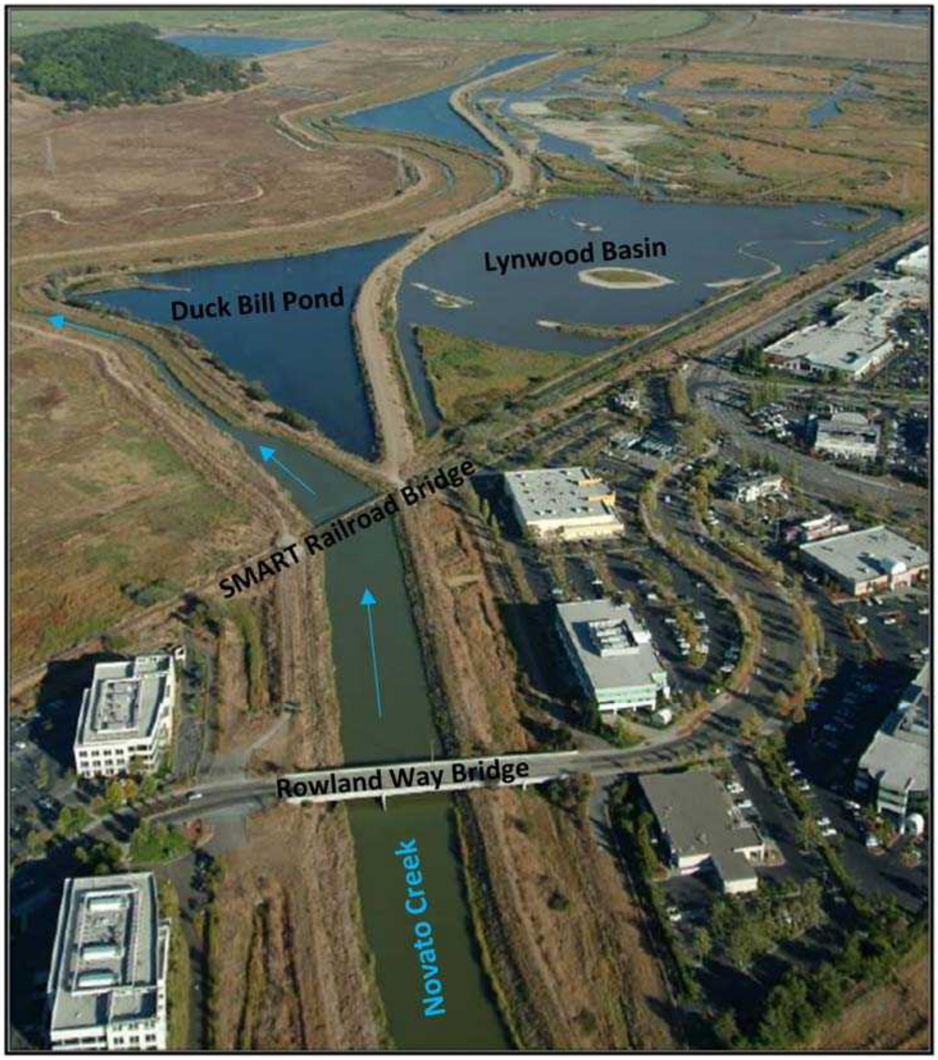
Hydraulic Evaluation of Novato Creek Levees



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1. Introduction

This levee evaluation and associated work for this project focus on levees along the Novato Creek reach between the Sonoma Marin Area Rail Transit (SMART) trestle and State Route 37 (SR-37), with an additional optional section along the left bank (left bank refers to left bank side of creek when looking downstream) of Novato Creek downstream of SR-37 (Figure 1). The Pacheco Pond levee being evaluated is located farther south of SR-37, to the east of Pacheco Pond and south of Bel Marin Keys Blvd. Specifically, the reaches of the Novato Creek levee system included under this hydraulic evaluation consist of three required levee sections and one optional levee section; the Novato Creek left bank levee upstream of SR-37, Lynwood levee, Pacheco Pond levee, and the optional Novato Creek left bank levee downstream of SR-37. Under the direction of Marin County Flood Control and Water Conservation District (District), the upper Novato Creek right bank levee (the black dashed line in Figure 1) is planned to be removed due to its relatively low height and frequent breaching; therefore, this levee was assumed removed under both existing and improved/raised levee conditions. The optional Novato Creek left bank levee downstream of SR-37 is the optional levee for geotechnical evaluation, not in the scope of this hydraulic evaluation.

The Novato Creek left bank levee upstream of SR-37 spans approximately 8,500 linear feet beginning at the SMART railroad bridge on the north side of Novato Creek and continues along the north and easterly side of Novato Creek terminating perpendicular to the SR-37 Bridge. The upper Novato Creek right bank levee (which is going to be removed) spans about 8,200 linear feet beginning at the SMART railroad bridge on the south side of Novato Creek and continues along the south and westerly side of Novato Creek terminating perpendicular to the SR-37 Bridge. Adjacent to the upper Novato Creek right bank levee to the west are two wildlife preserve ponds known as Duck Bill and Heron’s Beak ponds. To the east of the Novato Creek left bank levee upstream of SR-37 is the Deer Island Open Space Preserve, comprising approximately 280 acres. The lower Novato Creek left bank levee being considered for an additional optional evaluation is approximately 10,700 linear feet and is located downstream of SR-37. The Lynwood Levee is located to the west of the upper Novato Creek right bank levee and extends from the SMART railroad bridge southerly to SR-37 (about 6,700-ft). It separates the 278-acre Lynwood stormwater detention basin on the west side from the two wildlife preserve ponds on the east. The Lynwood stormwater detention basin is gravity fed and serves as both a stormwater detention area for a large portion of residential and commercial properties to the west and as a wildlife preserve, and is owned by the State of California Department of Fish & Wildlife. The two small ponds on the east of the Lynwood Levee were created primarily for wildlife habitat, but do also provide a small amount of additional stormwater detention as the Lynwood Pump Station has one pump discharging into the northerly Duck Bill pond and Novato Creek has a controlled overflow into Duck Bill pond for high water events. The Cheda Creek Pump Station discharges into the southerly Heron’s Beak pond and Novato Creek has also at times overflowed into Heron’s Beak pond on very high water events. There is no intended outlet for Duck Bill Pond, but the upper 3 to 4 feet of Heron’s Beak pond is drained by gravity through a manually-operated gate into Novato Creek during low tides.

Pacheco Pond is a storm water detention basin and wildlife habitat pond located south of SR-37. The pond is bordered by Bel Marin Keys Blvd to the north, the commercial Ignacio Industrial

Park to the west, vacant City of Novato lands to the southwest and the State of California lands to the southeast. The Hamilton Restoration project is taking place to the south on State lands. The eastern border of Pacheco Pond is held by an earthen levee approximately 3,800 linear feet in length. Pacheco Pond covers an area of approximately 120 acres and is fed by Pacheco Creek and Arroyo de San Jose. The pond drains beneath Bel Marin Keys Boulevard to the northwest, through a channel that parallels Bel Marin Keys Blvd, and then into Novato Creek through an existing concrete wall with multiple tide gates (see Figure 4 for the tidal gates). Stormwater flowing from Pacheco Pond discharges through the tide gates at the confluence with Novato Creek, which also control tidal back-flow into Pacheco Pond. High water in Novato Creek directly impacts the drainage of Pacheco Pond during storm events by not allowing drainage of the pond at the tides gates, which results in high water conditions along the Pacheco Pond levee.

There is a 100 linear-foot erodible weir along the Novato Creek left bank levee constructed in 2016. The weir is located approximately 300-ft downstream of the SMART trestle and was designed to divert rising Novato Creek water into West Deer Island Basin to prevent flooding at upstream developed areas in Downtown Novato. The top erodible portion of the weir is about 2 feet.

This hydraulic evaluation used the existing Novato Creek watershed HEC-HMS hydrologic model (developed by the District in 2013) and the existing Novato Creek watershed-wide HEC-RAS 1D/2D unsteady-flow hydraulic model (developed by Schaaf & Wheeler in 2018), and updated/modified the models as necessary to meet the needs of this specific study. The HEC-HMS hydrologic model provides flow inputs for the HEC-RAS hydraulic model.

This report documents the model updates/modifications and the results of hydraulic evaluation of the levees under both existing and improved/raised levee conditions. The improved/raised levee conditions considered the following three alternatives:

1) Baseline: Recommend improvements to maintain 50-year flood protection.
2) FEMA Accredited: Recommend improvements to secure FEMA accreditation.
3) Baseline with Sea Level Rise: Recommend improvements to provide 50-year flood protection for the year 2050.

The Novato Creek levees were originally designed and constructed to convey flows from a 50-year return interval flood (Q_{50} is about 3,865 cfs at the USGS gage as estimated by the District in 2013). That is why the Baseline calls for improvements to maintain 50-year flood protection. The levee assessment will seek to evaluate the adequacy of the heights and freeboards of the levees to contain the design flood events. Since the levees must contain both riverine floods and coastal floods, it follows that the assessment will need to analyze both *riverine* flood conditions and *coastal* flood conditions, independently, since simultaneous flooding from both sources is improbable. The model results for the two flood conditions will be overlaid to determine which flood condition “controls” and where.

Table 1 is a summary of the three modeling alternatives, objectives, and upstream flow and downstream tidal boundary conditions. Table 2 is a summary of formulated six modeling scenarios based on the three modeling alternatives, of which three scenarios for riverine flood (Scenarios 1a, 2a, and 3a) and three scenarios for coastal flood (Scenarios 1b, 2b, and 3b).

Coastal floods in the San Francisco Bay area are typically accompanied by storms, so some measure of riverine contribution should be accounted for. For the purpose of this levee evaluation, a 10-year storm event to accompany the 100-year coastal flood was assumed in the 100-year coastal flood analysis. The inclusion of a 10-year storm event with the 100-year coastal flood is considered a reasonable combination[1]; however, it is not required by FEMA for its 100-year coastal floodplain mapping. The difference between Scenario 1b and Scenario 2b is that the 10-year flow in the District-provided HEC-HMS model was assumed in Scenario 1b, while the 10-year flow based on FEMA FIS was assumed in Scenario 2b.

According to the 2017 FEMA effective Flood Insurance Study (FIS), the 100-year peak discharge at the USGS gage is 3,990 cfs. This FEMA-estimated 100-year peak discharge is just a little higher than the District-estimated 50-year peak discharge of about 3,865 cfs, and significant lower than the District-estimated 100-year peak discharge of about 4,800 cfs. The main reason for this difference is that the 2017 FEMA FIS relied on the USGS historical annual peak discharge data going back to at the latest 1987. The District updated the flood frequency analysis in 2013 using the USGS data through 2012.

Using the FEMA-estimated 100-year peak discharge for FEMA levee accreditation would be acceptable to FEMA. There is no need to use the District-updated higher peak discharge. Below is an excerpt from the 2019 FEMA Guidance for Flood Risk Analysis and Mapping/ Levees:

4.4 Accredited Levee Mapping and Notes

4.4.1 New Hydrologic and Hydraulic Analyses

If new hydrologic and/or hydraulic analyses for the exterior flooding source are submitted as part of a levee accreditation package, it must be reviewed to determine that it meets FEMA criteria before it can be used to revise the effective BFEs. If the new hydrologic and/or hydraulic analysis indicates the base flood hazards are less conservative than the effective, this review must occur and the effective BFEs must be updated before the levee can be accredited. However, if the new hydrologic and/or hydraulic analysis indicates the base flood hazards are more conservative than the effective, the levee system may be accredited without revising the BFEs and FEMA will determine if a future revision based on the new analysis is warranted.

The State of California Sea-Level Rise Guidance/2018 Update (California Natural Resources Agency 2017) provides a science-based methodology for state and local governments to analyze and assess the risks associated with sea level rise and incorporate sea level rise into their planning, permitting, and investment decisions. For the purpose of this study, the future sea level rise of 1.1 ft by 2050 under the “67% probability, high emissions” scenario (see Table 1 of the California Sea-Level Rise Guidance) was selected for the sea level rise modeling analysis[2].

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[1] For example, the 1/27/1983 coastal flood event, which has the highest recorded peak tide observed at the San Francisco Bay tidal gage station (NOAA #9414290) over its 150-year period of record, was accompanied by a 5 - 10 year storm event.

[2] Schaaf and Wheeler used the same guidance for the sea level rise in its modeling analysis but selected a different value of 1.9 ft for the sea level rise by 2050 (see Appendix A). This sea level rise has a 1-in-200 chance or 0.5% probability. Stetson judges that this probability is too conservative.

Table 1 Modeling Alternatives

Modeling Assumptions and Objective	Alternative Name and Description		
	1 **Baseline**	**2** **FEMA Accredited**	**3** **Baseline with Sea-Leve Rise**
	Recommend improvements to maintain 50-year protection	**Recommend improvements to secure FEMA accreditation**	**Recommend improvements to provide 50-year protection for the year 2050**
Riverine Flood Hydraulics Flow Assumption	District-Provided HMS model (50-yr flow)	100-yr flow based on FEMA FIS	District-provided HMS model (50-yr flow)
Riverine Flood Hydraulics Downstream Boundary Condition Assumption	MHHW for present day (FEMA)	MHHW for present day (FEMA)	District-provided MHHW for year 2050
Coastal Flood Hydraulics Downstream Boundary Assumption	100-yr Bay coastal water surface elevation (FEMA)	100-yr Bay coastal water surface elevation (FEMA)	District-provided approximate 100-yr Bay coastal water surface elevation for 2050
FEMA Accreditation per 44 CFR. 65.10?	No	Yes	No
USACE PL84-99* Compliant?	Yes	Yes	Yes

* Enrollment in the Rehabilitation & Inspection Program under Public Law 84-99 (PL 84-99) provides reimbursement for specific damages to levees that result from high-water events. Federally designed and constructed levees are enrolled at the end of construction; non-federally constructed levees (such as Novato Creek levees) have to apply and be accepted into the Public Law 84-99 program. To be included in the PL 84-99 program, a levee system or flood control project must be routinely inspected by the U.S. Army Corps of Engineers (USACE) and found to meet USACE construction standards and to be maintained in a fashion that does not deter from its structural integrity. A levee system must maintain an acceptable or minimally acceptable rating on 18 line items to remain active. The latest guidance from USACE is a Memorandum dated March 21, 2014 (Subject: Interim Policy for Determining Eligibility Status of Flood Risk Management Projects for the Rehabilitation Program Pursuant to Public Law (P.L.) 84-99) which provides the eligibility for non-federal levee systems.

Table 2a   Riverine Flood Modeling

Scenario	Channel Bed and Levee Condition	Upstream Inflow	Downstream Tidal Boundary Condition
Scenario 1a	Existing condition with removal of the Novato Creek right bank levee along the Heron's Beak and Duck Bill ponds	50-year flow in the District-provided HEC-HMS model	FEMA Present MHHW (6.3 ft NAVD88)
Scenario 2a		100-year flow based on FEMA FIS	FEMA Present MHHW (6.3 ft NAVD88)
Scenario 3a		50-year flow in the District-provided HEC-HMS model	Future 2050 MHHW (7.4 ft NAVD88) with SLR (1.1 ft)

1) 50-year peak flow in the District-provided HEC-HMS model: 3,865 cfs at the USGS gage.
2) 100-year peak flow based on FEMA FIS: 3,990 cfs at the USGS gage.
3) Source of sea level rise (SLR) by 2050: California Natural Resources Agency: *State of California Sea-Level Rise Guidance, 2018 Update (*"67% probability, high emissions").
4) Downstream tidal boundary: tidal hydrograph with the peak tide (MHHW) time shifted to match with the stream flow hydrograph peak time.

Table 2b   Coastal 100-Year Flood Modeling

Scenario	Channel Bed and Levee Condition	Upstream Inflow	Downstream Tidal Boundary Condition
Scenario 1b	Existing condition with removal of the Novato Creek right bank levee along the Heron's Beak and Duck Bill ponds	10-year flow in the District-provided HEC-HMS model	FEMA 100-year Bay Coastal water surface elevation (10 ft NAVD88)
Scenario 2b		10-year flow based on FEMA FIS	FEMA 100-year Bay Coastal water surface elevation (10 ft NAVD88)
Scenario 3b		10-year flow in the District-provided HEC-HMS model	Future 2050 100-year Bay Coastal water surface elevation (11.1 ft NAVD88) with SLR (1.1 ft)

1) Source of current 100-year tide: FEMA effective 2017 FIS.
2) 10-year peak flow in the District-provided HEC-HMS model: 2,050 cfs at the USGS gage.
3) 10-year peak flow based on FEMA FIS: 2,090 cfs at the USGS gage.
4) Downstream tidal boundary: tidal hydrograph with the peak tide (100-year tide) time shifted to match with the stream flow hydrograph peak time.

2. Updates/Modifications to the Existing HEC-RAS 1D/2D Hydraulic Model

The existing HEC-RAS 1D/2D unsteady-flow hydraulic model developed by Schaaf & Wheeler (S&W) for the Novato Creek watershed existing conditions was first provided to Stetson in early July 2018 (refer to Appendix A for the S&W model documentation). Stetson reviewed the model and provided comments on July 20, 2018 (refer to Appendix B for Stetson comments)[3]. S&W then revised the model by incorporating almost all Stetson comments (refer to Appendix C for S&W revisions to the model) and provided the revised model to Stetson on August 10, 2018.

The existing HEC-RAS 1D/2D model encompasses the entirety of Novato Creek from Stafford Lake to San Pablo Bay (See Figure 1 within Appendix A). Figure 2 shows the model configuration and hydraulic facilities included in the model. Novato Creek and the tributary Arroyo Avichi are modeled as 1D channels. The creeks floodplain and 14 bayland basins/ponds are modeled as 2D flow areas. The 14 bayland basins/ponds include West Deer Island Basin, Deer Island Basin, Farmers Basin (also known as South Deer Island Basin in older reports such as Appendix A), Duck Bill Pond, Heron's Beak Pond, Lynwood Basin, Leveroni Basin, Pacheco Pond, Basin A, Basin B, Basin C, Bel Marin Keys North, Bel Marin Keys South, and Bel Marin Keys V. Table 3 shows the initial water levels used in the hydraulic model for the 14 bayland basins/ponds. Most of the initial water surface elevations were from the KHE's 2014 Existing Conditions Study report except for the Pacheco Pond and the Duck Bill and Heron's Beak Ponds in which the mean higher high water (MHHW; 6.3 ft NAVD88) was used. The initial water level for the Pacheco Pond used in the KHE's 2014 Existing Conditions Study was 2.63 ft NAVD88, which is much lower than the MHHW. Pacheco Pond has some real water quality issues and mosquito impacts under the current operations regime. Using the MHHW as the initial water level for the Pacheco Pond is intended to use a conservative assumption for the levee height evaluation. As a matter of fact, the he Pacheco Pond Water Management Plan (DRAFT) prepared by the District in 2014 made some recommendations to change the current operations for maintaining the pond as a flood control basin and wildlife habitat.

No pumps are included in the existing HEC-RAS 1D/2D model. Stetson believes that not including pumps in the model is correct for a FEMA analysis, because the pumps would likely be assumed non-operable for an interior drainage study any way. The total pumping capacity of the four pump stations is about 250 cfs [Lynwood Pump Station (4 pumps): 145 cfs; Cheda Pump Station (2 pumps): 30 cfs; Simmons Pump Station (1 pump): 38 cfs; Farmers Pump Station (1 pump)]. This total pumping capacity would have little effect on the levee height evaluation during a 50-year or a FEMA 100-year flood event. A 50-year flood event has an

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[3] We also reviewed the following documents, models, and data, and identified data gaps and survey needs:

- The Novato Creek watershed HEC-HMS hydrologic model developed by the District and associated model documentation (2013), and model review comments prepared by WRECO (2013).
- Hydraulic Assessment of Novato Creek Existing Conditions (Kamman & WRECO, 2014).
- Novato Creek Hydraulic Study/ Analysis of Alternatives (Kamman & WRECO, 2016).
- Pacheco Pond Water Management Plan (DRAFT) prepared by the District (2014).
- FEMA Flood Insurance Study (effective 2017).
- 2016 topographic and bathymetric survey data.
- Interim Policy for Determining Eligibility Status of Flood Risk Management Projects for the Rehabilitation Program Pursuant to Public Law (P.L.) 84-99 (USACE, 2014).
- ER 1105-2-101: Risk Assessment for Flood Risk Management Studies (USACE, 2017).

estimated total peak discharge of about 13,000 cfs into the bayland area, including about 6,000 cfs at the SMART Bridge, 1,900 cfs into the bayland ponds north of Novato Creek, and 5,100 cfs into the bayland ponds south of Novato Creek. This estimated total Q_{50} of about 13,000 cfs is much higher the total pumping capacity of about 250 cfs.

No buildings in the floodplain are represented in the existing HEC-RAS 1D/2D model. Flooded buildings provide resistance to flows and may affect the water surface elevations at the buildings, but would be expected to have little effect on the levee height evaluation.

Table 3 Initial Water Levels for the 14 Bayland Basins/Ponds

Basin Name	**Initial Water Level** (ft NAVD88)
West Deer Island Basin	
Deer Island Basin	
Farmers Basin	
Duck Bill Pond	6.3
Heron's Beak Pond	6.3
Lynwood Basin	4.5
Leveroni Basin	
Pacheco Pond	6.3
Basin A	
Basin B	
Basin C	
BMK North	4.6
BMK South	3.6
BMK V	

Note: "Blank" initial water level means that the basin/pond is initially dry.

Stetson made the following further updates/revisions to the HEC-RAS 1D/2D model that was provided by S&W in August 2018:

- Updated the terrain model with the 2016 and 2018 survey data[4] received for the project (refer to Figure 3 for the 2016 and 2018 survey data), including:
    - 2018 topographic survey data for the Pacheco Pond levee (pink), the southwest levee of Farmers Basin (blue), the ground at the southwest corner of Lynwood Basin (blue), surveyed for this levee evaluation project.

[4] Both the 2016 and 2018 surveys were performed by CLE Engineering Inc. The 2016 survey was performed in March to April 2016 for the Pacheco Pond and tidal gates, and in February 2016 for other areas. The 2018 survey was performed in November 2018.

- 2018 bathymetric survey data for the Novato Creek channel reach upstream of the SMART crossing, Duck Bill Pond, and Heron's Beak Pond (blue), surveyed for this levee evaluation project.
    - 2018 bathymetric survey data for the Novato Creek channel reach below SR-37 (dark green), surveyed for Bel Marin Keys.
    - 2016 topographic survey data for the levees surrounding West Deer Island Basin, Deer Island Basin, and Lynwood Basin (orange).
    - 2016 bathymetric survey data for the northwest portion of Lynwood Basin (light green).
    - 2016 bathymetric survey data for Pacheco Pond (bright green).
- Updated the Novato Creek channel cross section profiles with the 2018 bathymetric survey data.
- Geo-referenced alignment for the levees to be evaluated.
- Updated levee crest profiles with the 2016 and 2018 levee elevation survey data.
- Updated the invert and top elevations of Pacheco Pond outflow tidal gates with the 2016 survey data (see Figure 4 for the Pacheco Pond outflow tidal gates).
- Fixed a few cross sections overshoot/undershoot issues and refined a few basin/pond boundaries.
- Fixed an incorrect flow input to the main channel for both the 50-year and 100-year flow inputs (the S&W model double counted the Pacheco Pond inflow to the model, apparently due to that S&W forgot to subtract it out from the main channel when they added inflow to Pacheco Pond requested by Stetson).

3. Model Simulations of Existing Conditions with the Right Bank Levee Removed

Under the District direction, the following three assumptions were made in the simulations of existing conditions:

- The Novato Creek right bank levee along the Duck Bill and Heron's Beak ponds (the black dashed line in Figure 1) was assumed removed.
- The erodible weir was assumed to be intact during the simulated flood events due to unknown erosion criteria for the weir.
- All existing and proposed pumps through the evaluated levees were assumed non-operable.

With above assumptions, the HEC-RAS 1D/2D model was used to simulate the water surface elevations for the six scenarios listed in Tables 2a and 2b.

Figures 5, 6, and 7 show the riverine flood inundation depths and extents for Scenarios 1a, 2a, and 3a, respectively. Similarly, Figures 8, 9, and 10 show the coastal flood inundation depths and extents for Scenarios 1b, 2b, and 3b, respectively. These figures also show the levee ground elevations, the simulated water surface elevations, and the identified overtopped project levee reaches.

Figure 11 shows the simulated water surface elevation (WSE) profiles for the six scenarios under existing conditions. Between SR-37 and the SMART railroad bridge, the riverine flood WSEs of Scenarios 1a, 2a, and 3a are basically the same, and the coastal flood WSEs of Scenarios 1b, 2b, and 3b are almost the same too, and the riverine flood WSEs are higher than the coastal flood WSEs. Therefore, the overtopped project levee reaches would be the same for the riverine flood scenarios (see Figures 5, 6, and 7), and more/longer than those for the coastal flood scenarios (see Figures 8, 9, and 10). The sea level rise modeled (1.1 feet by 2050) would have little effect on the riverine and coastal flood WSEs between SR-37 and the SMART railroad bridge. Given the relatively small channel size, streamflow hydraulics between SR-37 and the SMART railroad bridge, not the height of the tide, has a greater effect on the stream water level during a large flood event by pushing the tidal water downstream.

The erodible weir would not be overtopped under existing conditions.

Figure 12 compares the simulated WSE profiles between without and with removal of the right bank levee along the Duck Bill and Heron's Beak ponds. The difference represents the water surface reduction benefit by removing the right bank levee. Figure 12 shows a general decrease in WSE as a result of removal of the right bank levee by up to 1.0 ft (at the SMART railroad bridge) but an increase in WSE at and just upstream/downstream of the SR-37 Bridge. The increase in WSE near the SR-37 Bridge is the result of the higher backwater effect at the SR-37 Bridge. The removal of the right bank levee would result in lower WSE in the Novato Creek main channel and increase the capacity of the creek to convey floodwaters (allow more water in the channel) and reduce floodwater overflow into the floodplain at the Arroyo Avichi Creek confluence area. This increased in-channel flow would result in higher backwater effect at the SR-37 Bridge.

Findings from the Riverine 50-Year and FEMA 100-Year Flood Modeling (see Figures 5, 6, and 7):

1) The existing levee system would not be able to contain the District-estimated 50-year flood flow without overtopping.
2) The SR-37 near HWY 101 would be flooded.
3) A portion of commercial properties on the west side of the Lynwood Basin would be flooded.
4) A portion of residential properties on the west side of HWY 101 near the southwest corner of the Lynwood Basin would be flooded.
5) About 1,150 ft long levee reach of the Novato Creek left bank levee immediately upstream of SR-37 would be overtopped.
6) About 200 ft long middle reach of the Novato Creek left bank levee upstream of SR-37 would be overtopped.
7) About 810 ft long Lynwood levee reach immediately upstream of SR-37 would be overtopped.
8) Most of the Pacheco Pond levee would be overtopped. Note: This overtopping would be necessary for flood protection for the west side properties.
9) There would be overland flood flow (about 1,150 cfs during a 50-year riverine flood) from the Arroyo Avichi Creek confluence via Nave Gardens, Baccaglio Basin, and Scottsdale pond and marsh into Lynwood Basin, reducing the flood flow into the Novato Creek main channel. This overland flood flow originates from overflow of the Arroyo Avichi Creek right bank and overbank flow of the Novato Creek right bank near the confluence. Improving/raising the downstream levees to prevent the levee overtopping would increase the Novato Creek main channel WSE and, thus, result in more overland flood flow and flooding at the Arroyo Avichi Creek confluence area.

Below are additional findings from the riverine 50-year and FEMA 100-year flood modeling that are not shown in Figures 5, 6, and 7:

10) The top of the Pacheco Pond outlet tidal gates (2016 surveyed elevation at 9.6 ft NAVD88) would be overtopped, resulting overflow from Novato Creek into Pacheco Pond via the outflow channel, even if the tidal gates are closed.
11) A short Novato Creek left bank levee reach immediately downstream of SR-37 would be overtopped. This is the levee breach location during the recent 2/14/2019 storm event (an approximate 5-year flow event). Note: Evaluation of the Novato Creek left bank levee downstream of SR-37 is not in the scope of hydraulic analysis, but is in the optional task for geotechnical evaluation.
12) The Lynwood Basin south levee (along SR-37 on the north side) would be overtopped. Note: Evaluation of this levee is not in the scope of this levee evaluation project.

13) The Leveroni Basin north (along SR-37 on the south side), east, and south levees would be overtopped. Two levee breach-points occurred on the Leveroni Basin east levee during strong storm and high tide events in 2017. Note: These levees are not owned by the District and evaluation of these levees is not in the scope of this levee evaluation project.

<u>Findings from the 100-Year Coastal Flood Modeling (see Figures 8, 9, and 10):</u>

1) The existing levee system would not be able to contain the 100-year coastal flood without overtopping.
2) A portion of SR-37 near HWY 101 would be flooded.
3) No commercial properties on the west side of the Lynwood Basin would be flooded.
4) No residential properties on the west side of HWY 101 near the southwest corner of the Lynwood Basin would be flooded.
5) About 410 ft long levee reach of the Novato Creek left bank levee reach immediately upstream of SR-37 would be overtopped.
6) About 800 ft long Lynwood levee reach immediately upstream of SR-37 would be overtopped.
7) Most of the Pacheco Pond levee would be overtopped. Note: This overtopping would be necessary for flood protection for the west side properties.

Below are additional findings from the 100-year coastal flood modeling that are not shown in Figures 8, 9, and 10 (these additional findings are the same as the additional findings from the riverine flood modeling):

8) The top of the Pacheco Pond outlet tidal gates (2016 surveyed elevation at 9.6 ft NAVD88) would be overtopped, resulting overflow from Novato Creek into Pacheco Pond via the outflow channel, even if the tidal gates are closed.
9) A short Novato Creek left bank levee reach immediately downstream of SR-37 would be overtopped. This is the levee breach location during the recent 2/14/2019 storm event (an approximate 5-year flow event). Note: Evaluation of the Novato Creek left bank levee downstream of SR-37 is not in the scope of hydraulic analysis, but is in the optional task for geotechnical evaluation.
10) The Lynwood Basin south levee (along SR-37 on the north side) would be overtopped. Note: Evaluation of this levee is not in the scope of this levee evaluation project.
11) The Leveroni Basin north (along SR-37 on the south side), east, and south levees would be overtopped. Note: These levees are not owned by the District and evaluation of these levees is not in the scope of this levee evaluation project.

4. Model Simulations of Improved/Raised Levee Conditions to Generate WSEs for Geotechnical Alternatives Evaluation

Under the District direction, the following assumptions were made in the simulations of improved/raised levee conditions to generate WSEs for geotechnical alternatives evaluation:

- The Novato Creek right bank levee along the Duck Bill and Heron's Beak ponds (the black dashed line in Figure 1) was assumed removed (same as was modeled under existing conditions).
- The erodible weir was assumed to be intact during the simulated flood events due to unknown erosion criteria for the weir.
- Improvements were assumed only for the Novato Creek left bank levee upstream of SR-37 (except the erodible weir) and the Lynwood levee to contain the riverine and coastal floods without overtopping. No improvements were assumed for the Pacheco Pond levee and all other levees.
- No improvements were assumed to the Pacheco Pond outlet tidal gates, although the top of the tidal gates (2016 surveyed elevation at 9.6 ft NAVD88) would be overtopped during a riverine 50-year flood or a coastal 100-year flood.
- All existing and proposed pumps through the evaluated levees were assumed non-operable.
- A hypothetical floodwall on the Novato Creek right bank near the Arroyo Avichi creek confluence was assumed to prevent overtopping, allowing more flood flow in the Novato Creek main channel for evaluating the levees in a conservative manner.

The goal of these "improvements" is to develop WSEs for the geotechnical engineers to evaluate designs and costs for actual levee improvements. The final set of improvements will be developed as part of a separate Remedial Alternatives Report.

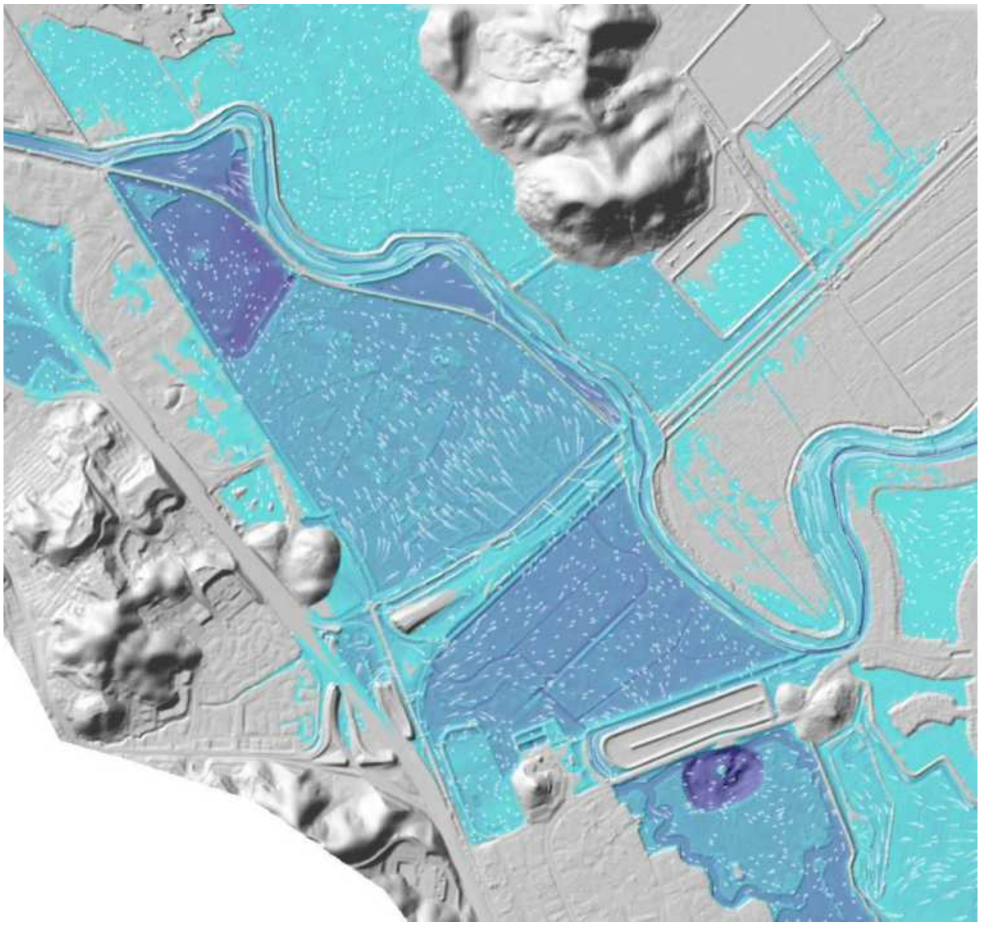
Figures 13 – 18 compare the simulated inundation extents between existing and improved/raised conditions for the six scenarios (1a, 2a, 3a, 1b, 2b, and 3b), respectively. Figures 19 – 21 compare the simulated inundation extents under improved/raised conditions between each comparable riverine and coastal flood conditions of the three alternatives, respectively (i.e., 1a vs. 1b; 2a vs. 2b; 3a vs. 3b).

Figure 22 shows the simulated WSE profiles for the six scenarios under improved/raised levee conditions. Between SR-37 and the SMART railroad bridge, the riverine flood WSEs of Scenarios 1a and 3a are basically the same, and are a little lower than Scenario 2a. The coastal flood WSEs of Scenarios 1b, 2b, and 3b are almost the same, and are lower than the riverine flood WSEs. The sea level rise would have little effect on the riverine and coastal flood WSEs between SR-37 and the SMART railroad bridge. Given the relatively small channel size, streamflow hydraulics between SR-37 and the SMART railroad bridge, not the height of the tide, has a greater effect on the stream water level during a large flood event by pushing the tidal water downstream.

Figures 23 – 25 compare the simulated WSE between existing and improved/raised levee conditions for the three riverine flood scenarios (1a, 2a, and 3a), respectively. Between SR-37 and the SMART railroad bridge, the simulated improved/raised levee conditions WSEs are about 0.6 – 0.9 ft higher than the simulated existing conditions WSEs. The higher improved/raised levee conditions WSEs are the result of (1) higher flood flows in the Novato Creek main channel due to the assumed hypothetical floodwall on the Novato Creek right bank near the Arroyo Avichi creek confluence for preventing overtopping, and (2) improved/raised levees of any overtopped reaches of the Novato Creek left bank levee upstream of SR-37 (except the erodible weir) and the Lynwood levee for containing the flood flows without any overtopping. The hypothetical floodwall would result in about 1,100 cfs more flood flow in the Novato Creek main channel. It is worth noting that under the improved/raised levee conditions, the erodible weir would be overtopped during a 50-year riverine flood but not be overtopped during a 100-year coastal flood.

Figures 13 – 15 show that compared to the existing conditions, during a riverine 50-year flood or FEMA 100-year flood, the improved/raised levee conditions modeled would make the flooding worse to the commercial properties on the west side of the Lynwood Basin. The reason for this is the higher flood flows in the Novato Creek main channel due to the assumed hypothetical floodwall on the Novato Creek right bank near the Arroyo Avichi creek confluence for preventing overtopping. The higher flood flows in the Novato Creek main channel would result in higher WSE in the downstream SR-37 which, in turn, result in more flood water into the Lynwood Basin from the downstream via overtopping of SR-37 (see the map below for flow directions indicated by the small white arrows). Similarly, during a riverine 50-year flood or FEMA 100-year flood, the improved/raised levee conditions would make the flooding worse to the residential properties on the west side of HWY 101 near the southwest corner of the Lynwood Basin. Without this assumed hypothetical floodwall, the flooding condition at the commercial properties should be improved a little (not worse) because the overtopping flow from Novato Creek into the Lynwood Basin at the downstream end of the Lynwood levee would be eliminated under the improved/raised levee conditions. It is important to note that the hypothetical floodwall is solely used to develop more conservative flows for the project alternative evaluation report work, which would allow us to overdesign a little the levee improvements now in case work is done upstream later. No projects that worsen flooding will be built.

Tables 4a and 4b are a summary of the simulated bayland basin/pond WSEs for the six scenarios under existing and improved/raised levee conditions, respectively. Figures 26, 27, and 28 graphically compare the simulated riverine flood WSEs of the bayland basin/pond WSEs between existing and improved/raised levee conditions for the three riverine flood scenarios (1a, 2a, and 3a). Compared to existing conditions, improved/raised levee conditions would increase the WSE of the Lynwood Basin by about 0.32 ft (10.45 – 10.13) during a riverine 50-year flood, 0.28 ft (10.58 – 10.30) during a riverine FEMA 100-year flood, and 0.21 ft (10.43 – 10.22) during a riverine 50-year flood with sea level rise. With sea level rise, both existing conditions and improved/raised levee conditions would have higher water surface elevations in the Lynwood Basin, but the WSE difference under the sea level rise condition would be less than that under the without sea level rise condition.



Simulated 2-Dimensional Flow Directions (Improved/Raised Levee Conditions)

Table 4a Simulated Bayland Basin/Pond WSEs – Existing Conditions with the Right Bank Levee Removed

Basin Name	Basin Bottom Elevation (ft NAVD88)	Riverine Flood WSE (ft NAVD88)			Coastal Flood WSE (ft NAVD88)		
		District Q50 (Scenario 1a)	FEMA Q100 (Scenario 2a)	District Q50 + SLR in 2050 (Scenario 3a)	FEMA 100yr Coastal Tide (Scenario 1b)	FEMA 100yr Coastal Tide (Scenario 2b)	FEMA 100yr Coastal Tide + SLR in 2050 (Scenario 3b)
West Deer Island Basin	3 to 4	4.39	4.57	4.53	4.14	4.15	4.14
Deer Island Basin	1 to 2	3.35	3.68	3.61	2.86	2.88	2.86
Farmers Basin	1 to 1.5	4.93	4.99	4.99	1.95	2.01	2.02
Lynwood Basin	-5 to 2.5	10.13	10.30	10.22	7.45	7.84	8.42
Leveroni Basin	0 to 1	10.04	10.20	10.12	7.65	8.10	8.42
Pacheco Pond	-1 to 3	9.76	9.78	9.76	9.39	9.41	9.42
Basin A	0 to 1	1.98	1.98	1.98	1.83	1.84	1.86
Basin B	-1 to 2	n/a	n/a	n/a	2.01	2.03	2.55
Basin C	1 to 2	1.18	1.76	1.72	n/a	n/a	n/a
BMK North	< 4	5.32	5.40	5.39	5.40	5.42	5.90
BMK South	< 2	3.60	3.60	3.60	3.61	3.61	4.01
BMK V	-3 to 0	2.13	2.18	2.16	0.98	1.02	1.08

Table 4b Simulated Bayland Basin/Pond WSEs – Improved/Raised Levee Conditions

Basin Name	Basin Bottom Elevation (ft NAVD88)	Riverine Flood WSE (ft NAVD88)			Coastal Flood WSE (ft NAVD88)		
		District Q50 (Scenario 1a)	FEMA Q100 (Scenario 2a)	District Q50 + SLR in 2050 (Scenario 3a)	FEMA 100yr Coastal Tide (Scenario 1b)	FEMA 100yr Coastal Tide (Scenario 2b)	FEMA 100yr Coastal Tide + SLR in 2050 (Scenario 3b)
West Deer Island Basin	3 to 4	6.01	6.61	6.05	4.14	4.15	4.14
Deer Island Basin	1 to 2	3.54	4.43	3.96	2.86	2.88	2.86
Farmers Basin	1 to 1.5	n/a	n/a	n/a	n/a	n/a	n/a
Lynwood Basin	-5 to 2.5	10.45	10.58	10.43	7.75	7.82	8.46
Leveroni Basin	0 to 1	10.37	10.50	10.35	8.08	8.10	8.47
Pacheco Pond	-1 to 3	9.76	9.79	9.77	9.38	9.40	9.41
Basin A	0 to 1	2.15	2.18	2.16	1.92	1.93	1.95
Basin B	-1 to 2	n/a	n/a	n/a	2.68	2.68	3.62
Basin C	1 to 2	n/a	n/a	n/a	n/a	n/a	n/a
BMK North	< 4	5.53	5.72	5.60	5.43	5.44	5.94
BMK South	< 2	3.60	3.60	3.60	3.61	3.61	4.03
BMK V	-3 to 0	2.15	2.20	2.16	0.98	1.00	1.05

5. Freeboard Assessment

Using the results of the hydraulic analysis for improved/raised levee conditions and the FEMA's applicable freeboard requirements, a freeboard assessment was conducted for the Lynwood levee, the Novato Creek left bank levee upstream of SR-37, and the Pacheco Pond levee. Per FEMA CFS65.10, the following requirements will be applicable:

Riverine Flood

- A minimum freeboard of three feet above the water-surface level of the base flood (FEMA 100-year flood);
- An additional one foot above the minimum is required within 100 feet upstream and downstream of structures (such as bridges) riverward of the levee or wherever the flow is constricted;
- An additional one-half foot above the minimum at the upstream end of the levee is also required, tapering to not less than the minimum at the downstream end of the levee;

Coastal Flood

- For coastal levees, the freeboard must be established at one foot above the height of the 1-percent wave or maximum wave runup (whichever is greater) associated with the 100-year stillwater surge elevation at the site.

For the purpose of this analysis, a freeboard of 3 ft for riverine flood and a freeboard of 1 ft for coastal flood were used. This is reasonable because there are no structures/bridges except the large SR-37 Bridge at the downstream end of the study reach[5], and there would be little wave effect in the study reach due to its small wind fetch and far away location from the bay. Wave runup is normally considered for coastal shorelines, not for tide-affected stream reaches.

Figure 29 is a layout of levee stationing that was used for the levee freeboard assessment.

Figures 30a, 30b, and 30c graphically present the freeboard assessment for the Lynwood levee for the three alternatives (Baseline, FEMA Accreditation, and Baseline with SLR), respectively. Most of the Lynwood levee would not meet the FEMA riverine freeboard requirement by up to about 5.6 ft (at stationing 71+00). The levee reach from stationing 62+50 to 71+00 would be overtopped by up to 2.6 ft during a FEMA 100-year riverine flood.

Figures 31a, 31b, and 31c graphically present the freeboard assessment for the Novato Creek left bank levee upstream of SR-37 for the three alternatives, respectively. The entire Novato Creek left bank levee upstream of SR-37 would not meet the FEMA riverine freeboard requirement by up to about 5.5 ft (at stationing 86+00). The levee reaches from stationing 40+00 to 43+50 and from stationing 72+50 to 86+00 would be overtopped by up to 0.8 ft and 2.5 ft, respectively, during a FEMA 100-year riverine flood.

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[5] The SMART railroad bridge is located at the upstream end of the study reach and has little backwater effect (see the WSE profiles). There is no need to consider additional freeboard requirement at/near this bridge.

Figure 32 graphically presents the water surface elevations[6] and ground elevations along the Pacheco Pond levee. Most of the levee would be overtopped with overtopping flow from the pond to the adjacent basin BMK V of the Hamilton Wetland Restoration Project. This overtopping would be necessary for flood protection for the west side properties and in fact occurred in the winter of 2019 where it led to erosion that needed repair. Under the direction of the District, no improvement/levee raise was assumed in the analysis. There is no need to conduct a freeboard assessment for the Pacheco Pond levee because overtopping of this levee is assumed to occur.

[6] Figure 32 shows that the simulated 100-year coastal water surface elevation in Pacheco Pond is about 9.4 ft NAVD88. This WSE is lower than the 100-year tide elevation. The reason for this is that the pond storage can attenuate a portion of the dynamic tidal flood volume, and there is a muting effect by the tidal gates and the Pacheco Pond outflow channel.

6. Qualitative Risk Analysis

Risk analysis is a process for describing the nature of the flood risk, including the likelihood and severity of consequences. There are two primary categories of risk analysis, namely quantitative analysis and qualitative analysis. For this project, a qualitative risk analysis was prepared based on the USACE guidance EM 1105-2-101.

The following three types of risks were considered in the qualitative analysis:

- Life safety risk – individual and societal life safety flood risk based on incremental and non-breach risk
- Economic risk based on incremental and non-breach risk
- Environmental and other non-monetary risks based on incremental and non-breach risk.

As discussed earlier, under existing conditions there would be overland flood flow (about 1,150 cfs during a 50-year riverine flood) from the Arroyo Avichi Creek confluence via Nave Gardens, Baccaglio Basin, and Scottsdale pond and marsh into Lynwood Basin, reducing the flood flow into the Novato Creek main channel. This overland flood flow originates from overflow of the Arroyo Avichi Creek right bank and overbank flow of the Novato Creek right bank near the confluence. Improving/raising the downstream levees to prevent the levee overtopping would increase the Novato Creek main channel WSE and, thus, result in more overland flood flow and flooding at the Arroyo Avichi Creek confluence area. This area is outside of the levee evaluation study area and, thus, is not included in this qualitative risk analysis.

It is worth noting that improving/raising the levees would make the levees accessible/passible during a large flood event to serve the Lynwood, Cheda, and Farmers pump stations, which would otherwise not be accessible/passible under existing conditions. However, operating the pump stations during a large flood event would have little effect on the life safety/economic/ environmental risks due to the small pumping capacity relative to the large flood discharge into the bayland area.

<u>Life Safety Risk</u>

The project area is within the Novato Creek baylands surrounded by vacant bayland basins or ponds. The level of life safety risk (human deaths/fatalities and injuries) associated with flooding in the vacant bayland basins/ponds would be extremely rare.

As shown in Figures 13-15, a portion of the commercial properties on the west side of the Lynwood Basin would be flooded during a riverine 50-year or FEMA 100-year flood. The flood water depth in this flooded area would be up to 2.0 ft under existing conditions and up to 2.3 ft under improved/raised levee conditions. The flow velocity in this flooded area would be up to 0.6 feet per second (fps) under existing conditions and up to 0.7 fps under improved/raised levee conditions. Individual and societal deaths/fatalities caused by these relatively shallow flood water depths and small velocities would be unlikely, but injuries would be possible. A coastal 100-year flood would not flood this area (see Figures 16-18).

Also shown in Figures 13-15, a portion of the residential properties on the west side of HWY 101 near the southwest corner of the Lynwood Basin would be flooded during a riverine 50-year or FEMA 100-year flood. The flood water depth in this flooded area would be up to 1.8 ft under existing conditions and up to 2.1 ft under improved/raised levee conditions. The flow velocity in this flooded area would be up to 0.5 fps under existing conditions and up to 0.6 fps under improved/raised levee conditions. Individual and societal deaths/fatalities caused by these relatively shallow flood water depths and small velocities would be unlikely, but injuries would be possible. A coastal 100-year flood would not flood this area (see Figures 16-18).

<u>Economic Risk</u>

Economic risk considered the following four primary elements:

- Physical damage to buildings and contents in the commercial properties on the west side of the Lynwood Basin;
- Physical damage to buildings and contents in the residential properties on the west side of HWY 101 near the southwest corner of the Lynwood Basin;
- Disruption of the SR-37 near HWY 101; and
- Emergency response costs.

As shown in Figures 13-15, a portion of the commercial properties on the west side of the Lynwood Basin and a portion of the residential properties on the west side of HWY 101 near the southwest corner of the Lynwood Basin would be flooded during a riverine 50-year or FEMA 100-year flood. Physical damage in the commercial area was analyzed in terms of flooded acreage and is presented in Table 5. Physical damage in the residential area was analyzed in terms of number of flooded parcels and is presented in Table 6. A coastal 100-year flood would not flood these two areas.

Also shown in Figures 13-15, the SR-37 near HWY 101 would be flooded during a riverine 50-year or FEMA 100-year flood with the flood water depth up 3.4 ft under existing conditions and up to 3.7 ft under improved/raised levee conditions. The flooded length of road would be approximately 8,000 ft under existing conditions and 3,500 ft under improved/raised levee conditions[7]. A riverine 50-year or FEMA 100-year flood would be very likely or certain to cause road closure and result in cost of repair, lost business hours due to cancelled or rerouted trips, and additional fuel consumption due to rerouted trips. A coastal 100-year flood would also flood the SR-37 near HWY 101 (see Figures 16-18) but would be less severe than a riverine 50-year or FEMA 100-year flood.

It would be certain that a riverine 50-year or FEMA 100-year flood would result in emergency response costs which would include but not be limited to the following types:

- Evacuation and rescue costs;
- Security costs;

[7] The deeper flood water depth is more limited to the west of the creek crossing. Under existing conditions, a considerable length of SR-37 on the east side of the creek crossing would be flooded due to overtopping flows along the Farmers Basin south levee (along the north side of SR-37) with flood water originating from the overtopping of the Novato Creek right bank levee reach immediately upstream of SR-37. Under improved/raised levee conditions, this overtopping source would be eliminated. That is why the flooded length of SR-37 would be less under improved/raised levee conditions.

- Dewatering, debris removal and cleanup costs; and
- Emergency flood management system repairs.

Environmental Risk

A riverine 50-year or FEMA 100-year flood could result in but not be limited to the following environmental and non-monetary impacts:

- Public health impacts in the flooded portion of the commercial properties on the west side of the Lynwood Basin;
- Public health impacts in the flooded portion of the residential properties on the west side of HWY 101 near the southwest corner of the Lynwood Basin;
- Ecosystem impacts on the bayland basins/ponds; and
- Aesthetic impacts on the bayland basins/ponds.

Table 5 Physical Damage in the Commercial Properties on the West Side of the Lynwood Basin

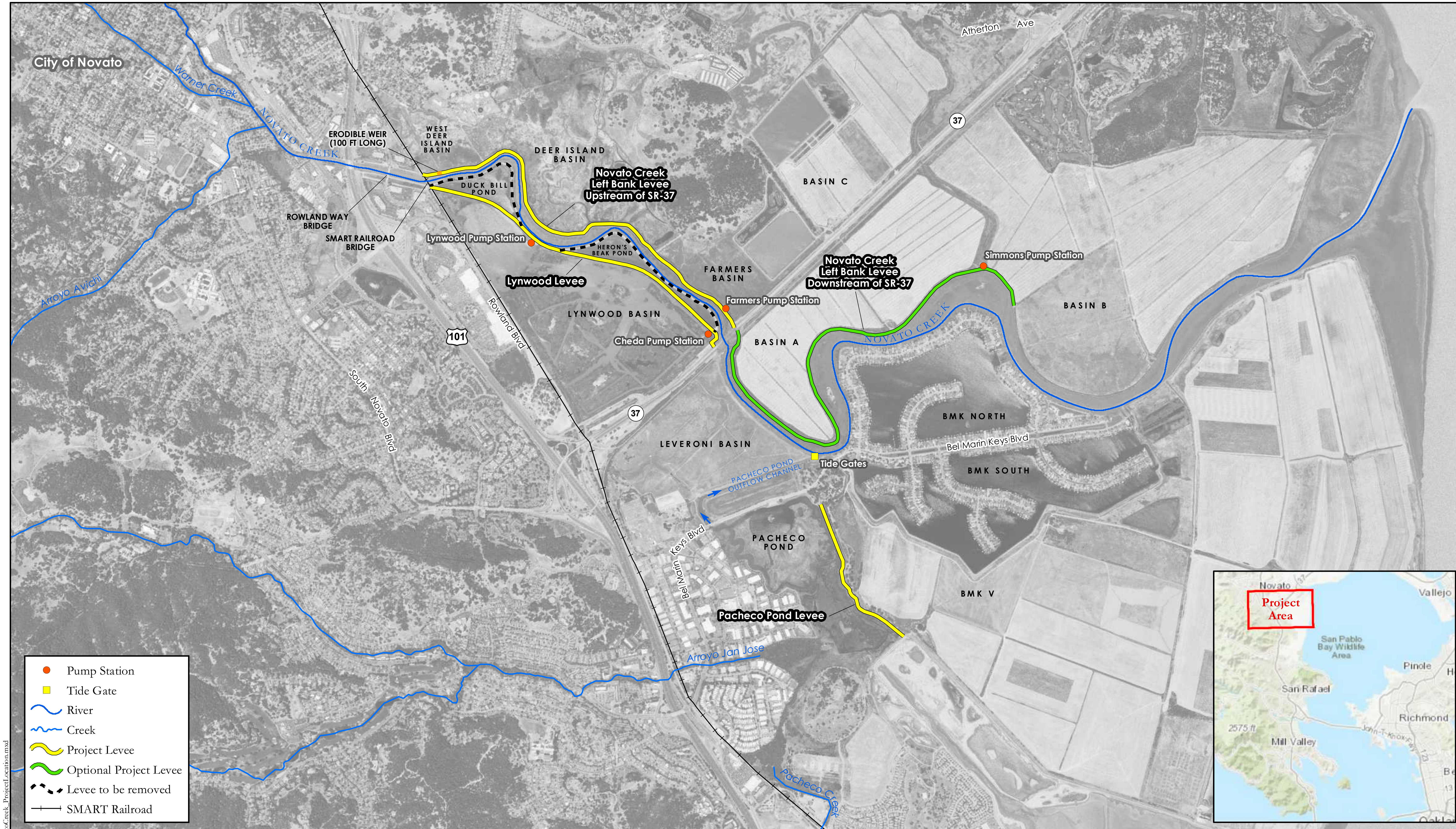
Riverine Flood Event	Existing Condition Inundated Acreage (acre)	Improved/Raised Levee Condition Inundated Acreage (acre)	Difference
Riverine 50-Year Flood	15.3	29.6	14.3
Riverine FEMA 100-Year Flood	26.9	34.0	7.1
Riverine 50-Year Flood with SLR	22.6	29.9	7.3

Table 6 Physical Damage in the Residential Properties on the West Side of HWY 101 near the Southwest Corner of the Lynwood Basin

Riverine Flood Event	Existing Condition Number of Inundated Parcels	Improved/Raised Levee Condition Number of Inundated Parcels	Difference
Riverine 50-Year Flood	9	115	106
Riverine FEMA 100-Year Flood	99	138	39
Riverine 50-Year Flood with SLR	65	111	46

Source of parcels: MarinMap.

FIGURE 1



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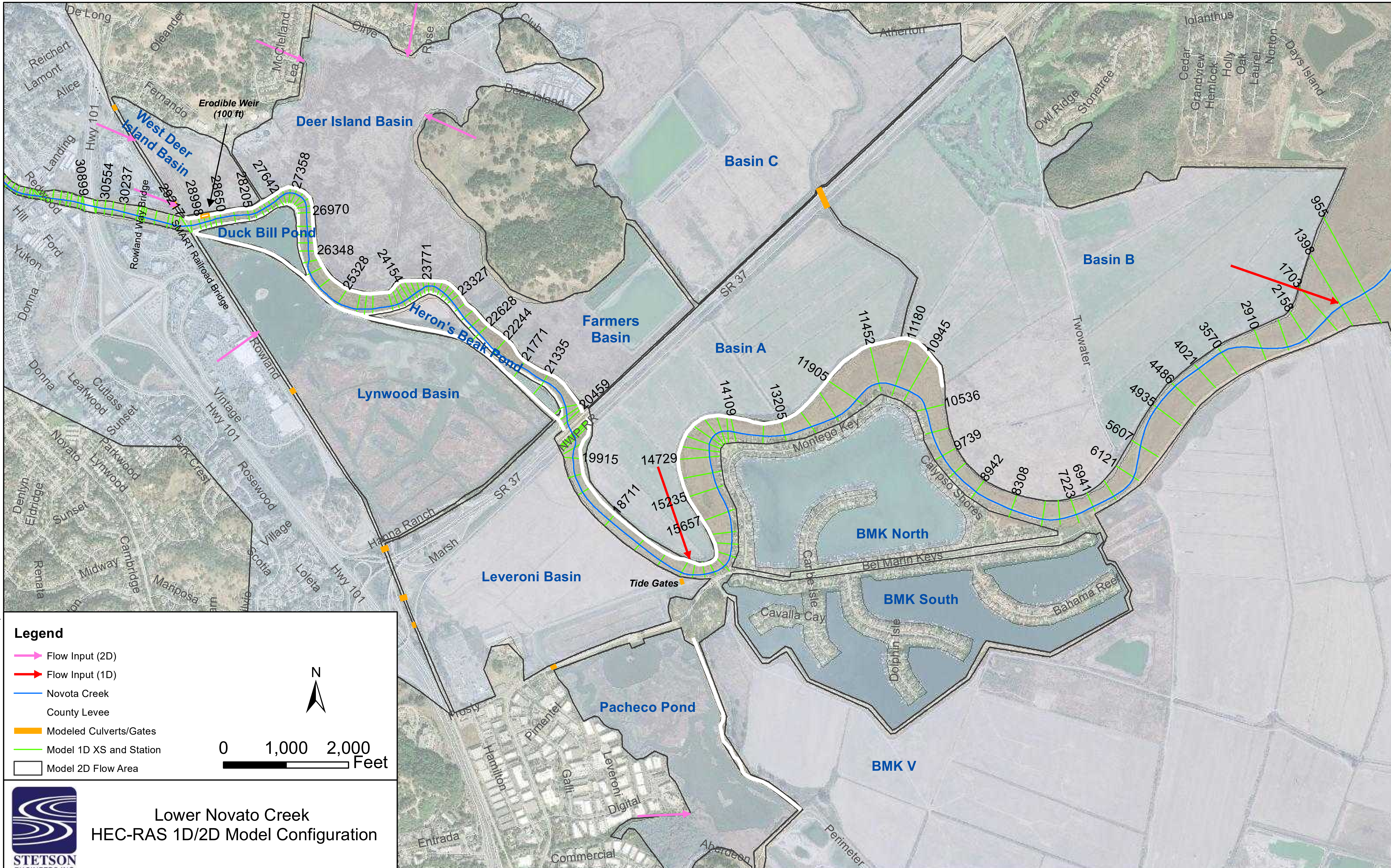
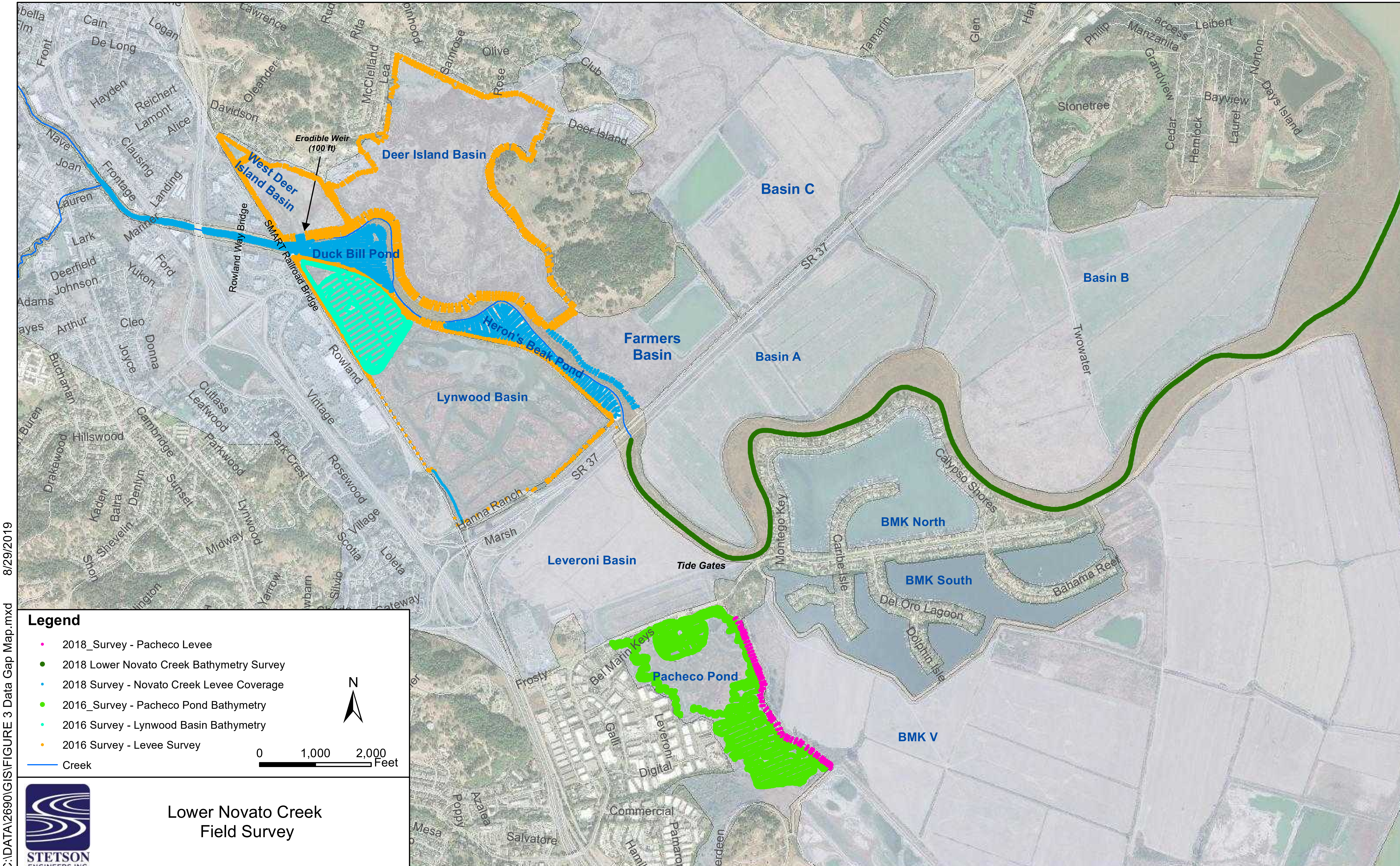
NOVATO CREEK LEVEE EVALUATION
PROJECT LOCATION

FIGURE 2



Lower Novato Creek
HEC-RAS 1D/2D Model Configuration

C:\DATA\2690\GIS\FIGURE 2 River Station Map.mxd
9/9/2019



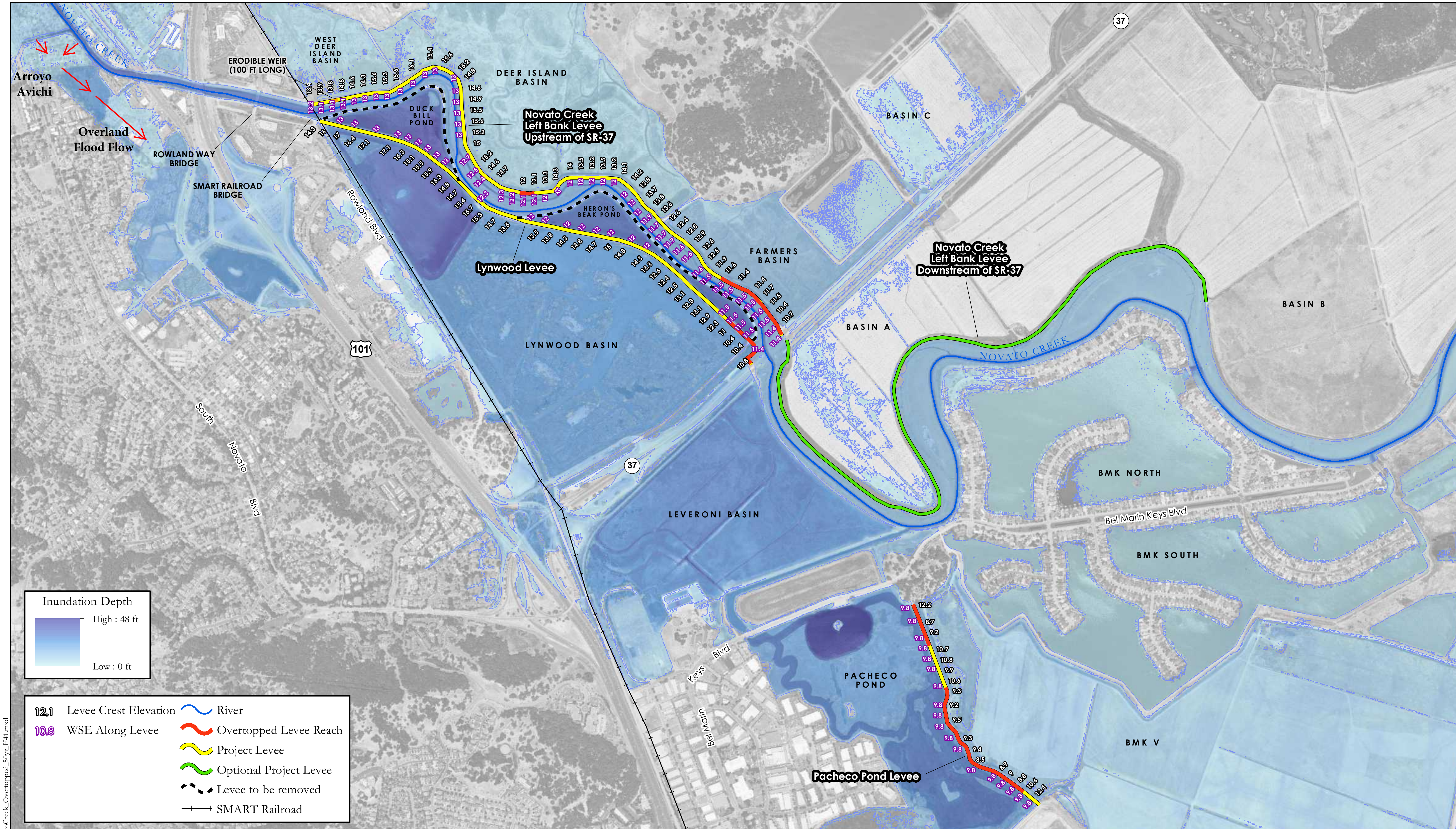
Lower Novato Creek
Field Survey

(a) Upstream Side

(b) Downstream Side

Figure 4 Pacheco Pond Outflow Tidal Gates

FIGURE 5



NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVED)
OVERTOPPED LEVEE REACHES UNDER RIVERIAN 50YR FLOOD

STETSON ENGINEERS INC.

0 625 1,250 Feet

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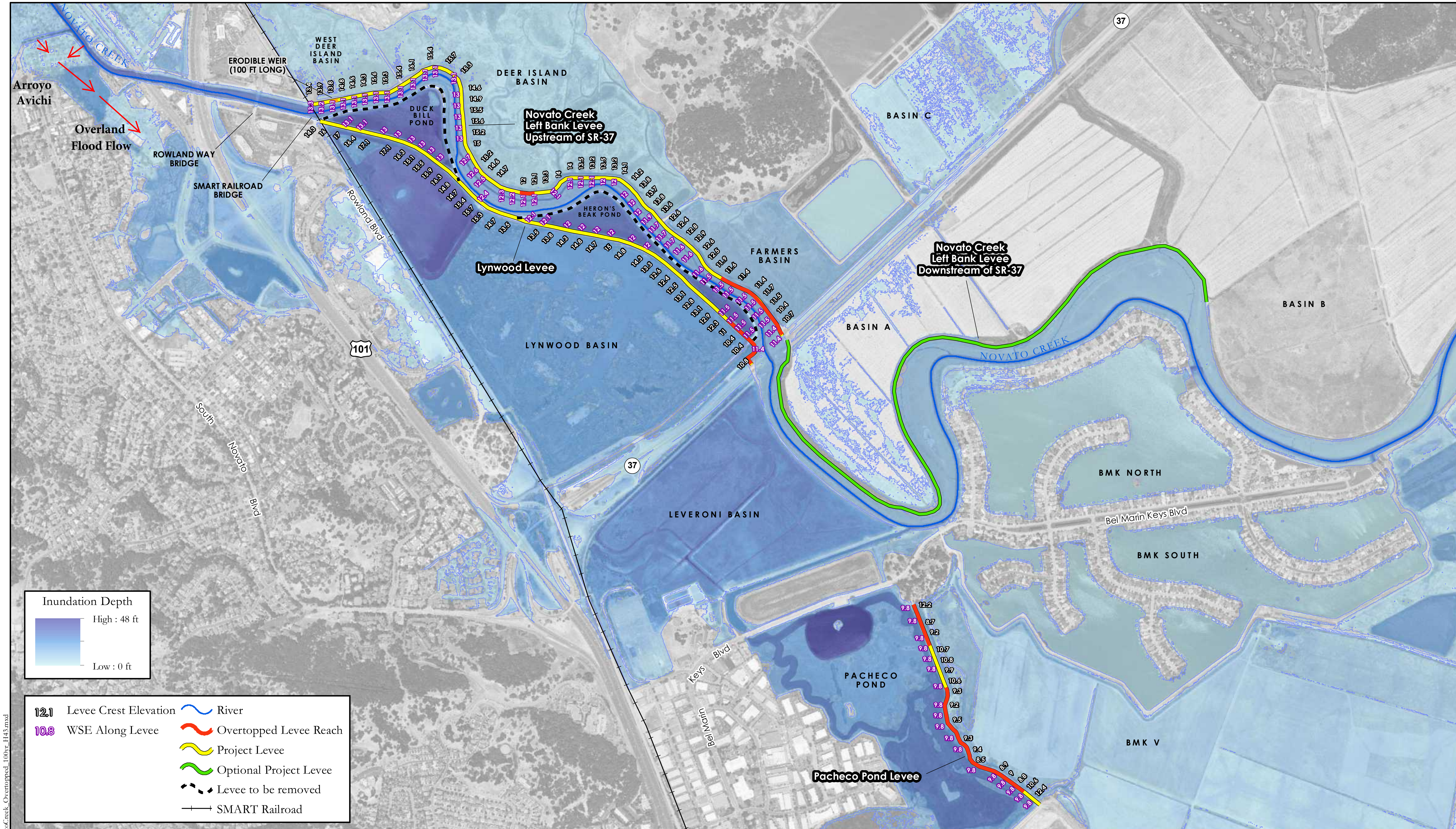

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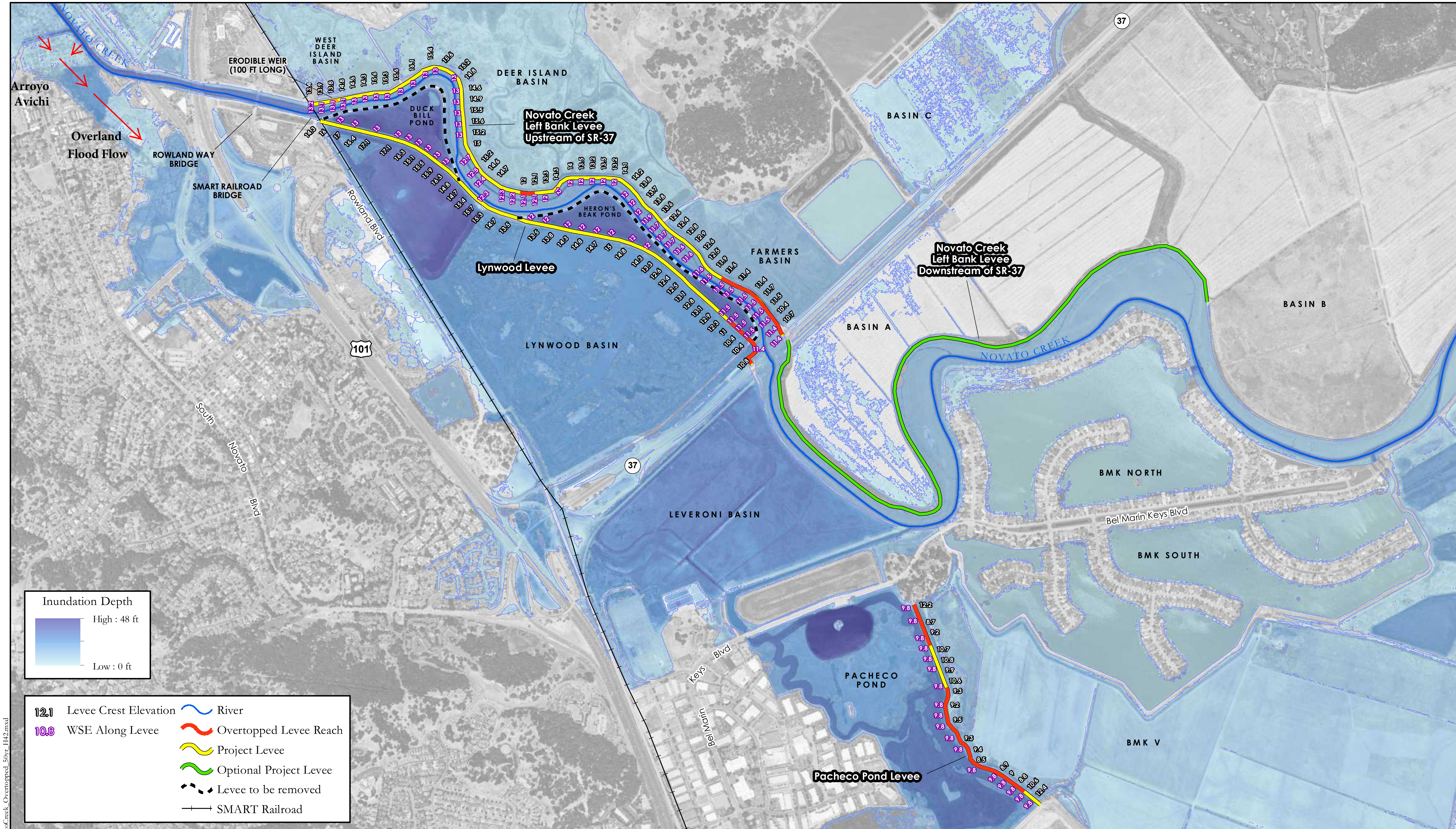
NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVED)
OVERTOPPED LEVEE REACHES UNDER RIVERIAN FEMA100YR FLOOD



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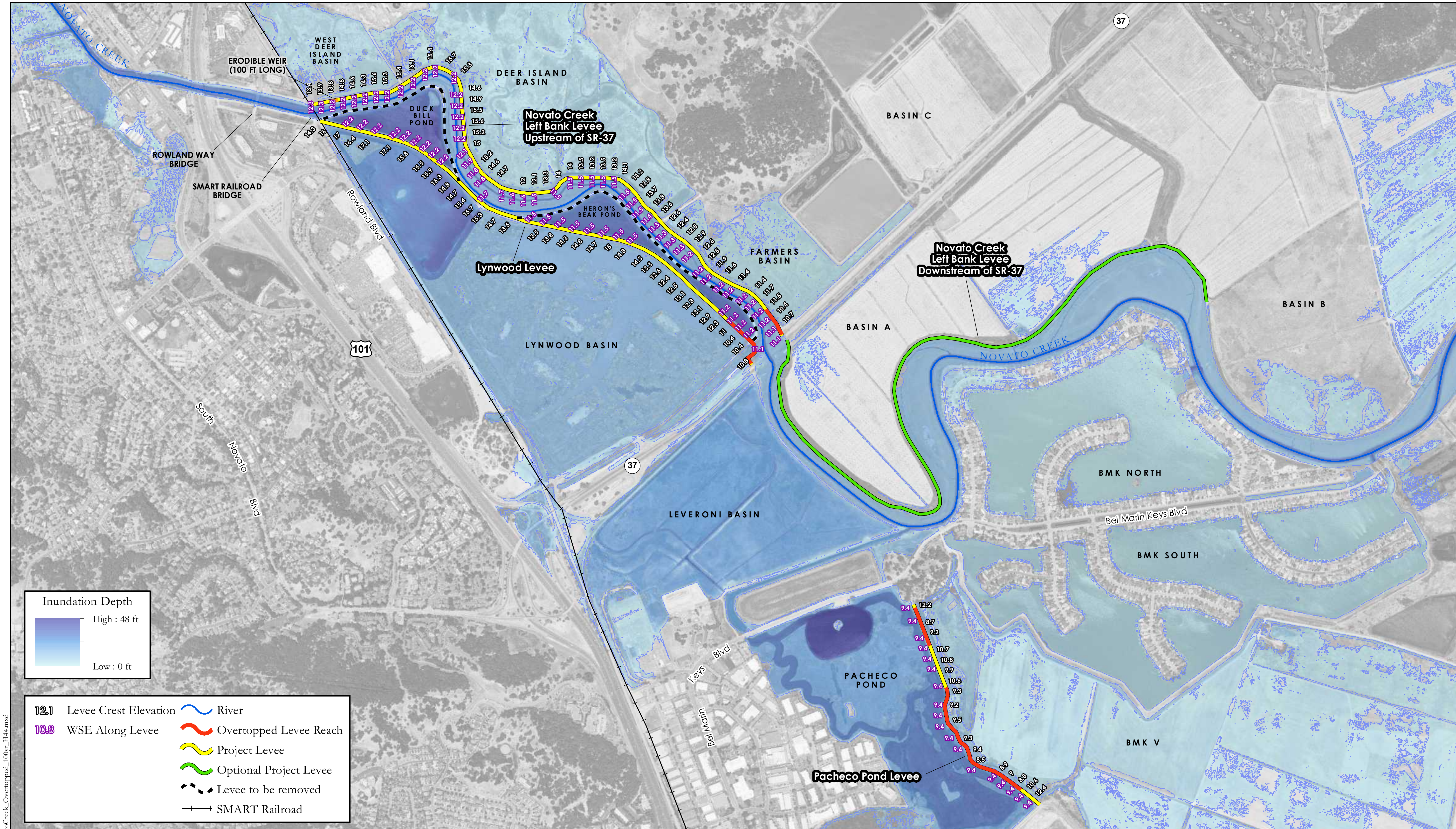
NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVED)
OVERTOPPED LEVEE REACHES UNDER RIVERIAN 50YR FLOOD AND SEA LEVEL RISE



NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVED)
OVERTOPPED LEVEE REACHES UNDER COASTAL 100YR FLOOD

0 625 1,250 Feet

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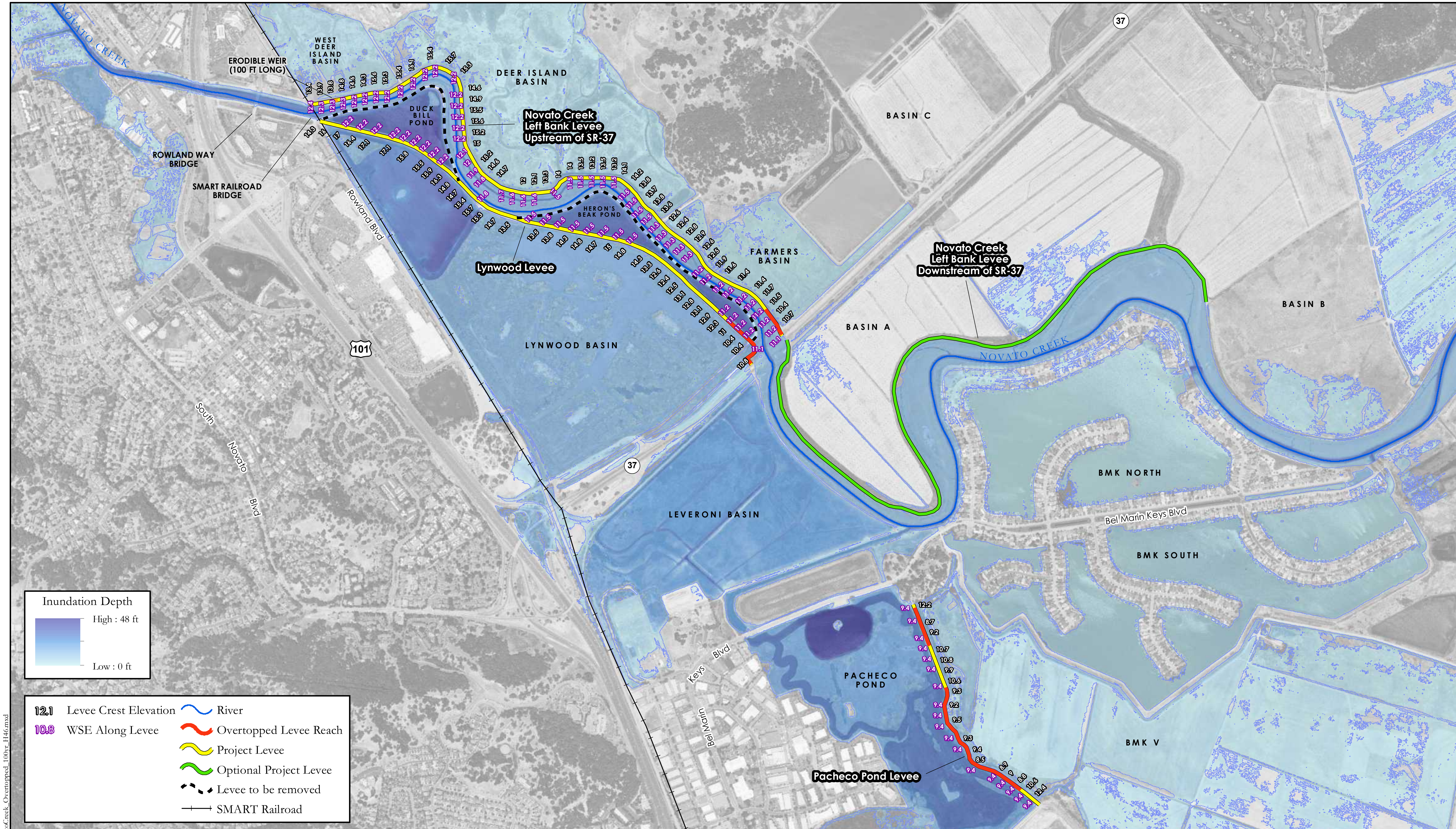
FIGURE 9



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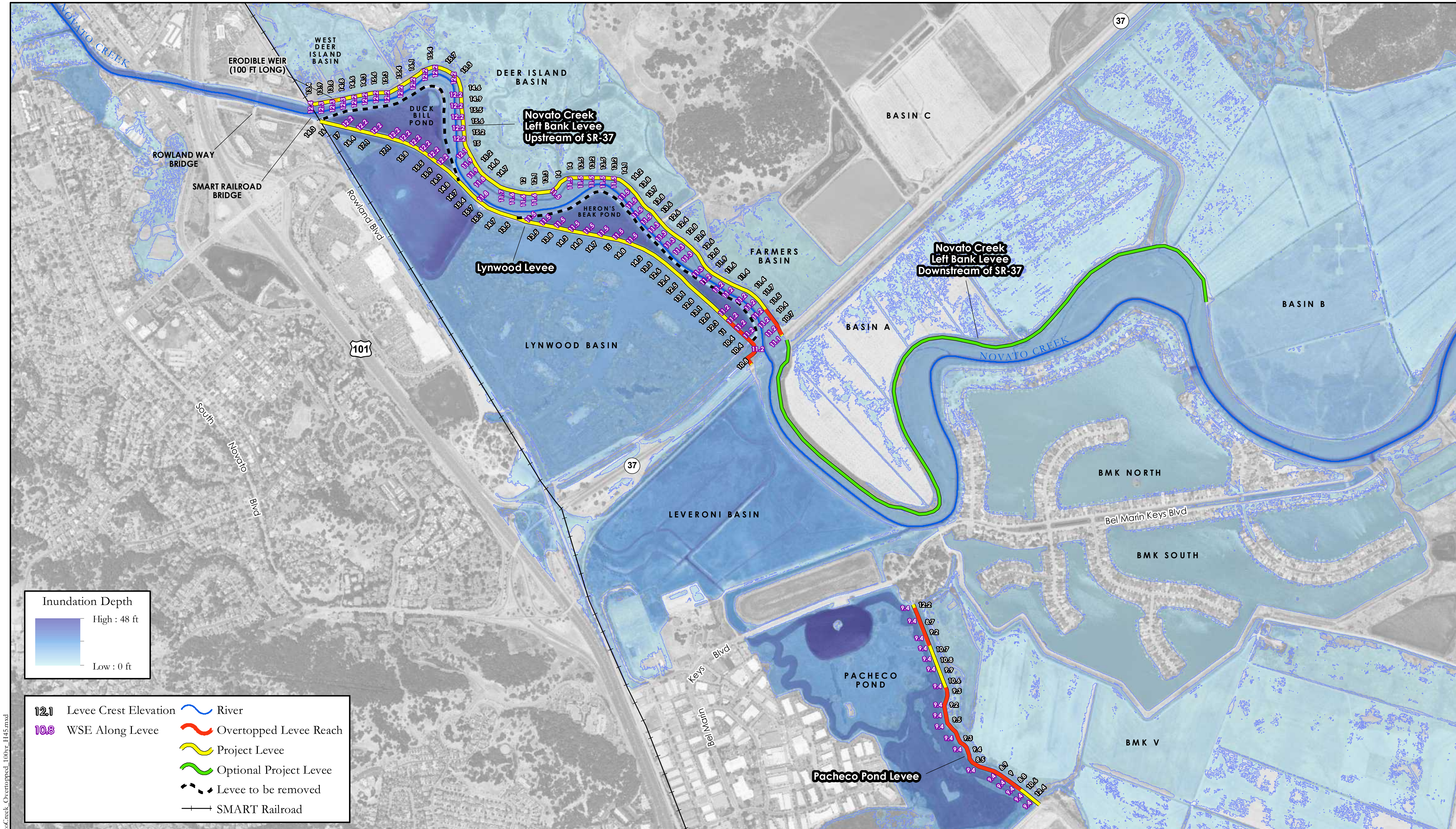
NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVAL)
OVERTOPPED LEVEE REACHES UNDER COASTAL 100YR FLOOD (FEMA)



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NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVAL)
OVERTOPPED LEVEE REACHES UNDER COASTAL 100YR FLOOD AND SEA LEVEL RISE

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Figure 11 Simulated Water Surface Profiles under Existing Conditions (with the Novato Creek Right Bank Levee Removed)

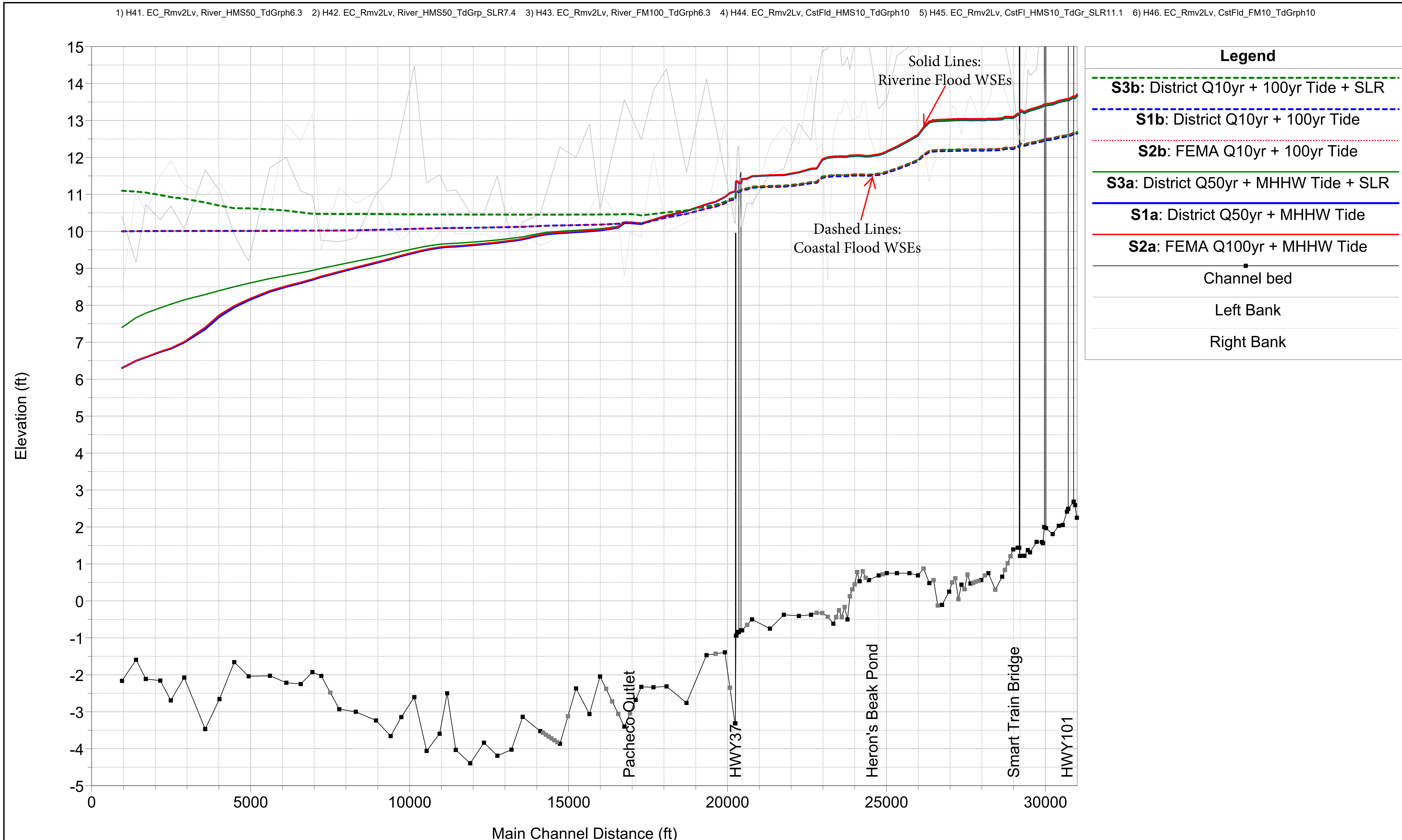
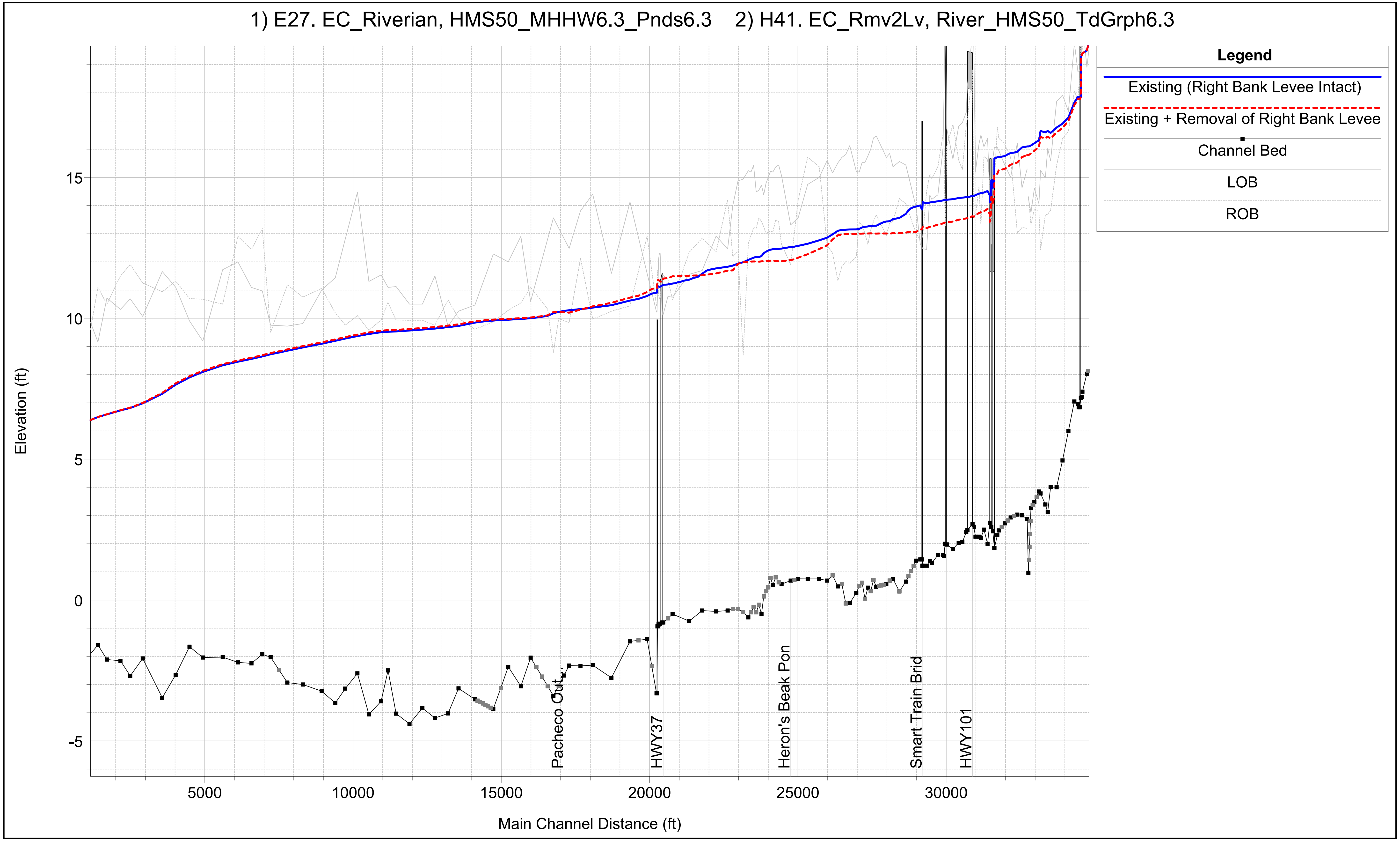
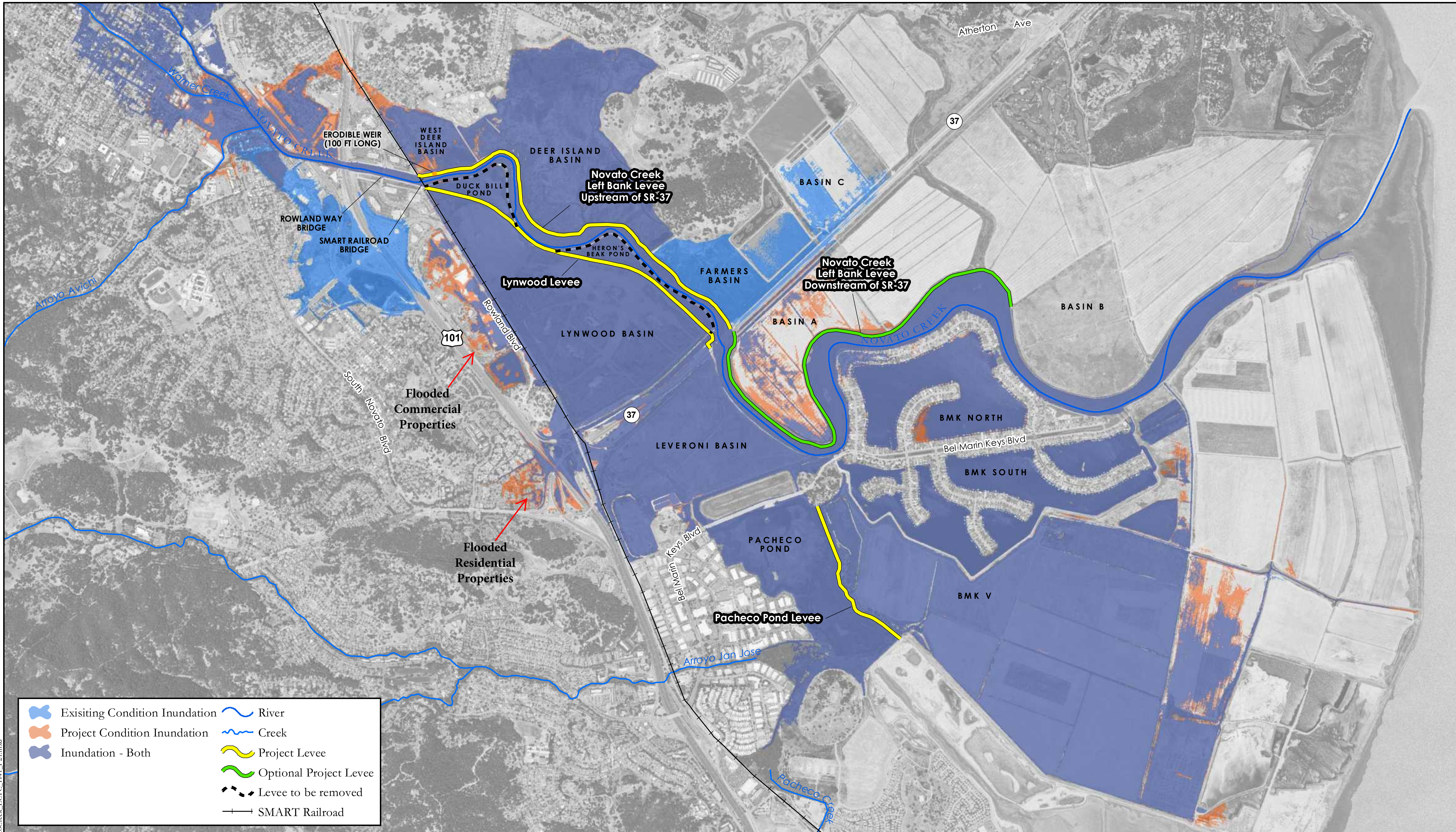


Figure 12 Simulated Water Surface Profiles under Existing Conditions between with and without Removal of the Novato Creek Right Bank Levee





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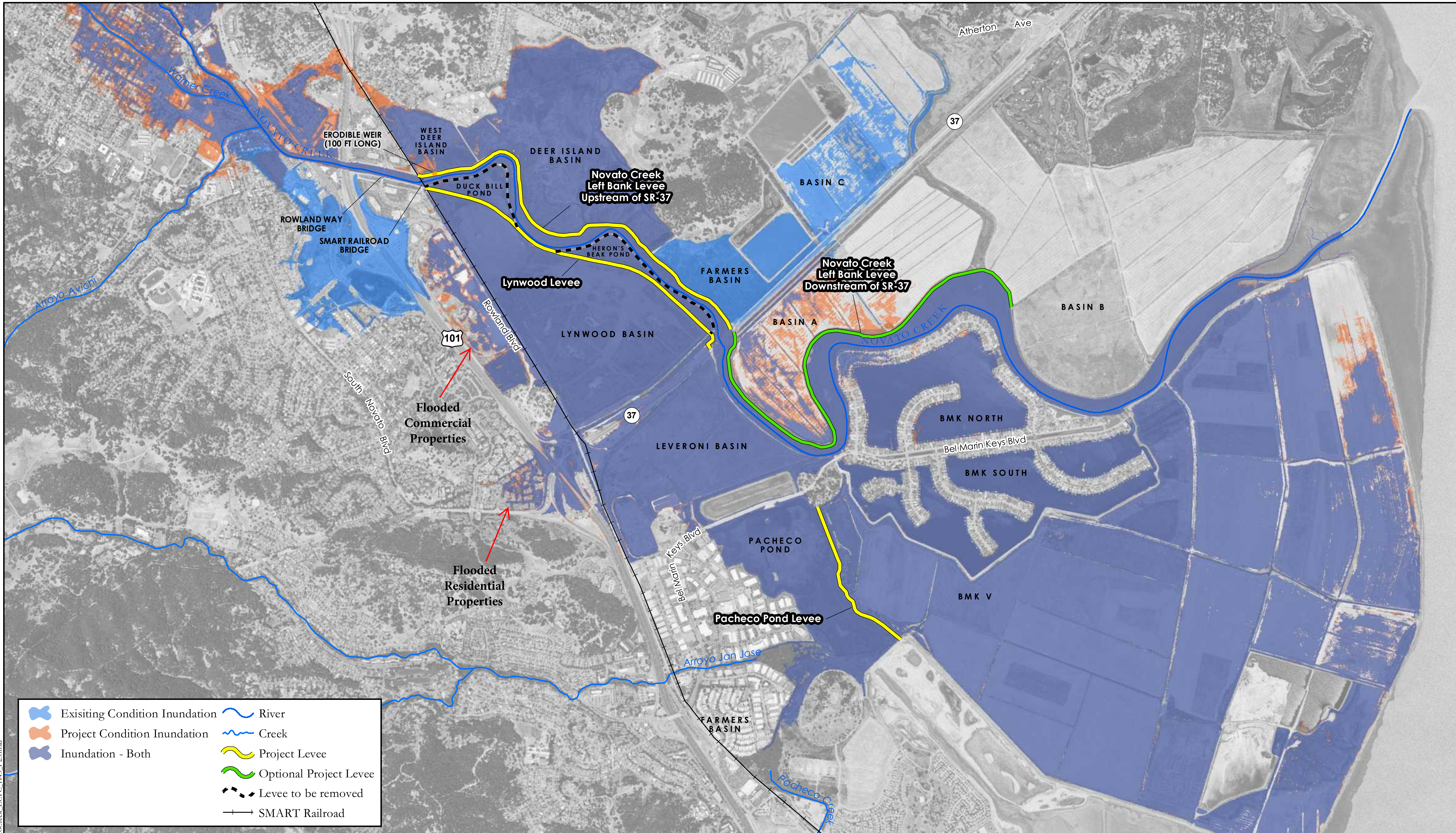
NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVAL) VS IMPROVED/RAISED LEVEE CONDITION
RIVERIAN 50YR FLOOD



NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVAL) VS IMPROVED/RAISED LEVEE CONDITION
FEMA 100YR RIVERIAN FLOOD

STETSON ENGINEERS INC.

0 950 1,900 Feet

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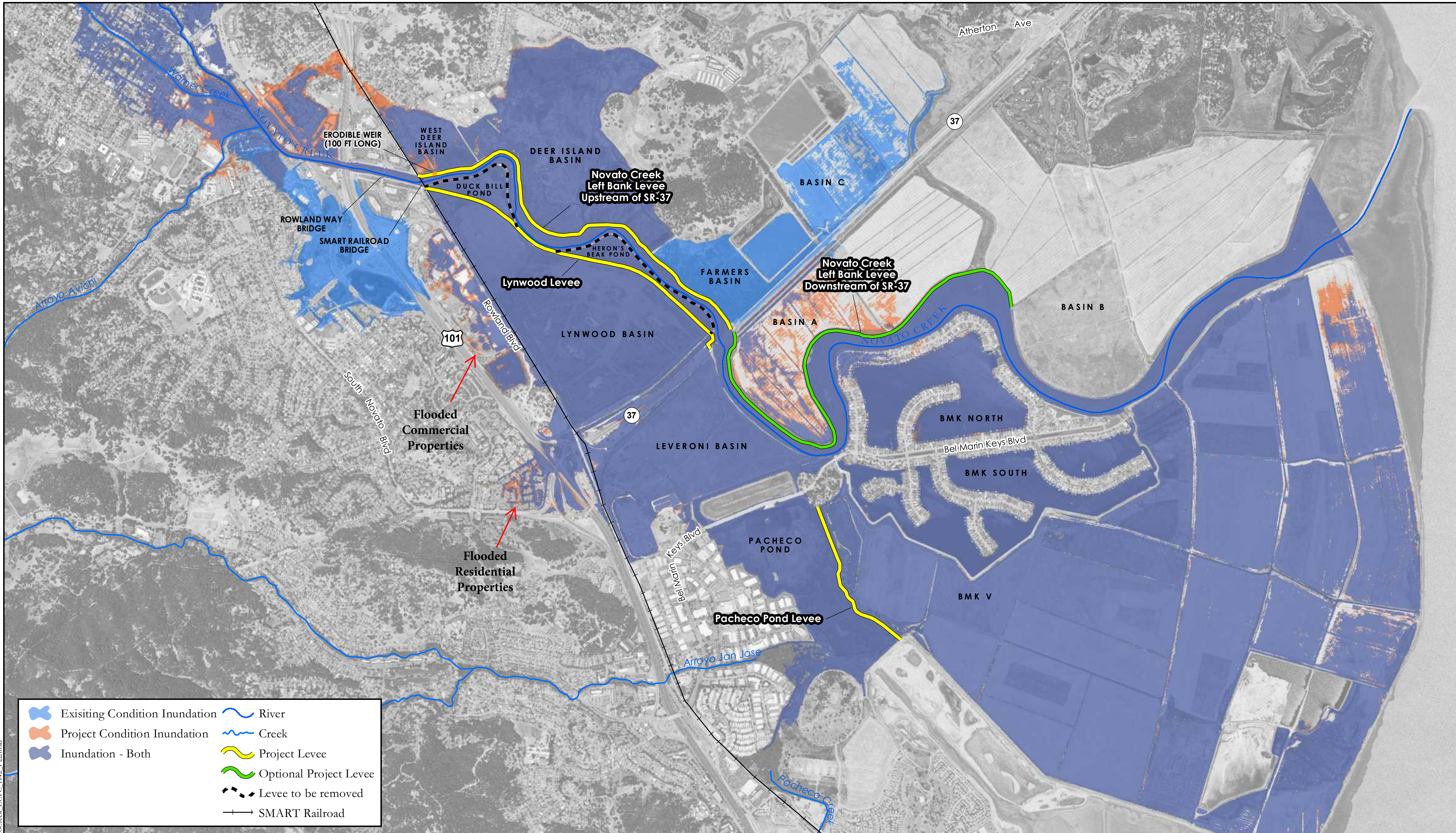

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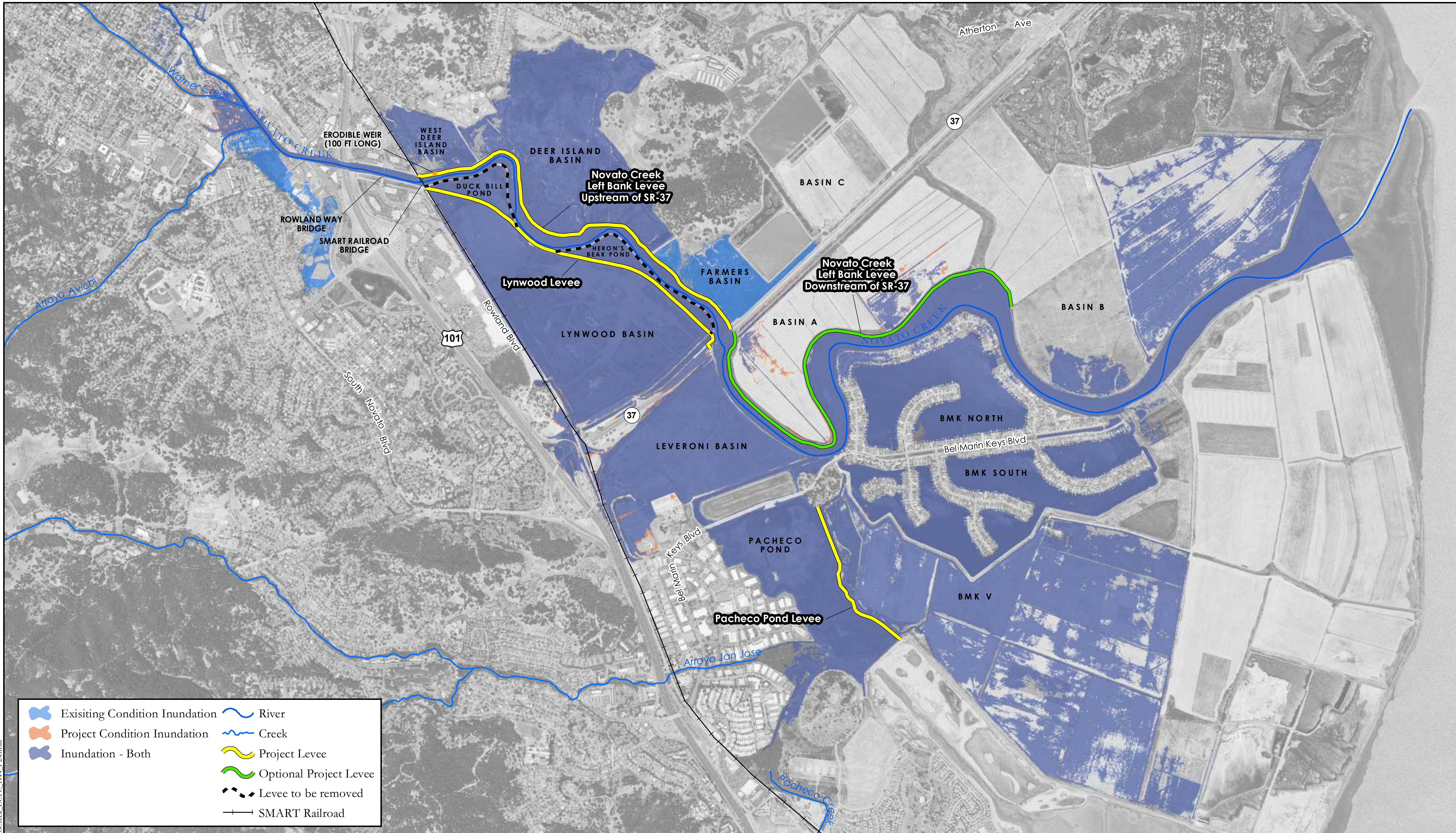
NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVAL) VS IMPROVED/RAISED LEVEE CONDITION
RIVERIAN 50YR FLOOD + SEA LEVEL RISE

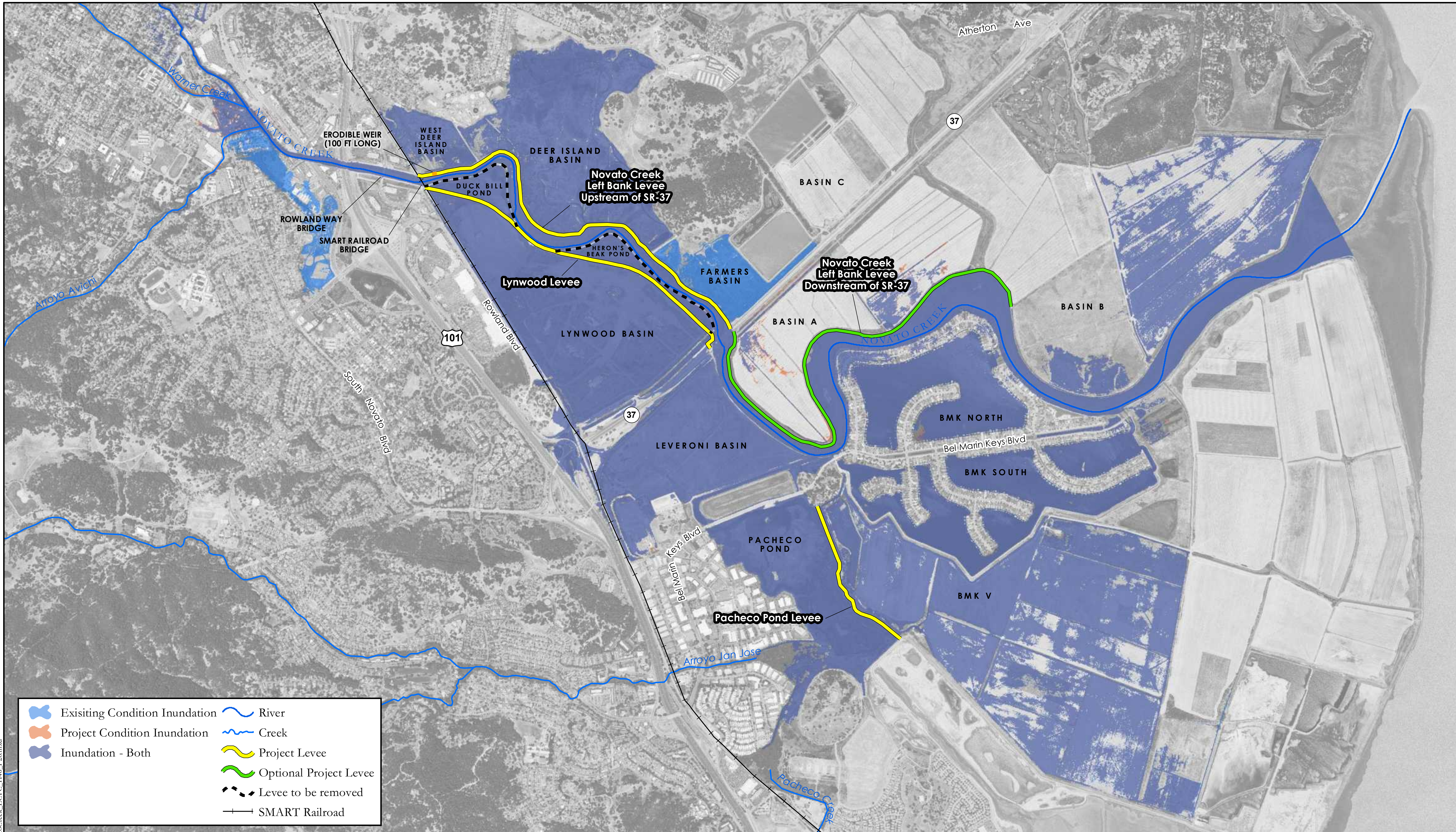


STETSON ENGINEERS INC.

NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVAL) VS IMPROVED/RAISED LEVEE CONDITION
RIVERIAN 10YR FLOOD + COASTAL 100YR TIDE

0 950 1,900 Feet

N



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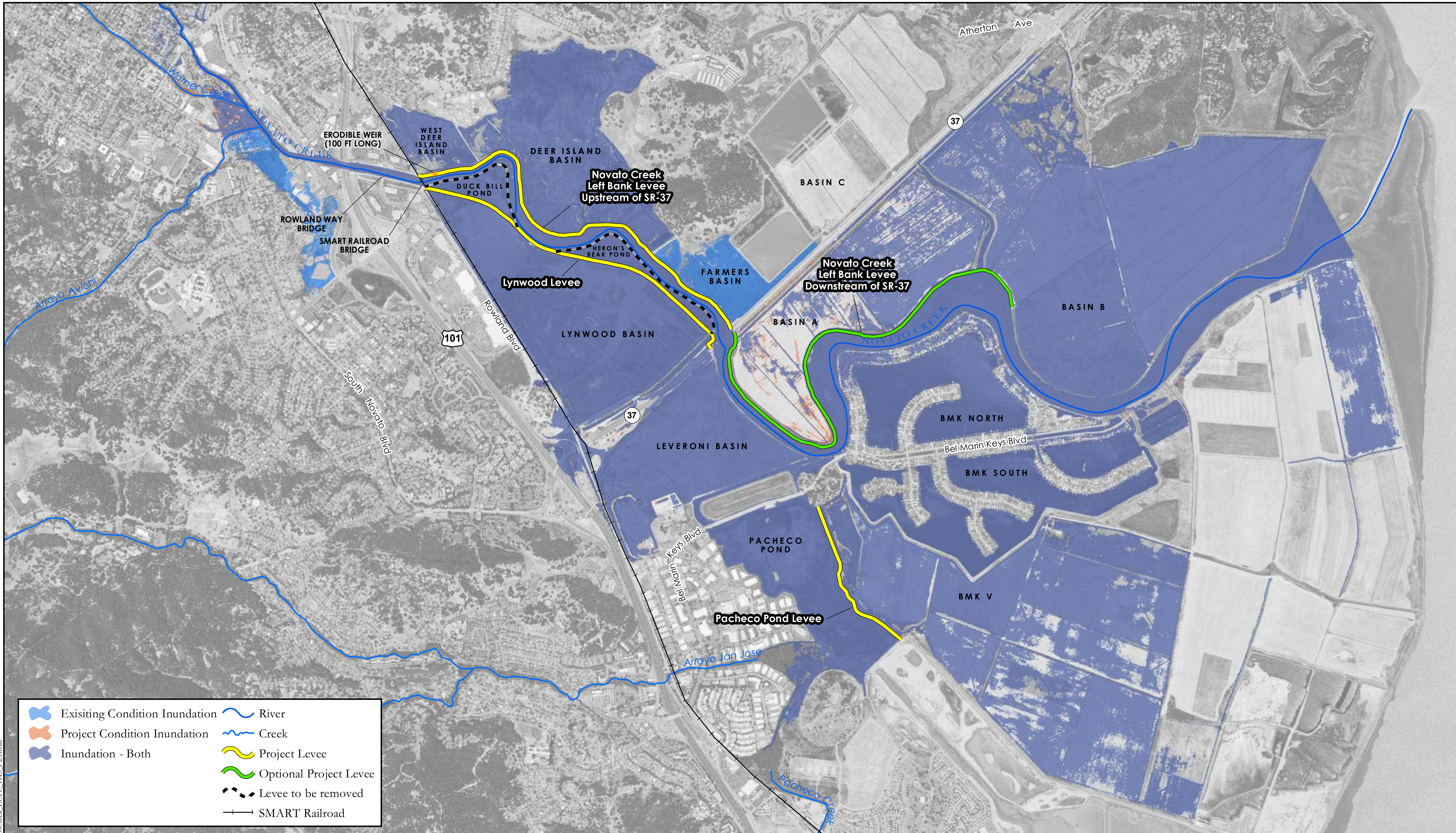
STETSON ENGINEERS INC.

NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVAL) VS IMPROVED/RAISED LEVEE CONDITION
RIVERIAN FEMA 10YR FLOOD + 100YR TIDE



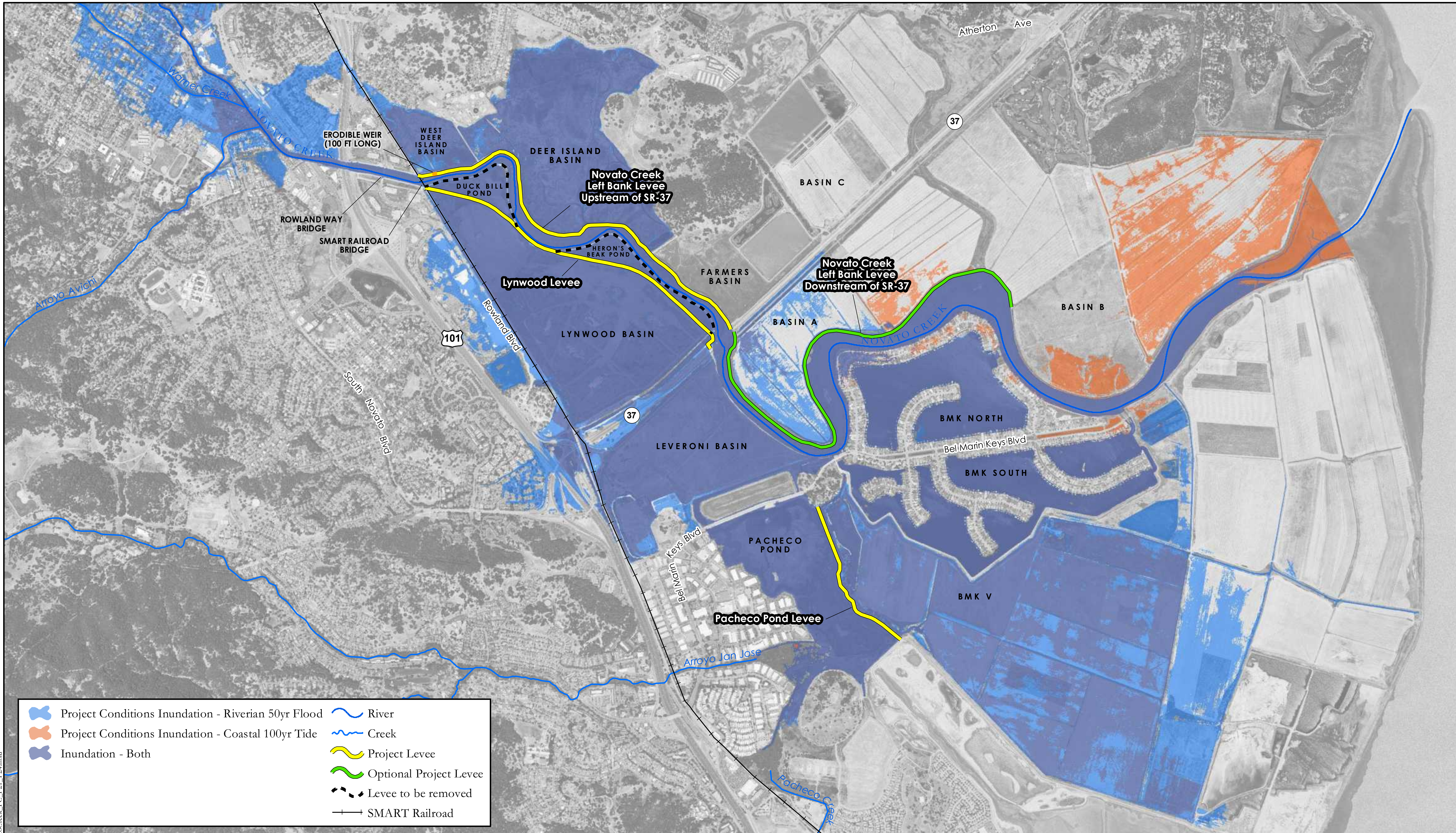
Document Path: J:\jn2690\NovatoCreek_ECPC_H45_F25.mxd

STETSON ENGINEERS INC.

NOVATO CREEK LEVEE EVALUATION
EXISTING CONDITION (WITH RIGHT BANK LEVEE REMOVAL) VS IMPROVED/RAISED LEVEE CONDITION
RIVERIAN 10YR FLOOD + COASTAL 100YR TIDE + SEA LEVEL RISE

0 950 1,900 Feet

N



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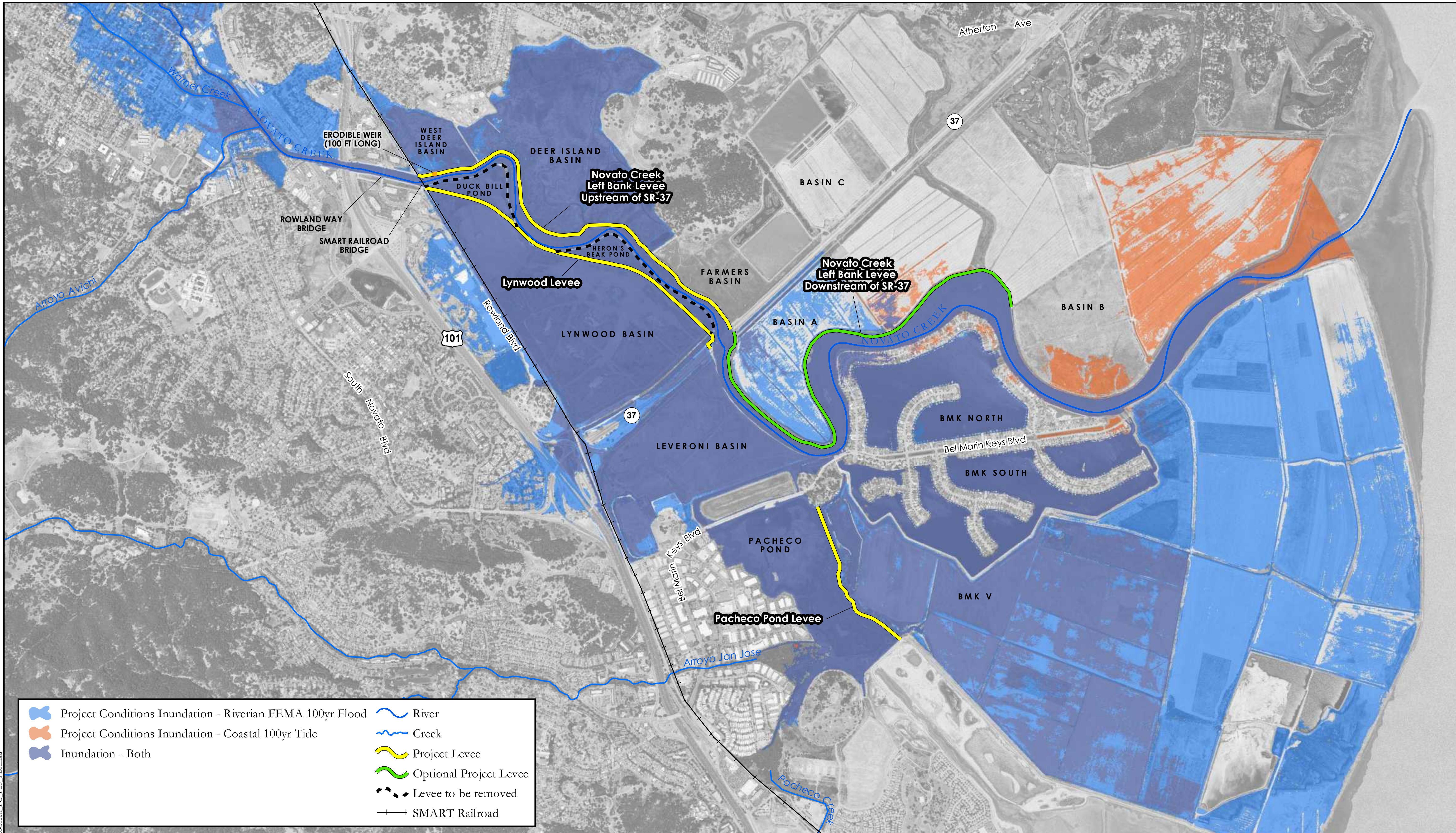
STETSON ENGINEERS INC.

NOVATO CREEK LEVEE EVALUATION
IMPROVED/RAISED LEVEE CONDITION
RIVERIAN 50YR FLOOD VS COASTAL 100YR TIDE



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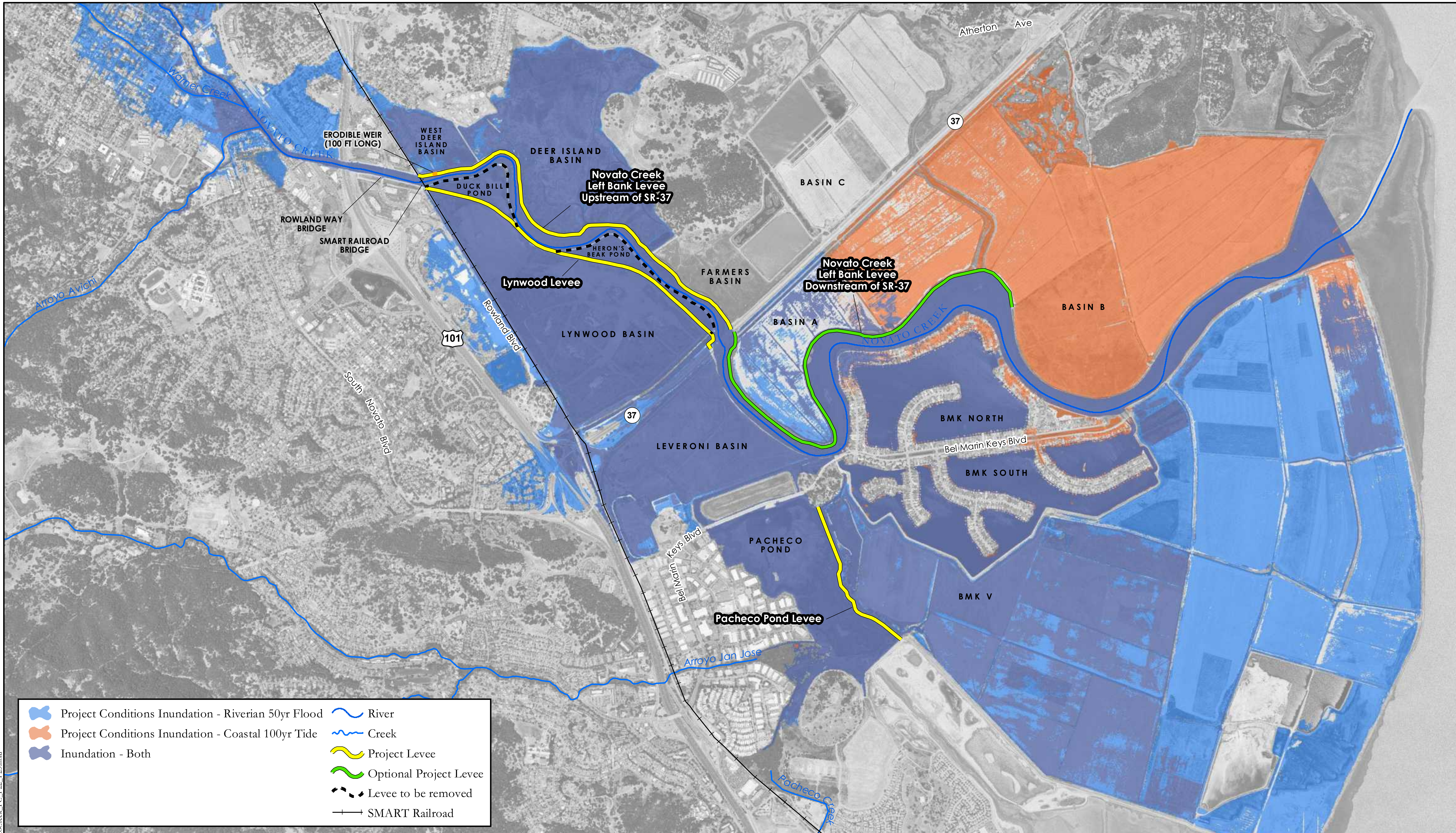
STETSON ENGINEERS INC.

NOVATO CREEK LEVEE EVALUATION
IMPROVED/RAISED LEVEE CONDITION
RIVERIAN FEMA 100YR FLOOD VS COASTAL 100YR TIDE



STETSON ENGINEERS INC.

NOVATO CREEK LEVEE EVALUATION
IMPROVED/RAISED LEVEE CONDITION
RIVERIAN 50YR FLOOD + SEA LEVEL RISE VS COASTAL 100YR TIDE + SEA LEVEL RISE

0 950 1,900 Feet

N

Figure 22 Simulated Water Surface Profiles under Improved/Raised Levee Conditions

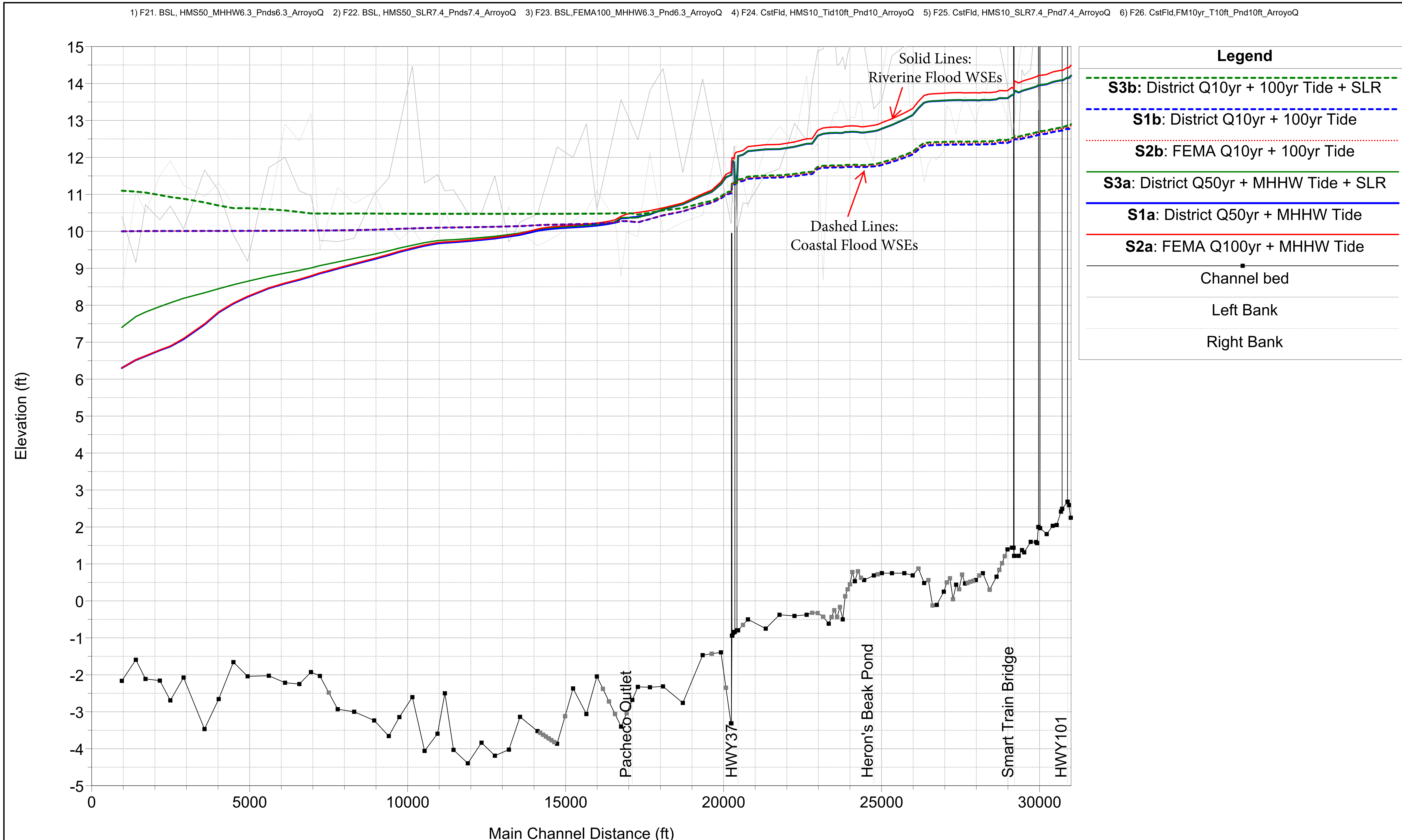


Figure 23 Comparison of Simulated Water Surface Profiles between Existing and Improved/Raised Levee Conditions - Riverine 50-Year Flood

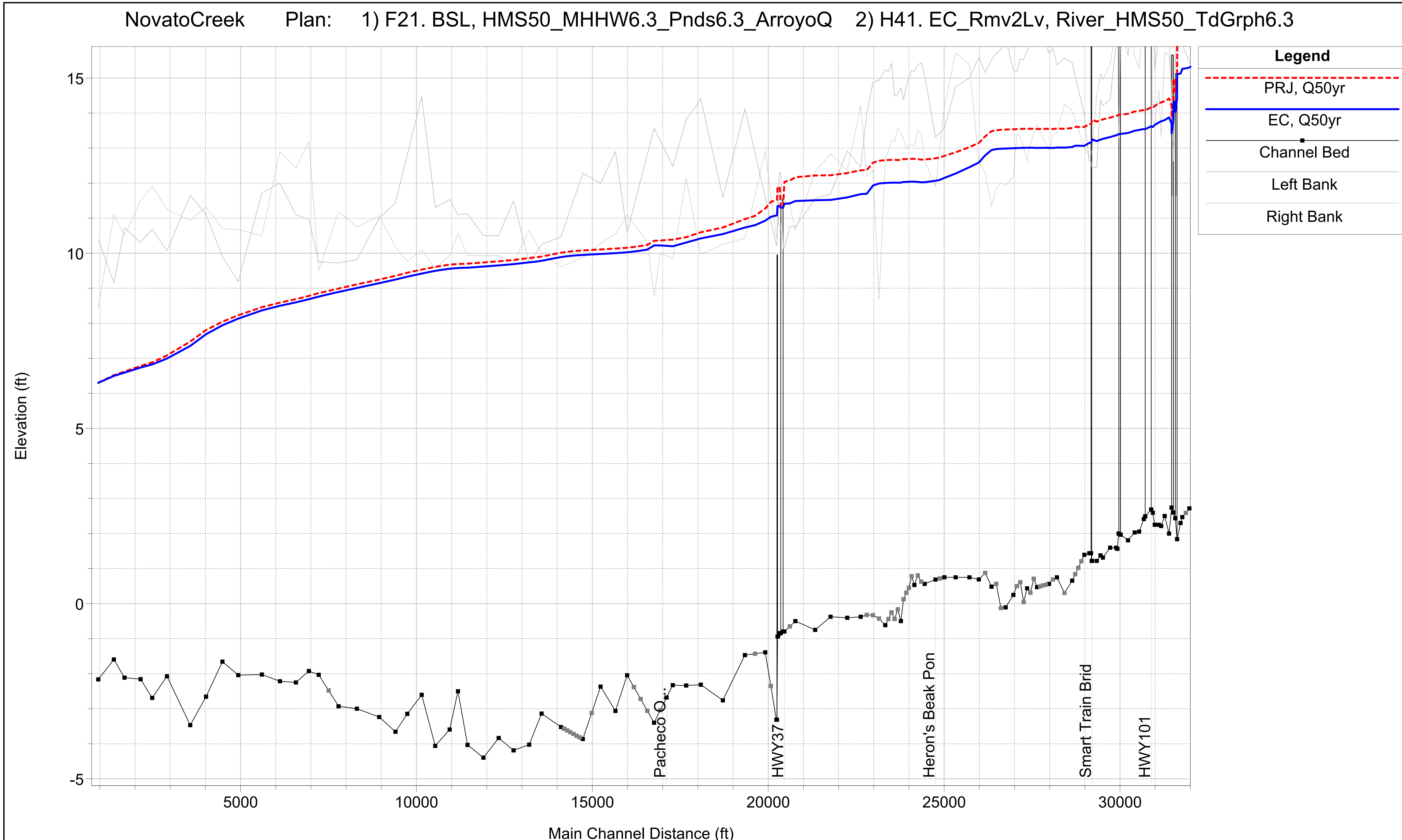


Figure 24 Comparison of Simulated Water Surface Profiles between Existing and Improved/Raised Levee Conditions - Riverine FEMA 100-Year Flood

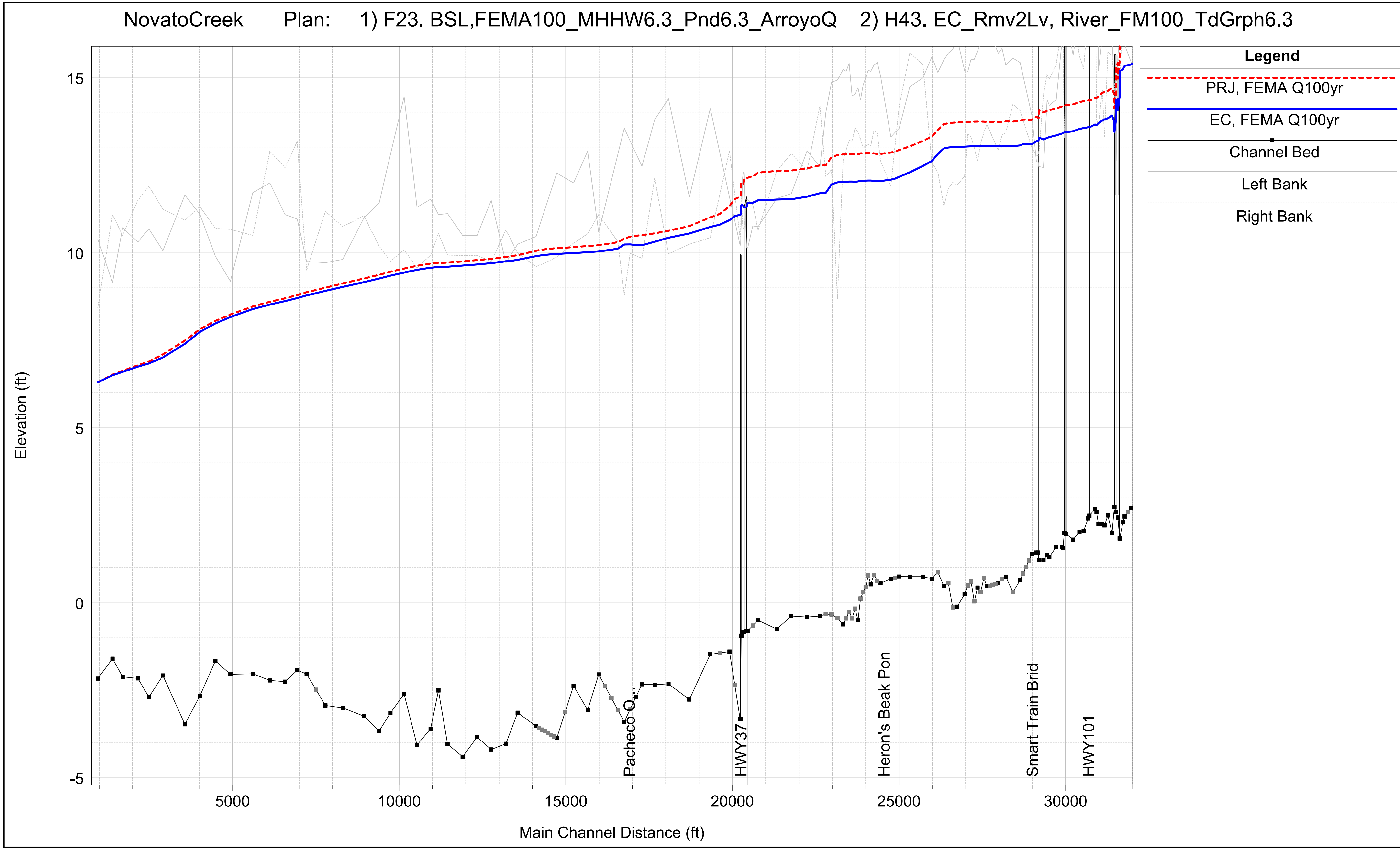
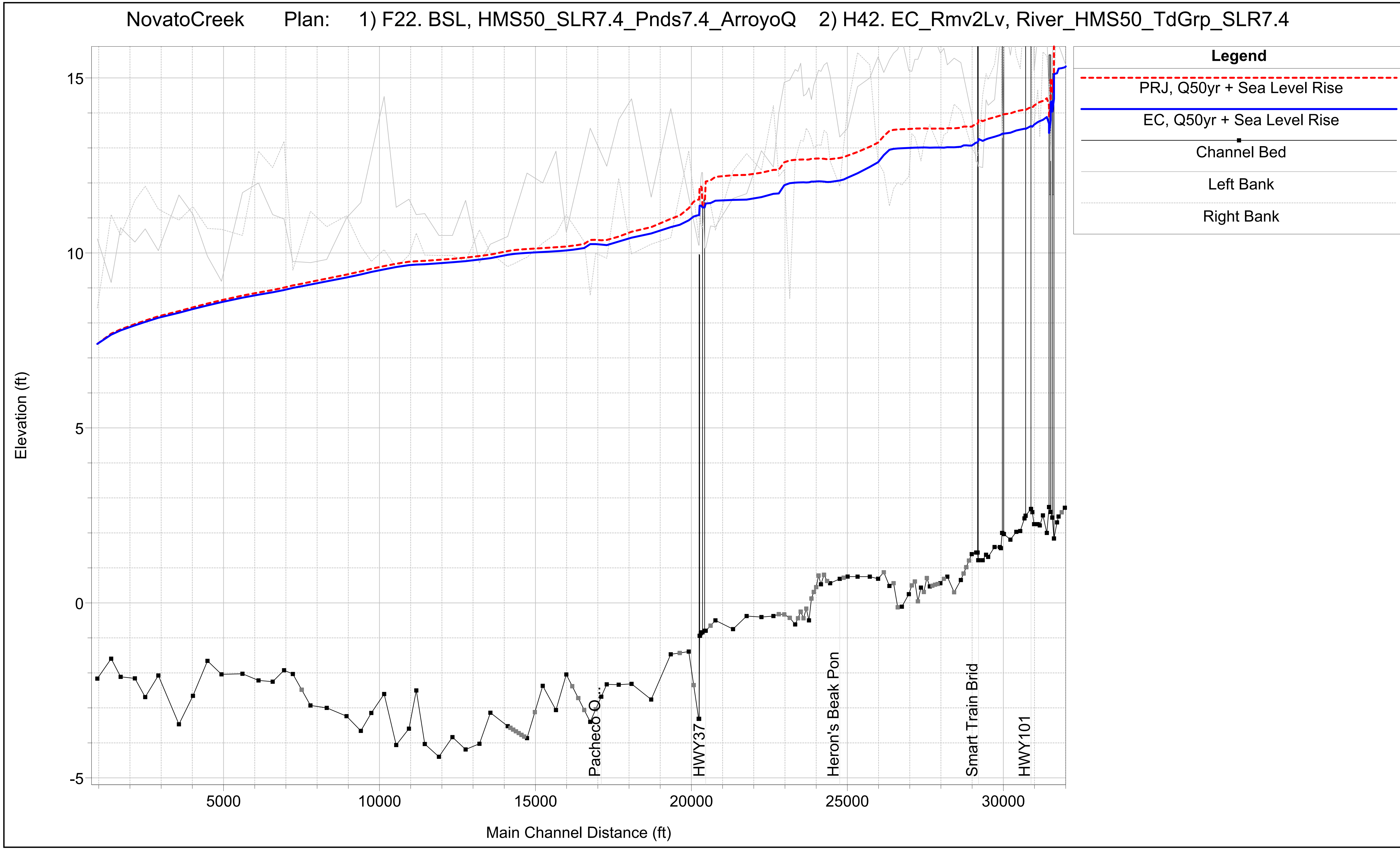


Figure 25 Comparison of Simulated Water Surface Profiles between Existing and Improved/Raised Levee Conditions - Riverine 50-Year Flood with Sea Level Rise



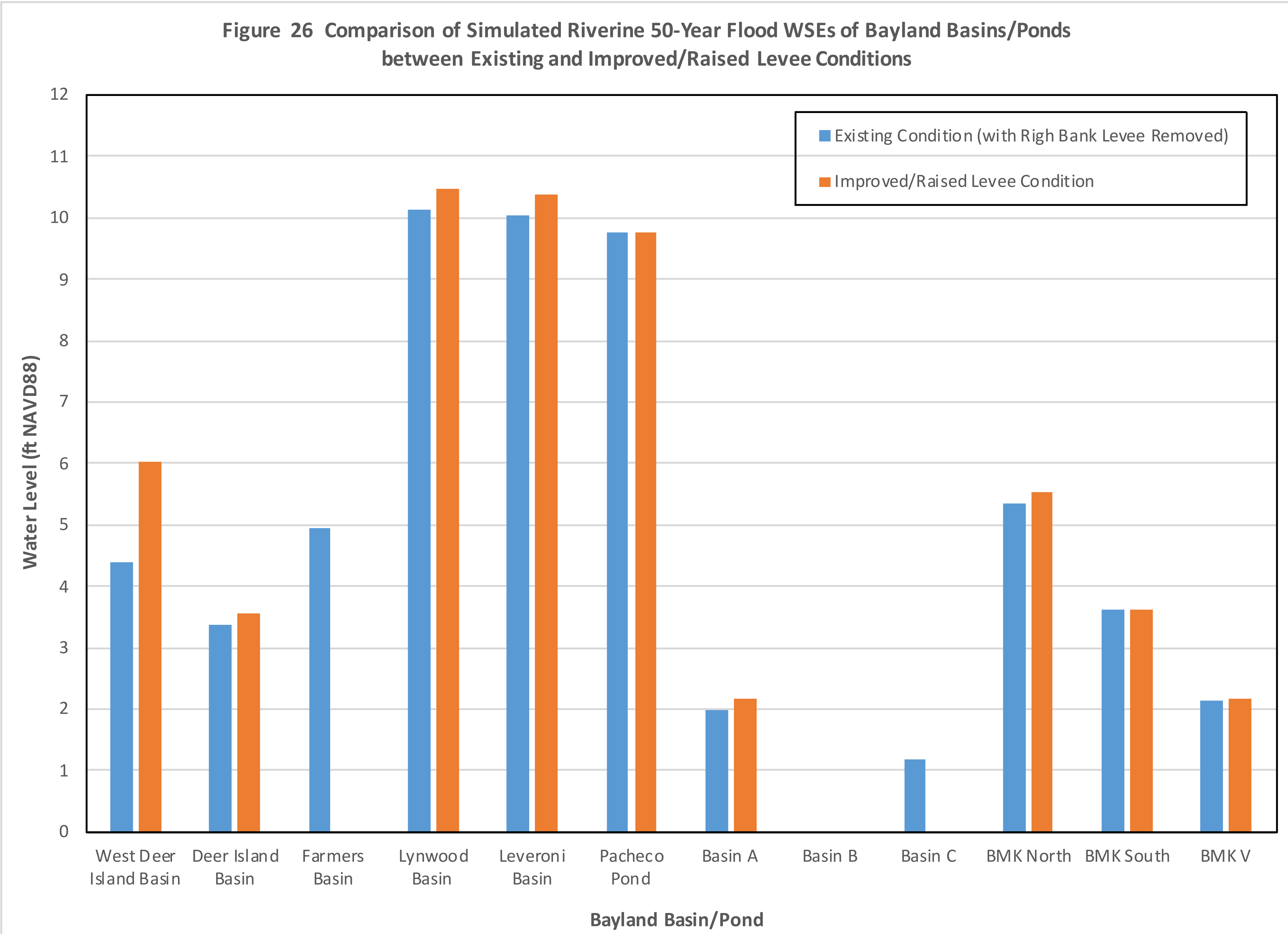


Figure 26 Comparison of Simulated Riverine 50-Year Flood WSEs of Bayland Basins/Ponds
between Existing and Improved/Raised Levee Conditions
Existing Condition (with Righ Bank Levee Removed)
Improved/Raised Levee Condition
Water Level (ft NAVD88)
0
1
2
3
4
5
6
7
8
9
10
11
12
West Deer Island Basin
Deer Island Basin
Farmers Basin
Lynwood Basin
Leveroni Basin
Pacheco Pond
Basin A
Basin B
Basin C
BMK North
BMK South
BMK V
Bayland Basin/Pond

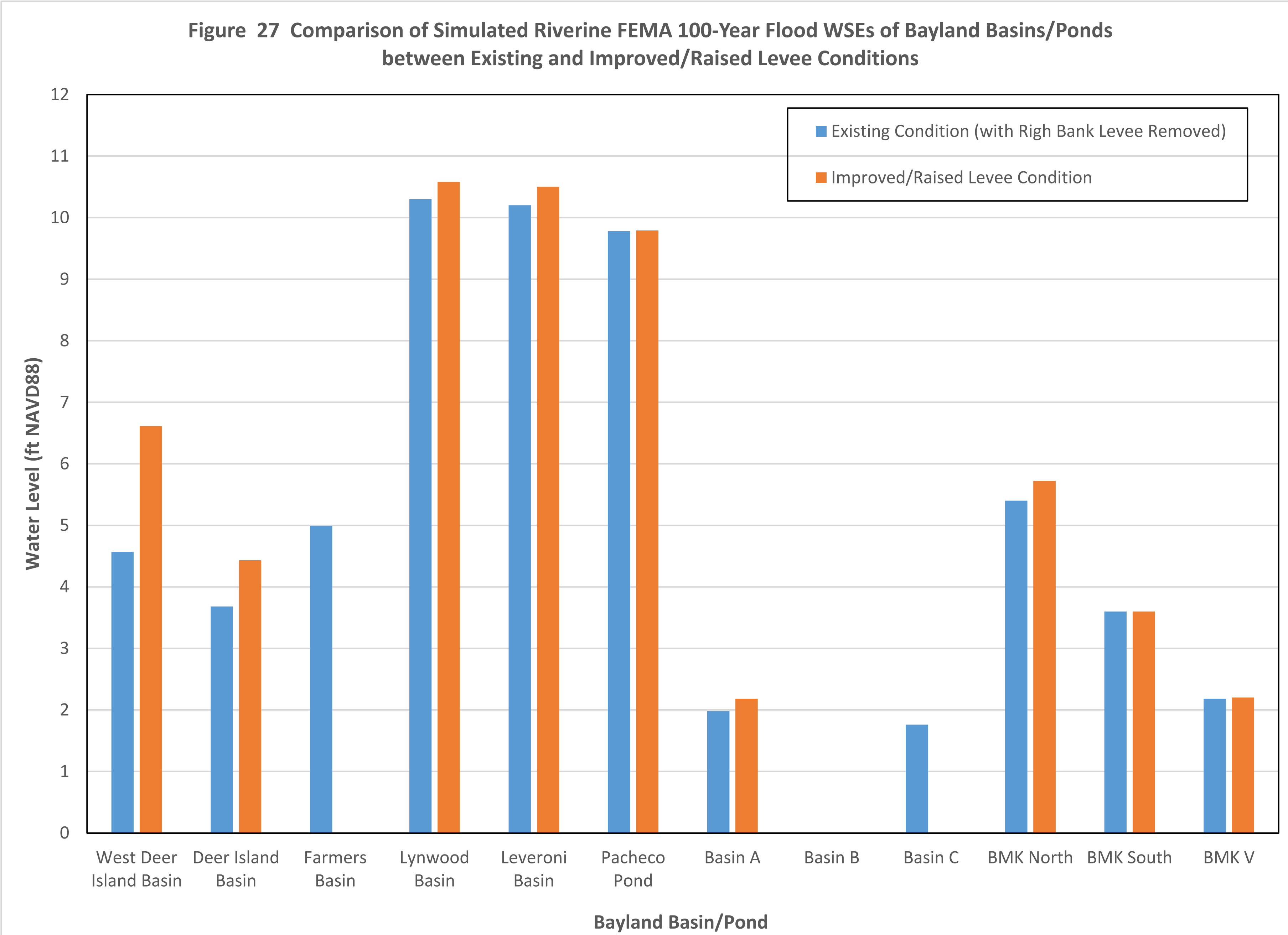


Figure 27 Comparison of Simulated Riverine FEMA 100-Year Flood WSEs of Bayland Basins/Ponds
between Existing and Improved/Raised Levee Conditions
Existing Condition (with Righ Bank Levee Removed)
Improved/Raised Levee Condition
Water Level (ft NAVD88)
0
1
2
3
4
5
6
7
8
9
10
11
12
West Deer Island Basin
Deer Island Basin
Farmers Basin
Lynwood Basin
Leveroni Basin
Pacheco Pond
Basin A
Basin B
Basin C
BMK North
BMK South
BMK V
Bayland Basin/Pond

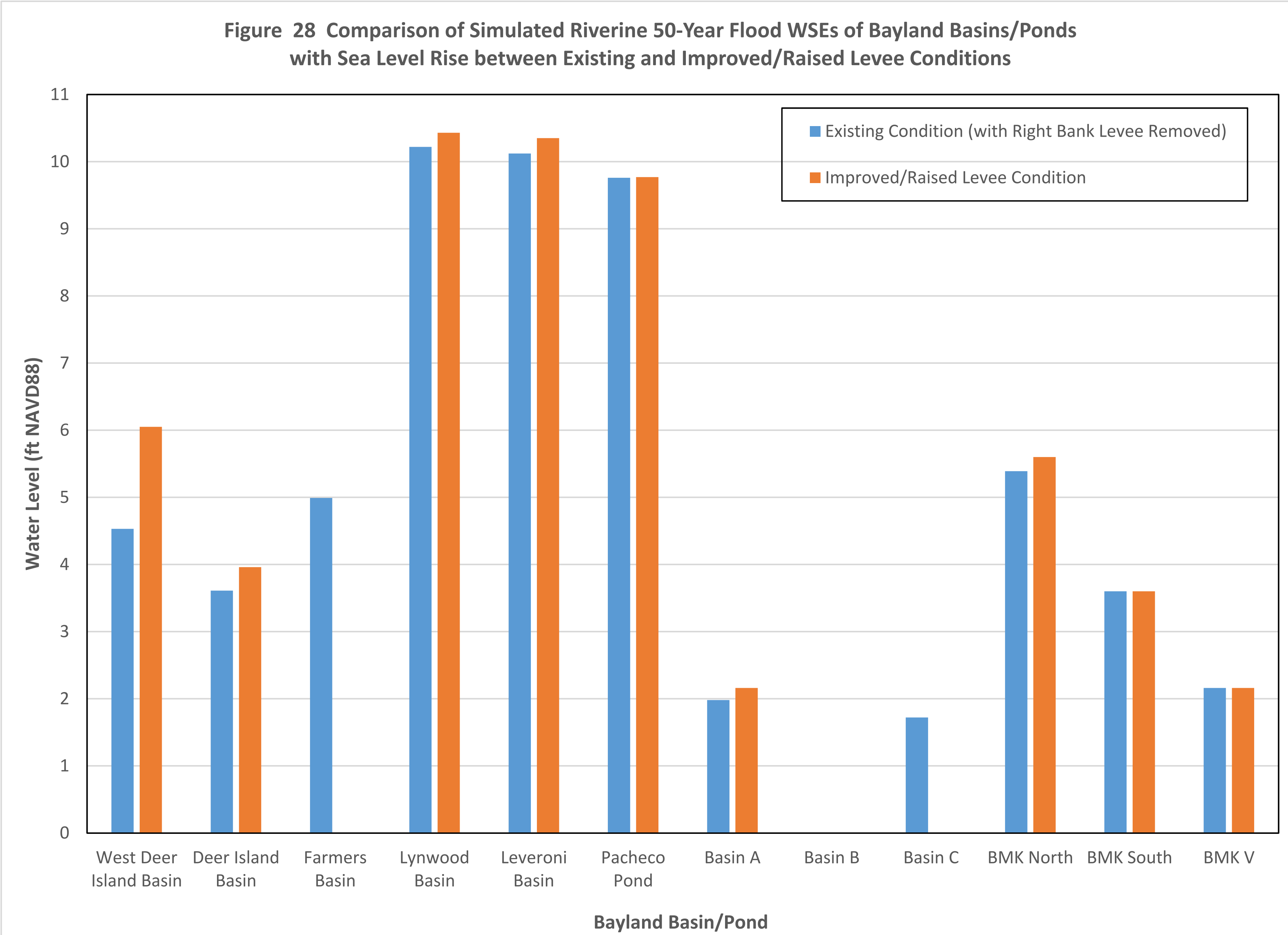
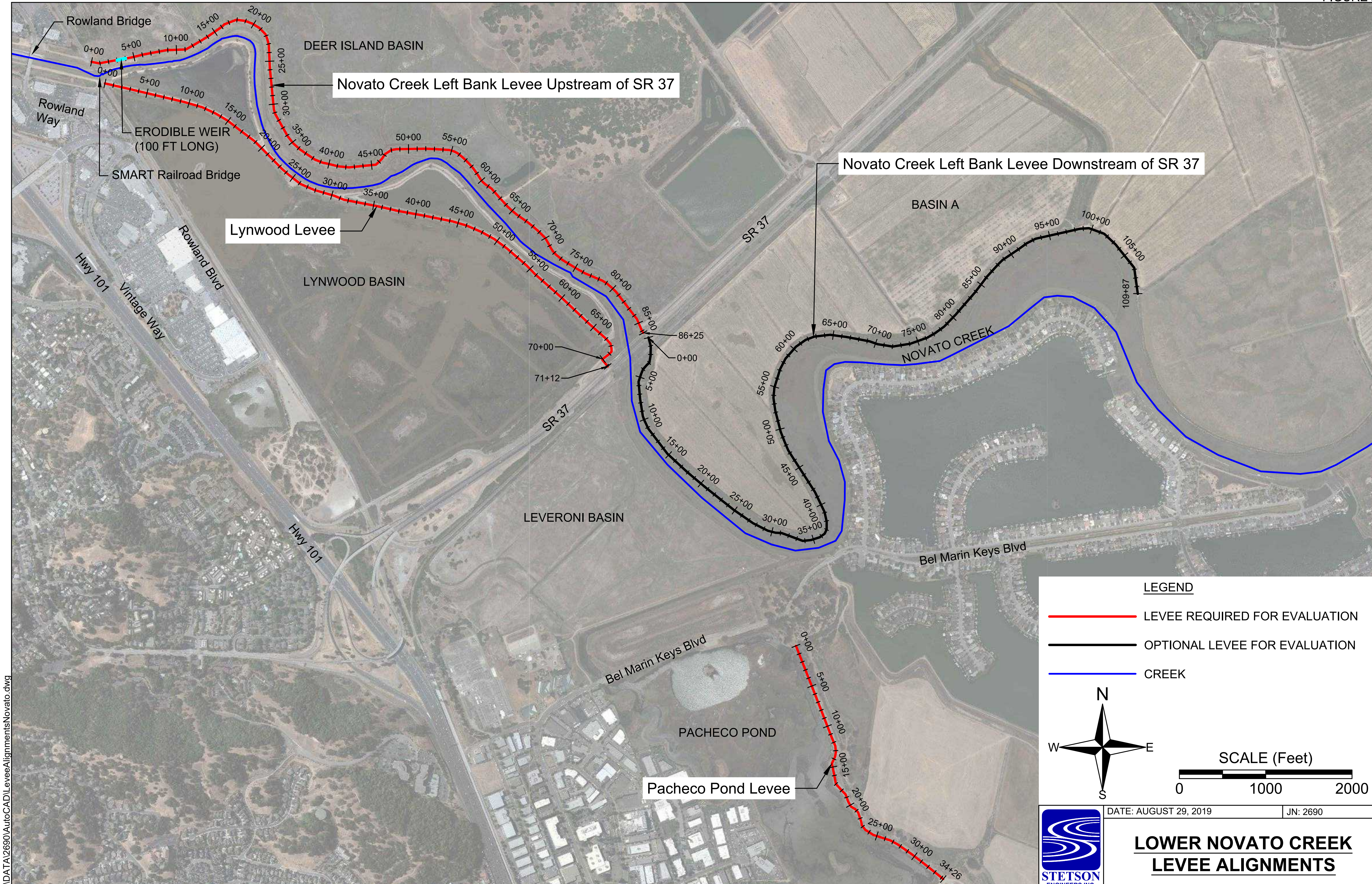


Figure 28 Comparison of Simulated Riverine 50-Year Flood WSEs of Bayland Basins/Ponds
with Sea Level Rise between Existing and Improved/Raised Levee Conditions
Existing Condition (with Right Bank Levee Removed)
Improved/Raised Levee Condition
Water Level (ft NAVD88)
0
1
2
3
4
5
6
7
8
9
10
11
West Deer Island Basin
Deer Island Basin
Farmers Basin
Lynwood Basin
Leveroni Basin
Pacheco Pond
Basin A
Basin B
Basin C
BMK North
BMK South
BMK V
Bayland Basin/Pond

FIGURE 29



DATE: AUGUST 29, 2019

JN: 2690

STETSON ENGINEERS INC.

LOWER NOVATO CREEK LEVEE ALIGNMENTS

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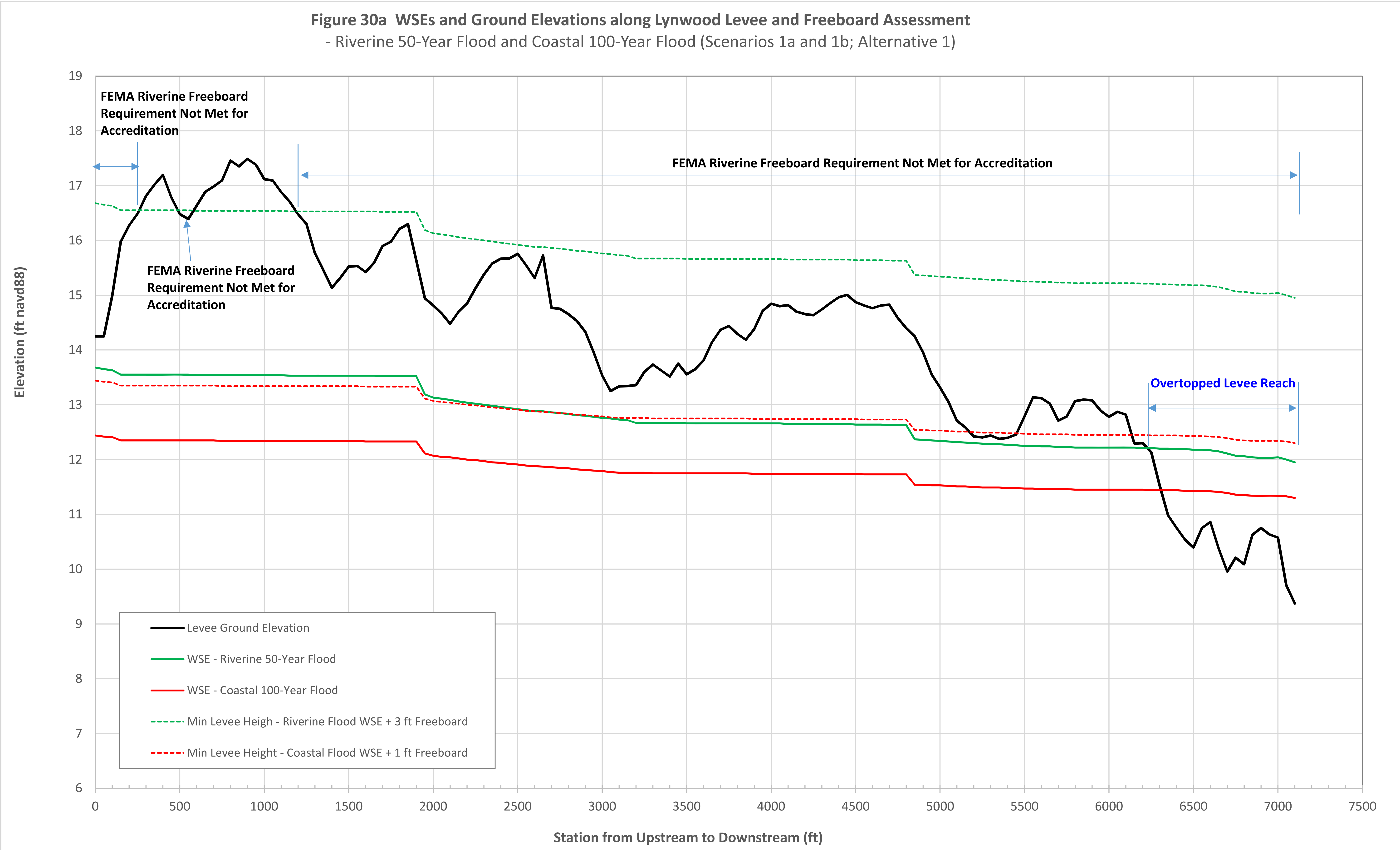


Figure 30a WSEs and Ground Elevations along Lynwood Levee and Freeboard Assessment
- Riverine 50-Year Flood and Coastal 100-Year Flood (Scenarios 1a and 1b; Alternative 1)
FEMA Riverine Freeboard Requirement Not Met for Accreditation
FEMA Riverine Freeboard Requirement Not Met for Accreditation
FEMA Riverine Freeboard Requirement Not Met for Accreditation
Overtopped Levee Reach
Elevation (ft navd88)
Station from Upstream to Downstream (ft)
19
18
17
16
15
14
13
12
11
10
9
8
7
6
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
Levee Ground Elevation
WSE - Riverine 50-Year Flood
WSE - Coastal 100-Year Flood
Min Levee Heigh - Riverine Flood WSE + 3 ft Freeboard
Min Levee Height - Coastal Flood WSE + 1 ft Freeboard

Figure 30b WSEs and Ground Elevations along Lynwood Levee and Freeboard Assessment
- Riverine FEMA 100-Year Flood and Coastal FEMA 100-Year Flood (Scenarios 2a and 2b; Alternative 2)

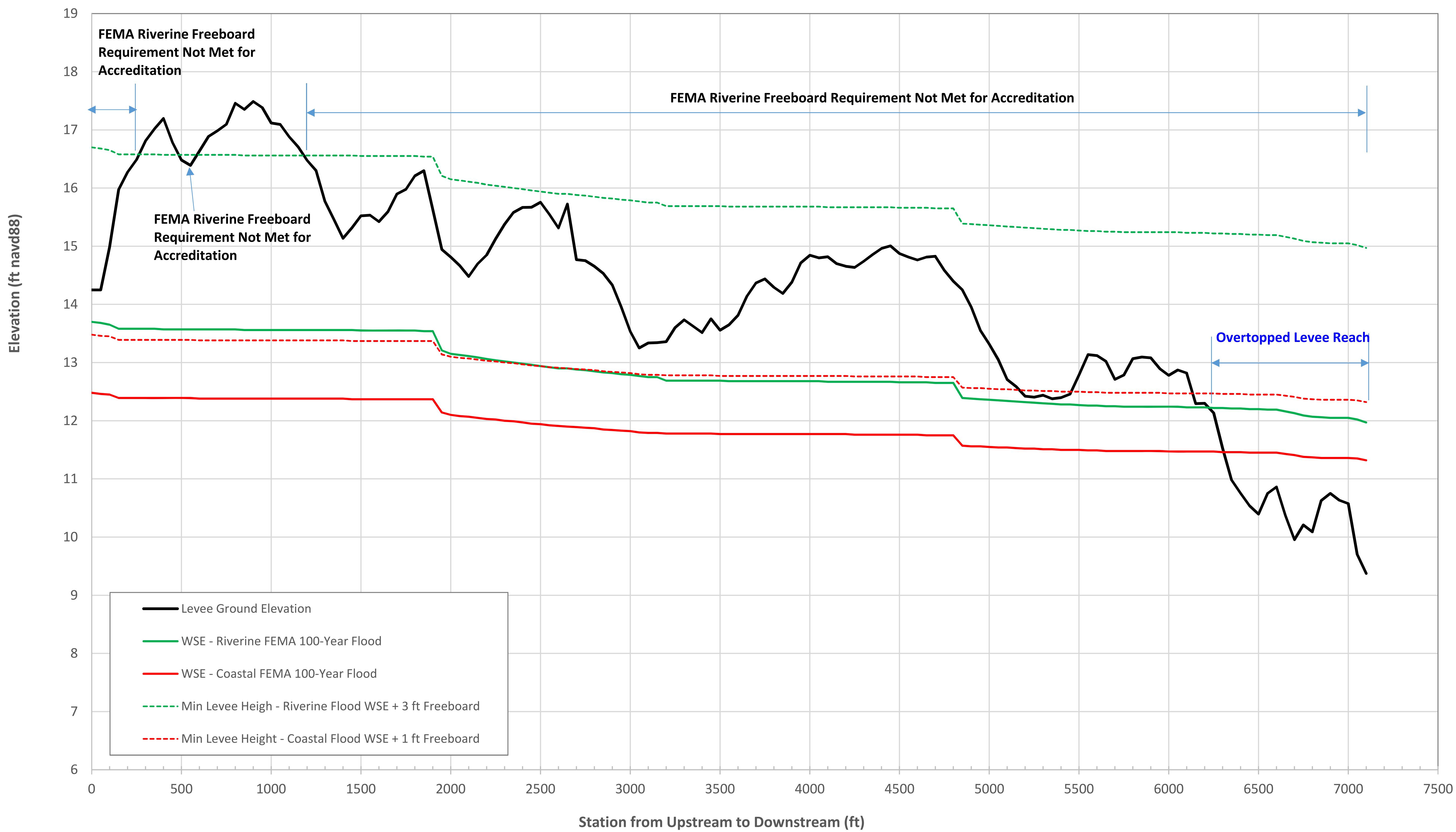
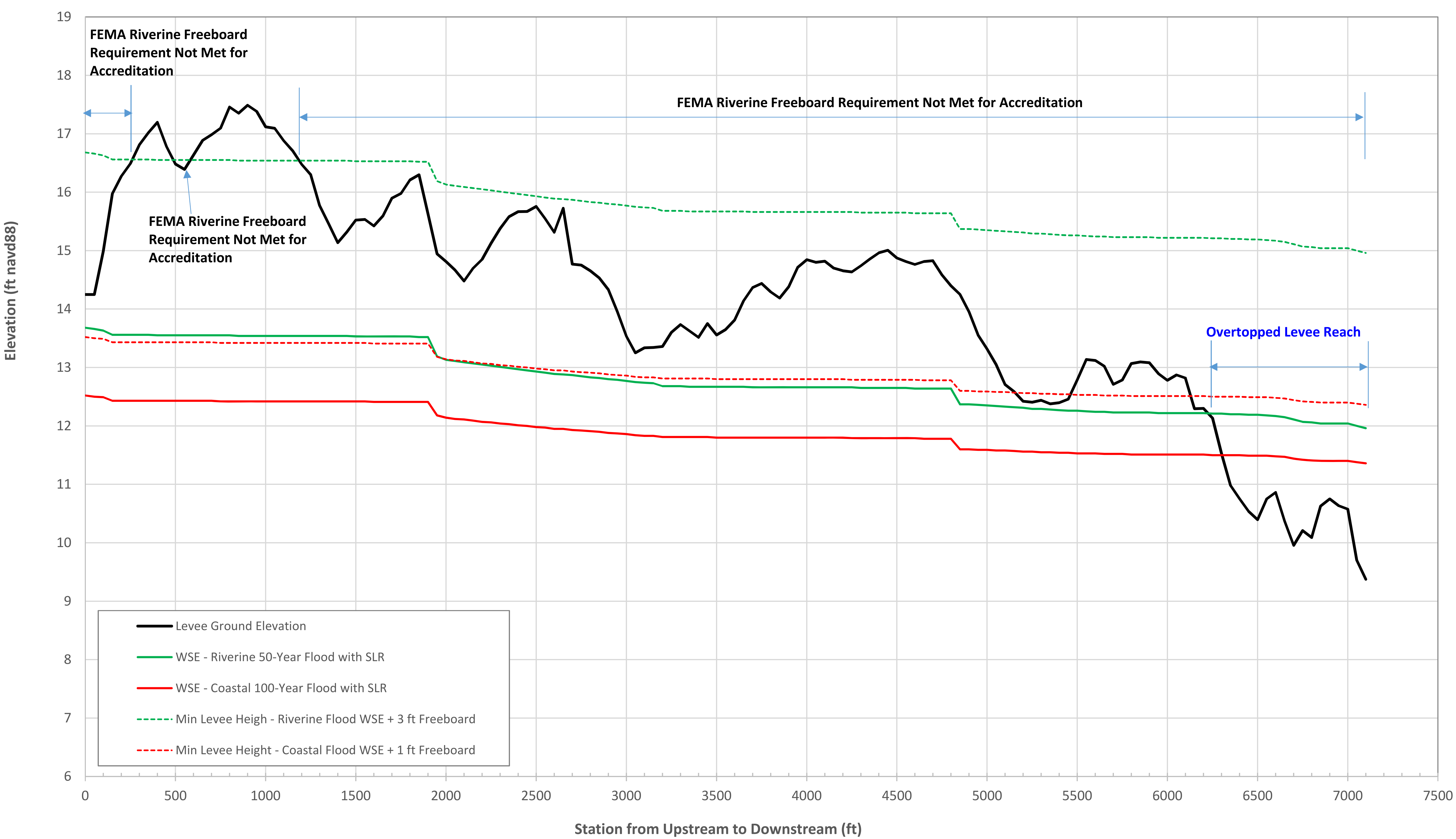


Figure 30c WSEs and Ground Elevations along Lynwood Levee and Freeboard Assessment

- Riverine 50-Year Flood and Coastal 100-Year Flood with Sea Level Rise (Scenarios 3a and 3b; Alternative 3)



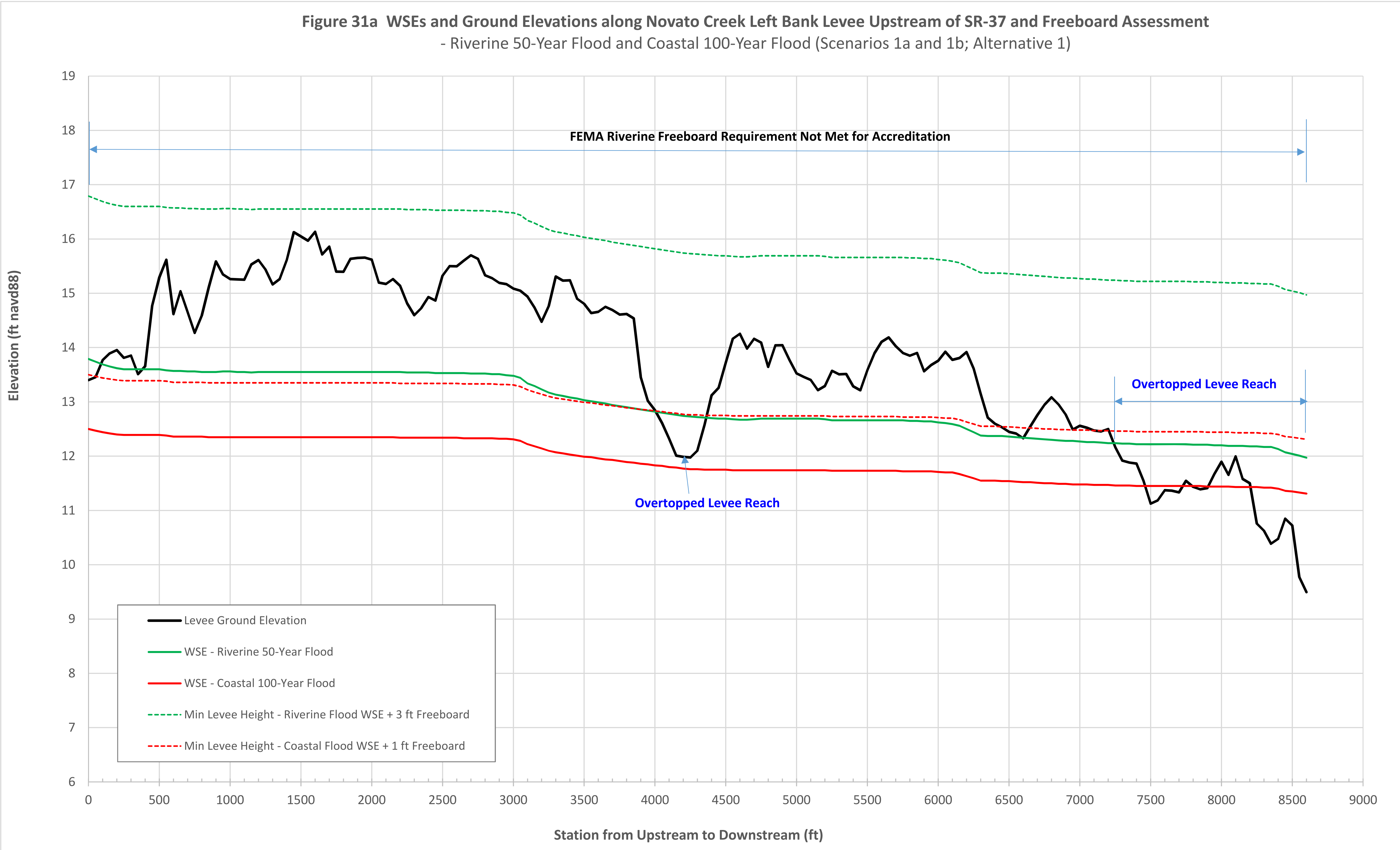


Figure 31a WSEs and Ground Elevations along Novato Creek Left Bank Levee Upstream of SR-37 and Freeboard Assessment
- Riverine 50-Year Flood and Coastal 100-Year Flood (Scenarios 1a and 1b; Alternative 1)
FEMA Riverine Freeboard Requirement Not Met for Accreditation
Overtopped Levee Reach
Overtopped Levee Reach
Elevation (ft navd88)
Station from Upstream to Downstream (ft)
Levee Ground Elevation
WSE - Riverine 50-Year Flood
WSE - Coastal 100-Year Flood
Min Levee Height - Riverine Flood WSE + 3 ft Freeboard
Min Levee Height - Coastal Flood WSE + 1 ft Freeboard
19
18
17
16
15
14
13
12
11
10
9
8
7
6
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000

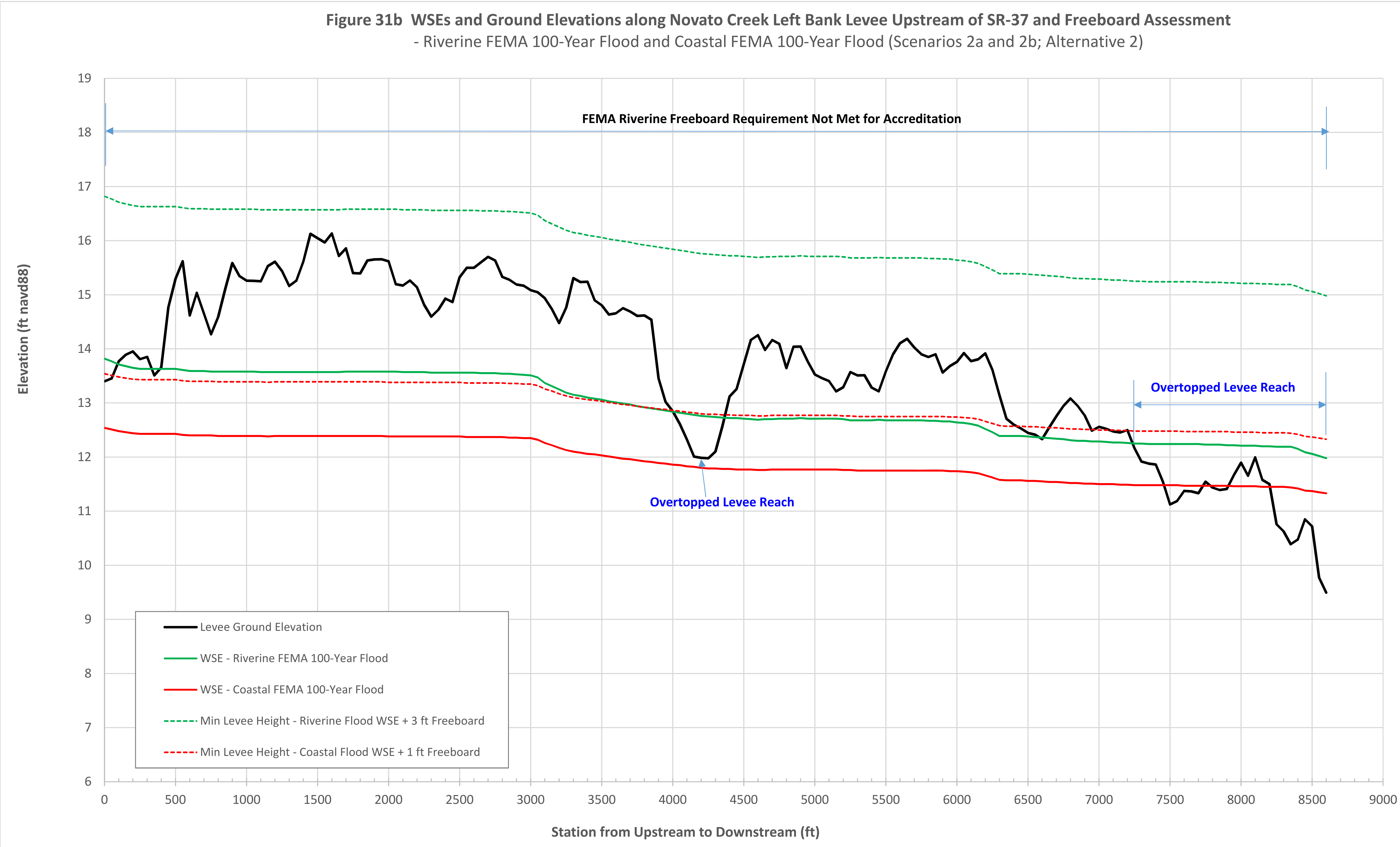


Figure 31b WSEs and Ground Elevations along Novato Creek Left Bank Levee Upstream of SR-37 and Freeboard Assessment
- Riverine FEMA 100-Year Flood and Coastal FEMA 100-Year Flood (Scenarios 2a and 2b; Alternative 2)
FEMA Riverine Freeboard Requirement Not Met for Accreditation
Overtopped Levee Reach
Overtopped Levee Reach
Elevation (ft navd88)
Station from Upstream to Downstream (ft)
19
18
17
16
15
14
13
12
11
10
9
8
7
6
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
Levee Ground Elevation
WSE - Riverine FEMA 100-Year Flood
WSE - Coastal FEMA 100-Year Flood
Min Levee Height - Riverine Flood WSE + 3 ft Freeboard
Min Levee Height - Coastal Flood WSE + 1 ft Freeboard

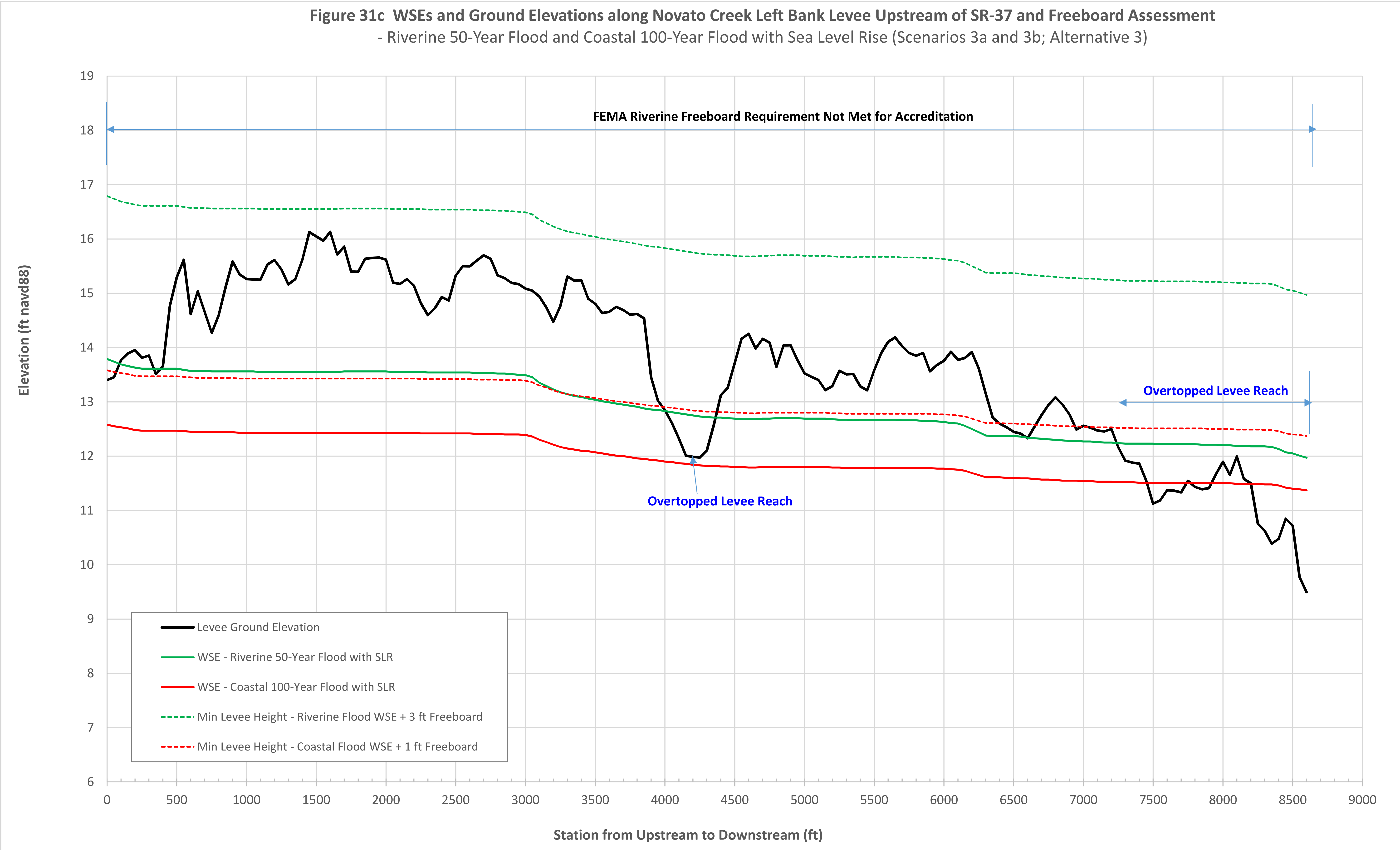


Figure 31c WSEs and Ground Elevations along Novato Creek Left Bank Levee Upstream of SR-37 and Freeboard Assessment
- Riverine 50-Year Flood and Coastal 100-Year Flood with Sea Level Rise (Scenarios 3a and 3b; Alternative 3)
FEMA Riverine Freeboard Requirement Not Met for Accreditation
Overtopped Levee Reach
Overtopped Levee Reach
Elevation (ft navd88)
Station from Upstream to Downstream (ft)
Levee Ground Elevation
WSE - Riverine 50-Year Flood with SLR
WSE - Coastal 100-Year Flood with SLR
Min Levee Height - Riverine Flood WSE + 3 ft Freeboard
Min Levee Height - Coastal Flood WSE + 1 ft Freeboard
19
18
17
16
15
14
13
12
11
10
9
8
7
6
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000

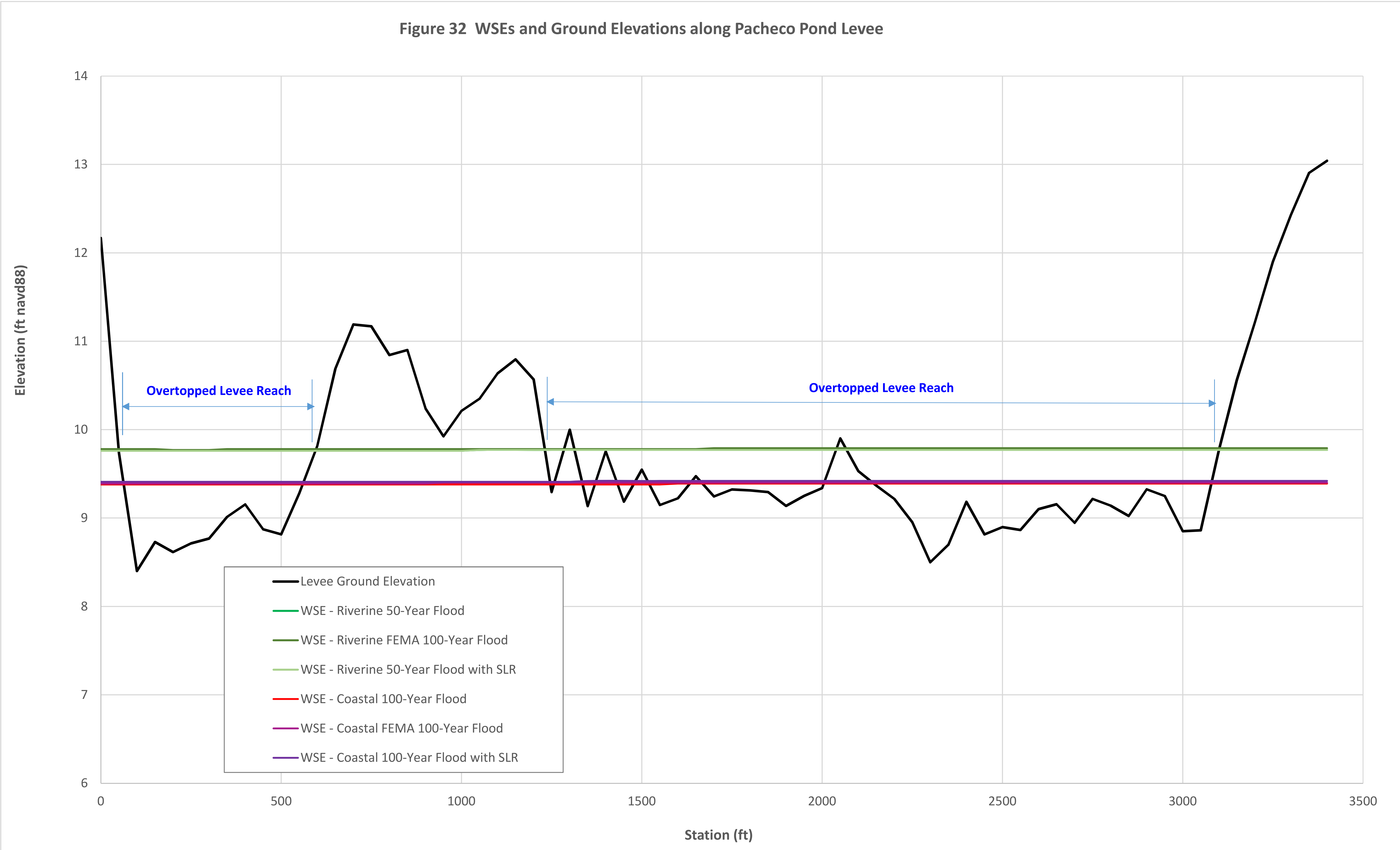


Figure 32 WSEs and Ground Elevations along Pacheco Pond Levee
Elevation (ft navd88)
Station (ft)
14
13
12
11
10
9
8
7
6
0
500
1000
1500
2000
2500
3000
3500
Overtopped Levee Reach
Overtopped Levee Reach
Levee Ground Elevation
WSE - Riverine 50-Year Flood
WSE - Riverine FEMA 100-Year Flood
WSE - Riverine 50-Year Flood with SLR
WSE - Coastal 100-Year Flood
WSE - Coastal FEMA 100-Year Flood
WSE - Coastal 100-Year Flood with SLR

Appendix A

Schaaf & Wheeler's HEC-RAS 1D/2D Model Documentation

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s&w@swsv.com

Schaaf & Wheeler
CONSULTING CIVIL ENGINEERS

MEMORANDUM

TO:	Roger Leventhal, P.E., Marin County	DATE:	July 2, 2018
FROM:	Charles D. Anderson, P.E.	JOB#:	MARN.03.16
SUBJECT:	Existing Condition Novato Creek HEC-RAS Model Documentation		

Model Development

Data Sources

The existing conditions Novato Creek HEC-RAS model is partially built from previous hydraulic models and analyses, but has been modified to include both one-dimensional channel and two-dimensional flow areas to evaluate overflows from the main creek channel. The primary source of data is the Novato Watershed Hydraulic Study (NWHS) prepared by Kamman Hydrology & Engineering (June 2014), which includes HEC-HMS models, HEC-RAS models, LiDAR data, survey data, record drawings, and reports. Other data sources include:

- Kamman Hydrology & Engineering, Inc. and WRECO. Novato Creek Hydraulic Study Analysis of Alternatives. March 2016
- Northwest Hydraulic Consultants (NHC) and Noble Consultants. HEC-RAS Model of Bel Marin Keys
- WRECO. HEC-RAS Model of Upper Novato Creek. June 25, 2014
- County of Marin and WRECO. HEC-HMS Model of the Novato Creek Watershed
- Caltrans State Highway 37 As-Builts
- SMART Novato Bridge As-Builts

Hydraulic Model Development

Novato Creek and the associated floodplain are modeled using the HEC-RAS 5.0.3 platform developed by the U.S. Army Corps of Engineers using the unsteady flow analysis option. This model encompasses the entirety of Novato Creek from Stafford Lake to San Pablo Bay. HEC-RAS 5.0.3 is selected because of its ability to model one-dimensional (1D) channel and two-dimensional (2D) overflow flow areas simultaneously.

The HEC-RAS model developed for this study is based on two previously established models for the NWHS, one developed by Northwest Hydraulic Consultants (NHC) and Noble Consultants, Inc. for lower Novato Creek, and the WRECO HEC-RAS model of upper Novato Creek. The NHC/Noble HEC-RAS model encompasses the creek reach generally adjacent to Bel Marin Keys, from the downstream face of the SMART bridge to the creek mouth at San Pablo Bay. This model's development is discussed in the Hydrologic and Hydraulic Supplemental Study – Phase II Draft Report Hydraulic, Hydrodynamics and Sedimentation in Novato Creek (September 2007). The WRECO HEC-RAS model encompasses Novato Creek from Stafford Lake to the downstream face of the SMART bridge.

Channel Data

Novato Creek and Arroyo Avichi are modeled as one-dimensional channels with lateral structures to their overbanks. Novato Creek is modeled between Stafford Lake and San Pablo Bay and Arroyo Avichi is modeled from approximately Arthur Street to the confluence with Novato Creek. Channel cross section data are taken from a digital elevation model (DEM) raster surface with a grid node spacing of 2 feet by 2 feet based on the NAVD datum. This surface has been created using a combination of the County's DEM and the DEM developed for the NWHS, which included bathymetric surveys completed in 2013. Cross section data have been verified at various locations in the model using previous survey data collected by the County. The roughness factors for the creeks are estimated based on models previously developed for Upper and Lower Novato Creek, confirmed during field reconnaissance.

Bridge Crossings

This model incorporates 13 bridge crossings over Novato Creek including from the upstream: Sutro Avenue, Thorsson Court, Novato Boulevard, Simmons Lane, Grant Avenue, 7th Street, Diablo Avenue, the Novato Fair Shopping Center access road, Redwood Boulevard, Redwood Highway (U.S. 101), Rowland Way, SMART, California Highway 37, and the Northwestern Pacific Railroad. There is also one culvert modeled on Arroyo Avichi at South Novato Boulevard. Bridge geometry has been obtained from the WRECO HEC-RAS model and verified using surveys and record drawing data where available. Bridge geometry for Highway 37 is taken from the NHC/Nobel HEC-RAS model. The SMART Novato Creek railroad bridge geometry is based on record drawings.

2D Flow Areas

This model includes 14 distinct 2D flow areas: North Deer Island, Deer Island, Duck's Bill Pond, Lynwood Pond, Lynwood Basin, Leveroni Basin, Pacheco Pond, Bel Marin Keys North, Bel Marin Keys South, Bel Marin Keys V, Basin A and Basin B, Basin C, North, and West. All storage areas are modeled as two-dimensional flow areas based on the ground terrain. The 2D flow areas adjacent to Novato Creek and Arroyo Avichi are hydraulically connected to the respective creek by lateral structures at the creek levees, since creek discharge that exceeds the bank full capacity will result in spill into these 2D flow areas. Flow is allowed to spill from flow area to flow area defined by the natural topography, using 2D area connections.

Lateral Structures

Levees are configured as lateral structures on both the left (northern) and right (southern) banks of Novato Creek and Arroyo Avichi. Levee elevation data for the lateral structures are obtained from the existing terrain model. Flows that exceed the capacity of the channel are modeled as spills over the lateral structures. The lateral structures are connected to 2D flow areas on both sides of Novato Creek and Arroyo Avichi.

The hydraulic model extents and elements are shown in Figure 1.

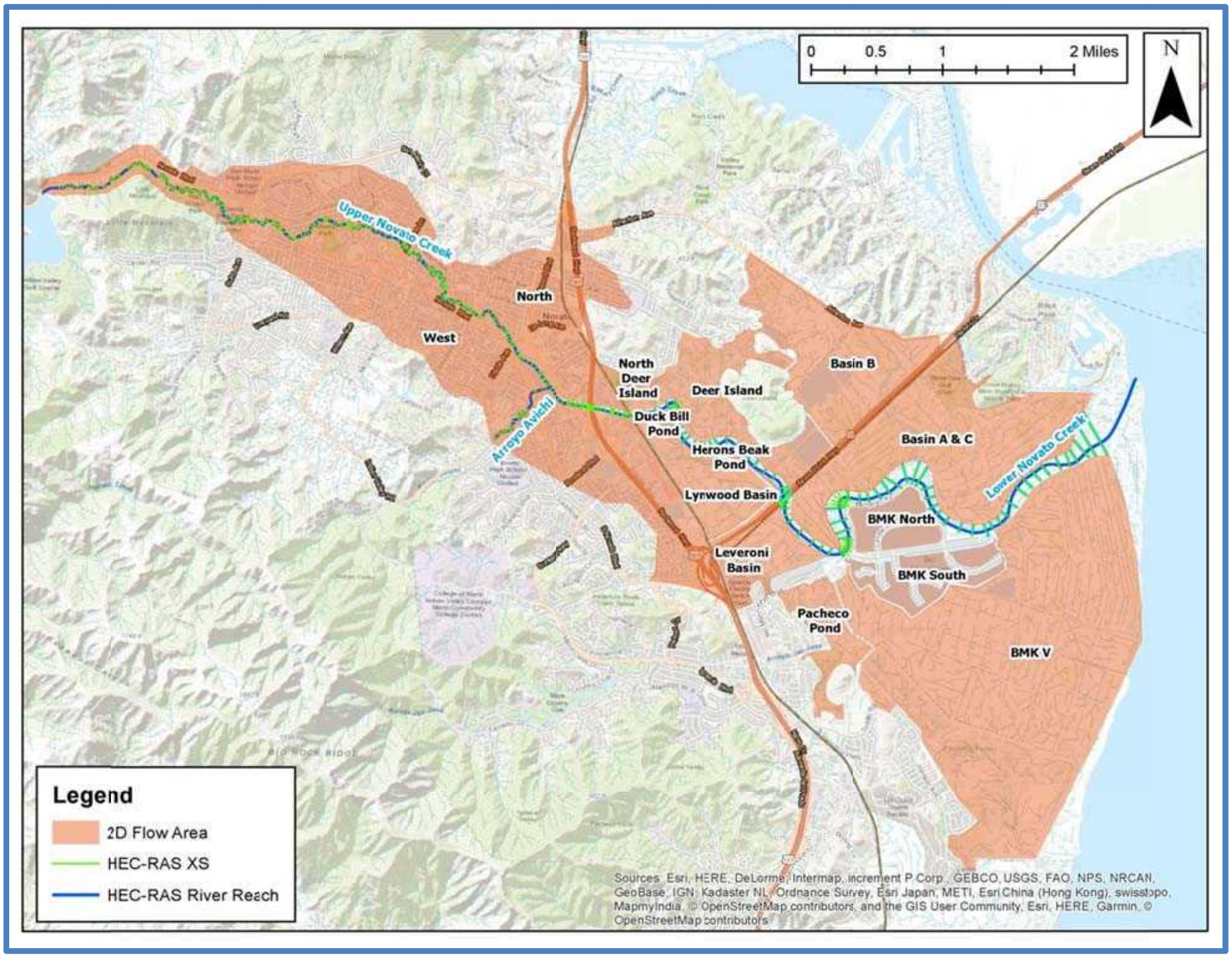


Figure 1. Schematic of HEC-RAS model for Novato Creek

Hydrologic Inputs

Hydrology was developed for the Novato Creek Watershed by Marin County Flood Control Division staff as part of the NWHS. This work is now fully captured in a HEC-HMS 4.2.1 model that includes 10-year, 50-year, and 100-year design storms. Hydrographs generated at various points in the watershed are used as boundary condition input for the HEC-RAS hydraulic model. WRECO conducted a review of the HEC-HMS model. The methodology, development, results, and WRECO's review of the hydrologic model are described in Appendix D of the Novato Creek Watershed Existing Conditions Hydraulics Study Report.

Since WRECO's review, Schaaf & Wheeler has updated the hydrologic model to redelineate eight smaller catchments in the vicinity of the Deer Island basin. These watersheds were updated to better model flow into Deer Island and North Deer Island basins. The methodology used to create rainfall hyetographs for these smaller catchments is consistent with WRECO's methodology. Catchments were delineated using the DEM for the hydraulic model and the City's storm drain system.

The hydrologic model is utilized to develop flow hydrograph time series for the three referenced design storm as inputs to the hydraulic model of Novato Creek. A flow hydrograph that represents the flows directly downstream of Stafford Lake is used as the upstream boundary condition for Novato Creek. The upstream boundary condition for Arroyo Avichi is configured as a flow hydrograph representing the flows coming into that creek. Warren Creek flows, which include the flows from Wilson Creek and Vineyard Creek, are represented as a lateral inflow hydrograph into Novato Creek at the confluence location. Runoff hydrographs from various local catchments tributary to Novato Creek are configured as lateral inflow hydrographs into Novato Creek and Arroyo Avichi at appropriate locations along their reaches. Additionally, five inflow hydrographs are configured as boundary conditions for North Deer Island and Deer Island basins at locations consistent with the City's storm drain system. A summary of where runoff hydrographs from the HEC-HMS model are applied to the HEC-RAS model is provided in Table 1 and Figure 2.

Table 1. Application of HEC-HMS flows to HEC-RAS model

HEC-HMS node	HEC-RAS Reach Name / Storage Area	HEC-RAS XS / BC	10-yr Peak Flow (cfs)	50-yr Peak Flow (cfs)	100-yr Peak Flow (cfs)
J251	Upper Novato	63664.15	411	1,092	1,550
W820-Bowman_canyon	Upper Novato	59436.71	667	1,240	1,487
W1780	Upper Novato	54707.19	91	149	175
W920	Upper Novato	52999.53	183	293	344
W930	Upper Novato	48978.77	436	695	812
R220B	Upper Novato	46867.02	220	341	413
Junction-1	Upper Novato	45170.89	297	439	503
W1610	Upper Novato	39926.28	78	110	134
R330-WarnerCreek	Upper Novato	33230.99	858	1,704	2,063
W1030	Lower Novato	32562.19	270	391	457
W1151	Lower Novato	32405.04	42	60	69
W1260	Lower Novato	20771.29	861	1,366	1,533
W1290+W1310+R570+R670	Lower Novato	16755.53	2,336	4,582	5,255
W1250	Lower Novato	1398.259	40	65	71
W1710	Arroyo Avichi	3726.241	280	614	709
W1700	Arroyo Avichi	716.8082	302	481	580
W1461	Deer Island	W1461	43	63	71
W1463+W141	Deer Island	W1463+W141	72	107	122
J41	Deer Island	J41Inflows	152	237	282
W248	North Deer Island	W248	33	47	53
W741+W323	North Deer Island	W741+W323	89	132	150

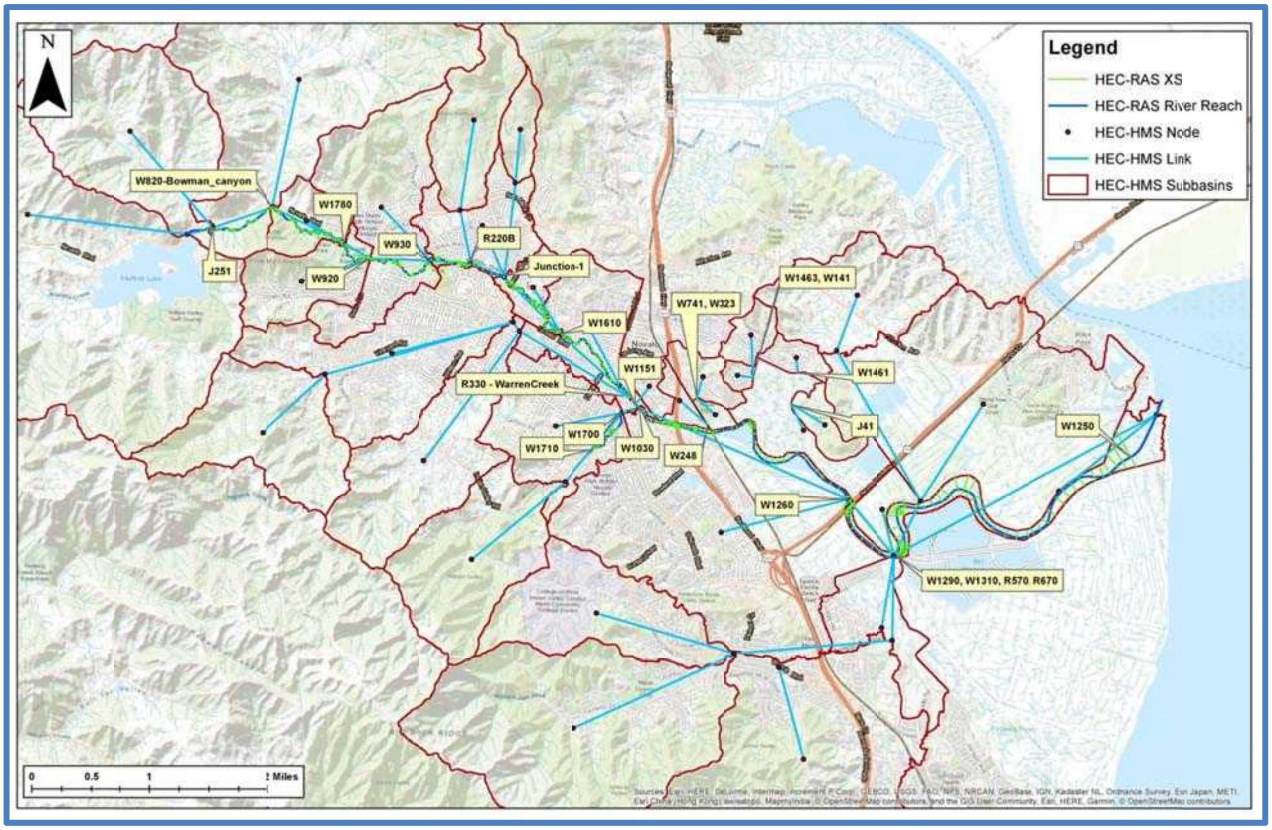


Figure 2. Hydrographs from HEC-HMS model applied to HEC-RAS model

Tidal Boundary Conditions

Traditionally Mean Higher High Water (MHHW) has been used as a backwater condition where riverine (freshwater) runoff meets an estuarine (saltwater) body. FEMA's *Guidance for Flood Risk Analysis and Mapping: Hydraulics: One-Dimensional Analysis* (November 2016) states:

> "When the downstream boundary of a modeled stream is within a coastal tidal reach, the tidal boundary of the model is taken as equal to the Mean Higher High Water (MHHW) level of the nearby tide station. Location of the tide station(s) must be verified to represent true downstream conditions. The tide level can be transferable to other locations along open coast; however, tide level at an estuary station is not transferable to locations beyond the estuary."

Mean Higher High Water at Mouth of Novato Creek

The nearest NOAA tide station is located at the mouth of the Petaluma River (Station 9415252). Mean Higher High Water is 9.35 feet on the MLLW datum, or 6.30 feet NAVD. AECOM published the *San Francisco Bay Tidal Datums and Extreme Tides Study* for FEMA in 2016. According to that study, MHHW at the mouth of the Petaluma River is 6.25 feet NAVD, so 6.3 feet NAVD is used as the MHHW boundary condition for hydraulic modeling.

Unsteady Design Tidal Boundary Conditions

The November 2016 FEMA guidelines also state:

> "The downstream boundary condition is usually a flood stage hydrograph or, less commonly, a flood flow hydrograph. The Mapping Partner must fully document the downstream boundary conditions including the sources of data and reasoning used to assign frequencies to the hydrographs."

Evidence shows that mean tide elevations are not necessarily an appropriate boundary condition when tide elevations in San Francisco Bay are elevated relative to predicted tides during periods of heavy rainfall. Furthermore, the relationship between coincident tides and maximum annual runoff can be quantified and used in the model, providing for a more statistically correct solution than an arbitrarily selected tide condition.

Astronomic Tides

A 19-year mean tide cycle is established for San Francisco Bay and other geographical locations on the West Coast. This cycle represents average tide heights over a specific period known as the tidal epoch, which spans the 19 years it takes for every possible combination of relative positions between the sun, moon and earth to occur. A mixed tide cycle predominates on the West Coast of the United States. This cycle consists of two high tides (one higher than the other) and two low tides (one lower than the other) each lunar day.

Based on calculations for these relative celestial positions, it is possible to predict tides for any day of the year at any time of day. *Astronomic tides,* created by the gravitational forces of the moon and sun acting on earth's oceans, are provided in tide prediction calendars. The mean tide cycle is simply the long-term average of astronomic tides. *Observed tides*, on the other hand, are actual tidal elevations recorded by National Oceanic and Atmospheric Administration (NOAA) gaging stations located throughout coastal areas.

Assessing the Conditional Probability of Coincident High Tide

To model an appropriate San Pablo Bay tidal cycle during a storm event of particular return period (with tides adjusted to the nearby Petaluma River location), elevations for each critical point in the tide cycle are adjusted based on the conditional probability of coincident occurrence with the annual maximum discharge of Novato Creek at Le Garner Park, which represents the closest USGS stream flow gaging location with sufficient length of record for analysis. This procedure is as described by Dixon (1986), whose hypothesis was that high tide events tend to occur the same day as flood flow events using conditional probability:

$$P_{(x,y)} = P(x|y)\,P(y)$$

where P(x,y) is the probability of occurrence of x and y; P(x|y) is the probability of occurrence of x given y; P(y) is the probability of occurrence of y; x is tide elevation; and y is maximum annual peak discharge. Since we are interested only in annual maximum discharges, P(y) is one and the probability of joint occurrence, P(x,y), is equal to the probability of x given y.

Coincident Design Tides at Mouth of Petaluma River / Novato Creek

Tide cycle points are taken from fitted probability curves of data, using the median plotting position for every recorded tide extreme that occurred within 24 hours of the recorded maximum annual discharge. Table 2 provides the values for each point on the tide cycle. Observed tide elevations at Golden Gate are translated to the Petaluma River by adding 0.1 foot to high tides and subtracting 0.1 foot from low tides.

Table 2: Novato Creek Coincident Tide

Tide	100-year Coincident at Golden Gate (feet MLLW)	100-year Coincident at Petaluma (feet MLLW)	100-year Coincident at Petaluma (feet NAVD)
Higher High	8.45	8.55	8.26
High	6.50	6.60	6.31
Low	5.45	5.35	5.06
Lower Low	3.04	2.94	2.65

The coincident tide cycle points listed in Table 2 are used to produce a sinuous design tide cycle based on the timing of the USACE's 19-year mean tide cycle for the Golden Gate Station. To translate tides from Golden Gate to the Petaluma River, high tide elevations are lagged 1.37 hours and low tide elevations are lagged 2.18 hours from the time of high tide at the Golden Gate. The timing of coincident tide elevations with the beginning of a storm event (rainfall) is a random process. A sensitivity analysis has been completed to determine the impact the timing of the tide cycle has on the hydraulics of Novato Creek at the North Deer Island location. It is determined that the water surface elevation of Novato Creek at this location is not particularly sensitive to the timing of the coincident 10-year high tide, likely due to the area of the downstream tidal prism. The 10-yr, 50-yr, and 100-yr coincident tide cycles are used as the respective flow downstream boundary condition. The 100-, 50-, and 10-year tide cycles are shown in Figure 3.

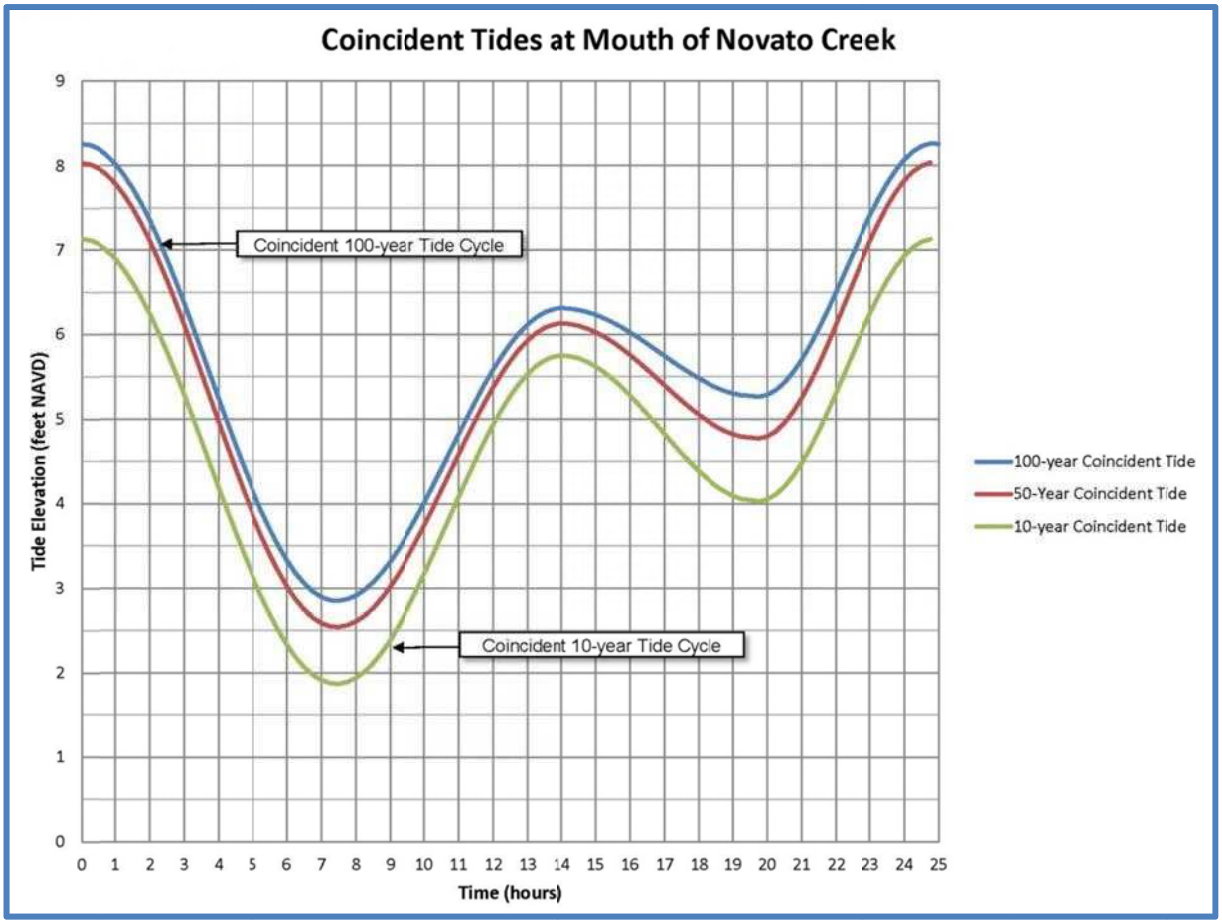


Figure 3: Coincident Tide Cycles

Sea Level Rise

Models that evaluate the impact of sea level rise on the tidal boundary condition assume an arithmetic change to a given boundary condition applied uniformly across the entire tidal cycle. That is, sea level rise is treated as a simple datum adjustment.

Projections of relative sea levels at San Francisco with a variety of future emissions scenarios were published in April 2017 by the California Ocean Protection Council.[1] Figure 4 shows future sea level rise curves for three 'representative concentration pathways', or RCPs and historical sea level rise since the nineteenth century. The set of RCPs reflects radiative forcing level (a globally averaged heat trapping capacity of the atmosphere) in 2100 relative to pre-industrial values. RCP 8.5 is consistent with "a future in which there are no significant global efforts to limit or reduce emissions."

For San Francisco at the Golden Gate Bridge, the median projected sea level rise by mid-century is 0.9 foot under all RCPs, the mid-century rise for RCP 8.5 is 1.9 feet with 99.5 percent confidence and the end of century sea level rise for RCP 8.5 is 6.9 feet with 99.5 percent confidence. Table 3 excerpts Table 1(b) from the 2017 COPC report, showing estimates for future sea level rise with associated probabilities.

[1] California Ocean Protection Council, Rising Seas in California: An Update on Sea-Level Rise Science, April 2017.

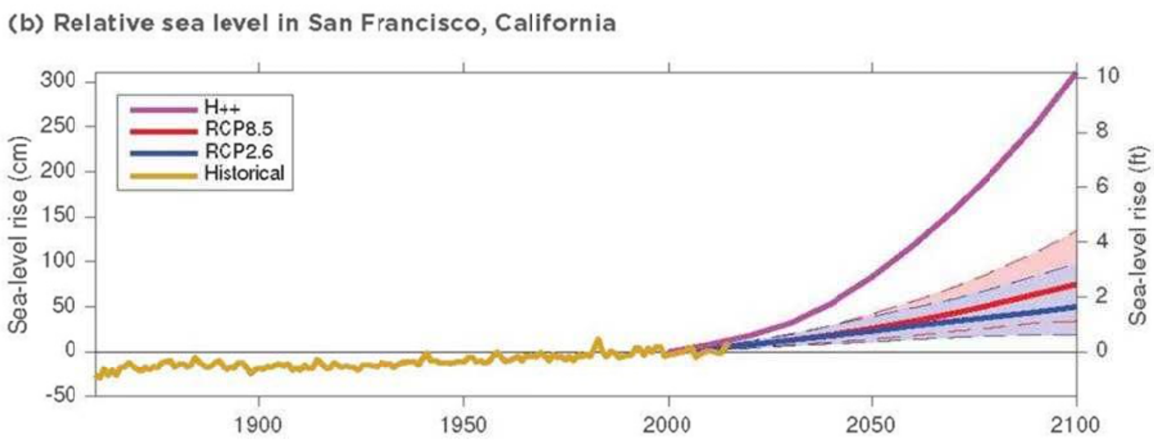


Figure 4: Future Sea Level Rise Estimates

Table 3: Predicted Sea Level Rise at Golden Gate

Feet above 1991-2009 mean	MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANGE
Year / Percentile	50% probability SLR meets or exceeds...	67% probability SLR is between...	5% probability SLR meets or exceeds...	0.5% probability SLR meets or exceeds...
2030	0.4	0.3 - 0.5	0.6	0.8
2050	0.9	0.6 - 1.1	1.4	1.9
2100 (RCP 2.6)	1.6	1.0 - 2.4	3.2	5.7
2100 (RCP 4.5)	1.9	1.2 - 2.7	3.5	5.9
2100 (RCP 8.5)	2.5	1.6 - 3.4	4.4	6.9
2100 (H++)	10			
2150 (RCP 2.6)	2.4	1.3 - 3.8	5.5	11.0
2150 (RCP 4.5)	3.0	1.7 - 4.6	6.4	11.7
2150 (RCP 8.5)	4.1	2.8 - 5.8	7.7	13.0
2150 (H++)	22			

RCP 2.6 represents a future emissions scenario that most closely corresponds to aspirational goals of the 2015 Paris Agreement for Climate Change, which calls for limiting the global mean warming to less than 2°C, with net-zero greenhouse gas emissions in the second half of this century. RCP 4.5 is a middling emissions scenario and the H++ scenario represents an extreme sea level rise scenario from the Fourth National Climate Assessment, that includes Antarctic ice mass loss and future ice sheet collapse.

The year 2050 MHHW is assumed to be 6.3 feet NAVD plus 1.9 feet or 8.2 feet NAVD.

Model Organization

All model scenarios utilize the same geometry file, 'NovatoCreekExisting'. RAS Mapper can be used to view depth, velocity, and water surface elevation results for all scenarios. Table 4 summarizes the basic model organization, with brief subsequent discussions of what each model represents and its intended purpose.

Table 4: Novato Creek Hydraulic Model Organization

Model	Plan Name	Geometry File	Flow File	D/S BC	Comp Interval	Hydro Output Interval	Mapping Output Interval
Baseline	Baseline	NovatoCreekExisting	50yrBaseline	MHHW (6.3 ft)	6 sec	5 min	15 min
FEMA	FEMA	NovatoCreekExisting	100yrFEMA	MHHW (6.3 ft)	6 sec	5 min	15 min
Sea Level Rise	SeaLevelRise	NovatoCreekExisting	50yrSLR	MHHW +1.9ft	6 sec	5 min	15 min
10-year Design	10yrDesign	NovatoCreekExisting	10yrNormal	10-year coincident tide cycle	6 sec	5 min	15 min
50-year Design	50yrDesign	NovatoCreekExisting	50yrCoinc	50-year coincident tide cycle	6 sec	5 min	15 min
100-year Design	100yrDesign	NovatoCreekExisting	100yrCoinc	100-year coincident tide cycle	6 sec	5 min	15 min

Baseline

This model provides existing conditions from which to assess improvements required to maintain 50-year protection. The downstream boundary condition is a constant water surface of 6.3 feet NAVD, or MHHW.

FEMA

Hydraulic analyses for the certification of levees and eventual FEMA accreditation will follow the FEMA *Guidelines and Specifications for Flood Hazard Mapping Partners.* The downstream boundary condition is a constant water surface of 6.3 feet NAVD (MHHW) and 100-year hydrology is used. This model is for existing conditions with all levees assumed to hold during overtopping.

Baseline with Sea Level Rise

This model provides for the baseline 50-year water surface profile and overflows assuming existing conditions, levees holding during overtopping and a constant-stage downstream boundary equal to MHHW plus 1.9 feet to include anticipated sea level rise for 2050.

Design Models - Existing Conditions

These models represent existing condition baselines for other County-proposed project hydraulics not necessarily related to the LOLE. The models use flow hydrographs imported from HEC-HMS as the upstream boundary condition and the respective coincident tide cycles for the downstream boundary condition.

Appendix B

Stetson’s Review Comments on the HEC-RAS 1D/2D Model

Preliminary Review Comments on the Novato Creek HEC-RAS 1D/2D Model

Stetson Engineers Inc.
(7/20/2018)

This preliminary review focused on the lower portion of Novato Creek, which is the study area of the Novato Creek Levee Evaluation Project.

1. Questions on model calibration/verification

   The model used a Manning's n of 0.02 for the lower portion of Novato Creek. Our field visit on 7/18/2018 found that there is dense vegetation in the creek. Is the model calibrated and verified?

2. Questions on initial WSEs of bayland ponds

   Table 1 below shows the initial WSEs of the bayland ponds used in the Novato Creek HEC-RAS 1D/2D model. These initial WSEs are different from those used in the KHE's 2014 existing conditions study (Table 2). How were the initial WSEs for the ponds determined?

Table 1 Initial WSEs of Bayland Ponds Used in the HEC-RAS 1D/2D Model

Initial Elevation of Storage Areas/2D Flow Areas (Optional) | Import Min SA Elevation(s)

Keep initial elevations constant during warmup

	Storage Area/2D Flow Area	Initial Elevation
1	Basin A and B	
2	Basin C	-2.5
3	BMK North	-2.23
4	BMK South	3.63
5	BMK V	-12
6	Deer Island	-0.63
7	Duck Bill Pond	6.08
8	Leveroni Basin	-5
9	Lynwood Basin	-2
10	Lynwood Pond	4.5
11	North	0
12	NorthDeerIsland	
13	Pacheco Pond	3.55
14	West	0

Table 2 Initial WSEs of Bayland Ponds Used in the KHE's Existing Conditions Study
(Table 6.1 of KHE 2014 Existing Conditions Report)

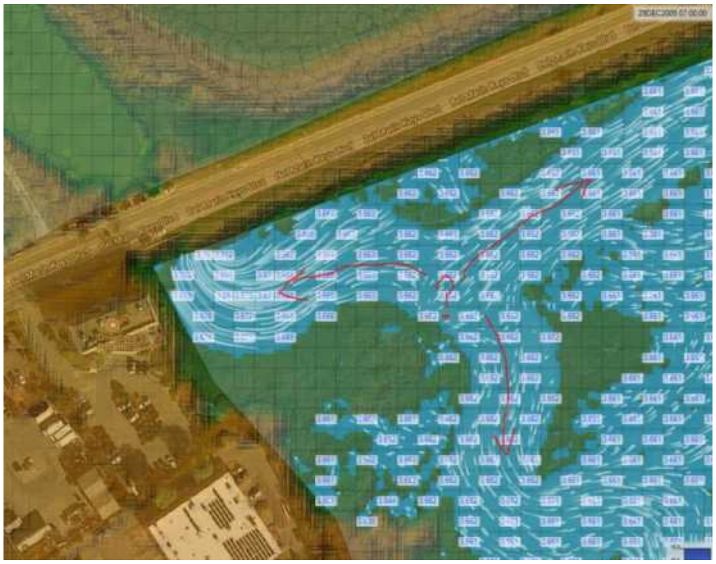
Pond	Initial Water Surface Elevation (ft., NAVD88)
Lynwood Basin	
Central Basin	4.5
Duckbill Pond	3.3
Heron's Beak Pond	2.0
Pacheco Pond	2.63
BMKCSD	
North Lagoon	4.6
South Lagoon	3.6

3. Inappropriate inflow input locations

   Refer to Figure 1 in attached PDF file flow input locations of the HEC-RAS 1D/2D model. The model lacks of flow inputs to Pacheco Pond and Lynwood Pond, which would affect the evaluation of levees along these ponds. Other flow input locations also need be adjusted as well for accurate representation of the system.

4. Questionable inflow source to Pacheco Pond

   As shown in figure below, current model result (Plan: 100yrDesign) shows an internal inflow source to Pacheco Pond at the arrow-marked area, and Pacheco Pond WSE has increased from initial 3.55 ft at 0:00 to 3.7 ft at 7:00. However, examination of the model input flow file does not show any inflow source to Pacheco Pond. The model result is unexplainable and, thus, the model is not reliable for the evaluation of Pacheco Pond levee.



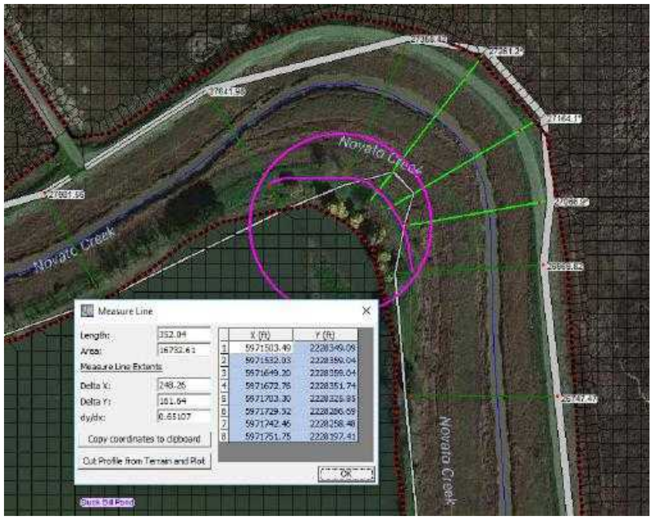
Unexplainable Flow Field in Pacheco Pond

5. The Levees (Lateral Structures) between 1D and 2D models were not geo-referenced, and the levee crest elevations were solely represented by TOB at 1D XS locations. Such configuration has the following issues:
   a. Incorrect representation of levee length

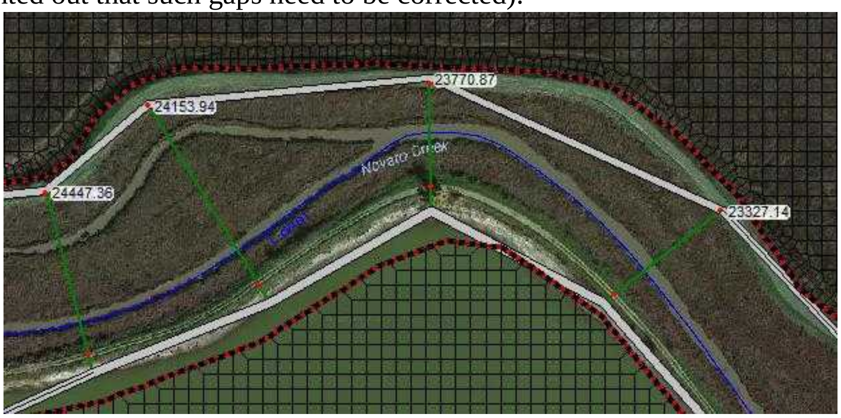
      For example, in the screenshot below, the levee length from XS 26969.82 to XS 27641.98 is 569 ft in the model, while the actual length is 352 ft, which is a big difference (62%). If the levees had been geo-referenced, such errors would not exist because the model will automatically report error.

   b. Insufficient representation of levee crest elevations

      The model only sees the levee crest defined by the top of banks at XS locations and linearly interpolates levee crest between XSs. Any non-linear variation between XSs won't be seen by model, which may lead to incorrect overtopping calculations.



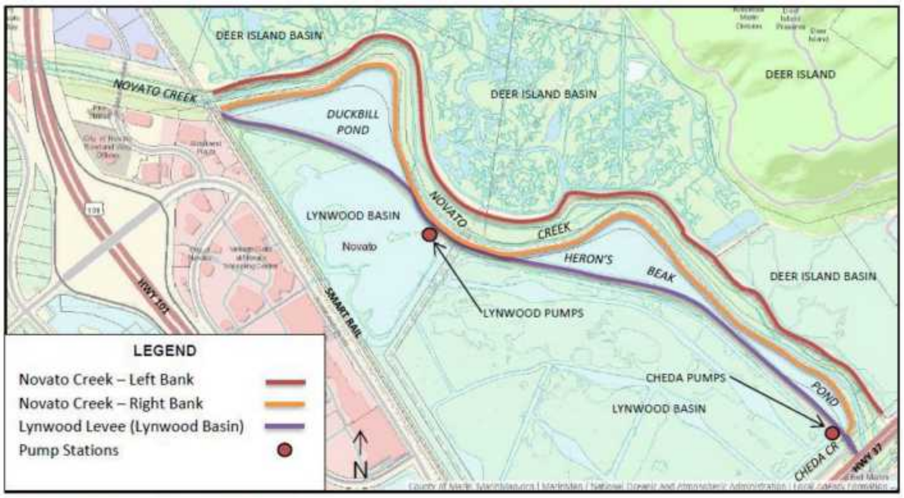
6. The 2D Flow Area boundary delineation does not cover the entire pond, which leads to underestimate of pond capacity, and also creates gaps that will never be inundated during inundation mapping (Note: During the review of the Ross Valley HEC-RAS 1D/2D model, USACE reviewer specifically pointed out that such gaps need to be corrected).



7. Insufficient mapping limit due to insufficient 2D Flow Area delineation which leads to inaccurate representation of pond volume and insufficient inundation mapping limit.

8. Lack of full interconnections between ponds and the Novato Creek channel

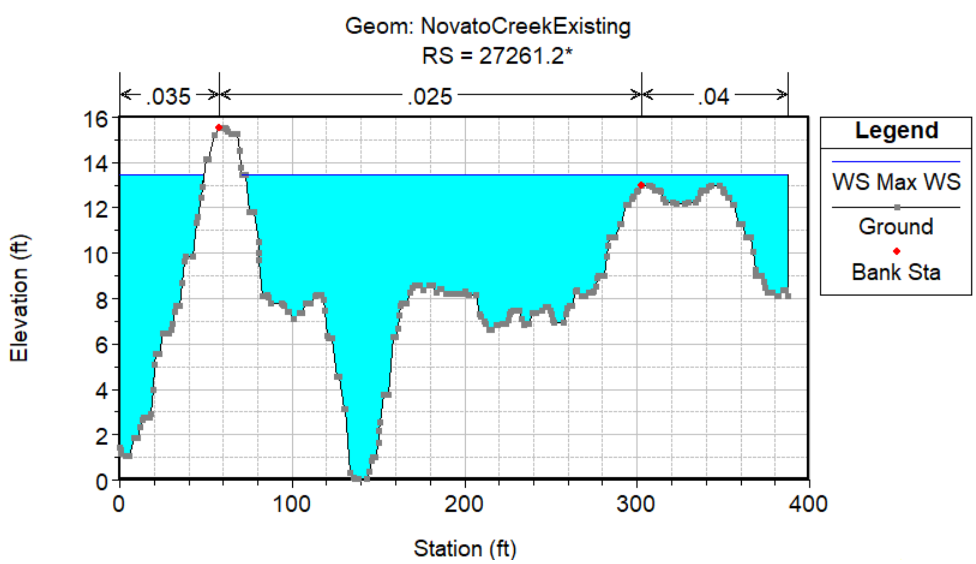
   For example, there are two pump stations (see figure below), but the model does not have the pumps. The model also does not have a complete representation of culverts and tidal gates.



Map 3. Location of Levees to be Evaluated.

9. Incorrect bridge representations of HWY 101 Bridge and Redwood Blvd double bridges
   a. Refer to screenshots below, in reality, the HWY 101 has one single bridge and the Redwood Blvd has two bridges. However, the model represented these two bridges in an opposite way.
   b. Both Bridges have skew angle with the channel, especially for Redwood Blvd double bridges, with a skew of > 45 degrees. However, the model does not skew any of these XS, and probably the bridge openings were not skewed either.

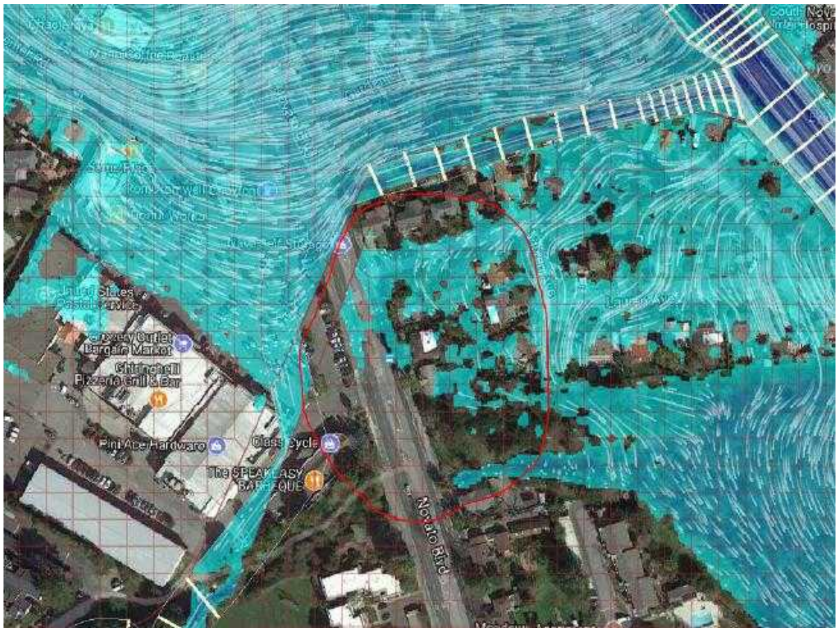
10. See figure below, the 1D in-channel model XS extends to outside of the levee, which creates an “artificial in-channel capacity” that may underestimate of in-channel WSE. (BTW, River stations in this model kept 2 decimal digits, which is unnecessary and complicate the reading of river stations. Rounding to integer is suggested).



The following two comments are related to the upper portion of the Novato Creek HEC-RAS model. Incorrect/inadequate representation of the upper portion hydraulics may result in unreliable flow input to the lower portion for levee evaluation.

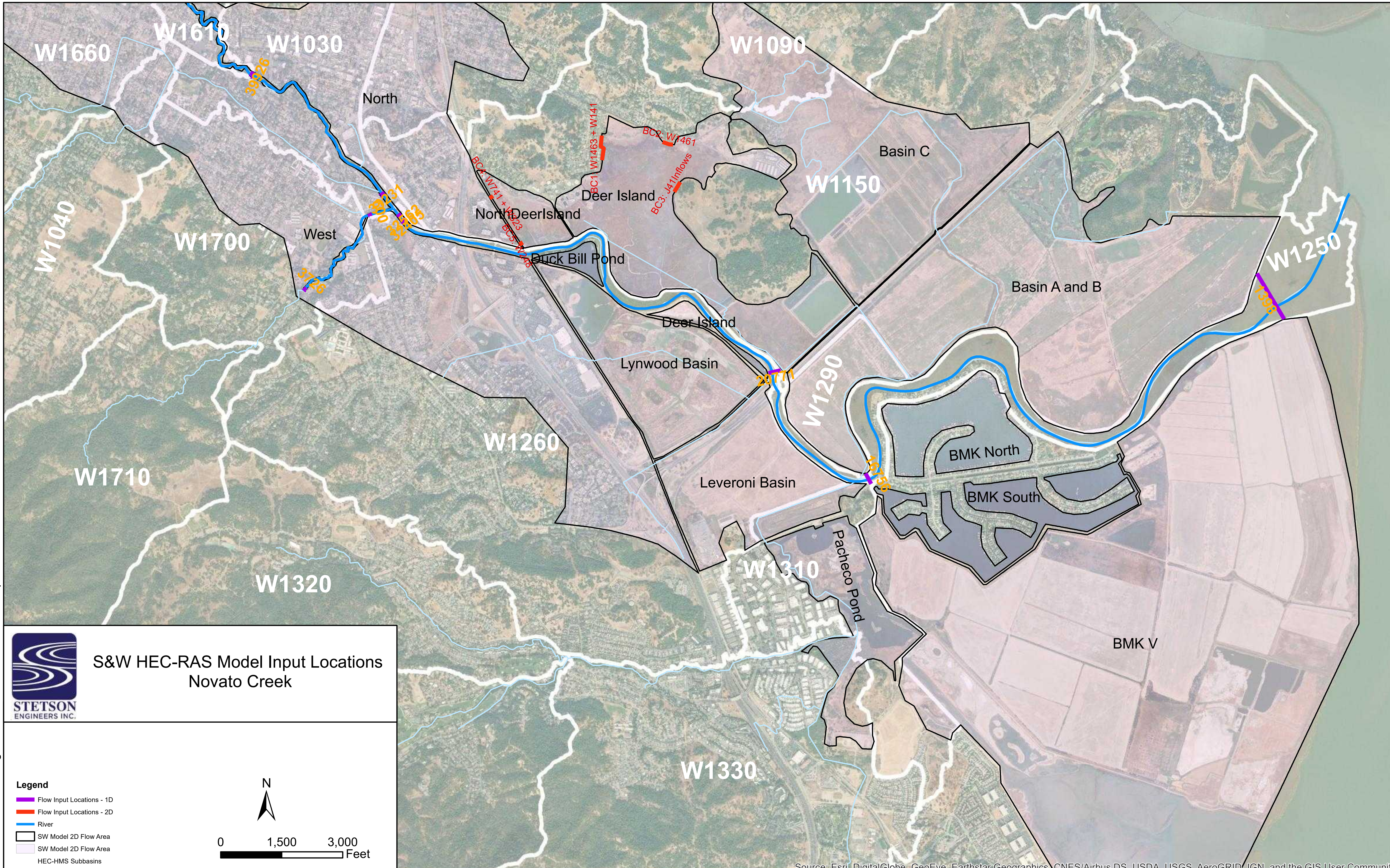
11. Incorrect model configuration lead to incorrect floodplain inundation

    The figure below shows an artificial glass wall that incorrectly forces flood water turn direction at the Novato Blvd crossing of Arroyo-Avichi Creek. Red circle area should have been flooded.



12. Significant XS interpolation between sparse XS at meandering reach leads to unrealistic representation of lateral links.

FIGURE 1



C:\DATA\2690\GIS\Fig 1 Novato Creek Modle Flow Input Locations.mxd 7/20/2018

Appendix C

Schaaf & Wheeler's Revisions to the HEC-RAS 1D/2D Model

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Schaaf & Wheeler
CONSULTING CIVIL ENGINEERS

MEMORANDUM

TO:	Roger Leventhal, PE	DATE:	August 10, 2018
FROM:	Charles D. Anderson, PE Melissa E. Reardon	JOB#:	MARN.03.16
SUBJECT:	Final Novato Creek Hydraulic Model Revisions Incorporating Review Comments from Stetson Engineers		

Schaaf & Wheeler has revised the HEC-RAS 5.0.3 model for existing conditions within the Novato Creek watershed to reflect review comments made by Stetson Engineers on July 20, 2018 as documented herein. Stetson's review focused on the lower reaches of Novato Creek, which is their study area for the Novato Creek Levee Evaluation Project. Please note that since the original completion of the existing conditions model, HEC-RAS has been updated to (the short-lived) version 5.0.4 and now version 5.0.5; but after unsuccessfully attempting to run the model in RAS 5.0.4, we have elected to leave the software platform in HEC-RAS version 5.0.3.

Model Calibration and Verification

> The model used a Manning's n of 0.02 for the lower portion of Novato Creek. Our field visit on 7/18/2018 found that there is dense vegetation in the creek. Is the model calibrated and verified?

This is our mistake. When we performed additional modeling to evaluate the tidal prism for Deer Island restoration using the mean tide cycle, we evaluated sensitivity to channel roughness in Novato Creek, dropping the value to 0.020 to reflect the smoother channel bed under low flow conditions. Unfortunately, we forgot to change this parameter back to our original channel roughness between Highway 101 and San Pablo Bay when we compiled the model sent to Stetson. This has been corrected.

KHE's creek model assumes a Manning's n of 0.035 "based on field observations and professional judgement."[1] From our own field reconnaissance, we computed composite roughness coefficients at flood stage using a method that equally weights ten compositing formulae found in the literature. Our calculated composite n is 0.026 between Highway 101 and the SMART Bridge, and 0.030 to 0.035 between SMART and San Pablo Bay.

According to the Kamman report, their existing conditions model's channel and marsh plain roughness coefficients are calibrated to the spring tide low flow period of June 21-26, 2012; verified with observed water level data for a storm that occurred between November 28 and December 6, 2012.

[1] Kamman Hydrology & Engineering, Inc., "Hydraulic Assessment of Existing Conditions: Novato Creek Watershed Project, June 2014.

Schaaf & Wheeler has not performed any additional calibration as we are unaware of extreme event calibration data other than noting that during the February 2017 event, the Novato Creek water surface elevation anecdotally approached the soffit of the SMART Bridge, and the existing 10-year model generally replicates this behavior. (The February 2017 event was roughly an 8-year event based on Corte Madera Creek streamflow gage records.)

Initial WSELs of Bayland Ponds

The initial water surface elevations for the various two-dimensional flow areas representing the Baylands ponds have been reset to the values from Kamman's Existing Conditions Study, with the exception of the initial water surface for Pacheco Pond, which is set at the tide gate invert.

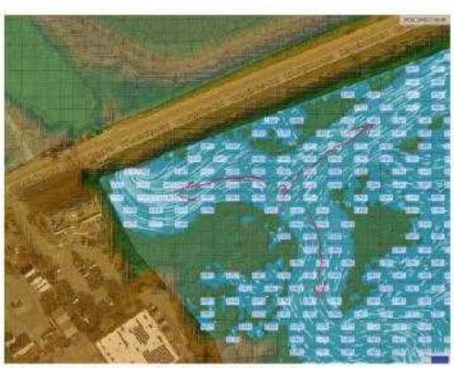
Inappropriate Flow Input Locations

> Refer to Figure 1 in attached PDF file flow input locations of the HEC-RAS 1D/2D model. The model lacks of flow inputs to Pacheco Pond and Lynwood Pond, which would affect the evaluation of levees along these ponds. Other flow input locations also need be adjusted as well for accurate representation of the system.

Inflow from the watershed tributary to Pacheco Pond, including the Pacheco Pond area itself, has been moved to discharge into the Pacheco Pond 2D mesh, rather than directly into Novato Creek downstream from Pacheco Pond. Similarly inflow from the watershed tributary to Lynwood Pond, including the pond area itself, has been relocated to the major storm drain outfall to Lynwood Pond at the SMART tracks. WRECO's HEC-HMS parameters have not been changed. "Other flow input locations" is nebulous; we did split some watersheds and adjust flow input locations north of Deer Island to better evaluate the potential impacts of an ecotone setback levee.

Questionable Inflow Source to Pacheco Pond

> As shown in figure below, current model result (Plan: 100yrDesign) shows an internal inflow source to Pacheco Pond at the arrow-marked area, and Pacheco Pond WSE has increased from initial 3.55 ft at 0:00 to 3.7 ft at 7:00. However, examination of the model input flow file does not show any inflow source to Pacheco Pond. The model result is unexplainable and, thus, the model is not reliable for the evaluation of Pacheco Pond levee.



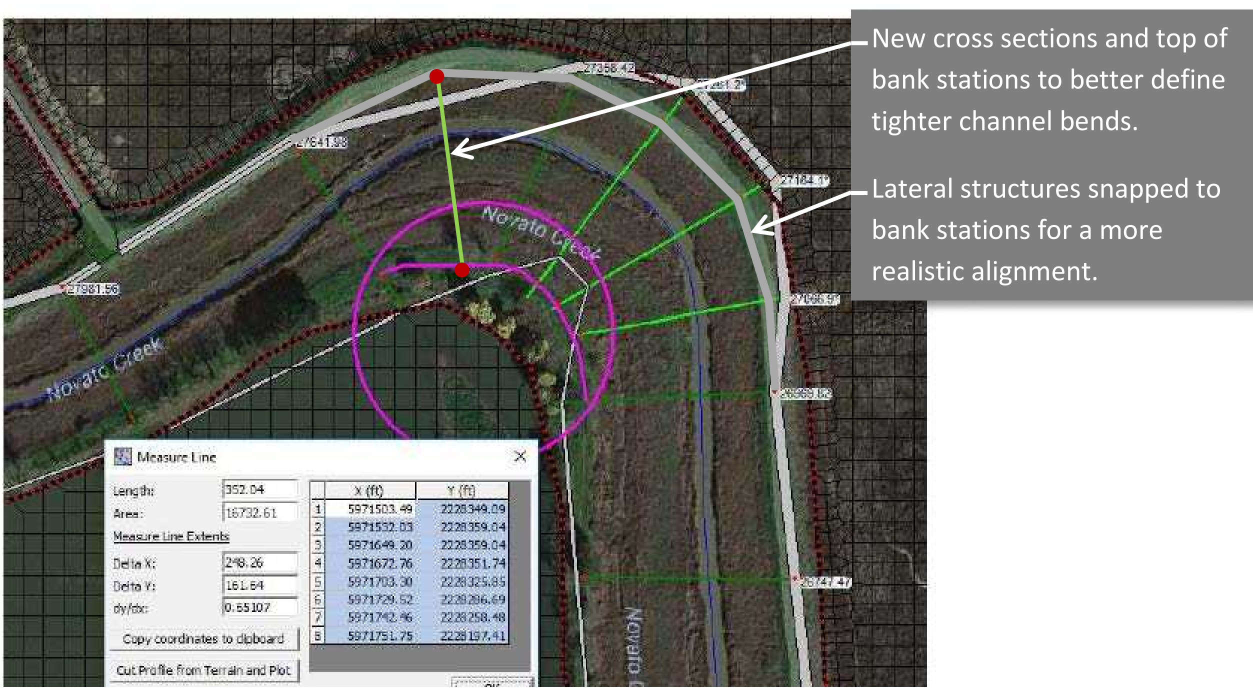
Unexplainable Flow Field in Pacheco Pond

This is indeed inexplicable. Tide gates should have prevented flow into the basin until levee overtopping. However, the model is stable and this flow produces an artificial increase in water depth of only 0.15 foot early in the hydrograph. Also, moving the inflow location to upstream of the pond masks this.

Lateral Structures

> The Levees (Lateral Structures) between 1D and 2D models were not geo-referenced, and the levee crest elevations were solely represented by TOB at 1D XS locations. Such configuration has the following issues:
>
> a. Incorrect representation of levee length
>
> For example, in the screenshot below, the levee length from XS 26969.82 to XS 27641.98 is 569 ft in the model, while the actual length is 352 ft, which is a big difference (62%). If the levees had been geo-referenced, such errors would not exist because the model will automatically report error.
>
> b. Insufficient representation of levee crest elevations
>
> The model only sees the levee crest defined by the top of banks at XS locations and linearly interpolates levee crest between XSs. Any non-linear variation between XSs won't be seen by model, which may lead to incorrect overtopping calculations.

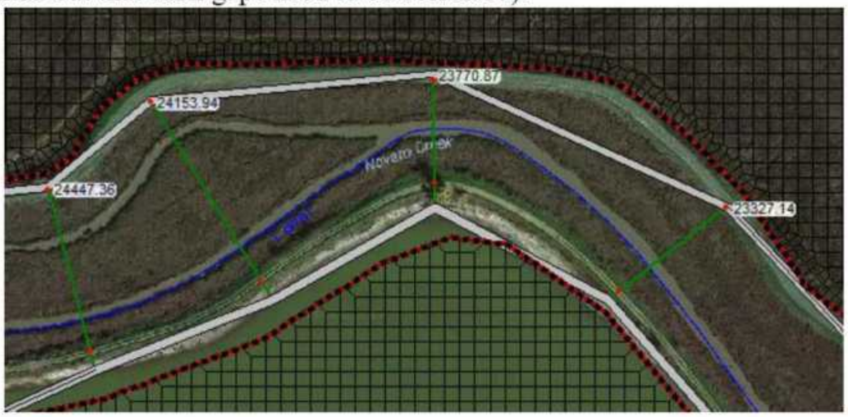
We have added cross sections cut from the same terrain model to better define lateral structure alignments, and the lateral structures are all now "snapped" to the top of bank locations, which have been individually verified as being at the appropriate cross sectional location. A schematic example of this technique is provided in the image below.



Regarding the use of the top of bank elevations to define lateral structure profiles, these are the best data available. Terrain information based on LiDAR data for linear features such as levees has often proven to be unreliable and the County did not undertake field levee profile surveys.

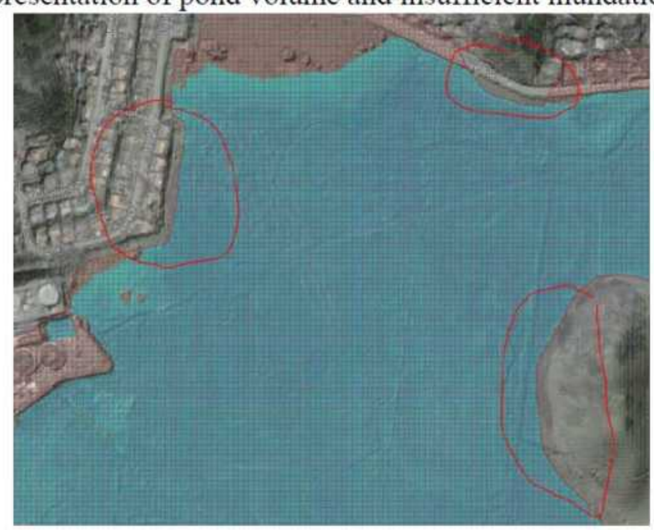
2D Flow Area Boundary Delineation

The 2D Flow Area boundary delineation does not cover the entire pond, which leads to underestimate of pond capacity, and also creates gaps that will never be inundated during inundation mapping (Note: During the review of the Ross Valley HEC-RAS 1D/2D model, USACE reviewer specifically pointed out that such gaps need to be corrected).



The 2D flow mesh boundaries have been adjusted to match the bounding lateral structures. This does cause model error where ground elevations in mesh cells adjacent to lateral structures are higher than the defined elevation of the lateral structure, so the lateral structure elevations are adjusted to be infinitesimally higher than the adjacent terrain.

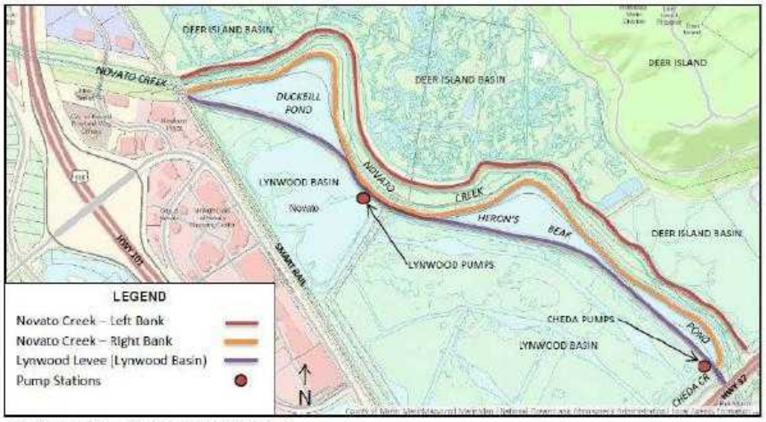
Insufficient mapping limit due to insufficient 2D Flow Area delineation which leads to inaccurate representation of pond volume and insufficient inundation mapping limit.



2D flow boundaries have been extended to clear high ground/ bluffs except where inflow locations are established to model storm runoff outfalls, to place local inflow into the 2D mesh at an appropriate location. If the mesh were extended further up the hill “to be safe”, that inflow would then be allowed to flow down the hill per ground elevations rather than into the 2D mesh at the outfall location.

Pond Interconnections and Pump Stations

For example, there are two pump stations (see figure below), but the model does not have the pumps. The model also does not have a complete representation of culverts and tidal gates.



Map 3. Location of Levees to be Evaluated.

At County direction, we are not including pumps in the models used to evaluate the impact of Deer Island restoration on flooding. This makes particular sense for a FEMA analysis, because the pumps would likely be assumed non-operable for an Interior Drainage Study. Tide gates were initially coded in the model with a rule set to replicate backflow protection, but this has proven not to work entirely correctly in HEC-RAS. At the start of each time step, each rule set is evaluated to check for changed to the operation of a given hydraulic structure. But a rule set is only called once during a time step, even if the program iterates during that given time step, so the rule may not reflect the converged solution at the time step. This means we see backflow through the tide gate, for example, at Pacheco Pond when it should not occur. For this reason tide gates are assumed to be closed during flood events.

Highway 101 and Redwood Boulevard Bridges

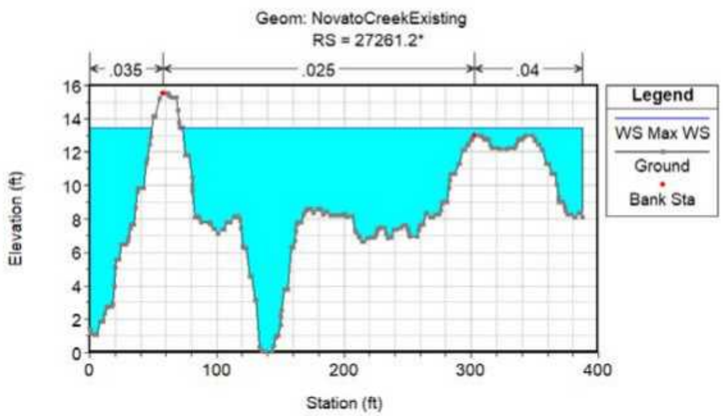
Incorrect bridge representations of HWY 101 Bridge and Redwood Blvd double bridges

a. Refer to screenshots below, in reality, the HWY 101 has one single bridge and the Redwood Blvd has two bridges. However, the model represented these two bridges in an opposite way.
b. Both Bridges have skew angle with the channel, especially for Redwood Blvd double bridges, with a skew of > 45 degrees. However, the model does not skew any of these XS, and probably the bridge openings were not skewed either.

Bridge modeling at these two locations has been revised to include the cross section and bridge skew. Highway 101 is now modeled as a single bridge and Redwood Boulevard is now modeled as a twin bridge, using the data already included in the model.

Levee Limits

See figure below, the 1D in-channel model XS extends to outside of the levee, which creates an "artificial in-channel capacity" that may underestimate of in-channel WSE. (BTW, River stations in this model kept 2 decimal digits, which is unnecessary and complicate the reading of river stations. Rounding to integer is suggested).



Cross sections have been modified (points deleted) to eliminate flow conveyance in the channel direction beyond the limits of lateral structures, which are generally defined at the top of bank stations as shown in the figure above. Ineffective area boundaries are not sufficient for this purpose, as they would allow for the double-counting of storage, which is already accounted for in the 2D mesh.

Flow Boundary Formed by Underground Culvert

Incorrect model configuration lead to incorrect floodplain inundation

The figure below shows an artificial glass wall that incorrectly forces flood water turn direction at the Novato Blvd crossing of Arroyo-Avichi Creek. Red circle area should have been flooded.

This isn't a glass wall per se; it is the underground culvert for Arroyo Avichi. In HEC-RAS 5.0.3, we do not believe one location can be simultaneously occupied by a 1D channel structure and a 2D flow mesh. There may be a way to build in dummy lateral structures to make the floodplain limits "look right", but this model limitation does not appear to significantly affect total return flow to Novato Creek.

Cross Section Interpolation on Arroyo Avichi

Significant XS interpolation between sparse XS at meandering reach leads to unrealistic representation of lateral links.

Lateral structures have been corrected in this location, using additional cross sections cut from the terrain model, as described previously.