ATTACHMENT A

Geotechnical Summary Report, Rio Oso Flood Risk Reduction Feasibility Project

Geotechnical Summary Report

Rio Oso Flood Risk Reduction Feasibility Project

Rio Oso

Sutter County, CA

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Contents

Tables

Figures

Exhibits

Appendices

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1 Introduction

1.1 Background

As part of the State of California Department of Water Resources (DWR) Small Community Flood Risk Reduction Program (SCFRRP), Sutter County is preparing the Rio Oso Flood Risk Reduction Feasibility Project (Project) for the town of Rio Oso. Sutter County has retained the services of a project team consisting of MBK Engineers, HDR Engineering, Inc. (HDR), Wood Rodgers, and Larsen Wurzel & Associates, Inc. The project team has been tasked with performing a feasibility level baseline assessment of the Project for a 100-year flood event.

Rio Oso is situated upstream of State Highway 70 along the Bear River as shown on Figure 1 – Vicinity Map. Reclamation District (RD) 1001 maintains the levees surrounding Rio Oso. The town of Rio Oso is protected from flooding by State Plan of Flood Control (SPFC) levees along the left (south) bank of Yankee Slough, the left (south) bank of Bear River, and the left (east) bank of the Feather River. The levee segments near the study area are shown on Figure 2 – Project Location Map. This study includes Segments 283 and 145 and a similar study carried out for the town of Nicolaus covers Segment 247.

1.2 Purpose and Scope

The purpose of the project is to perform a feasibility level evaluation of the project levees protecting the town of Rio Oso. This report documents the feasibility level geotechnical evaluation performed by HDR. As part of this study, HDR performed the following:

- Reviewed existing geotechnical exploration data and analysis performed by others from DWR's NULE program.
- Performed geotechnical subsurface exploration with four Cone Penetration Tests (CPT) and one mud-rotary boring.
- Performed slope stability and seepage analysis on selected levee cross-sections.
- Evaluated potential seismic hazard considerations.
- Evaluated potential remediation alternatives to deficient levee segments.
- Evaluated potential borrow area locations near the town of Rio Oso, and
- Prepared this technical memorandum documenting our evaluation.

1.3 Datum and Stations

The vertical datum used for the project is the North American Vertical Datum of 1988 (NAVD88). The horizontal datum is the North American Datum of 1983 (NAD83). All coordinates and elevations are presented in feet.

2 Levee Past Performance

The past performance of levees included in this geotechnical assessment for the town of Rio Oso is documented in the NULE Geotechnical Assessment Report (GAR) (URS, 2011). Past performance events documented by NULE include levee break, underseepage, through seepage, erosion, overtopping, and slope instability. The summary of past performance for the levee segments maintained by RD 1001 is shown in Figure 3 – Past Performance Summary Map. This study was focused on the levee alignments on the left banks of Bear River and Yankee Slough.

Since construction, the levees protecting Rio Oso have experienced multiple high water events, including high water in 1950, 1986, 1997, 2006, and 2007. Detailed descriptions of levee segment past performance, based on NULE documents, are provided below.

2.1 Segment 145

Segment 145 is located along the left (south) bank of Yankee Slough. The segment extends from the beginning of the left bank levee of Yankee Slough to the east, extending about 3.7 miles west to the confluence of Yankee Slough with the Bear River. The segment is 3.7 miles long and maintained by RD 1001. The levee segment was constructed during the early 1900s. The base map of Sacramento River Valley dated 1910 shows the proposal to build Levee Mile (LM) 1 to LM 2. The map dated 1925 shows the segment was constructed to the proposed grade around 1925. The levee was reconstructed by the USACE around the 1950s.

A levee break, an overtopping, and erosions have been reported for Segment 145. The locations, types of events, and documented mitigations for Segment 145 are detailed in Table 1.

Table 1. Segment 145 Reported Levee Performance Events

Flood Season	Reported Performance Event	Approximate Location (LM)	Mitigation
Unknown	Waterside erosion	1.17	Repair may or may not have occurred, not documented.
1950	Levee break	3.36 to 3.45	Repaired by the USACE.
1997	Overtopping resulting in crown damage	3.12	Repair may or may not have occurred, not documented.
2006	Waterside erosion	1.28 to 1.30	Repair made, but not documented.
2006	Waterside erosion	1.39 to 1.43	Repair made, but not documented.
2006	Waterside erosion	1.48 to 1.54	Repair made, but not documented.
2006	Waterside erosion	1.62 to 1.64	Repair made, but not documented.
2006	Waterside erosion	1.82 to 2.22	Repair made, but not documented.
2006	Waterside erosion	2.24 to 2.28	Repair made, but not documented.
2007	Waterside erosion, approximately 950 feet of intermittent erosion sites.	1.0 to 1.8	Repaired under PL 84-99

Source: URS, 2011
PL 88-49: Public Law 84-99 authorizes an emergency fund to be expended at the discretion of Chief of Engineers (USACE) for flood fighting and rescue operations; repair or restoration of flood control works threatened, damaged, or destroyed by flood, or nonstructural alternatives; where-in local maintaining agencies in good standing can solicit and receive repair funding through federal government appropriations.

2.2 Segment 283

Segment 283 is along the left (south) bank of the Bear River and Yankee Slough. The segment extends from the left bank of Yankee Slough for about 0.35 miles before its confluence with the Bear River, then continues downstream along the left bank of the Bear River for about 2.65 miles, and ending at the confluence of the Bear River and the Feather River. The segment is 3 miles long and maintained by RD 1001. The levee segment was constructed beginning in the late 1800s and completed in 1964. The levee was reconstructed by the USACE in 1959 from LM 9.42 to LM 12.60. The levee section was reconstructed by the State Division of Highways in 1961 at the State Highway 70 crossing.

Reported levee performance events include a levee break, and several underseepage and erosion events. The locations, types of events, and documented mitigations for Segment 283 are detailed in Table 2.

Table 2. Segment 283 Reported Levee Performance Events

Flood Season	Reported Performance Event	Approximate Location (LM)	Mitigation
Unknown	Erosion, 300 feet long.	10.07	Not documented.
Recurring	Underseepage, 100 to 200 feet away from levee.	10.14 to 12.60	Not documented.
1950	Levee breach.	9.9	Not documented.
1986	Underseepage was reported along the stretch from Highway 70 to Berry Road.	10.14 to 12.60	Not documented.
1986	225 feet of erosion, 15 to 18 feet of embankment. Two sinkholes developed as a result of erosion.	10.4	Repair made, but not documented.
1986	Bank erosion approximately 150 feet long. Rodent holes were observed on eroded levee slope and one sinkhole developed.	11.85 to 11.95	Repair made, but not documented.
1997	Waterside erosion.	4.14 (Yankee Slough)	Not documented.
1997	Waterside berm erosion.	9.80 to 9.81	Not documented.
1997	Waterside erosion.	9.91	Not documented.
1997	Underseepage was reported along the stretch from Highway 70 to Berry Road.	10.14 to 12.60	Not documented.
1997	Crown damage from overtopping.	10.74	Not documented.
1997	Waterside bank eroded.	11.0 to 12.0	Repair made, but not documented.
2006	Waterside erosion.	10.7	Not documented.
2006	Waterside erosion, approximately 1200 feet.	11.1	Repair in progress.
2006	Waterside erosion.	11.58	Not documented.
2007	Waterside erosion.	11.83	Repair in progress.
2007	Erosion, whole bank rotational failure, 237 feet.	12.2	Not documented.

Source: URS, 2011

3 Geology

3.1 Area Geology

Rio Oso is located near the confluence of the Bear River and the Feather River in the northern part of the Sacramento Valley which lies in the Great Valley geomorphic province. The Great Valley geomorphic province extends through much of central California and is broadly comprised of the Sacramento Valley to the north and the San Joaquin Valley to the south, each drained by their namesake rivers. The Sacramento Valley is bounded by the Sierra Nevada Range to the east and the Coast Ranges to the west. The Great Valley geomorphic province is a large, elongated structural trough that contains a thick sequence of predominantly sedimentary formations that range in age from Jurassic (206 to 144 million years old) to Recent. From the late Triassic Period until the late Jurassic, this area was part of the continental shelf and ocean floor on which the marine Great Valley sequence was deposited. By the early Pleistocene Epoch (about 1.8 million years ago), after uplift of the Coast Ranges, the present boundaries of the Great Valley were well developed and deposition changed from marine to mostly continental. Surficial units within the project area are predominantly Pleistocene and Holocene alluvial deposits.

Materials underlying the northern portion of the Sacramento Valley consist primarily of Holocene alluvial deposits from the Sacramento River and its east-flowing tributaries that drain the Coast Ranges located west of the project area. These Holocene materials consist of stream and basin deposits from clay to boulder size and overlie older alluvial formations.

3.2 Study Area Surficial Geology and Geomorphology

The Rio Oso study area lies in the eastern Sacramento Valley, between the Sacramento River to the west and the Sierra Nevada foothills to the east, near the confluence of the Bear and Feather Rivers (URS, 2011). The Bear River is the principal west-flowing drainage between the Yuba and American Rivers, and its watershed has been highly altered in the past with hydraulic gold mining. Yankee Slough is a tributary to the Bear River located to the north of Rio Oso and confluences with the Bear River near the State Highway 70 Bridge. Geomorphic analyses for NULE consisted of mapping of geomorphology/surficial geology in corridors along the Project and non-Project NULE levees. The mapping was carried out at two levels. Level 2-I mapping was based primarily on the compilation and analysis of existing regional geologic and geomorphic information at a final scale of 1:62,000. Level 2-II mapping was original mapping at a scale of 1:24,000. More details regarding the DWR geomorphic assessment are provided in Geotechnical Data Report (GDR) URS (2012) and summarized below.

The Level 2-II geomorphic mapping indicates Holocene deposits at depth with a veneer of historical alluvium at the surface on the south side of Yankee slough. The gravelly and silty sands comprising the historical alluvium are unconsolidated and highly permeable. On the upper part of Yankee slough, the levee overlies older sediments, including Holocene alluvium or the Pleistocene Riverbank Formation. Upper Yankee Slough is partially underlain by the dense alluvium fan sediments of the Riverbank Formation with a two to three feet thick duripan at or near the surface. Based on these geological conditions, underseepage would be expected near the lower portion of the Yankee Slough, with decreasing potential for underseepage on the upper portion.

The Bear River and its watershed have been highly altered with hydraulic gold mining in the past. Up to 15 feet of mining debris has been measured near Bear River in the past studies based on sediment probing. The mining debris, primarily sand with some gravel and silt, blankets the former valley floor of the Bear River and the existing levees are built atop this debris. Yankee Slough is unaffected by the mining debris except in the downstream stretch where it flows through Bear River sediment before their confluence. Level 2-II geomorphic mapping of the study area for NULE is included as Appendix A.

3.3 Area Seismicity

The Sacramento area has a relatively low seismic hazard when compared to other parts of California. The most active faults, such as the San Andreas, Hayward, Calaveras, and others, are at least 60 miles away from the project area. The California Department of Conservation, Earthquakes of California (magnitude 5+), 1769 to 2015 database showed 1892 Vacaville Winters earthquake event of Mw 6.6 as the nearest event of significant historical seismicity (i.e. > Magnitude (Mw) 5.0) near Rio Oso located approximately 40 miles to the southeast (Eaton, 1986).

The closest seismically capable structures to the project are the Foothill fault system and the Great Valley Fault Zone (GVFZ), also known as the Coast Ranges Fault Zone or Coast Ranges-Sierra Block fault zone. The Foothills fault zone comprises of northwest trending, steeply east-dipping to vertical faults in the western foothills of the Sierra Nevada Mountains. The GVFZ comprises a series of blind (i.e. no surface expression of the fault plane) reverse faults along the western margin of the Great Valley that constitute the boundary between the Coast Ranges block and the Sierra Nevada block. Some of the faults in this system have ruptured recently, namely the Coalinga fault, suggesting that this fault system is active along its entire length (Helley and Harwood, 1985).

The closest fault to the project within the GVFZ is the Dunnigan Hills Fault. The Dunnigan Hills fault is Quaternary active fault with a slip rate best estimate of 0.6 mm/yr and a maximum magnitude of 6.5 (Field et al., 2013). The closest fault to the project within the Foothills fault system in the Swain Ravine – Spenceville fault with a slip rate best estimate of 0.05 mm/yr and a maximum magnitude of 6.5 (Anderson and Ake, 2008). Due to the very low slip rates, the impact of hazard from the Foothills fault system is low. A fault map showing the project locations and earthquake events is included as Figure 4 – Fault Map.

4 Geotechnical Data Summary

4.1 Site Conditions

4.1.1 Levee Geometry

The levee height of Segment 145 varies between10 to 15 feet (measured from the landside toe) at the west end of the segment. At approximately LM 2.7, the levee height is about 10 feet and begins decreasing to about 6 to 7 feet at the east end of the segment (LM 0).

The levee height of Segment 283 varies from 23 to 25 feet (also measured above the landside toe) at the west end of the segment at the confluence of the Bear River and the Feather River down to about 17 to 18 feet at the east end of the segment near the confluence with Yankee Slough and the Bear River.

Crest widths range from approximately 20 to 30 feet for both Segments 283 and 145. For both segments, the landside slopes are inclined approximately 2H:1V to 3H:1V, and the waterside slopes are inclined approximately 3H:1V to 3.5H:1V (URS, 2011).

4.1.2 Encroachments and Penetrations

Fifteen pipes penetrate Segment 145 with pipe diameters ranging from 3 to 36 inches and located approximately 1 to 15 feet below the levee crown. No penetrations are recorded for Segment 283. Swanson Road and Pleasant Grove Road cross Segment 145 at LM 2.55 and LM 0.8 respectively. Highway 70 crosses Segment 283 at LM 10.1 (URS, 2011). Additional survey for levee penetrations within the study area was not carried out.

4.2 Previously Existing Explorations

No previous geotechnical explorations exist for Segment 145. USACE records show that 29 borings were drilled near the Bear River to a maximum depth of 104 feet. The borings were carried out for the State Highway 70 Bridge on the Bear River. Caltrans boring 02-9 for the Bear River Bridge widening project, located approximately on the crest of the Segment 283 levee, indicates the levee consists of loose to medium-dense silty sands and sandy silts and the foundation soils consist of loose to medium dense silty sands, clayey silty sands, coarse sands, and gravel. Geotechnical explorations have not been conducted as a part of the NULE program.

The available subsurface explorations generally indicate the Segment 283 levee consists of loose to medium dense silty sands to sandy silts and the foundation materials consist of loose to medium-dense silty sands, clayey silty sands, coarse sands, and gravel. No previously existing geotechnical investigations were available for Segment 145.

4.3 Subsurface Conditions

Based on the level 2-II geomorphic mapping conducted by URS (URS, 2012), Segment 145 overlies Holocene alluvium, Pleistocene Modesto Formation, historical overbank deposits, alluvium, and channel deposits. The levee consists primarily of sands and silty sands, and the foundation soils consist of stiff to hard clays and silty clays with occasional sand and gravel layers.

Segment 284 overlies alluvial and overbank deposits from LM 0.0 to about LM 1.1, mainly consisting of sands, silts, and minor clays and gravels. From LM 1.1 to LM 4.0, the levee is underlain by basin deposits consisting of fine-grained materials like silts and clays. The rest of the levee, from LM 4.0 to LM 5.4, is underlain by Late Pleistocene Lower Modesto Formation which likely consists of unconsolidated to semi-consolidated clays and silts with some sand and gravel.

4.4 Supplemental Explorations

The review of existing geotechnical exploration showed geotechnical explorations have not been conducted as part of past investigations for the existing levees surrounding Rio Oso. For this study, four CPTs and one mud-rotary boring were advanced to the depth of 50 feet. The supplemental exploration locations are shown on Figure 5 – Supplemental Exploration Location. The explorations were carried out on the landside of the levee toe outside of the levee easements. The CPT sounding logs and boring logs from the exploration program along with the existing explorations are presented in Appendix B. Laboratory testing was carried out on representative samples from the mud-rotary boring. The laboratory test results are presented in Appendix C.

The exploration program showed the existing levee is underlain by a layer of clay and silt which, in turn, is underlain by a layer of silty sand and silt. The stratigraphy indicates a potential for underseepage issues due to the presence of a ditch near the landside toe. The levee prism was assumed to be primarily composed of silty sands. The silty sand material is predominantly available in the area alongside the levee as indicated by the supplemental explorations and geomorphic mapping. The silty sand levee prism indicates high potential for through seepage issues.

5 Reach Summary

The levee segment in the study area was not subdivided into reaches as part of the NULE program. The existing geotechnical explorations and the explorations carried out for this study were used to divide the levee segments into reaches as shown on Figure 6 – Reach Summary. The goal was to identify the minimum number of reaches that could represent the most critical features in the levee segment.

A separate reach was identified when a major change in conditions potentially affecting levee performance was noted. Reasons for identifying a separate reach included significant change in levee geometry, the presence of a landside ditch, changes in subsurface conditions, or recorded levee performance issues during high water events.

The reach summary for the study area levees are shown in Table 3 below.

Table 3. Reach Summary

Maintained By	Segment	Reach	Levee	DWR Stationing	Levee Miles	Project Stationing
RD1001	145	A	Yankee Slough Left Bank	YS-L 1019+40 to 1211+75	LM 0.0 to 3.7	YS 231+17 to YS 38+30
RD1001	283	A	Yankee Slough Left Bank and Bear River Left Bank	YS-L 1019+30 to 1000+00 and BR-L 1150+00 to 1136+00	LM YS 3.7 to 4 and BR 9.8 to 10.1	YS 38+30 to YS 4+64
RD1001	283	B	Bear River Left Bank	BR-L 1136+00 to 1085+00	LM BR 10.1 to 11	YS 4+64 to YS 0+00 and BR 130+72 to BR 85+00
RD1001	283	C	Bear River Left Bank	BR-L 1085+00 to 1000+00	LM BR 11 to 12.6	BR 85+00 to BR 0+00

The number of reaches and reach boundaries developed as part of this study may change during the preparation of design documents. Further investigations and analyses required as part of final design and construction will provide an opportunity to refine the reaches and reach boundaries.

6 Engineering Analyses

6.1 NULE Program Analyses

The Rio Oso study area levees were not evaluated as part of NULE program. However, the preliminary information for the subject levees summarized in the GAR (URS, 2011) indicated the subject levees are lacking sufficient data to assign a hazard levels for underseepage, through seepage, and stability. The anticipated hazard level was low to moderate likelihood of either levee failure or the need to flood-fight to prevent levee failure.

6.2 Updated Existing Conditions Analysis

HDR's geotechnical assessment is focused on identifying feasibility level remediation alternatives for a 100-year level of protection. HDR performed geotechnical analyses to evaluate levee underseepage, through seepage, and slope stability using the 100-year WSE. Analyses were performed in general accordance with FEMA 44CRF65.10 and the following agency and industry standards:

- Engineering Manual (EM) 1110-2-1913 - Design and Construction of Levees (USACE, 2000).
- Engineering Technical Letter (ETL) 1110-2-569 - Design Guidance for Levee Underseepage (USACE, 2005).
- Engineer Regulation (ER) 1110-2-1806 - Earthquake Design and Evaluation for Civil Works Projects (USACE, 2016).
- Engineering Circular (EC) 1110-2-6067 - USACE Process for the National Flood Insurance Program (NFIP) Levee Systems Evaluation (USACE, 2010).
- Idriss and Boulanger (2008), Soil Liquefaction During Earthquakes.

6.2.1 Water Surface Elevation

The 100-year WSEs for the Bear River, and Yankee Slough were developed by MBK Engineers and provided for HDR's use in the feasibility level geotechnical assessment. The 100-year WSEs for the cross-sections analyzed for this study along the Feather River levee are presented in Table 4 below.

Table 4. Summary of Water Surface Elevations for Analyzed Cross Sections

Segment	Reach	DWR Stationing	100 year WSE (feet)
145	A	YS-L 1030+60	59.5
283	B	BR-L 1106+12	56.4
283	C	BR-L 1080+27	55.9

Source: MBK, 2019

6.2.2 Cross-Section Selection

Three cross-sections were selected for seepage and stability analyses using the 100-year WSE for the Feather River Levee. Additionally, one cross-section was selected to assess liquefaction triggering and seismically induced settlement based on the thick, loose, coarse-grained cohesionless soil (sand and gravel) identified by the explorations. The cross-sections and associated analyses performed are summarized in Table 5.

Table 5. Analyzed Cross-sections

Segment	Reach	DWR Stationing	Analyses Performed		
			Seepage	Stability	Liquefaction
145	A	YS-L 1030+60	X	X	
283	B	BR-L 1106+12	X	X	X
283	C	BR-L 1080+27	X	X	

6.2.3 Seepage Analyses

HDR performed a steady-state seepage analysis on the selected cross-sections identified in Table 5.

There are two modes of seepage that are of concern with regards to levee performance: underseepage and through seepage.

Underseepage problems commonly occur when a surficial layer of fine-grained, relatively impervious soils, also known as a blanket layer, overlays a layer of coarse-grained, more pervious soil. At times of flood stage, pressure builds up in the confined coarse-grained sublayers and can cause subsurface erosion or piping at or beyond the landside toe of the levee. This occurs when water is pushed through the discontinuities within the blanket layer and carries soil particles as it travels to the surface, potentially forming seeps that could lead to internal erosion and sand boils. Over a period of time, this could lead to failure of the levee foundation as increasing amounts of soil are internally eroded away.

Through seepage occurs when water enters the waterside slope of the levee and exits through the landside slope. Through seepage can cause surficial erosion at the landside face and possibly internal erosion of the levee as soil particles are carried through the slope. Through seepage also impacts the stability of the levee slope by increasing internal pore pressures, which can decrease the shear strength of the soil and make the slope more susceptible to failure. Levees constructed of silt material are most susceptible to through seepage erosion.

Seepage Criteria

Based on USACE's ETL 1110-2-569 (USACE, 2005), the seepage criteria shown in Table 6 were used to evaluate the subject levee.

Table 6. Seepage Criteria

Location	Allowable Exit Gradient
Underseepage: Average Vertical Exit Gradient at Landside Levee Toe (i_{ave})	≤ 0.5
Through Seepage	Phreatic surface should not exit the landside levee face if levee consists of erodible material.
Underseepage at Drainage Ditch or Low Point	Exit gradient in the bottom of the ditch should not exceed 0.5 at the landside levee toe and should not exceed 0.8 at a distance 150 feet landward of the landside levee toe and beyond. Between the landside levee toe and 150 feet landward of the landside levee toe, the maximum allowable exit gradient in the bottom of the ditch increases linearly from 0.5 to 0.8.

Hydraulic Conductivity

Material permeability characteristics for HDR analyses were adopted from the Guidance Document for Geotechnical Analyses (URS, 2015). Permeability characteristics include saturated hydraulic conductivity (k) and the ratio of vertical to horizontal permeability (anisotropy ratio). The hydraulic conductivity values used for each cross-section are shown on the seepage model figures presented in Appendix D.

Seepage Model Development

The finite element computer program SEEP/W, part of the Geostudio 2016 version 8.16 software package, was used to model the selected levee sections. The existing topography was obtained using the CVFED LiDAR data for study area. The hydraulic conductivity values were developed for each soil layer as described above. The models extend to the river channel centerline and landward 2,000 feet from the centerline of the levee.

The Guidance Document (URS, 2015) was used to determine the boundary conditions. Generally, the boundary conditions for the SEEP/W models are:

- Nodes along the channel bottom and waterside embankment slope were set to the 100-year WSE.
- Nodes along the waterside vertical edge were generally set to no flow condition based on Guidance Document for Geotechnical Analyses (URS, 2015).
- Nodes along the bottom of the model were set to have a no flow condition.
- Nodes on the landside vertical edge were set to the landside ground surface elevation.
- Nodes on the landside levee slope and the landside ground surface were modeled as potential seepage faces.

Steady-State Seepage Results

The average vertical exit gradient (i_{ave}) is calculated as the total head drop in the vertical direction at the landside levee toe or low spot divided by the blanket thickness. In addition, phreatic breakout above the levee landside toe was evaluated. The results of the seepage analyses are presented in Table 7 and graphically in Appendix D. Reach A meets the underseepage criteria but does not meet the through seepage criteria. Reach B and C both do not meet the underseepage and through seepage criteria.

Table 7. 100-year WSE Seepage Analysis Results

Segment	Reach	DWR Stationing	WSE (feet)	i_{ave} (toe)	i_{ave} (low spot)	Through Seepage Breakout Point (feet above toe)	Erodible Levee Material
145	A	YS-L 1030+60	59.5	0.14	0.41	**4**	**Does not meet criteria**
283	B	BR-L 1106+12	56.4	**1.13**	-	**6.4**	**Does not meet criteria**
283	C	BR-L 1080+27	55.9	**1.36**	-	**7.0**	**Does not meet criteria**

Note: Bold values do not meet USACE criteria

6.2.4 Settlement

FEMA 44CFR65.10 states that the minimum freeboard must be maintained if levee settlement occurs. Typical causes of settlement are the compressibility of the levee embankment or foundation soils and liquefaction induced settlement.

The Rio Oso area levee embankment and foundation materials are mainly comprised of granular soils with layers of cohesive soils. Settlement in granular soils is normally small and occurs quickly with little additional long-term settlement, static settlement is expected to have occurred during or shortly after levee construction. For the levee embankment or foundation materials comprised of fine-grained soils like silt and clay, consolidation settlement can occur over a longer timeframe. However, due to the age of the study area levees, primary consolidation settlement is no longer expected to be occurring.

For this feasibility level geotechnical assessment, the liquefaction potential of levee foundation materials was estimated. Liquefaction potential was evaluated in general accordance with the standard penetration test (SPT) procedures described in Idriss and Boulanger (2008). The depth of water table was assumed at the elevation of the levee toe for the analysis. Ground motion characteristics considered as part of evaluation of liquefaction potential included the peak ground acceleration (PGA) with a 100-year recurrence interval, earthquake magnitude (moment magnitude, Mw), and distance to the seismic source (r). Rio Oso study area corresponds to seismic site class D. Ground motion characteristics for this analysis were determined using the USGS Unified Hazard Tool and are shown in Table 8. The liquefaction evaluation indicated that there is a low likelihood that significant liquefaction would occur at the levee based on a 100-year seismic event. Further analyses of liquefaction induced settlement and post-earthquake slope stability were not performed as part of this feasibility level geotechnical assessment.

Table 8. Ground Motion Characteristics

Latitude (deg)	Longitude (deg)	Site Class	Return Period (year)	PGA (g)	Mw	r (km)
38.961181	-121.53992	D	100	0.1	6.78	83.31

Source: USGS Unified Hazard Tool (https://earthquake.usgs.gov/hazards/interactive/)

6.2.5 Seismic Hazards

The levees in the study area are not located in the vicinity of any faults and therefore are not subject to fault surface rupture hazard or fault displacements. The main seismic hazard to the study area levees is ground shaking associated with earthquakes. The closest seismically capable structure is the Swain Ravine – Spenceville fault, which is part of the Foothills fault system; however, this fault system has a very low slip rate and hazard. Several other faults associated with the Great Valley fault zone are located approximately 30 miles from the study area and also have low slip rates and hazards.

6.2.6 Stability Analysis

Embankment and foundation stability analyses were performed using the same stratigraphy and models used for the seepage analyses. Stability analyses performed evaluated the landside slope under steady-state conditions using the 100-year WSE and the waterside slope under rapid drawdown (RDD) conditions. .

Stability Criteria

EM 1110-2-1913 (USACE, 2000) identifies four types (cases) of loading conditions for slope stability analysis as described below. The minimum slope stability factor of safety (FS) against failure for each case is presented in the Table 9.

Case 1 – End of construction

This case addresses slope stability at the end of construction of the levee. According to EM 1110-2-1913, this case represents undrained conditions for impervious levee embankments and foundation soils (i.e. excess pore pressure is present because the soil has not had time to drain since being loaded). Due to the elapsed time since construction was completed on the levees, this case was not analyzed.

Case 2 – Rapid Drawdown

This case represents a condition where the flood stage fully saturates a majority of the levee embankment; then the water falls from the 100-year WSE (before drawdown) to the elevation of the landside levee toe (after drawdown) faster than the soil can drain. The factor of safety against slope instability (FS) varies with persistence of the flood pool level. A minimum required FS of 1.0 applies when the water level is unlikely to persist for long periods preceding drawdown, and a minimum required FS of 1.2 applies when the water level is likely to persist for long periods prior to drawdown. For this study, minimum FS of 1.2 was used. Only the waterside slope of the levee is considered subject to potential failure under RDD conditions.

Case 3 – Steady-State

This case occurs when the water remains at or near flood stage levels, thus fully saturating the embankment soils.

Case 4 – Earthquake (Seismic) Loading

Earthquake loading is not typically considered in analyzing the stability of levees due to the low probability of an earthquake coinciding with periods of high water. However, it is recommended that seismic stability be considered if:

- The peak ground acceleration (PGA) for a 100-year earthquake is greater than 0.10 g for the site.
- If liquefaction is indicated based on the site PGA.

EC 1110-2-6067 recommends a minimum FS of 1.2 for post-earthquake stability of levees. Due to low liquefaction potential and PGA of 0.1g, seismic stability was not analyzed.

Table 9. Slope Stability Criteria

Condition	Allowable FS
End of Construction	Not Analyzed
Rapid Drawdown	≥ 1.2
Steady-State	≥1.4
Post-earthquake	Not Analyzed Based on Evaluation of Liquefaction Potential

Material Properties for Slope Stability Analyses

The effective shear strength, total shear strength, and unit weight values used for each cross-section analyzed were obtained from the Guidance Document for Geotechnical Analyses (URS, 2015). The strength values used for each cross-section are shown on the stability model figures in Appendix E.

Slope Stability Analysis Method

The limit equilibrium computer program SLOPE/W, part of the Geostudio 2016 version 8.16 software package, was used for the slope stability analysis of the select cross-sections identified in Table 5.

Spencer's Method of Slices was used for calculating factors of safety (FS). Pore pressures computed by SEEP/W were imported into SLOPE/W for use in the analyses. The entry and exit search method was used. For the steady-state slope stability analysis, the entry point ranged from the waterside to landside edges of the levee crest, and the exit point ranged from a point on the landside slope approximately one third of the levee height from the landside toe to a distance beyond the landside toe approximately equal to twice the embankment height. For the rapid drawdown stability analysis, the entry point range extended from the landside to waterside edges of the levee crest, and the exit point ranged from a point beyond the waterside toe approximately equal to twice the embankment height to approximately one third up the waterside slope.

SLOPE/W performs analysis on each of the potential entry/exit combinations to find the critical slip surface. If the critical slip surface was located at the extremes of either the entry or exit range, the entry or exit range was extended to capture the critical slip surface. In order to eliminate identifying surficial failures, a minimum slip surface depth of five feet was used.

Results of Slope Stability Analysis

The results of the stability analyses using the 100-year WSE are presented in Table 10 and graphically in Appendix E. Reaches A and B do not meet the minimum recommended FS's for landside steady-state but meet the minimum FS's for waterside rapid drawdown. Reach C does not meet the minimum recommended FS's for landside steady-state and waterside rapid drawdown.

Table 10. 100-year WSE Slope Stability Analysis Results

Segment	Reach	DWR Stationing	WSE (feet)	Landside Steady State FS	Rapid Drawdown FS
145	A	YS-L 1030+60	59.5	**0.95**	1.51
283	B	BR-L 1106+12	56.4	**1.04**	1.4
283	C	BR-L 1080+27	55.9	**1.15**	**1.15**

Note: Bold values do not meet USACE criteria

6.3 Erosion, Freeboard, and Geometry

Erosion, freeboard, and geometry remediation recommendations were not evaluated for this study due to the lack of NULE data and no additional data were collected as part of this feasibility level geotechnical assessment.

7 Feasibility Level Levee Evaluation

7.1 Levee Deficiencies

Seepage and slope stability analyses were performed as previously described. The available information on the past performance of the subject levees were studied. The performance of the Rio Oso area levees analyzed for this study using the 100-year WSE is summarized in Table 11.

Table 11. 100 year WSE Deficiencies

Segment	Reach	Assessment Type			Notes
		Under Seepage	Through Seepage	Stability	
145	A	Meets Criteria	**Does Not Meet Criteria**	**Does Not Meet Criteria**	Using 100 year WSE, underseepage criteria and waterside rapid draw down stability criteria were met. Past stability events noted. Ditch near the landside toe noted. Levee embankment assumed to consist of silty sand and does not meet through seepage criteria.
283	A	Meets Criteria	**Does Not Meet Criteria**	**Does Not Meet Criteria**	Not analyzed. Similar to Segment 145, Reach A.
283	B	**Does Not Meet Criteria**	**Does Not Meet Criteria**	Meets Criteria	Using 100 year WSE, underseepage criteria and landside steady state slope stability criteria were not met. Past stability and seepage events noted. Thin landside blanket layer. Levee embankment assumed to consist of silty sand and does not meet through seepage criteria.
283	C	**Does Not Meet Criteria**	**Does Not Meet Criteria**	**Does Not Meet Criteria**	Using 100 year WSE, underseepage criteria, waterside rapid draw down stability criteria, and landside steady state slope stability criteria were not met. Past seepage and stability events noted. Through seepage criteria not met using sandy silt levee embankment.

7.2 Potential Remediation Alternatives

The Segments and Reaches that did not meet the criteria for a 100-year flood were evaluated for one or more remediation alternatives. In general, the remediation alternatives considered consist of cutoff wall, drained stability berm, undrained seepage berm, drained seepage berm, combined drained stability and seepage berm, landside ditch fill, and waterside rock slope protection. Remediation alternatives for the 100-year WSE are shown in Table 12 and graphically in Appendix F.

Table 12. 100 year WSE Remediation Alternatives

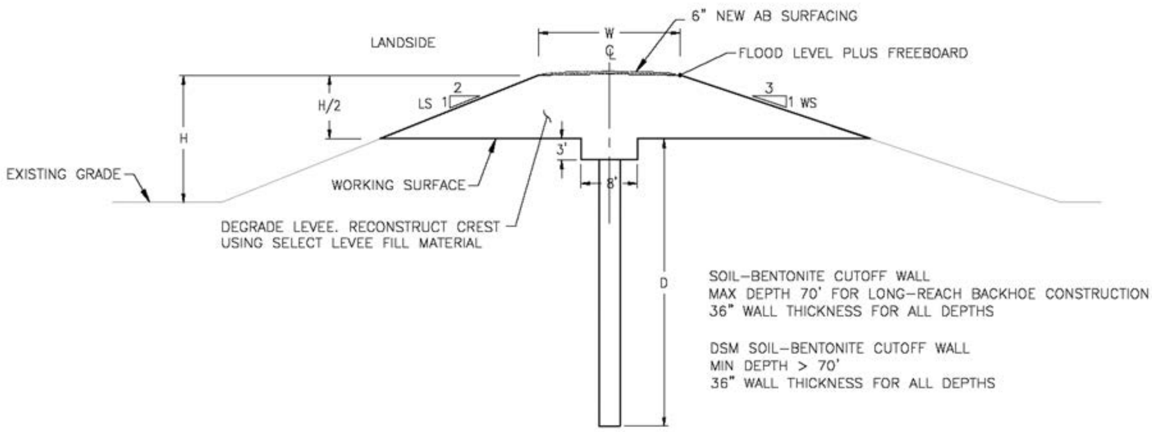
Segment	Reach	DWR Stationing	Levee Miles	Project Stationing	Remediation Alternative 1	Remediation Alternative 2	Notes
145	A	YS-L 1019+40 to 1211+75	LM 0.0 to 3.7	YS 231+17 to YS 38+30	Drained Stability Berm - 15 feet wide and backfill landside depression with locally available materials	Cutoff Wall – 14 feet below half-levee degrade/ 16 feet below one third-levee degrade	Geometry mitigation may be necessary in addition to cutoff wall for embankment sections smaller than standard size of 20 feet crown width or slopes steeper than 2H:1V on landside and 3H:1V on waterside.
283	A	YS-L 1019+30 to 1000+00 and BR-L 1150+00 to 1136+00	LM YS 3.7 to 4 and BR 9.8 to 10.1	YS 38+30 to YS 4+64	Drained Stability Berm - 15 feet wide and backfill landside depression with locally available materials	Cutoff Wall – 14 feet below half-levee degrade/ 16 feet below one third-levee degrade	Geometry mitigation may be necessary in addition to cutoff wall for embankment sections smaller than standard size of 20 feet crown width and with slopes steeper than 2H:1V on landside and 3H:1V on waterside.
283	B	BR-L 1136+00 to 1085+00	LM BR 10.1 to 11	YS 4+64 to YS 0+00 and BR 130+72 to BR 85+00	Combined Drained Stability and Seepage Berm - 150 feet wide	Cutoff Wall – 35 feet below half-levee degrade/ 40 feet below one third-levee degrade	Low permeability stratum to key in the toe of the cutoff wall not available.
283	C	BR-L 1085+00 to 1000+00	LM BR 11 to 12.6	BR 85+00 to BR 0+00	Waterside Slope - Rock Slope Protection; Landside - Combined Drained Stability and Seepage Berm - 60 feet wide	Waterside Slope - Rock Slope Protection; Cutoff Wall – 55 feet below half-levee degrade/ 60 feet below one third-levee degrade	Low permeability stratum to key in the toe of the cutoff wall not available.

7.2.1 Cutoff Wall

Cutoff walls will mitigate underseepage by providing a seepage barrier within the levee and its foundation. Proposed cutoff walls should extend at least 5 feet into lower permeability stratum. If the lower permeability stratum is located at greater depths, use of a cutoff wall as a mitigation measure may become cost prohibitive. Cutoff walls could consist of conventional soil-bentonite (SB) material or soil, cement and bentonite (SCB) or if desired, interlocking sheetpiles. Penetrations through the levee would require special consideration if found to be in conflict with the cutoff wall.

For cutoff wall construction, the existing levee crown is degraded one third to one half of the current levee height to create a working platform that provides sufficient space for construction equipment. SB cutoff walls are constructed using an excavator with a long-reach boom capable of digging a trench to a maximum depth of approximately 70. The trench width is typically 3 feet. Bentonite or cement-bentonite slurry is placed in the trench as it is excavated to prevent caving while the backfill material is mixed. The excavated soil is then mixed with the appropriate soil-bentonite (SB) slurry to achieve the required cutoff wall permeability, and then backfilled into the trench. Deep Soil Mixing (DSM) walls are used if the depth of the cutoff wall is greater than 70 feet. After installation of the cutoff wall, the levee is rebuilt to the pre-construction geometry using degraded levee material or imported fine-grained soils that meet requirements for select (impermeable) levee fill. A typical SB cutoff wall cross-section is shown as Exhibit 1.

Exhibit 1. Typical SB Cutoff Wall

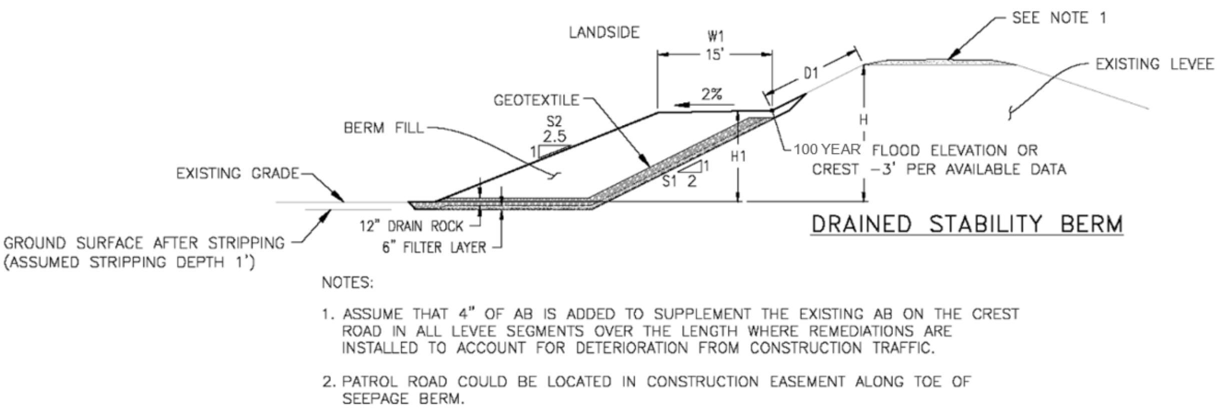


An interlocking sheetpile system could be used in lieu of a SB cutoff wall. The interlocking sheetpile system would be installed through the levee crown with minimal levee degrade. The wall alignment along the levee crown could be trenched 2 to 3 feet to allow driving the top of the sheetpiles below the levee crest.

7.2.2 Drained Stability Berm

Drained stability berms will mitigate landside slope stability and/or through seepage. In the case of mitigating landside stability, the drained stability berm will provide additional weight at the toe to resist forces that develop along a slip surface. In the case of mitigating through seepage, filter material will retain existing embankment material in place and allow seepage to safely flow from the embankment. Drained stability berms are constructed by stripping approximately 1 foot of soil from the existing ground surface, placing filter material, placing drain material, and then placing a protected layer of embankment soil. A typical drained stability berm is shown as Exhibit 2. For the purposes of assessing project feasibility, assume that drained stability berms extend a minimum of 40 feet (two times the levee height) beyond the ends of the levee segment needing improvement. The extended improvement area is intended to address end-around effects. The drained seepage berm will discharge captured water at the berm toe and grading to provide positive drainage away from the levee will be required.

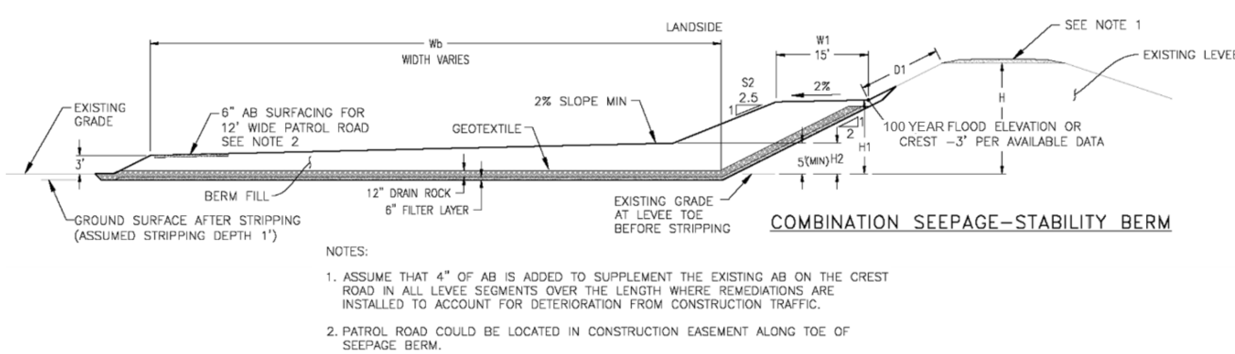
Exhibit 2. Typical Drained Stability Berm



7.2.3 Combined Drained Stability and Seepage Berm

Combined drained stability and seepage berms can be used to remediate underseepage, through seepage, and landside levee embankment slope instability. The berm includes a drainage layer on the foundation and levee landside slope that is comprised of drain rock over a sand filter layer placed on the foundation. A geotextile fabric separates the drain rock from the overlying berm fill. Berms are constructed by stripping approximately 1 foot of soil from the existing ground surface, placing geotextile filter material, placing drain material, and then placing a protected layer of embankment soil. The berm fill should be more pervious than the existing levee and shallow foundation layer. A typical combined drained stability and seepage berm is shown as Exhibit 3. For the purposes of assessing project feasibility, assume that combined drained stability and seepage berms extend a minimum of 40 feet (two times the levee height) beyond the ends of the levee segment needing improvement. The extended improvement area is intended to address end-around effects. The drained seepage berm will discharge captured water at the berm toe and grading to provide positive drainage away from the levee will be required.

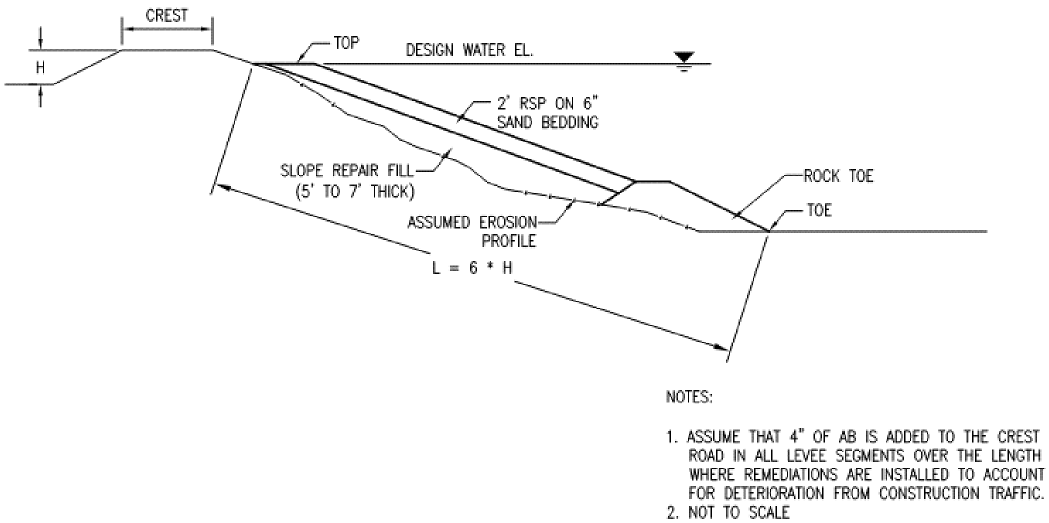
Exhibit 3. Typical Combined Drained Stability and Seepage Berm



7.2.4 Erosion Remediation – Rock Slope Revetment

Rock slope revetment can be used to remediate erosion and generally consists of 6 inches of sand bedding overlain by 2 feet of rip-rap. Earthwork should be performed before placing sand bedding to backfill eroded areas and reshape the surface. Rock slope revetment generally extends from the waterside toe to the design WSE. A typical rock slope protection is shown as Exhibit 4.

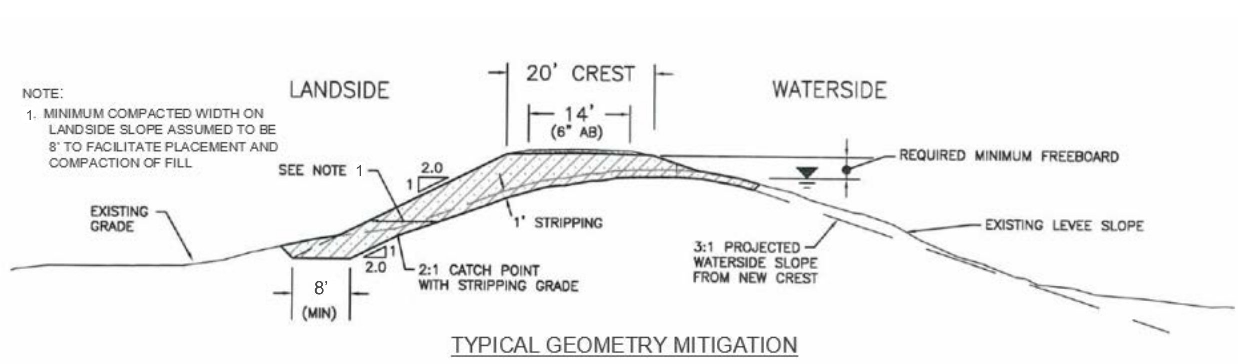
Exhibit 4. Typical Rock Slope Protection



7.2.5 Geometry Mitigation

Geometry mitigation can be used to remediate the existing levee embankment prism to the standard levee dimensions. Remediation should be performed by landside widening and crest raising. The minimum width of the landside widening is at least 8 feet to ensure that the new fill section is wide enough to facilitate placement and compaction of the material by construction equipment. This landside remediation method eliminates significant work on the waterside of the levee thus minimizing environmental impact. A typical geometry mitigation is shown as Exhibit 5.

Exhibit 5. Typical Geometry Mitigation



8 Borrow Area Recommendations

Potential borrow areas for the study area were located using the USDA Web Soil Survey (WSS) tool (https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx). The WSS tool was used to draw areas of interest adjacent to and near the levee reaches. A soil map was obtained from the WSS tool which delineated various soil types identified within the area of interest. Along with the soil map, a range of engineering properties for each soil unit used for classification was also obtained from the web tool. Comparing the typical engineering properties of each soil unit with the typical engineering properties of levee fill materials, potential borrow areas were identified and marked. Typical specifications of materials that are suitable for use as levee fill are shown in Table 13. Special construction details (e.g., 4:1 slopes) may be substituted where materials meeting the typical levee fill specifications are not readily attainable, but all levee fill materials must be free of organics and materials that cannot be properly compacted (e.g., saturated soils must be dried).

Table 13. Typical levee fill specifications

Specification	Levee Fill	ASTM Test
Percent Passing - 3 inch	100	D6913
Percent Passing - No. 200	≥ 20	D6913
Liquid Limit	≤ 50	D4318
Plasticity Index	≥ 8	D4318

In general, soil units identified as majority lean clay (CL) were selected as potential borrow areas. From these potential borrow areas, the locations closest to the levees were selected and marked. These potential borrow areas are shown in Figure 7 – Potential Borrow Area.

Additional screening for preliminary engineering design will need to evaluate actual soil engineering properties, depth to groundwater, landowner agreement(s), potential haul routes, and permitting requirements (e.g., erosion and sediment control, United States Army Corps of Engineers 404/401, environmental and cultural resources surveys, mining, others).

9 Geotechnical Design-Level Scope Recommendations

This document describes the feasibility level geotechnical assessment of the Rio Oso study area levees. The following items are recommended to be included in the design level scope:

- Supplemental explorations
  - Along the crown, waterside, and landside of the Bear River Left Bank Levee, and Yankee Slough Left Bank Levee in accordance with regulatory and industry standards for design.
  - As necessary based on the selected remediation alternative(s) to reduce the flood risk of Rio Oso.
- Seepage and Stability Analysis
  - Additional analysis for existing conditions using the additional investigations along the Bear River Levee, and Yankee Slough Levee.
  - Additional analysis for remediation alternatives using the additional investigations for the study area levees.
  - Supplemental analyses as necessary based on the selected remediation alternative(s).
- Perform detailed design analyses in accordance with regulatory and industry standards for the selected remediation alternatives.
- Update seismic hazard assessment and evaluate liquefaction potential for additional cross sections.
- Updated erosion, geometry and freeboard analysis for the study area levees.
- Evaluate end around seepage if a combination of cutoff wall and drained berm are considered due to site constraints.
- Develop an updated inventory of encroachments and penetrations.
- Identification and evaluation of the penetrations (majority pipelines) through the study area levees. Each penetration must be relocated above the 100 year WSE or evaluated by a qualified engineer with variance from Central Valley Flood Protection Board (CVFPB).
- Further investigate potential borrow areas for material compliance as embankment fill.

10 Limitations

This report has been prepared for the use of MBK Engineers and its consultants for specific application to the Rio Oso Flood Risk Reduction Feasibility Project in accordance with generally accepted geotechnical engineering practice. No warranty, express or implied, is made. The analyses and recommendations submitted are based on the data available to HDR at the time of this geotechnical investigation. This report does not reflect subsurface soil variations that may occur between the locations of the explorations or variations in groundwater conditions which may occur over a period of time. Variations in conditions may become evident during subsequent studies and construction, at which time re-evaluation of the conclusions may become necessary. Potential remedial measures for the Rio Oso Flood Risk Reduction Feasibility Project are presented in this report based upon review of investigations prepared by URS consultants for DWR as part of the NULE program and our professional interpretation of the geotechnical data. Four CPTs and one mud-rotary boring authorized as part of the grant funding for the feasibility level analyses were carried out. Levee penetrations, free board, geometry and effect due to encroaching structures were not evaluated as part of this study. Additional evaluations will be required to support the feasibility studies and development of the preliminary remedial design. The evaluations included herein are not suitable for work beyond this feasibility study.

In the event of design changes in the project after the final report is submitted, the recommendations should be reviewed and possibly modified with HDR's participation.

Historical explorations and testing were not performed by HDR, and HDR cannot vouch for the accuracy of data and information obtained by others. Data by others should not be relied upon unless the originator of that data is available to confirm its accuracy.

This geotechnical study did not include an investigation regarding the existence, location, or type of possible hazardous materials. If any hazardous materials are encountered during construction of the project, the proper regulatory officials should be notified immediately.

11 References

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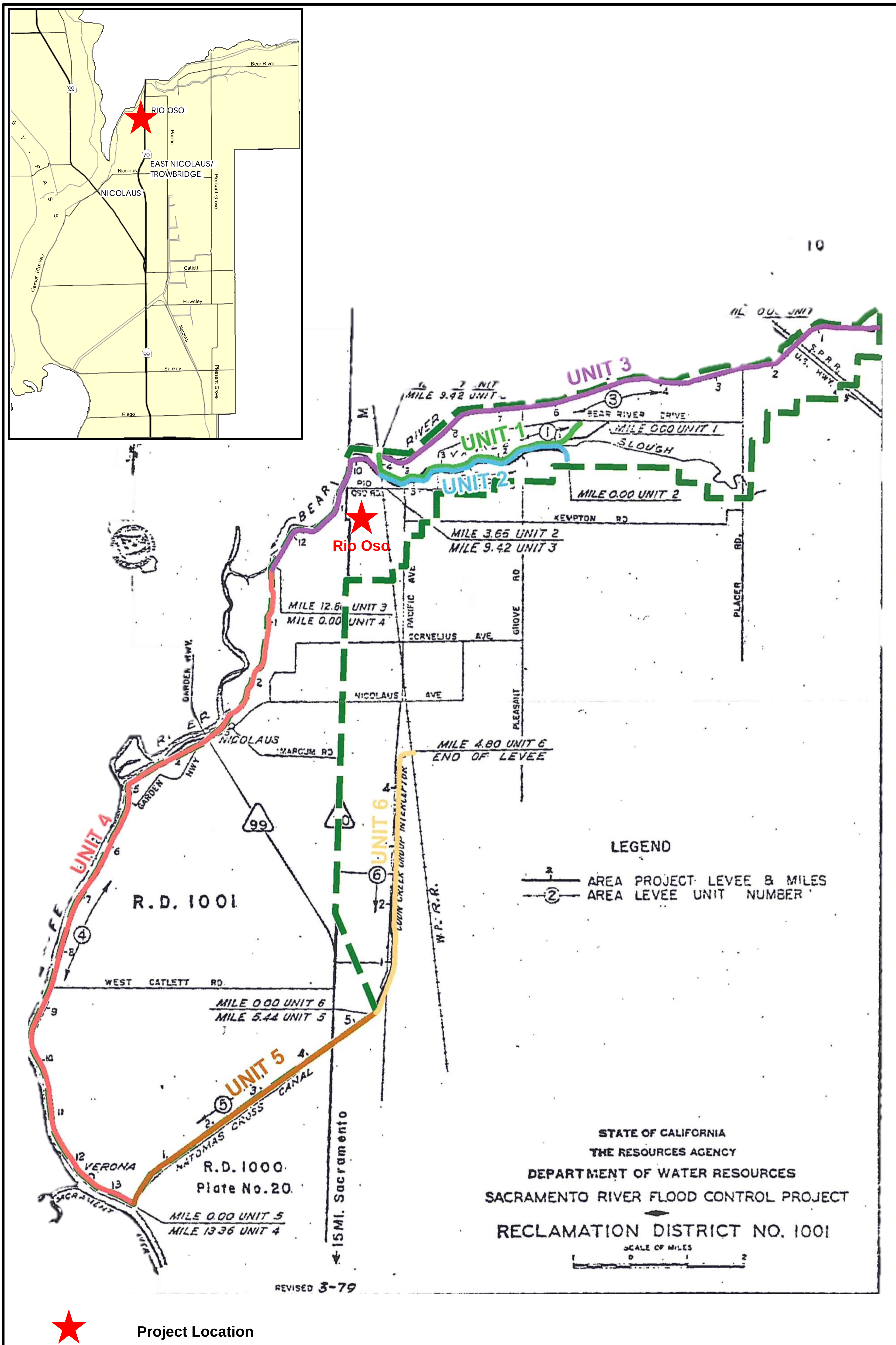
Figures



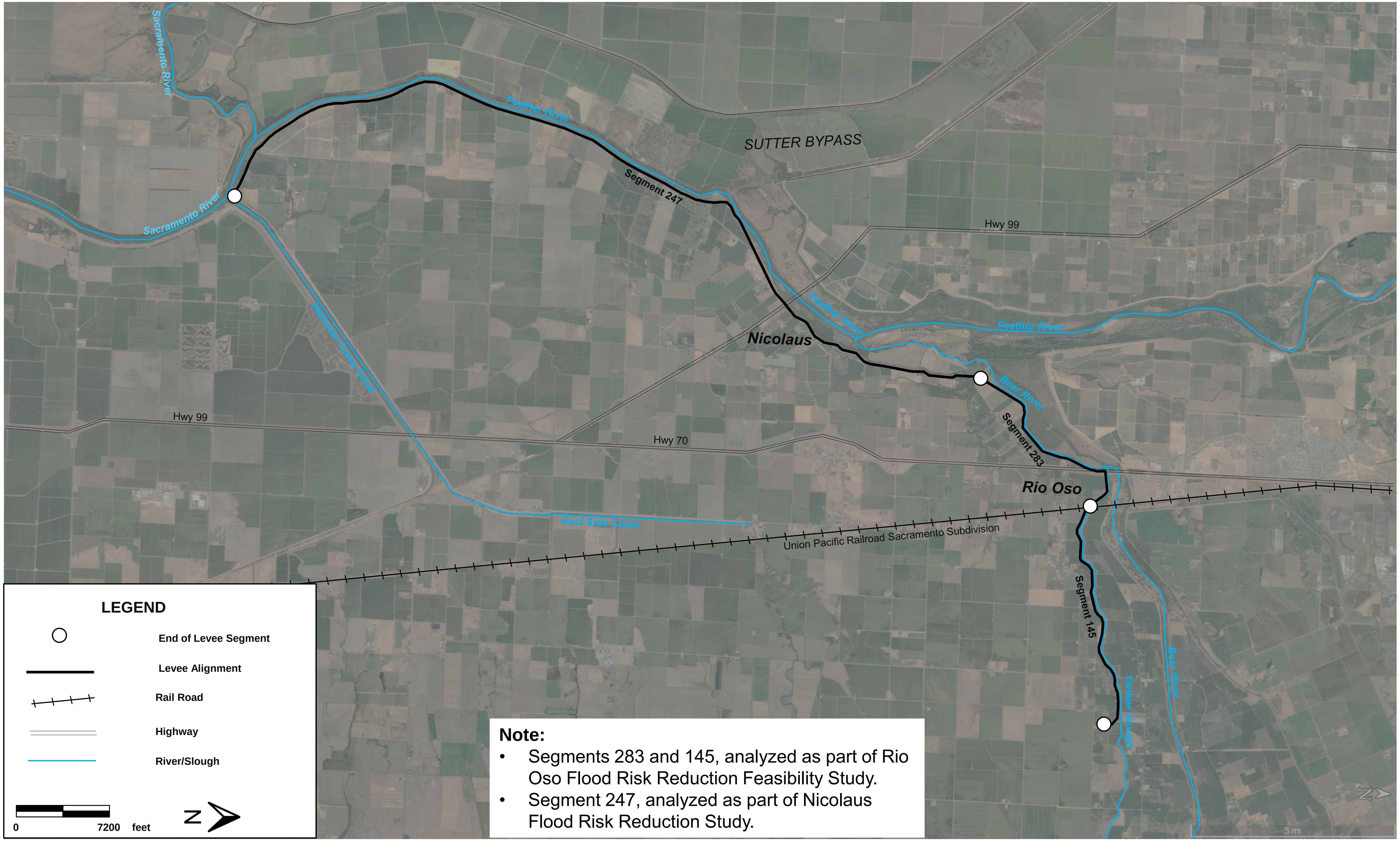
NOTES: Source: RD 1001

Rio Oso Flood Risk Reduction Feasibility Study

Vicinity Map

July 2019

FIGURE 1



Note:

- Segments 283 and 145, analyzed as part of Rio Oso Flood Risk Reduction Feasibility Study.
- Segment 247, analyzed as part of Nicolaus Flood Risk Reduction Study.

NOTES:

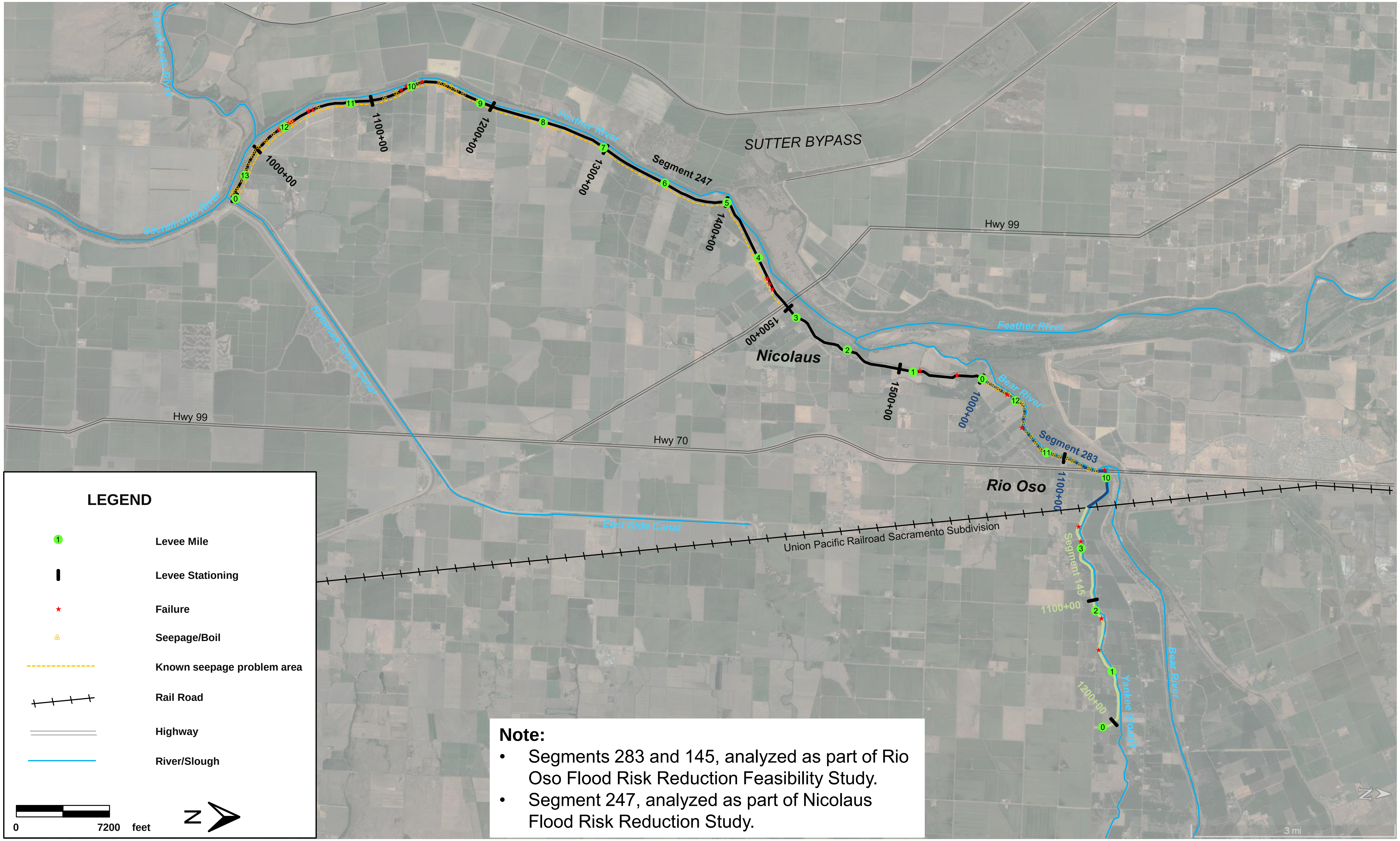
Rio Oso Flood Risk Reduction Feasibility Study

HDR

Project Location Map

July 2019

FIGURE 2



Note:

- Segments 283 and 145, analyzed as part of Rio Oso Flood Risk Reduction Feasibility Study.
- Segment 247, analyzed as part of Nicolaus Flood Risk Reduction Study.

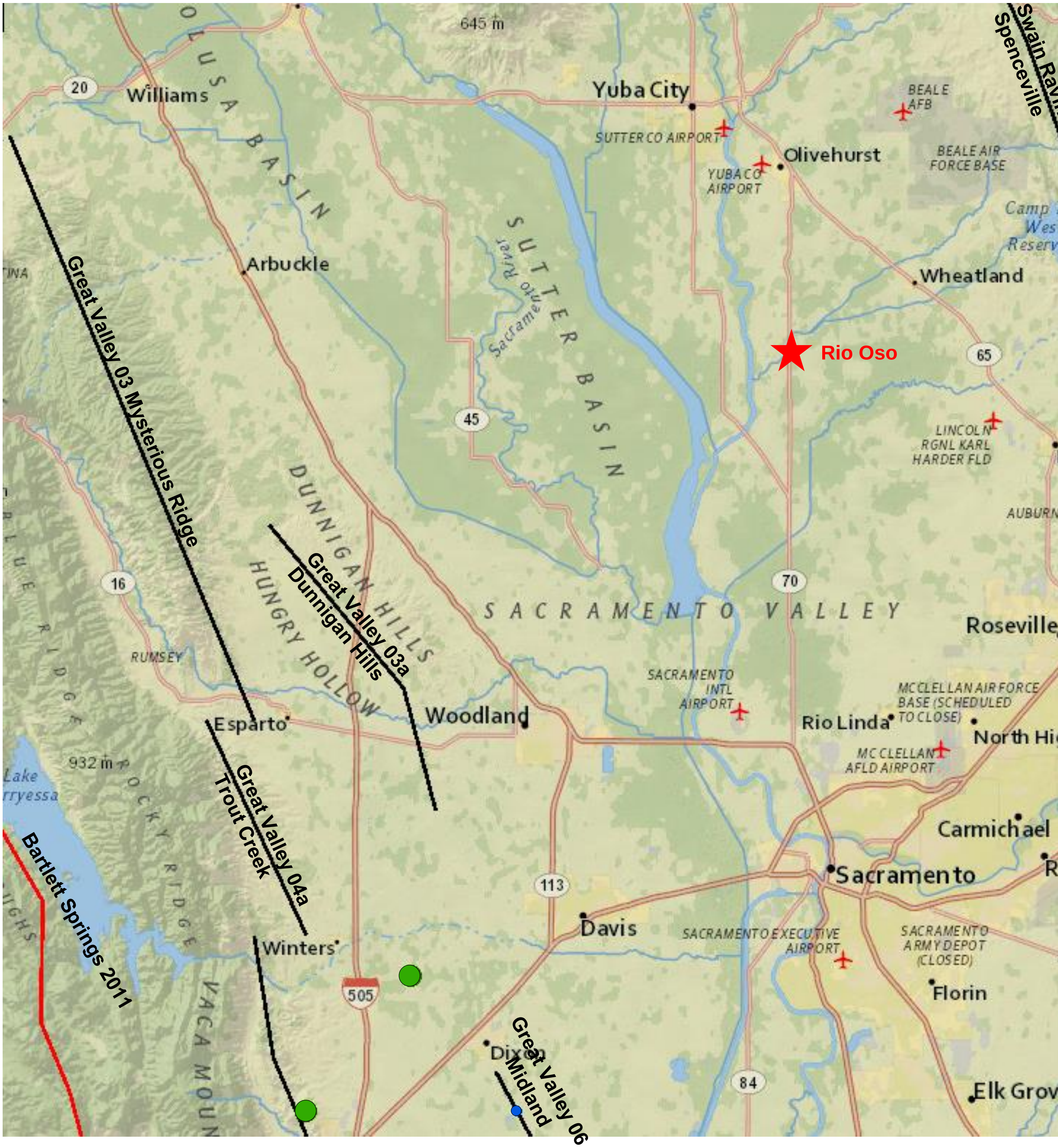
NOTES: NULE GAR (URS, 2011) – Source of past performance information

Rio Oso Flood Risk Reduction Feasibility Study

HDR

Past Performance Summary Map

July 2019 FIGURE 3



Project Location

Historic Earthquake Magnitude 5-6

Historic Earthquake Magnitude 6-7

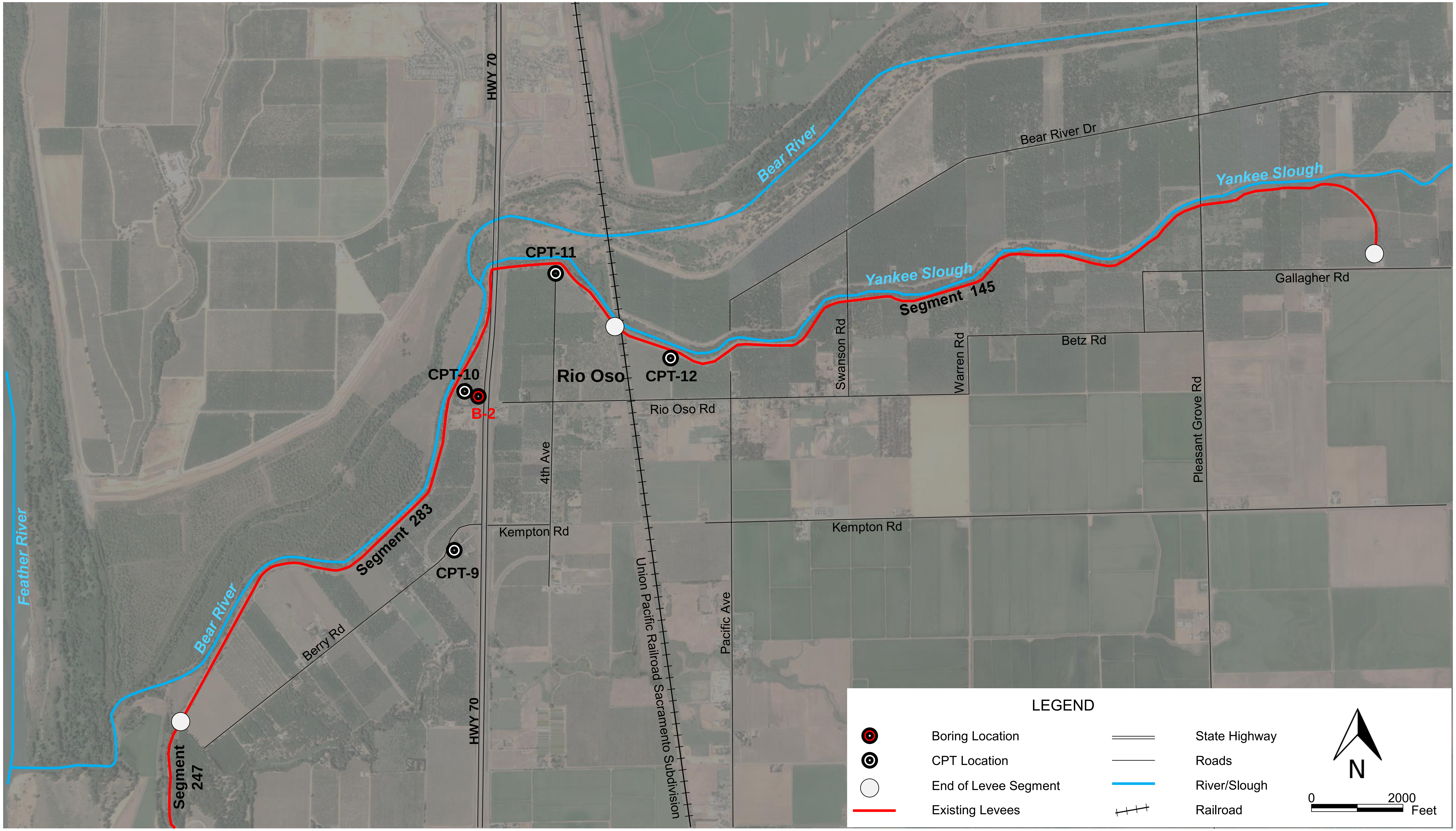
Thrust Fault

Strike Slip Fault

N

Not to Scale

NOTES:	Rio Oso Flood Risk Reduction Feasibility Study	HDR	**Fault Map**
			July 2019 FIGURE 4



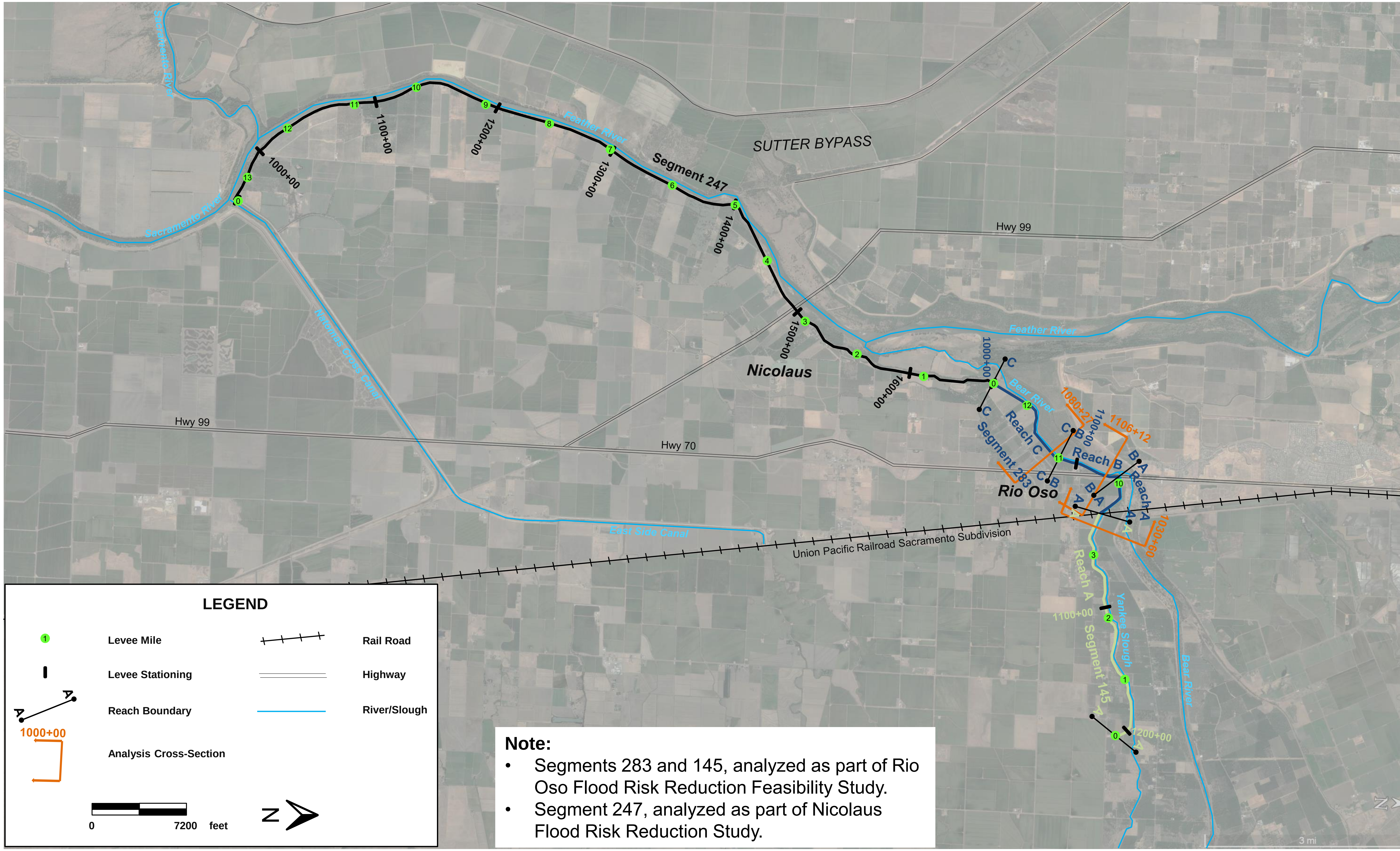
NOTES: Image Source: Google Earth Pro 2019

Rio Oso Flood Risk Reduction Feasibility Study

Supplemental Exploration Location

July 2019

FIGURE 5



Note:

- Segments 283 and 145, analyzed as part of Rio Oso Flood Risk Reduction Feasibility Study.
- Segment 247, analyzed as part of Nicolaus Flood Risk Reduction Study.

NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

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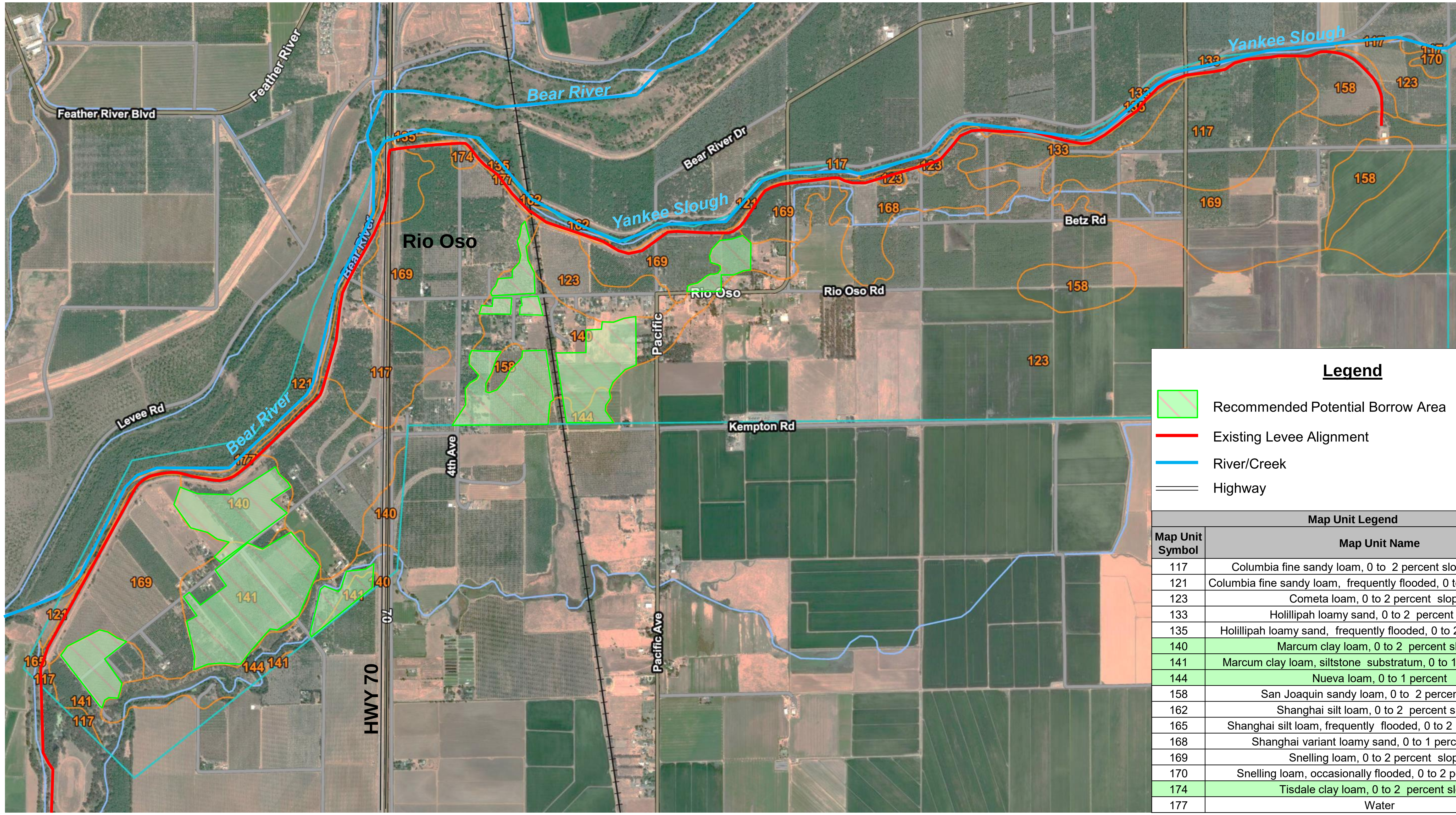
Reach Summary

July 2019 FIGURE 6



Legend

- Recommended Potential Borrow Area
- Existing Levee Alignment
- River/Creek
- Highway

N

Map Unit Legend	
Map Unit Symbol	Map Unit Name
117	Columbia fine sandy loam, 0 to 2 percent slopes, MLRA 17
121	Columbia fine sandy loam, frequently flooded, 0 to 2 percent slopes
123	Cometa loam, 0 to 2 percent slopes
133	Holillipah loamy sand, 0 to 2 percent slopes
135	Holillipah loamy sand, frequently flooded, 0 to 2 percent slopes
140	Marcum clay loam, 0 to 2 percent slopes
141	Marcum clay loam, siltstone substratum, 0 to 1 percent slopes
144	Nueva loam, 0 to 1 percent
158	San Joaquin sandy loam, 0 to 2 percent slopes
162	Shanghai silt loam, 0 to 2 percent slopes
165	Shanghai silt loam, frequently flooded, 0 to 2 percent slopes
168	Shanghai variant loamy sand, 0 to 1 percent slopes
169	Snelling loam, 0 to 2 percent slopes
170	Snelling loam, occasionally flooded, 0 to 2 percent slopes
174	Tisdale clay loam, 0 to 2 percent slopes
177	Water

NOTES: Source: USDA Web Soil Survey
https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Map Units selected for borrow are highlighted with green color

Rio Oso Flood Risk Reduction Feasibility Study

HDR

Potential Borrow Area

July 2019 FIGURE 7

Appendix A – Geomorphic Mapping

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). Screened back semi-transparent mapping shown on this plate is from Urban Levee Evaluation (ULE) program, RD-784 Study Area (WLA, September 2009), which is not assessed in this investigation. For clarity, the ULE surficial geologic map units are omitted from the Bear River explanation.
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

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, dotted where concealed.

Canal

Levee; artificial fill prism, generally <60 ft in width.

Vp	Vernal pool; seasonally submerged or saturated depression usually indicative of an underlying hardpan.
W 1937	Water; date indicates year of historic dataset.
C	Canal, circa 1937.
BP/Ra	Borrow pit present in 1937; unit after slash indicates the deposit in which the borrow pit is located.

Geologic Units

AF	Artificial fill, circa 1937.
L	Levee (made of artificial fill), circa 1937.
R	Road embankment (made of artificial fill), circa 1937.
RR	Railroad embankment (made of artificial fill), circa 1937.

HISTORICAL (Derived from hydraulic mining debris)

Rob	Overbank deposits; sand with lesser silt and clay; deposited during high-stage water flow, overtopping channel banks.
Rcs	Crevasse splay deposits; fine sand and silt deposited from breaching of natural or artificial levees.
Rdf	Distributary fan deposits; sand and silt.
Rch	Channel deposits; well-sorted sand and trace fine gravel.
Rb	Channel bar deposits; fine gravel, sand, and silt deposited in or along channel lateral margins.
Rcu	Cut off channel (chute); occurs on insides of meander bends within the river channel; sand and fine gravel.
Rdc	Distributary channel deposits, sand, silt, and clay; channelized flow conducting sediment to floodplain.
Rofc	Overflow channel deposits; vertically stratified sand, silt, and clay in floodplain channels occupied primarily when high-stage water overtops channel banks.
Rt	Undifferentiated terrace; abandoned floodplain likely containing channel and overbank deposits.
Ra	Alluvial deposits undifferentiated; sand, silt, and minor lenses of fine gravel.
Ra/Qru	Veneer of historical alluvial deposits (less than 3-feet thick), overlying the upper member of the Riverbank Formation.

HOLOCENE

Hob	Overbank deposits; silt, clay, and lesser sand; deposited during high-stage water flow, overtopping channel banks.
Hch	Channel deposits; well-sorted sand and trace fine gravel.
Ha	Alluvial deposits, undifferentiated; sand, silt, and minor lenses of gravel. (*) indicates Holocene deposits locally mantled by a thin veneer of historical sediment (less than 3' thick). (?) indicates deposits could be Upper Modesto Formation in age.
Hs	Marsh deposits; silt and clay, possibly with organic-rich beds; perennially or seasonally submerged.

PLEISTOCENE

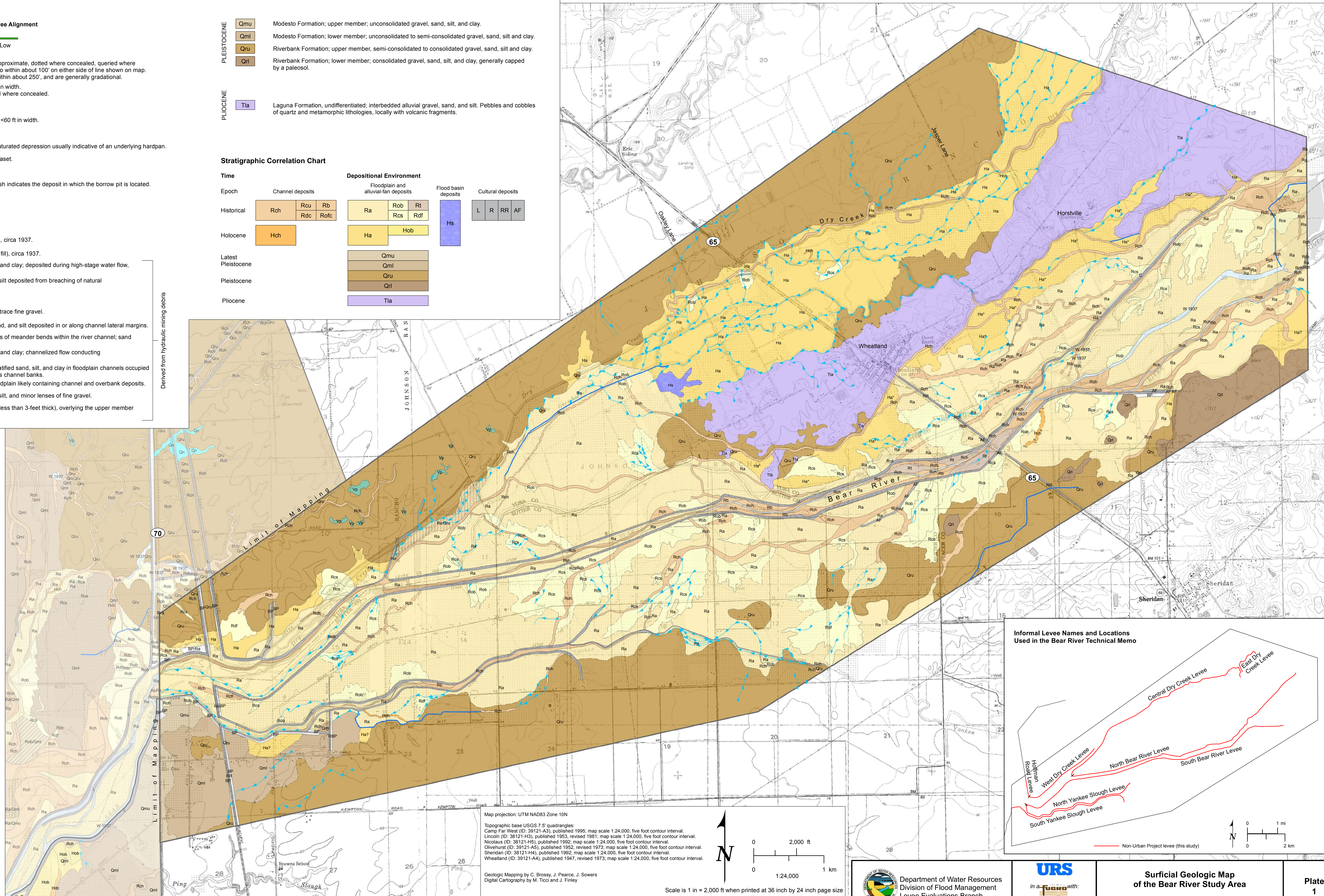
Qmu	Modesto Formation; upper member; unconsolidated gravel, sand, silt, and clay.
Qml	Modesto Formation; lower member; unconsolidated to semi-consolidated gravel, sand, silt and clay.
Qru	Riverbank Formation; upper member, semi-consolidated to consolidated gravel, sand, silt and clay.
Qrl	Riverbank Formation; lower member; consolidated gravel, sand, silt, and clay, generally capped by a paleosol.

PLIOCENE

Tla	Laguna Formation, undifferentiated; interbedded alluvial gravel, sand, and silt. Pebbles and cobbles of quartz and metamorphic lithologies, locally with volcanic fragments.

Stratigraphic Correlation Chart

Time: Epoch	Channel deposits	Floodplain and alluvial-fan deposits	Flood basin deposits	Cultural deposits
Historical	Rch, Rcu, Rb, Rdc, Rofc	Ra, Rob, Rt, Rcs, Rdf	Hs	L, R, RR, AF
Holocene	Hch	Ha, Hob	Hs	
Latest Pleistocene		Qmu, Qml		
Pleistocene		Qru, Qrl		
Pliocene		Tla		



Map projection: UTM NAD83 Zone 10N

Topographic base USGS 7.5' quadrangles:
Camp Far West (ID: 39121-A3), published 1995; map scale 1:24,000, five foot contour interval.
Lincoln (ID: 38121-H3), published 1953, revised 1981; map scale 1:24,000, five foot contour interval.
Nicolaus (ID: 38121-H5), published 1992; map scale 1:24,000, five foot contour interval.
Olivehurst (ID: 39121-A5), published 1952, revised 1973; map scale 1:24,000, five foot contour interval.
Sheridan (ID: 38121-H4), published 1992; map scale 1:24,000, five foot contour interval.
Wheatland (ID: 39121-A4), published 1947, revised 1973; map scale 1:24,000, five foot contour interval.

Geologic Mapping by C. Brossy, J. Pearce, J. Sowers
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 36 inch by 24 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 the Bear River Study Area

NORTH NON-URBAN LEVEE EVALUATIONS

Plate 1

1965_2_NULE_BearRiver_Plate.mxd MGT 12/21/2010

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).

Screened back semi-transparent mapping shown on this plate is from Urban Levee Evaluation (ULE) program, Sutter, RD-784, and Natomas NWS Study Areas, which are not assessed in this investigation. For clarity, the ULE surficial geologic map units are omitted from the Feather River explanation.

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 accurate to within about 250' on either side.

Narrow channel, generally <100 ft in width. Dashed where approximate, dotted where concealed.

A — A' Cross section location

Rm 2.3 River mile marker, from posted values on USGS topographic base map.

W 1937 Water; date indicates year of historical dataset.

BP Borrow pit present in 1937.

Geologic Units

	AF	Artificial fill, circa 1937.
	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.
HISTORICAL	Rcs	Crevasse splay deposits; fine sand and silt with clay deposited from breaching of natural levees.
HISTORICAL	Rdf	Distributary fan deposits; sand, silt and clay.
HISTORICAL	Rch	Channel deposits; well-sorted sand and trace fine gravel.
HISTORICAL	Rms	Channel meander scroll deposits; sand, silt, and clay from lateral channel migration.
HISTORICAL	Rb	Channel bar deposits; fine gravel, sand, and silt deposited in or along channel lateral margins.
HISTORICAL	Rdc	Distributary channel deposits, sand, silt, and clay; channelized flow conducting sediment to floodplain.
HISTORICAL	Rofc	Overflow channel deposits; vertically stratified sand, silt, and clay in floodplain channels occupied primarily when high-stage water overtops channel banks.
HISTORICAL	Ra	Alluvial deposits undifferentiated; sand, silt, and minor lenses of fine gravel.
HOLOCENE	Hob	Overbank deposits; silt, clay, and lesser sand; deposited during high-stage water flow, overtopping channel banks.
HOLOCENE	Hob/Qml	Veneer of overbank deposits (less than 5-feet thick), overlying the lower member of the Modesto Formation.
HOLOCENE	Hcs	Crevasse splay deposits; fine sand and silt with clay deposited from breaching of natural or artificial levees.
HOLOCENE	Hdf	Distributary fan deposits; sand, silt, and clay.
HOLOCENE	Hch	Channel deposits; well-sorted sand and trace fine gravel.
HOLOCENE	Hb	Channel bar deposits; fine gravel, sand, and silt deposited in or along channel lateral margins.
HOLOCENE	Hdc	Distributary channel deposits, sand, silt, and clay; channelized flow conducting sediment to floodplain.
HOLOCENE	Ha	Alluvial deposits, undifferentiated; sand, silt, and minor lenses of gravel.
HOLOCENE	Hn	Basin deposits; fine sand, silt and clay.
HOLOCENE	Hn/Qm	Veneer of basin deposits (less than 5-feet thick), overlying the Modesto Formation.
HOLOCENE	Hs	Marsh deposits; silt and clay, possibly with organic-rich beds; perennially or seasonally submerged.
PLEISTOCENE	Qmu	Modesto Formation; upper member; unconsolidated gravel, sand, silt, and clay.
PLEISTOCENE	Qml	Modesto Formation; lower member; unconsolidated to semi-consolidated gravel, sand, silt and clay.
PLEISTOCENE	Qru	Riverbank Formation; upper member, semi-consolidated to consolidated gravel, sand, silt and minor clay.
PLEISTOCENE	Qrl	Riverbank Formation; lower member; consolidated gravel, sand, silt, and clay, generally capped by a paleo-soil with strong duripan horizon.

Stratigraphic Correlation Chart

Time / Epoch	Channel deposits	Floodplain and alluvial-fan deposits	Flood basin deposits	Cultural deposits
Historical	Rch; Rms, Rb; Rdc, Rofc	Ra; Rob; Rcs, Rdf	Hs, Hn	L, AF
Holocene	Hch; Hb; Hdc	Ha; Hob; Hcs, Hdf		
Latest Pleistocene		Qmu; Qml		
Pleistocene		Qru; Qrl		

Map projection: UTM NAD83 Zone 10N

Topographic base USGS 7.5' quadrangles:
Knights Landing (ID: 38121-G6), published 1952, revised 1981; map scale 1:24,000, five foot contour interval.
Nicolaus (ID: 38121-H5), published 1992; map scale 1:24,000, five foot contour interval.
Sutter Causeway (ID: 38121-H6), published 1952, revised 1973; map scale 1:24,000, five foot contour interval.
Verona (ID: 38121-G5), published 1967, revised 1978; map scale 1:24,000, five foot contour interval.

Geologic Mapping by S. Dee and J. Pearce
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 38 inch by 23 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 the Feather River South of Bear River Study Area

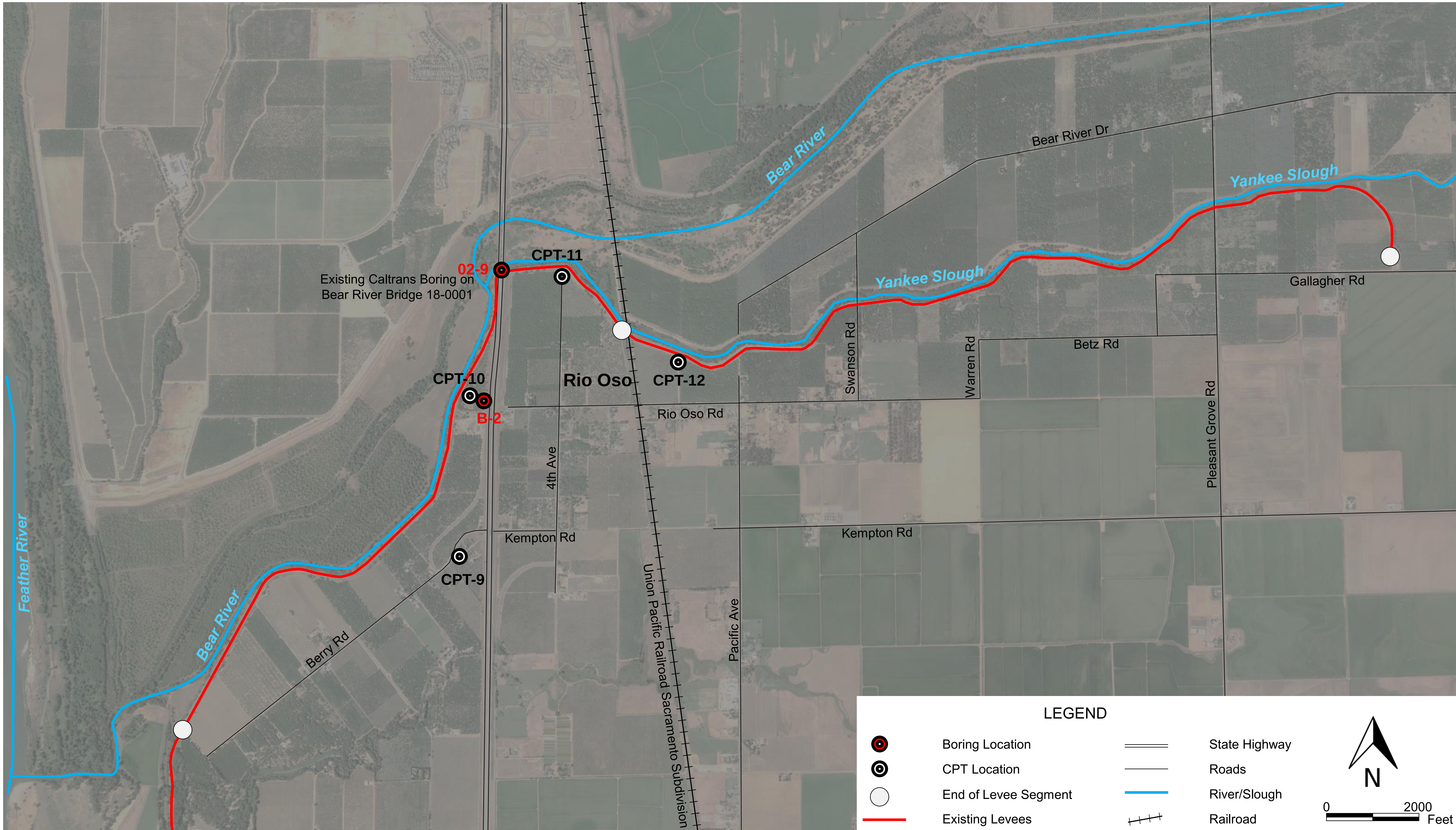
NORTH NON-URBAN LEVEE EVALUATIONS

Plate 1

NULE Level 2-II: Feather River South Geomorphic Assessment

1965_2_NULE_FeatherSouth_Plate.mxd MGT 12/21/2010

Appendix B – Boring and CPT Logs



NOTES: Image Source: Google Earth Pro 2019

Rio Oso Flood Risk Reduction Feasibility Study

HDR

Exploration Location

July 2019

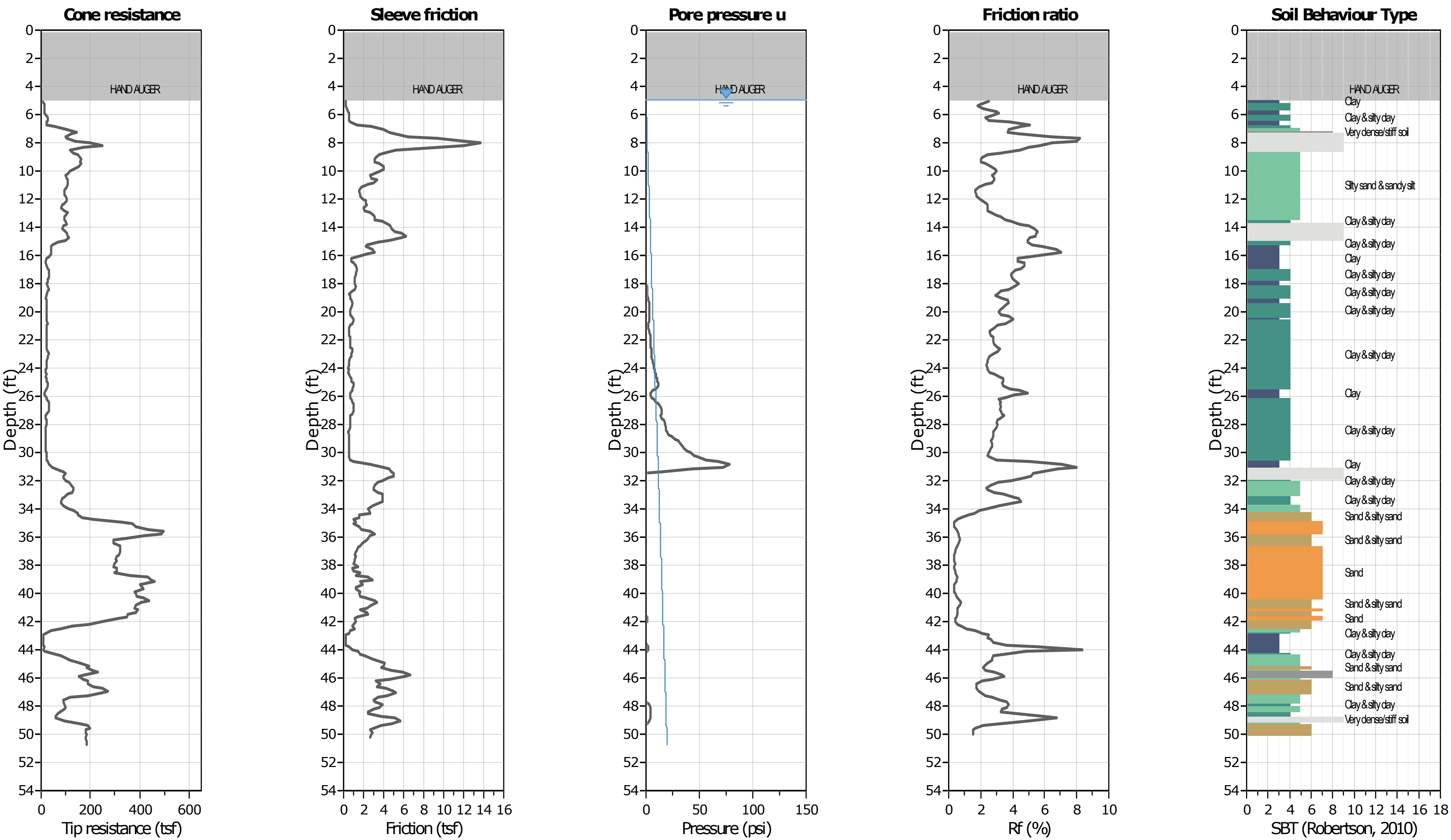
FIGURE B-1

HDR Inc.
2365 Iron Point Rd.
Folsom CA, 95630

CPT: CPT-09

Total depth: 50.69 ft, Date: 3/27/2019
Surface Elevation: 43.00 ft
Coords: lat 38.952404° lon -121.546283°

Project: Rio Oso Flood Risk Reduction Feasibility Study
Location: Rio Oso, CA



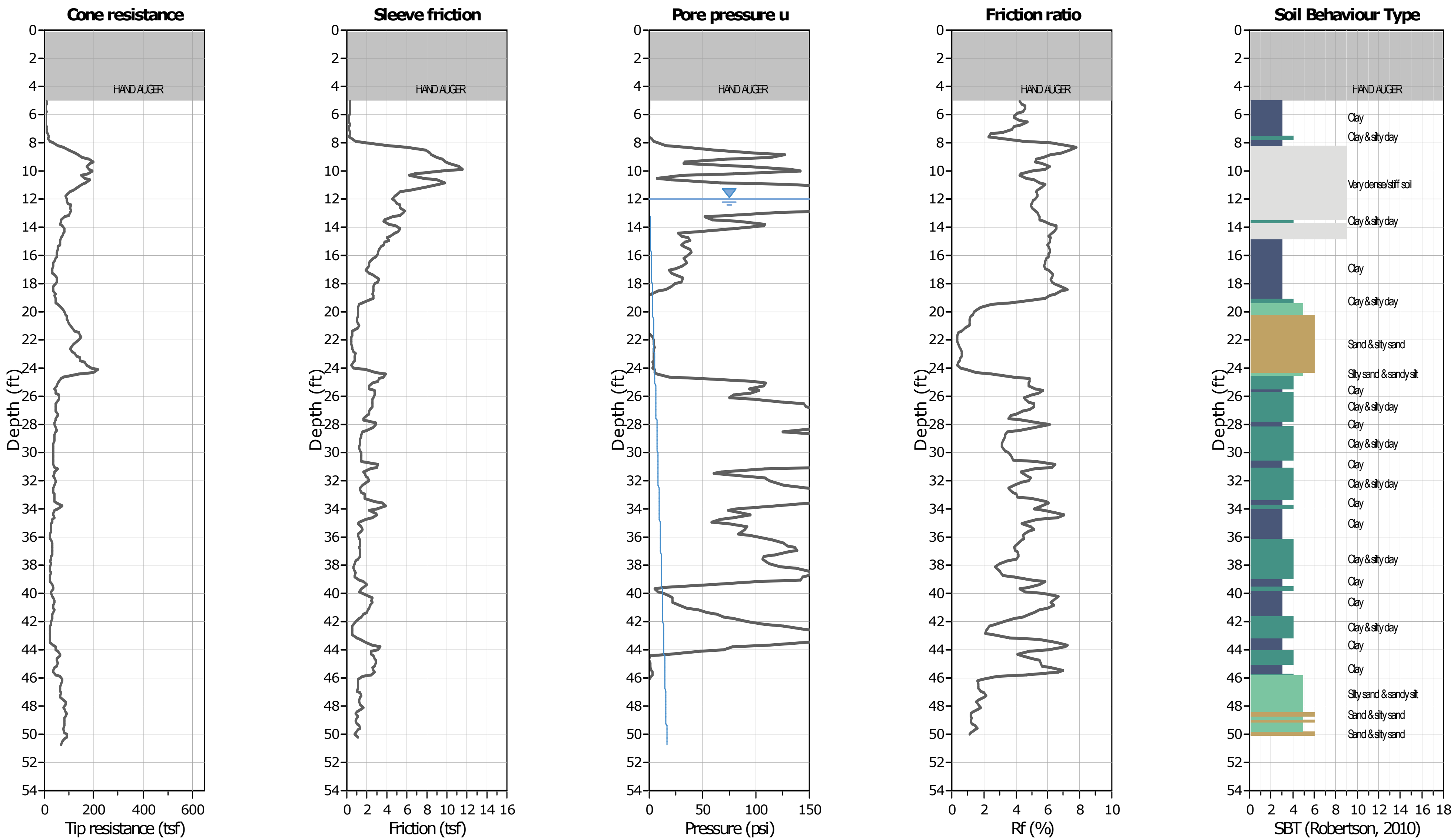
1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty clay
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to clayey sand
9. Very stiff fine grained

HDR Inc.
2365 Iron Point Rd.
Folsom CA, 95630

CPT: CPT-10

Total depth: 50.69 ft, Date: 3/27/2019
Surface Elevation: 44.00 ft
Coords: lat 38.961717° lon -121.54525°

Project: **Rio Oso Flood Risk Reduction Feasibility Study**
Location: **Rio Oso, CA**



1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty clay
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to clayey sand
9. Very stiff fine grained

UNIFIED SOIL CLASSIFICATION SYSTEM (ASTM D-2487)

MATERIAL TYPES	CRITERIA FOR ASSIGNING SOIL GROUP NAMES			GROUP SYMBOL	SOIL GROUP NAMES & LEGEND
COARSE-GRAINED SOILS >50% RETAINED ON NO. 200 SIEVE	GRAVELS >50% OF COARSE FRACTION RETAINED ON NO 4. SIEVE	CLEAN GRAVELS <5% FINES	$C_u \geq 4$ AND $1 \leq C_c \leq 3$	GW	WELL-GRADED GRAVEL
			$C_u < 4$ AND/OR $1 > C_c > 3$	GP	POORLY-GRADED GRAVEL
		GRAVELS WITH FINES >12% FINES	FINES CLASSIFY AS ML OR MH	GM	SILTY GRAVEL
			FINES CLASSIFY AS CL OR CH	GC	CLAYEY GRAVEL
	SANDS >50% OF COARSE FRACTION PASSES NO 4. SIEVE	CLEAN SANDS <5% FINES	$C_u \geq 6$ AND $1 \leq C_c \leq 3$	SW	WELL-GRADED SAND
			$C_u < 6$ AND/OR $1 > C_c > 3$	SP	POORLY-GRADED SAND
		SANDS AND FINES >12% FINES	FINES CLASSIFY AS ML OR MH	SM	SILTY SAND
			FINES CLASSIFY AS CL OR CH	SC	CLAYEY SAND
FINE-GRAINED SOILS >50% PASSES NO. 200 SIEVE	SILTS AND CLAYS LIQUID LIMIT<50	INORGANIC	PI>7 AND PLOTS>"A" LINE	CL	LEAN CLAY
			PI<4 OR PLOTS<"A" LINE	ML	SILT
		ORGANIC	LL (oven dried)/LL (not dried)<0.75	OL	ORGANIC CLAY OR SILT
	SILTS AND CLAYS LIQUID LIMIT>50	INORGANIC	PI PLOTS >"A" LINE	CH	FAT CLAY
			PI PLOTS <"A" LINE	MH	ELASTIC SILT
		ORGANIC	LL (oven dried)/LL (not dried)<0.75	OH	ORGANIC CLAY OR SILT
HIGHLY ORGANIC SOILS		PRIMARILY ORGANIC MATTER, DARK IN COLOR, AND ORGANIC ODOR		PT	PEAT

OTHER SYMBOLS

MATERIALS

- Asphalt
- Aggregate Base
- Topsoil
- Bedrock

PIEZOMETER

- Grout Seal or Fill
- Bentonite Seal or Fill
- Sand Pack + Solid Pipe
- Sand Pack + Slotted Pipe

SAMPLERS

- SPT (2" OD)
- Modified California (3" OD)
- California (2.5" OD)
- Shelby Tube
- Pitcher Barrel
- HQ Core
- Grab/Bulk

INITIAL WATER LEVEL MEASUREMENT(WITH DATE)

STABILIZED WATER LEVEL MEASUREMENT(WITH DATE)

GRAIN SIZES

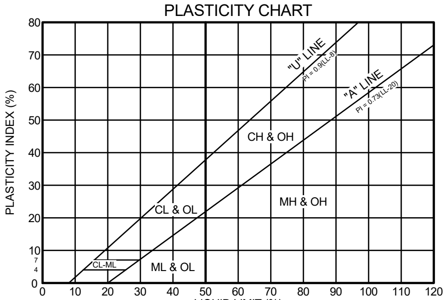
U.S. STANDARD SIEVE	200	40	10	4	3/4"	3"	12"
SILTS AND CLAYS	SAND			GRAVEL		COBBLES	BOULDERS
	FINE	MEDIUM	COARSE	FINE	COARSE		

PENETRATION RESISTANCE

SAND & GRAVEL		SILT & CLAY		
RELATIVE DENSITY	BLOWS/FOOT*	CONSISTENCY	BLOWS/FOOT*	UNC. COMP. STRENGTH (KSF)
VERY LOOSE	0 - 4	VERY SOFT	0 - 1	0 - 1/2
LOOSE	5 - 10	SOFT	2 - 4	1/2 - 1
MEDIUM DENSE	11 - 30	MEDIUM STIFF	5 - 8	1 - 2
DENSE	31 - 50	STIFF	9 - 15	2 - 4
VERY DENSE	OVER 50	VERY STIFF	16 - 30	4 - 8
		HARD	OVER 30	OVER 8

* NUMBER OF BLOWS OF 140 LB HAMMER FALLING 30 INCHES TO DRIVE A 2 INCH O.D. (1-3/8 INCH I.D.) SPLIT-BARREL SAMPLER THE LAST 12 INCHES OF AN 18-INCH DRIVE (ASTM-1586 STANDARD PENETRATION TEST).

PLASTICITY CHART



LABORATORY TESTS

AT	ATTERBERG LIMITS
CD	CONSOLIDATED DRAINED TRIAXIAL
CN	CONSOLIDATION
CR	CORROSIVITY
CU	CONSOLIDATED UNDRAINED TRIAXIAL
DS	DIRECT SHEAR
HY	HYDROMETER
PR	PERMEABILITY
RV	R-VALUE
SA	SIEVE ANALYSIS
TC	CYCLIC TRIAXIAL
UC	UNCONFINED COMPRESSION
UU	UNCONSOLIDATED UNDRAINED TRIAXIAL
-200	% PASSING NO. 200 SIEVE

PROPERTIES

c	COHESION
DD	DRY DENSITY
EI	EXPANSION INDEX
LL	LIQUID LIMIT
MC	MOISTURE CONTENT
N_f	FIELD BLOW COUNT
PI	PLASTICITY INDEX
Su	UNDRAINED STRENGTH

UNDRAINED SHEAR STRENGTH

V	FIELD VANE
P	POCKET PENETROMETER
T	TORVANE
Q	UNCONFINED COMPRESSION
U	UNCONSOLIDATED UNDRAINED TRIAXIAL

INCREASING VISUAL MOISTURE CONTENT

WET
MOIST
DRY

Boring and Test Pit Legend

Rio Oso Flood Risk Reduction Feasibility Project
Rio Oso, CA

Date: JUN 2019

Figure: LEGEND

HDR	Project: Rio Oso Flood Risk Reduction Feasibility Project		Boring ID:	Sheet 1 of 2 Sheets
	Project Location: Rio Oso, CA		B-2	
	Project Number: 10147729			
Start Date: 2/28/2019	End Date: 2/28/2019	Logged By: Hamed Mousavi	Checked By: T. OBrien	Date Checked: 6/5/2019
Drilling Company (Rig Type): Taber Drilling (Diedrich D-120)		Inspector:	Weather Conditions: Cloudy/Sunny	
Drill Method: Mud / Hand		Drilled By: Rick	Elevation Top of Boring: 44.0 ft. Vertical Datum: NAVD88	
Drill Bit (Type/Size): Spade / 4 inch		Total Depth Drilled: 51.5 ft.	Latitude: 38.961697° Horizontal Datum: WGS84	Longitude: -121.545179°
Hammer Type: Automatic		Hole Backfill: Neat Cement Grout	Northing: Coordinate System:	Easting:
Hammer Efficiency:	Rod Type: AWJ	Total Number of Samples: 18 Disturbed: 18 Undisturbed: 0	Initial Groundwater Depth: 20 ft (;) Static Groundwater Depth:	

ELEV	DEPTH	Blows/6" or Press.	N_f	DESCRIPTION OF MATERIALS	% REC	Samp No.	Fines	LL	PI	DD	MC	Su (ksf)	REMARKS
	0			4" Asphalt.		S-1							Hand Auger to 5 ft
				Aggregate Base.									
				LEAN CLAY (CL): brown, moist, low plasticity.									
40													
	5	6 6 8	14	Stiff.	100	S-2	59	22	9	99	10	4.50 P	4" spade bit
		1 2 6	8	SANDY SILT (ML): medium stiff, brown, moist.	100	S-3							
35													
	10	6 15 24	39	Hard.	100	S-4	66	30	6		26	1.00 P	
		18 28 42	70	SANDY LEAN CLAY (CL): hard, brown, moist.	100	S-5	64	31	8		16	2.50 P	
30													
	15	21 28 37	65	Fine gray sand.	100	S-6	67	32	9		18	4.50 P	
		9 18 25	43		83	S-7						3.50 P	
25													
	20 ▽	4 7 12	19	CLAYEY SAND (SC): medium dense, brown, wet, fine sand.	100	S-8	29				24		Ground water at 20 feet Switched to mud rotary
		8 12 16	28	Well-Graded SAND with Silt and Gravel (SW-SM): dense, dark gray, wet, with fine to coarse sand, fine to medium coarse subangular to rounded gravel up to 3/4".	56	S-9	8				12		
20													
	25	4 5 9	14	SILT (ML): stiff, brown, moist.	61	S-10		42	10		42		
15													Hole caved, driller pushed the casing. Mud leaked from between the casing and hole. Pushed casing to 31.5 ft depth to plug the leak.

HDR SOIL BORING LOG 2017_MARCH_R1; 10147729 - SMALL COMMUNITIES - RIO OSO.GPJ; HDR_FOLSOM_OAKLAND_MARCH 2017_WIP.GLB; 6/17/19

HDR Engineering, Inc.

![HDR]	Project: Rio Oso Flood Risk Reduction Feasibility Project	Boring ID:	Sheet
	Project Location: Rio Oso, CA	B-2	2 of 2 Sheets
	Project Number: 10147729		

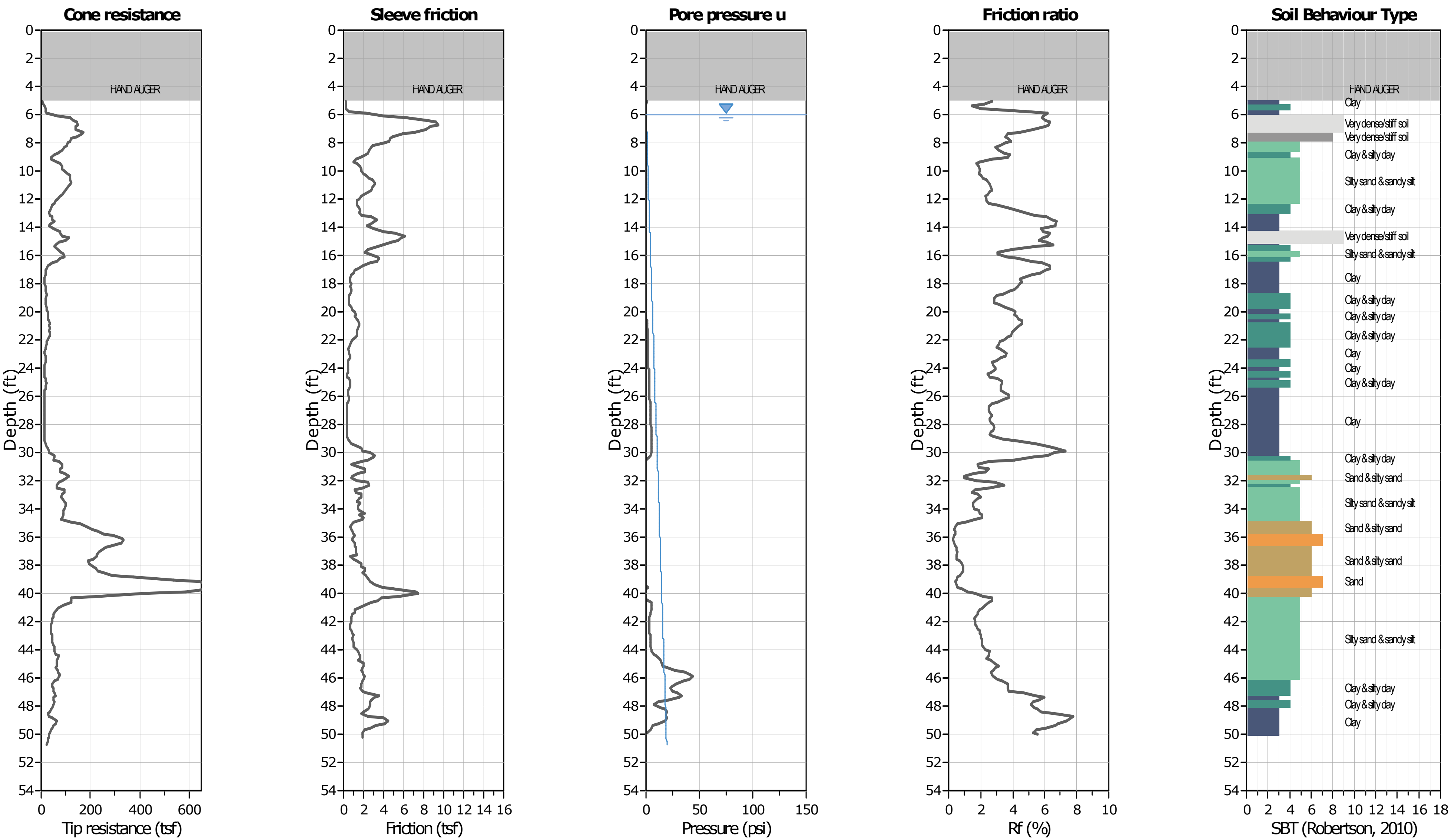
ELEV	DEPTH	SAMPLE	Blows/6" or Press.	N_f	LEGEND	DESCRIPTION OF MATERIALS	% REC	Samp No.	Fines	LL	PI	DD	MC	Su (ksf)	REMARKS
						Laboratory (Fines, LL, PI, DD, MC)									
10			6 8 9	17		Very stiff, coarse gravel in the upper 6" of sampler.	72	S-11						3.50 P	
	35		7 8 15	23		SILT with Sand (ML): very stiff, brown, moist.	67	S-12	82	37	10	80	42	3.50 P	
5			5 5 7	12		SILT (ML): stiff, brown, moist.	0	S-13							No recovery in ModCAL sampler.
	40		7 7 8	15			100	S-14						1.00 P	
0			6 6 1.5	7.5			100	S-15						1.50 P	
	45		3 3 4	7		Medium stiff.	100	S-16						0.50 P	
-5			3 4 3	7			83	S-17							
	50		7 8 8	16		Very stiff.	100	S-18	88	35	8		39	1.50 P	

Boring terminated at 51.5 feet depth. Backfilled with neat cement grout (8 bags cement).

HDR Inc.
2365 Iron Point Rd.
Folsom CA, 95630

CPT: CPT-11
Total depth: 50.69 ft, Date: 3/27/2019
Surface Elevation: 45.00 ft
Coords: lat 38.969318° lon -121.538308°

Project: **Rio Oso Flood Risk Reduction Feasibility Study**
Location: **Rio Oso, CA**



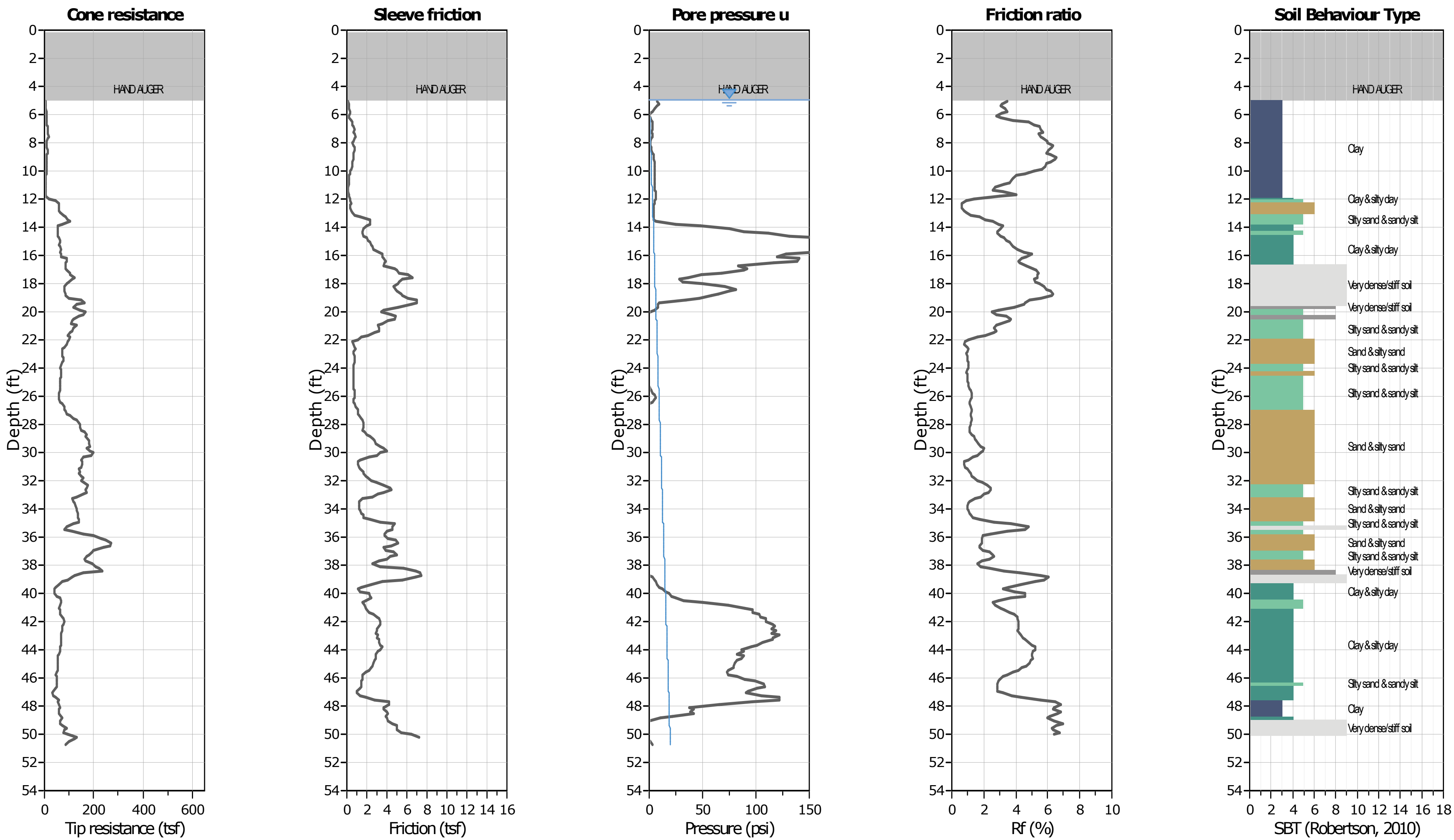
SBT legend

1. Sensitive fine grained	4. Clayey silt to silty clay	7. Gravely sand to sand
2. Organic material	5. Silty sand to sandy silt	8. Very stiff sand to clayey sand
3. Clay to silty clay	6. Clean sand to silty sand	9. Very stiff fine grained

HDR Inc.
2365 Iron Point Rd.
Folsom CA, 95630

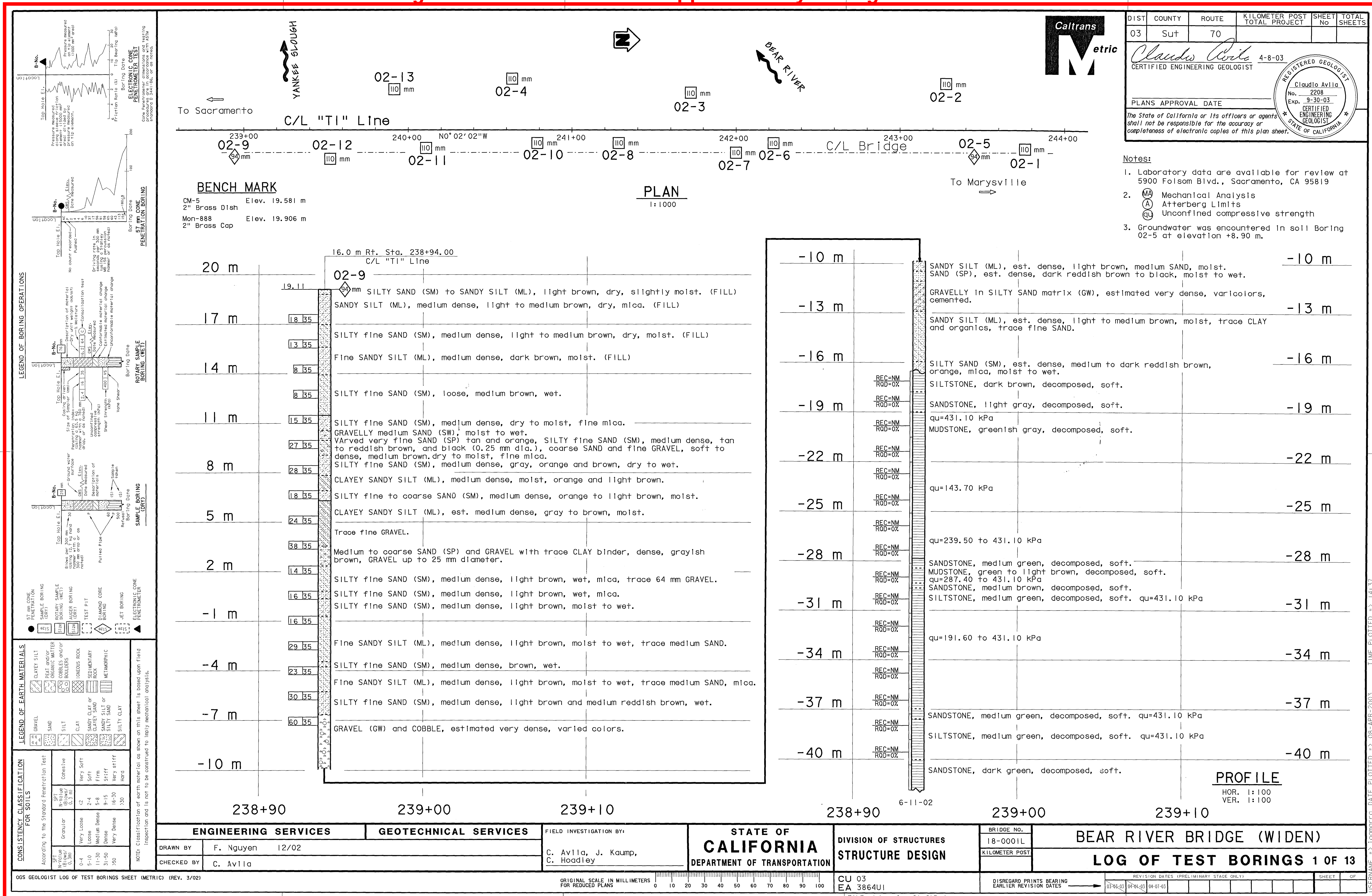
CPT: CPT-12
Total depth: 50.69 ft, Date: 4/22/2019
Surface Elevation: 44.00 ft
Coords: lat 38.964096° lon -121.529337°

Project: **Rio Oso Flood Risk Reduction Feasibility Study**
Location: **Rio Oso, CA**



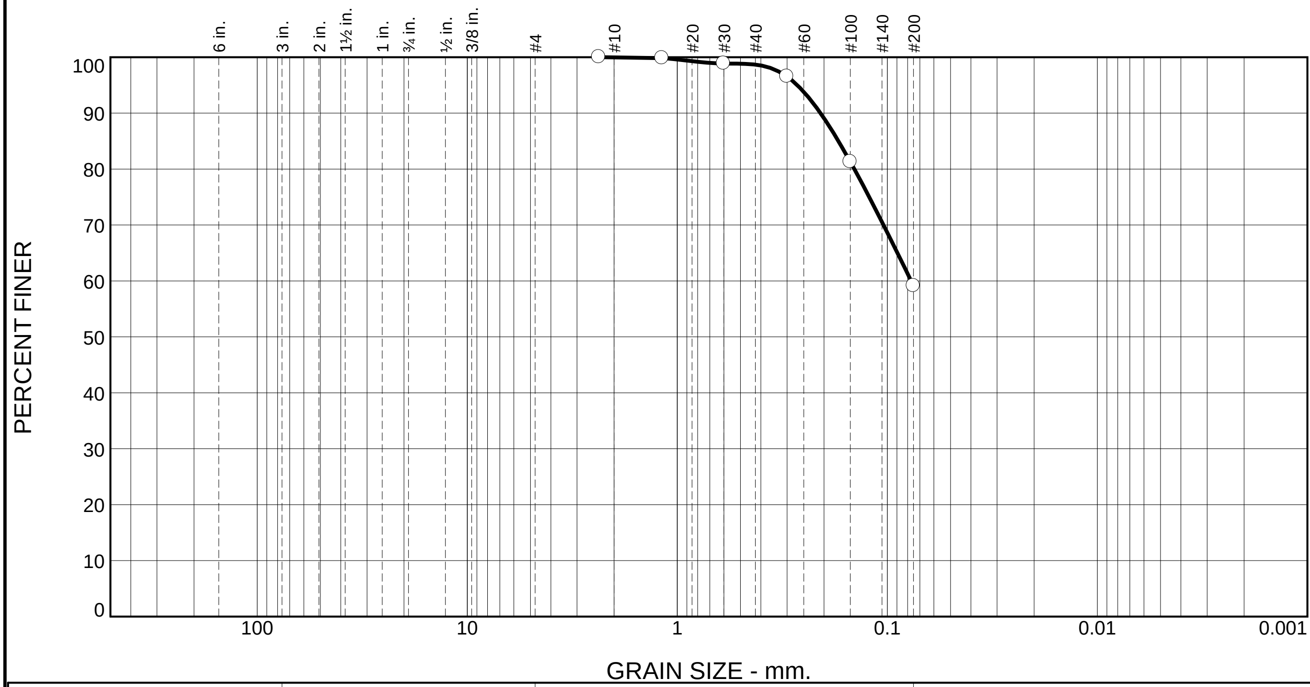
1. Sensitive fine grained
2. Organic material
3. Clay to silty clay
4. Clayey silt to silty clay
5. Silty sand to sandy silt
6. Clean sand to silty sand
7. Gravely sand to sand
8. Very stiff sand to clayey sand
9. Very stiff fine grained

Caltrans - Bear River Bridge 18-0001 LOTB - 2003 - approximately through the crown of Bear River Left Levee



Appendix C – Laboratory Test Results

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	
0	0	0	0	1	40	59

Test Results (ASTM D6913 & ASTM D1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#8	100		
#16	100		
#30	99		
#50	97		
#100	81		
#200	59		

* (no specification provided)

Material Description

Dark red-brown

Atterberg Limits (ASTM D 4318)

PL= **LL=** **PI=**

Classification

USCS (D 2487)= **AASHTO (M 145)=**

Coefficients

D_{90}= 0.2080 D_{85}= 0.1710 D_{60}= 0.0770
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

F.M.=0.23

Date Received: 4/19/19 **Date Tested:** 4/30/19

Tested By: JM

Checked By: JML

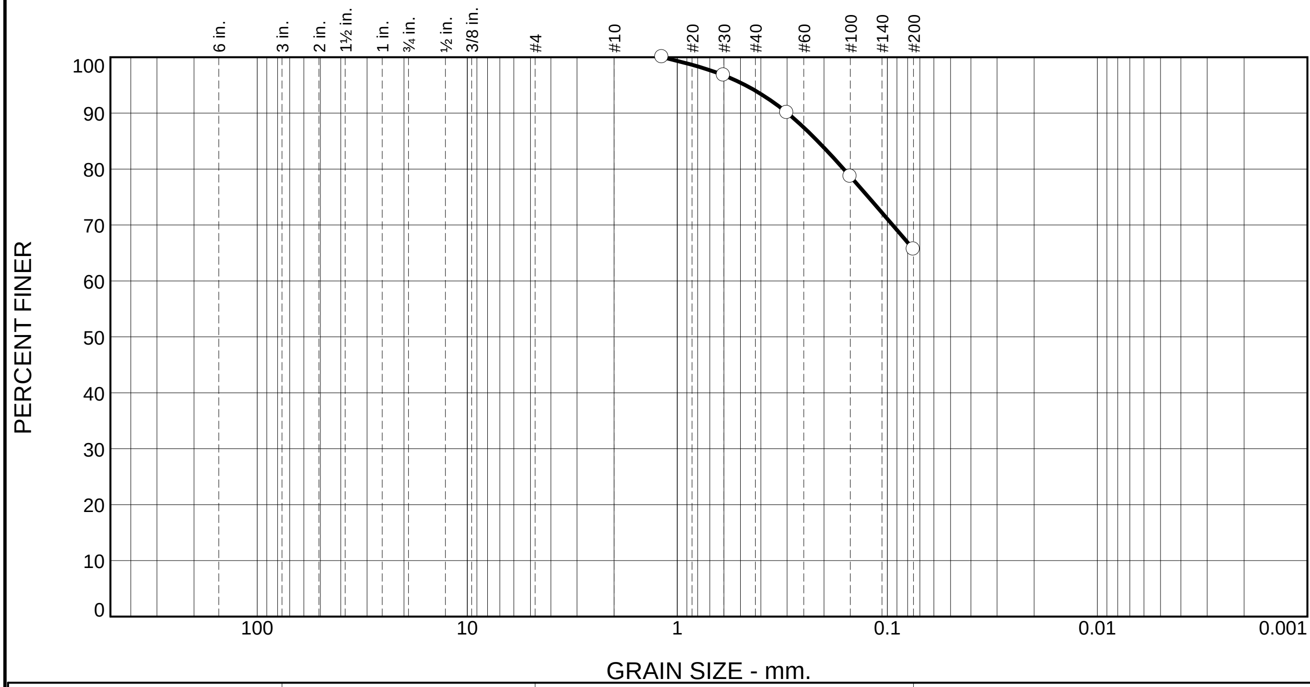
Title: PM

Location: MOD CAL: B-2 **Date Sampled:** -
Sample Number: 42770 **Depth:** 5.5'-6.5'

GS GULF SHORE EXPLORATION AND TESTING

Client: HDR, Inc.
Project: Small Communities - Rio Oso
Project No: 19-147 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	
0	0	0	0	6	28	66

Test Results (ASTM D6913 & ASTM D1140)			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#16	100		
#30	97		
#50	90		
#100	79		
#200	66		

* (no specification provided)

Material Description

Brown sandy silt

Atterberg Limits (ASTM D 4318)

PL= 24 **LL=** 30 **PI=** 6

Classification

USCS (D 2487)= ML **AASHTO (M 145)=** A-4(3)

Coefficients

D_{90}= 0.2985 D_{85}= 0.2147 D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

F.M.=0.35

Date Received: 4/19/19 **Date Tested:** 5/15/19

Tested By: JM

Checked By: JML

Title: PM

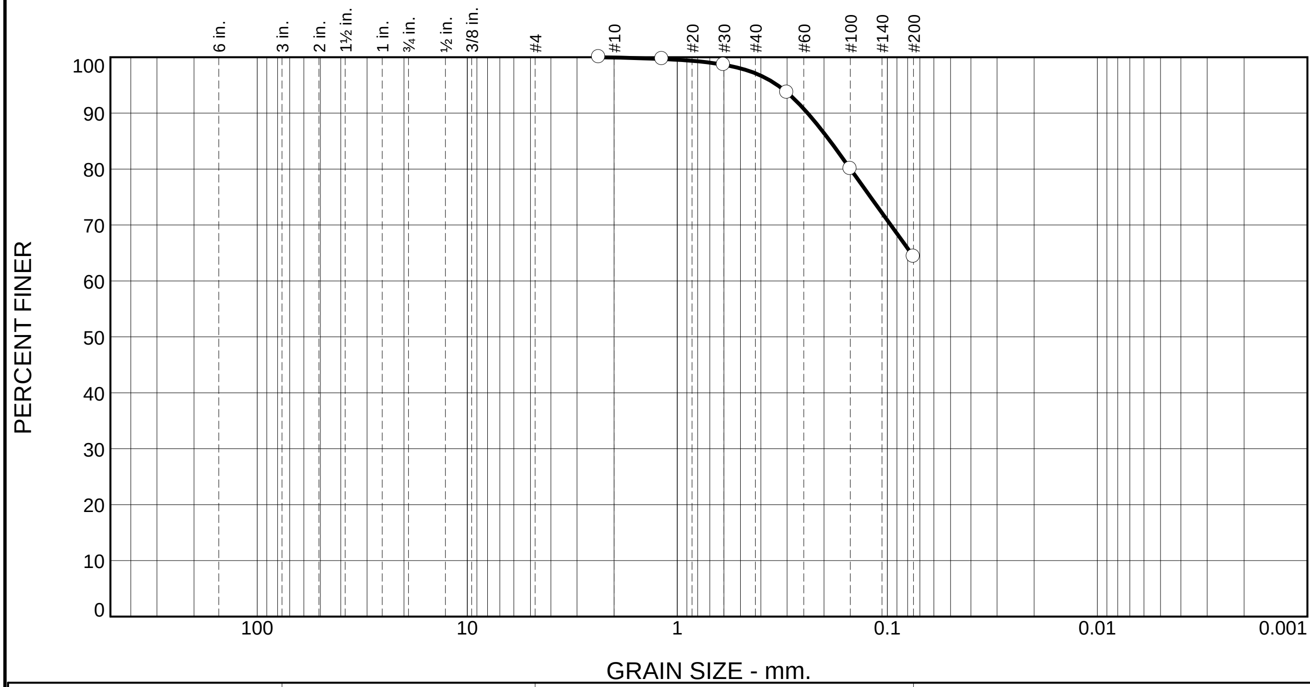
Location: Split Spoon: B-2 **Date Sampled:** -
Sample Number: 42763 **Depth:** 10.5'-11.5'

GULF SHORE EXPLORATION AND TESTING

Client: HDR, Inc.
Project: Small Communities - Rio Oso

Project No: 19-147 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	
0	0	0	0	3	33	64

Test Results (ASTM D6913 & ASTM D1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#8	100		
#16	100		
#30	99		
#50	94		
#100	80		
#200	64		

* (no specification provided)

Material Description

Brown sandy lean clay

Atterberg Limits (ASTM D 4318)

PL= 23 **LL=** 31 **PI=** 8

Classification

USCS (D 2487)= CL **AASHTO (M 145)=** A-4(4)

Coefficients

D_{90}= 0.2393 D_{85}= 0.1873 D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

F.M.=0.28

Date Received: 4/19/19 **Date Tested:** 5/15/19

Tested By: JM

Checked By: JML

Title: PM

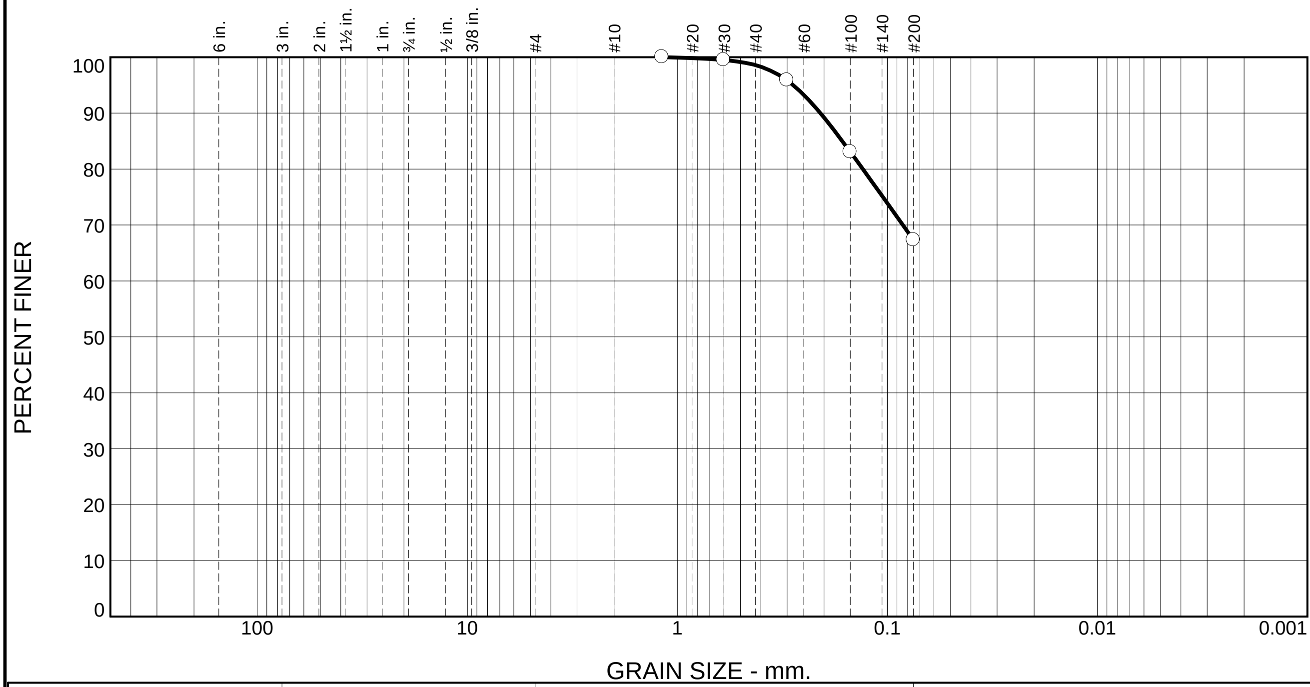
Location: Split Spoon: B-2
Sample Number: 42764 **Depth:** 13.0'-14.0' **Date Sampled:** -

GS GULF SHORE EXPLORATION AND TESTING

Client: HDR, Inc.
Project: Small Communities - Rio Oso

Project No: 19-147 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	
0	0	0	0	1	32	67

Test Results (ASTM D6913 & ASTM D1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#16	100		
#30	99		
#50	96		
#100	83		
#200	67		

* (no specification provided)

Material Description

Brown sandy lean clay

Atterberg Limits (ASTM D 4318)

PL= 23 **LL=** 32 **PI=** 9

Classification

USCS (D 2487)= CL **AASHTO (M 145)=** A-4(5)

Coefficients

D_{90}= 0.2083 D_{85}= 0.1638 D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

F.M.=0.22

Date Received: 4/19/19 **Date Tested:** 5/17/19

Tested By: JM

Checked By: JML

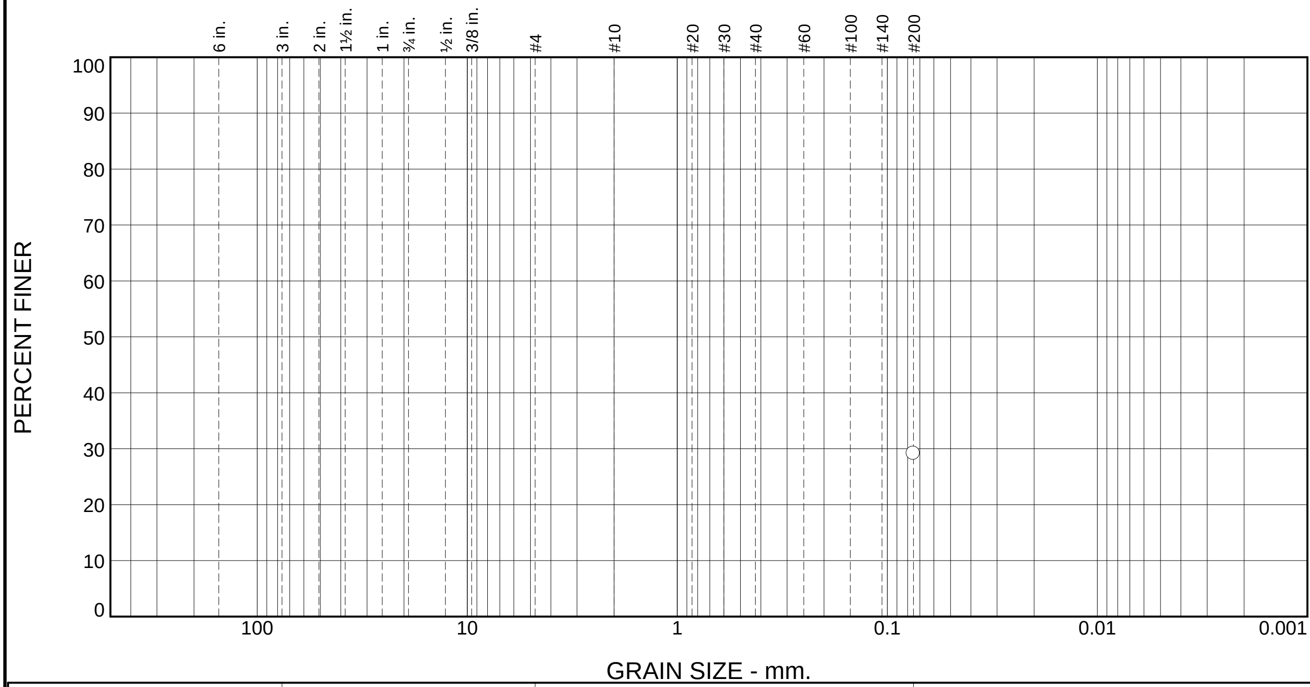
Title: PM

Location: Split Spoon: B-2
Sample Number: 42765 **Depth:** 15.5'-16.5'
Date Sampled: -

GULF SHORE EXPLORATION AND TESTING

Client: HDR, Inc.
Project: Small Communities - Rio Oso
Project No: 19-147 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	
						29

Test Results (ASTM D6913 & ASTM D1140)			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#200	29		

* (no specification provided)

Material Description

Atterberg Limits (ASTM D 4318)

PL= LL= PI=

Classification

USCS (D 2487)= AASHTO (M 145)=

Coefficients

D_{90}= D_{85}= D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

Date Received: 4/19/19 **Date Tested:** 5/17/19

Tested By: BM/JM

Checked By: JML

Title: PM

Location: Split Spoon: B-2
Sample Number: 42769 **Depth:** 20.5'-21.5'

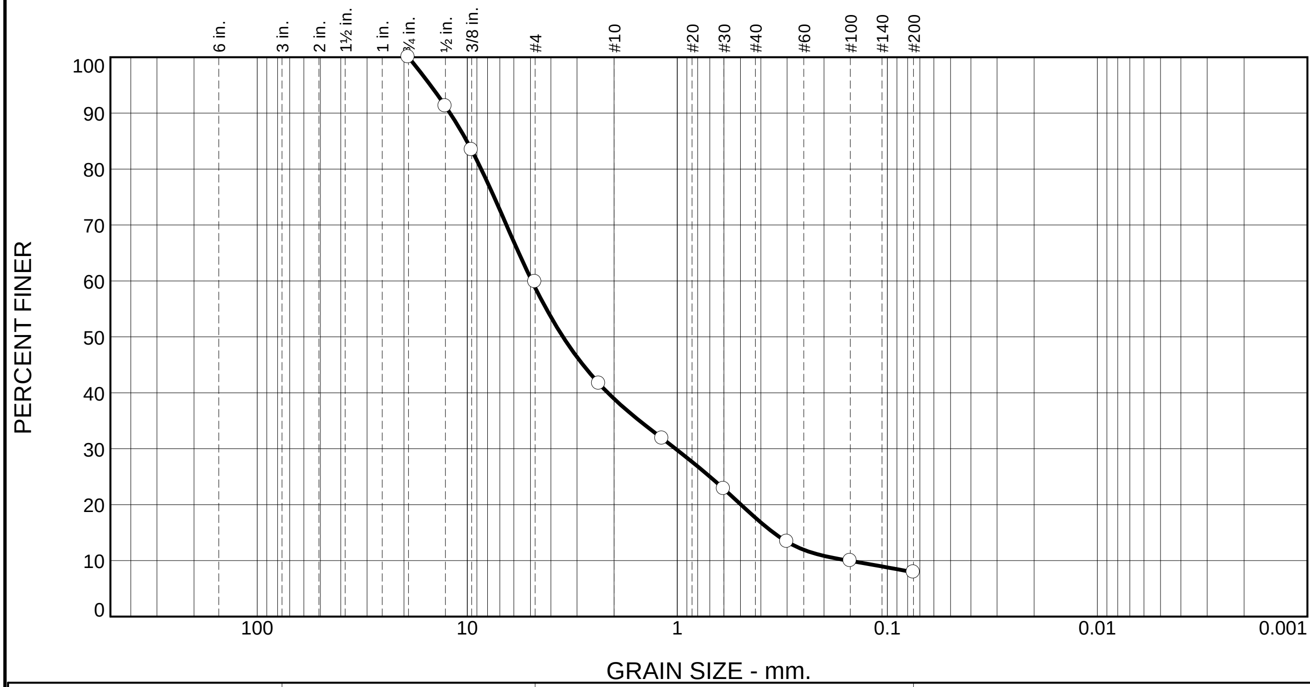
Date Sampled: -

GS GULF SHORE EXPLORATION AND TESTING

Client: HDR, Inc.
Project: Small Communities - Rio Oso

Project No: 19-147 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	
0	0	41	20	21	10	8

Test Results (ASTM D6913 & ASTM D1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3/4 Inch	100		
1/2 Inch	91		
3/8 Inch	83		
#4	59		
#8	42		
#16	32		
#30	23		
#50	13		
#100	10		
#200	7.9		

* (no specification provided)

Material Description

Brown well-graded sand with silt and gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SW-SM **AASHTO (M 145)=** A-1-a

Coefficients

D_{90}= 12.0639	D_{85}= 10.0355	D_{60}= 4.9237
D_{50}= 3.4987	D_{30}= 1.0189	D_{15}= 0.3483
D_{10}= 0.1529	C_u= 32.19	C_c= 1.38

Remarks

F.M.=4.38

Date Received: 4/19/19 **Date Tested:** 5/17/19

Tested By: BM/JM

Checked By: JML

Title: PM

Location: Split Spoon: B-2 **Date Sampled:** -

Sample Number: 42766 **Depth:** 23.0'-24.0'

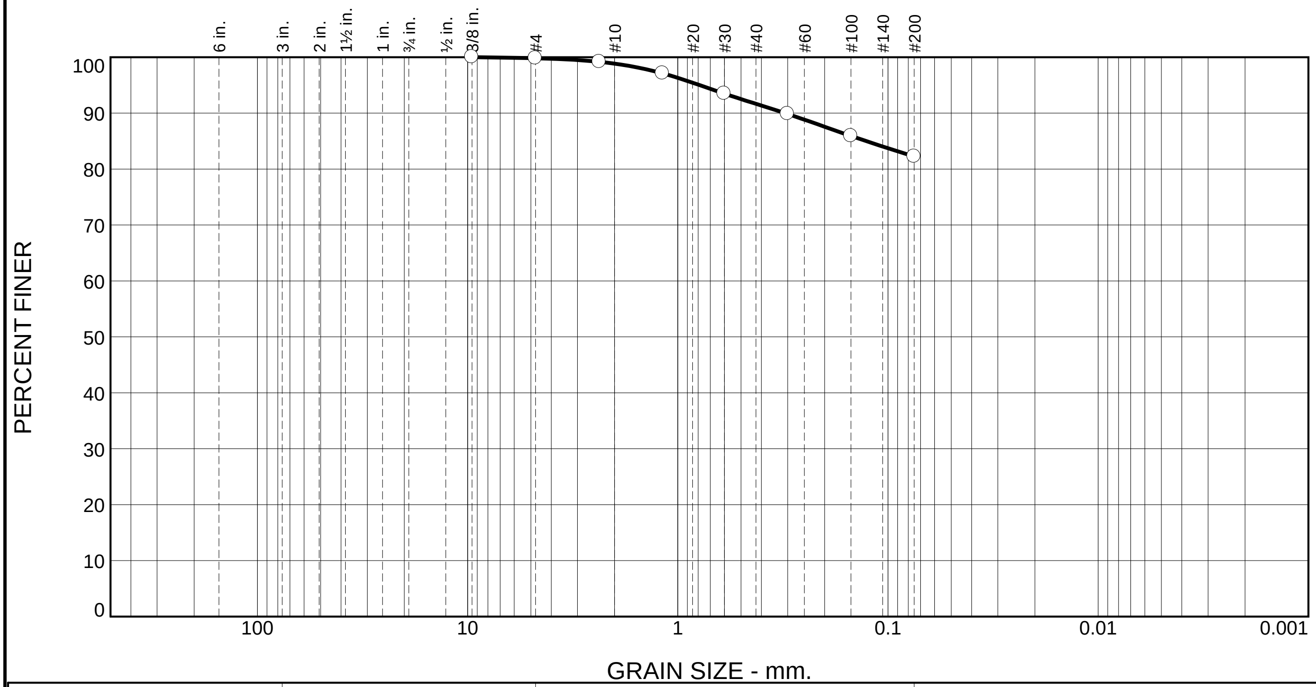
GULF SHORE EXPLORATION AND TESTING

Client: HDR, Inc.

Project: Small Communities - Rio Oso

Project No: 19-147 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	
0	0	0	1	7	10	82

Test Results (ASTM D6913 & ASTM D1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3/8 Inch	100		
#4	100		
#8	99		
#16	97		
#30	93		
#50	90		
#100	86		
#200	82		

* (no specification provided)

Material Description

Brown

Atterberg Limits (ASTM D 4318)

PL= **LL=** **PI=**

Classification

USCS (D 2487)= **AASHTO (M 145)=**

Coefficients

D_{90}= 0.3089 D_{85}= 0.1268 D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

F.M.=0.35

Date Received: 4/19/19 **Date Tested:** 4/30/19

Tested By: JM

Checked By: JML

Title: PM

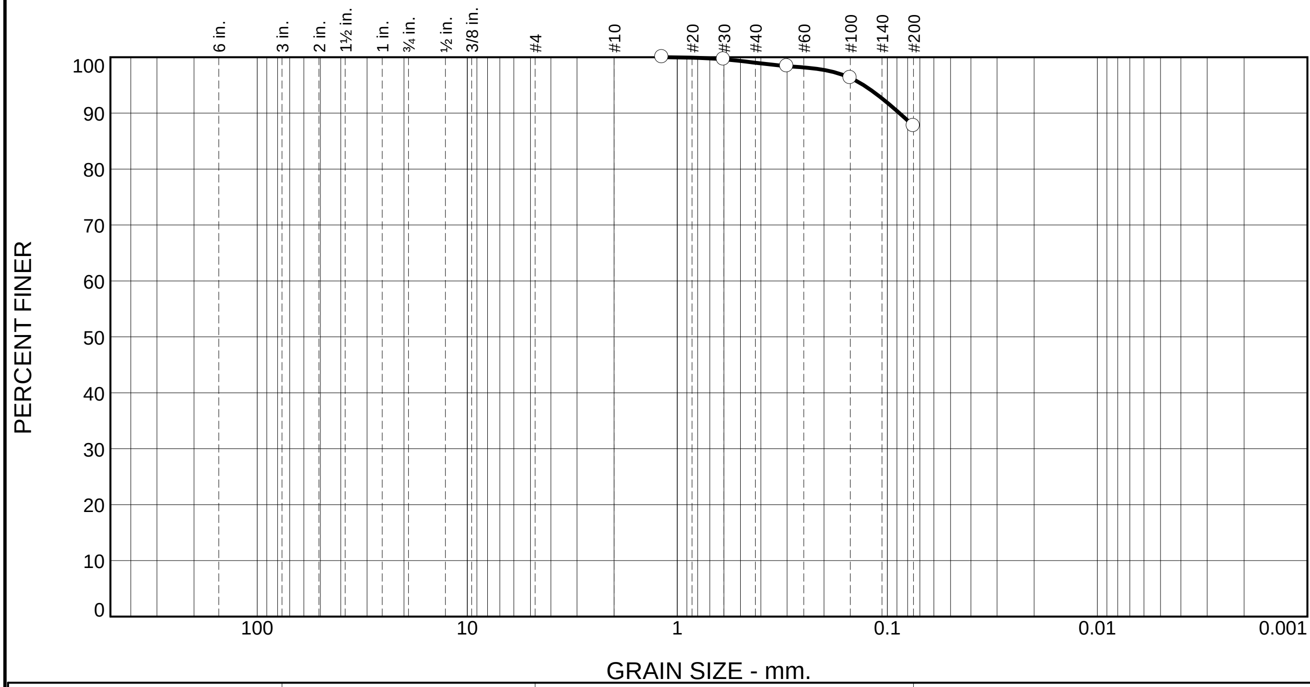
Location: MOD CAL: B-2
Sample Number: 42771 **Depth:** 35.0'-36.5' **Date Sampled:** -

GULF SHORE EXPLORATION AND TESTING

Client: HDR, Inc.
Project: Small Communities - Rio Oso

Project No: 19-147 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines
	Coarse	Fine	Coarse	Medium	Fine	
0	0	0	0	1	11	88

Test Results (ASTM D6913 & ASTM D1140)			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#16	100		
#30	100		
#50	98		
#100	96		
#200	88		

* (no specification provided)

Material Description

Brown silt

Atterberg Limits (ASTM D 4318)

PL= 27 **LL=** 35 **PI=** 8

Classification

USCS (D 2487)= ML **AASHTO (M 145)=** A-4(8)

Coefficients

D_{90}= 0.0876 D_{85}= D_{60}=
D_{50}= D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

F.M.=0.06

Date Received: 4/19/19 **Date Tested:** 5/20/19

Tested By: CJ

Checked By: JML

Title: PM

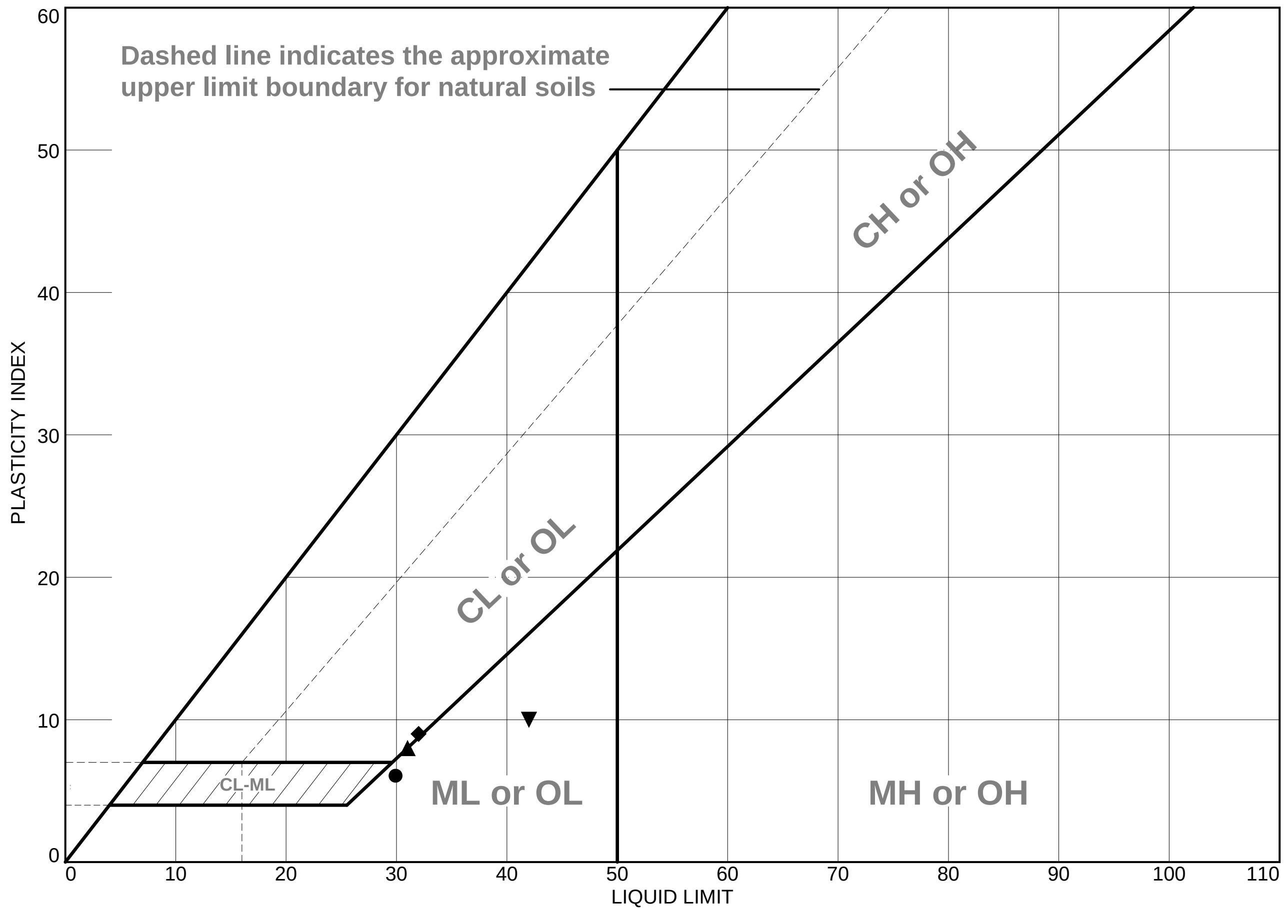
Location: Split Spoon: B-2 **Date Sampled:** -
Sample Number: 42768 **Depth:** 50.5'-51.5'

GS GULF SHORE EXPLORATION AND TESTING

Client: HDR, Inc.
Project: Small Communities - Rio Oso

Project No: 19-147 **Figure**

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Brown sandy silt	30	24	6	94	66	ML
■	Brown well-graded sand with silt and gravel	NV	NP	NP	18	7.9	SW-SM
▲	Brown sandy lean clay	31	23	8	97	64	CL
◆	Brown sandy lean clay	32	23	9	99	67	CL
▼		42	32	10			

Project No. 19-147 **Client:** HDR, Inc.

Project: Small Communities - Rio Oso

●**Location:** Split Spoon: B-2 **Depth:** 10.5'-11.5' **Sample Number:** 42763

■**Location:** Split Spoon: B-2 **Depth:** 23.0'-24.0' **Sample Number:** 42766

▲**Location:** Split Spoon: B-2 **Depth:** 13.0'-14.0' **Sample Number:** 42764

◆**Location:** Split Spoon: B-2 **Depth:** 15.5'-16.5' **Sample Number:** 42765

▼**Location:** Split Spoon: B-2 **Depth:** 25.5'-26.5' **Sample Number:** 42767

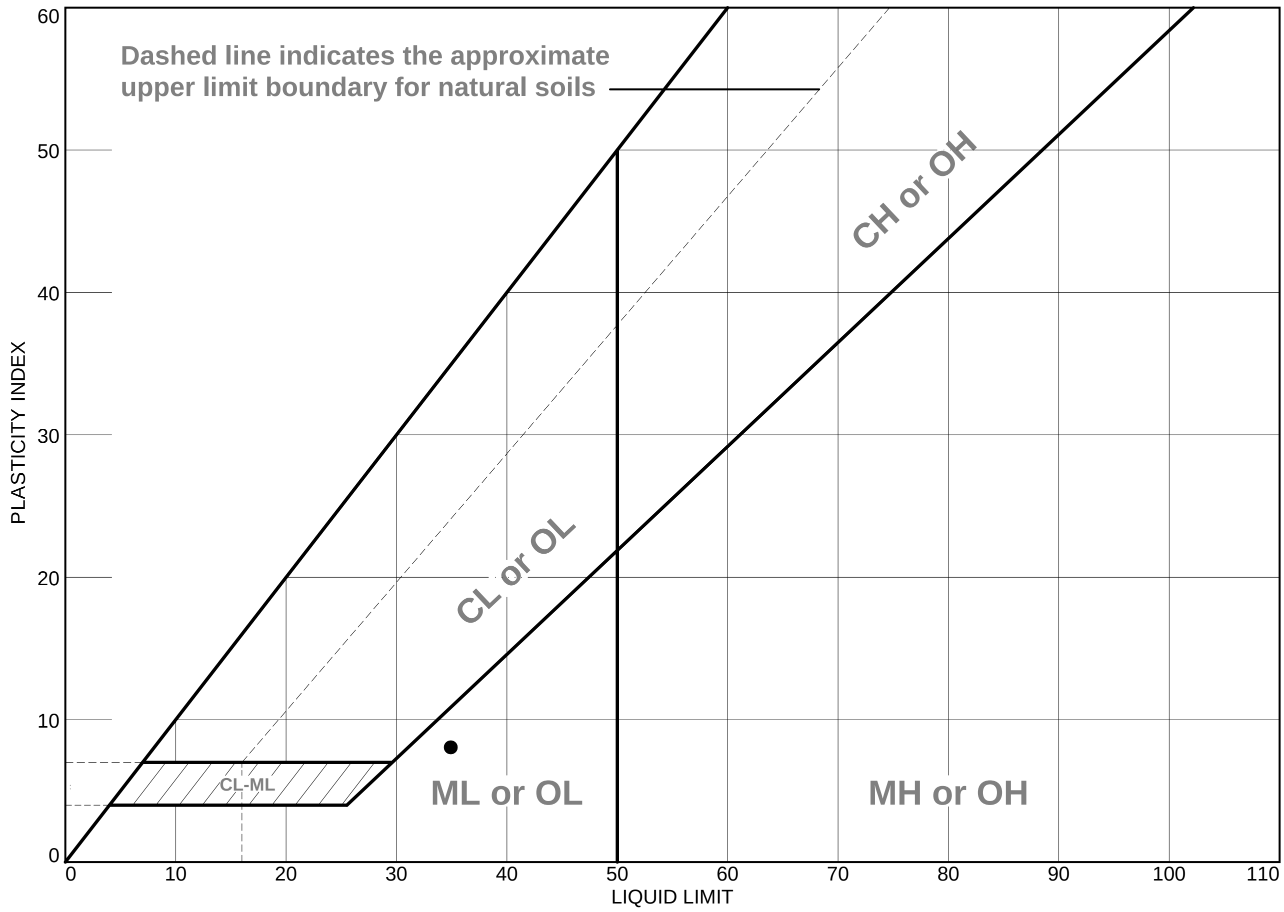
GULF SHORE EXPLORATION AND TESTING

Remarks:

Figure

Tested By: ○ SL □ BM △ SL ◇ SL ▽ SL **Checked By:** JML

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Brown silt	35	27	8	99	88	ML

Project No. 19-147 **Client:** HDR, Inc.

Project: Small Communities - Rio Oso

● **Location:** Split Spoon: B-2 **Depth:** 50.5'-51.5' **Sample Number:** 42768

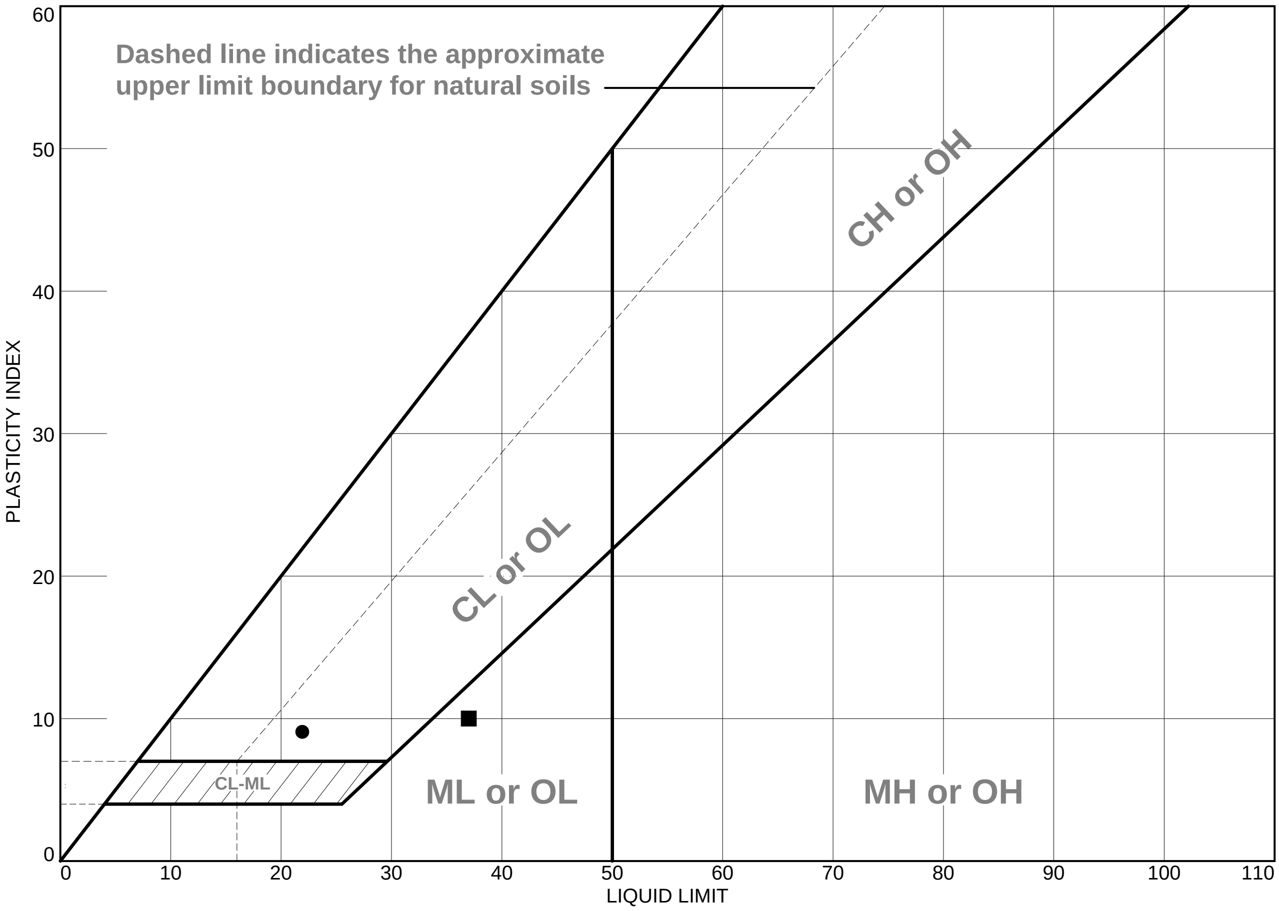
Remarks:

GS GULF SHORE EXPLORATION AND TESTING

Figure

Tested By: AS **Checked By:** JML

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Dark red-brown sandy lean clay	22	13	9	99	59	CL
■	Brown silt with sand	37	27	10	92	82	ML

Project No. 19-147 **Client:** HDR, Inc.

Project: Small Communities - Rio Oso

● **Location:** MOD CAL: B-2 **Depth:** 5.5'-6.5' **Sample Number:** 42770

■ **Location:** MOD CAL: B-2 **Depth:** 35.0'-36.5' **Sample Number:** 42771

Remarks:

GS GULF SHORE EXPLORATION AND TESTING

Figure

Tested By: SL **Checked By:** JML

MOISTURE CONTENT TEST RESULTS

Sample Identification	Depth, ft.	Moisture Content, %
Split Spoon B-2	10.5'-11.5'	26.4
Split Spoon B-2	13.0'-14.0'	15.5
Split Spoon B-2	15.5'-16.5'	17.6
Split Spoon B-2	23.0'-24.0'	12.2
Split Spoon B-2	25.5'-26.5'	41.5
Split Spoon B-2	50.5'-51.5'	38.6
Split Spoon B-2	20.5'-21.5'	24.2

Test Method: ASTM D2216

PROJECT NUMBER:	19-147	May 20, 2019	Small Communities - Rio Oso

GULF SHORE EXPLORATION AND TESTING

3362 Fitzgerald Road
Rancho Cordova, CA 95742
Phone: (916) 939-4117
FAX: (916) 635-4315

MOISTURE CONTENT & UNIT WEIGHT TEST RESULTS

Sample Identification	Depth, ft.	Wet Unit Weight, lb/ft.^{3}	Dry Unit Weight, lb/ft.^{3}	Moisture Content, %
MOD CAL: B-2	5.5'-6.5'	108.6	99.0	9.7
MOD CAL: B-2	35.0'-36.5'	113.8	80.1	42.1

Test Method: ASTM D2216, ASTM D2937

PROJECT NUMBER: **19-147** April 26, 2019

GS GULF SHORE EXPLORATION AND TESTING

3362 Fitzgerald Road
Rancho Cordova, CA 95742
Phone: (916) 939-4117
FAX: (916) 635-4315

Small Communities - Rio Oso

SOIL SPECIFIC GRAVITY

Sample Identification	Specific Gravity
MOD CAL B-2 (5.5'-6.5')	2.67
MOD CAL B-2 (35.0'-36.5')	2.58

Test Method: ASTM D854

PROJECT NUMBER:	19-147	May 28, 2019	Small Communities - Rio Oso

GULF SHORE EXPLORATION AND TESTING

3362 Fitzgerald Road
Rancho Cordova, CA 95742
Phone: (916) 939-4117
FAX: (916) 635-4315

SOIL SPECIFIC GRAVITY

Sample Identification	Specific Gravity
Split Spoon B-2 (23.0'-24.0')	2.72

Test Method: ASTM D854

PROJECT NUMBER: **19-147** May 16, 2019

GULF SHORE EXPLORATION AND TESTING

3362 Fitzgerald Road
Rancho Cordova, CA 95742
Phone: (916) 939-4117
FAX: (916) 635-4315

Small Community - Rio Oso

MOISTURE AND ORGANIC CONTENT TEST RESULTS

Sample Identification	Depth, ft.	Organic Content, %	Moisture Content, %
MOD CAL: B-2	5.5'-6.5'	3.3	9.7
MOD CAL: B-2	35.0'-36.5'	4.8	42.1

Test Method: ASTM D2974

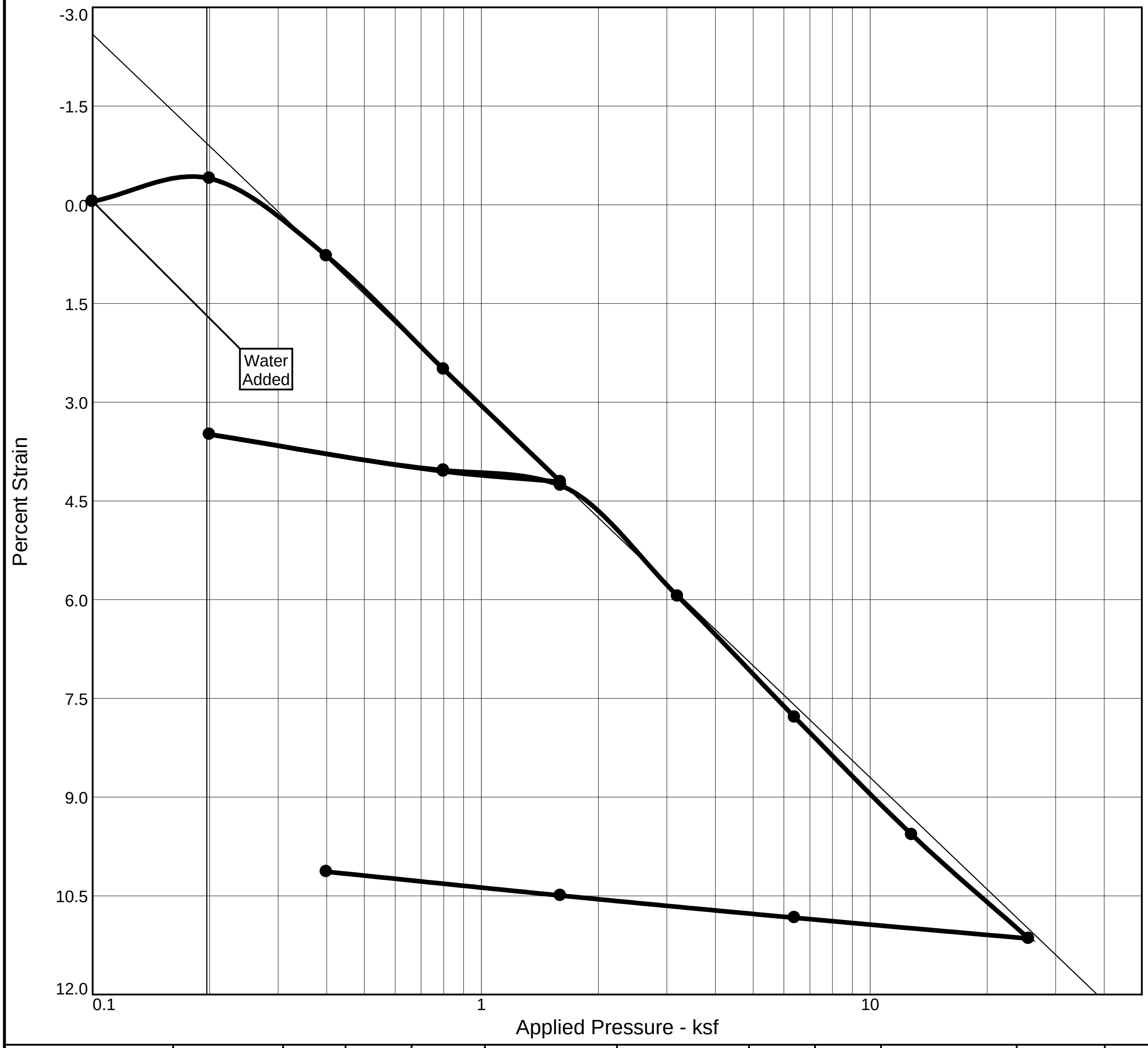
PROJECT NUMBER: **19-147** April 30, 2019

GS GULF SHORE EXPLORATION AND TESTING

3362 Fitzgerald Road
Rancho Cordova, CA 95742
Phone: (916) 939-4117
FAX: (916) 635-4315

Small Communities - Rio Oso

CONSOLIDATION TEST REPORT



Natural		Dry Dens. (pcf)	LL	PI	Sp. Gr.	Overburden (ksf)	P_c (ksf)	C_c	C_s	Swell Press. (ksf)	Swell %	e_o
Sat.	Moist.											
48.2 %	17.1 %	85.7	22	9	2.67	0	0.2	0.11	0.01		0.0	0.945

MATERIAL DESCRIPTION	USCS	AASHTO
Dark red-brown sandy lean clay	CL	A-4(2)

Project No. 19-147 **Client:** HDR, Inc.

Project: Small Communities - Rio Oso

Location: MOD CAL: B-2 **Depth:** 5.5'-6.5' **Sample Number:** 42770

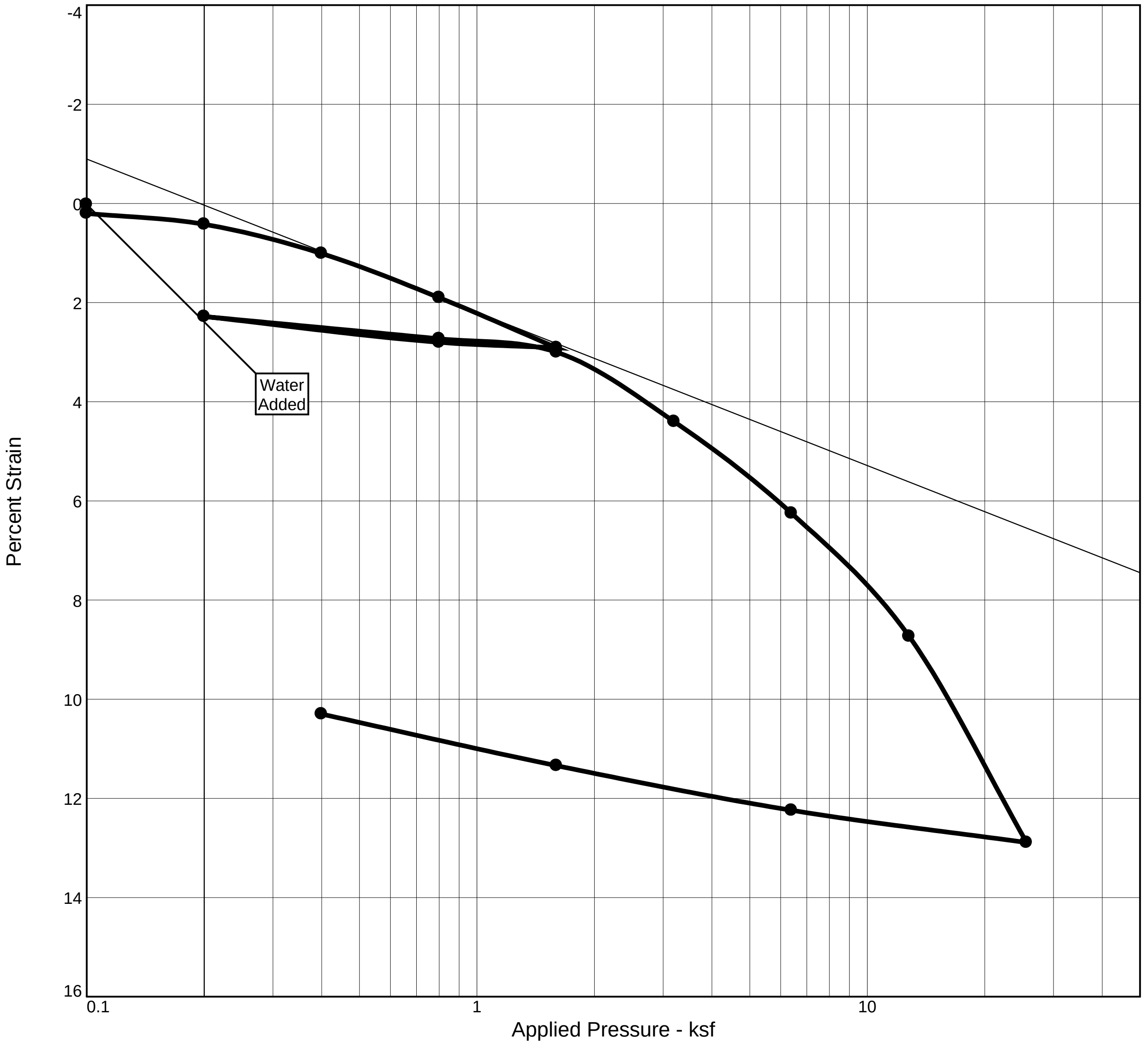
GS GULF SHORE EXPLORATION AND TESTING

Remarks:

Figure

Tested By: MPW **Checked By:** JML

CONSOLIDATION TEST REPORT



Natural		Dry Dens. (pcf)	LL	PI	Sp. Gr.	Overburden (ksf)	P_c (ksf)	C_c	C_s	Swell Press. (ksf)	Clpse. %	e_o
Sat.	Moist.											
99.8 %	40.7 %	78.4	37	10	2.58	0	0.3	0.06	0.02		0.2	1.053

MATERIAL DESCRIPTION	USCS	AASHTO
Brown silt with sand	ML	A-4(9)

Project No. 19-147 **Client:** HDR, Inc.

Project: Small Communities - Rio Oso

Location: MOD CAL: B-2 **Depth:** 35.0'-36.5' **Sample Number:** 42771

GULF SHORE EXPLORATION AND TESTING

Remarks:

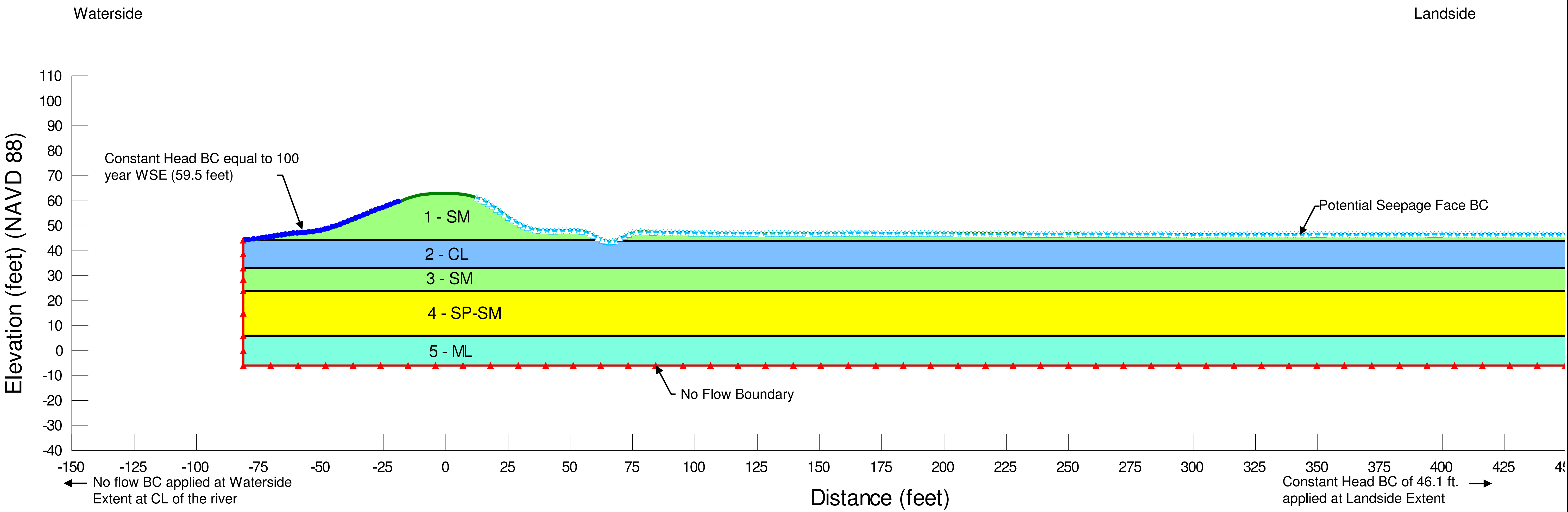
Figure

Tested By: MPW **Checked By:** JML

Appendix D – Seepage Analysis

Reach A (YS-L 1030+60)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	**SM**	2.834	1.0E-3	0.25
2	**CL**	0.028	1.0E-5	0.25
3	**SM**	2.834	1.0E-3	0.25
4	**SP-SM**	11.336	4.0E-3	0.25
5	**ML**	0.028	1.0E-5	0.25



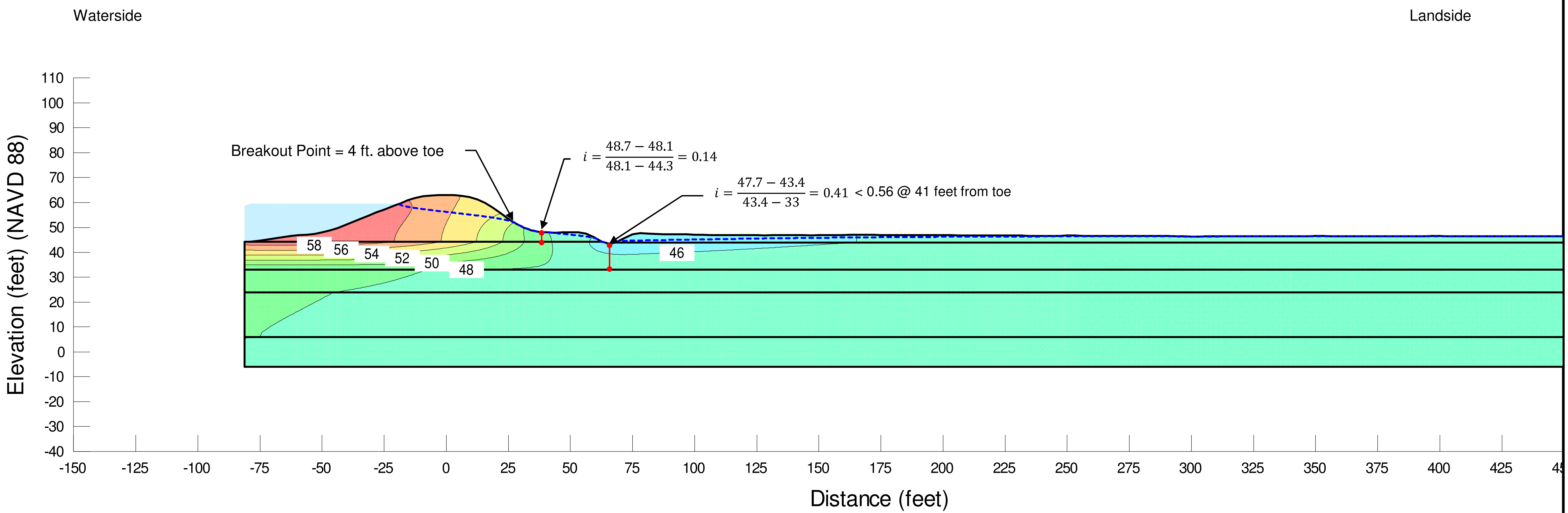
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Reach A (YS-L 1030+60)
Seepage Model-100 year WSE

July 2019

FIGURE D-1



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

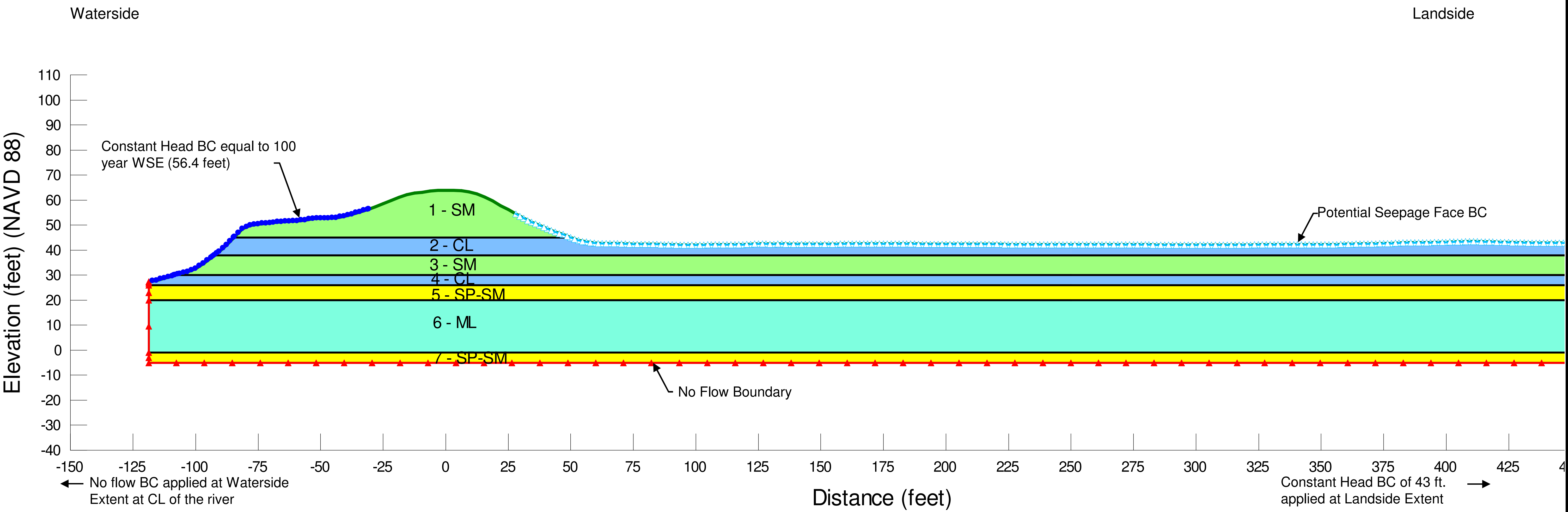
Reach A (YS-L 1030+60) Seepage Result-100 year WSE

July 2019

FIGURE D-2

Reach B (BR-L 1106+12)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	SM	2.834	1.0E-3	0.25
2	CL	0.028	1.0E-5	0.25
3	SM	2.834	1.0E-3	0.25
4	CL	0.028	1.0E-5	0.25
5	SP-SM	11.336	4.0E-3	0.25
6	ML	0.028	1.0E-5	0.25
7	SP-SM	11.336	4.0E-3	0.25



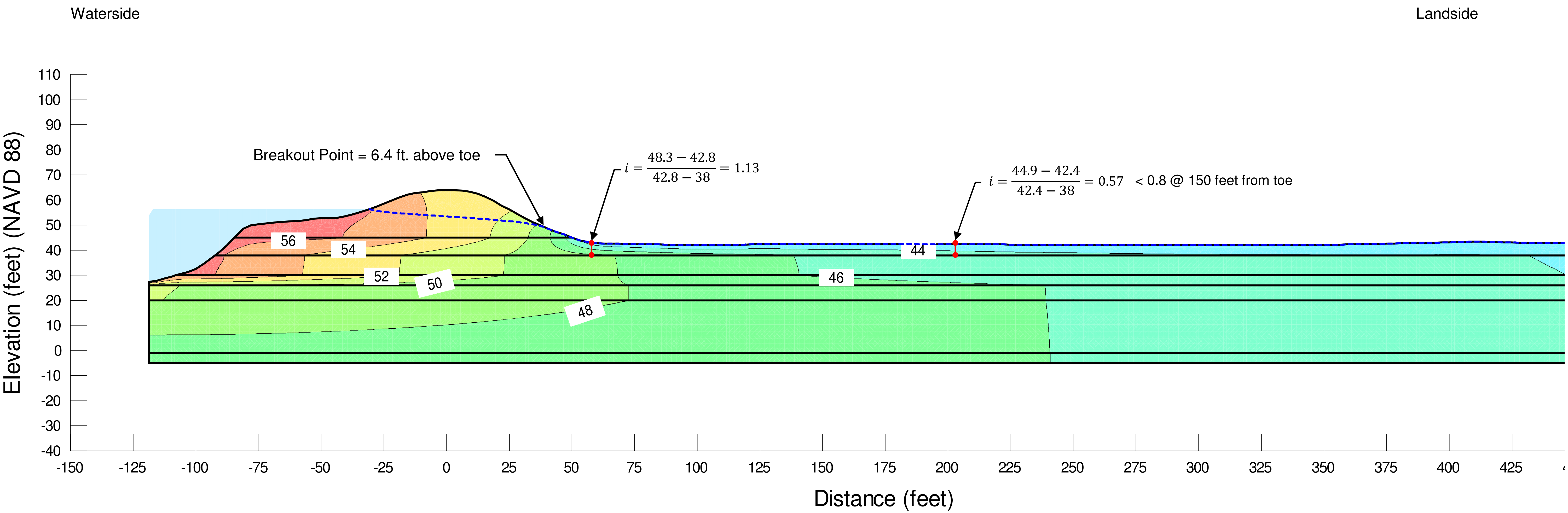
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Reach B (BR-L 1106+12) Seepage Model-100 year WSE

July 2019

FIGURE D-3



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

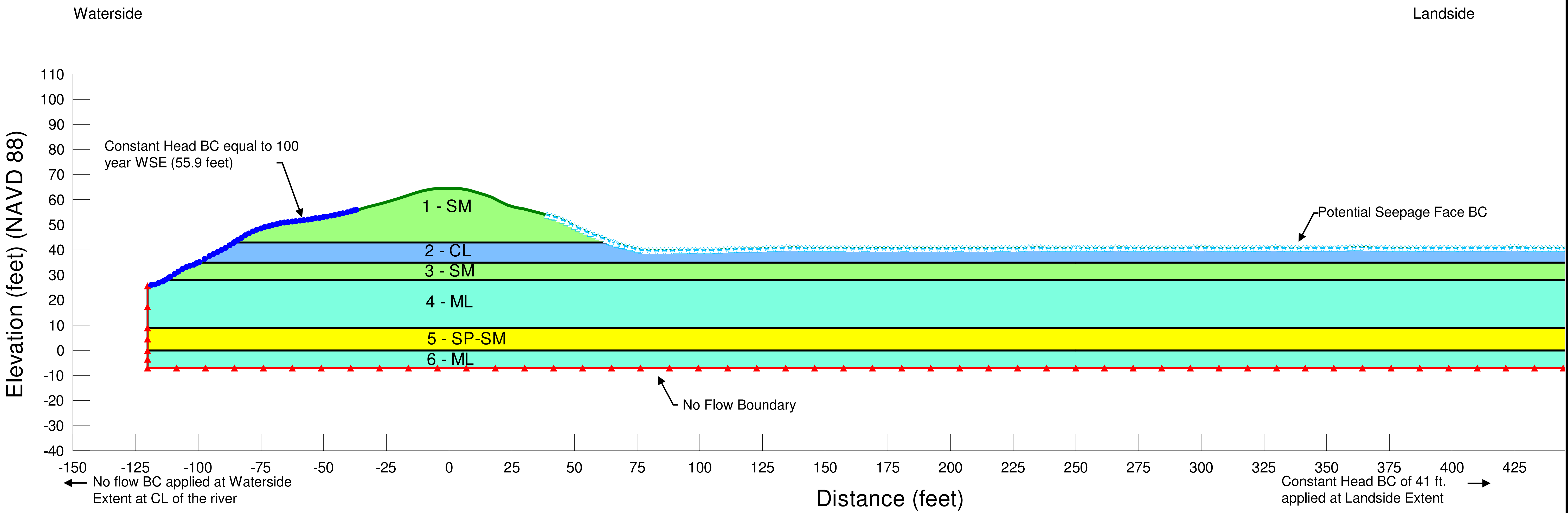
Reach B (BR-L 1106+12) Seepage Result-100 year WSE

July 2019

FIGURE D-4

Reach C (BR-L 1080+27)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	SM	2.834	1.0E-3	0.25
2	CL	0.028	1.0E-5	0.25
3	SM	2.834	1.0E-3	0.25
4	ML	0.028	1.0E-5	0.25
5	SP-SM	11.336	4.0E-3	0.25
6	ML	0.028	1.0E-5	0.25



NOTES:

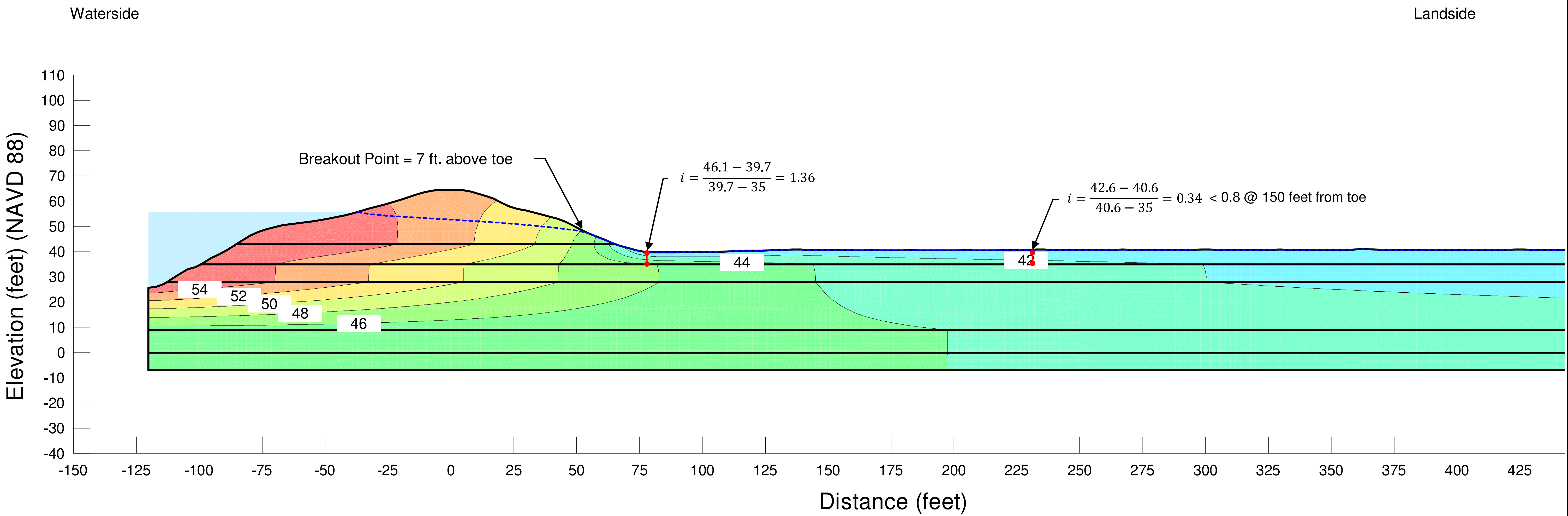
Rio Oso Flood Risk Reduction Feasibility Study

HDR

Reach C (BR-L 1080+27) Seepage Model-100 year WSE

July 2019

FIGURE D-5



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Reach C (BR-L 1080+27)
Seepage Result-100 year WSE

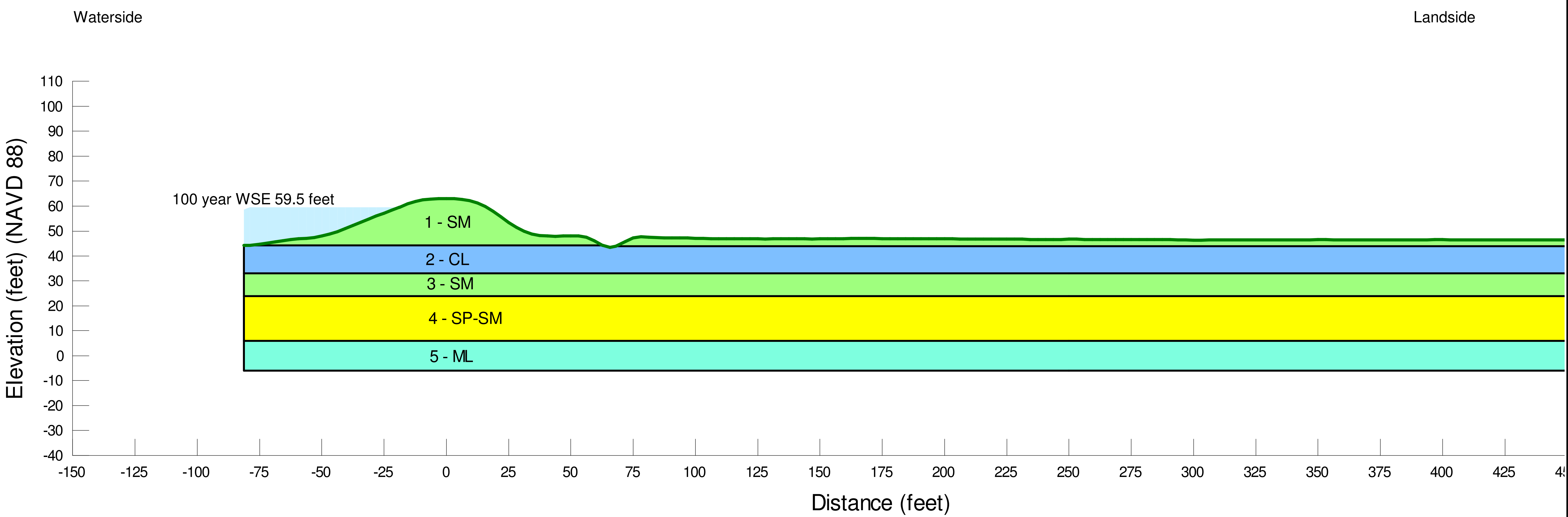
July 2019

FIGURE D-6

Appendix E – Stability Analysis

Reach A (YS-L 1030+60)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**SP-SM**	125	0	34	-	-
5	**ML**	120	50	31	360	4



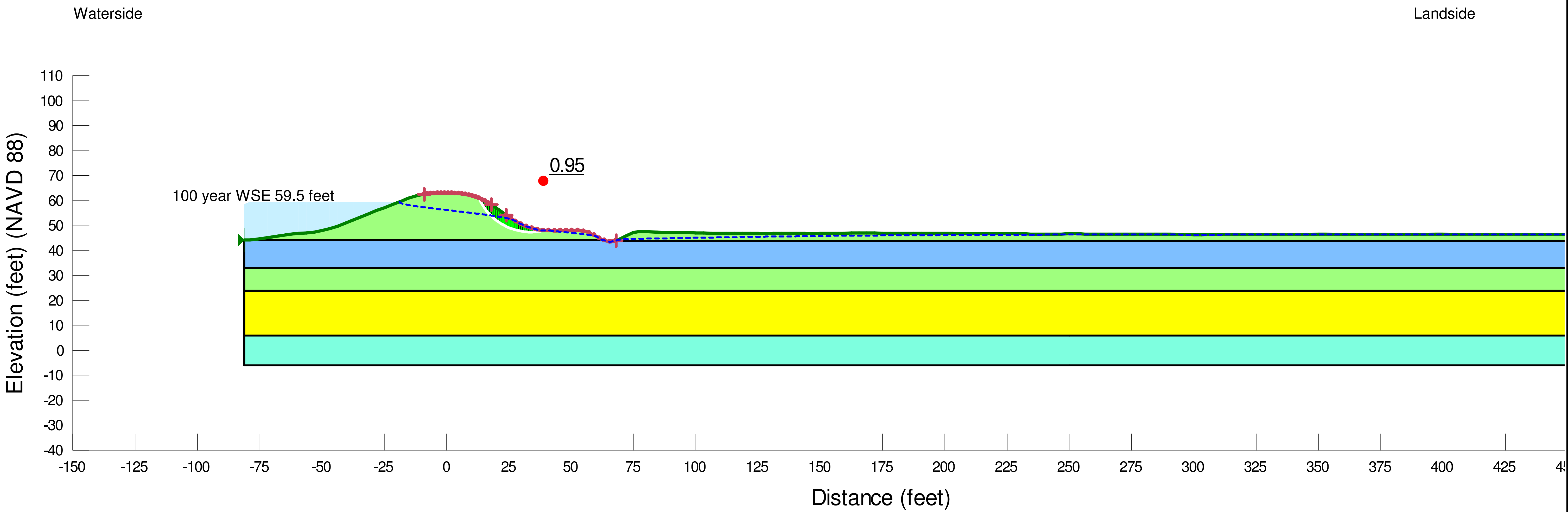
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Reach A (YS-L 1030+60)
Slope Stability Model

July 2019

FIGURE E-1



NOTES:

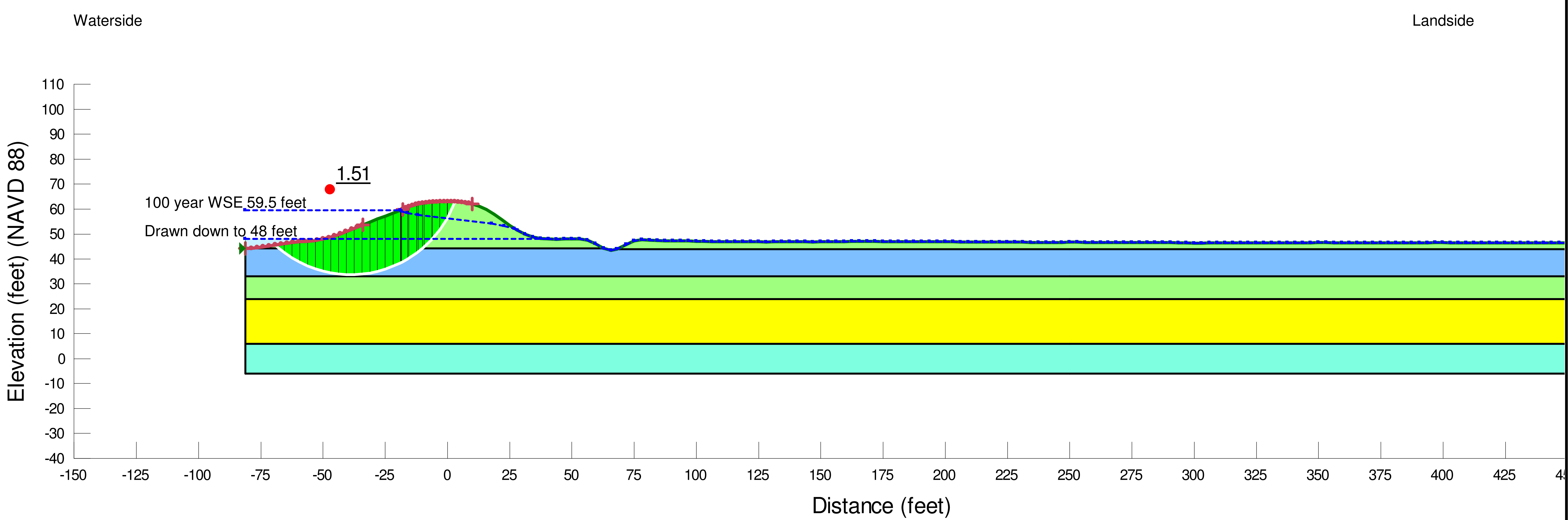
Rio Oso Flood Risk Reduction Feasibility Study

Reach A (YS-L 1030+60)

Slope Stability Result-Steady State Landside-100 year WSE

July 2019

FIGURE E-2



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

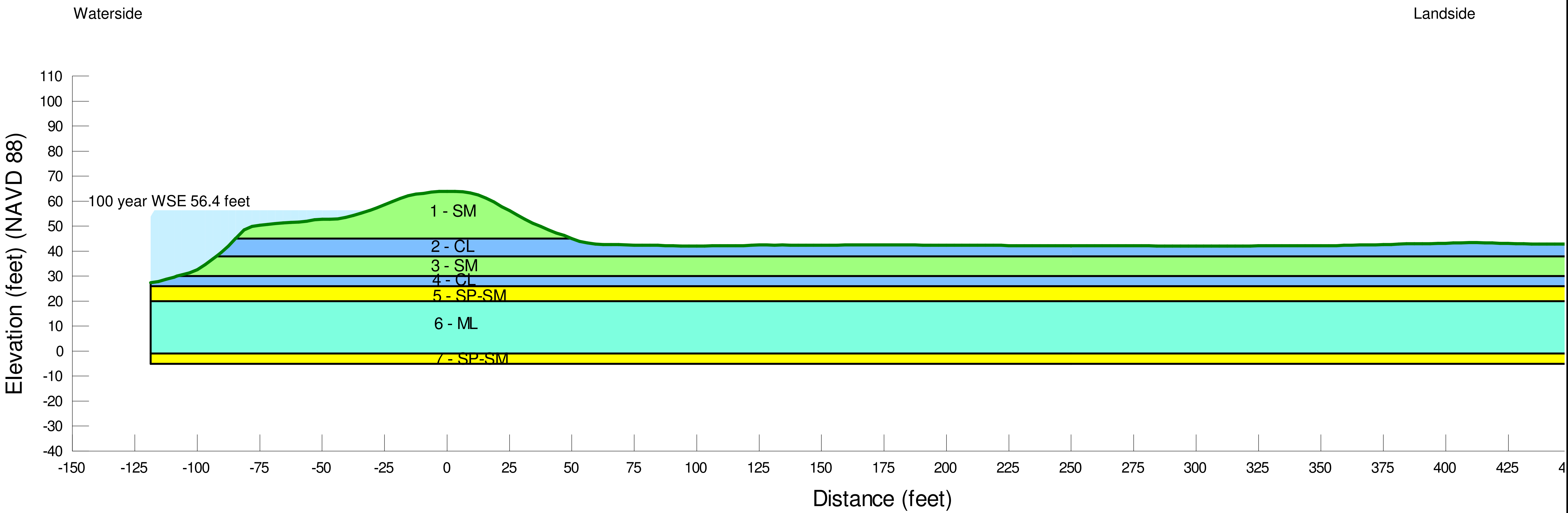
Reach A (YS-L 1030+60)
Slope Stability Result-Waterside RDD-100 year WSE

July 2019

FIGURE E-3

Reach B (BR-L 1106+12)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**CL**	120	100	31	360	4
5	**SP-SM**	125	0	34	-	-
6	**ML**	120	50	31	360	4
7	**SP-SM**	125	0	34	-	-



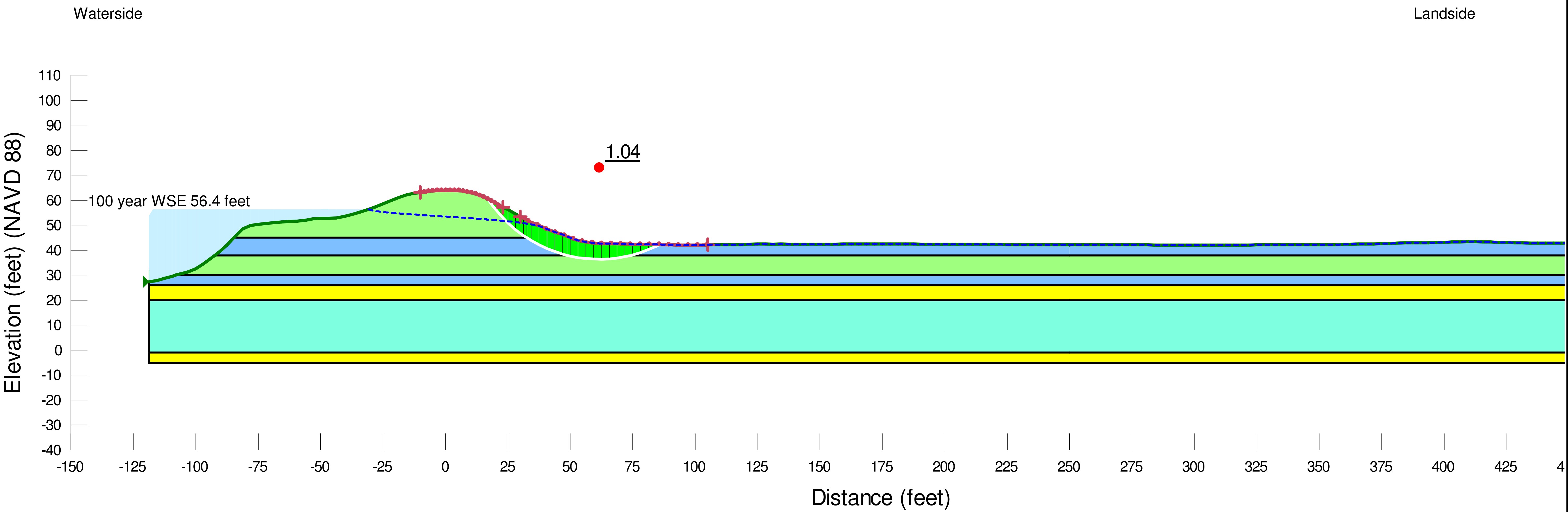
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Reach B (BR-L 1106+12)
Slope Stability Model

July 2019

FIGURE E-4



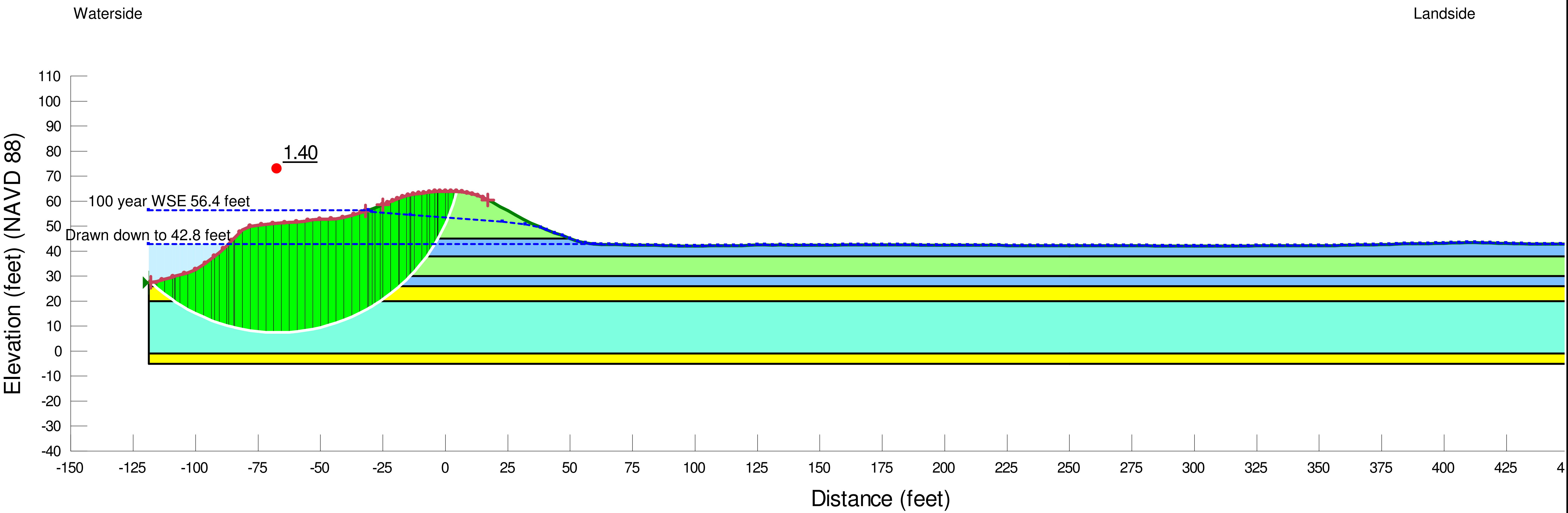
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Reach B (BR-L 1106+12)
Slope Stability Result-Steady State Landside-100 year WSE

July 2019

FIGURE E-5



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

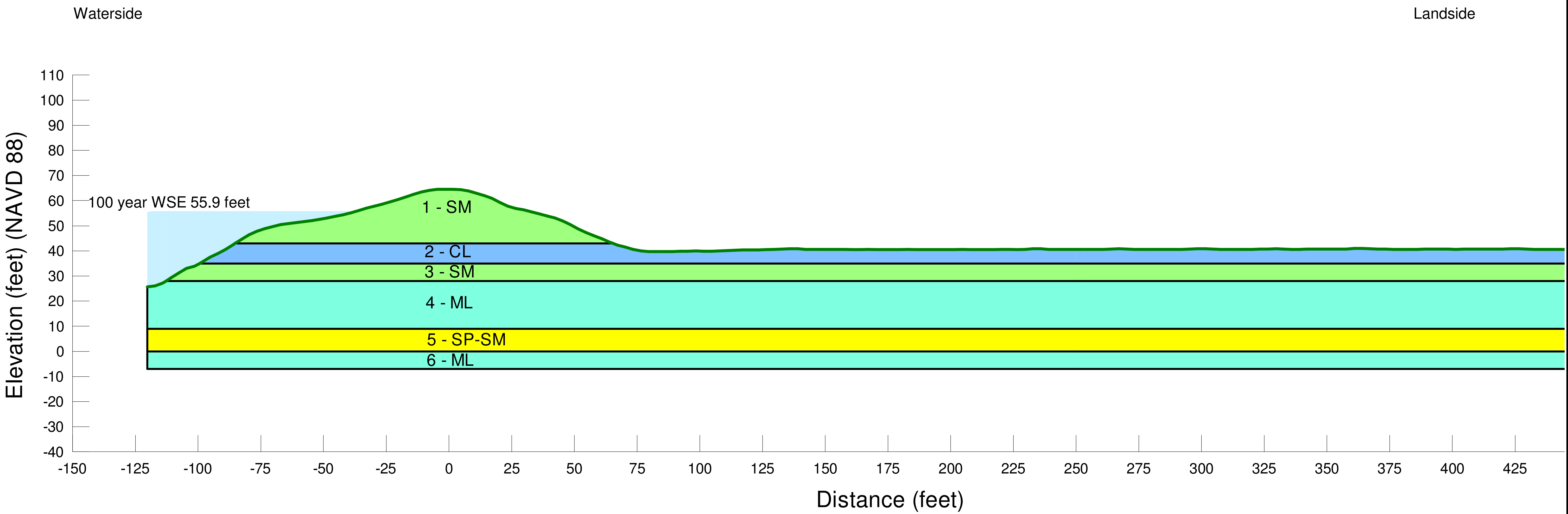
Reach B (BR-L 1106+12)
Slope Stability Result-
Waterside RDD-100 year WSE

July 2019

FIGURE E-6

Reach C (BR-L 1080+27)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**ML**	120	50	31	360	4
5	**SP-SM**	125	0	34	-	-
6	**ML**	120	50	31	360	4



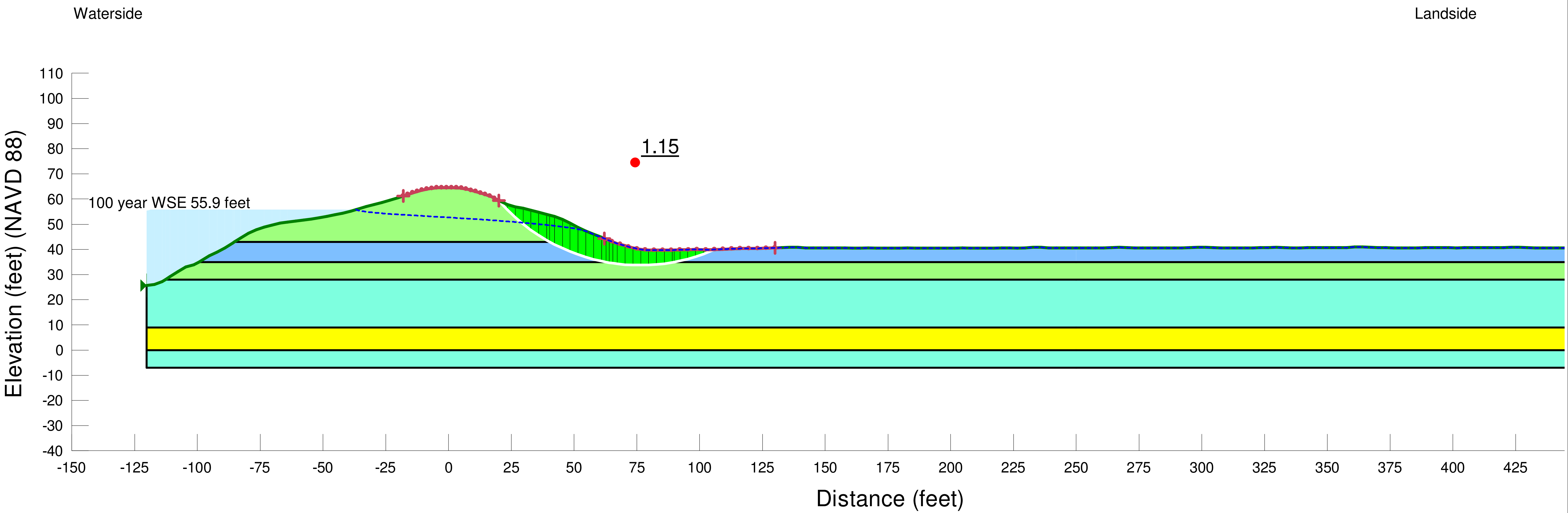
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

HDR

Reach C (BR-L 1080+27)
Slope Stability Model

July 2019 FIGURE E-7



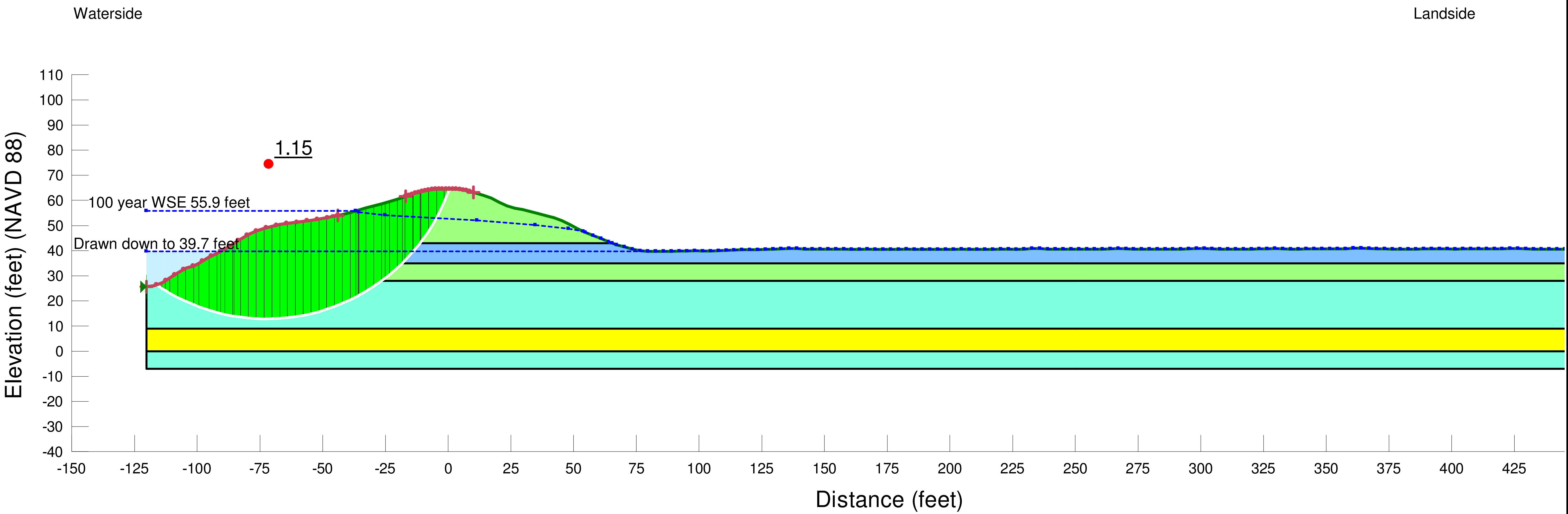
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Reach C (BR-L 1080+27)
Slope Stability Result-Steady State Landside-100 year WSE

July 2019

FIGURE E-8



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Reach C (BR-L 1080+27)
Slope Stability Result-Waterside RDD-100 year WSE

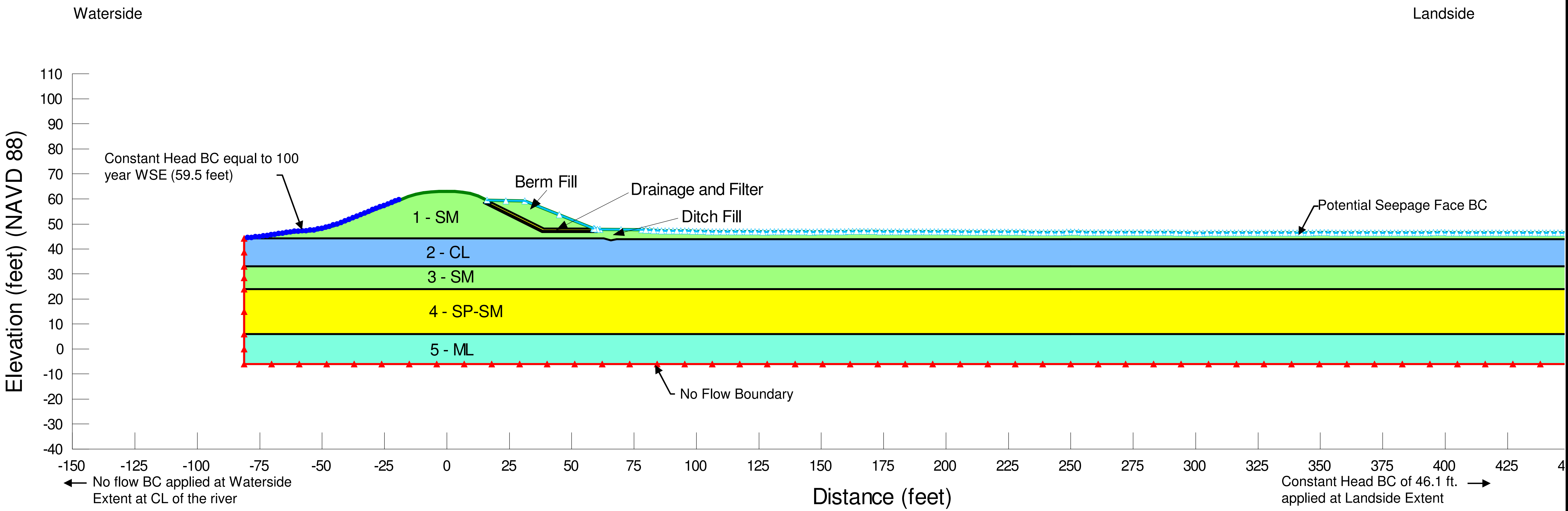
July 2019

FIGURE E-9

Appendix F – Remediation Alternatives Analysis

Reach A (YS-L 1030+60)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	SM	2.834	1.0E-3	0.25
2	CL	0.028	1.0E-5	0.25
3	SM	2.834	1.0E-3	0.25
4	SP-SM	11.336	4.0E-3	0.25
5	ML	0.028	1.0E-5	0.25
Berm Fill	SM	2.834	1.0E-3	0.25
Drain	SP	141.696	5.0E-2	1
Filter	SP	2.834	1.0E-3	1



NOTES:

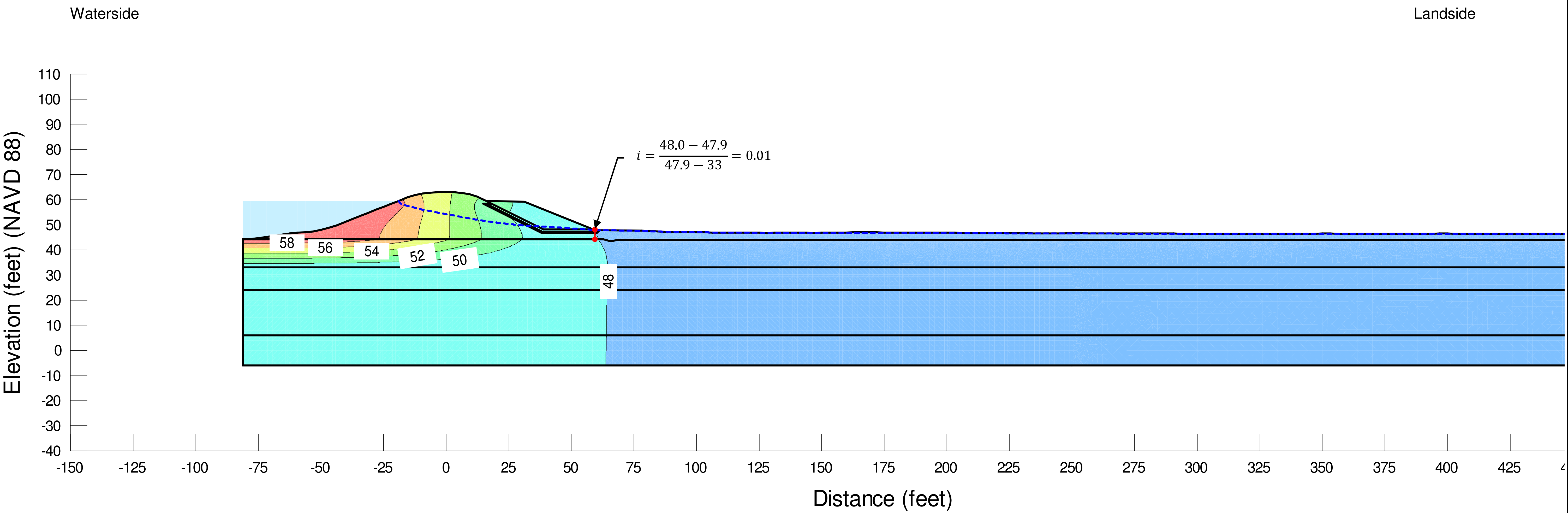
Rio Oso Flood Risk Reduction Feasibility Study

HDR

Segment 145 Reach A (YS-L 1030+60) Stability Berm Seepage Model-100 year WSE

Aug 2019

FIGURE F-1



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

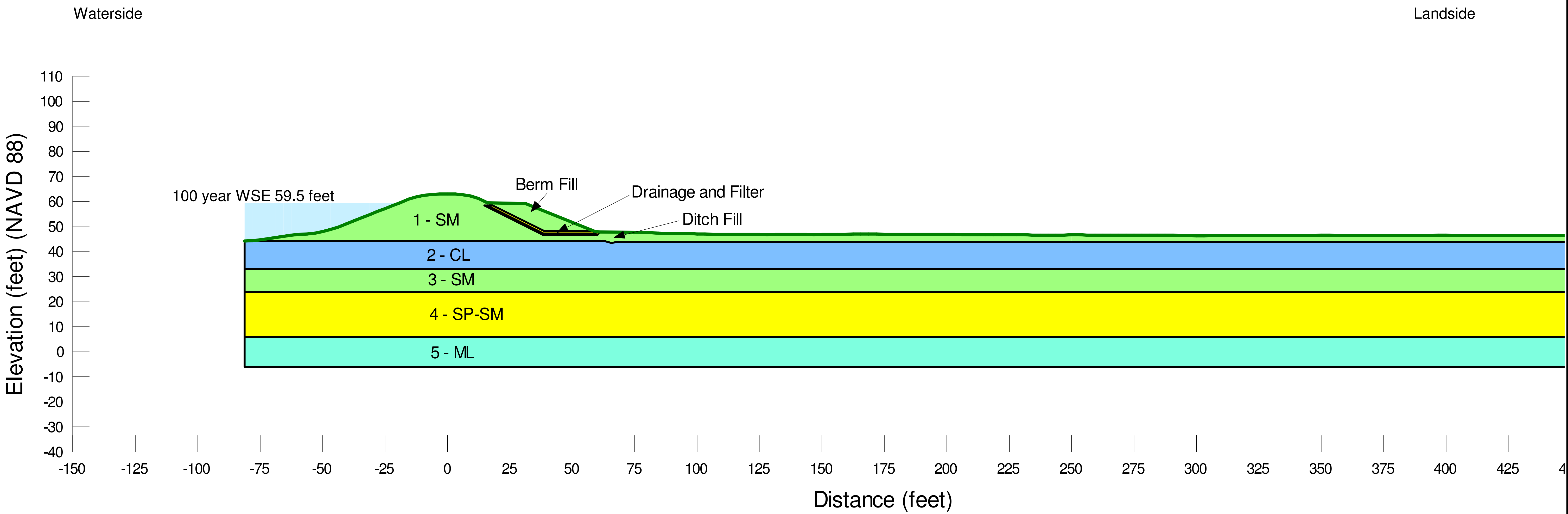
Segment 145 Reach A (YS-L 1030+60) Stability Berm Seepage Result-100 year WSE

Aug 2019

FIGURE F-2

Reach A (YS-L 1030+60)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**SP-SM**	125	0	34	-	-
5	**ML**	120	50	31	360	4
Berm Fill	**SM**	120	0	34	-	-
Drain	**SP**	130	0	34	-	-
Filter	**SP**	130	0	32	-	-



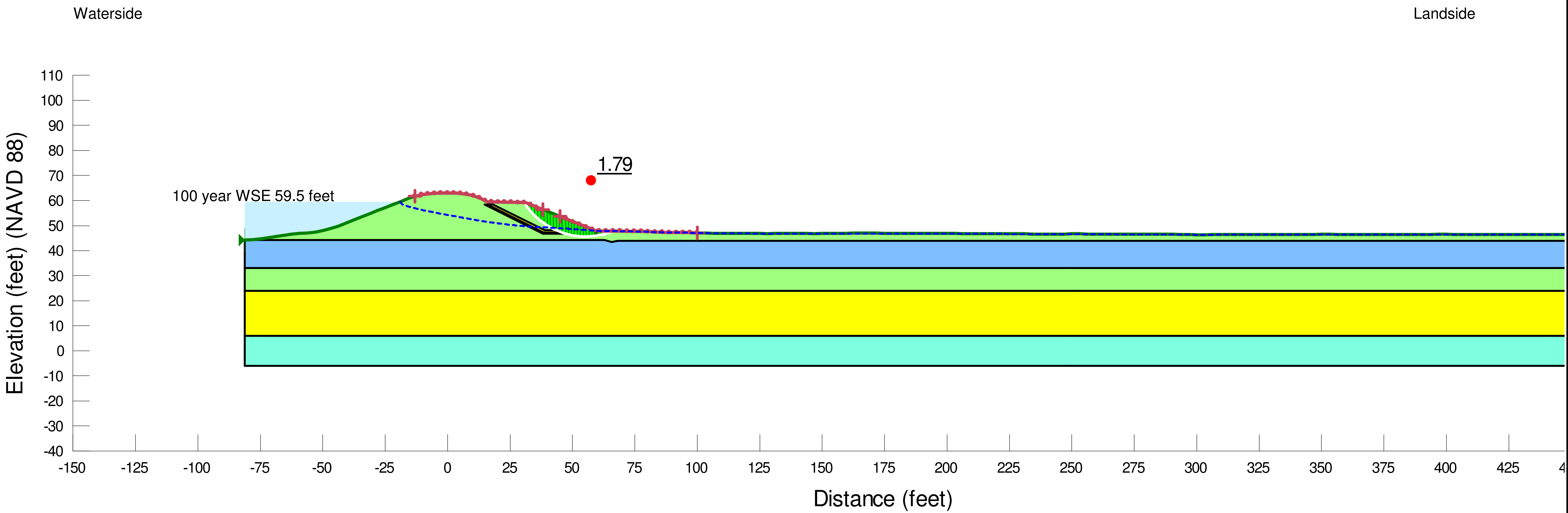
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 145 Reach A (YS-L 1030+60) Stability Berm Slope Stability Model

Aug 2019

FIGURE F-3



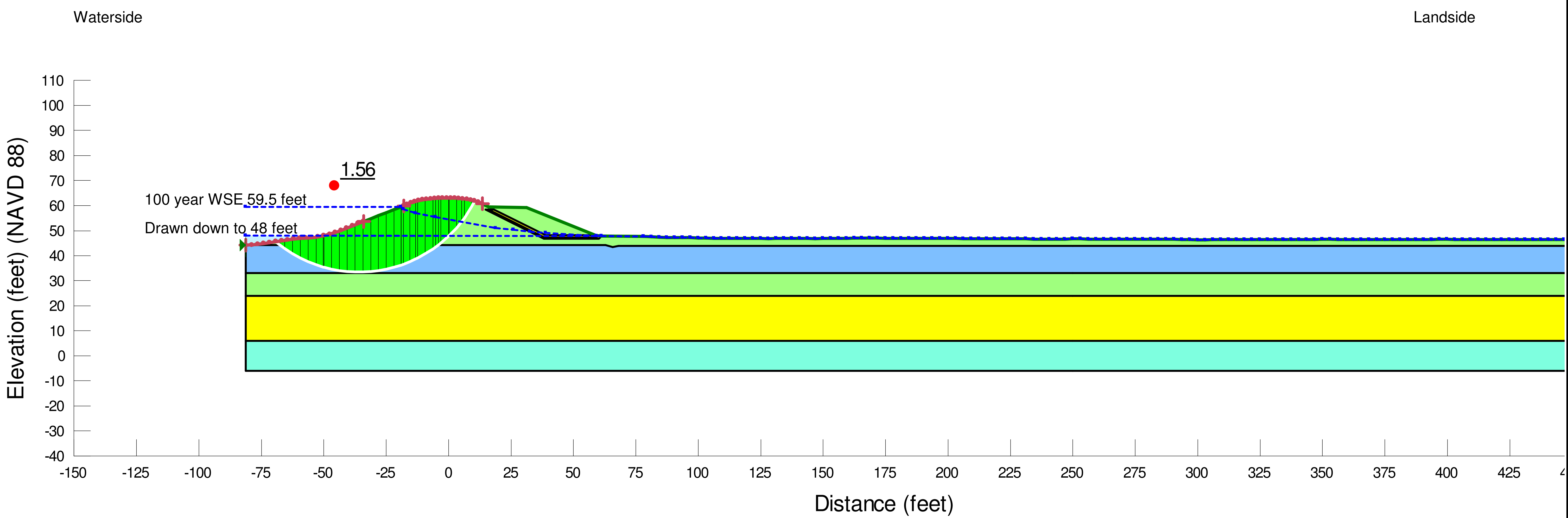
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 145 Reach A (YS-L 1030+60) Stability Berm Slope Stability Result-Steady State Landside-100 year WSE

Aug 2019

FIGURE F-4



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

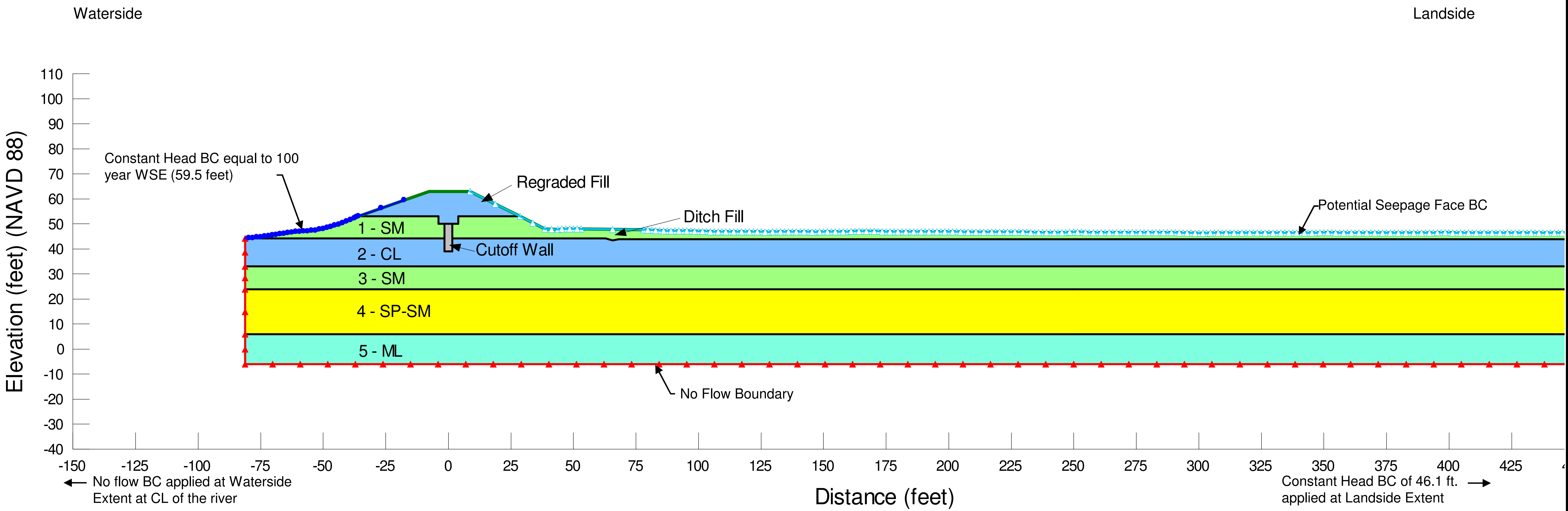
Segment 145 Reach A (YS-L 1030+60) Stability Berm Slope Stability Result-Waterside RDD-100 year WSE

Aug 2019

FIGURE F-5

Reach A (YS-L 1030+60)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	**SM**	2.834	1.0E-3	0.25
2	**CL**	0.028	1.0E-5	0.25
3	**SM**	2.834	1.0E-3	0.25
4	**SP-SM**	11.336	4.0E-3	0.25
5	**ML**	0.028	1.0E-5	0.25
Regraded Fill	**CL**	0.00283	1.0E-6	0.25
Cutoff Wall	**SCB**	0.000283	1.0E-7	1



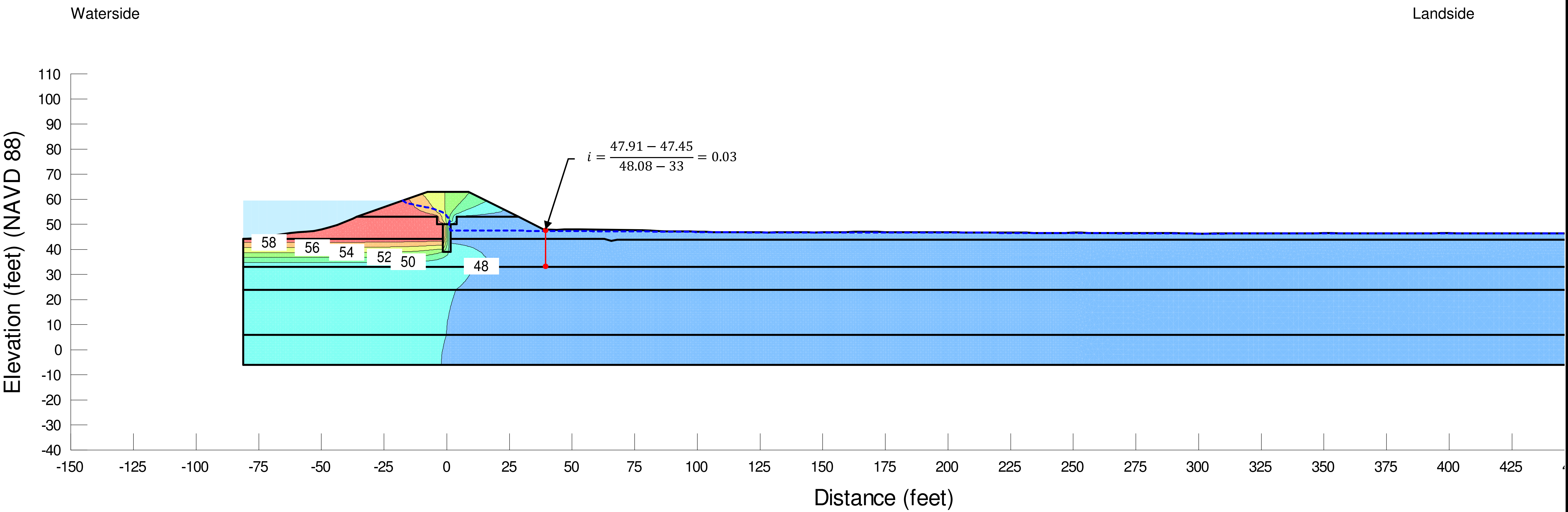
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 145 Reach A (YS-L 1030+60) Cutoff Wall Half Levee Degrade Seepage Model-100 year WSE

Aug 2019

FIGURE F-6



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

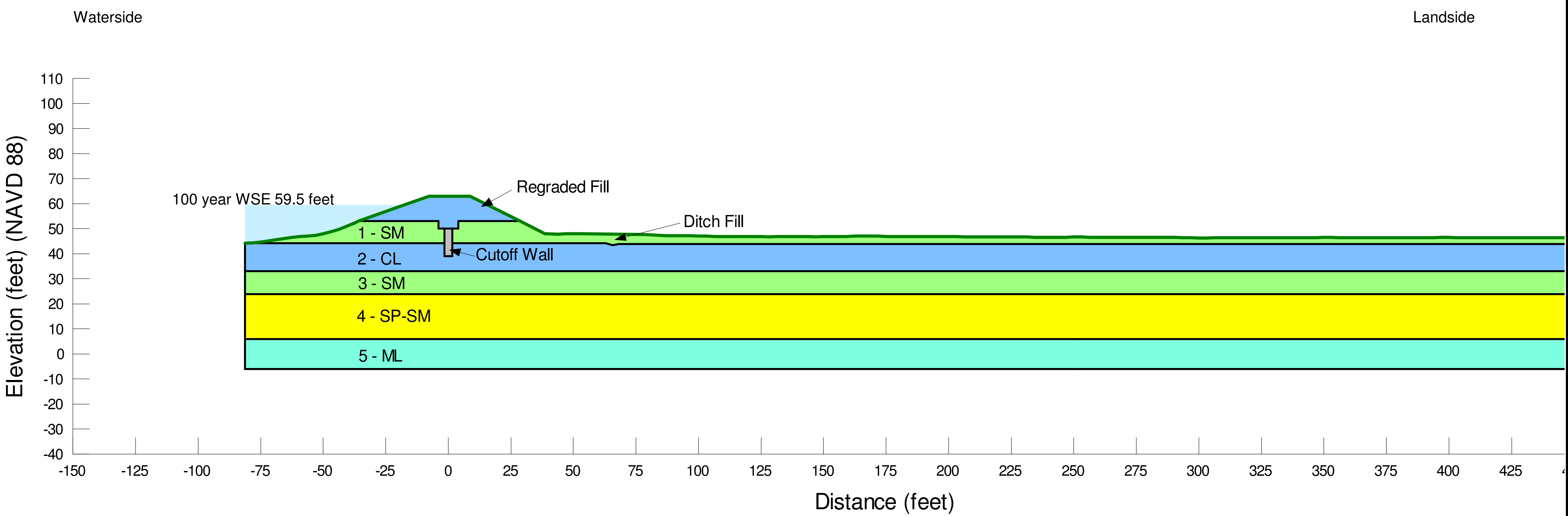
Segment 145 Reach A (YS-L 1030+60) Cutoff Wall Half Levee Degrade Seepage Result-100 year WSE

Aug 2019

FIGURE F-7

Reach A (YS-L 1030+60)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**SP-SM**	125	0	34	-	-
5	**ML**	120	50	31	360	4
Regraded Fill	**CL**	125	100	31	360	4
Cutoff Wall	**SCB**	120	500	0	500	0



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

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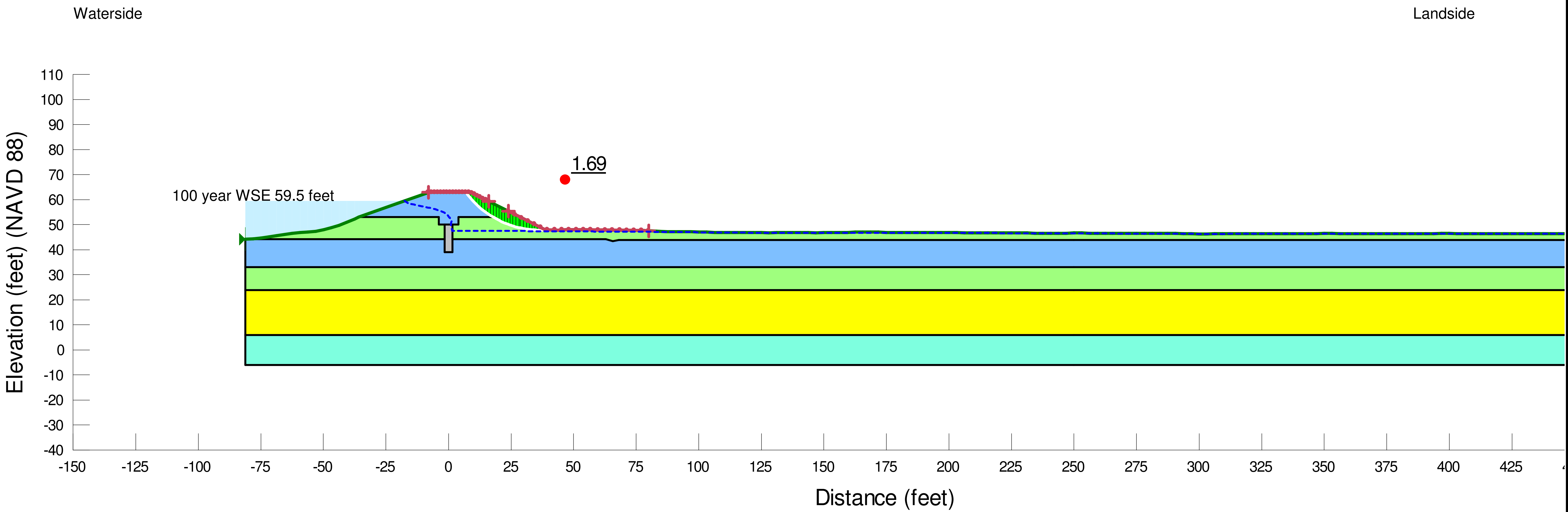
Segment 145 Reach A (YS-L 1030+60) Cutoff Wall Half Levee Degrade Slope Stability Model

Aug 2019

FIGURE F-8



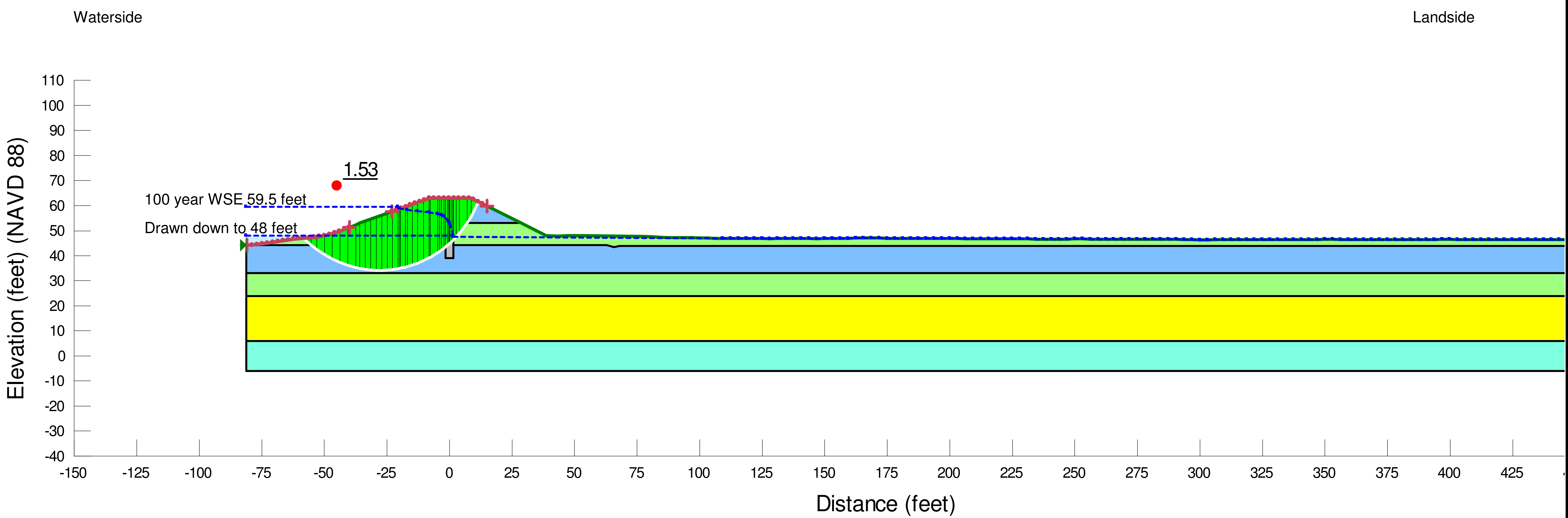
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 145 Reach A (YS-L 1030+60) Cutoff Wall Half Levee Degrade Slope Stability Result-Steady State Landside-100 year WSE

Aug 2019

FIGURE F-9



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

HDR

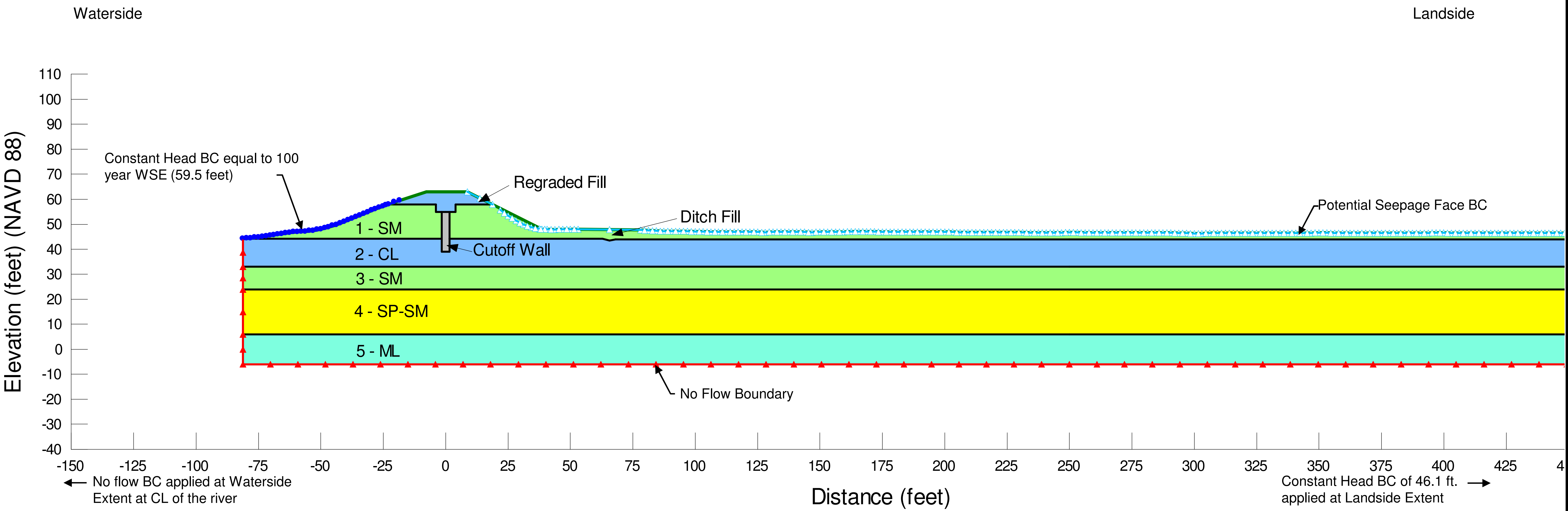
Segment 145 Reach A (YS-L 1030+60) Cutoff Wall Half Levee Degrade Slope Stability Result-Waterside RDD-100 year WSE

Aug 2019

FIGURE F-10

Reach A (YS-L 1030+60)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	SM	2.834	1.0E-3	0.25
2	CL	0.028	1.0E-5	0.25
3	SM	2.834	1.0E-3	0.25
4	SP-SM	11.336	4.0E-3	0.25
5	ML	0.028	1.0E-5	0.25
Regraded Fill	CL	0.00283	1.0E-6	0.25
Cutoff Wall	SCB	0.000283	1.0E-7	1



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

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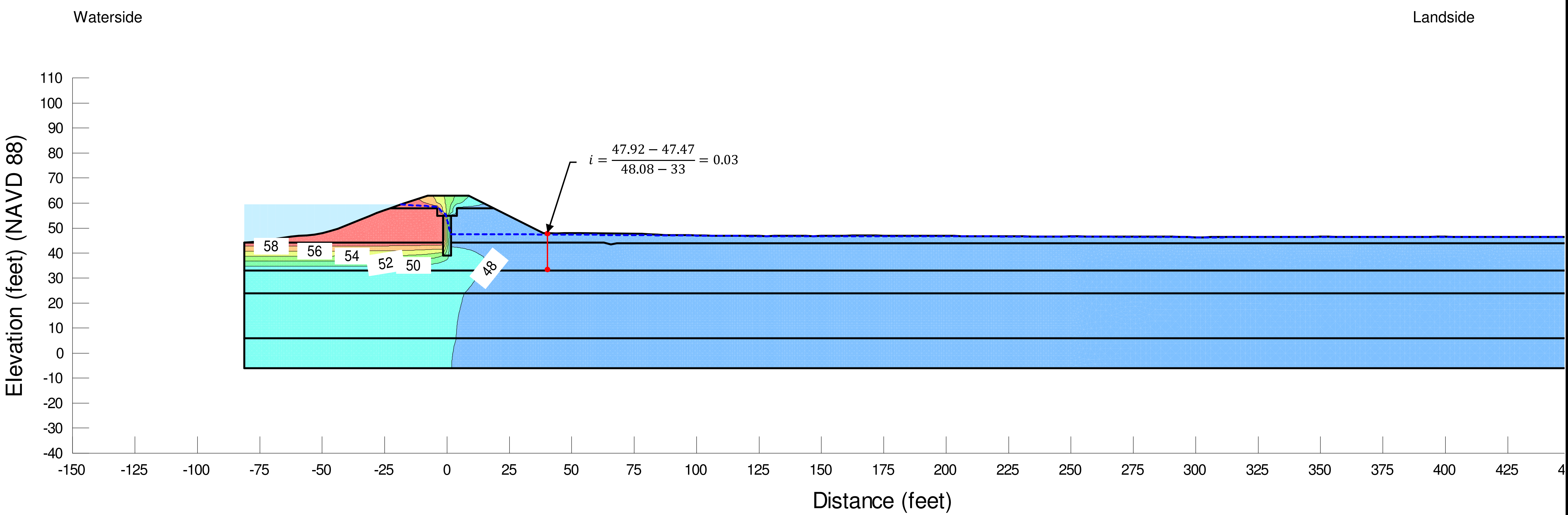
Segment 145 Reach A (YS-L 1030+60) Cutoff Wall Third Levee Degrade Seepage Model-100 year WSE

Aug 2019

FIGURE F-11



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

HDR

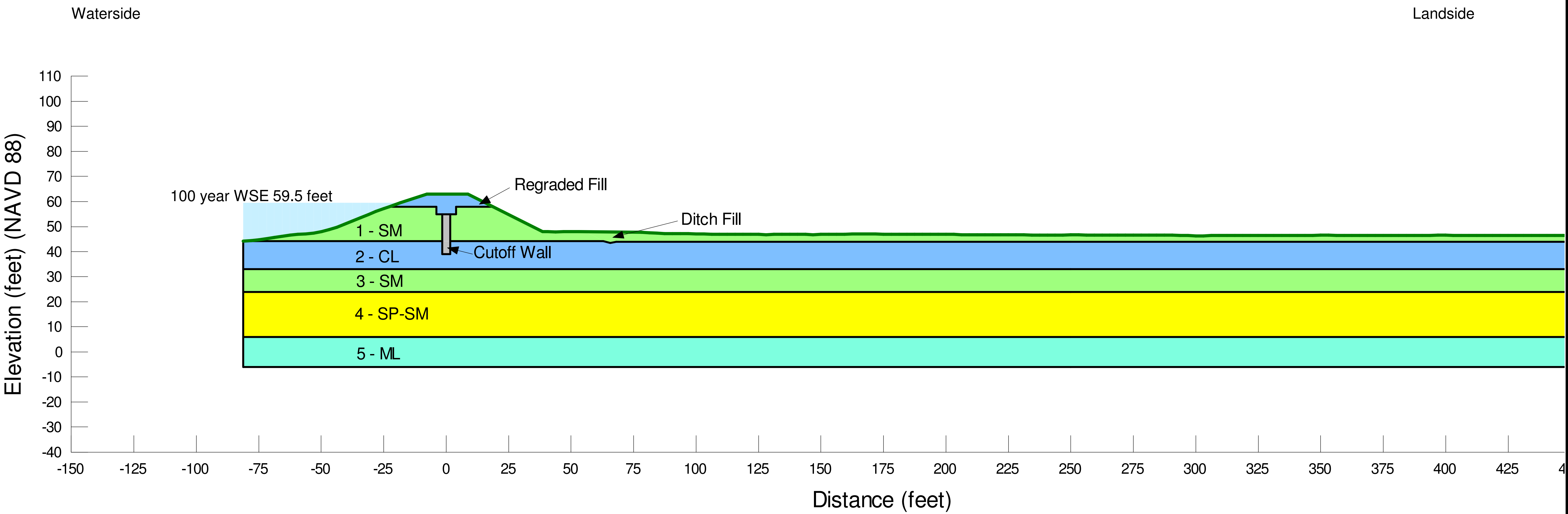
Segment 145 Reach A (YS-L 1030+60) Cutoff Wall Third Levee Degrade Seepage Result-100 year WSE

Aug 2019

FIGURE F-12

Reach A (YS-L 1030+60)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**SP-SM**	125	0	34	-	-
5	**ML**	120	50	31	360	4
Regraded Fill	**CL**	125	100	31	360	4
Cutoff Wall	**SCB**	120	500	0	500	0



NOTES:

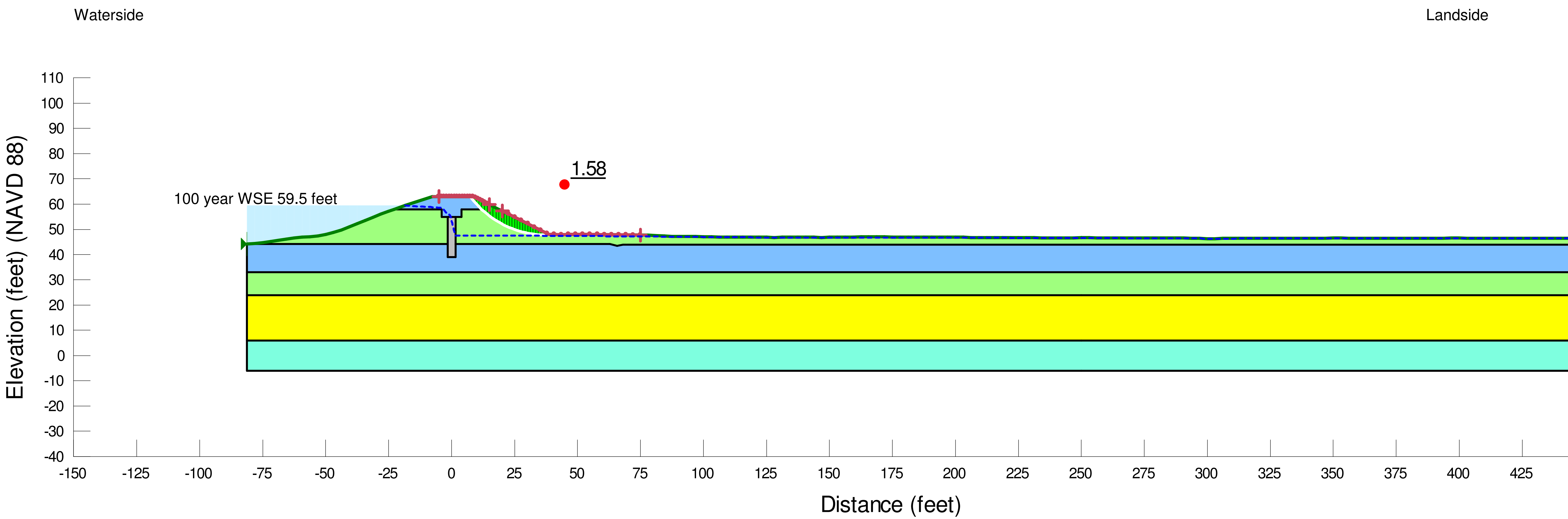
Rio Oso Flood Risk Reduction Feasibility Study

HDR

Segment 145 Reach A (YS-L 1030+60) Cutoff Wall Third Levee Degrade Slope Stability Model

Aug 2019

FIGURE F-13



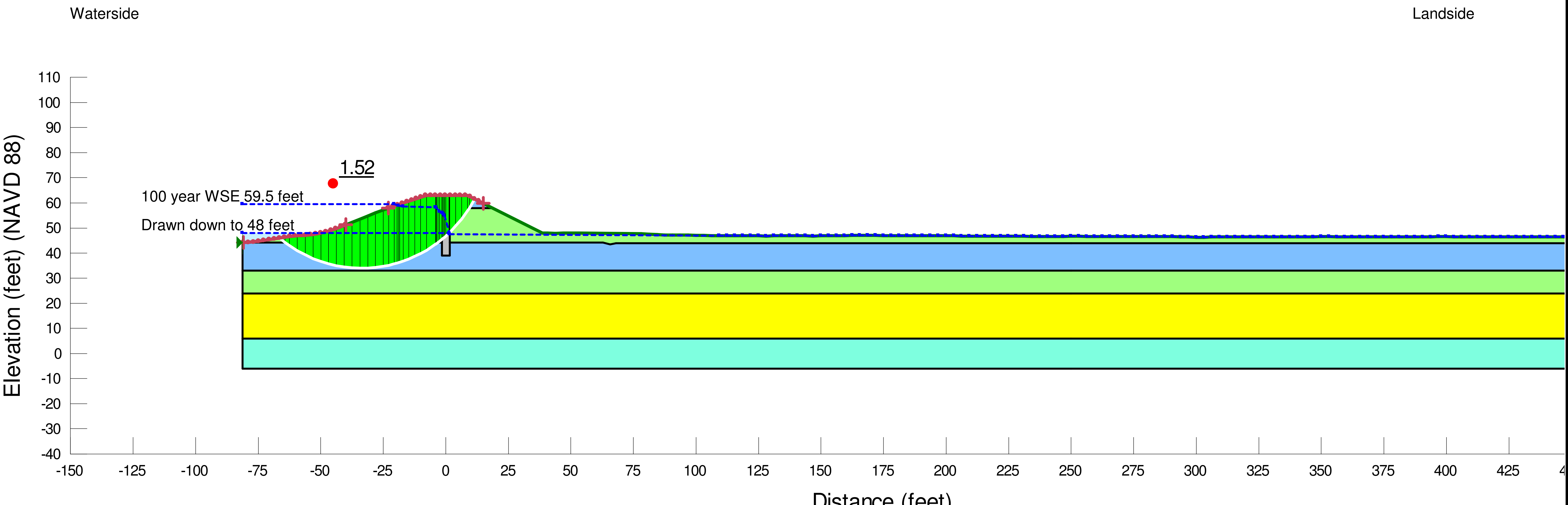
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 145 Reach A (YS-L 1030+60) Cutoff Wall Third Levee Degrade Slope Stability Result-Steady State Landside-100 year WSE

Aug 2019

FIGURE F-14



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

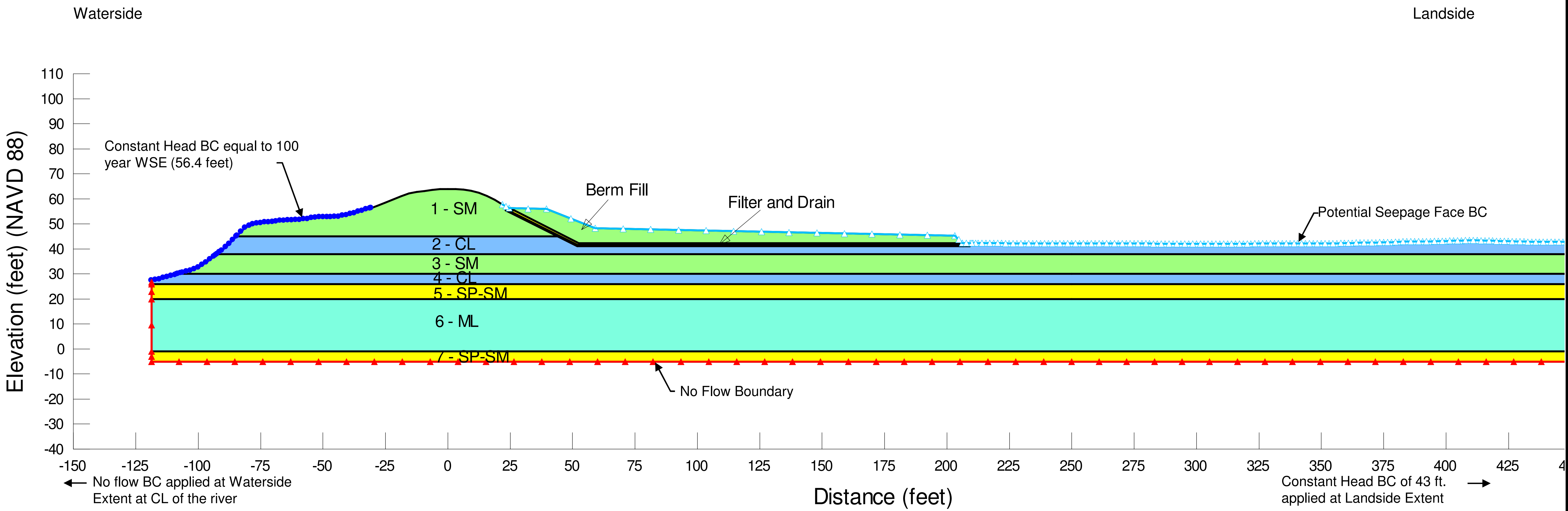
Segment 145 Reach A (YS-L 1030+60) Cutoff Wall Third Levee Degrade Slope Stability Result-Waterside RDD-100 year WSE

Aug 2019

FIGURE F-15

Reach B (BR-L 1106+12)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	**SM**	2.834	1.0E-3	0.25
2	**CL**	0.028	1.0E-5	0.25
3	**SM**	2.834	1.0E-3	0.25
4	**CL**	0.028	1.0E-5	0.25
5	**SP-SM**	11.336	4.0E-3	0.25
6	**ML**	0.028	1.0E-5	0.25
7	**SP-SM**	11.336	4.0E-3	0.25
Berm Fill	**SM**	2.834	1.0E-3	0.25
Drain	**SP**	141.696	5.0E-2	1
Filter	**SP**	2.834	1.0E-3	1



NOTES:

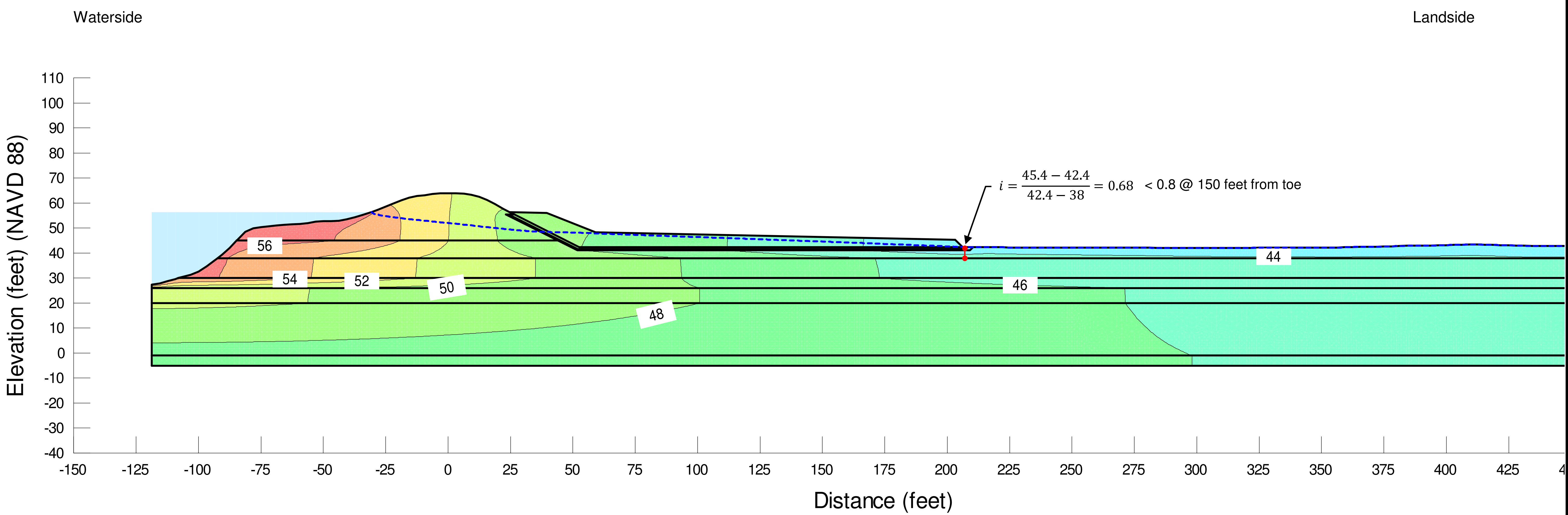
Rio Oso Flood Risk Reduction Feasibility Study

HDR

Segment 283 Reach B (BR-L 1106+12) Combined Berm Seepage Model-100 year WSE

Aug 2019

FIGURE F-16



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

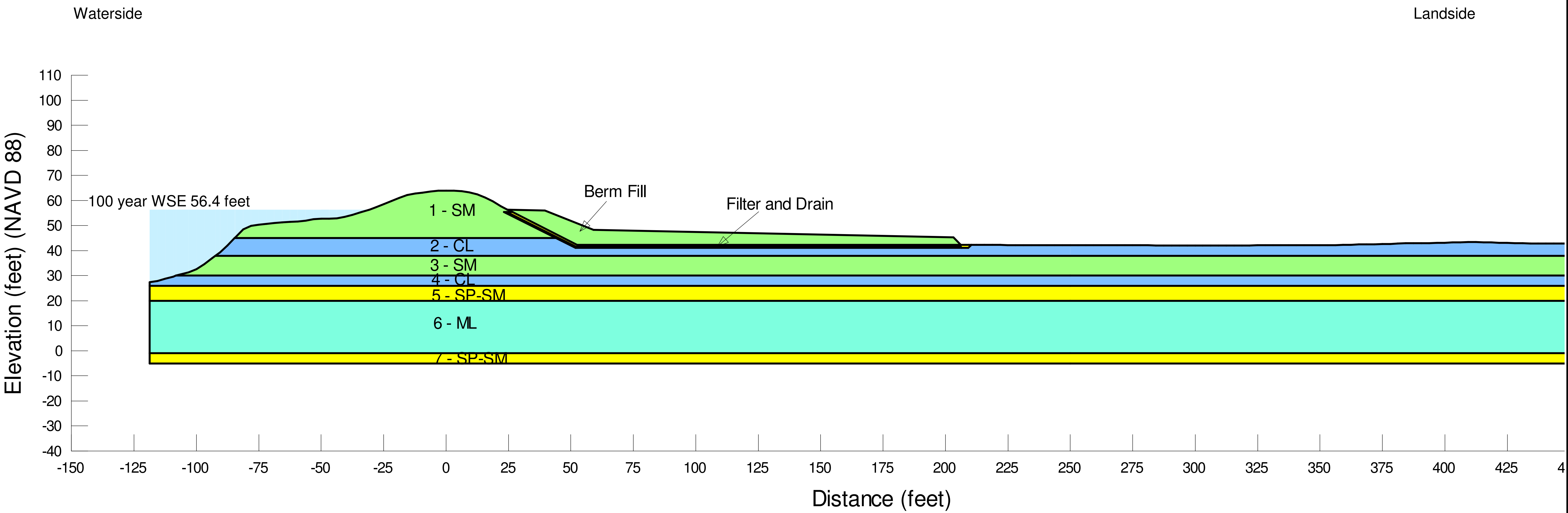
Segment 283 Reach B (BR-L 1106+12) Combined Berm Seepage Result-100 year WSE

Aug 2019

FIGURE F-17

Reach B (BR-L 1106+12)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**CL**	120	100	31	360	4
5	**SP-SM**	125	0	34	-	-
6	**ML**	120	50	31	360	4
7	**SP-SM**	125	0	34	-	-
Berm Fill	**SM**	120	0	34	-	-
Drain	**SP**	130	0	34	-	-
Filter	**SP**	130	0	32	-	-



NOTES:

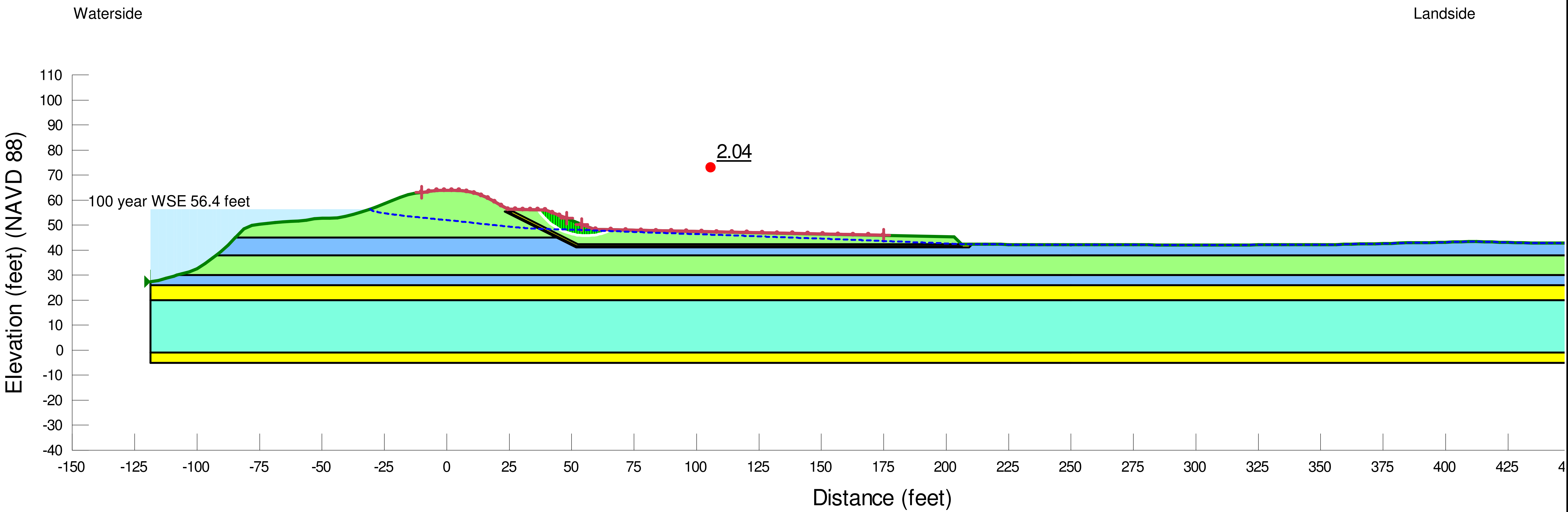
Rio Oso Flood Risk Reduction Feasibility Study

HDR

Segment 283 Reach B (BR-L 1106+12) Combined Berm Slope Stability Model

Aug 2019

FIGURE F-18



NOTES:

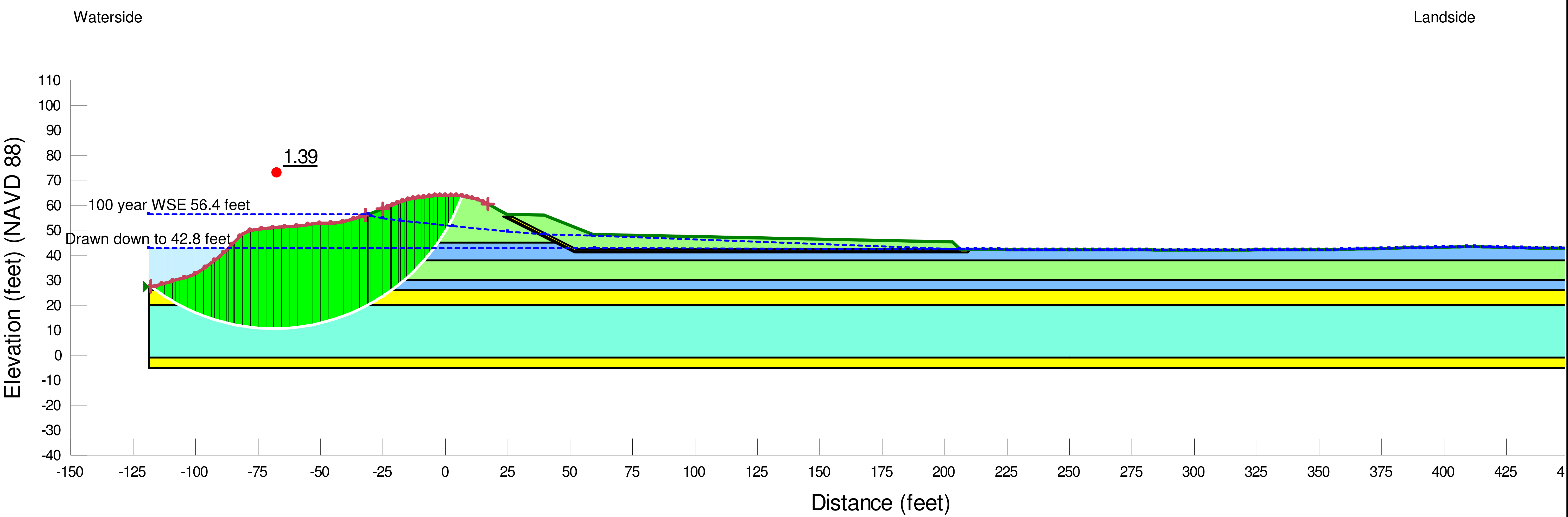
Rio Oso Flood Risk Reduction Feasibility Study

HDR

Segment 283 Reach B (BR-L 1106+12) Combined Berm Slope Stability Result-Steady State Landside-100 year WSE

Aug 2019

FIGURE F-19



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

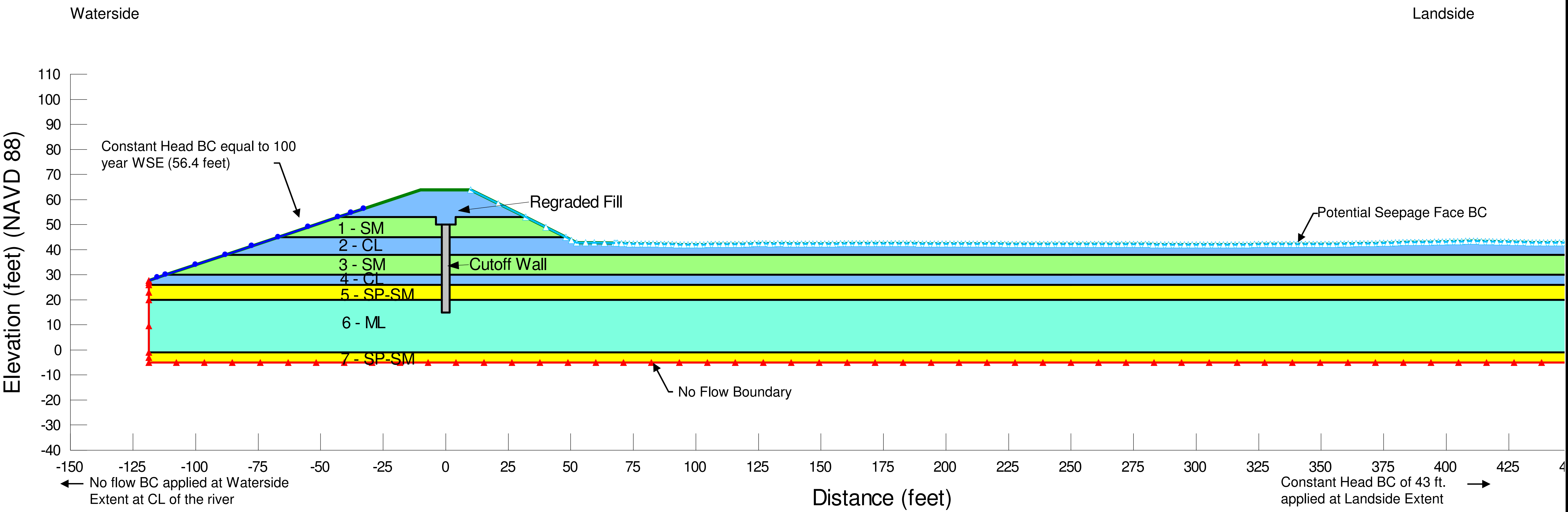
Segment 283 Reach B (BR-L 1106+12) Combined Berm Slope Stability Result- Waterside RDD-100 year WSE

Aug 2019

FIGURE F-20

Reach B (BR-L 1106+12)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	**SM**	2.834	1.0E-3	0.25
2	**CL**	0.028	1.0E-5	0.25
3	**SM**	2.834	1.0E-3	0.25
4	**CL**	0.028	1.0E-5	0.25
5	**SP-SM**	11.336	4.0E-3	0.25
6	**ML**	0.028	1.0E-5	0.25
7	**SP-SM**	11.336	4.0E-3	0.25
Regraded Fill	**CL**	0.00283	1.0E-6	0.25
Cutoff Wall	**SCB**	0.000283	1.0E-7	1



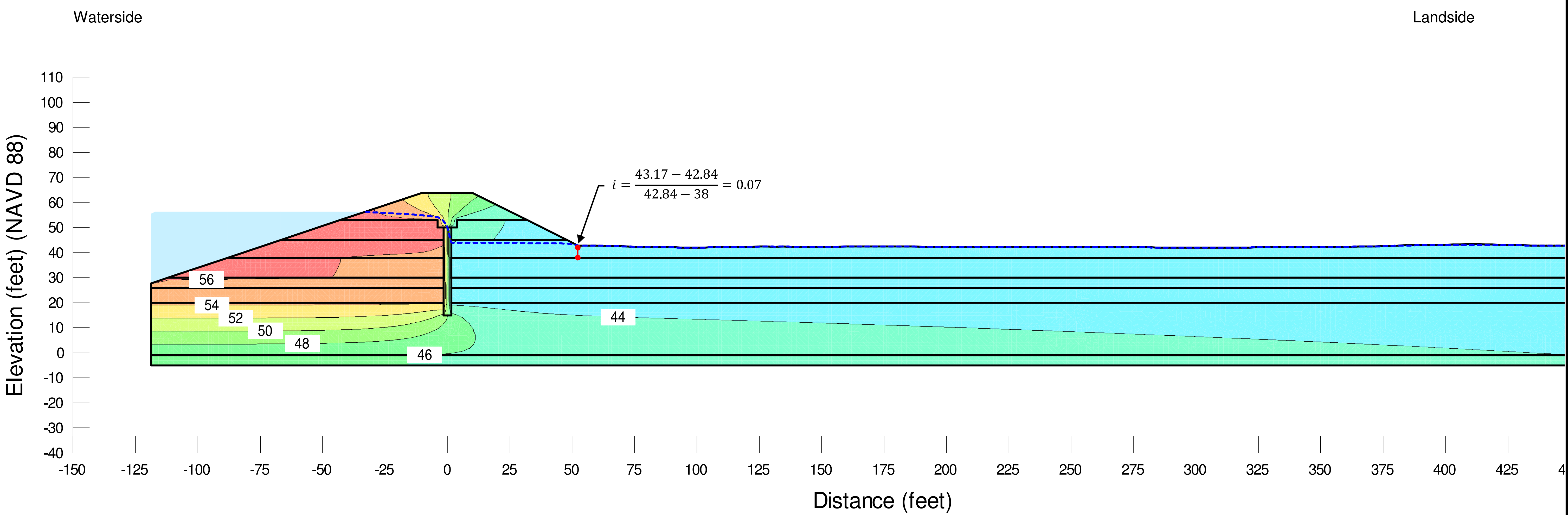
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 283 Reach B (BR-L 1106+12) Cutoff Wall Half Levee Degrade Seepage Model-100 year WSE

Aug 2019

FIGURE F-21



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

HDR

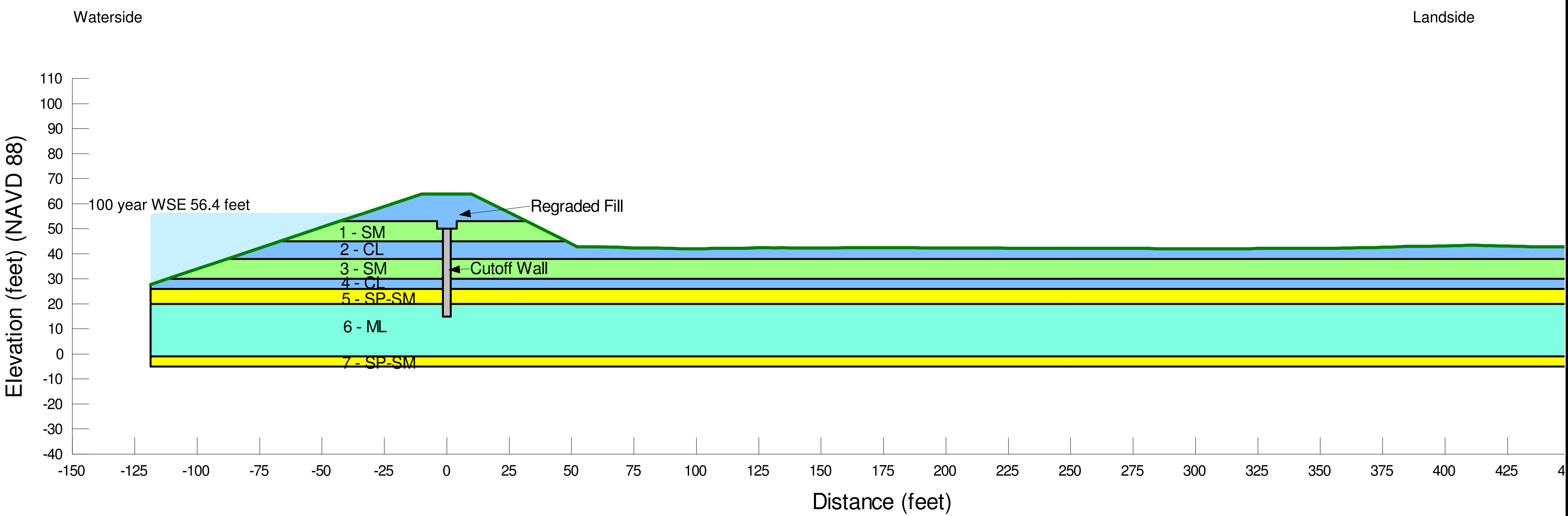
Segment 283 Reach B (BR-L 1106+12) Cutoff Wall Half Levee Degrade Seepage Result-100 year WSE

Aug 2019

FIGURE F-22

Reach B (BR-L 1106+12)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**CL**	120	100	31	360	4
5	**SP-SM**	125	0	34	-	-
6	**ML**	120	50	31	360	4
7	**SP-SM**	125	0	34	-	-
Regraded Fill	**CL**	125	100	31	360	4
Cutoff Wall	**SCB**	120	500	0	500	0



NOTES:

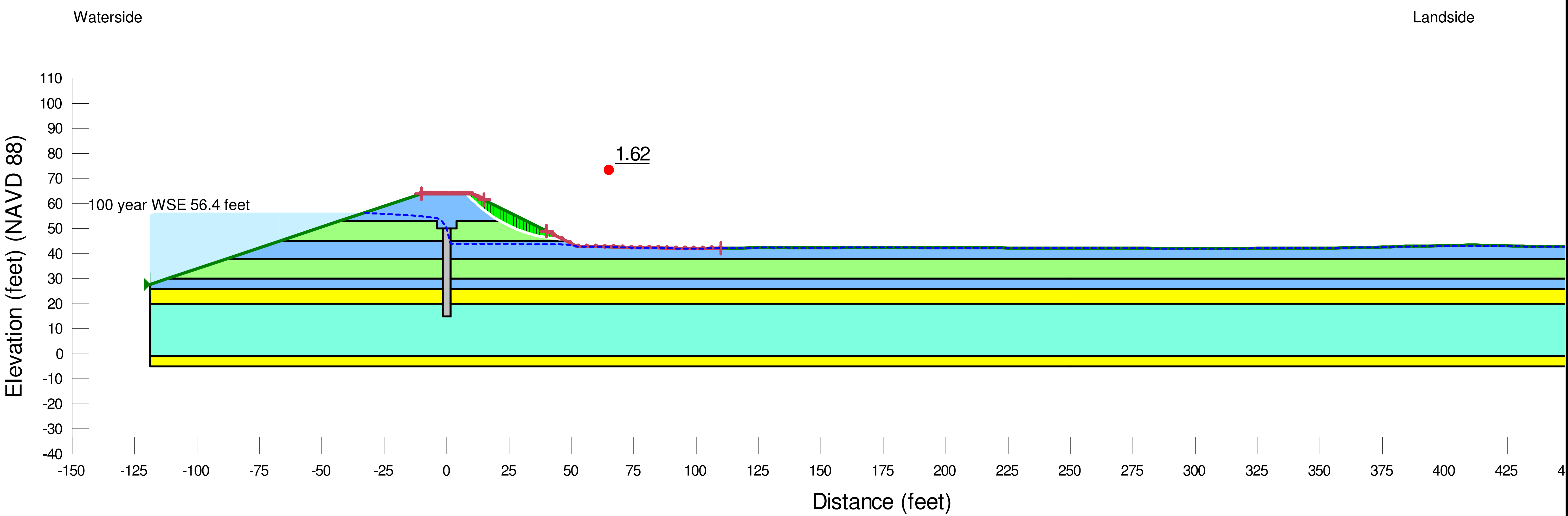
Rio Oso Flood Risk Reduction Feasibility Study

HDR

Segment 283 Reach B (BR-L 1106+12) Cutoff Wall Half Levee Degrade Slope Stability Model

Aug 2019

FIGURE F-23



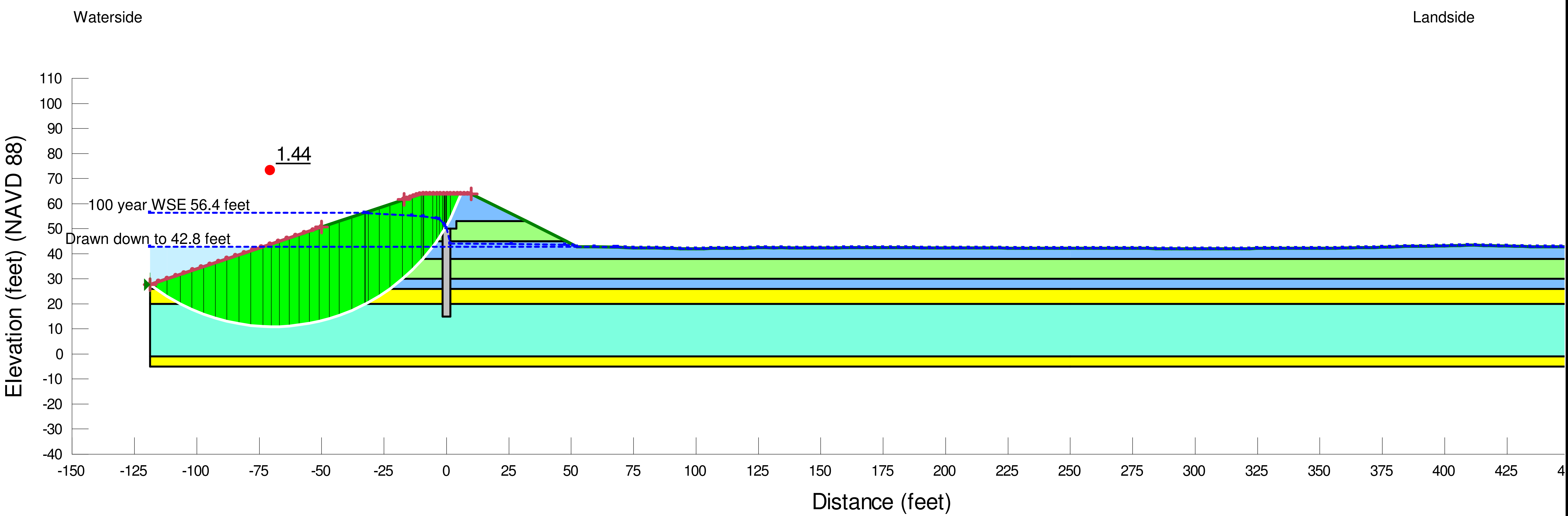
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 283 Reach B (BR-L 1106+12) Cutoff Wall Half Levee Degrade Slope Stability Result-Steady State Landside-100 year WSE

Aug 2019

FIGURE F-24



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

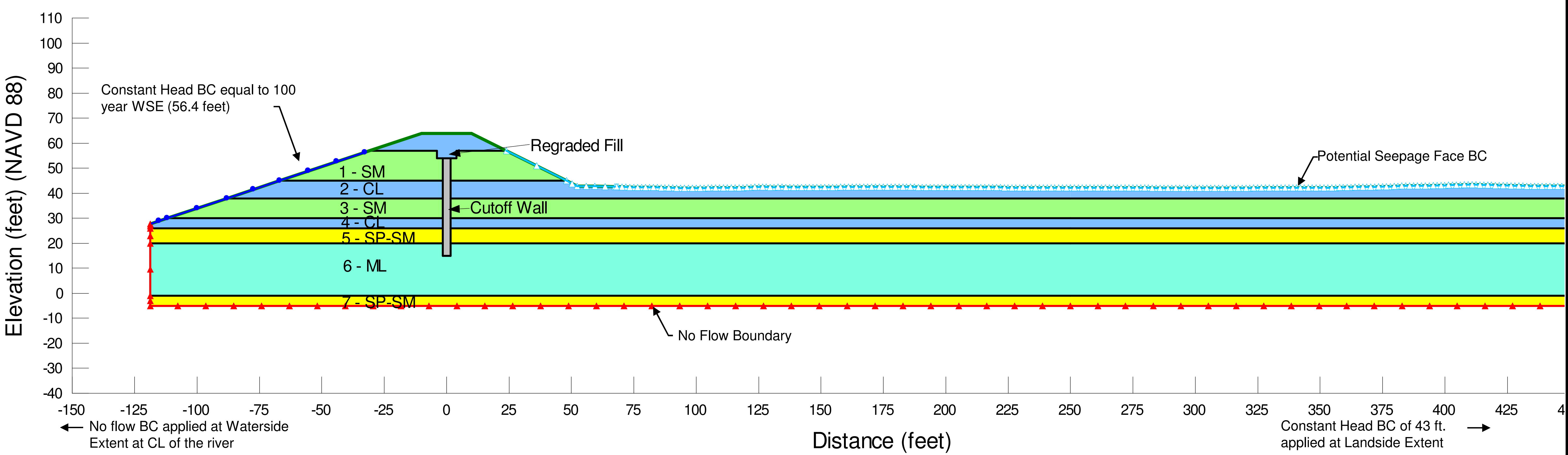
Segment 283 Reach B (BR-L 1106+12) Cutoff Wall Half Levee Degrade Slope Stability Result-Waterside RDD-100 year WSE

Aug 2019

FIGURE F-25

Reach B (BR-L 1106+12)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	**SM**	2.834	1.0E-3	0.25
2	**CL**	0.028	1.0E-5	0.25
3	**SM**	2.834	1.0E-3	0.25
4	**CL**	0.028	1.0E-5	0.25
5	**SP-SM**	11.336	4.0E-3	0.25
6	**ML**	0.028	1.0E-5	0.25
7	**SP-SM**	11.336	4.0E-3	0.25
Regraded Fill	**CL**	0.00283	1.0E-6	0.25
Cutoff Wall	**SCB**	0.000283	1.0E-7	1



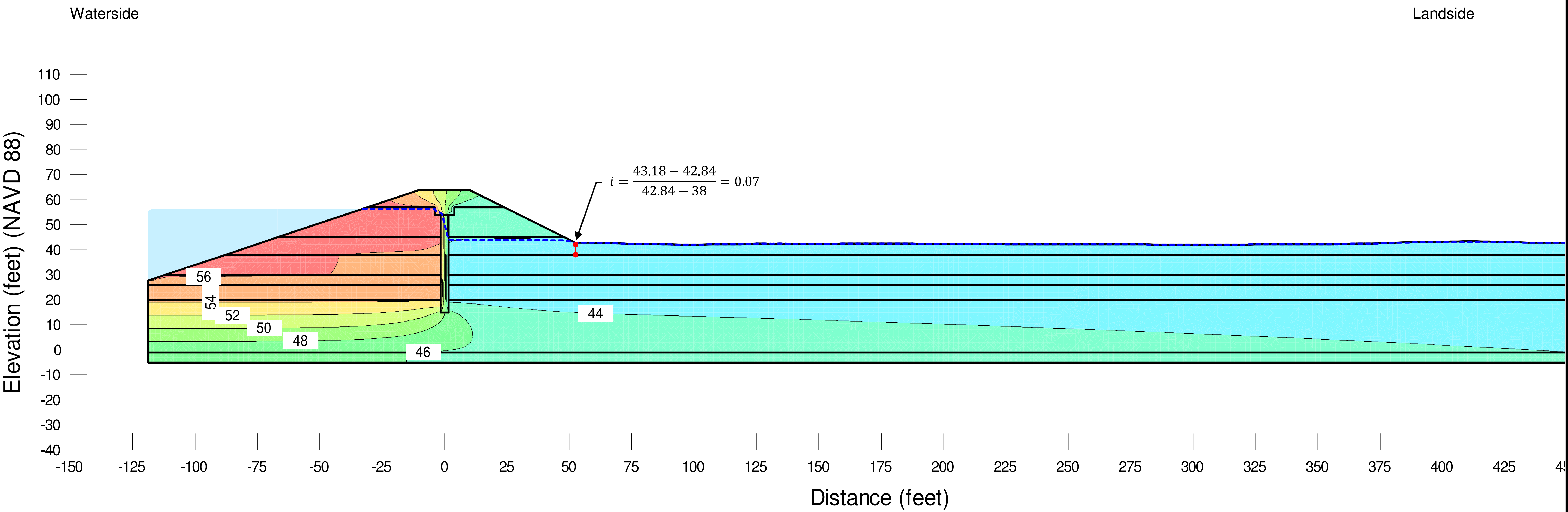
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 283 Reach B (BR-L 1106+12) Cutoff Wall Third Levee Degrade Seepage Model-100 year WSE

Aug 2019

FIGURE F-26



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

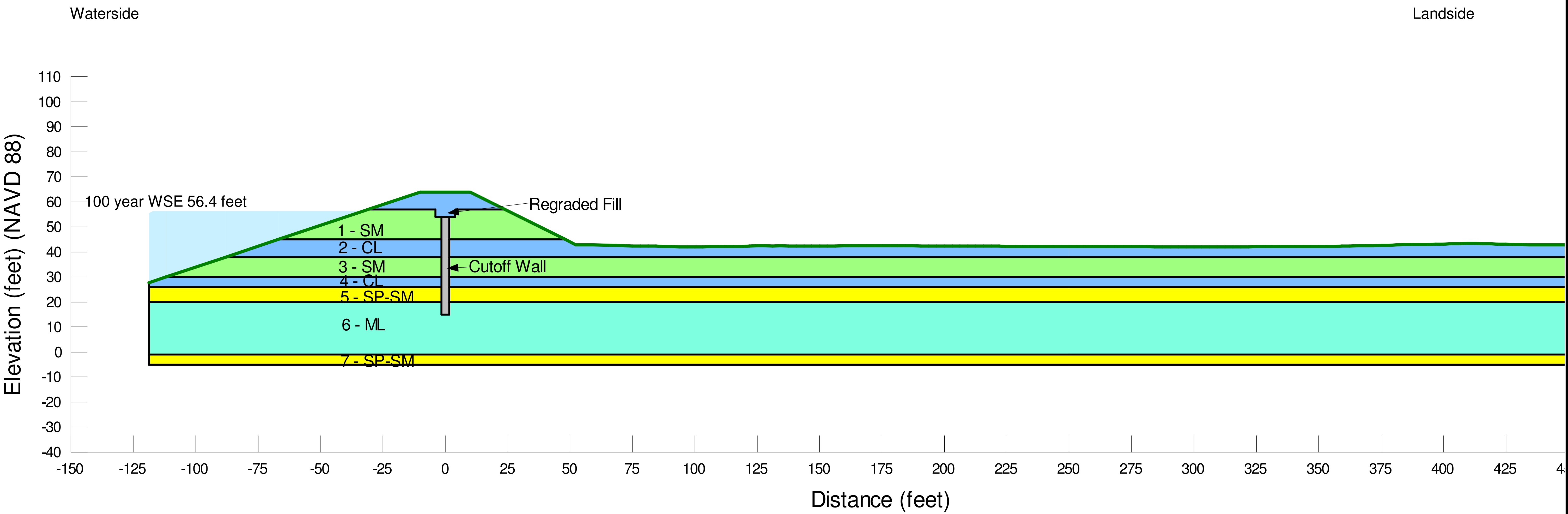
Segment 283 Reach B (BR-L 1106+12) Cutoff Wall Third Levee Degrade Seepage Result-100 year WSE

Aug 2019

FIGURE F-27

Reach B (BR-L 1106+12)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**CL**	120	100	31	360	4
5	**SP-SM**	125	0	34	-	-
6	**ML**	120	50	31	360	4
7	**SP-SM**	125	0	34	-	-
Regraded Fill	**CL**	125	100	31	360	4
Cutoff Wall	**SCB**	120	500	0	500	0



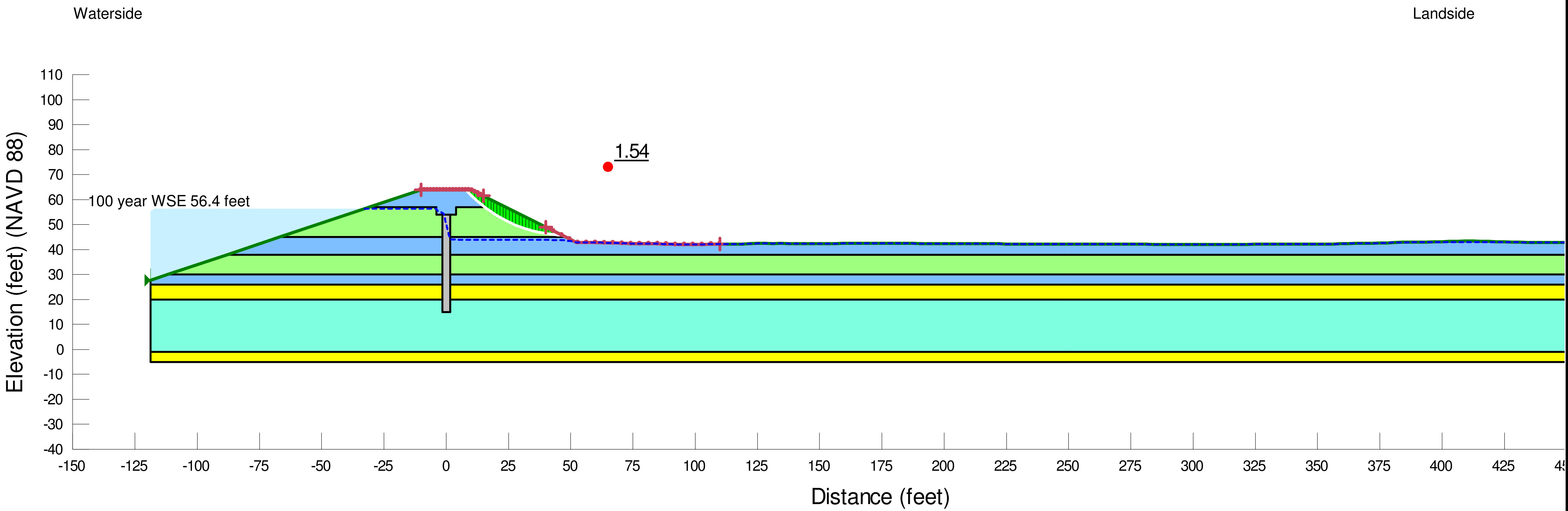
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 283 Reach B (BR-L 1106+12) Cutoff Wall Third Levee Degrade Slope Stability Model

Aug 2019

FIGURE F-28



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

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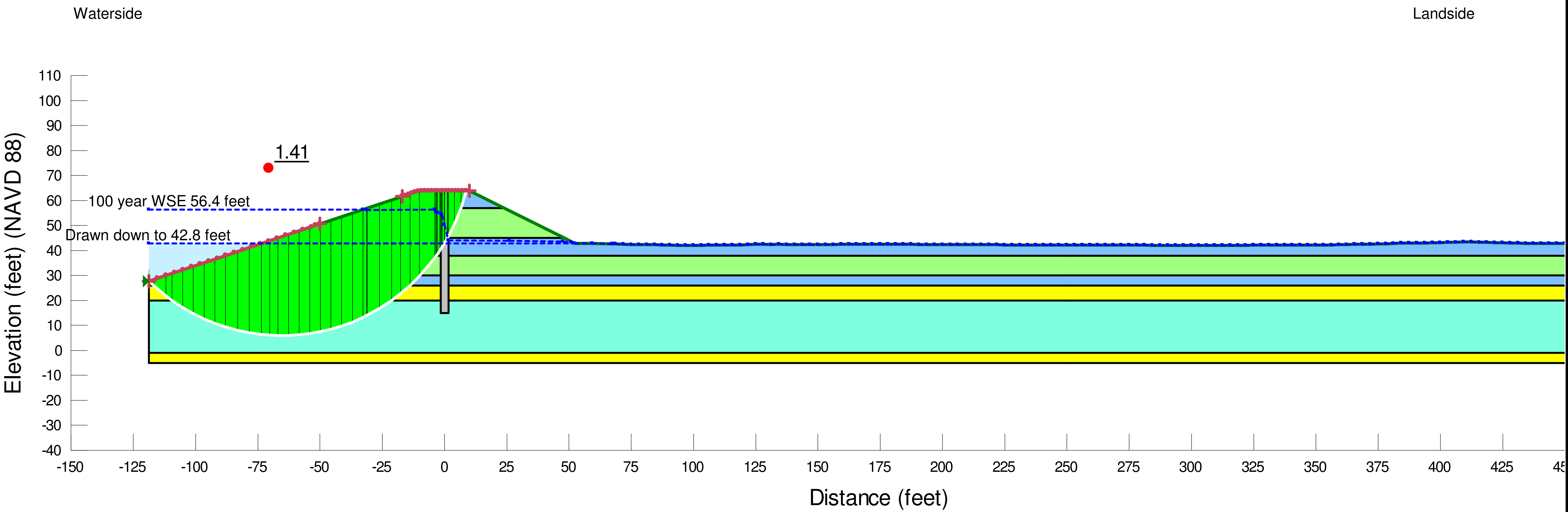
Segment 283 Reach B (BR-L 1106+12) Cutoff Wall Third Levee Degrade Slope Stability Result-Steady State Landside-100 year WSE

Aug 2019

FIGURE F-29



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

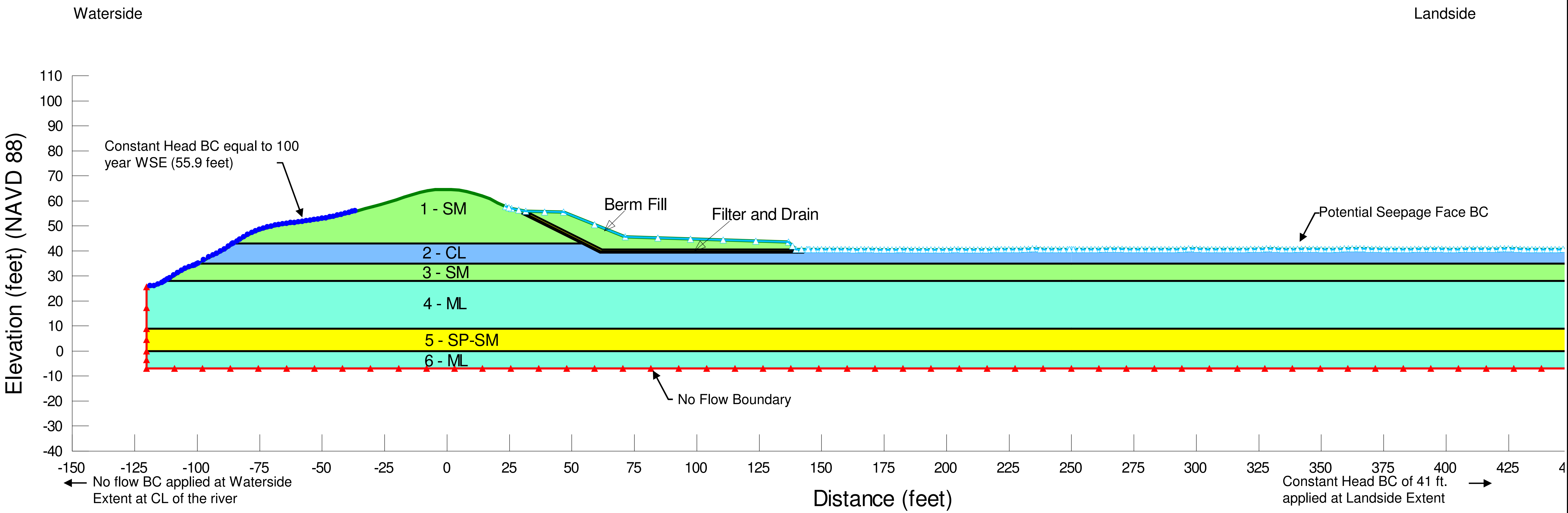
Segment 283 Reach B (BR-L 1106+12) Cutoff Wall Third Levee Degrade Slope Stability Result-Waterside RDD-100 year WSE

Aug 2019

FIGURE F-30

Reach C (BR-L 1080+27)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	SM	2.834	1.0E-3	0.25
2	CL	0.028	1.0E-5	0.25
3	SM	2.834	1.0E-3	0.25
4	ML	0.028	1.0E-5	0.25
5	SP-SM	11.336	4.0E-3	0.25
6	ML	0.028	1.0E-5	0.25
Berm Fill	SM	2.834	1.0E-3	0.25
Drain	SP	141.696	5.0E-2	1
Filter	SP	2.834	1.0E-3	1



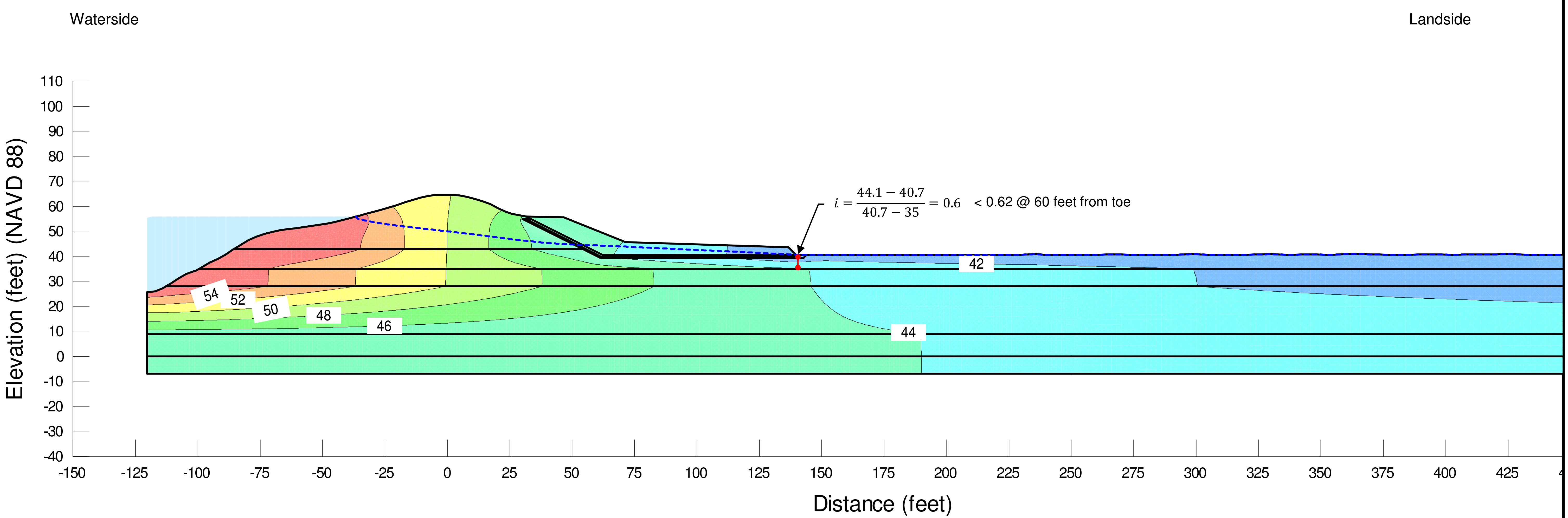
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 283 Reach C (BR-L 1080+27) Combined Berm Seepage Model-100 year WSE

Aug 2019

FIGURE F-31



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

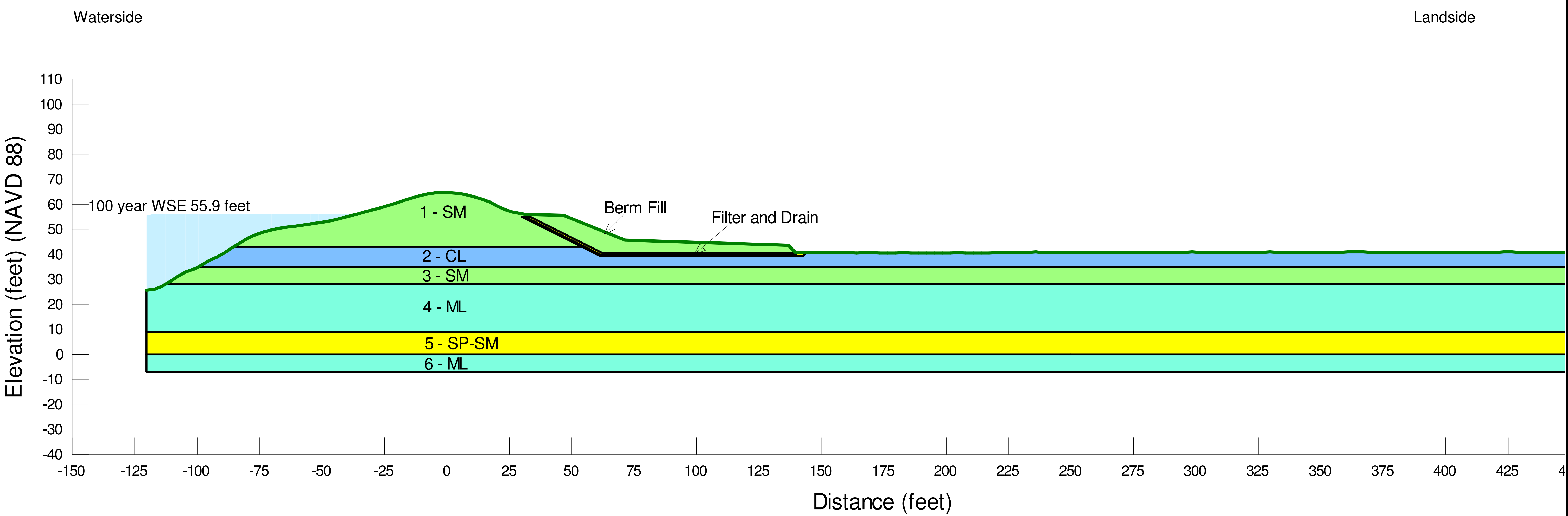
Segment 283 Reach C (BR-L 1080+27) Combined Berm Seepage Result-100 year WSE

Aug 2019

FIGURE F-32

Reach C (BR-L 1080+27)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**ML**	120	50	31	360	4
5	**SP-SM**	125	0	34	-	-
6	**ML**	120	50	31	360	4
Berm Fill	**SM**	120	0	34	-	-
Drain	**SP**	130	0	34	-	-
Filter	**SP**	130	0	32	-	-



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

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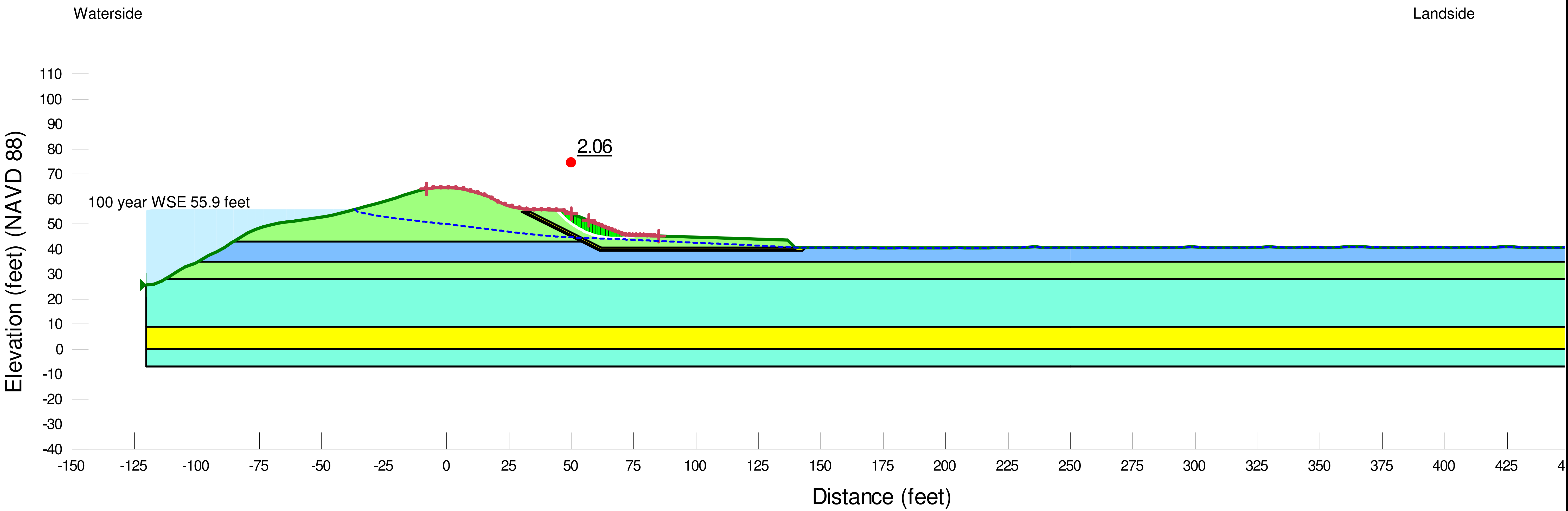
Segment 283 Reach C (BR-L 1080+27) Combined Berm Slope Stability Model

Aug 2019

FIGURE F-33



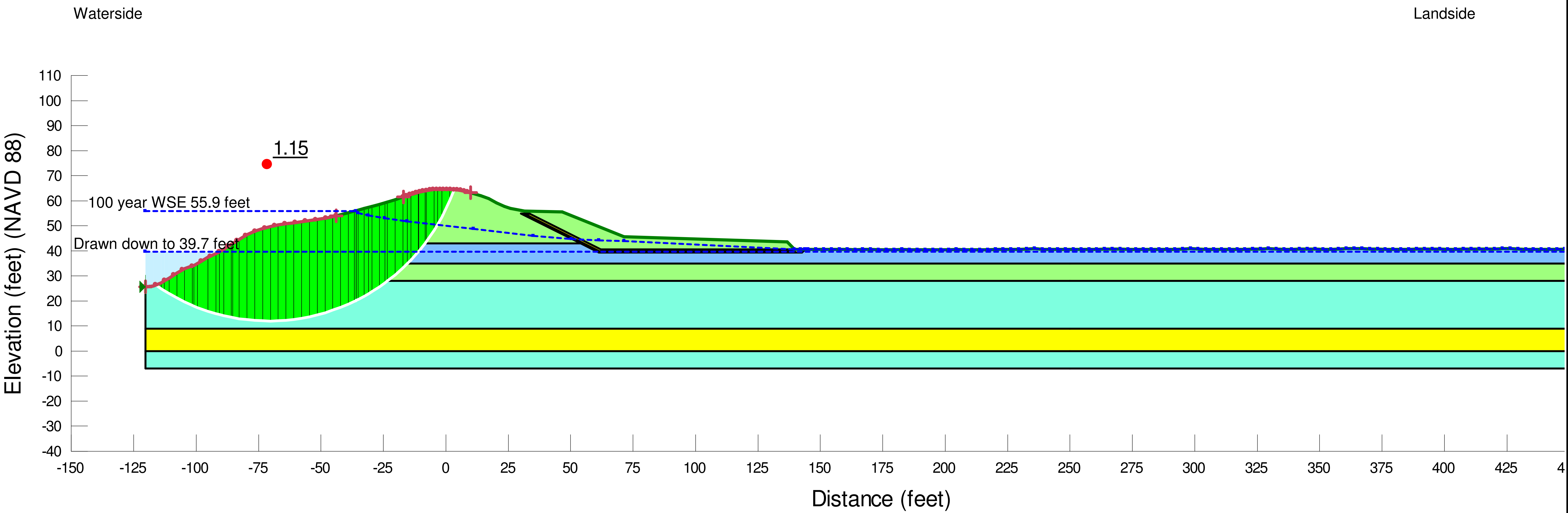
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 283 Reach C (BR-L 1080+27) Combined Berm Slope Stability Result-Steady State Landside-100 year WSE

Aug 2019

FIGURE F-34



NOTES:

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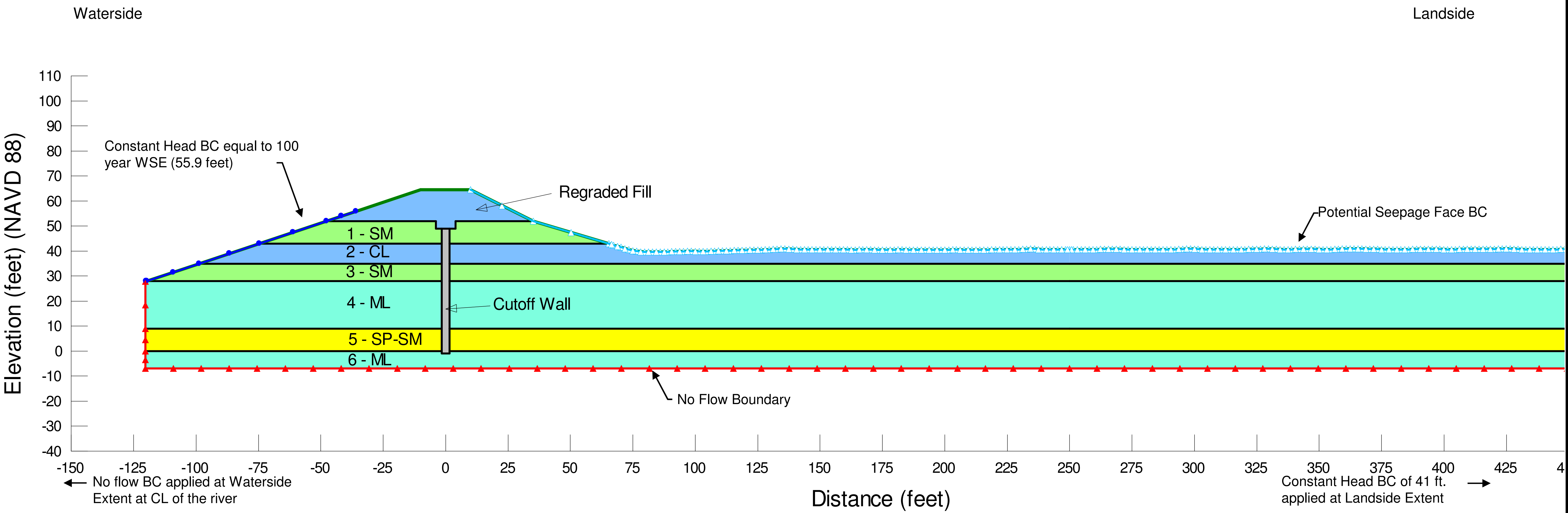
Segment 283 Reach C (BR-L 1080+27) Combined Berm Slope Stability Result-Waterside RDD-100 year WSE

Aug 2019

FIGURE F-35

Reach C (BR-L 1080+27)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	SM	2.834	1.0E-3	0.25
2	CL	0.028	1.0E-5	0.25
3	SM	2.834	1.0E-3	0.25
4	ML	0.028	1.0E-5	0.25
5	SP-SM	11.336	4.0E-3	0.25
6	ML	0.028	1.0E-5	0.25
Regraded Fill	CL	0.00283	1.0E-6	0.25
Cutoff Wall	SCB	0.000283	1.0E-7	1



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

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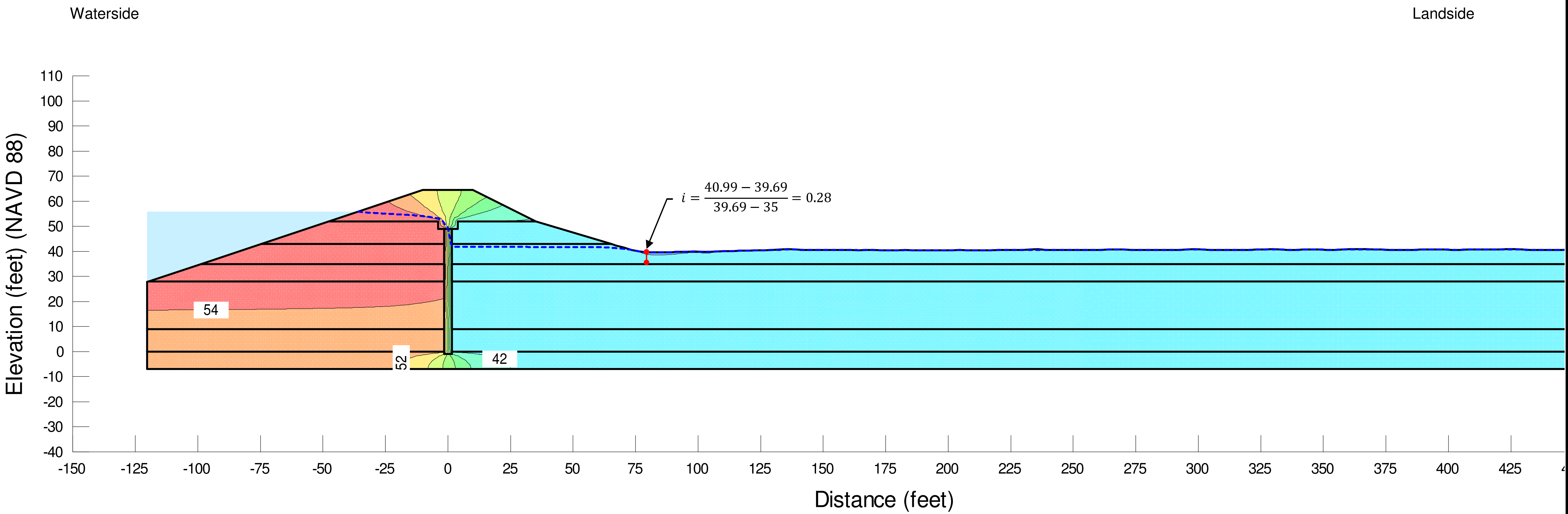
Segment 283 Reach C (BR-L 1080+27) Cutoff Wall Half Levee Degrade Seepage Model-100 year WSE

Aug 2019

FIGURE F-36



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

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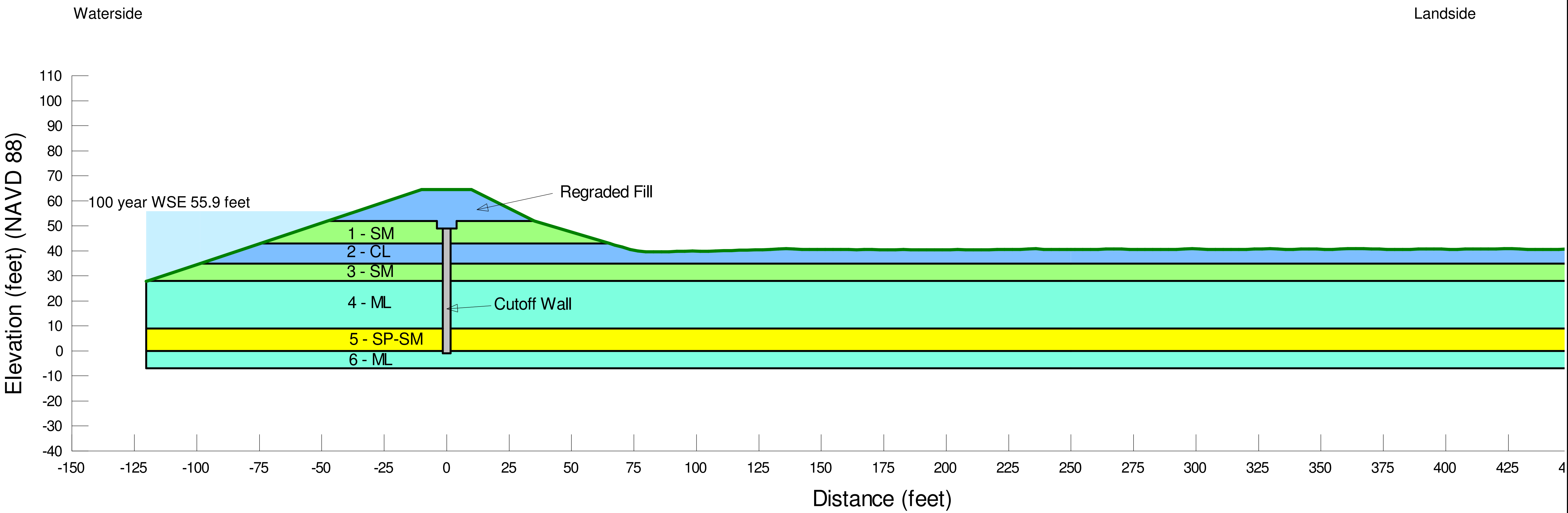
Segment 283 Reach C (BR-L 1080+27) Cutoff Wall Half Levee Degrade Seepage Result-100 year WSE

Aug 2019

FIGURE F-37

Reach C (BR-L 1080+27)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**ML**	120	50	31	360	4
5	**SP-SM**	125	0	34	-	-
6	**ML**	120	50	31	360	4
Regraded Fill	**CL**	125	100	31	360	4
Cutoff Wall	**SCB**	120	500	0	500	0



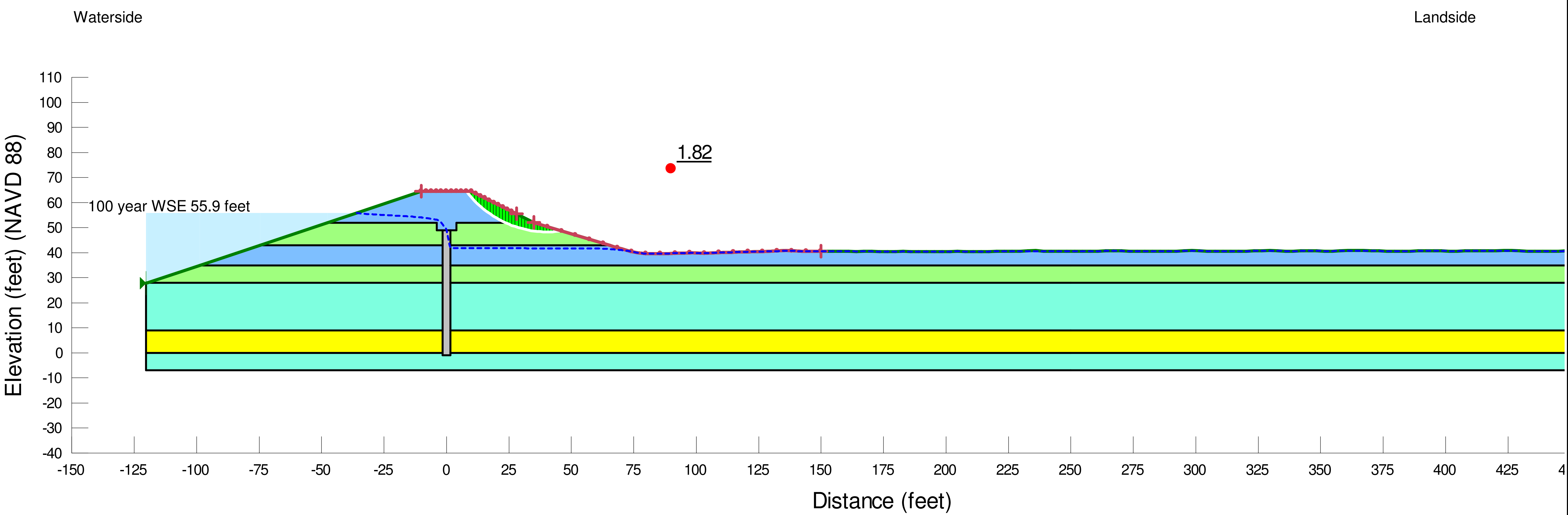
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 283 Reach C (BR-L 1080+27) Cutoff Wall Half Levee Degrade Slope Stability Model

Aug 2019

FIGURE F-38



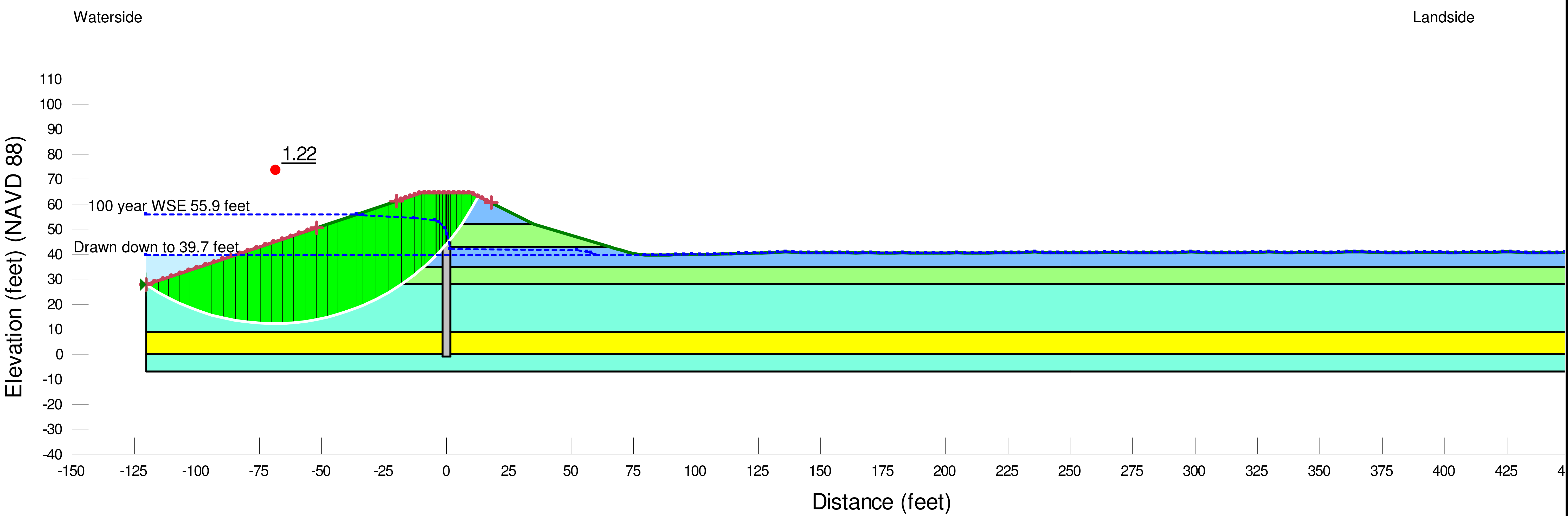
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 283 Reach C (BR-L 1080+27) Cutoff Wall Half Levee Degrade Slope Stability Result-Steady State Landside-100 year WSE

Aug 2019

FIGURE F-39



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

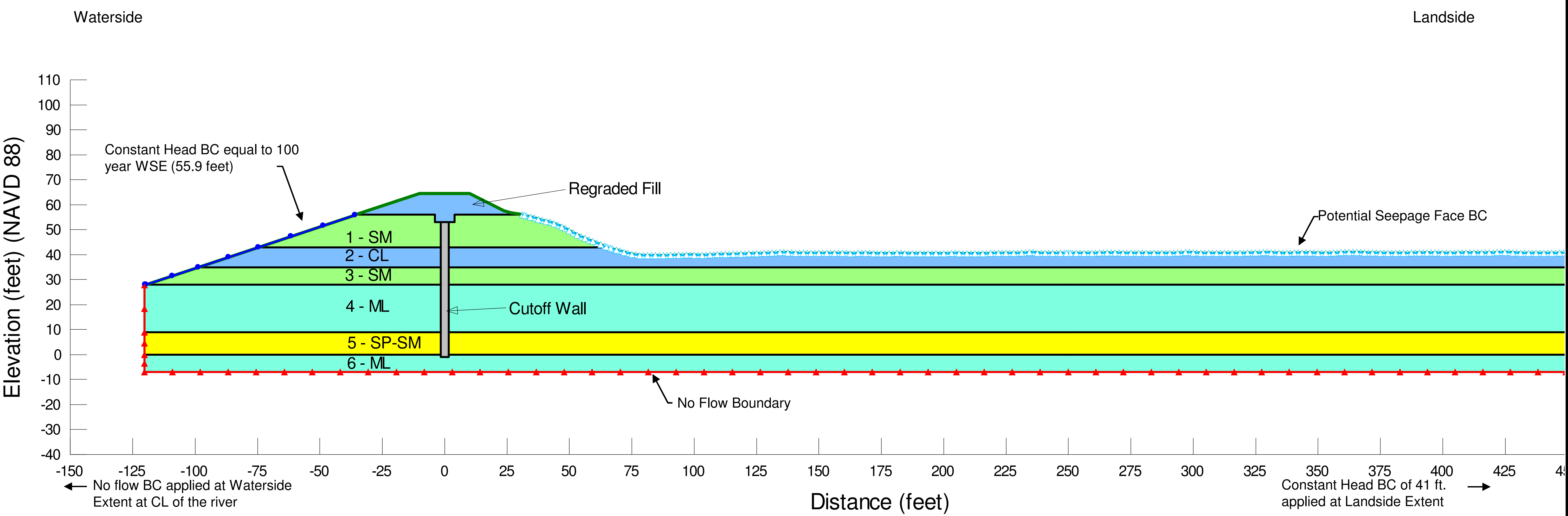
Segment 283 Reach C (BR-L 1080+27) Cutoff Wall Half Levee Degrade Slope Stability Result-Waterside RDD-100 year WSE

Aug 2019

FIGURE F-40

Reach C (BR-L 1080+27)

Layer	Material	Hydraulic Conductivity		
		k_h (ft/days)	k_h (cm/sec)	k_v/k_h
1	SM	2.834	1.0E-3	0.25
2	CL	0.028	1.0E-5	0.25
3	SM	2.834	1.0E-3	0.25
4	ML	0.028	1.0E-5	0.25
5	SP-SM	11.336	4.0E-3	0.25
6	ML	0.028	1.0E-5	0.25
Regraded Fill	CL	0.00283	1.0E-6	0.25
Cutoff Wall	SCB	0.000283	1.0E-7	1



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

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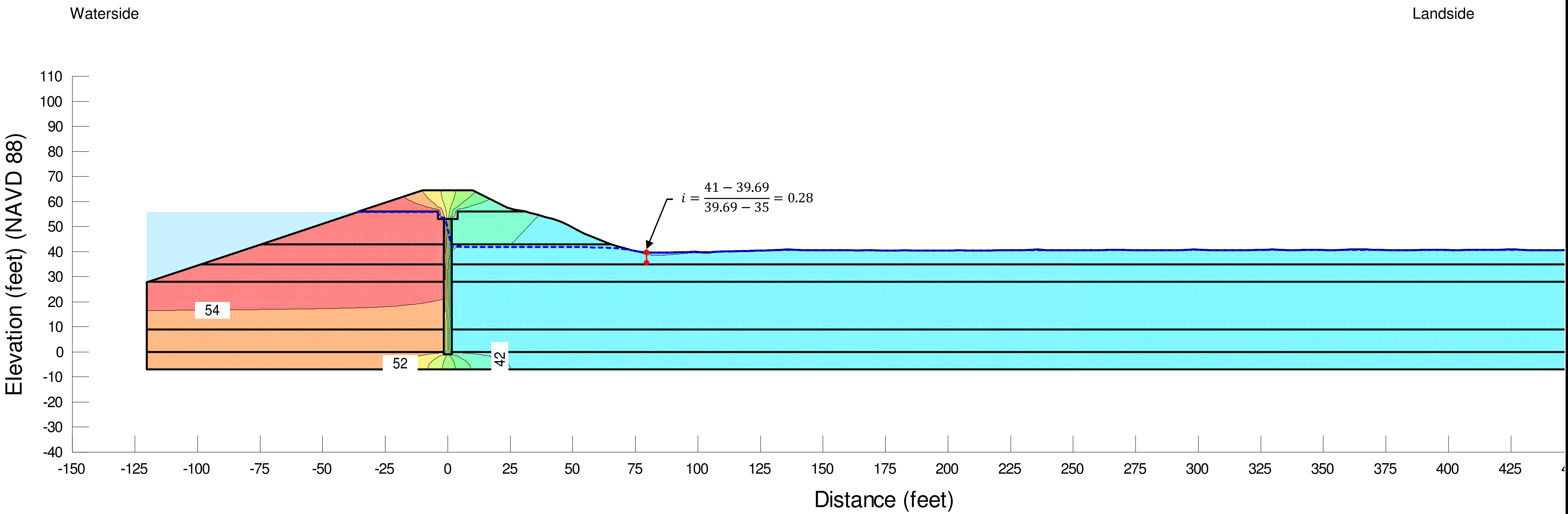
Segment 283 Reach C (BR-L 1080+27) Cutoff Wall Third Levee Degrade Seepage Model-100 year WSE

Aug 2019

FIGURE F-41



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

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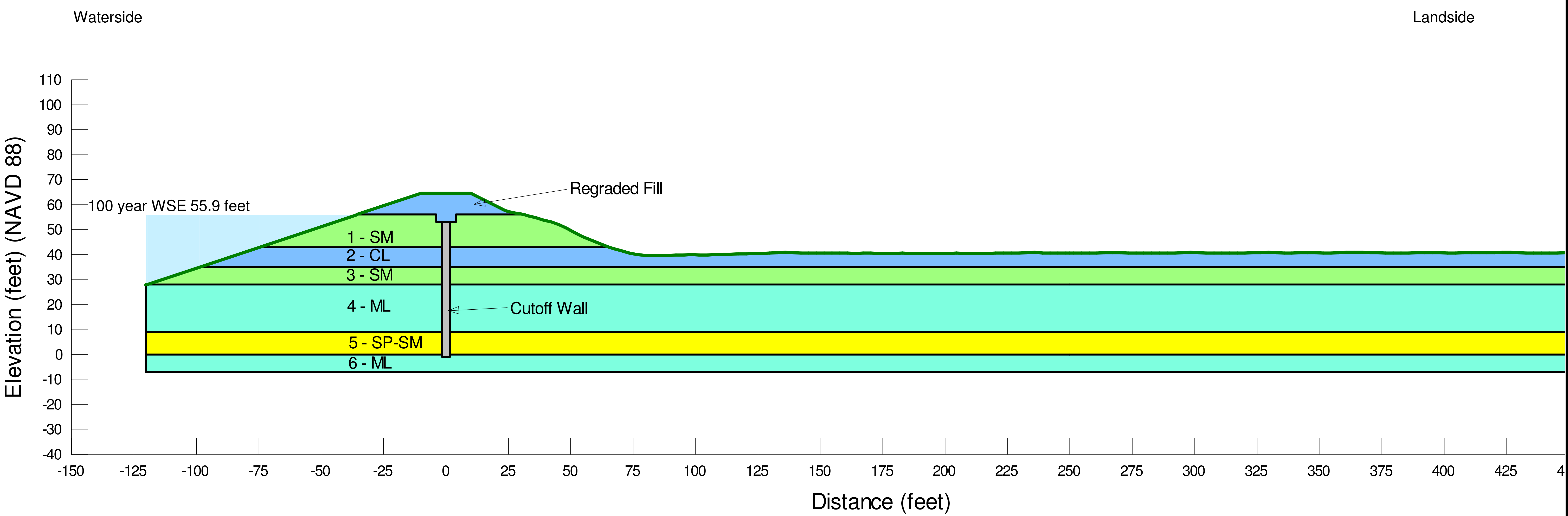
Segment 283 Reach C (BR-L 1080+27) Cutoff Wall Third Levee Degrade Seepage Result-100 year WSE

Aug 2019

FIGURE F-42

Reach C (BR-L 1080+27)

Layer	Material	Total Unit Weight (pcf)	Shear Strength			
			C' (psf)	Φ' (deg)	C (psf)	Φ (deg)
1	**SM**	125	0	33	-	-
2	**CL**	120	100	31	360	4
3	**SM**	125	0	32	-	-
4	**ML**	120	50	31	360	4
5	**SP-SM**	125	0	34	-	-
6	**ML**	120	50	31	360	4
Regraded Fill	**CL**	125	100	31	360	4
Cutoff Wall	**SCB**	120	500	0	500	0



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

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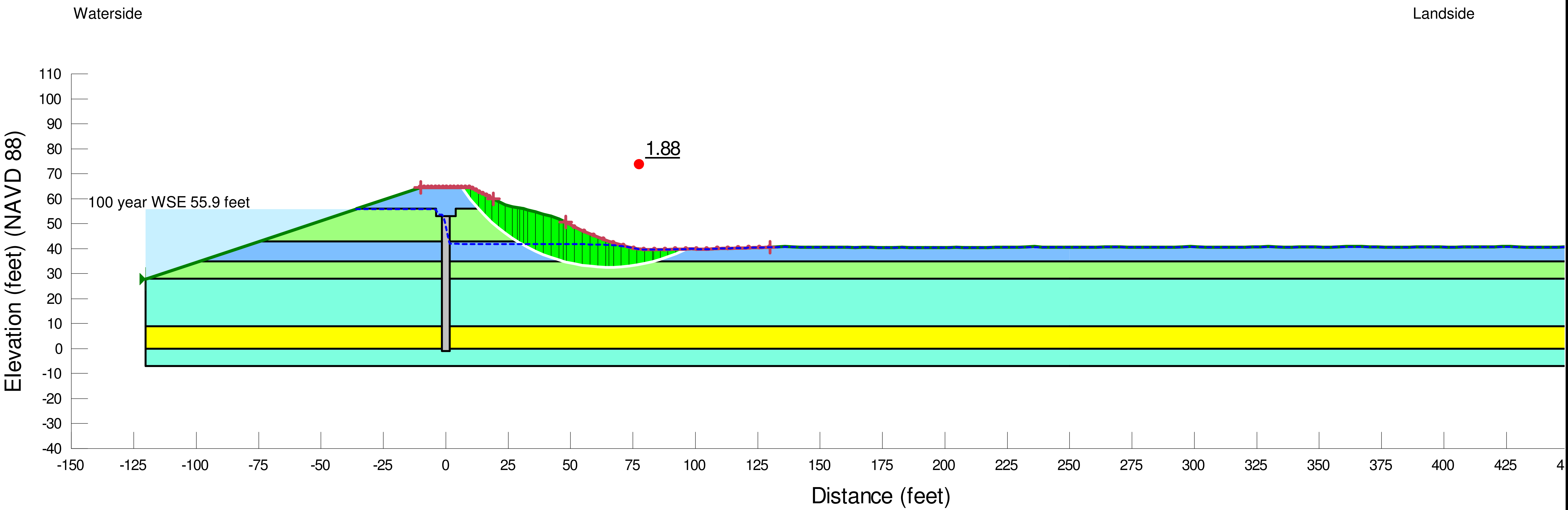
Segment 283 Reach C (BR-L 1080+27) Cutoff Wall Third Levee Degrade Slope Stability Model

Aug 2019

FIGURE F-43



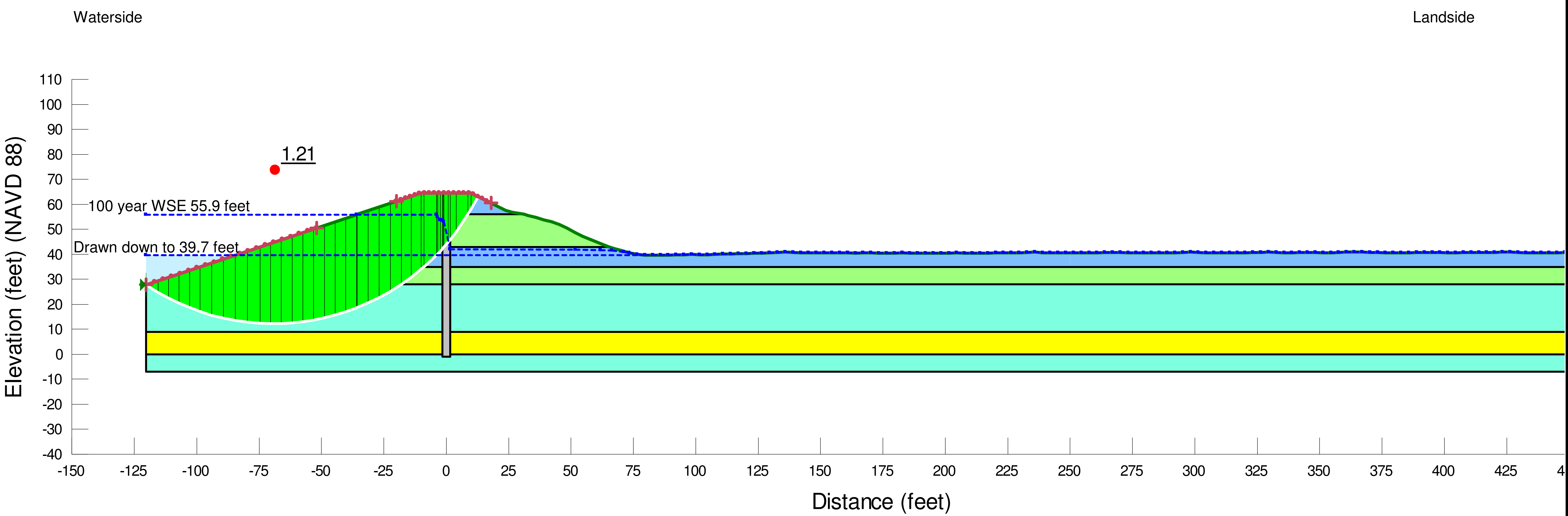
NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 283 Reach C (BR-L 1080+27) Cutoff Wall Third Levee Degrade Slope Stability Result-Steady State Landside-100 year WSE

Aug 2019

FIGURE F-44



NOTES:

Rio Oso Flood Risk Reduction Feasibility Study

Segment 283 Reach C (BR-L 1080+27) Cutoff Wall Third Levee Degrade Slope Stability Result-Waterside RDD-100 year WSE

Aug 2019

FIGURE F-45