Appendix D

Middle Eastside Bypass Geotechnical Assessment

August 2013

SAN JOAQUIN RIVER
RESTORATION PROGRAM

URS

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Technical Memorandum

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Project	San Joaquin River Restoration Program (SJRRP)
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Subject	Middle Eastside Bypass Geotechnical Assessment
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1 INTRODUCTION

The Bureau of Reclamation (Reclamation), lead agency for the SJRRP, has initiated restoration releases from Friant Dam (Interim Flows) and is evaluating alternatives for routing of long-term restoration flows to support reintroduction of fish into the San Joaquin River, as required by the Stipulation of Settlement (Settlement). DWR is not a settling party in the Settlement; however, the State of California has signed a Memorandum of Understanding with the settling parties under which DWR states it will assist in various aspects of the planning, design, and construction of physical improvements identified in the Settlement, including projects related to flood protection, levee relocation, construction standards, and maintenance.

DWR's DFM has been tasked to assess the impacts of Restoration flows under the SJRRP on flood management and operations in the restoration area and to develop strategies to manage those impacts. DFM has developed the San Joaquin Levee Evaluation (SJLE) Project to assist the SJRRP in identifying potential flood impacts to levee seepage and stability due to current and future Restoration flows under the SJRRP.

The restoration area in the SJRRP comprises approximately 260 miles of levees located between Gravelly Ford, approximately 32 miles downstream of Friant Dam, Fresno, in the east and the confluence of the Merced River and the San Joaquin River to the northwest (Figure 1).

In connection with DWR's Non-Urban Levee Evaluations (NULE) Project for the Central Valley flood control system, URS is providing geotechnical engineering support services in relation to the SJRRP. Under NULE Project Task Order U113, URS will conduct geotechnical analyses and prepare geotechnical memoranda and reports for approximately 40 miles of SJRRP study area levees.

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As one of the first sub-tasks, URS has performed preliminary seepage and stability analysis in support of providing recommendations to DWR regarding channel capacity relative to acceptable geotechnical performance. The following text outlines the approach and criteria used in assessing geotechnical performance, gives the results of analyses and offers recommendations for increasing channel flows to meet Reclamation objectives.

2 STUDY AREA FOR CHANNEL CAPACITY ASSESSMENT

Until adequate data are available to determine levee performance relative to geotechnical criteria, Reclamation is limiting the release of Interim and Restoration flows to those which would remain in-channel. In-channel flows are flows that maintain a water surface elevation at or below the elevation of the landside levee toe (i.e., the base of the levee), as determined by DWR using one-dimensional HEC-RAS hydraulic modeling. Based on the hydraulic modeling by Tetra Tech, Inc (TTI), three sites (Sites 1, 2 and 3) along the Middle Eastside Bypass were identified that limited channel capacities for the entire Bypass (Figure 1). TTI's capacity results for the Middle Eastside Bypass were extremely low due to ground elevations on the landside being lower than the waterside toe in certain locations.

The purpose of the evaluation performed by URS, is to determine the amount of water that can be placed on the waterside levee slopes without exceeding geotechnical criteria for stability and seepage at these three sites. For the purposes of providing recommendations for channel capacity assessment, DWR directed URS to use Sites 1, 2 and 3 for performing geotechnical analysis.

3 GEOLOGY, GEOMORPHOLOGY, AND PAST PERFORMANCE

The west levee of the Middle Eastside Bypass is at the eastern boundary of the San Joaquin River Basin geomorphic domain, a broad, low-relief area bordered to the east by distal alluvial fan margins. This area was historically described as a seasonal marsh prior to modern flood control. Historical records indicate deposits in this mostly lower-energy environment tend to be finer-grained (e.g., silt and clay) with limited stratigraphic variability. Coarser-grained, higher-energy deposits (e.g., silty sand) increase in frequency and abundance with San Joaquin River proximity, where channel meander processes deposit coarser material derived from the upstream channel meander belt domain.

The east levee of the Middle Eastside Bypass is located at the western boundary of the Sierra Nevada Fans geomorphic domain. These alluvial fans are reportedly composed of late Pleistocene Modesto and Riverbank Formations, which consist of semi-consolidated clay to gravel. Younger, less-consolidated fan sediments and natural levees are deposited atop these formations. Grain size generally decreases as distance from source increases.

Level 2-1 geomorphic assessment, performed as part of the NULE Project, was based on mapping by Marchand (1976) and Lettis (1982) and indicates the majority of the Middle Eastside Bypass is underlain by Holocene and Historical Overbank Deposits (Rob and Hob). These deposits are composed of sand, silt, and clay with trace fine gravel, deposited during

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high-stage water flow that overtopped the historical channel banks. Holocene and Historical distributary channel deposits (Hch and Rch) are mapped crossing the levees throughout the bypass. Hch deposits are composed of sand and silt with trace gravel, finning upwards. Rch deposits are composed of sand, silt, and clay with trace gravel deposited in areas of channelized flow transporting sediment to the floodplain.

Documented past performance events in the area of the Middle Eastside Bypass include seepage, boils, sloughing, cracking, widespread erosion, and near overtopping. There are no documented reports of breaches. According to the district representative, the Middle Eastside Bypass experiences chronic seepage and inundation issues during high water events. The district representative indicated that through seepage is not as significant a problem as compared to underseepage.

4 GEOTECHNICAL APPROACH AND CRITERIA

At the direction of DWR, only seepage and stability analyses were considered in geotechnical evaluation of the levees at Sites 1, 2 and 3. Nuissance seepage and groundwater impacts were not considered in the evaluation.

Selection of geotechnical parameters for analysis (strength and hydraulic conductivity) are based on protocols and recommendations in the *Guidance Document for Geotechnical Analyses* (Guidance Document) (Revision 13, URS, 2013), which was developed as part of DWR's Urban Levee Evaluations (ULE) Project.

Due to a lack of exploration data along the landside and waterside toe, analysis cross sections have been developed by laterally extrapolating levee crest exploration data horizontally across the model.

Each analysis cross-section, including the base model and any sensitivity cases, were analyzed for four different water surface elevations (WSE) so that the analysis results could be plotted versus WSE. These plots were used to interpolate the WSE corresponding to acceptable criteria for seepage (see Section 4.1) and stability (see Section 4.2). The four different WSEs used to generate plots were:

- In channel flow with approximately 2 feet below the waterside levee toe,
- WSE equivalent to approximately 3 feet to 4 feet of water above the waterside levee toe,
- WSE equivalent to half levee height,
- WSE equivalent to physical top of levee minus 3-foot.

The following sections provide details about the approach and criteria used for analysis.

4.1 Seepage Analysis

Underseepage may cause piping and internal erosion of materials due to excessive pore water pressure under foundation blanket layers, and may negatively impact slope stability by

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reducing effective stresses in both embankment and foundation soils. Underseepage conditions are generally expressed by an average vertical exit gradient. Excessive average vertical exit gradients can result in the formation of sand boils, piping, and levee failure if left unrepaired.

Based on USACE and DWR publications, an average vertical exit gradient equal to or less than the following values (Table 4-1) were used to determine whether a levee section met criteria.

Table 4-1. Critical Gradient at Different Locations

Landside Levee Toe	Between Levee/Berm Toe and Up to 150 feet Landward[1]	Existing Landside Berm Toe[2]	Between Existing Levee Toe and Berm Toe[3]
≤ 0.5	≤ 0.5 to ≤ 0.8	≤ 0.5 to ≤ 0.8	≤ 0.5 to ≤ 0.8

Notes:
1 The criteria for an intermediate point up to 150 feet from levee/berm toe will be linearly interpolated from 0.5 to 0.8 to address thinning blankets and/or topographic low points.
2 The criteria for an existing berm toe will be linearly interpolated from 0.5 to 0.8 up to 150 feet from the berm toe
3 The criteria at an intermediate location between the levee toe and berm toe will be based on a linear interpolation within the allowable gradients or factors of safety. See the Urban Levee Design Criteria (ULDC) (DWR, 2012).

Steady-state seepage analyses were performed in accordance with USACE Engineer Manual (EM) 1110-2-1913, *Design and Construction of Levees* (USACE, 2000). The objectives of seepage analysis are to:

- Estimate the average vertical hydraulic exit gradients, primarily around the levee toe area, bottom of landside ditches or depressions, and around the toe of landside seepage berms, if present, for selected water level conditions. Plot results of average vertical hydraulic exit gradient versus WSE and determine the WSE at which the critical gradient is met.
- Calculate steady-state phreatic levels and pore pressures in levee embankment and foundation soils for selected water level conditions and export pore pressure information for use in the slope stability analysis.

Steady-state seepage analyses were performed using SEEP/W, a two-dimensional, finite element software program developed by GEO-SLOPE International, Ltd. SEEP/W analyzes groundwater seepage and the development of porewater pressures in soils.

The following boundary conditions were used during steady-state seepage analyses:

- Each SEEP/W model was extended landward approximately 2,000 feet to assure that boundary elements are not adversely impacting the analyses.
- On the waterside, analysis models were extended to the middle of the river channel.
- No-flow conditions were applied on the waterside vertical edge.

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- Total head boundary conditions were applied on the landside vertical edge corresponding to the lowest point of landside ground surface elevation to prevent unrealistic flow back from landside.
- Bottom nodes were specified as a no-flow boundary (i.e., the default condition for SEEP/W).

In some cases, a fixed total head boundary condition was applied on the waterside vertical edge to charge subsurface aquifer layers to simulate truncation of the waterside blanket.

4.2 Static Slope Stability

Steady-state slope stability analyses were performed in accordance with USACE manuals (EM) 1110-2-1913, *Design and Construction of Levees* (USACE, 2000) and EM 1110-2-1902, *Slope Stability* (USACE, 2003). The objective of landside stability analysis was to evaluate long-term landside slope stability conditions under selected water level conditions.

Steady-state slope stability analyses were performed using SLOPE/W, a two-dimensional limit equilibrium stability analysis software program developed by GEO-SLOPE International, Ltd. following the Spencer Method.

Spencer's method is a limit equilibrium method of analysis that assumes a potential sliding surface can be modeled by subdividing the mass above the sliding surface into a number of vertical slices. Moments are calculated for a hypothetical circle center and an iterative process is used to arrive at force and moment equilibrium. In Spencer's Method, it is assumed the interslice forces among all slices in the potential sliding mass are parallel (i.e., all interslice forces have the same inclination).

The same stratigraphy and models used for steady-state seepage were used for stability analysis. Porewater pressures calculated by SEEP/W models were imported into SLOPE/W for use during analyses.

Slope stability analyses were performed using a minimum 3- to 5-foot depth criteria for critical circle search routines in SLOPE/W software. This approach was adopted to screen out shallow surficial sloughing, which are considered maintenance problems. SLOPE/W searches also included deeper shear surfaces involving the levee crown. Based on USACE and DWR publications, a minimum factor of safety of 1.4 is required for slip surfaces that could affect the overall stability of the levee, i.e. deeper seated failures that intersect with the levee crown and impact the full height of the levee.

The steady-state seepage slope stability models used effective shear strengths for the different soil layers that correspond to a drained condition during the analysis water levels.

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5 GEOTECHNICAL ANALYSIS OF EXISTING CONDITIONS

5.1 Site 1

The analysis cross section for Site 1 is along the left bank of the levee at Station 1460+00. The levee in this portion of the system has a height of around 11 feet to 13 feet, with a levee crown width of 10 feet to 15 feet. Waterside and landside slopes are approximately 3.6H:1V and 2.5H:1V, respectively. This section of levee has a 3 feet to 4 feet deep landside ditch located approximately 30 feet from the landside levee toe. The analysis cross section is shown in Figure 2.

Based on the exploration data available, the levee embankment comprises a mixture of silty and clayey sand, silt and clay. Subsurface materials consist of silts and clays with interbeds of silty sand and clayey sand. A variable landside blanket thickness is indicated by the explorations. For the purpose of analysis, a base model was established using information from cone penetrometer test (CPT) WCLESB_006C, which indicates a landside blanket condition approximately 4 feet thick. Due to the presence of a landside ditch, the blanket thickness is reduced to a thickness of around 1.5 feet (Figure 2).

Due to the variability in blanket thickness in this section of the levee, an additional analysis model was created using information obtained from CPT WCLESB_004C. This exploration shows a 10-foot-thick landside blanket. The analysis cross section is shown in Figure 3. The purpose for this additional model was to assess the sensitivity of the levee to underseepage with a range of blanket thicknesses.

Soil strength and seepage parameters selected for analysis were determined using a combination of exploration data, engineering judgment, knowledge of the materials in the area, and information the Guidance Document (Revision 13, 2013).

A series of sensitivity analyses using different material properties and/or a change in boundary conditions were run on each analysis cross section to cover a range of possible field conditions. Changes made to the base model for the purpose of sensitivity analysis were carried into a new model and labeled accordingly.

Seven sensitivity analyses were performed to assess the effects on seepage and stability, as detailed below.

- Sensitivity 1: the base model with the landside ditch filled with water.
- Sensitivity 2: the base model with the ditch empty, reduced strength parameters for the top three soil layers, and increased permeability contrast between the SC blanket and ML aquifer layers.
- Sensitivity 3: Sensitivity Case 2, but with the blanket layer assumed to be cracked at the landside ditch.
- Sensitivity 4: Sensitivity Case 2, but with the landside ditch filled with water.

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- Sensitivity 5: base cross section with subsurface stratigraphy from CPT 004C indicating a 10-foot-thick landside blanket and with ditch empty conditions.
- Sensitivity 6: Sensitivity Case 4 with waterside boundary conditions change to total head conditions to charge subsurface layers to mimic truncation of waterside blanket and directly connect the aquifer layer to the waterside channel.
- Sensitivity 7: Sensitivity Case 4 with landside ditch full of water

The analysis results for the base model and sensitivity runs are summarized in Section 6, Table 6-1.

The analysis results show that underseepage is the controlling geotechnical failure mode for Site 1 assuming ditch empty conditions, but when modeling ditch full conditions landside slope stability controls. According to the levee maintenance district, the landside ditches normally run full during the wet season. However, given that it is not clear when water could be released from Friant dam, it is possible that the levee could experience water with ditch full or ditch empty conditions.

Based on the above, it is considered that sensitivity case 3 is representative for the ditch empty condition taking into account the potential for cracking of the blanket layer at the bottom of the ditch and that sensitivity case 4 is representative for the ditch full condition. Therefore, a WSE of between +100.7 feet (NAVD88) and+104.7 feet (NAVD88) is acceptable at this location for ditch empty and ditch full conditions respectively. This corresponds to between approximately 1-foot (ditch empty) and 4 feet (ditch full) of water on the waterside of the levee relative to the landside toe elevation.

5.2 Site 2

The analysis cross section for Site 2 is along the left bank of the levee at Station 1191+00. The levee in this portion of the system has a height of around 11 feet to 13 feet, with a levee crown width of 10 feet to 15 feet. Waterside and landside slopes are approximately 2.9H:1V and 2.4H:1V, respectively. This section of levee does not have a landside ditch and no noticeable landside depressions that could thin the blanket. The analysis cross section is shown in Figure 4.

Based on the exploration data available, the levee embankment comprises silts and clays. Foundation materials consist of silts and clays with interbeds of silty sand and clayey sand. A landside blanket in excess of 12 feet is present in this portion of the levee. For the purpose of analysis, a base model was established using information from CPT WCLESB_032C and boring WCLESB_007A, which indicates a 12.5-foot-thick landside blanket overlying a clayey sand/silty sand aquifer (Figure 4).

Soil strength and seepage parameters selected for analysis were determined using a combination of exploration data, engineering judgment, knowledge of the materials in the area, and information the Guidance Document (Revision 13;URS, 2013).

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A single sensitivity analysis was performed for this analysis cross section, which consisted of reducing the strength parameters for the top three soil layers and increasing the permeability contrast between the blanket and underlying aquifer layer.

The analysis results for the base model and sensitivity runs are summarized in Section 6, Table 6-1.

The analysis results show that landside slope stability is the controlling geotechnical failure mode for Site 2. Of the different models analyzed, sensitivity case 1 with reduced strength parameters is considered representative given that we do not have any laboratory test data available. Therefore, a critical factor of safety WSE, i.e. a WSE that corresponds to a factor of safety of 1.4, of +104 feet (NAVD88) is acceptable at this location. This corresponds to approximately 6.5-foot of water on the waterside of the levee relative to the landside toe elevation.

5.3 Site 3

The analysis cross section for Site 3 is located along the left bank of the levee at Station 1396+50. The levee in this portion of the system has a height of around 12 feet to 15 feet, with a levee crown width of 10 feet to 15 feet. Waterside and landside slopes are approximately 2.9H:1V and 2.1H:1V, respectively. This section of levee does not have a landside ditch, but there is a slight landside depression approximately 30 landward of the landside levee toe. The analysis cross section is shown in Figure 5.

Based on the exploration data available, the levee embankment comprises silts and clays. Subsurface materials consist of silts and clays with interbeds of sand, silty sand and clayey sand. A variable landside blanket thickness is indicated by explorations. For the purpose of analysis, a base model was established using information from CPT WCLESB_012C and boring WCLESB_003A, which indicates a 5- to 6-foot-thick landside blanket overlying a sand and silty sand aquifer (Figure 5).

Soil strength and seepage parameters selected for analysis were determined using a combination of exploration data, engineering judgment, knowledge of the materials in the area, and information the Guidance Document (Revision 13; URS, 2013).

Two sensitivity analyses were performed to assess effects on seepage and stability, as detailed below.

- Sensitivity 1: base model with waterside boundary conditions change to total head conditions to charge subsurface layers to mimic truncation of waterside blanket and directly connect the aquifer layer to the waterside channel.
- Sensitivity 2: Sensitivity Case 1 with an increased permeability contrast between the blanket and aquifer.

The analysis results for the base model and sensitivity runs are summarized in Section 6. Table 6-1.

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The analysis results show that underseepage is the controlling geotechnical failure mode for Site 3. Of the different models analyzed, sensitivity case 2 is considered representative given that the waterside blanket could have been eroded during past flood events, thereby providing a direct connection to the aquifer layer. Therefore, a critical gradient WSE, i.e. a WSE that corresponds to a hydraulic gradient that matches criteria, of +101.7 feet (NAVD88) is acceptable at this location. This corresponds to approximately 3.5-foot of water on the waterside of the levee relative to the landside toe elevation.

6 ANALYSIS RESULTS

The results of geotechnical analysis for Sites 1, 2 and 3 are summarized in Table 6-1.

Table 6-1. Summary of Preliminary Analysis Results for Channel Capacity Assessment

Site and Stationing	Sensitivity Case	Top of Levee Elevation (feet)	Landside Toe Elevation (feet)	Critical Gradient Water Surface Elevation (WSE)[1]	Critical Factor of Safety WSE[2]
Site 1: Station 1460+00 Left Bank	Primary: base model (BM) with empty ditch	112.07	100.5	102.3	105.5
	Sensitivity 1: BM with full ditch			>109.1	105.0
	Sensitivity 2: BM with empty ditch and parameter change			99.5	105.5
	Sensitivity 3: BM with empty ditch, parameter change and cracked blanket			100.7	106.4
	Sensitivity 4: BM with full ditch and parameter change			109.0	104.7
	Sensitivity 5: 10-foot blanket BM with empty ditch			105.2	107.1
	Sensitivity 6: 10-foot blanket BM with empty ditch and boundary change			105.2	107.1
	Sensitivity 7: 10-foot blanket BM with full ditch			>109.1	107.1
Site 2: Station 1191+00 Left Bank	Base Model	108.9	97.5	>105.9	105.9
	Sensitivity 1: BM with parameter change			>105.9	104.0
Site 3: Station 1396+50 Left Bank	BM	112.2	98.0	104.9	109.2
	Sensitivity 1: BM change boundary			102.4	106.3
	Sensitivity 2: BM with truncation of waterside blanket and changed parameters			101.7	105.8

Notes:
1 Critical Gradient WSE is the WSE at which the hydraulic gradient matches the criteria limit at that location (see Section 4.1 for criteria limits based on offset distance from the landside levee toe)
2 Critical Factor of Safety WSE is the WSE at which a slip surface that could impact the global stability of the levee has a FOS of 1.4.

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Preliminary geotechnical analyses indicate that the amount of water that can be placed on the waterside levee slopes without exceeding geotechnical criteria varies depending on location within the Middle Eastside Bypass. Based on the discussions presented in Section 5, the following maximum water levels are considered appropriate for Sites1, 2 and 3.

Table 6-2. Summary of Preliminary Analysis Results for Channel Capacity Assessment [1]

Location	Controlling Geotechnical Criteria	Maximum Water Surface Elevation (feet) (NAVD88)	Approximate Height of Water on the Levee[2] (feet)
Site 1 (Ditch Empty)	Seepage	100.7	1.2
Site 1 (Ditch Full)	Slope Stability	104.7	5.2
Site 2	Slope Stability	104	6.5
Site 3	Seepage	101.7	3.7

Note:
[1] Height of water on the levee at a particular location does not necessarily translate directly to another site, i.e. if water were at a height of 1 foot on the levee at Site 1, then the height of water on the levee at a different location could be different.
[2] Height of water relative to the typical landside ground elevation

Based on the results presented in Table 6-2, conditions at Site 1 control the channel capacity of the Middle Eastside Bypass from the perspective of geotechnical criteria.

7 LIMITATIONS

This technical memorandum was prepared in accordance with the standard of care commonly used for seepage and stability analysis as the state-of-practice in the engineering profession. Standard of care is defined as the ordinary diligence exercised by fellow practitioners in this area performing the same services under similar circumstances during the same period.

Only seepage and stability conditions were considered for the purpose of this Technical Memorandum. Other geotechnical performance conditions, such as erosion, freeboard, rapid drawdown and seismic deformation were not assessed.

Seepage and stability criteria used in this review are based on standard USACE and ULDC criteria. As with any deterministic criteria, there is always a margin of risk associated with these criteria.

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The analysis results and recommendations presented in this technical memorandum are based on preliminary data and the results and recommendations should be refined once more detailed information becomes available.

The effects of nuisance seepage (through seepage and shallow foundation underseepage) that are known to be an issue in this levee system were not considered in the preparation of this technical memorandum.

Interceptor trench drains are known to exist along the levee system offset a distance from the landside levee toe. The details of these interceptor drains are not that well known, but it is understood that they have not been engineered to check filter compatibility between the drain and the surrounding soils. These drains are pumped all year round and could be a potential source for piping of material. The presence and impact of these drains was not considered as part of our analysis.

Notwithstanding the information presented in this Technical Memorandum, standard Operation & Maintenance flood monitoring should continue to occur.

This technical memorandum is for the use and benefit of the DWR. Use by any other party is at their own discretion and risk.

8 REFERENCES

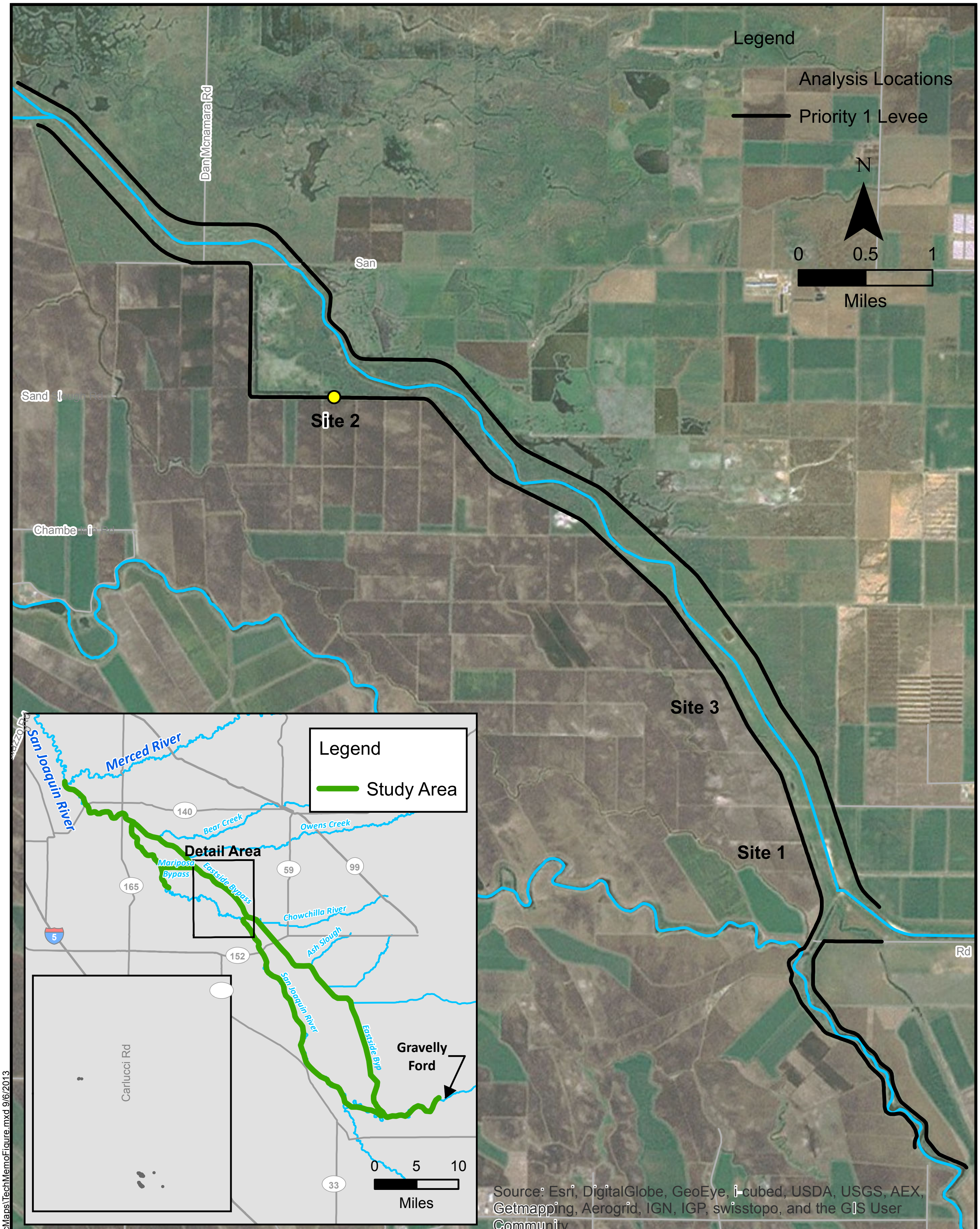
DWR. 2012. Urban Levee Design Criteria, May 2012

URS. 2013. Guidance Document for Geotechnical Analyses, Revision 13; September 2013

USACE. 2000. Engineers Manual 1110-2-1913 Engineering and Design - Design and Construction of Levees, 30 April 2000.

USACE. 2003. Engineers Manual 1110-2-1902 Engineering and Design – Slope Stability, 31 October 2003.

FIGURES



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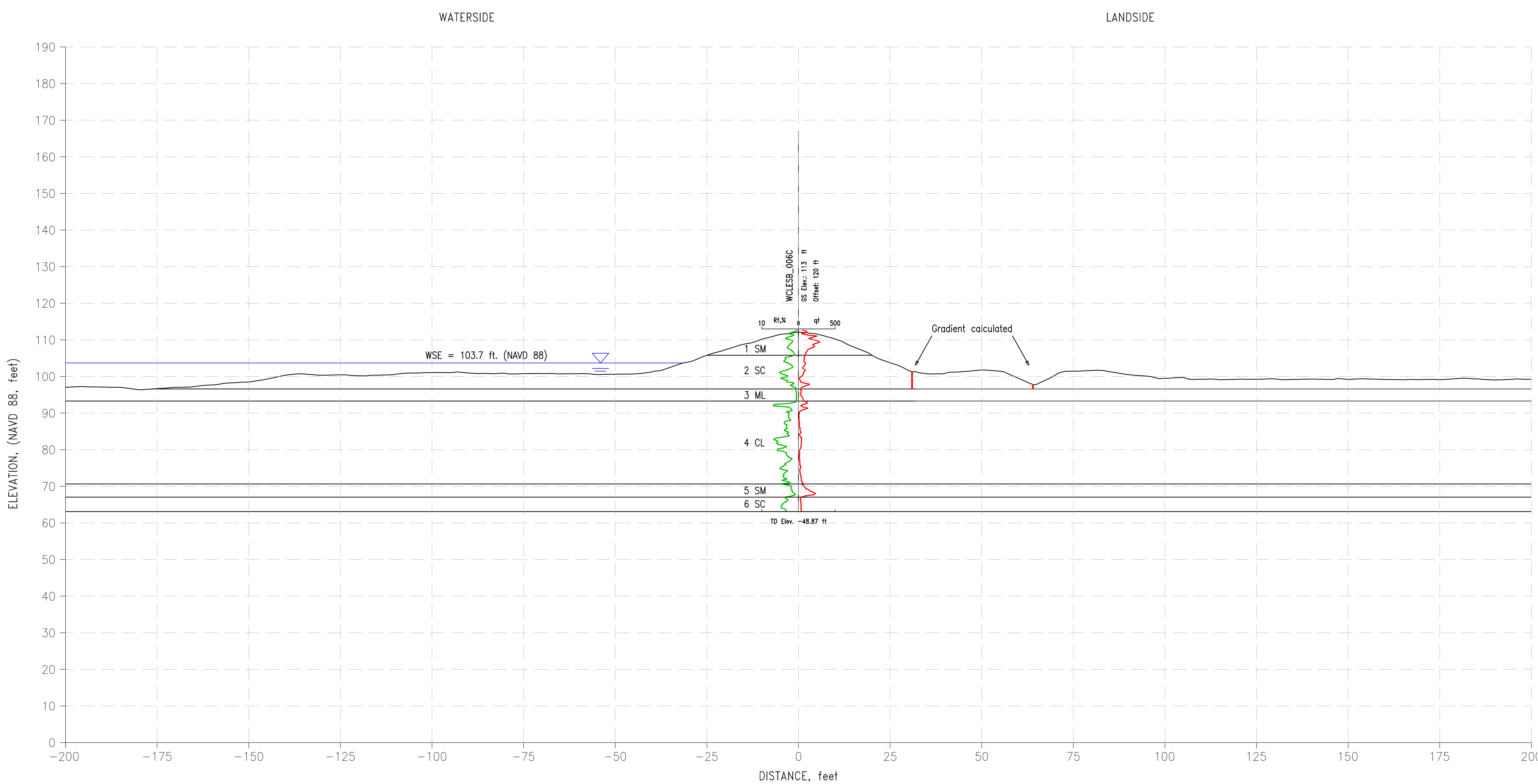
Department of Water Resources Division of Flood Management	URS	Site Location Map SJRRP	**Figure 1**



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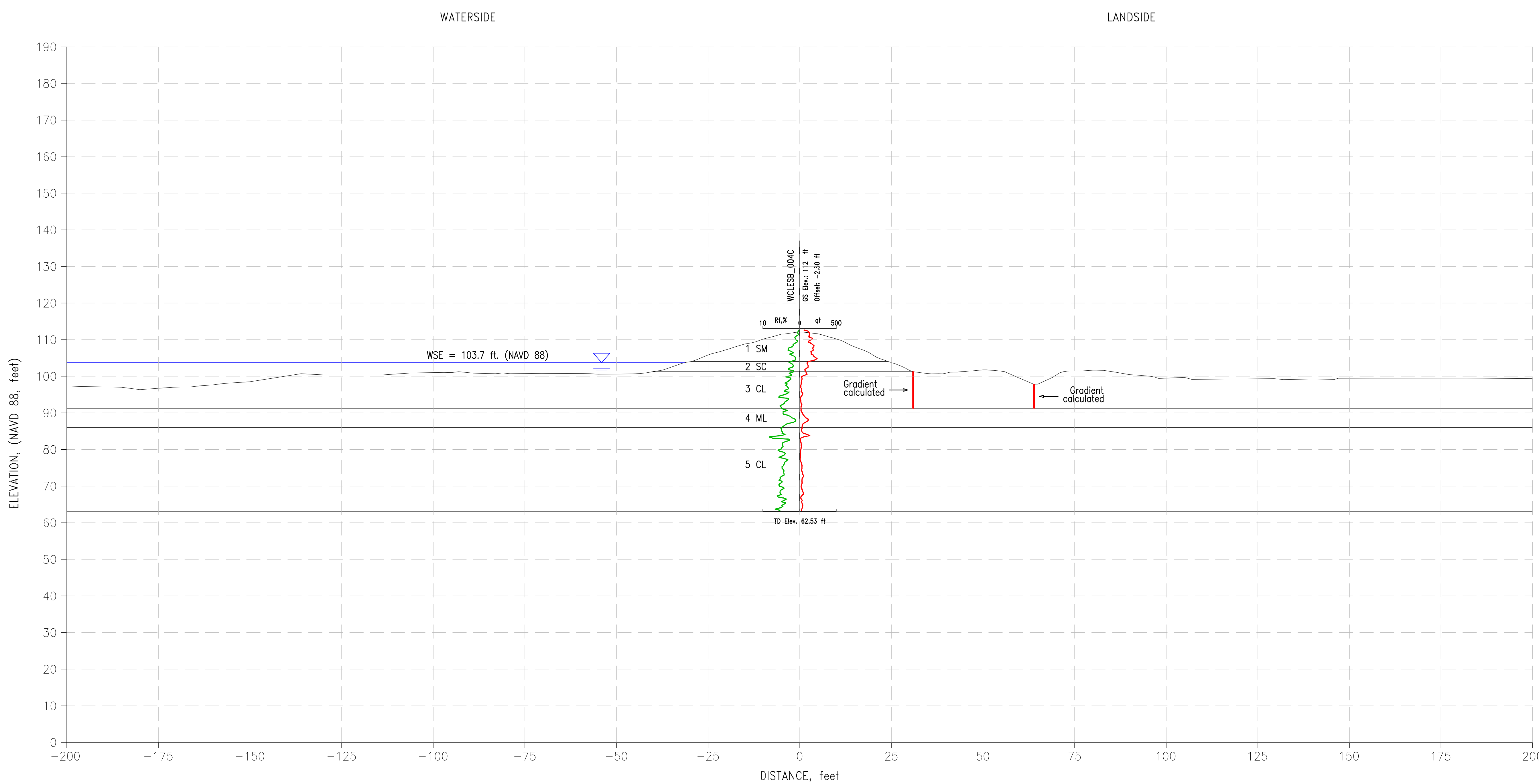
Department of Water Resources Division of Flood Management	URS	CONTRACT NUMBER 4600008101	PREPARED BY T. Hull	SAN JOAQUIN RIVER RESTORATION PROJECT DWR LEVEE EVALUATIONS	TRANSVERSE CROSS SECTION SITE 1 Station 1460+00 Base Model	FIGURE 2
		TASK ORDER TO U113	CHECKED BY M. Hughes			



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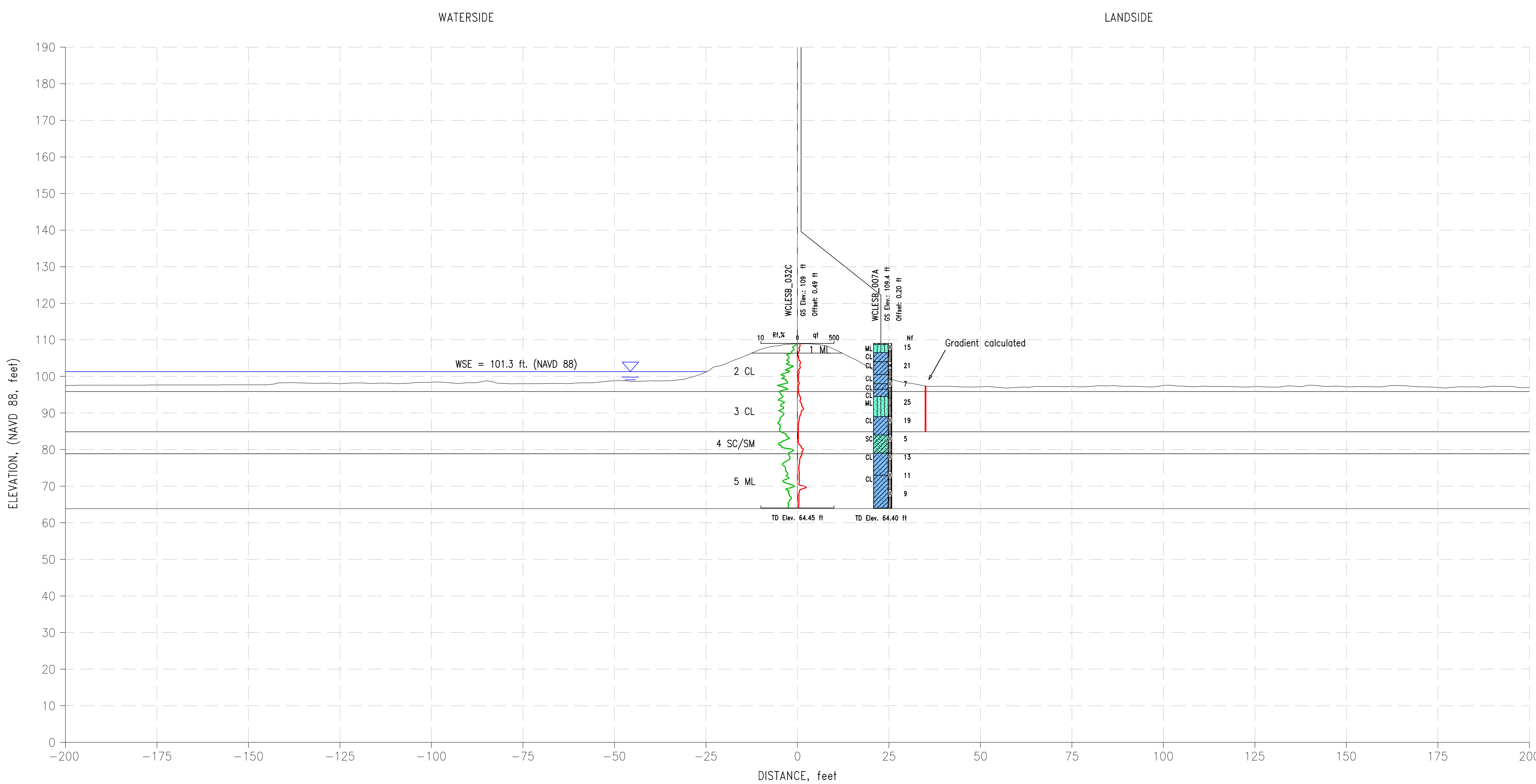
CONTRACT NUMBER 4600008101	PREPARED BY T. Hull	SAN JOAQUIN RIVER RESTORATION PROJECT DWR LEVEE EVALUATIONS	TRANSVERSE CROSS SECTION SITE 1 STATION 1460+00 10 ft. Blanket Model	FIGURE 3
TASK ORDER TO U113	CHECKED BY M. Hughes			



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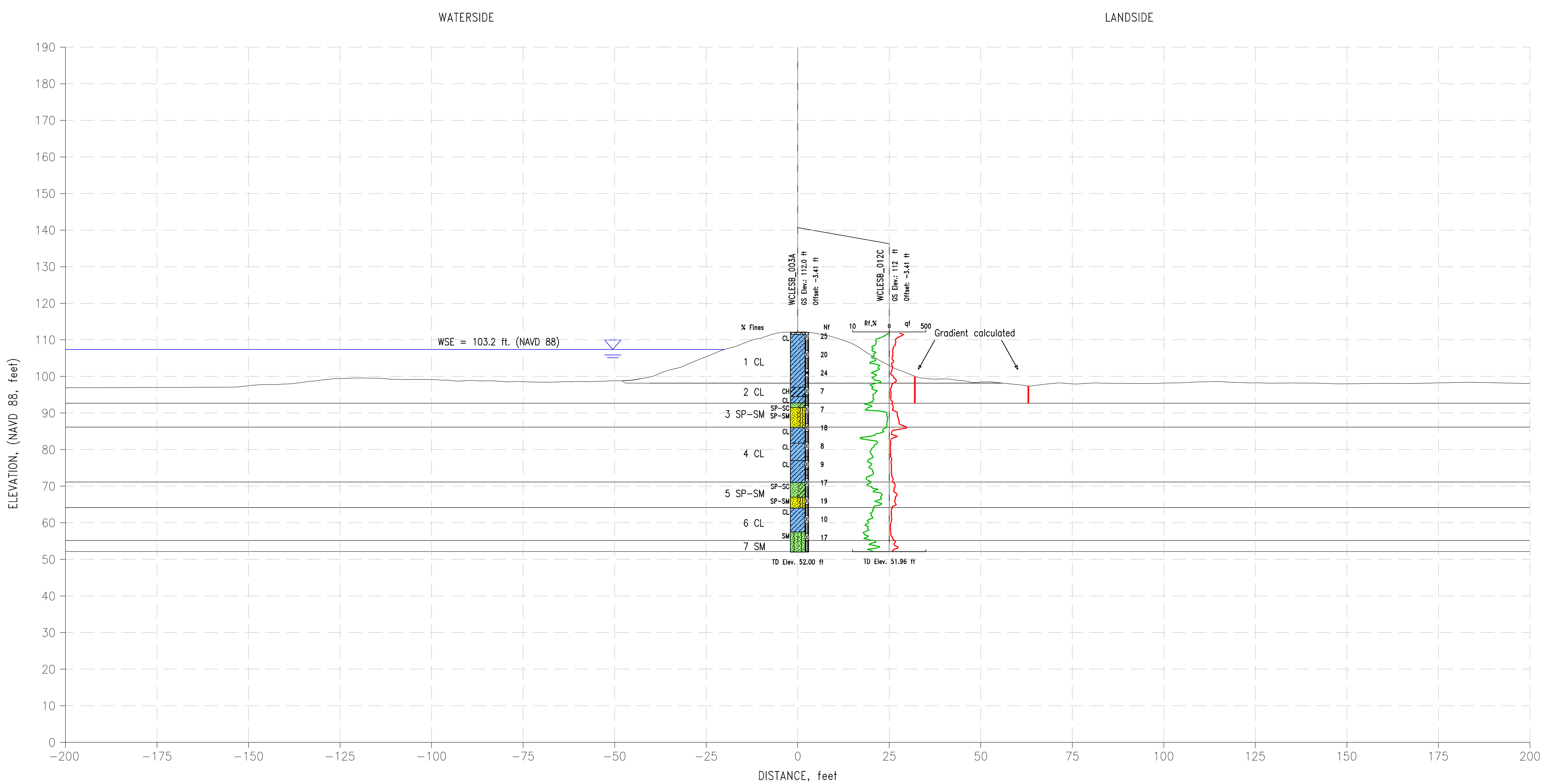
CONTRACT NUMBER 4600008101	PREPARED BY T. Hull	SAN JOAQUIN RIVER RESTORATION PROJECT DWR LEVEE EVALUATIONS	TRANSVERSE CROSS SECTION SITE 2 STATION 1191+00 BASE MODEL	FIGURE 4
TASK ORDER TO U113	CHECKED BY M. Hughes			



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SAN JOAQUIN RIVER RESTORATION PROJECT
DWR LEVEE EVALUATIONS

TRANSVERSE CROSS SECTION
SITE 3
STATION 1396+50 BASE MODEL

FIGURE
5