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4.1 INTRODUCTION

4.1.1 Background

The Sacramento–San Joaquin River Delta (Delta) has approximately 1,100 miles of levees of significant height (up to 25 feet) that continuously impound sloughs and river waters and protect agriculture and urban areas within islands and tracts. The floors of the islands in the central and western Delta are below sea level by several feet as a result of subsidence from the farming of organic soils.

The vulnerability of existing levees under various stressing events was assessed as part of Phase 1 of the Delta Risk Management Strategy (DRMS). Stressing events include seismic events, flood events, and normal or "sunny-day" events. Phase 1 of DRMS also assessed the effects of climate change and subsidence on these events. A model was developed to quantify the risks and the potential impacts of present and future levee failures in the Delta.

4.1.2 Purpose and Scope

The purpose of Building Block 1.2, Upgraded Delta Levees, is to discuss the upgrades to Delta levees that could be implemented to reduce risk. The discussion in this section provides background information; develops conceptual upgrades, cost estimates, and a risk reduction estimate; and summarizes the findings and conclusions.

This building block was developed as one of the alternatives to reduce the likelihood of levee failures. The building block consists of two sub-building blocks:

- Selected Delta levees (about 764 miles of levees) upgraded to Public Law 84-99 (PL 84-99) standards (Figure 4-1)
- Selected Delta levees (about 187 miles of levees) upgraded to Urban Project Levee (UPL) standards (Figure 4-2)

4.1.3 Objective and Approach

The objective of the levee improvements considered in this building block is to confirm the engineering feasibility of the improvements, evaluate their effects on risk reduction, and estimate order-of-magnitude costs. The approach is to use the risk model developed in Phase 1 of DRMS to conduct a conceptual–level evaluation of the building block.

Typical upgraded levee cross sections were developed for a range of subsurface conditions (i.e., no peat, 10 feet of peat, 20 feet of peat, 30 feet of peat, and 40 feet of peat) to estimate cost and risk reduction using the available geotechnical database and information from the Geographic Information System (GIS) database specifically prepared for the DRMS project.

As the consulting team was evaluating this building block, the Department of Water Resources (DWR) was concurrently undertaking a project to complete the Light Detecting and Ranging (LiDAR) survey of the entire study area. However, the LiDAR survey information was not available at the time the building block was analyzed. The analysis can be further refined in the near future, once the LiDAR digitization of the Delta levees is complete.

4.2 DESCRIPTION OF IMPROVEMENT

This building block consists of two separate improvements: (1) upgrading 764 miles of Delta levees to PL 84-99 standards and (2) upgrading 187 miles of Delta Levees to UPL standards. Typical cross sections for each levee type are presented on Figures 4-3 and 4-4.

After the 1986 flood in the Central Valley, DWR provided funds through its Delta Levees Maintenance Subvention Program to maintain and upgrade levees, with the goal of raising levee crowns to 1 foot above the height of the estimated 100-year flood stage to meet state Hazard Mitigation Plan (HMP) standards. Many non-project ("local") levees were upgraded to HMP standards using the state funds, with local cost sharing. Therefore, for this building block we assume that only modest upgrades are needed for all central Delta levees to meet the HMP standard, at a cost of less than $50 million.

Existing levees can be built to various standards, depending on the level of flood protection desired. The major difference between the PL 84-99 and UPL standards is the freeboard requirement. The PL 84-99 standard requires a freeboard of 1.5 feet (Figure 4-3), whereas the UPL requires a freeboard of 3.0 feet (Figure 4-4). The UPL standard also requires a waterside slope of 2 horizontal to 1 vertical (2H:1V), which in turn requires placement of rock fill on the waterside of the existing levee. Most federal project levees in the Delta already meet the PL 84-99 standard, and these levees were removed from the list of potential candidates for a PL 84-99 upgrade. The geometry of the levee will significantly influence how the levee responds to seismic and hydraulic forces.

4.2.1 Approach

The basic approach and development procedure for this building block included the following steps:

- Select 764 miles of levees outside of urban areas for upgrade to PL 84-99 standards and 187 miles of levees within urban areas for upgrade to UPL standards.
- Identify the levee sections not presently meeting the design criteria.
- Develop parametric upgrade cross sections for different depths of organic soils.
- Assign parametric cross sections to levee sections not meeting the design criteria.
- Estimate upgrade quantities and costs per unit lengths for each parametric cross section.
- Use the two preceding steps to estimate upgrade costs by island and total upgrade costs.

4.2.2 Select 764 Miles of Levees for Upgrade to PL 84-99 Standards

The islands were selected for upgrade using the following criteria:

- All islands protected by non-project levees that do not contain urban centers
- Islands were ranked in order of decreasing projected risk of failure due to floods. The risk of failure was calculated in Phase 1 of DRMS.

4.2.3 Select 187 Miles of Levees for Upgrade to UPL Standards

The islands were selected for upgrade using the following criteria:

- All levees protecting urban centers
- Islands were ranked in order of decreasing projected risk of failure due to floods. The risk of failure was calculated in Phase 1 of DRMS.
- Recommendations are also made to upgrade levees to UPL standards around historical towns.

4.2.4 Develop Parametric Upgrade Cross Sections

Parametric levee upgrade geometries were developed and analyzed. Specifically, levee upgraded geometries satisfying PL 84-99 and UPL standards were developed for organic soil thicknesses of 0, 10, 20, 30, and 40 feet (five typical sections for each upgrade). After reviewing the ground elevations on the landside of the levees, the consulting team selected a representative ground elevation of -10 feet (North American Vertical Datum) for all parametric cross sections (this parameter can be further refined once the LiDAR-based levee geometric discretization is complete). The parametric upgrade sections were selected to have a minimum crest width of 16 feet and a minimum static factor of safety of 1.25 for PL 84-99 levees and a minimum crest width of 20 feet and a minimum static factor of safety of 1.4 for UPL levees on both the waterside and the landside. The resulting five parametric cross sections meeting the PL 84-99 criteria are shown on Figures 4-5a through 4-5e, and the five parametric cross sections meeting the UPL criteria are shown on Figures 4-6a through 4-6e.

4.2.5 Assign Site-Specific Parametric Upgrade Cross Sections

Subsurface conditions under the levees in the central Delta have previously been characterized at 100-foot intervals in terms of the thickness of the organic soils. Using these characterizations of existing subsurface conditions, the consulting team developed upgraded cross sections for each 100-foot segment of Delta levee. The upgraded parametric cross sections were grouped into five common categories. Each category was assigned an identification index as shown in the following list:

Organic Soil Thickness (feet)	PL 84-99 Cross Section	Urban Project Levee Cross Section
0	PL 0	UPL 0
10	PL 10	UPL 10
20	PL 20	UPL 20
30	PL 30	UPL 30
40	PL 40	UPL 40

4.3 IMPROVEMENT COSTS

4.3.1 Approach

As discussed in Section 4.2, suites of parametric levee upgrade cross sections were developed that spanned the range of reasonably expected levee subsurface conditions and design criteria that were considered for each upgrade. The extent to which these cross sections satisfy the design criteria for the specified subsurface conditions was analyzed, and any necessary changes to the cross sections were made.

Because the costs of the levee upgrades are highly dependent on the source of suitable fill materials (on-island fill versus imported fill), the consulting team developed information on the extent to which suitable fill materials for the levee upgrades are available on the islands.

The consulting team estimated fill quantities using the parametric levee upgrade cross sections. Referring to the estimated fill quantities, the team then identified on-site borrow sources, if available, or off-site sources. Finally, the team developed the estimated costs of repair based on these conditions.

The type of levee upgrade was developed based on the previously defined subsurface parameters (organic soil depth and the presence or absence of loose, potentially liquefiable sand below the organic soils) along each island's levee. Consequently, a levee upgrade cross section that would satisfy the specific upgrade criteria (PL 84-99 or UPL standards) at each location along each island's levee could be identified and defined.

Once the section-by-section conceptual levee upgrade design was accomplished, the estimated upgrade costs were known on a section-by-section basis, and the upgrade costs per island for each upgrade could be calculated.

4.3.2 Review of Availability of On-Island Fill Material

The volumes of potentially suitable construction materials for use in upgrading selected levees to the PL 84-99 or UPL standards or constructing setback (seismic-resistant) levees, which are discussed in Section 8, Building Block 1.6, Armored Pathway (Through-Delta Conveyance), were identified. Table 4-1 summarizes the soil types, in accordance with the Uniform Classification System, their properties, and their suitability for levee construction or upgrade.

The preliminary results of this study yielded estimates that sufficient on-island levee materials are available for PL 84-99 and UPL upgrades, and import materials are required for upgrades involving setback and seismic-resistant levees.

4.3.3 Parametric Cross Sections

As discussed in Section 4.2, several parametric cross sections were developed and analyzed for the two types of upgrades (PL 84-99 and UPL). For each of these parametric cross sections, the material quantities per unit length (such as fill quantities) were calculated. Based on these quantities, the cost of upgrade for each cross section was developed per unit length of levee.

Finally, the quantities and cost of repair for each levee upgrade standard (PL 84-99 and UPL) were established for each 100-foot levee section of each island levee, for each island, and for the entire Delta.

4.3.4 Cost Estimates of Parametric Cross Sections

The unit costs of all 10 parametric cross sections were estimated, first by foot and then by mile of levee upgrade. The results of these cost estimates are summarized in Table 4-2 for upgrades to PL 84-99 standards and Table 4-3 for upgrades to UPL standards. The principles informing the development of these cost estimates were to make them simple, transparent, and reproducible.

The quantities of the various materials and services required for each parametric cross section were derived from the respective cross sections. As discussed above, the cost estimates for the PL 84-99 and UPL upgrades for the selected islands are based on the use of on-island fill. Unlike upgrades to PL 84-99 standards, upgrades to UPL standards call for placement of rock fill on the waterside slopes of the affected levees.

4.4 RISK REDUCTION ESTIMATES

This building block consists of upgrades to PL 84-99 and UPL design standards. As discussed above, it was assumed that (1) all levees in the Delta already meet the HMP standard design criteria, and (2) the designated project levees in the Delta already meet the PL 84-99 standards. The PL 84-99 and UPL standards reduce the risk of flood-induced levee failures but only minimally reduce the risk of seismic-induced levee failures.

4.4.1 Flood Risk Reduction

The reduction in the frequency of levee failure due to flooding was estimated using a simplified method of levee under-seepage evaluation. The average landside gradients for both existing and improved levee configurations were calculated using a simplified method called “blanket theory,” an empirically based hand calculation method developed by the U.S. Army Corps of Engineers (USACE 1956, 2000b). Blanket theory uses performance data and measured seepage conditions from numerous sites in the Mississippi Valley combined with a theoretically based model to develop predictions for under-seepage flow conditions, pressures, and failure potential as a function of site conditions and flood level rise above the levee landside toe. The sites that were evaluated in those studies and used to develop blanket theory are characterized as having a relatively thin layer of relatively low-permeability soil (i.e., the blanket) overlying a more permeable material directly connected to the river. This condition is the same as conditions throughout the Delta, and therefore private consultants and the USACE have used blanket theory widely to evaluate seepage conditions and cross-check the results of finite-element seepage models.

The calculated average exit gradients through the blanket were used to estimate the reduction in the exit gradients. The fragility curves developed in Phase 1 were used to estimate the reduction in the probability of failure due to flooding as a function of the reduced exit gradient. The fragility curves relate the vertical exit gradient to the probability of failure. Raising the crest of the levees would also contribute to the reduction of the probability of failure by overtopping.

The combined upgrade of the levees to the PL 84-99 and the UPL standards would result in an estimated reduction of 58 percent to the probability of flood-induced failure.

4.4.2 Seismic Risk Reduction

Upgrading levees to the PL 84-99 and UPL standards would do little to reduce the risk of failure under seismic loading.

4.4.3 Summary of Delta-Wide Risk Reduction Estimates

The above value (58 percent reduction) represents the risk reduction potential of this building block. To estimate the risk reduction for the entire Delta, the number of levee miles that are not improved should be included in the estimate. This risk reduction value needs to be combined with other building blocks in the relevant scenarios to estimate the overall risk reduction benefit of each trial scenario.

4.5 FINDINGS

The key findings for the two types of levee upgrades considered here are as follows:

- Most of the Delta levees already meet the HMP standard.
- Some of the levees in the central Delta (project levees) already meet the PL 84-99 standards.
- The cost of upgrading 764 miles of selected non-project levees (levees that do not meet PL 84-99 standards) in the central Delta to PL 84-99 standards is about $1.2 billion.
- The cost of upgrading 187 miles of selected levees around urban centers to UPL standards is $750 million.
- Upgrading levees to meet the target standards will reduce the probability of failure due to flooding. However, these upgrades do not guarantee that the upgraded levees, particularly those upgraded to PL 84-99 standards, will not fail during a 100-year flood. The 1.5 feet of freeboard is insufficient for regions subject to high winds during floods.
- Upgrading levees to meet the PL 84-99 and UPL standards does not reduce the seismic risk of levee failure.

Tables

Table 4-1 Summary of Suitable Materials

Upgrade Type	Soil Characteristics (Uniform Classification System)
PL 84-99 or UPL	Any soils except organic soils (P, OH, OG) and Fat Clay (CH)
Seismic-Resistant Setback	Low plasticity soils (CL, SC, GC) with PI > 8 and LL < 50

Table 4-2 Summary of Cost Estimate for Upgrading 764 Miles of Levees to PL 84-99 Standards

Analysis Zone	Levee Length (mile)	Conceptual Levee Construction Cost ($million)
Atlas Tract (west)	3.0	5.5
Bacon Island	14.3	37.2
Bouldin Island	17.9	50.6
Brack Tract	10.8	19.5
Bradford Island	7.4	23.0
Brannan-Andrus Island	41.1	61.9
Cache Haas Area	18.2	12.3
Canal Ranch	10.6	19.1
Coney Island	5.5	14.5
Cosumnes River Area	6.8	8.1
Dead Horse Island	2.6	4.7
Dutch Slough	1.8	3.1
Ehrheardt Club	7.4	8.9
Empire Tract	10.5	18.9
Fabian Tract	23.9	32.1
Glanville Tract	17.6	27.1
Holland Tract	11.0	23.3
Hotchkiss Tract	8.7	15.1
Jersey Island	15.5	41.6
Jones Tract	18.7	33.6
King Island	9.1	16.3
Libby McNeil Tract	3.7	5.0
Little Egbert Tract	10.3	19.7
Mandeville Island	14.3	44.4
McCormack Williamson Tract	8.7	15.7
McDonald Tract	13.7	32.3
McMullin Ranch-River Junction	19.5	14.5
Medford Island	5.9	14.0
Netherlands	41.8	1.5
New Hope Tract	13.6	20.3
Palm-Orwood Tract	16.5	28.7
Paradise Junction	7.0	2.5
Pescadero	9.0	3.1
Peter's Pocket	8.2	1.2
Pico Naglee Tract	10.1	12.1
Pierson District	15.9	13.2
Quimby Island	7.0	18.8
Rindge Tract	15.8	28.4
Rio Blanco Tract	5.8	7.0
Roberts Islands	56.6	54.5
Sherman Island	19.4	34.7
Shima Tract - WEST	6.9	12.5

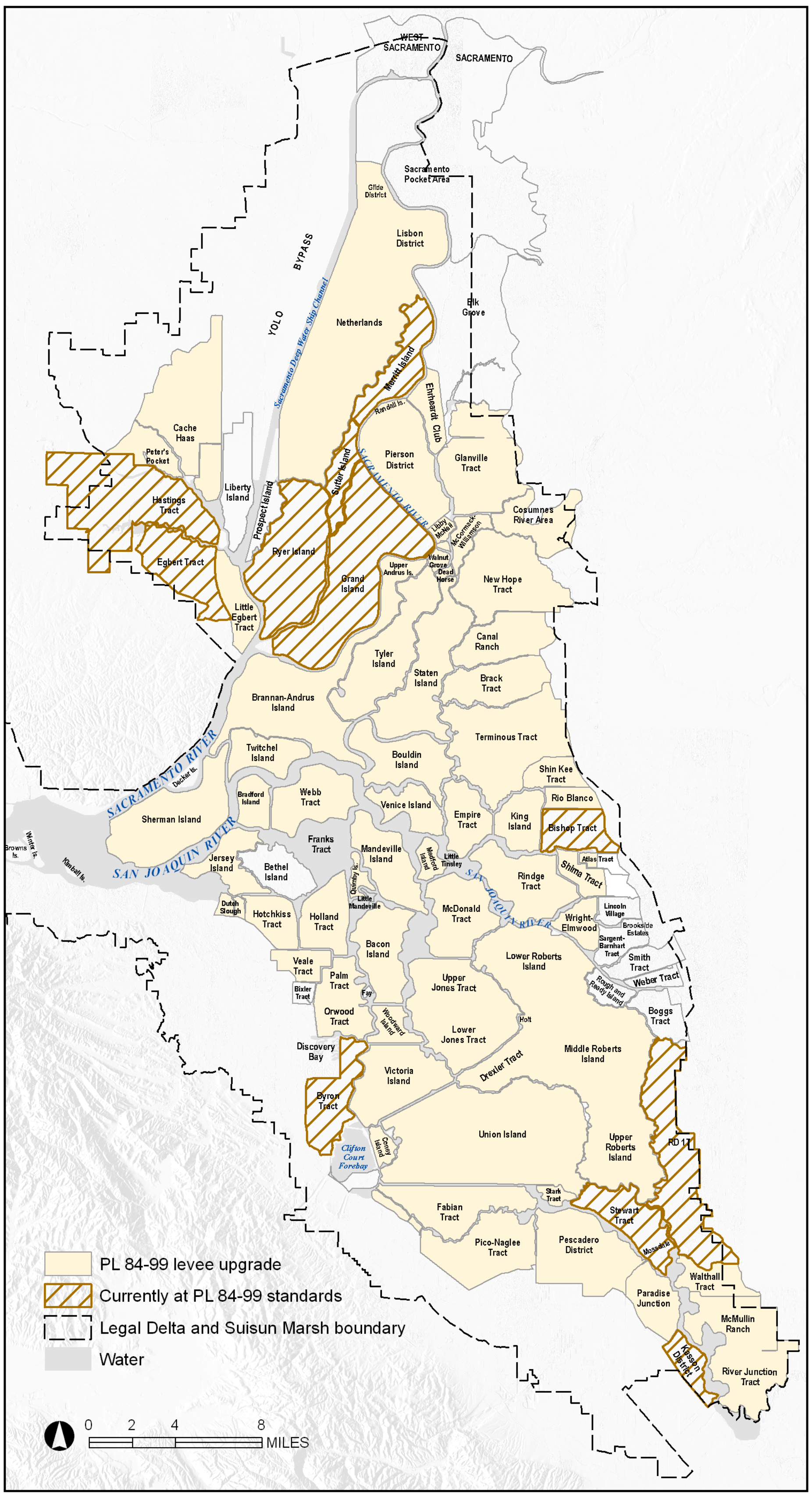
Table 4-2 Summary of Cost Estimate for Upgrading 764 Miles of Levees to PL 84-99 Standards

Analysis Zone	Levee Length (mile)	Conceptual Levee Construction Cost ($million)
Shin Kee Tract	6.5	7.8
Stark Tract	5.1	2.7
Staten Island	25.3	45.6
Terminous Tract	20.5	34.3
Twitchell Island	11.9	15.7
Tyler Island	22.9	19.3
Union Island	33.0	54.4
Veale Tract	5.4	8.0
Venice Island	12.4	34.6
Victoria Island	15.0	36.2
Walnut Grove	2.9	3.6
Walthall Tract	6.2	4.0
Webb Tract	12.9	40.0
Woodward Island	8.9	16.1
Wright-Elmwood Tract	7.1	13.6
Total	**768.2**	**1.196.0**

Table 4-3 Summary of Cost Estimate for Upgrading 187 Miles of Levees to Urban Project Levee Standards

Analysis Zone	Levee Length (mile)	Conceptual Levee Construction Cost ($million)
Atlas Tract (East of)	1.6	6.6
Bethel Island	11.5	19.6
Bishop Tract	8.7	37.6
Boggs Tract	6.1	25.0
Elk Grove	32.4	132.7
Lincoln Village	5.6	22.8
RD 17	15.8	64.6
Sacramento Urban Area	15.7	64.6
Sargent Barnhart Tract	7.9	36.1
Shima Tract (East of)	0.1	0.7
Smith Tract	5.8	27.0
Rough & Ready Island	6.8	33.3
Weber Tract	3.8	15.5
West Sacramento	23.4	95.9
Areas around historic towns	41.9	168.3
Total	**187.0**	**750.4**

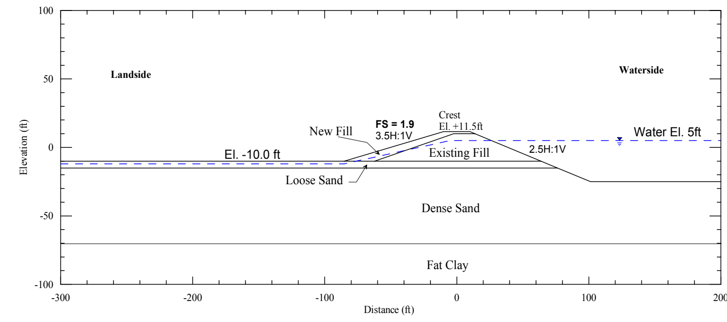
Figures



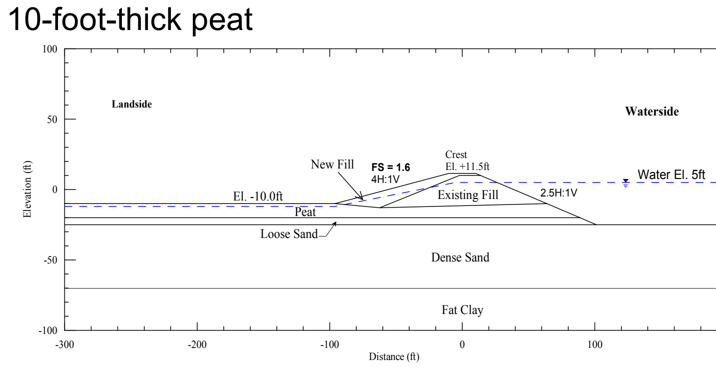
Plan View of Improvement Area

Typical Cross Sections

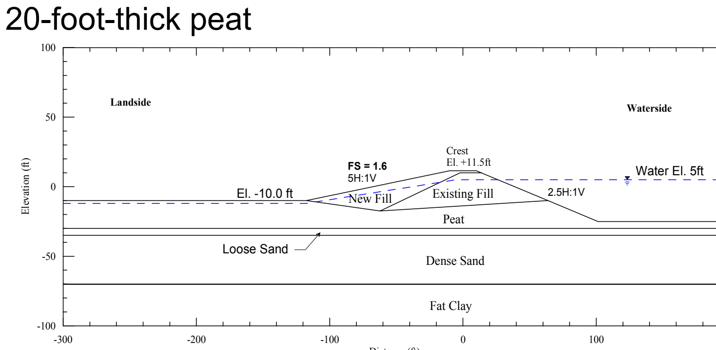
(1) No peat



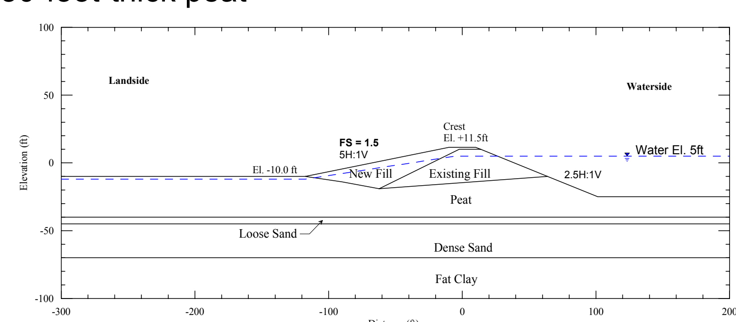
(2) 10-foot-thick peat



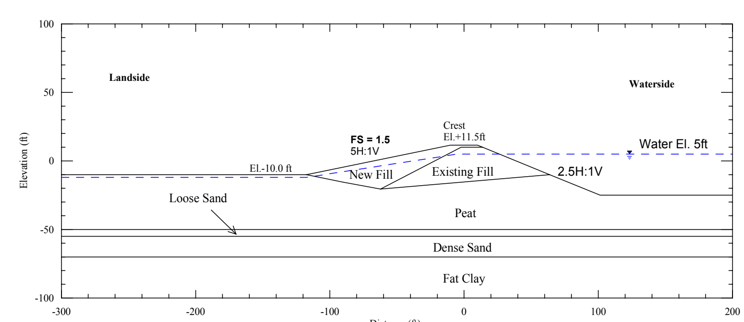
(3) 20-foot-thick peat



(4) 30-foot-thick peat



(5) 40-foot-thick Peat



Note:
- Width of the crest is 20 feet
- Peat thickness represents the thickness of free field peat

Project Information:

PL 84-99 requires levees to be upgraded to the following standards:

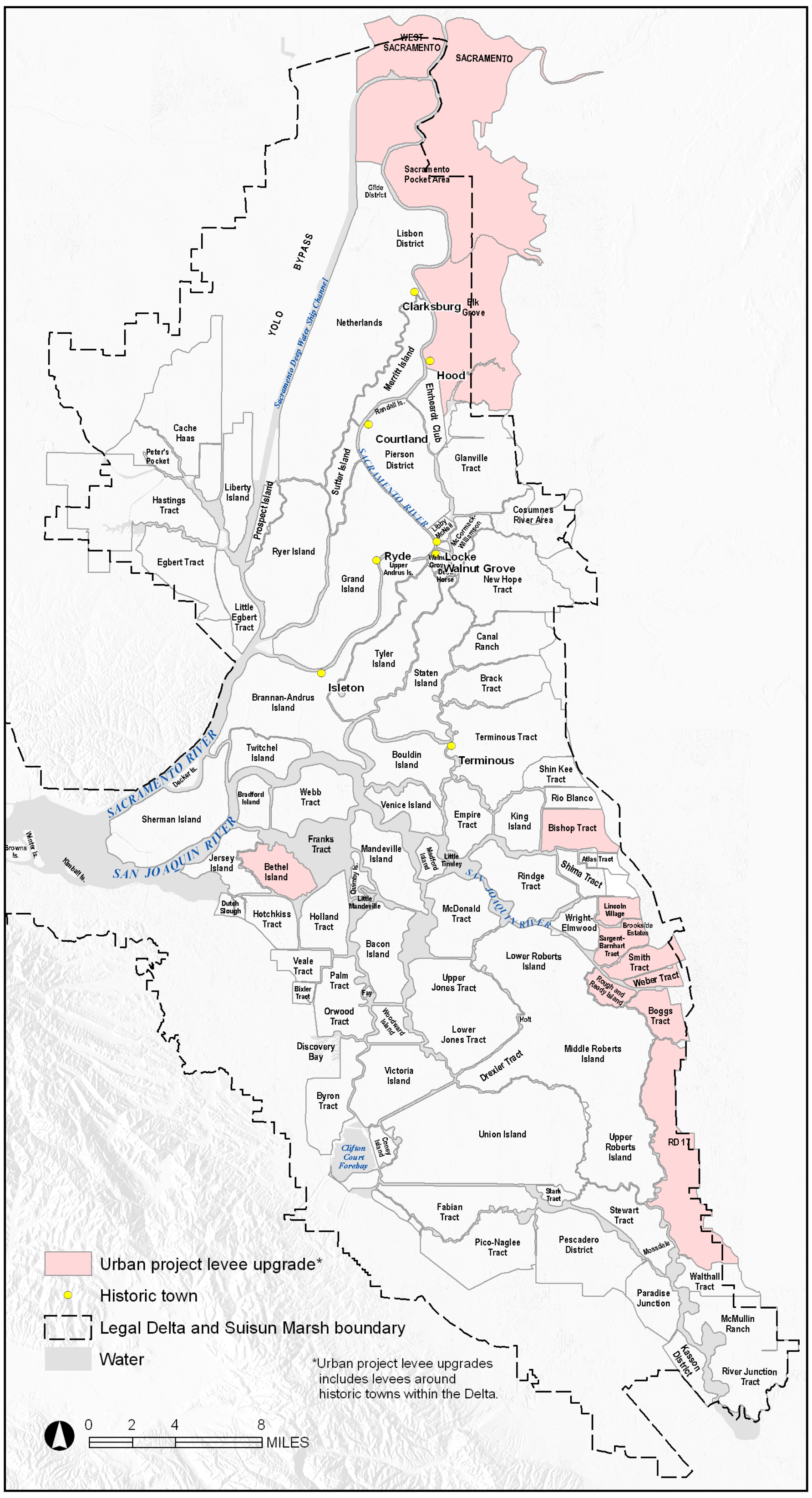
- Maximum Waterside Slope 2H:1V
- Maximum Landside Slope (Varies with Peat thickness and levee height) 2H:1V to 5H:1V
- Minimum Crest Width 16 feet
- Minimum 1.5 feet of freeboard above 100-year flood stage

Levee Length for upgrade ~ 764 miles

Cost
- On Island: ~$1.8 Million/mile, Total Cost $1.2 Billion

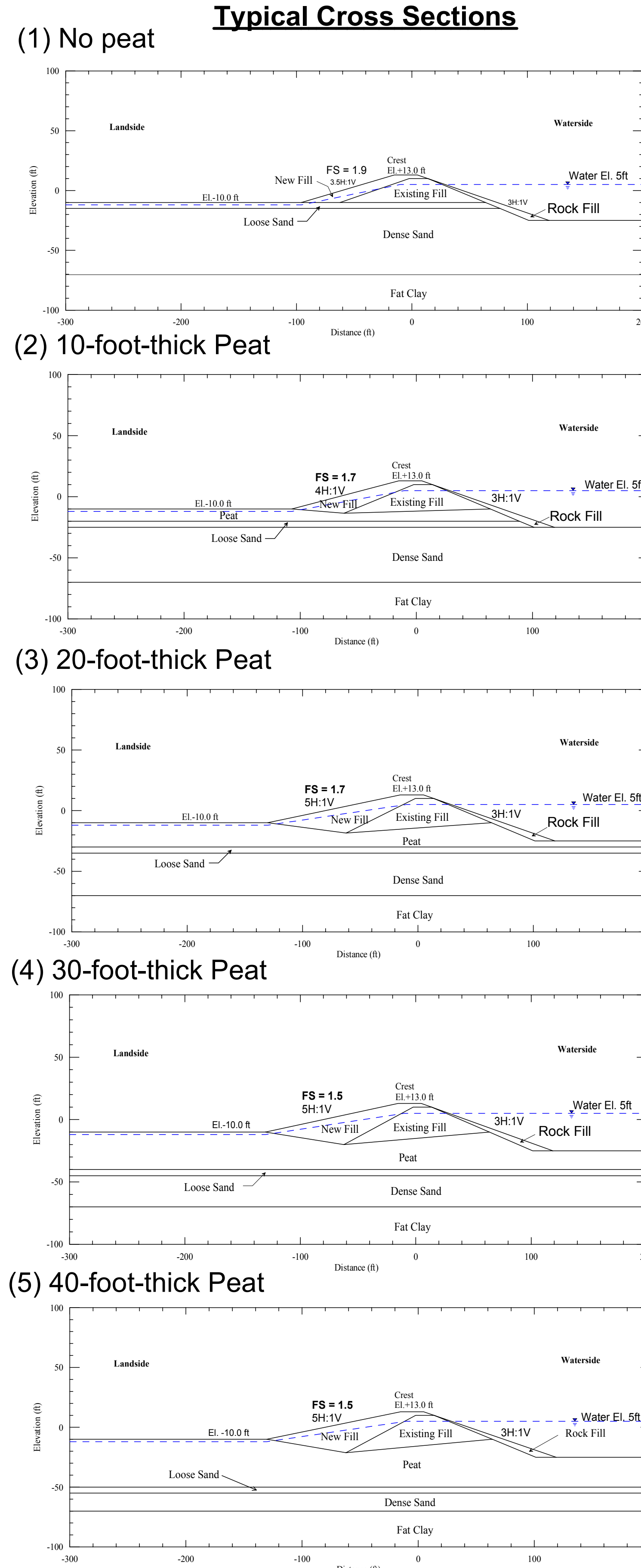
Benefits:

- Reduce flood risk due to overtopping, seepage/underseepage
- Minimal reduction to seismic risk
- Reduce somewhat the risk of saltwater intrusion, export interruption, and impact to ecosystems



Plan View of Improvement Area

Typical Cross Sections



Note:
- Width of the crest is 20 feet
- Peat thickness represents the thickness of free field peat

Project Information:

Urban levees should meet the following standards:

- Maximum waterside slope 3H:1V
- Maximum landside slope 3H:1V
- Minimum crest width 20 feet
- Minimum 3.0 feet of freeboard above 100-year flood stage

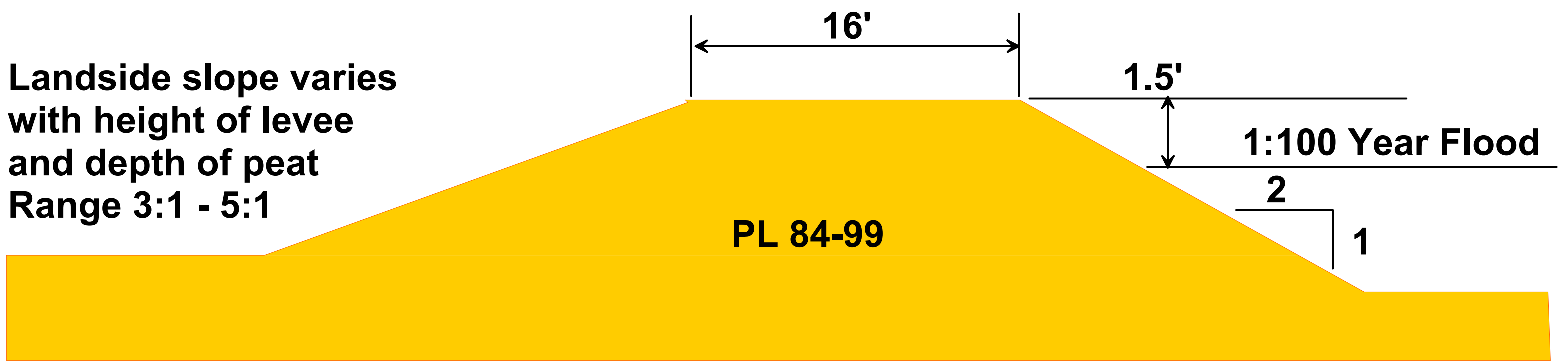
Levee length for upgrade ~ 187 miles

Cost
- On island Fill: ~$4.9 Million/mile , Total Cost $754 Million

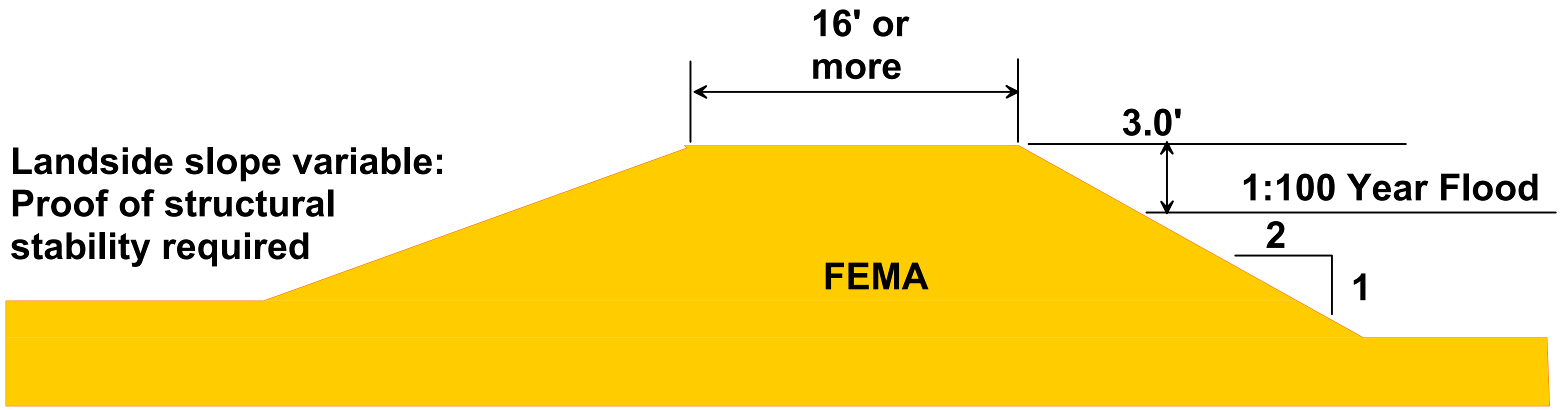
(include rock fill on waterside)

Benefits:

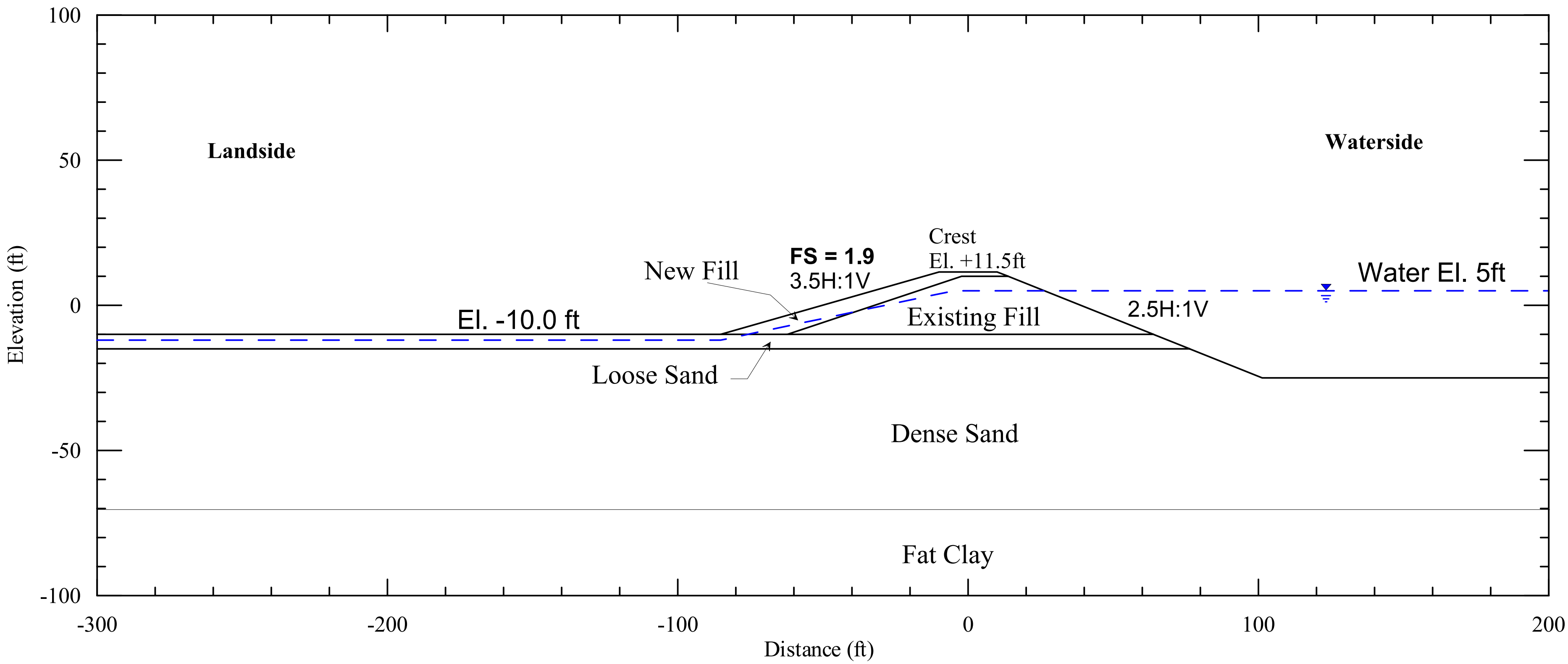
- Improves static stability
- Reduces flood risk due to overtopping, seepage/underseepage
- Minimal reduction to seismic risk



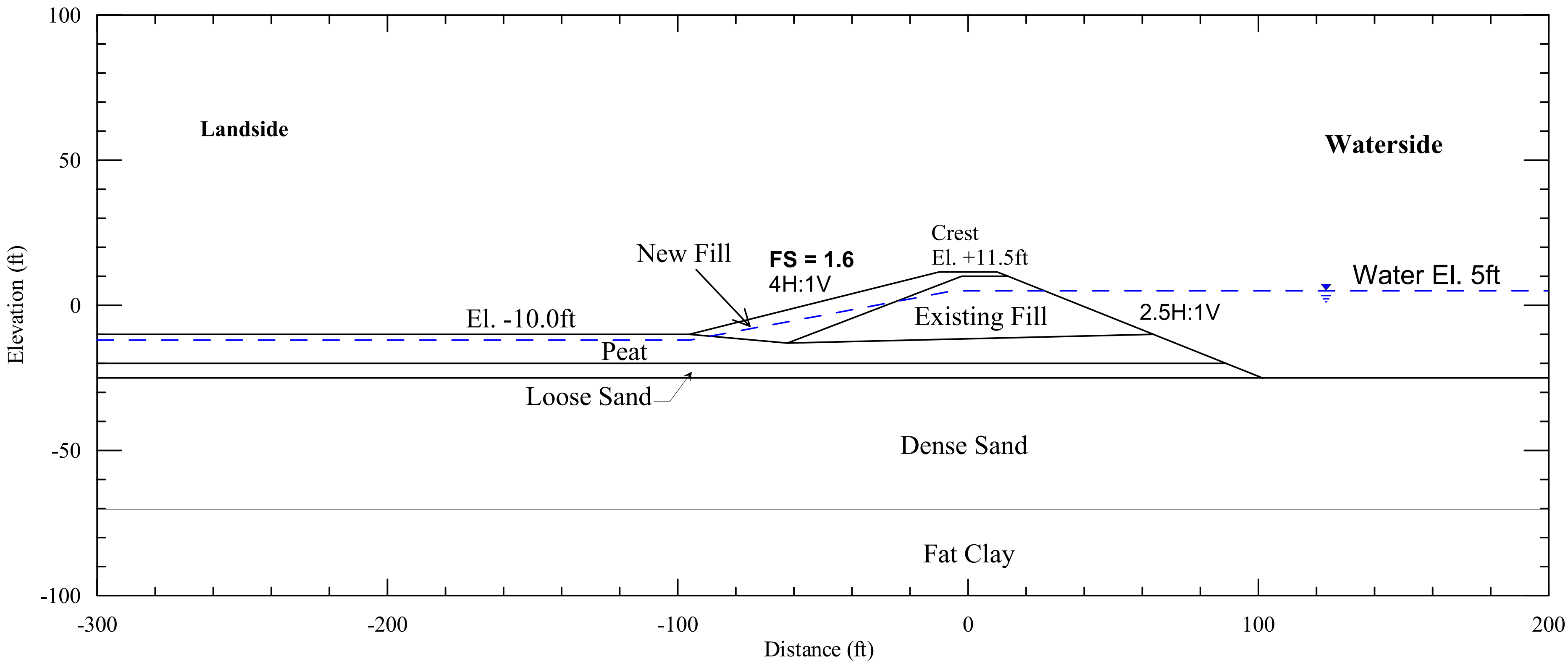
Delta Risk Management Strategy (DRMS)- Phase 2		Typical Cross Section PL 84-99 Standards	Figure 4-3
URS	Project No. 26815935		



Delta Risk Management Strategy (DRMS) - Phase 2		Typical Cross Section Urban Project Levee (UPL) Standards	Figure 4-4
URS	Project No. 26815935		



URS	Project No. 26815935 Delta Risk Management Strategy (DRMS) Phase 2	Parametric Cross Section PL 84-99, 0 feet peat (PL 0)	Figure 4-5a



URS	Project No. 26815935 Delta Risk Management Strategy (DRMS) Phase 2	Parametric Cross Section PL 84-99, 10 feet peat (PL 10)	Figure 4-5b

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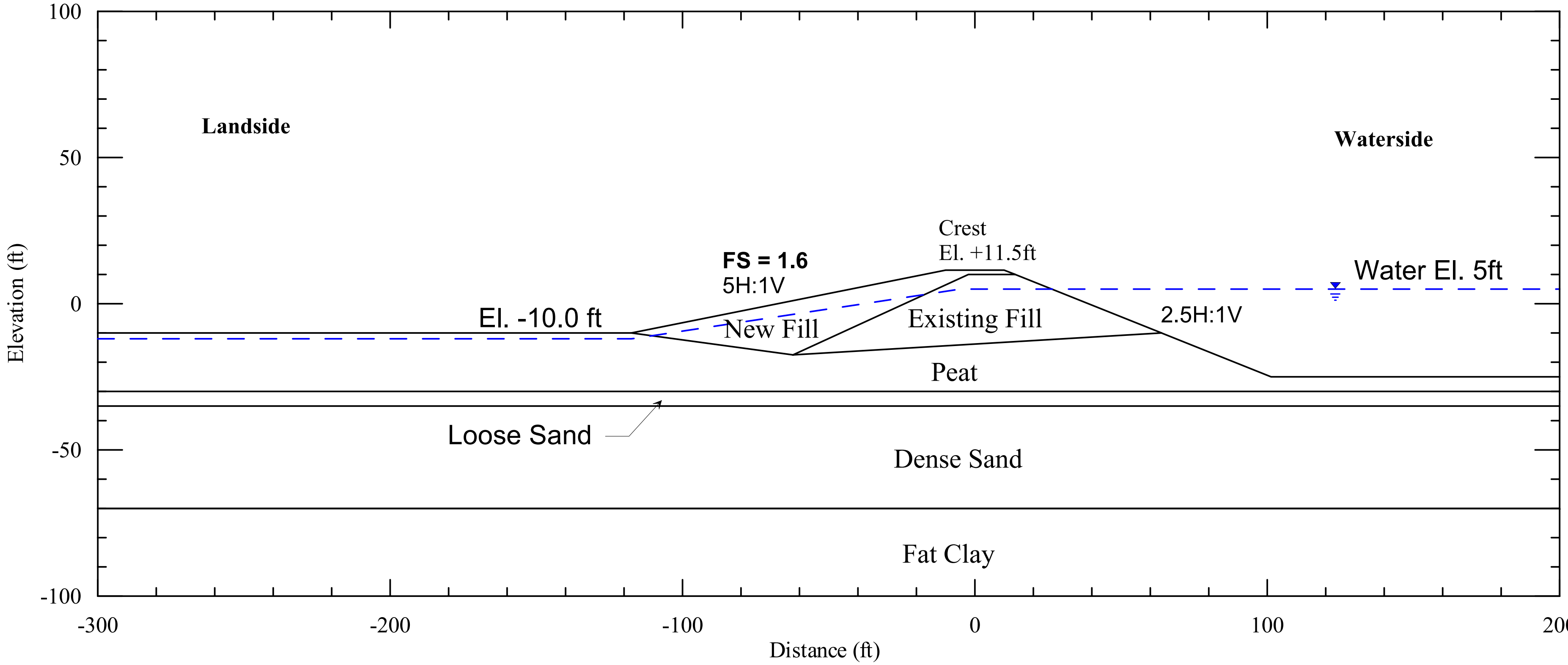

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Project No. 26815935

Delta Risk Management Strategy (DRMS) Phase 2

Parametric Cross Section
PL 84-99, 20 feet peat (PL 20)

Figure 4-5c

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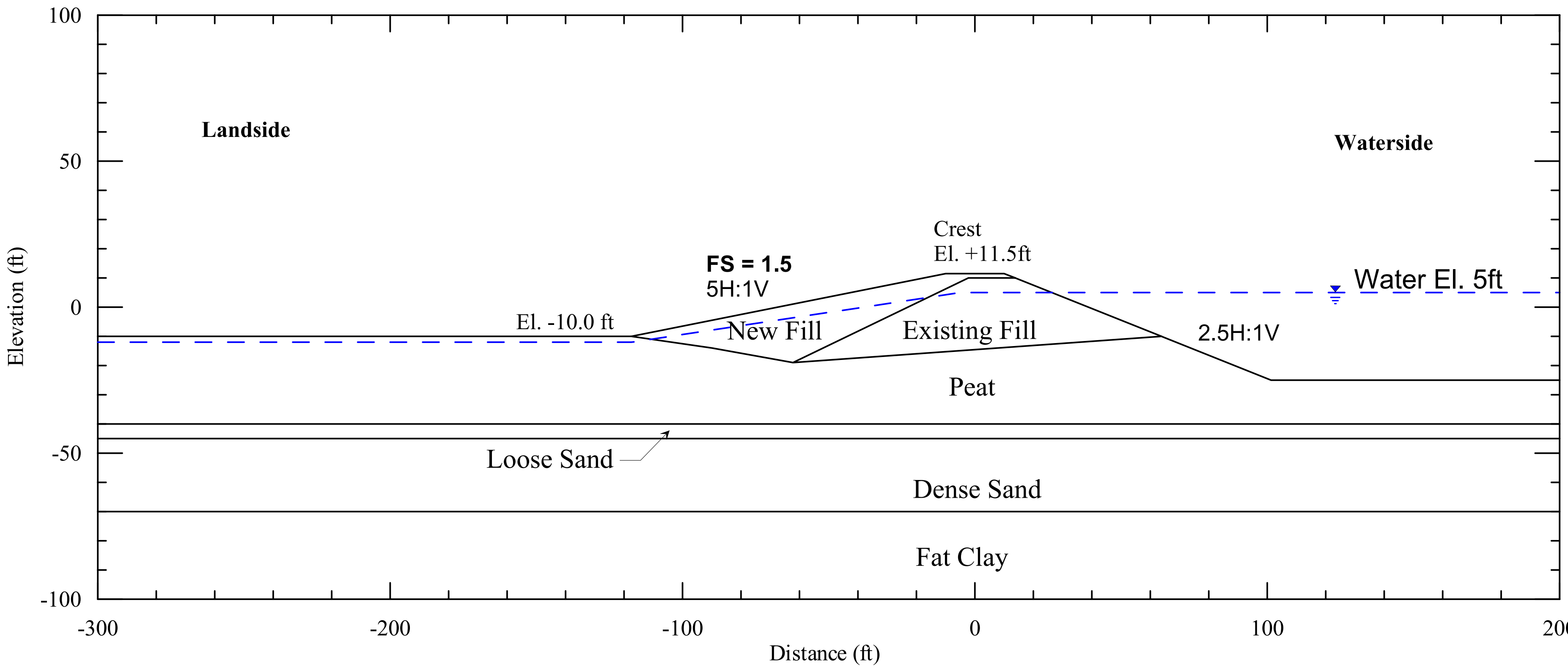

URS	Project No. 26815935 Delta Risk Management Strategy (DRMS) Phase 2	Parametric Cross Section PL 84-99, 30 feet peat (PL 30)	Figure 4-5d

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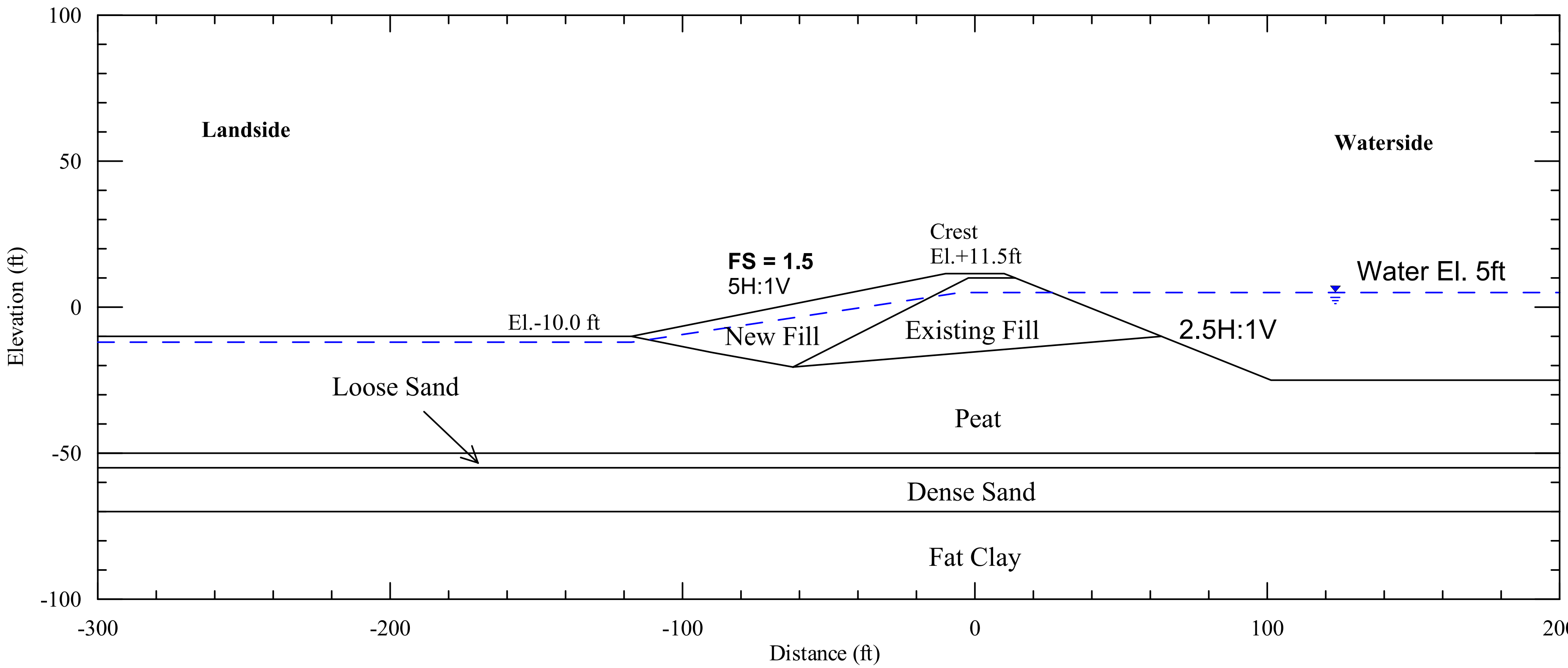

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Project No. 26815935

Delta Risk Management Strategy (DRMS) Phase 2

Parametric Cross Section
PL 84-99, 40 feet peat (PL 40)

Figure 4-5e

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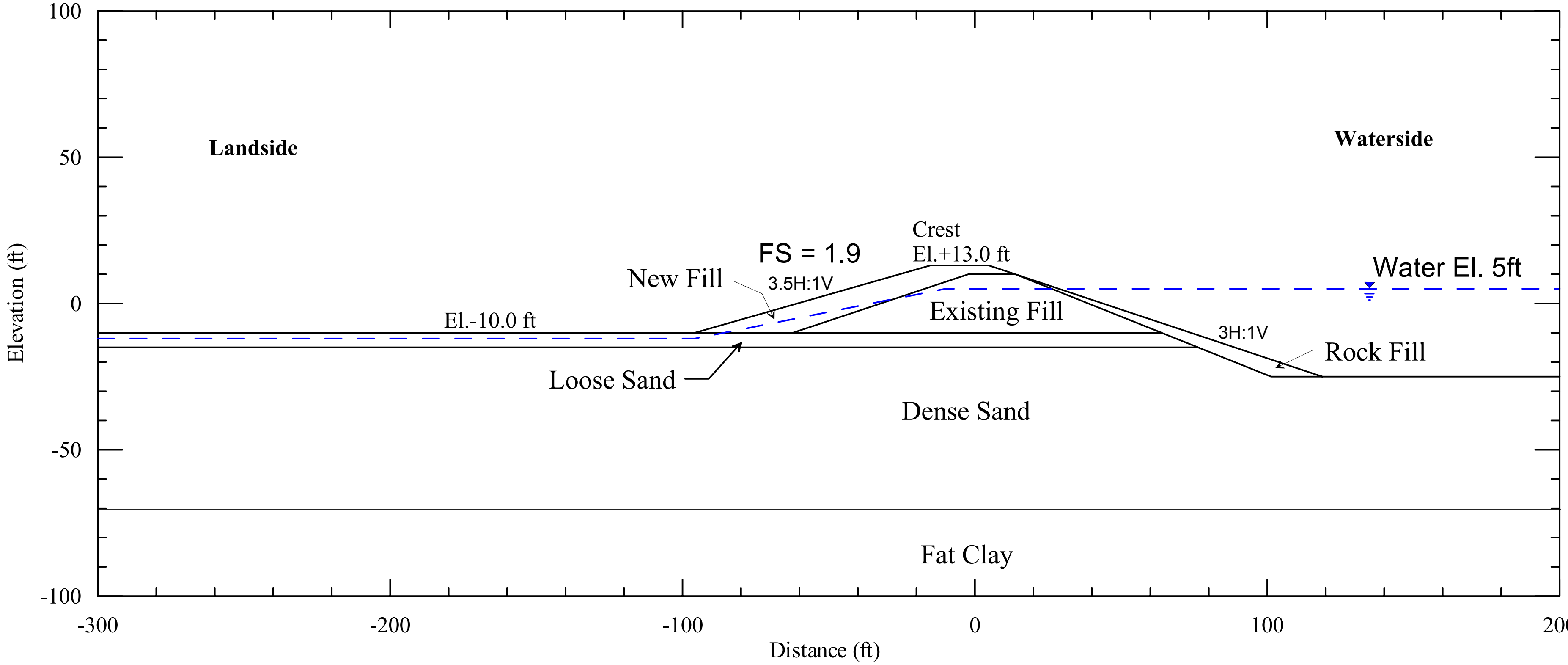

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Delta Risk Management Strategy (DRMS) Phase 2

Parametric Cross Section
Urban Project Levee, 0 feet peat (UPL 0)

Figure 4-6a

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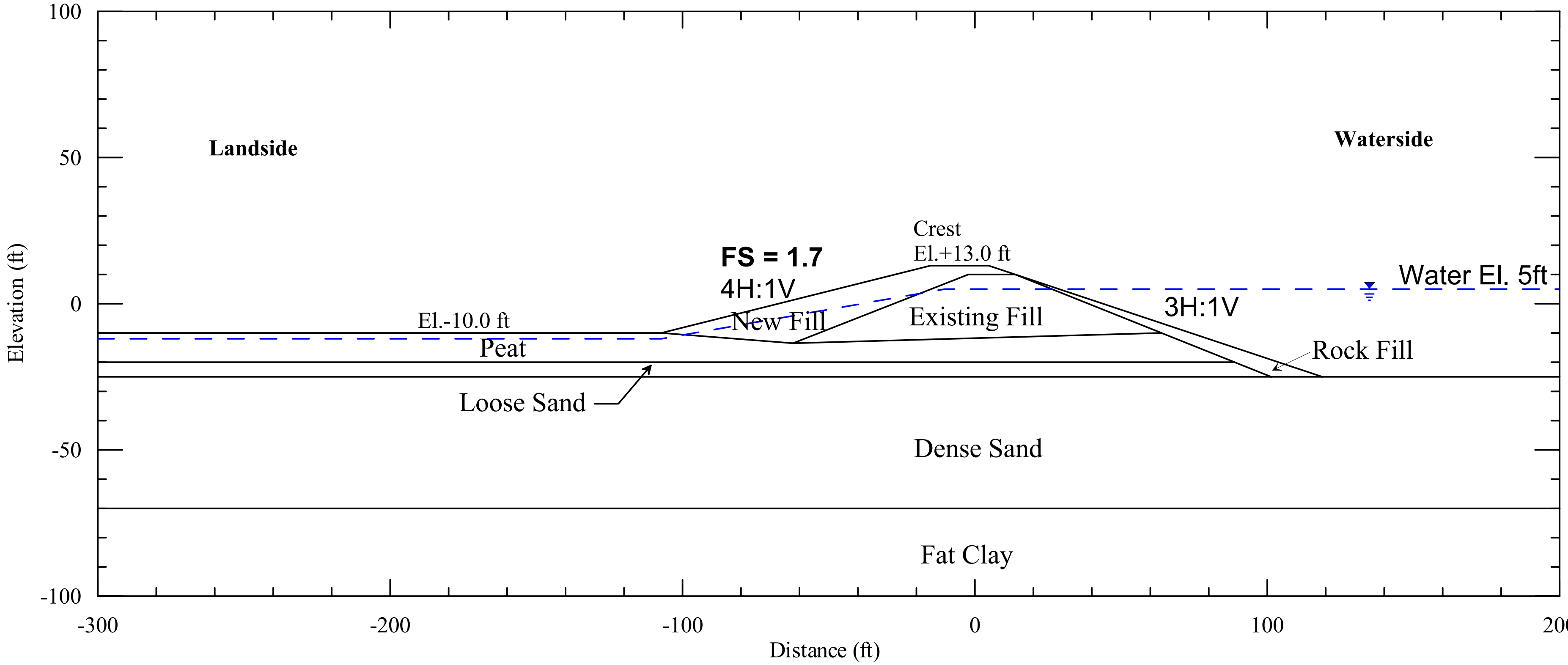

URS	Project No. 26815935	Parametric Cross Section Urban Project Levee, 10 feet peat (UPL 10)	Figure 4-6b
	Delta Risk Management Strategy (DRMS) Phase 2		

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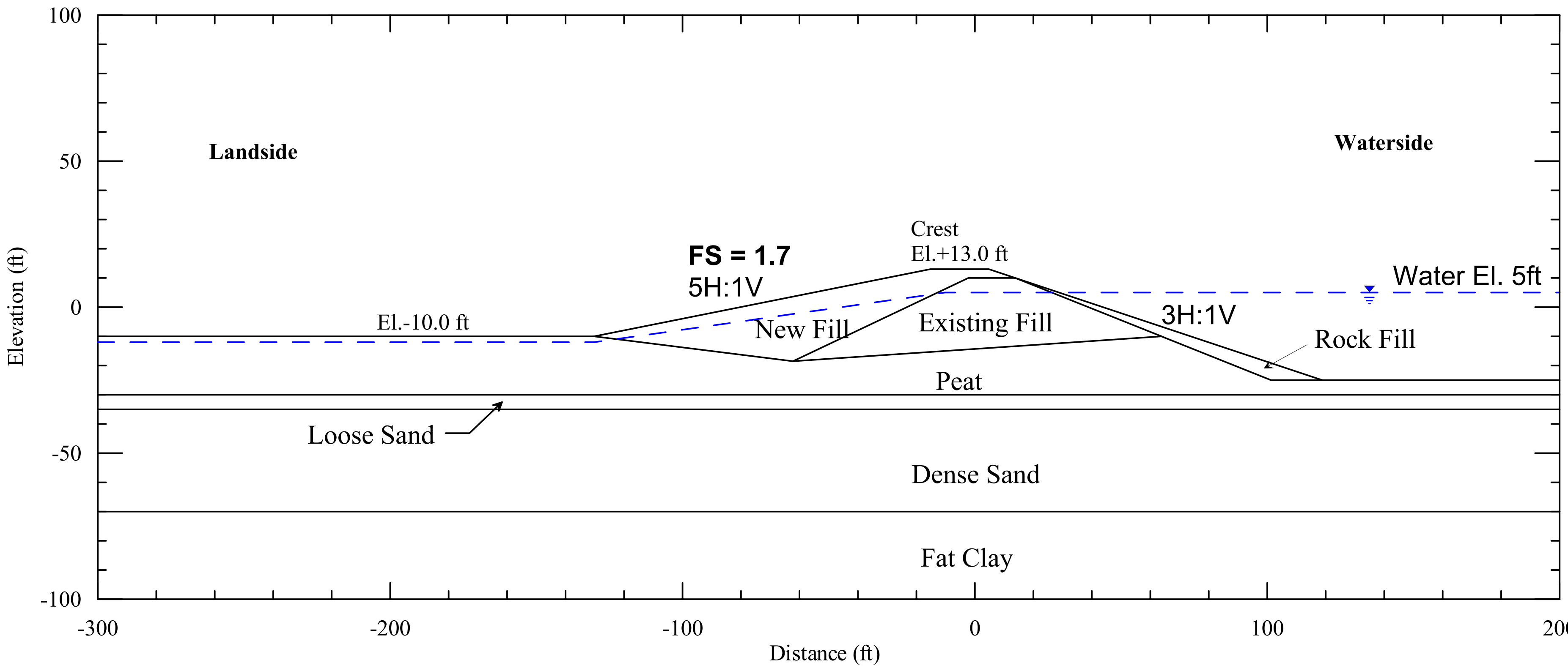

URS

Project No. 26815935

Delta Risk Management Strategy (DRMS) Phase 2

Parametric Cross Section
Urban Project Levee, 20 feet peat (UPL 20)

Figure 4-6c

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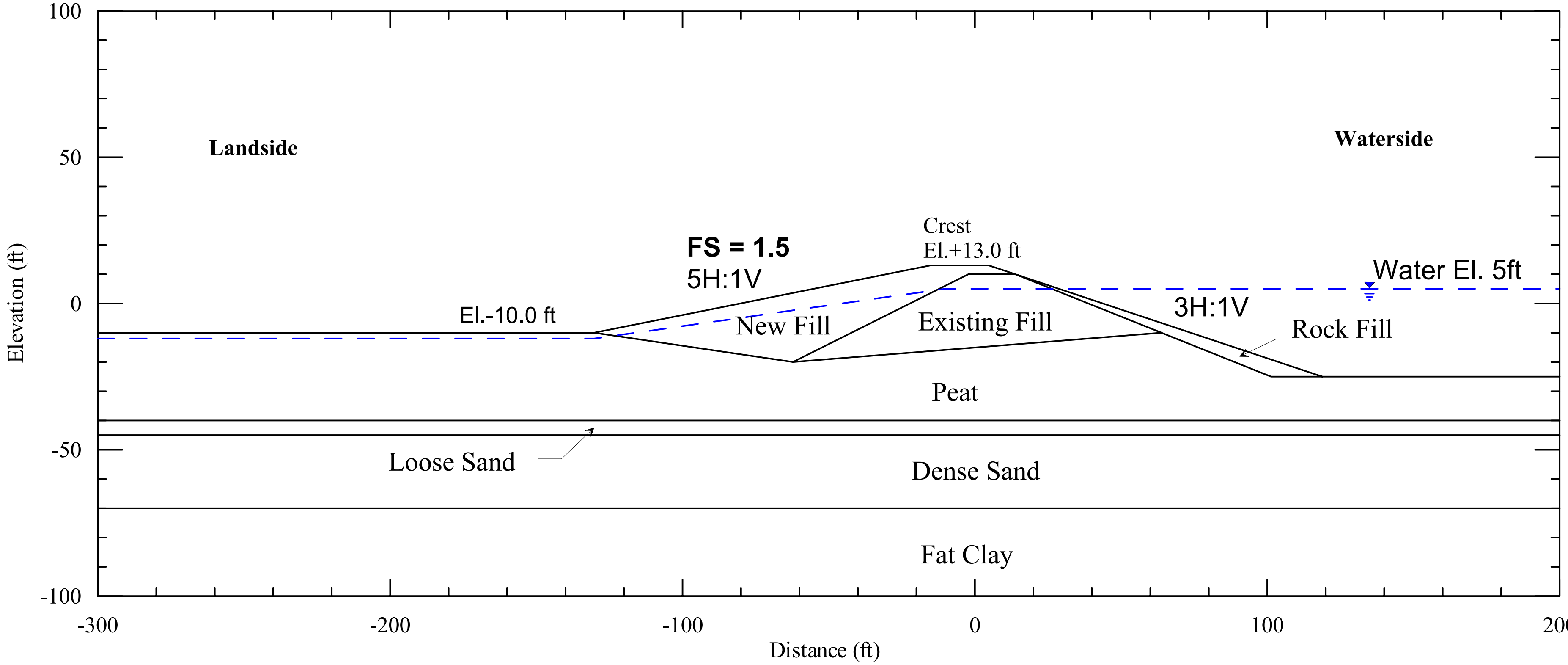

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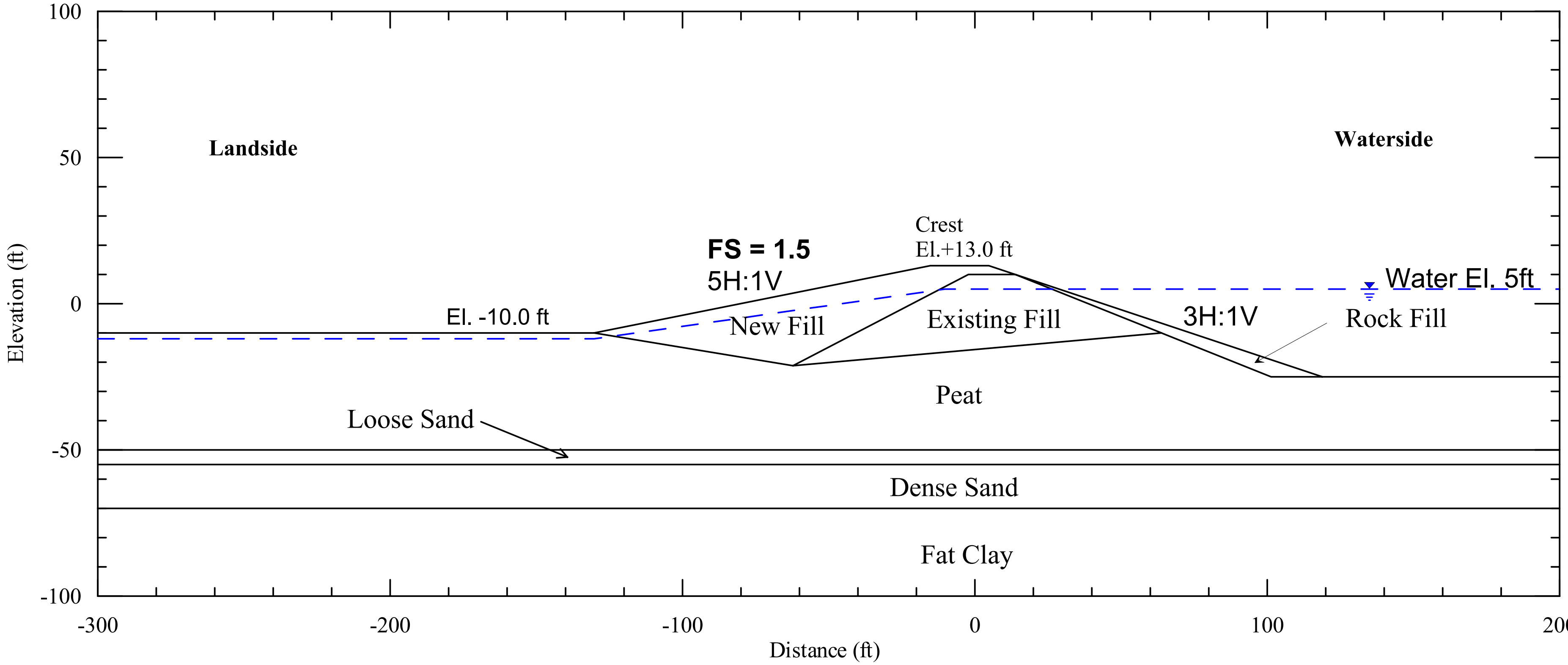
Project No. 26815935

Delta Risk Management Strategy (DRMS) Phase 2

Parametric Cross Section
Urban Project Levee, 30 feet peat (UPL 30)

Figure 4-6d

X:\x_geo\DWR-RISK-2005\Task Orders\Task Order 13 Levee Improvement\30 ft PEAT\30ft peat_SL 05302007



URS	Project No. 26815935 Delta Risk Management Strategy (DRMS) Phase 2	Parametric Cross Section Urban Project Levee, 40 feet peat (UPL 40)	Figure 4-6e

X:\x_geo\DWR-RISK-2005\Task Orders\Task Order 13 Levee Improvement\30 ft PEAT\30ft peat_SL 05302007