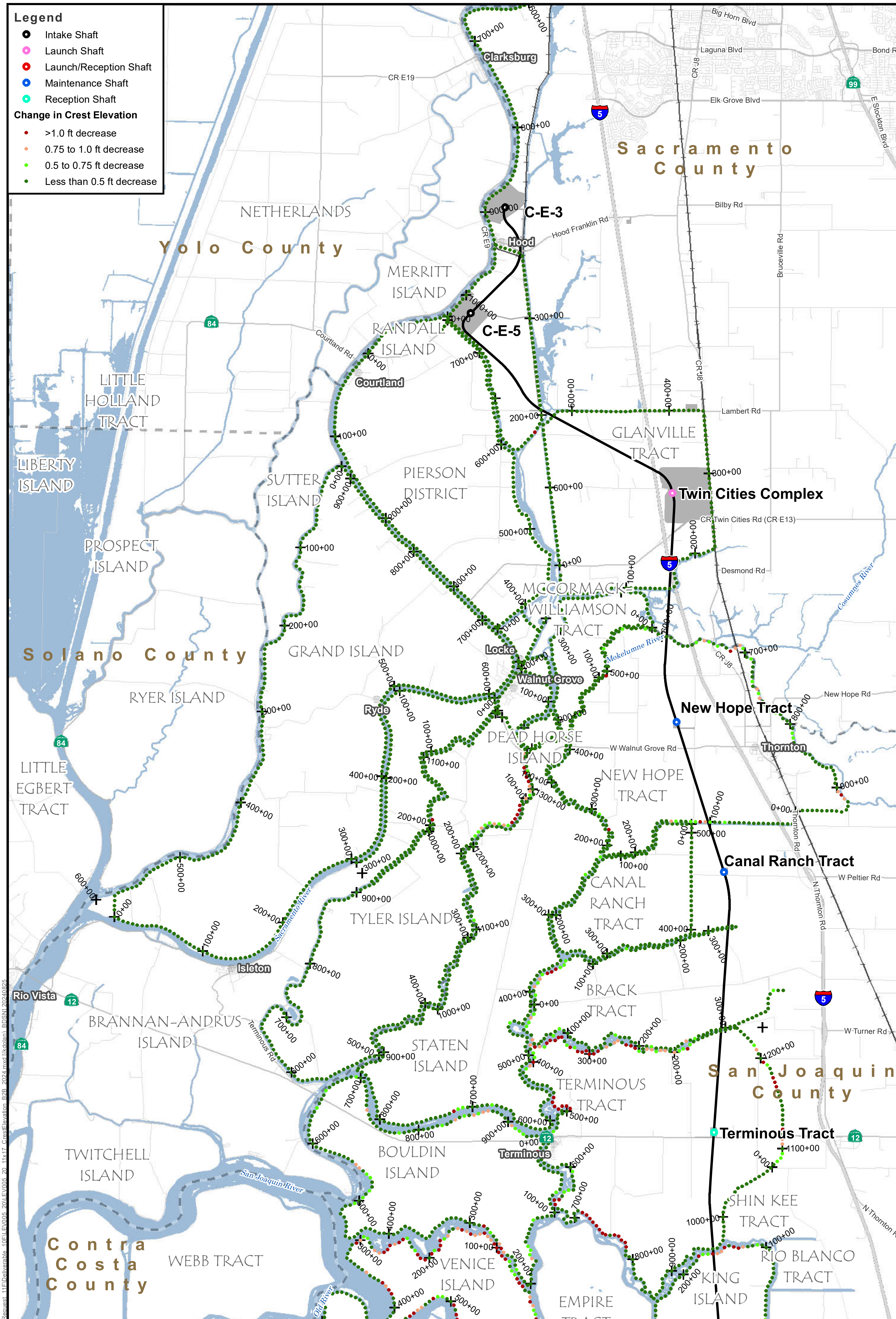
T:\WG_38\GIS_33_00\GISRequest_11E\Deliverable_10E\LEV005_20\LEV005_20_11x17_SLR_B2B_2024.mxd (jfdolan_BDSN) 20240825

DCA DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

For Illustration Purposes Only

Figure 3-4b
Available Freeboard with Sea Level Rise

Data Source: DCA, DWR



DCA DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

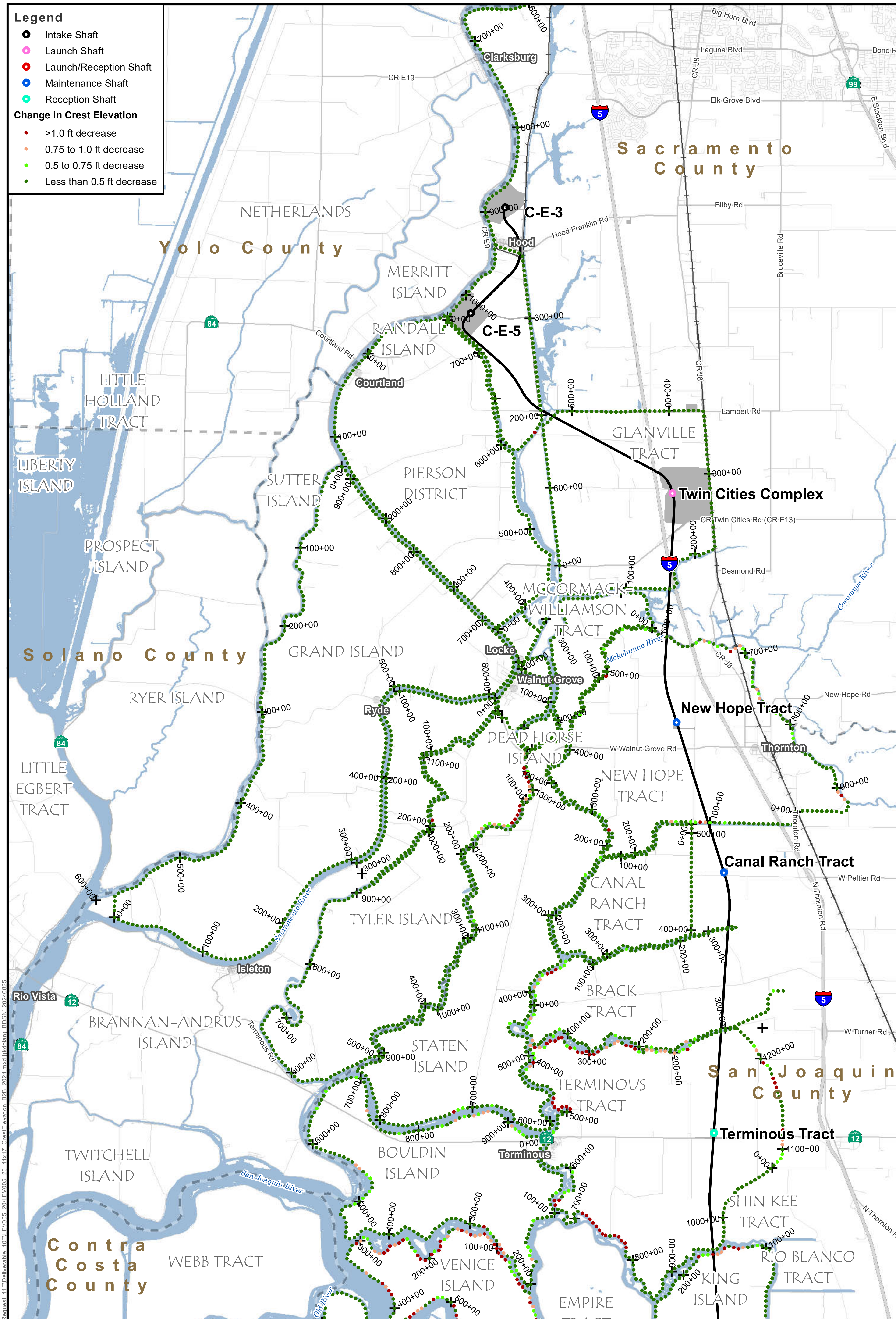
For Illustration Purposes Only

N

0 1.75 Miles

Figure 3-5a
Change in Crest Elevation from 2007 to 2017

Data Source: DCA, DWR



DCA DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

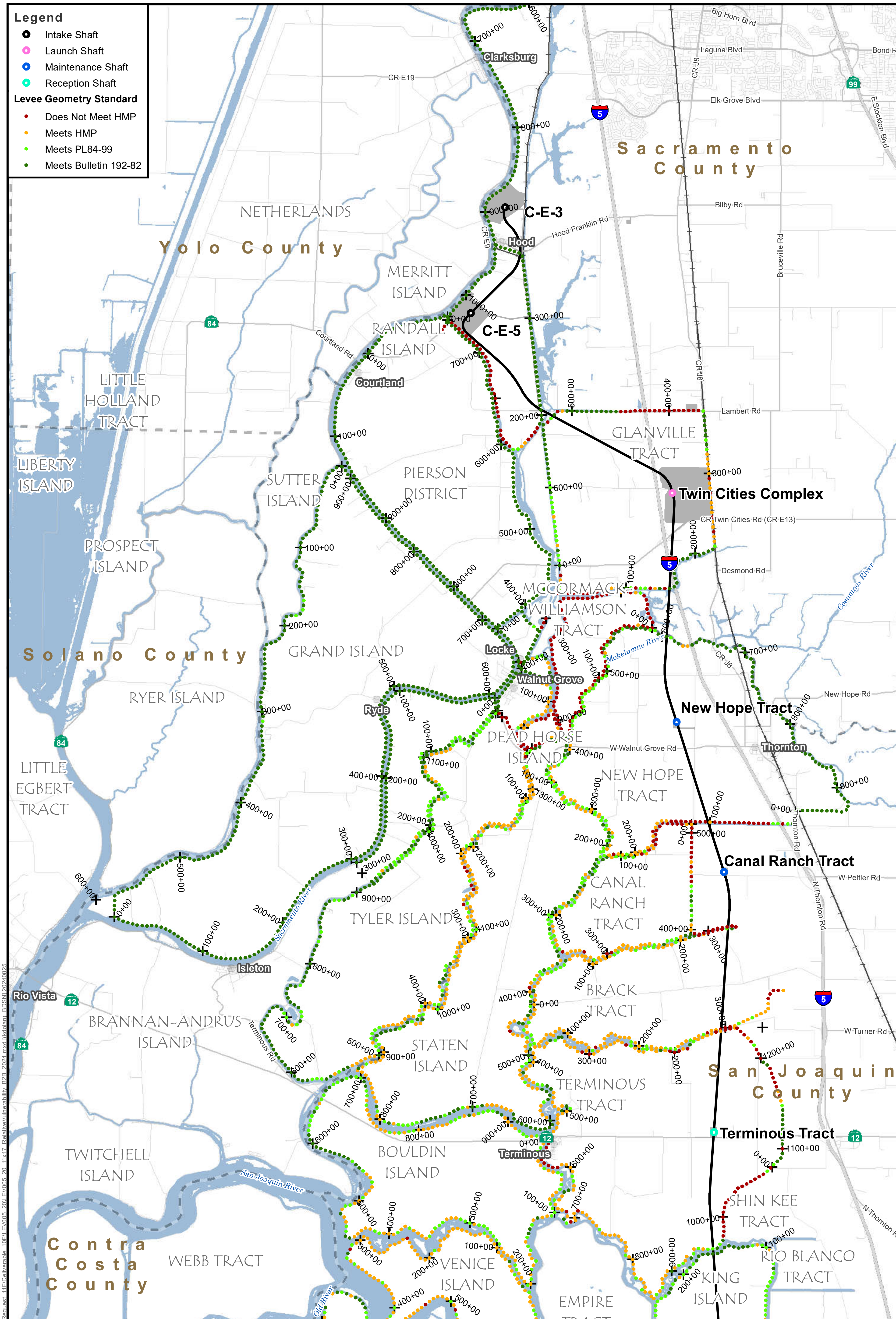
For Illustration Purposes Only

N

0 1.75 Miles

Figure 3-5b
Change in Crest Elevation from 2007 to 2017

Data Source: DCA, DWR



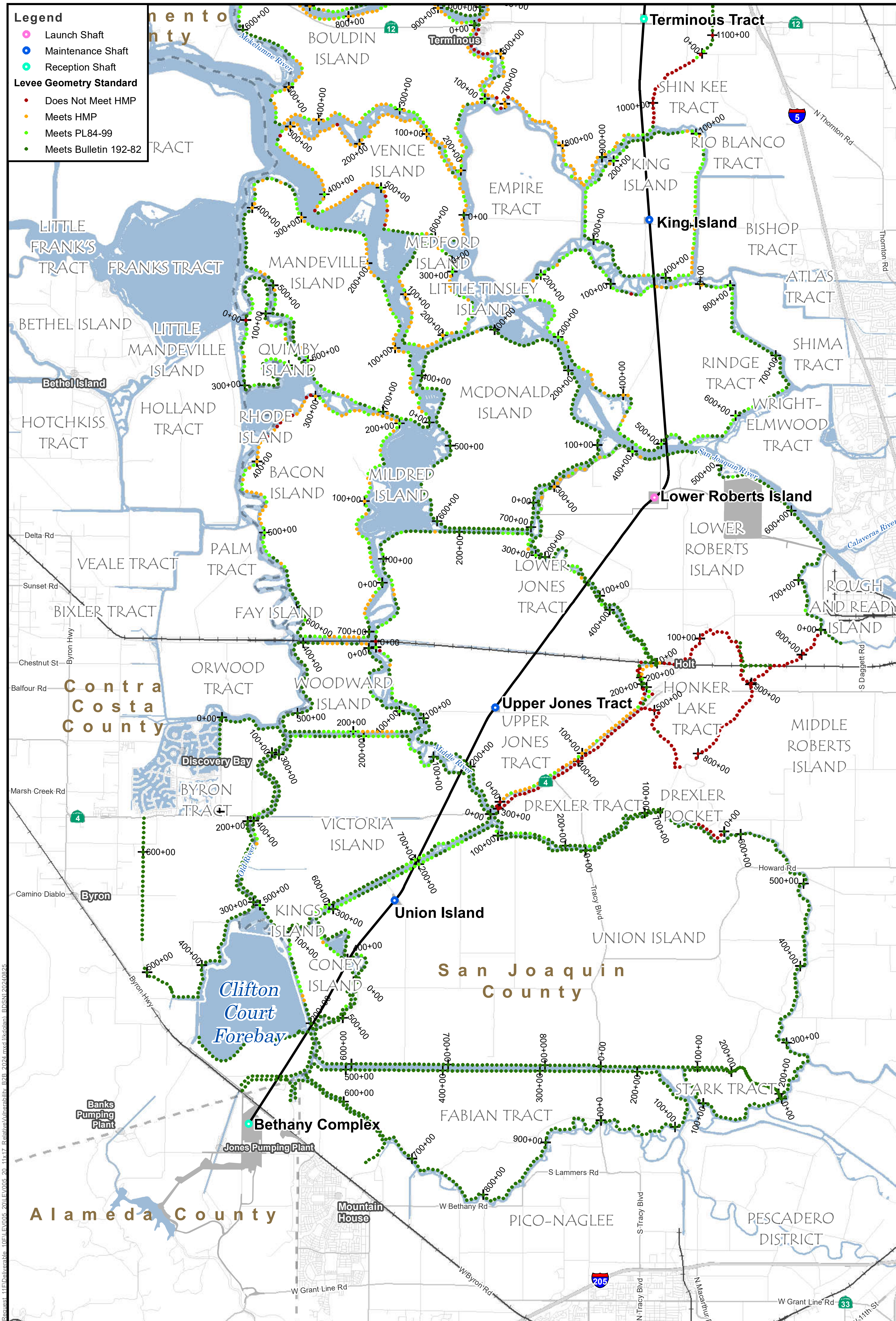
For Illustration Purposes Only

N

0 1.75 Miles

Figure 3-6a
Relative Levee Vulnerability Rating

Data Source: DCA, DWR



For Illustration Purposes Only

N

0 1.75 Miles

Figure 3-6b
Relative Levee Vulnerability Rating

Data Source: DCA, DWR