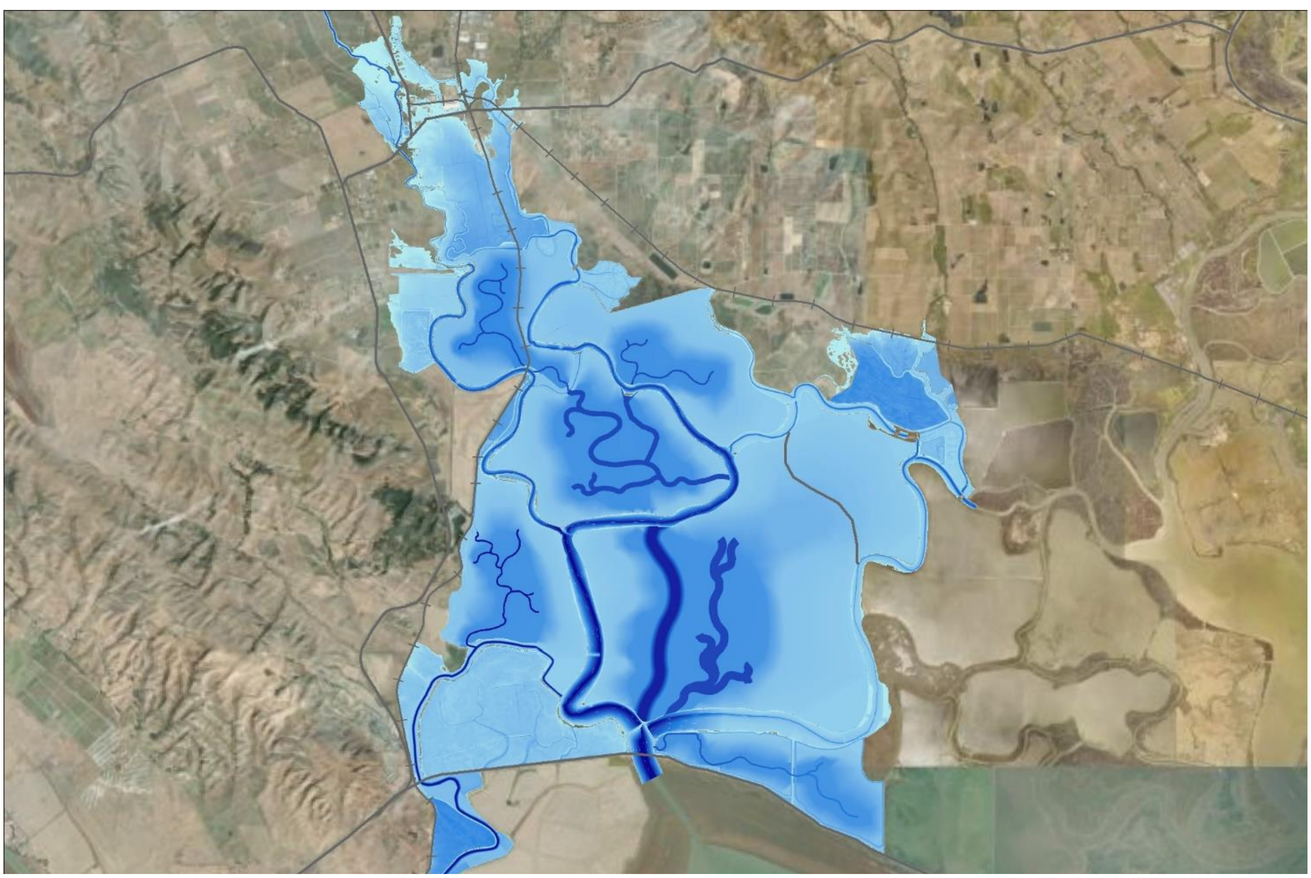
DRAFT

SONOMA CREEK BAYLANDS STRATEGY

Hydrodynamic modeling appendix

Prepared for
Sonoma Land Trust

January, 2020



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1 INTRODUCTION

The Sonoma Land Trust is developing the Sonoma Creek Baylands Strategy, a multi-benefit land management strategy that combines landscape-scale restoration, flood protection, and public access within the former tidal wetlands at the freshwater-saltwater interface between Sonoma Creek and San Pablo Bay. The strategy is focused downstream of Highway 121, where several large parcels which formerly supported tidal wetland habitat were historically leveed off and converted to agricultural use. A map of the project site and parcels under consideration for tidal restoration is shown in Figure 1. The site is also constrained by significant transportation infrastructure including Highway 37 which runs along the southern end of the Sonoma Creek Baylands, the Sonoma Marin Area Rail Transit (SMART) rail line which runs through several of the parcels, and Highway 121 which runs east-west along the north end of the Sonoma Creek Baylands and is near the fluvial-tidal interface. In recent years, the U.S. Fish and Wildlife, and California Department of Fish and Wildlife have acquired parts of the Baylands complex. This has presented the opportunity for restoring tidal inundation to the system, restoring thousands of acres of tidal marsh and wetland habitat, and improving flood conditions for local and upstream communities. The Strategy is being developed to assess long term potential restoration scenarios while accounting for constraints that are expected to persist into the future.

Three restoration scenarios were developed and analyzed for this project (Alternative 1) a maximum tidal restoration scenario, (Alternative 2) a restoration scenario constrained by existing landuse, infrastructure, and ownership, and (Alternative 3) a scenario reflecting significant tidal restoration with measures to minimize impacts to existing tidal marsh. These were compared to a No Action scenario without additional restoration. To support analysis of potential restoration scenarios, understand tradeoffs between scenarios, and inform restoration project components, ESA developed a hydrodynamic model of the Sonoma Creek Baylands system. The hydrodynamic model—a coupled one-dimensional/two-dimensional model—a was adapted from prior modeling conducted by ESA (formerly PWA, and ESA PWA). Hydrologic scenarios were identified to bracket key conditions for regular tidal inundation as well as extreme flood conditions. ESA calibrated the model to the New Year's Eve 2005 flood event— an approximately 1% annual chance event and the largest flood event on record for the system. The model was used to simulate the physical hydrologic processes of the site under current and proposed restored conditions, as well as current and future hydrology under climate change, to estimate key hydraulic parameters including depth, duration, and extent of flooding on- and off-site, channel velocities, residence time, and tidal circulation in the restored areas and existing channel network.

2 KEY FINDINGS AND CONCLUSIONS

ESA analyzed Baseline, No-action, and three restoration alternatives under a range of hydrologic scenarios. The results indicate that the larger-scale restoration scenarios have the potential to reduce peak flood stage as well as flood depth, extent, and duration in some areas. The key findings of the analysis include:

- For present day and future climate conditions hydrology, Alternatives 1, 2, and 3 result in decreased water level from Camp 2 downstream on Sonoma Creek and Schell Creek. Only Alternative 3 results in decreased stage on both Creeks upstream of Highway 121. Under No-action future conditions, peak stage is increased on both Sonoma Creek and Schell Creek.

- On Sonoma Creek at the north end of Camp 2, model results show a reduction in stage of 2.9, 3.3, and 4.4 ft for Alternatives 1, 2, and 3 respectively for a 1% chance flow with a typical tide. Immediately upstream of Highway 121, peak stage is reduced by 1.2’ for Alternative 3 for this event.

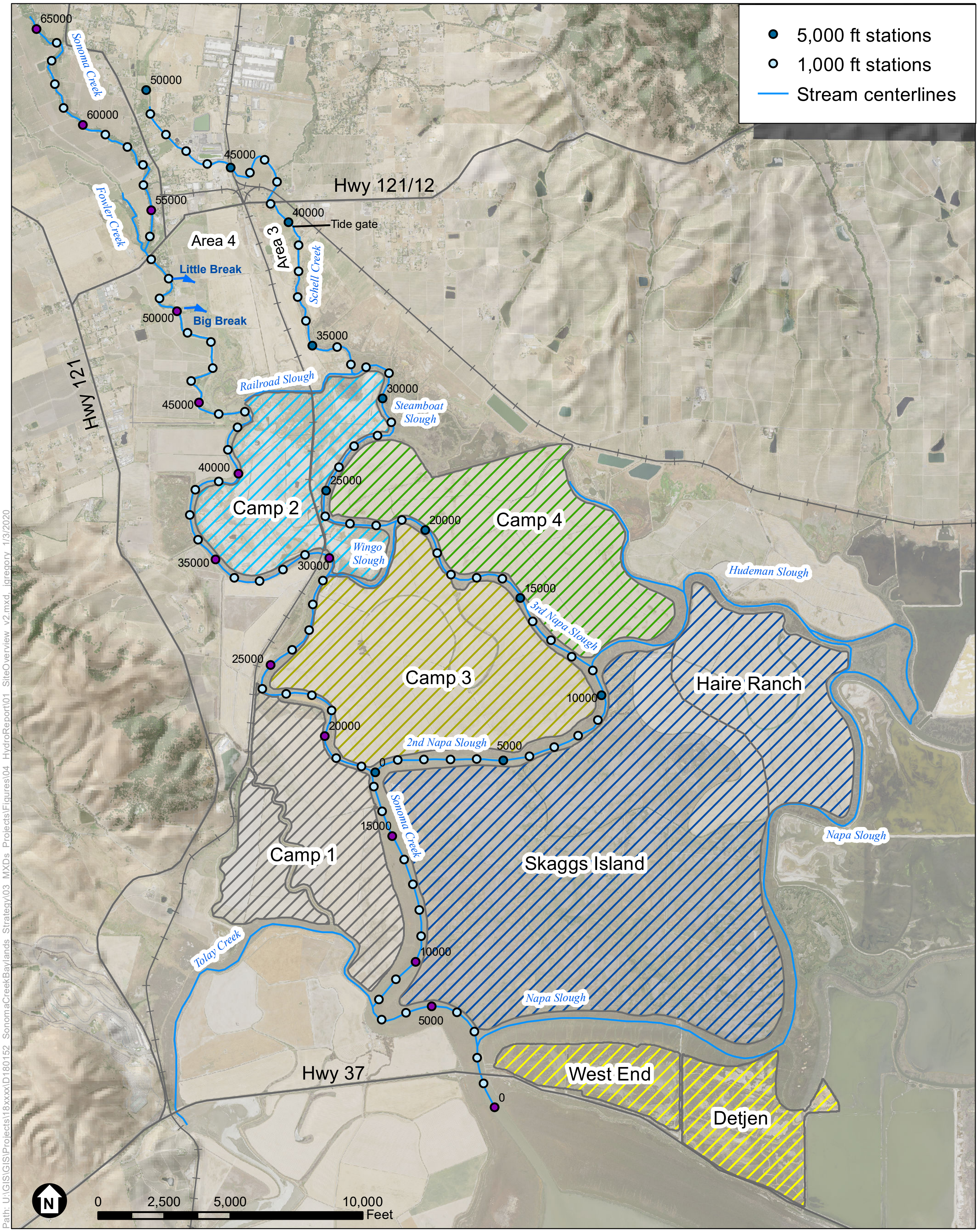
- Modeling of the No-action scenario suggests that for 2050 conditions, peak stage on Sonoma Creek increases by 0.9 ft at the north end of Camp 2 for a 1% chance flow with an elevated tide. Peak stage on Schell Creek increases by 1.0 ft at the tide gate and by 0.6 ft immediately upstream of Highway 121.

- Under existing conditions, out of bank flooding upstream of Highway 121 inundates approximately 500 acres. This area is reduced by 12 acres under Alternative 1, 10 acres under Alternative 2, and 50 acres under Alternative 3. Under the No-action scenario with future conditions hydrology, inundation increases by 9 acres.

- Average flooded depth is decreased upstream of Highway 121 for all Alternatives. Alternatives 1 and 2 reduce flood depth by 0.1 ft or more in 40% (~200 acres) of the flooded area upstream of the highway. Alternative 3 reduces flood depth in 90% (~400 acres) of this area.

- Flooding duration is significantly reduced under restored conditions in the floodplain area between Sonoma Creek and Schell Creek upstream of Camp 2. Ponded area which drains down from peak stage by 3ft in 50 hours under existing conditions, drains down by 7 ft in 33 hours under Alternative 3. At the intersection of Highway 121 and Highway 12, flooded depth is lower by a maximum of 0.7 ft and an average of 0.3 ft over the full 30-hour period of inundation.

- Channel velocities at the mouth of Sonoma Creek are increased by the increased tidal prism added for the restoration scenarios. Velocity is increased to a similar degree under the No-action scenario for which Skaggs is the only parcel breached. The breaching on Skaggs appears to drive much of this increase suggesting that modifying the location and size of the Skaggs breach, grading or filling Skaggs could help mitigate increased velocities at the mouth.



SOURCE: NAIP (2014 aerial imagery)

Sonoma Creek Baylands Strategy

Figure 1
Project site overview

ESA

3 PROJECT BACKGROUND

3.1 Hydrologic Setting

The Sonoma Creek watershed drains an area of approximately 170 square miles, originating from the northeast in the Mayacamas Mountains. The watershed drains the eastern slopes of the Sonoma Mountains and the western slopes of the Mayacamas Range. Major tributaries include Fowler Creek, Champlin Creek, Rodgers Creek, Felder Creek, Lewis Creek, Carriger Creek, Dowdall Creek, Asbury Creek, Yulupa Creek, Bear Creek, Calabazas Creek, Nathanson Creek, Schell Creek, and Arroyo Seco. The main stem of Sonoma Creek begins in steep mountainous terrain in the Mayacamas Range and flows westerly before reaching the valley floor, flattening out and passing through vineyards and into Kenwood. The creek then turns southerly, flowing through Glen Ellen and Eldridge and, eventually, the City of Sonoma where the creek is relatively urbanized. Downstream of the City of Sonoma, the Creek passes through large vineyard parcels before passing under Highway 121 where it joins the Napa-Sonoma Marsh complex. Here the channel substantially flattens out and becomes increasingly uniform in shape and meandering as conditions change from being fluvially to tidally dominant. The Creek flows along the western perimeter of Camp 2 before flowing under a railroad crossing near the inlet to Wingo Slough. Downstream of Wingo Slough, the Creek runs along the western perimeter of Camp 3 before joining Napa Slough where the channel substantially enlarges (from approximately 30-feet to 150-feet top width) and continues along the western perimeter of Skaggs Island. The channel continues to increase in size and eventually passes under Highway 37 as it flows into the northern edge of San Pablo Bay—a northern portion of the San Francisco Bay.

The project site and contributing watershed has cool, wet winters and very dry summers with most precipitation falling between the months of December and March each year. Average annual rainfall is 39.5 inches and ranges from 47.9 inches in the headwaters to 25.8 inches near the mouth of the Creek (PRISM, 2012).

In 2008, ESA (as PWA) conducted a hydrologic modeling analysis to characterize flow statistics for Sonoma Creek and its tributaries (PWA, 2008). A summary of peak flow statistics from this analysis for Sonoma Creek at Agua Caliente is provided in Table 1. From this analysis, it was estimated that the design 1% annual chance flow on Sonoma Creek at Agua Caliente is 20,663 cfs. Further downstream at Highway 121, the upstream boundary of the project site, the peak 1% annual chance flow on Sonoma Creek and Schell Creek is 24,360 and 3,100 cfs respectively.

Table 1. Peak flow statistics on Sonoma Creek based on modeled and observed data

Return Period (years)	Existing Peak Discharge (cfs)	Future Peak Discharge (cfs)	Updated Bulletin 17B Peak Discharge (cfs)
2	2,654	2,913	4,697
10	10,055	10,643	10,460
25	13,905	14,607	13,000
100	19,821	20,663	16,170

During flood events, flows passing under Highway 121 on Sonoma Creek break out in two low points along the left bank. The upstream and downstream breakout locations are referred to as Little Break (STA 520+00) and Big Break (STA 500+00) respectively. Little Break is a low point in the bank which is regularly repaired after large flood events. The breakout from Big Break is more formalized and discharge is conveyed in a channelized section to the east of Sonoma Creek. The overflows from Sonoma Creek upstream of Camp 2 flow easterly into adjacent vineyard and are impounded north of the berms along Railroad Slough. Schell Creek also breaks out in several locations on both the east and west sides. Flow from the western side of Schell Creek is similarly impounded by the Railroad Slough berms. An existing rail line runs north-south through this area separating overbank flows from Sonoma Creek and Schell Creek. During large flood events, such as the New Year's Eve flood of 2005, this railroad washes out in several places and is later repaired. Flow to the east of Schell Creek floods a significant area of existing agricultural land.

The levees along Camp 2 have failed in large flood events including the NYE 2005 event as well as a large flood which occurred in late February, 2019. The levees along Camp 4 are low enough such that this parcel also flooded during those events. Camp 1 experienced a moderate degree of flooding during the NYE 2005 event. Some degree of flooding is observed on Skaggs Island during these types of large floods which is likely a combination of inflooding and, potentially, minor overtopping. No significant tidal breaches have formed on this parcel. Camp 3 has not flooded during these events.

3.2 Project scenarios

ESA used the model to evaluate a range of landscape conditions (restoration scenarios) and hydrologic conditions. Landscape and hydrologic conditions were evaluated for present day and year 2050 conditions.

3.2.1 Alternative Conditions Scenarios

Five alternative conditions scenarios were evaluated.

1. Baseline conditions – Baseline conditions reflects site conditions under current management of the project site. For this condition, it was assumed that all levees around existing parcels are intact at elevations reflected in the 2014 Sonoma County LiDAR topographic dataset (Sonoma County, 2014). Baseline conditions provide a point of reference for existing conditions and for comparison with known historic flood events.
2. No Action conditions - The No Action scenario reflects conditions with assumed foreseeable changes in the absence of new large-scale wetland restoration. For this scenario, it was assumed that, due either to intentional intervention or levee degradation, Skaggs Island is fully tidal. Levees included in the restoration alternatives (below) to protect private land on the east side of Schell Creek and west side of Sonoma Creek were assumed in place. All other locations were expected to be maintained at present conditions as reflected in the 2014 LiDAR. The Sonoma Creek channel downstream of

Skaggs Island was assumed to be scoured to accommodate the additional tidal prism from Skaggs.

3. Alternative 1 – This alternative represents a broad scale tidal restoration condition for the project site. The alternative assumes that Skaggs Island and Camps 1-4 are fully tidal. Levees along Railroad Slough were removed to allow conveyance from Sonoma Creek into Camp 2 and downstream areas. Additionally, levees along the right bank of Schell Creek north of Camp 2 were removed to allow floodwater to escape this channel earlier than current conditions and reduce water levels in Schell Creek. Levees along Wingo Slough were removed to increase flow exchange from Camp 2 to Camp 3 for fluvial and tidal conditions. The Camps 1-4 and Skaggs Island parcels were assumed to be filled to a mix of habitat elevations from mudflat to low to high tidal marsh. It was assumed that the channel network had adjusted to the additional tidal prism from the restored parcels.
4. Alternative 2 – This alternative represents less tidal restoration and less fill in the restored parcels. The purpose of this alternative was to evaluate a condition that has less impact on existing infrastructure and would require less imported fill to construct. Under this alternative, the Railroad Slough berms are left intact, as is the right (west) levee on Schell Creek upstream of Camp 2. The portion of Camp 2 west of the Railroad is not restored to tidal action while the portion to the east is. Camp 4 is left at current conditions and is not restored to tidal action. It was assumed that the channel network had adjusted to the additional tidal prism from the restored parcels.
5. Alternative 3 – This alternative represents a modification of Alternative 1 with the primary conveyance in the system for tidal and fluvial flows routed through Camp 2, Camp 3, and Skaggs Island. The Railroad Slough berms are removed for this alternative. Levee breaches and tidal channels in Camps 1-4 and Skaggs Island allow tidal action in those parcels. This alternative is configured to protect existing marsh habitat in the channel network by focusing flow and tidal prism in newly graded channels rather than scouring the existing channels. It was assumed that the mouth of Sonoma Creek had scoured to accommodate the increase in tidal prism under this alternative. All other channels were assumed to match baseline conditions.

3.2.2 Hydrologic Scenarios

Three hydrologic scenarios were selected to bracket the range of conditions relevant to assessing the hydraulic impact of restoration scenarios. The hydrologic scenarios reflect various combinations of tidal conditions and streamflow in the primary channels. The hydrologic scenarios include:

1. 1% annual chance flow, typical tides – This scenario reflects a large flood from the Sonoma Creek watershed and a tide signal ranging between typical mean higher-high water (MHHW) and mean lower-low water (MLLW). This scenario reflects was included to bracket the effect of the alternatives on a large flood in the absence of an elevated tide.
2. 1% annual chance flow, storm surge tide – This scenario reflects a large flood condition coincident with an elevated tide level in San Pablo Bay. This captures extreme flow and tide conditions at the site.

3. 1% annual chance flow at 2050, storm surge tide with 2050 sea-level rise – This scenario reflects extreme fluvial and coastal flooding including future climate change impacts on precipitation and sea-level.

The peak flows on Sonoma Creek and Schell Creek and the peak tide level for each of these scenarios is summarized in Table 2.

Table 2. Peak flows and tide levels for hydrologic scenarios

Time period	Hydrologic scenario	Peak flow (cfs)		Peak tide (ft NAVD)	Short ID
		Sonoma Creek	Schell Creek		
Present day	1% annual chance flow, typical tides	24,360	3,100	6.7	1% flow, typical tide
	1% annual chance flow, storm surge tide			9.2	1% flow, elevated tide
2050	2050 1% annual chance flow, storm surge tide + 2050 sea-level rise	27,100	3,400	11.1	2050 1% flow, elevated tide w/SLR

In addition to these 1% flood scenarios, a typical tide condition with base flow was modeled for existing and w/SLR conditions to assess parcel inundation extents and tidal muting under typical tidal cycles with background watershed flow contribution.

The 2050 hydrologic scenarios reflect assumptions for the influence of climate change on coastal water levels and future rainfall intensity. The approach and assumptions made in characterizing climate change impacts to these variables are summarized in the following section.

3.2.2.1 Climate change analysis

Climate change impacts to sea-level rise and watershed hydrology were characterized for mid-century (2050) conditions. Sea-level rise increases were based on California statewide guidance (OPC, 2018). This guidance provides sea-level rise estimates for various risk scenarios. The highest risk scenario is appropriate for critical infrastructure, however, given that the landuse at the current site is primarily agricultural it was assumed that a medium-high risk scenario was appropriate. For this category, the estimated increase in sea-level by 2050 is 1.9 ft.

For future conditions, discharge, downscaled rainfall data was used as input to the hydrologic model developed by PWA for estimating design discharges. Climate model data developed as part of the International Governmental Panel on Climate Change's fifth Assessment Report has been downscaled to more regional scale information by various research agencies. The latest California statewide Climate Assessment report utilized datasets created by researchers at Scripps which has been downscaled to 6km x 6km grid cells of daily climate data from 1950 to 2100 (Pierce, 2014) covering the conterminous United States. ESA used extreme value analysis with the daily rainfall totals from this dataset to estimate rainfall depths for the 1% annual chance event at 2050. The 2050 1% annual chance rainfall was estimated in this way for a medium-high emissions scenario (RCP 8.5). The climate grids overlaid with the watershed model subbasins is shown in Figure 2.

Statewide guidance on scenario selection for climate change by the CA Department of Water Resources (DWR, 2015) recommends using this emissions scenario at mid-century when most of the scenarios are undifferentiated. Data from 29 climate models was processed to generate an estimate of future design rainfall. Using this methodology, an average increase of 7% over the Sonoma Creek Watershed was estimated for 2050. This value reflects an average over all climate models and the standard deviation among models was 16%.

The rainfall depth for the 2050 1% annual chance event was increased by 7% and run through the hydrologic model for the Sonoma Creek watershed. The peak flow increased by 11% from 24,360 to 27,100 cfs.

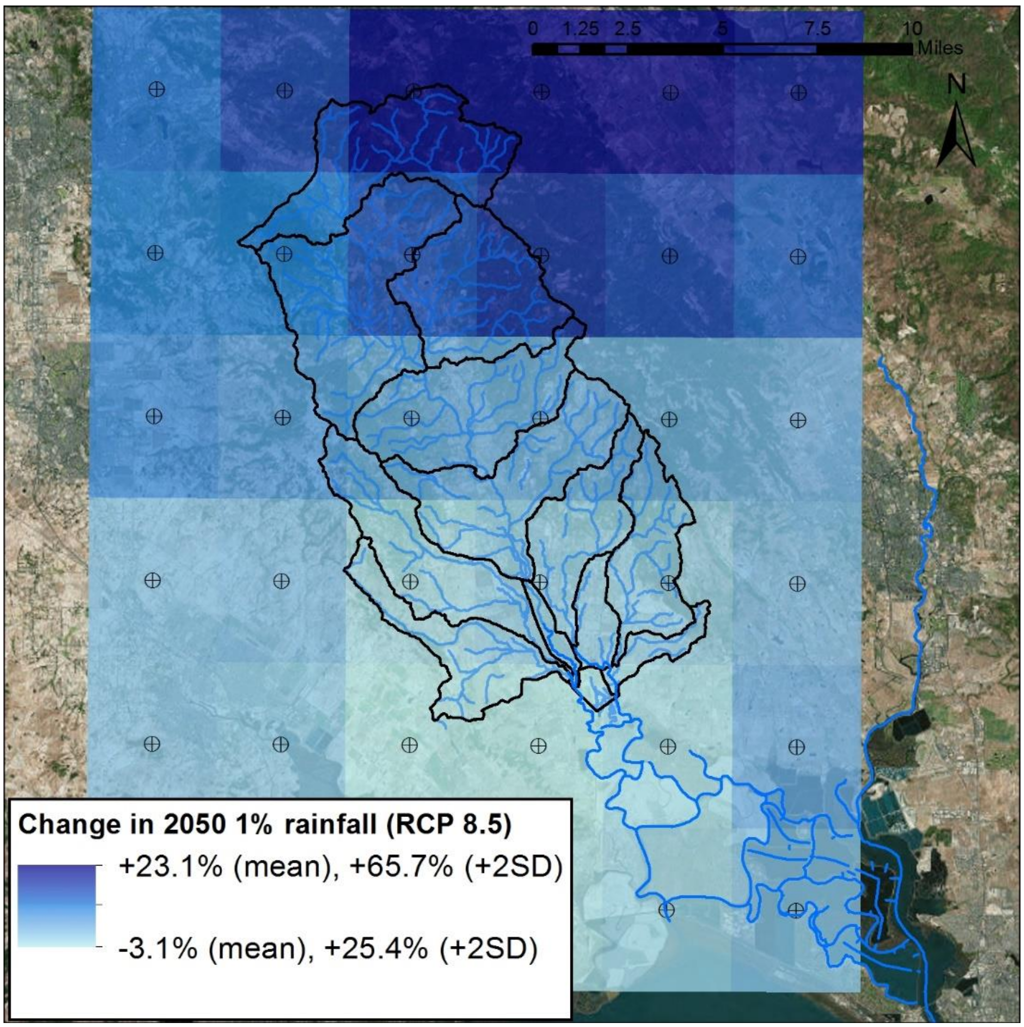


Figure 2. Map of climate change grid cells and hydrologic model subbasins

4 HYDRODYNAMIC MODEL DEVELOPMENT

A coupled one-dimensional/two-dimensional (1D/2D) hydrodynamic model was developed to analyze the range of landscape and hydrologic scenarios for this project. The model was adapted from a prior model developed by ESA (as PWA) in 2008, and updated in 2012 (ES PWA, 2012). Several refinements were applied to the original model as described in the following sections.

4.1 Software package

The original ESA PWA model was constructed using the MIKE-FLOOD modeling software by DHI. The MIKE-FLOOD model was converted to TUFLOW (Two-dimensional Unsteady FLOW), a depth-averaged, one and two-dimensional surface flow model by the model developers. ESA selected TUFLOW for its ability to model both flood and tidal flows, its computational speed, and its simple file structure that allows the modeler to easily iterate between model scenarios.

The TUFLOW HPC (Heavily Parallelized Compute) solver allows for high speed execution of model runs, significantly reducing run times. The HPC solver uses full one-dimensional (1D) free surface St Venant flow equations.

4.2 Elevation data

All elevations are vertically referenced to the North American Vertical Datum of 1988 (NAVD88) and are stated in feet unless otherwise specified. A recent high-resolution LiDAR dataset covering Sonoma County was surveyed in 2014. ESA replaced the topography in all overbank areas in the 2D model domain with this dataset to reflect the latest ground conditions and improve the accuracy of the floodplain data. Cross-section data for all areas above the tidal channel in the 1D model domain was also replaced with 2014 LiDAR data.

Additionally, ESA conducted one day of field reconnaissance and topographic survey (March, 2019) to validate the LiDAR and existing cross sectional survey data in key locations where breakouts are known to occur and where the LiDAR survey may have been obscured by vegetation. ESA surveyed the breakout locations known as ‘little break’ and ‘big break’ and incorporated the surveyed data into the model to ensure the elevations here were captured correctly.

4.3 Two-dimensional domain

ESA expanded the downstream extent of the 2D model domain from Camp 3 to the Bay in order to capture floodplain hydraulics for Skaggs Island, Camp 1, West End, Detjens, Tolay Creek and other adjacent areas. Topographic data was updated with the 1-meter grid resolution Sonoma County LiDAR dataset (2014) sampled to 5-meters for the entire model domain. The Sonoma

County LiDAR did not cover a few areas of the 2D model domain including the mouth of Tolay Creek. The topography for these areas were updated using a 5-meter grid resolution corrected LiDAR dataset for vegetation published by NOAA (Buffington, *et. al.*, 2019).

In addition, elevations of areas with known overbank breakouts and levees were updated. Elevation data for Little Break and Big Break were added to the two-dimensional domain as breaklines.

In addition to updating the topography, ESA updated the computation mesh settings, including decreasing the mesh cell size from a 15-meter to 5-meter grid. This increase reflects an increase in the model resolution by nine times.

Surface roughness was updated using data from uniform to varied using land use data from the Sonoma County Vegetation Map (citation). Values for manning's n roughness values are summarized in Table 3.

Table 3. Manning's roughness values

Land Use	Manning's n
No Data	0.03
Annual Cropland	0.06
Barren	0.04
Deciduous Forest	0.1
Developed, low intensity	0.06
Forest and Woodland	0.1
Herbaceous	0.08
Herbaceous Wetland	0.1
Intensively Managed Hayfield	0.045
Orchard	0.08
Pasture	0.06
Roads	0.022
Shrub/shrub	0.08
Sparsely vegetated salt marsh	0.06
Sparsely vegetated wetland	0.08
Vineyard	0.08
Water	0.035

4.4 One-dimensional domain

All existing conditions cross sections within the 1D/2D domain were modified to include the overbank terrain from LiDAR from levee to levee. The low flow channel from the MIKE model was preserved and spliced into cross sections derived from the LiDAR terrain. The channel roughness was maintained at 0.03. Alternative conditions channel dimensions were represented based on hydraulic geometry equations after Williams *et al* (2002) relating tidal prism (i.e. storage volume between mean lower-low water and mean higher-high water) and cross-sectional area, top width, and average depth below ground surface. This was implemented in the channel network for Alternatives 1 and 2 for all channels, and just at the mouth of Sonoma Creek for Alternative 3 and the No-action scenario.

4.5 Boundary conditions

The flow and tide time series' applied for the three hydrologic scenarios are shown in Figure 3. Discharge data for the Sonoma Creek watershed was derived from modeling conducted previously by ESA (as PWA) (PWA, 2004). Inflow locations on Sonoma Creek include Sonoma Creek at Watmaugh Road, Fowler Creek at Highway 121, and Schell Creek at Highway 121. Inflow locations on the Napa River include Oak Knoll Avenue, downstream of Milliken Creek, downstream of Napa Creek, downstream of Tulucay Creek, and downstream of Carneros Creek. Typical tidal conditions were derived from tide gage data for previous modeling by ESA (ESA PWA, 2012).

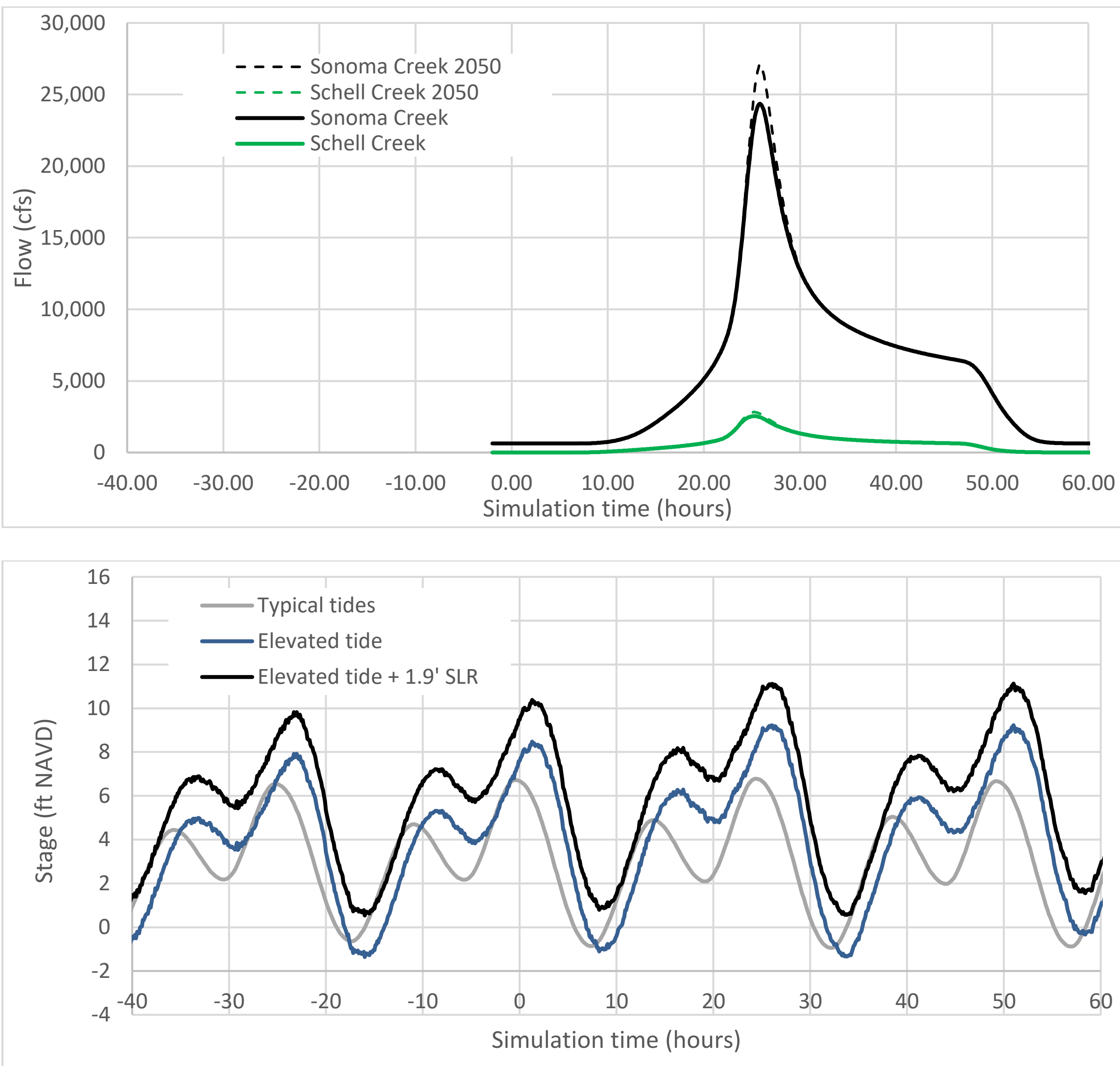


Figure 3. Discharge and tide boundary conditions for present and future hydrologic scenarios

5 MODEL RESULTS AND DISCUSSION

The model was used to evaluate the range of site conditions including no-action and each of the project alternatives, under typical tides, joint fluvial-tidal flooding, and both these conditions with climate change impacts on sea-level and extreme streamflow. Key hydraulic variables including peak flood stage, maximum inundation, flood duration, channel velocities, and discharge were extracted from the model for each of these scenarios. This section summarizes the results of the modeling.

5.1 Flood impacts

5.1.1 Peak stage

Maximum water surface elevation profiles for each alternative for the 1% flow, typical tides scenario are shown in Figure 4 and Figure 5 for Sonoma Creek and Schell Creek respectively. For the 1% flow, elevated tide scenario, profiles are shown in Figure 6 and Figure 7, and for the 2050 1% flow, elevated tide with SLR scenario, in Figure 8 and Figure 9 for Sonoma Creek and Schell Creek respectively. The change in water surface elevation at key locations for both creeks under these flow scenarios is summarized in Table 4.

Table 4. Change in peak water surface elevation for alternatives relative to existing conditions

Location	1% flow, typical tide			1% flow, elevated tide			2050 1% flow, elevated tide w/SLR[1]			
	Alt 1	Alt 2	Alt 3	Alt 1	Alt 2	Alt 3	Alt 1	Alt 2	Alt 3	No-action
Sonoma Creek										
Immediately U/S of Hwy 121	0.0	0.0	-1.2	0.0	0.0	-1.2	0.0	0.0	-1.2	0.0
Big Break	-0.1	-0.1	-1.6	-0.1	-0.1	-1.6	-0.1	-0.1	-1.6	0.0
Northwest Corner of Camp 2	-2.9	-3.3	-4.1	-2.2	-2.0	-2.7	-1.1	-1.0	-1.3	0.9
Wingo Slough	-1.5	-2.1	-2.0	-0.6	-0.5	-0.5	0.7	0.8	1.0	0.3
2nd Napa Slough	-0.9	-0.6	-0.7	-0.2	-0.1	-0.2	0.9	1.0	1.2	0.2
Mouth of Channel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Schell Creek										
Immediately U/S of Hwy 121	-0.4	-0.2	-0.3	-0.4	-0.2	-0.3	-0.3	-0.1	-0.2	0.6
Tide gate	-2.7	-0.9	-2.9	-2.3	-0.8	-2.2	-1.4	-0.6	-1.2	1.0
Junction with Steamboat Slough	-3.8	-1.3	-3.1	-2.9	-1.1	-2.2	-1.7	-1.0	-1.1	0.7
Junction with 3rd Napa Slough	-2.6	-1.9	-2.2	-0.8	-0.5	-0.5	0.6	0.7	1.0	0.3
Junction with 2nd Napa Slough	-1.5	-1.2	-1.3	-0.3	-0.2	-0.1	1.0	1.1	1.5	0.4
Junction with Sonoma Creek	-0.8	-0.6	-0.7	-0.2	-0.1	-0.2	0.9	1.0	1.2	0.2

[1] For the 2050 scenario, Existing and No-actions model results do not behave as anticipated. Affected results are shown in grey text. Specifically, peak stage does not persist upstream from the mouth of

Sonoma Creek at the max tide level of 11.1 ft NAVD. However, results are included for these runs for the purposes of completeness and transparency.

For Alternative 1, the water surface elevation on Sonoma Creek is lowered downstream of Big Break. Upstream of here, the peak water surface merges with existing conditions. However, inundation in the Sonoma Creek overbanks is reduced moderately. On Schell Creek, water surface is reduced downstream of Highway 121 but peak water levels remain unchanged upstream of the road crossing.

For Alternative 2, the water surface elevation on Sonoma Creek is lowered downstream of Camp 2 but increases slightly between Camp 2 and Big Break. This is a result of constraining flow on both Schell Creek and Sonoma Creek between raised levees without compensating by increasing conveyance across Railroad Slough as included in the other alternatives. Upstream of Big Break, the peak water surface merges with existing conditions. However, inundation in the Sonoma Creek overbanks is reduced moderately. On Schell Creek, water surface is reduced downstream of Highway 121 but peak water levels remain unchanged upstream of the road crossing.

For Alternative 3, the water surface elevation is lowered on Sonoma Creek from the mouth to approximately 1 mile upstream of Highway 121 under typical tides. Under higher tide levels, water surface for this alternative merges with existing conditions upstream of the mouth, however, the reductions upstream of Highway 121 persist. On Schell Creek, water surface is reduced downstream of Highway 121 and peak water levels are slightly lower than existing conditions upstream of the road crossing.

For the No-action alternative, water levels on Sonoma Creek are increased from Big Break to midway through Camp 2 for the 2050 1% flood. Upstream of Big Break, water levels are not changed. On Schell Creek, water levels are increased from Camp 2 to the upstream end of the model. This increases flood extent and depths upstream of Highway 121. This suggests that future flooding would worsen for large floods under the No-action scenario considered for this analysis.

5.1.2 Inundation depth

The result of change in peak stage is reflected in inundation depths in flooded areas outside of the main channels. Change in maximum depth relative to Existing Conditions for the three hydrologic scenarios and three restoration scenarios for areas upstream of Camp 2 in Figure 10 to Figure 18. Results for the No-action scenario are shown in Figure 19. Decreases in inundation depth are shown in green color bands and increases in yellow to red. Change between -0.1 and 0.1 ft is shown in grey to screen out the effect of minor perturbations in the model results. All alternatives result in some reduction in inundation depth upstream of Highway 121, however, Alternative 3 generates the most widespread reductions with over 400 of the 500 acres flooded reduced by 0.1ft or more. The No-action alternative raises water levels along Sonoma Creek and Schell Creek resulting in increases north of Camp 2 as well as upstream of Highway 121 around Schell Creek. A summary of the area for which depth is increased or decreased by 0.1ft upstream of Highway 121 for each of the alternatives and No-action is included in Table 5.

Table 5. Area (ac) upstream of Highway 121 changed by >0.1 ft relative to existing conditions

	Hydrologic scenario	No-action	Alt 1	Alt 2	Alt 3
Area with depth reduction	1% flow, typical tide	-	196	193	410
	1% flow, elevated tide	-	196	193	409
	2050 1% flow, elevated tide w/SLR	0	196	190	410
Area with depth increase	1% flow, typical tide	0	0	17	1
	1% flow, elevated tide	0	0	36	2
	2050 1% flow, elevated tide w/SLR	86	9	56	1

As this table indicates, the depth reduction for Alternatives 1 and 2 reduce is comparable—covering around 40% of the flooded area. For Alternative 3, the depth reduction covers approximately 90% of the total flooded area. Under the No-action scenario, flood depth is increased for approximately 20% of the flooded area. Depth increases are observed for significant areas under Alternative 2 and some minor increases are observed under Alternative 3. This suggests that minor landscape modifications may be required to eliminate any increase in flooding while achieving the significant flood reductions accomplished under Alternative 3.

5.1.3 Inundation extent

The maximum flood extents for Existing Conditions, No-action, Alternative 1, Alternative 2, and Alternative 3 are shown for the three flow scenarios in Figure 20 to Figure 23. The inundation plots show that significant areas are removed from flooding to the east and west of the restored parcels for all alternatives. The area west of Sonoma Creek near the Sonoma Valley Airport is removed from flooding until 2050. Additionally, the area east of Schell Creek and north of Camp 2 along several vineyards is excluded from flooding in all alternatives and all hydrologic scenarios. The area north of Camp 1 and west of the railroad is removed from flooding for all alternatives and all hydrologic scenarios. The total flooded area upstream and downstream of Highway 121 is summarized in Table 6.

Table 6. Peak flooded area (ac) for all alternatives

	Upstream of State Highway 121			Downstream of State Highway 121		
Scenario	1% flow, typical tide	1% flow, elevated tide	2050 1% flow, elevated tide	1% flow, typical tide	1% flow elevated tie	2050 1% flow, elevated tide
Existing conditions	502	502	502	5,402	8,875	13,640
No-action	N/A	N/A	511	N/A	N/A	13,526
Alt 1	490	490	491	9,984	11,426	14,387
Alt 2	492	492	492	9,926	11,498	14,024
Alt 3	452	452	452	10,562	12,593	14,532

The table shows that upstream of Highway 121, the peak flooded area is reduced under Alternative 1 by 12 acres, by 10 acres under Alternative 2, and by 50 acres under Alternative 3. Under the No Action alternative for future conditions hydrology, inundation increases by 9 acres.

Downstream of Highway 121, peak inundation is increased significantly relative to existing conditions as a result of restoring currently leveed parcels to tidal action. Thus, though some areas are fully removed from flooding under the restoration alternatives, peak inundation increases by 2,510 acres, 2,570 acres, and 3,700 acres downstream of Highway 121 for Alternatives 1, 2, and 3 respectively.

5.1.4 Inundation duration

In addition to peak inundation benefits accorded by the restored scenarios, inundation duration is significantly reduced in areas both upstream and downstream of Highway 121. Water level time series at an overbank location in Area 4 just north of Railroad Slough and on Highway 12 at Highway 121 are shown in Figure 24 and Figure 25 respectively.

In Area 4, flows leaving Sonoma Creek to the east and Schell Creek to the west pile up in Areas 3 and 4 north of the berms along Railroad Slough. Under existing conditions, this area is not tidal, and is only inundated periodically by high streamflows. With the railroad slough berms removed (Alternative 1 and 3), the area becomes fully tidal and would be inundated during high tide; however, during a large flood event, the area would also drain much more quickly and peak water levels would be significantly reduced. Under Alternative 3, water level peaks at 11.1 ft NAVD and drops to 3.9 ft after 33 hours while under Existing Conditions, water level peaks at 13.3 ft and only drops to 10.3 ft after 51 hours. The simulation does not continue past this point; however, water levels are known to persist for several weeks in these areas after a flood event. Alternatives 1 and 3 substantially lower the peak water level in Area 4 by 2.6 and 2.0 ft respectively for the 1%, elevated tide scenario. Due to increased conveyance capacity for tidal flows, Alternative 3 has a slightly higher peak than Alternative 1 but also drains more rapidly and more completely. Alternative 2 increases water levels in this scenario by 0.6 ft in this area as the raised railroad constrains overflows from Sonoma Creek.

Upstream of the Highway 121 crossing with Sonoma Creek, at the Hwy 12 and Hwy 121 intersection, Alternatives 1 and 2 closely match Existing Conditions with a slightly lower peak and similar drawdown timing while Alternative 3 has a significantly lower peak and drains down more rapidly. At peak stage, Alternative 3 is 0.7 ft lower than Existing Conditions and is lower by an average of 0.3 ft for the full 30-hour period during which this location is inundated. Alternatives 1 and 2 decrease peak water levels by 0.2 ft with an average decrease of 0.05 over the 30-hour inundation period.

5.2 Channel Velocities

By opening tidal action to the currently leveed parcels and adding new tidal prism, the restoration alternatives have the potential to influence channel velocities. Plots of velocity at the mouth of Sonoma Creek over the simulation for the three hydrologic scenarios are shown in Figure 26 to Figure 28. Positive velocity represents flow downstream towards the bay, and negative velocity represents flow from the Bay upstream. These plots show that typical and maximum velocities are increased relative to Existing Conditions for all alternatives and the No-action scenario.

Alternative 3 reflects the largest increase in velocities. Peak velocity for the 2050 1% flow, elevated tide w/SLR scenario increases by 3.4 ft/s for the No-action scenario, 4.0 ft/s for Alternative 1, 3.8 ft/s for Alternative 2, and 5.2 ft/s for Alternative 3 respectively.

The No-action velocity time series matches fairly closely with Alternatives 1 and 2. Given that the only area breached under No-action is Skaggs Island, this suggests that the additional prism in Skaggs accounts for much of the velocity increases for the alternatives. This suggests that the size and location of breaches on Skaggs Island should be further analyzed to evaluate options for mitigating velocity impacts. Other options for mitigation may involve reconfiguring the Highway 37 crossing over Sonoma Creek. The hydrodynamic model would provide a valuable tool for designing a modified Highway crossing to accommodate future site conditions.

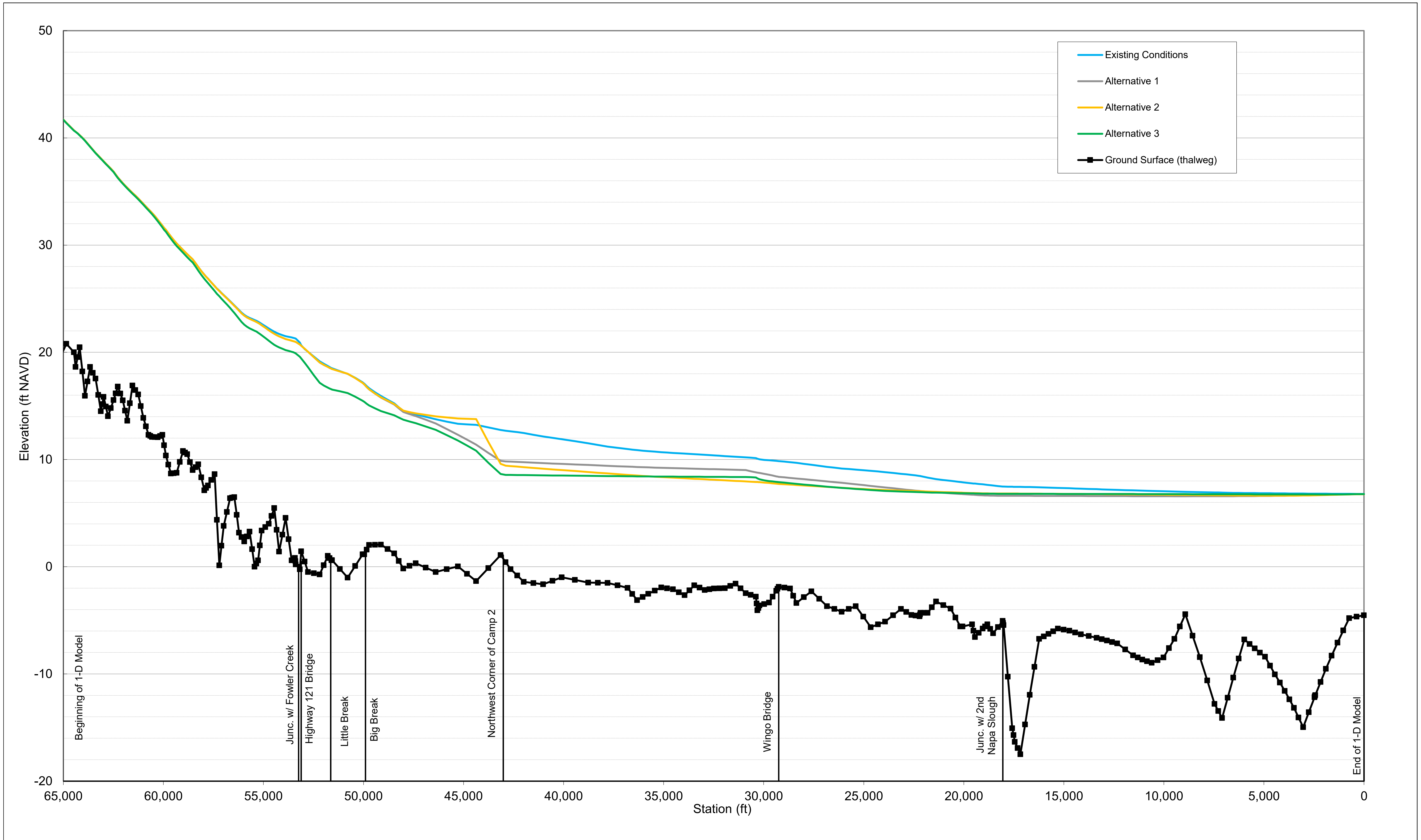


Figure 4
Sonoma Creek water surface profiles
1% flow, typical tide

ESA

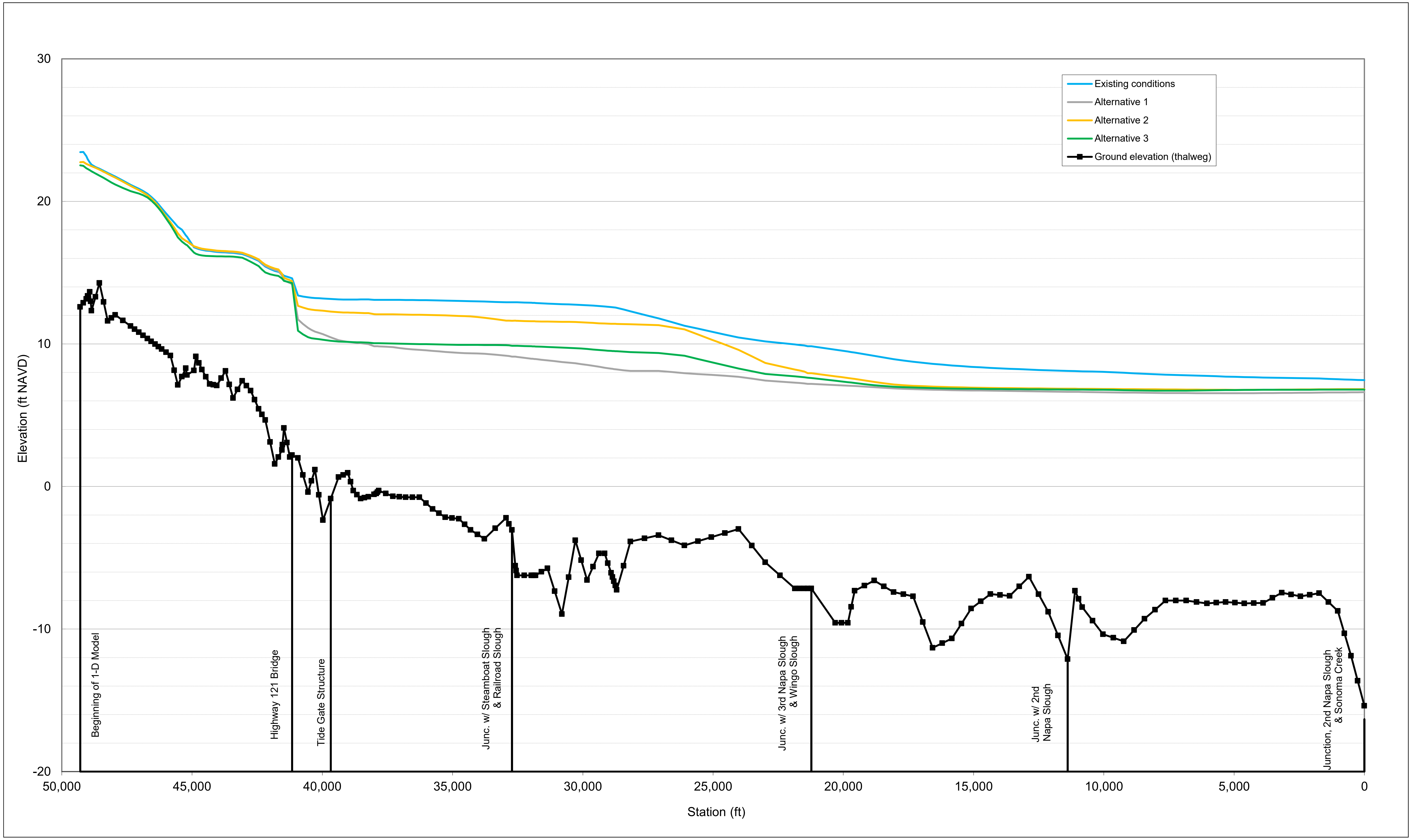


Figure 5
Schell Creek water surface profiles
1% flow, typical tide

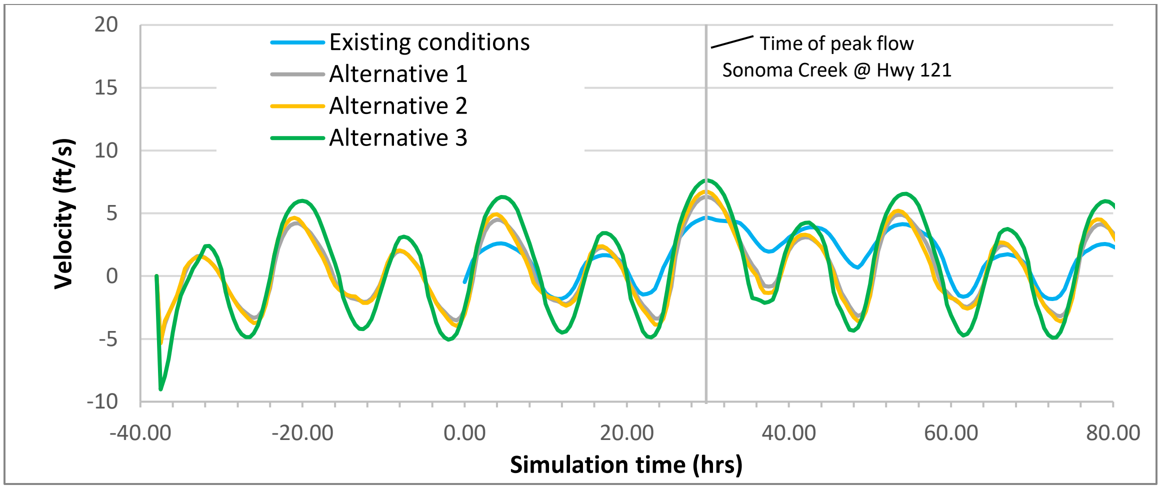


Figure 26. Velocity time series comparisons for all alternatives. 1% flow, typical tide.

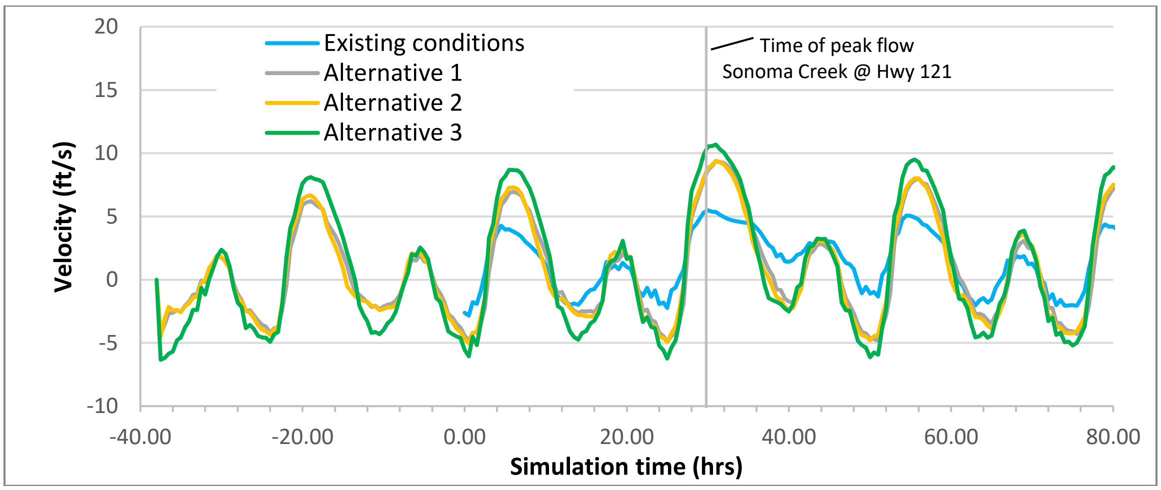


Figure 27. Velocity time series comparisons for all alternatives. 1% flow, elevated tide.

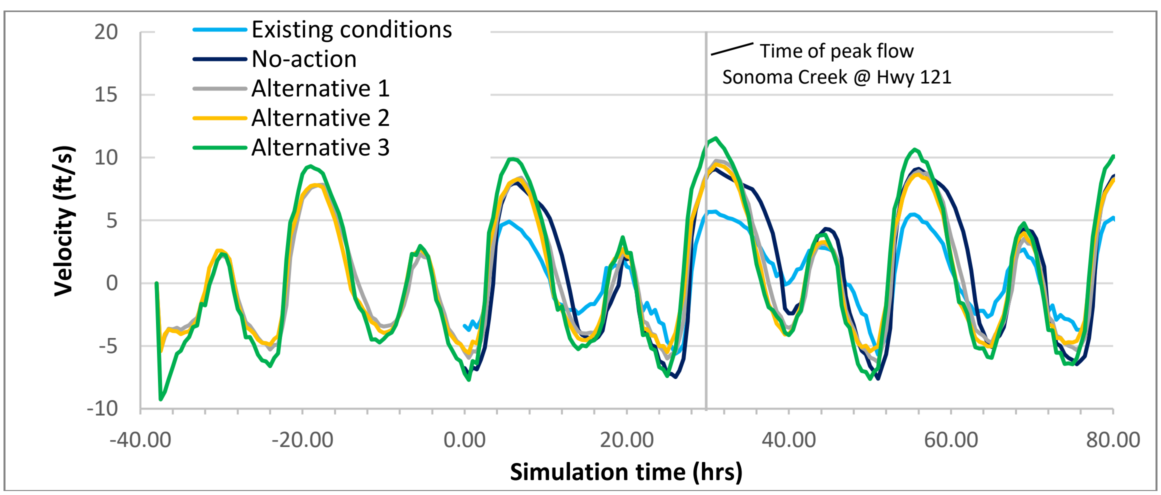


Figure 28. Velocity time series comparisons for all alternatives. 2050 1% flow, elevated tide w/SLR.

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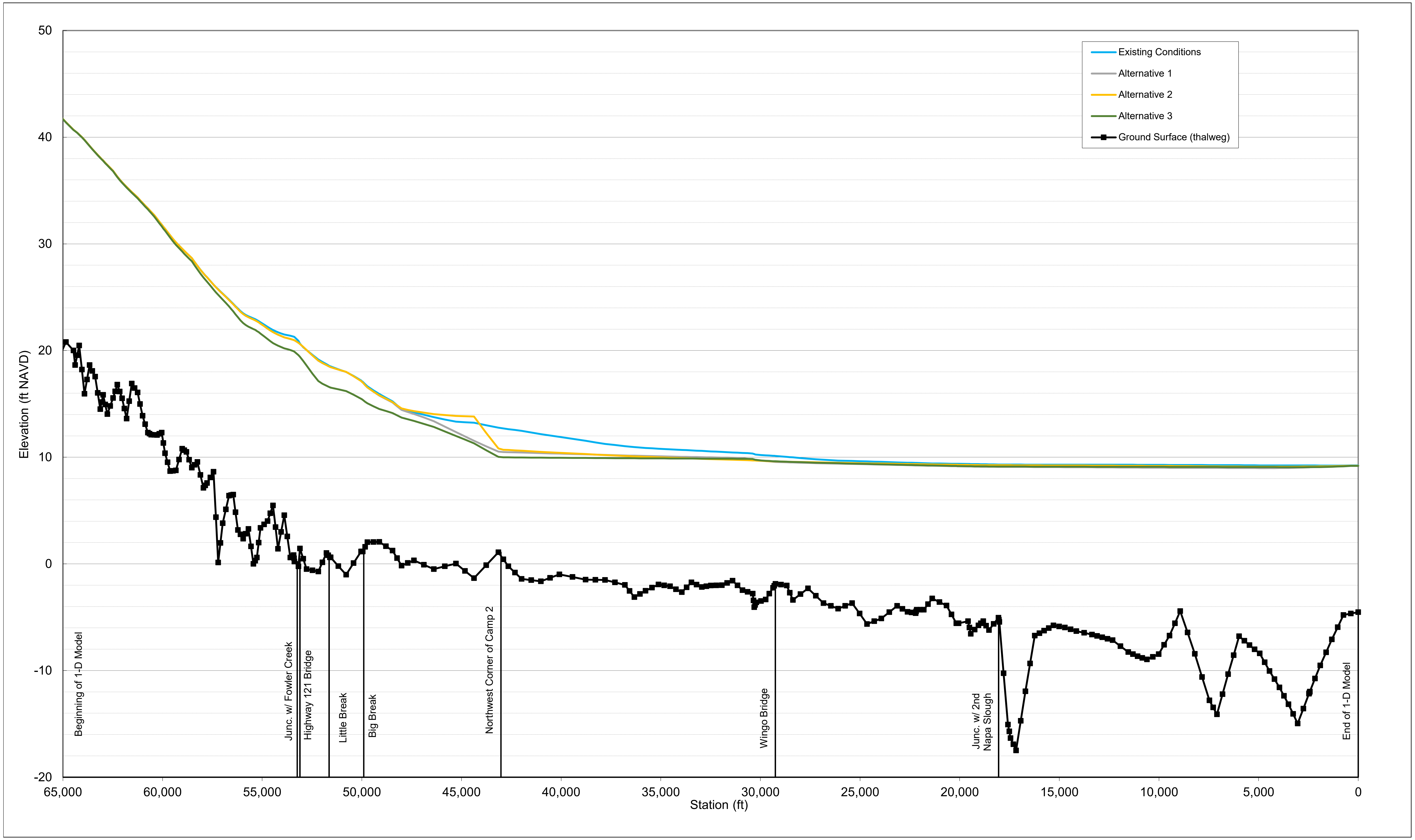


Lower Sonoma Creek Strategy. D180152.01

Figure 6
Sonoma Creek water surface profiles
1% flow, elevated tide

ESA

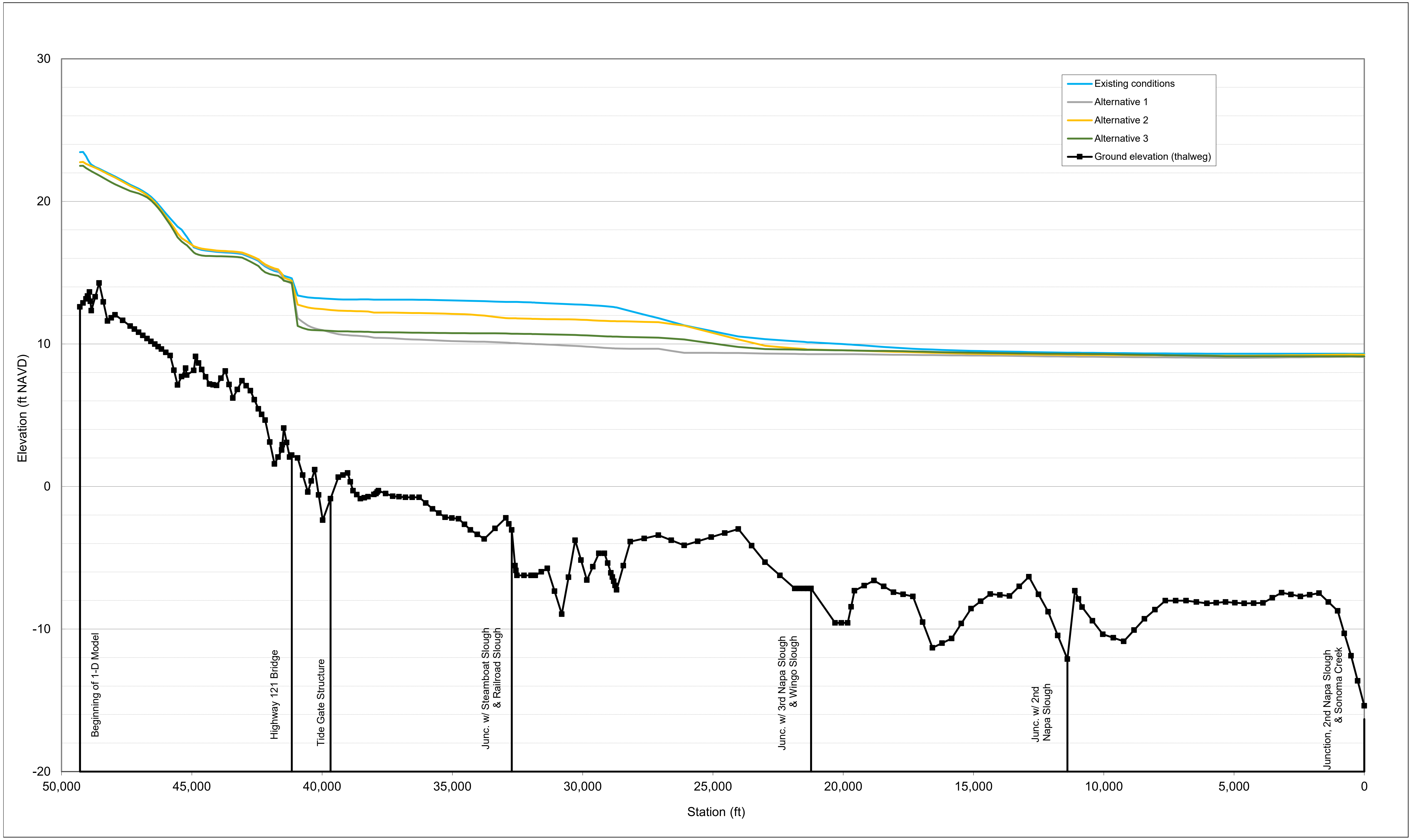
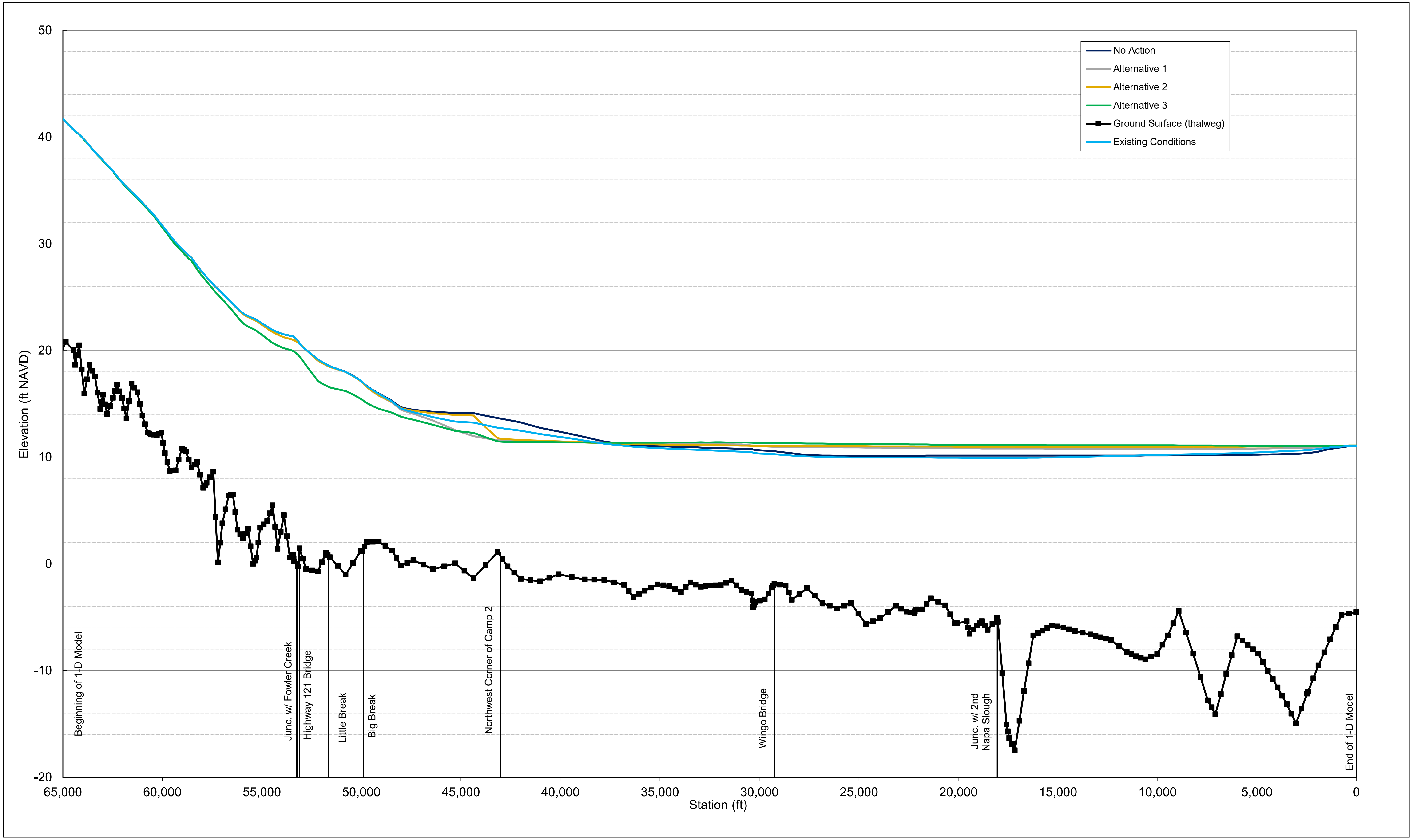


Figure 7

Schell Creek water surface profiles
1% flow, elevated tide

ESA

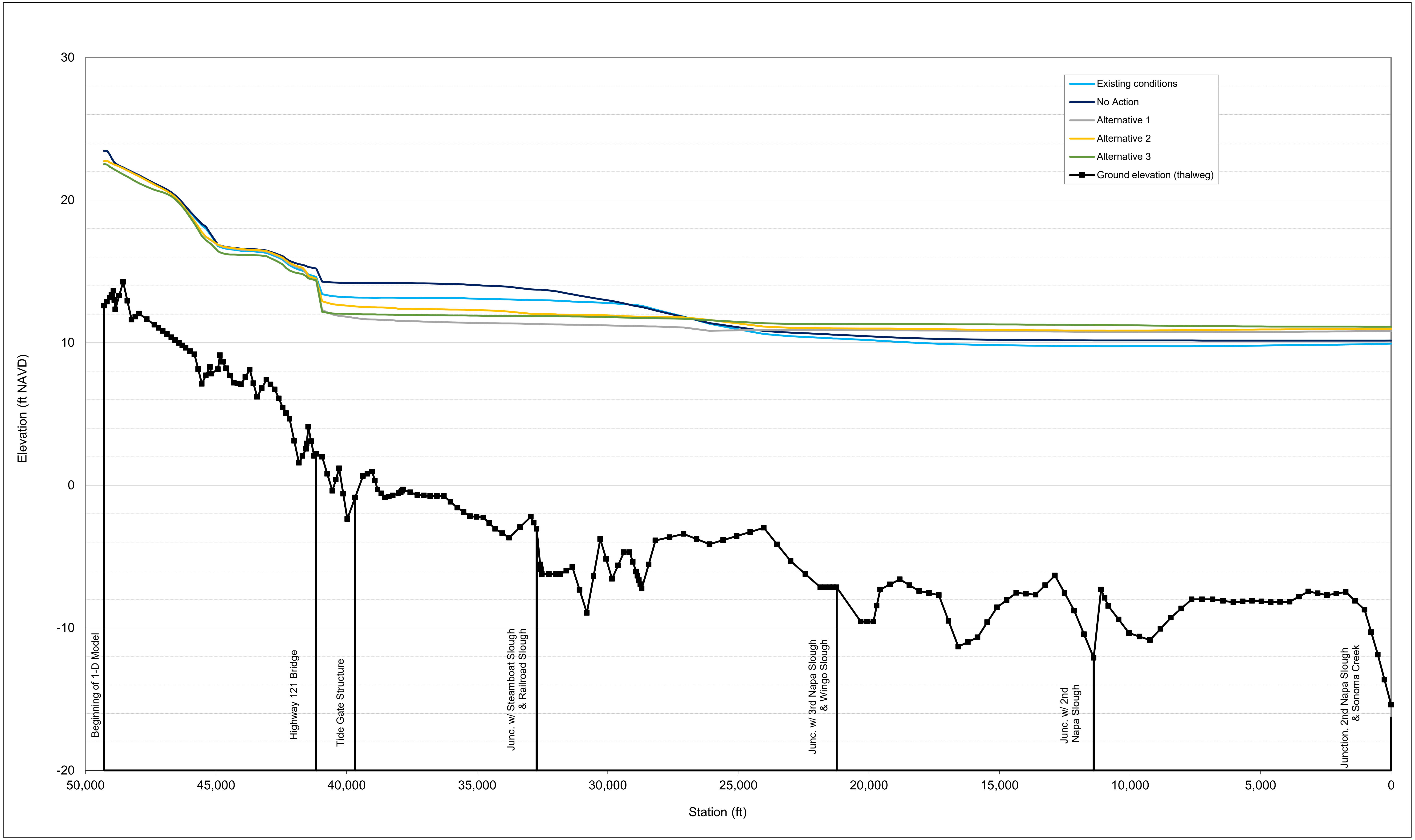


Lower Sonoma Creek Strategy. D180152.01

Figure 8

Sonoma Creek water surface profiles
2050 1% flow, elevated tide w/SLR

ESA

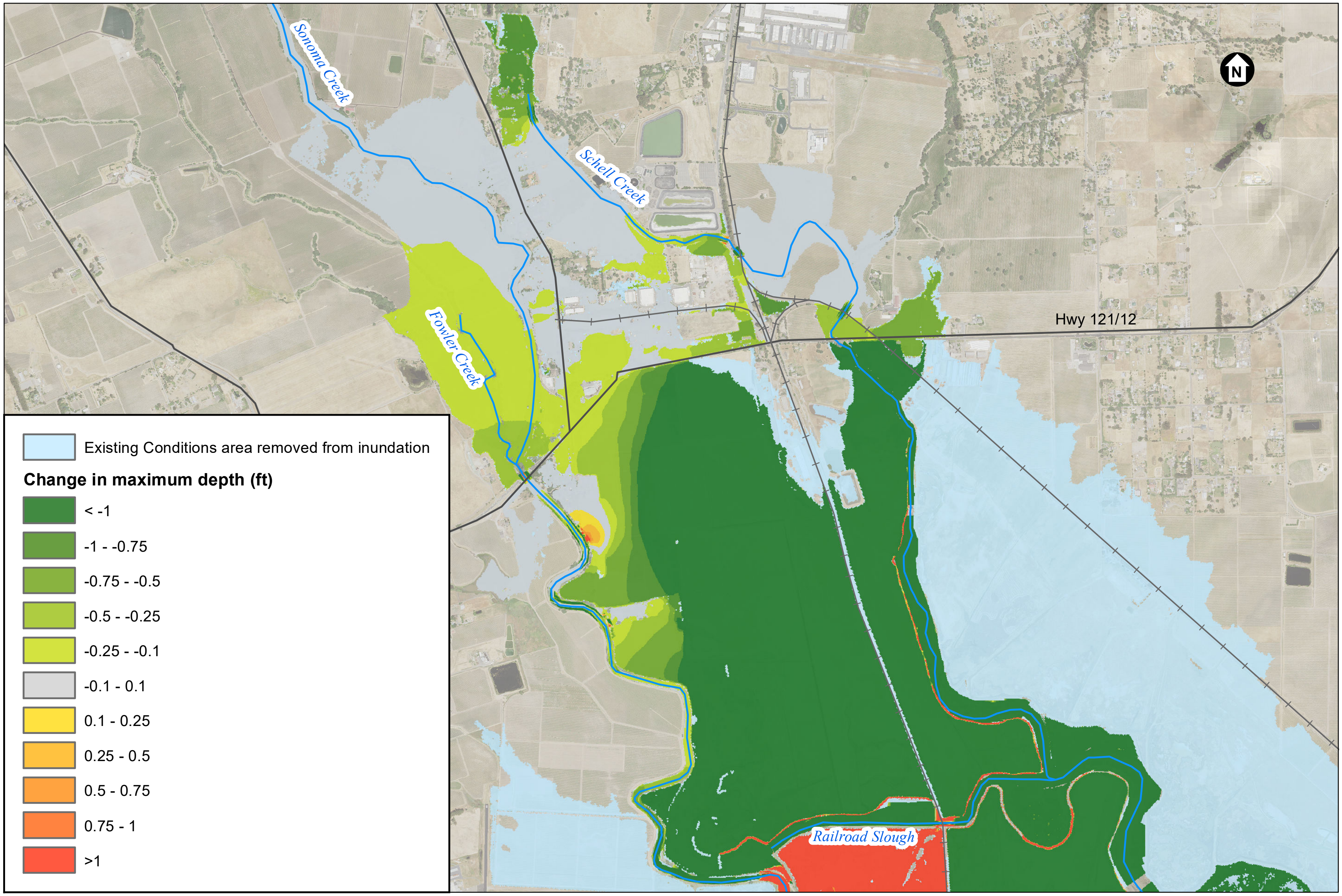


Lower Sonoma Creek Strategy. D180152.01

Figure 9

Schell Creek water surface profiles
2050 1% flow, elevated tide w/SLR

ESA



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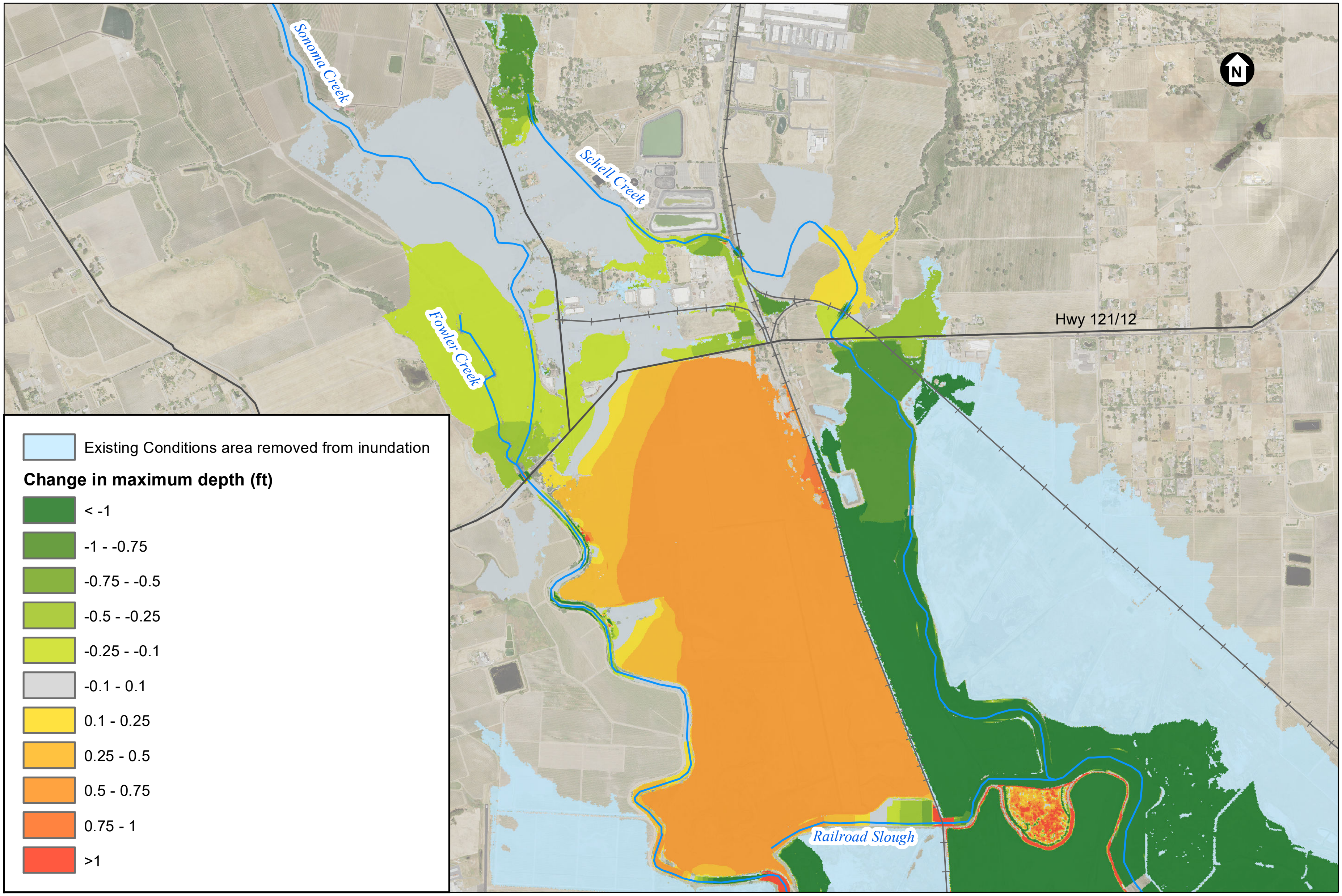
SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

Figure 10
Change in maximum depth, 1% flow, typical tide
Alternative 1 minus Existing Conditions

ESA



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SOURCE: NAIP (2014 aerial)

Figure 11
Change in maximum depth, 1% flow, typical tide
Alternative 2 minus Existing Conditions

ESA

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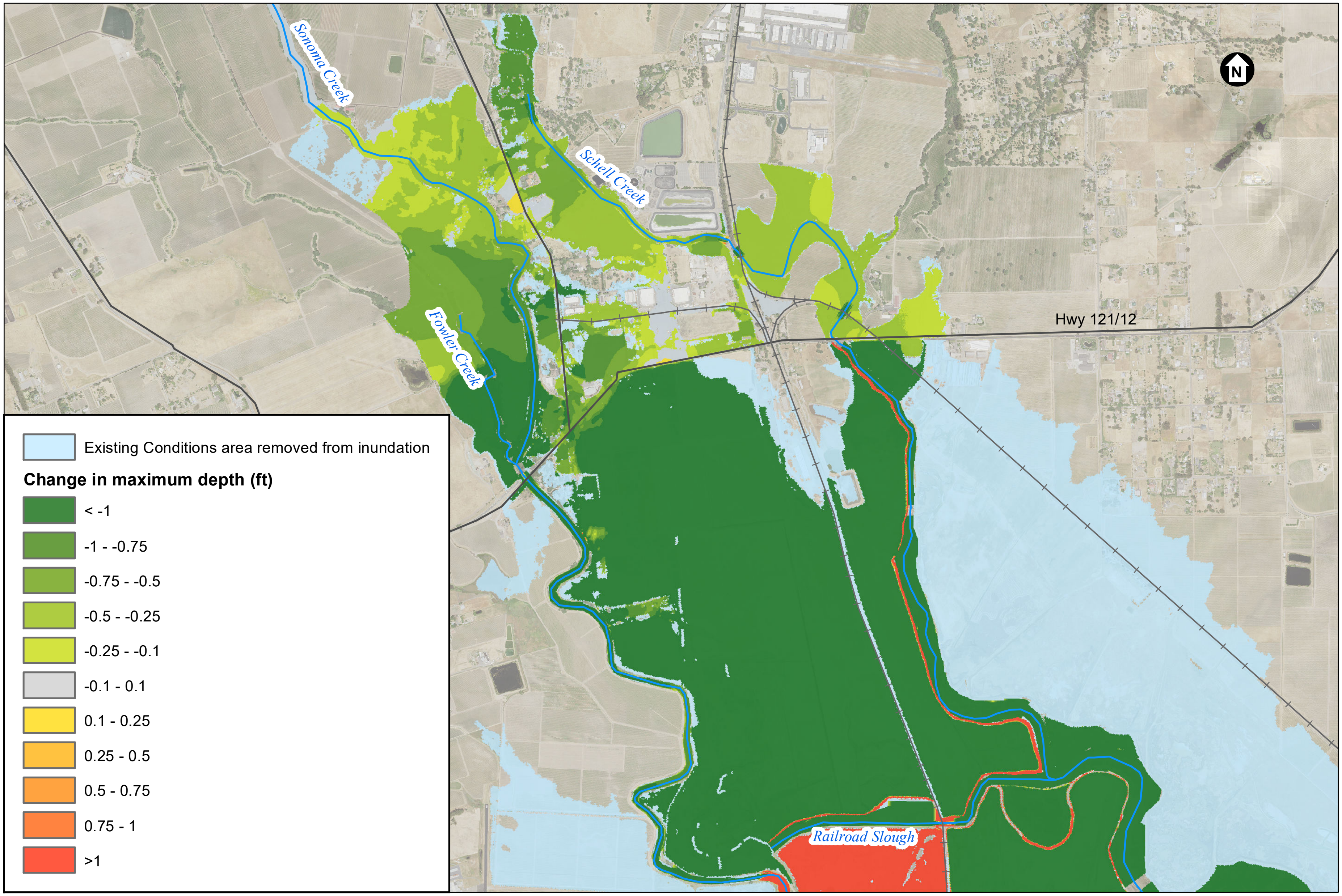

SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

ESA

Figure 12
Change in maximum depth, 1% flow, typical tide
Alternative 3 minus Existing Conditions

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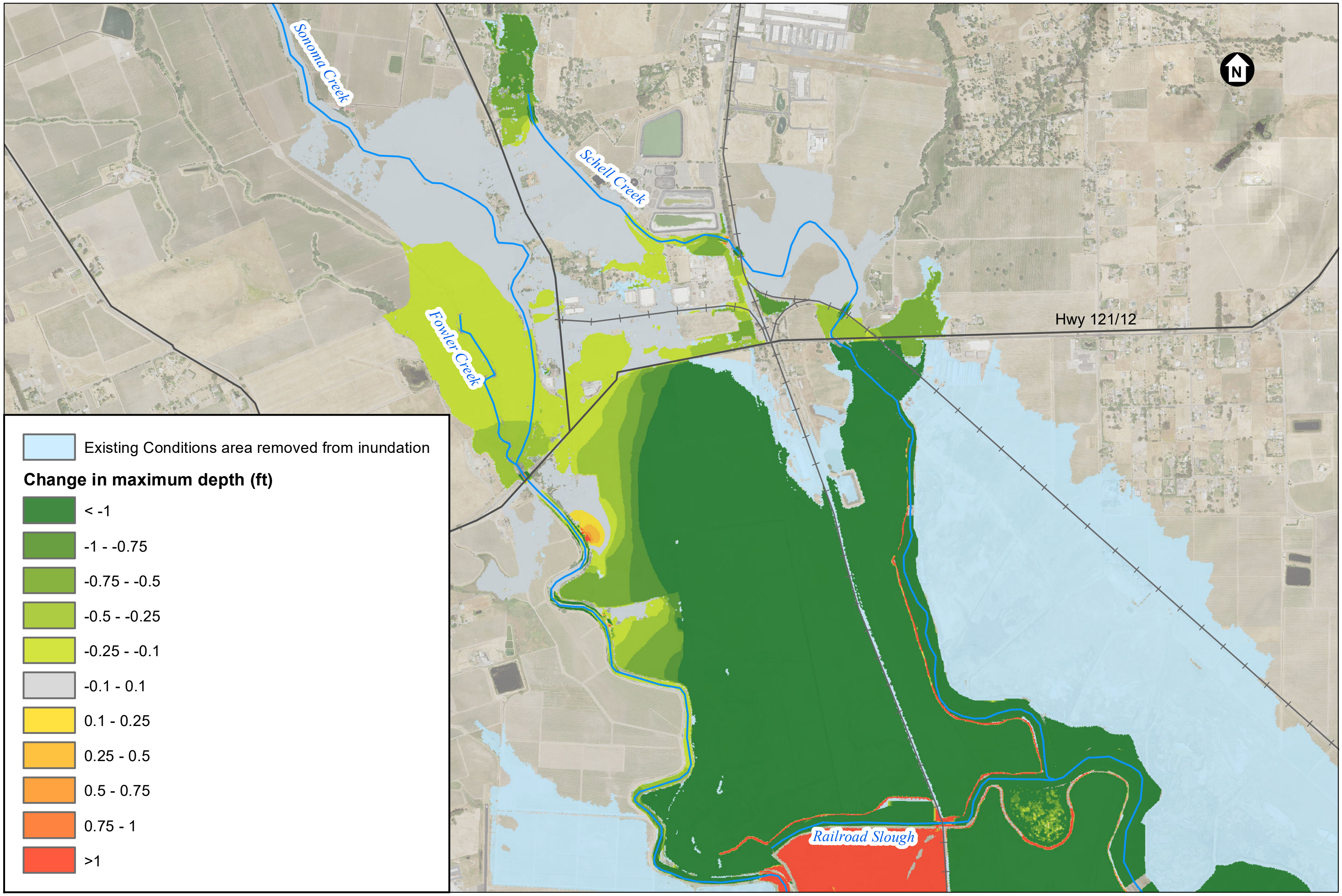
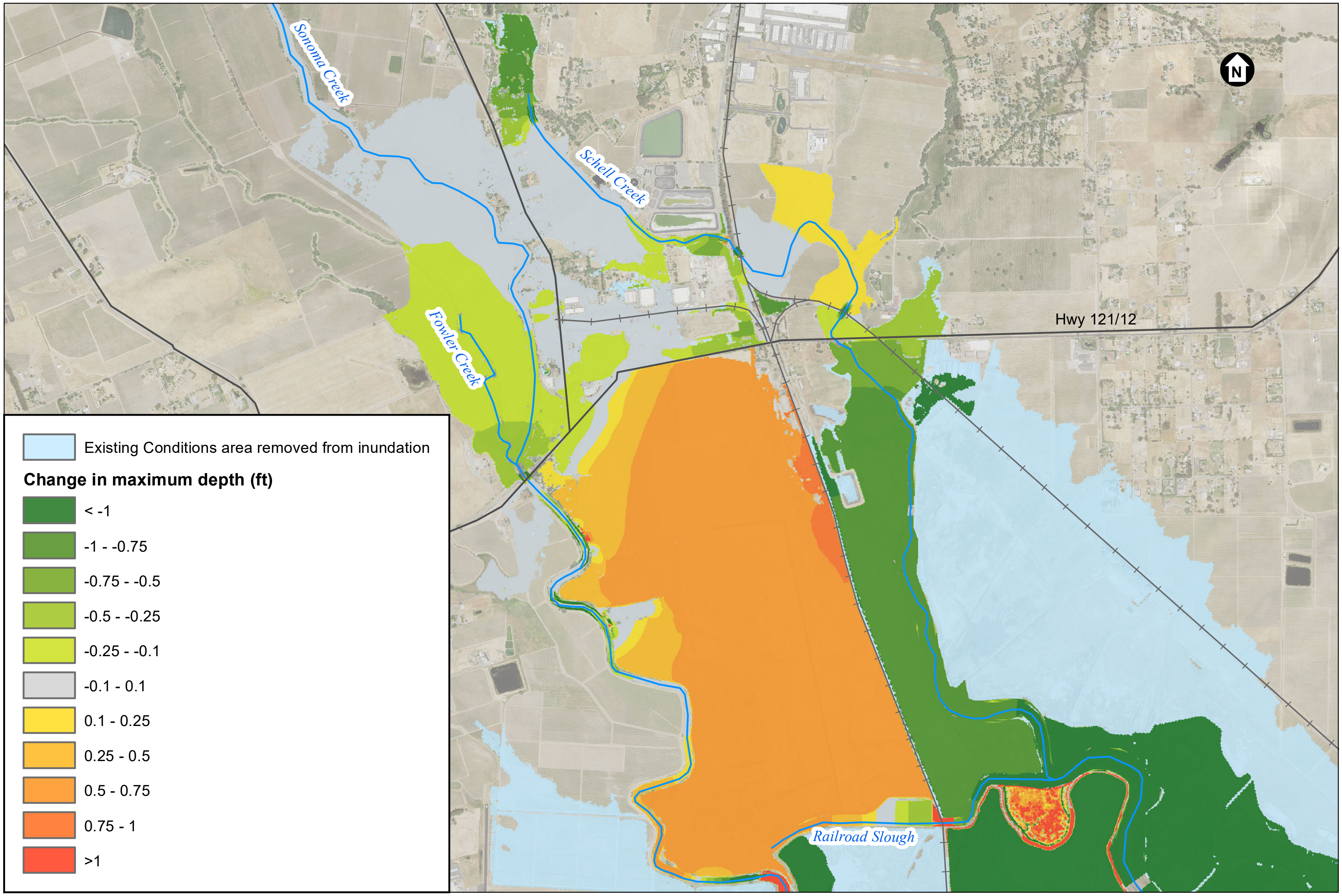


SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

ESA

Figure 13
Change in maximum depth, 1% flow, elevated tide
Alternative 1 minus Existing Conditions



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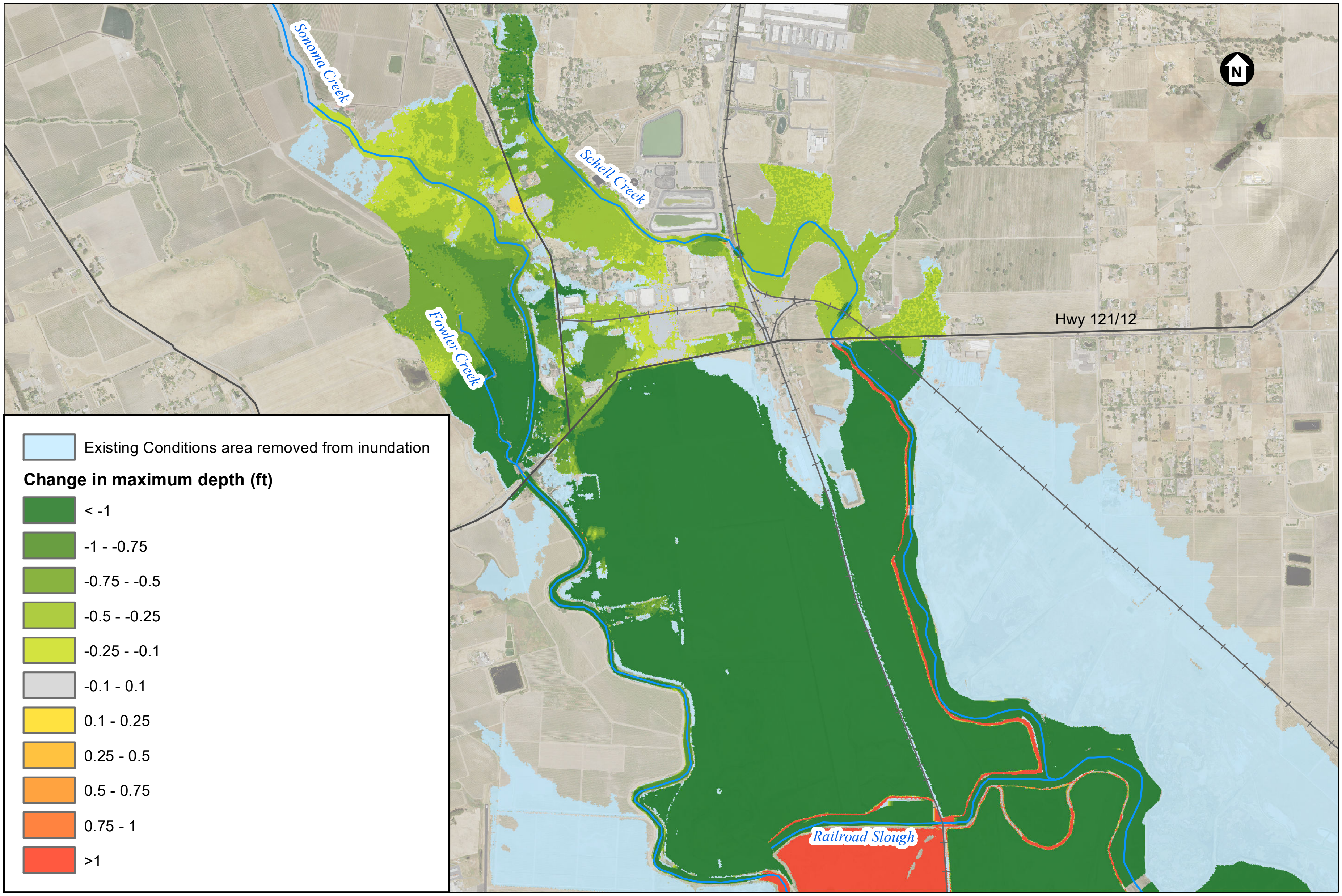
SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

Figure 14
Change in maximum depth, 1% flow, elevated tide
Alternative 2 minus Existing Conditions

ESA



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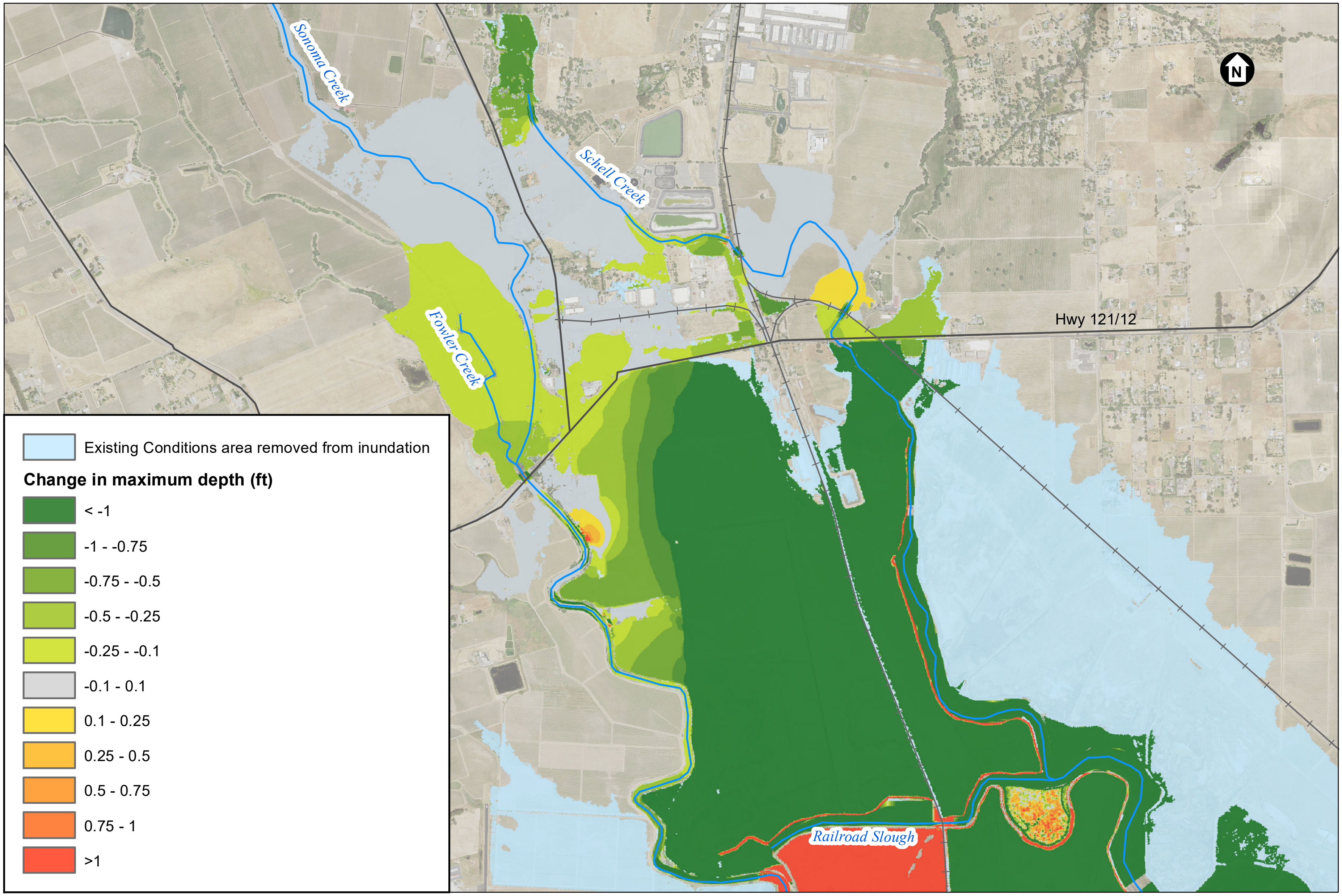
SOURCE: NAIP (2014 aerial)

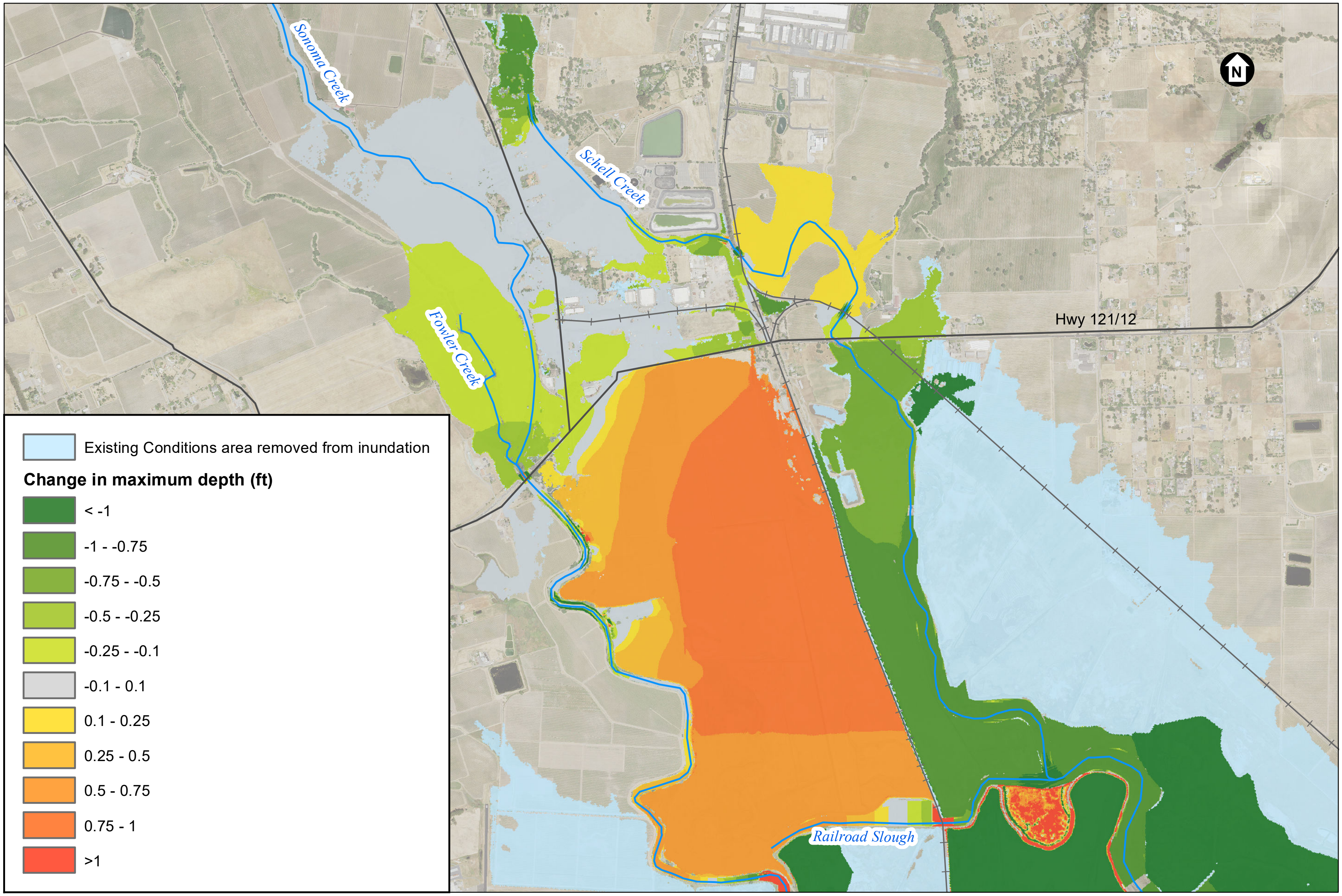
Figure 15
Change in maximum depth, 1% flow, elevated tide
Alternative 3 minus Existing Conditions



SOURCE: NAIP (2014 aerial)

Figure 16
Change in maximum depth, 2050 1% flow, elevated tide w/SLR
Alternative 1 minus Existing Conditions

ESA



SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

Figure 17
Change in maximum depth, 2050 1% flow, elevated tide w/SLR
Alternative 2 minus Existing Conditions

ESA

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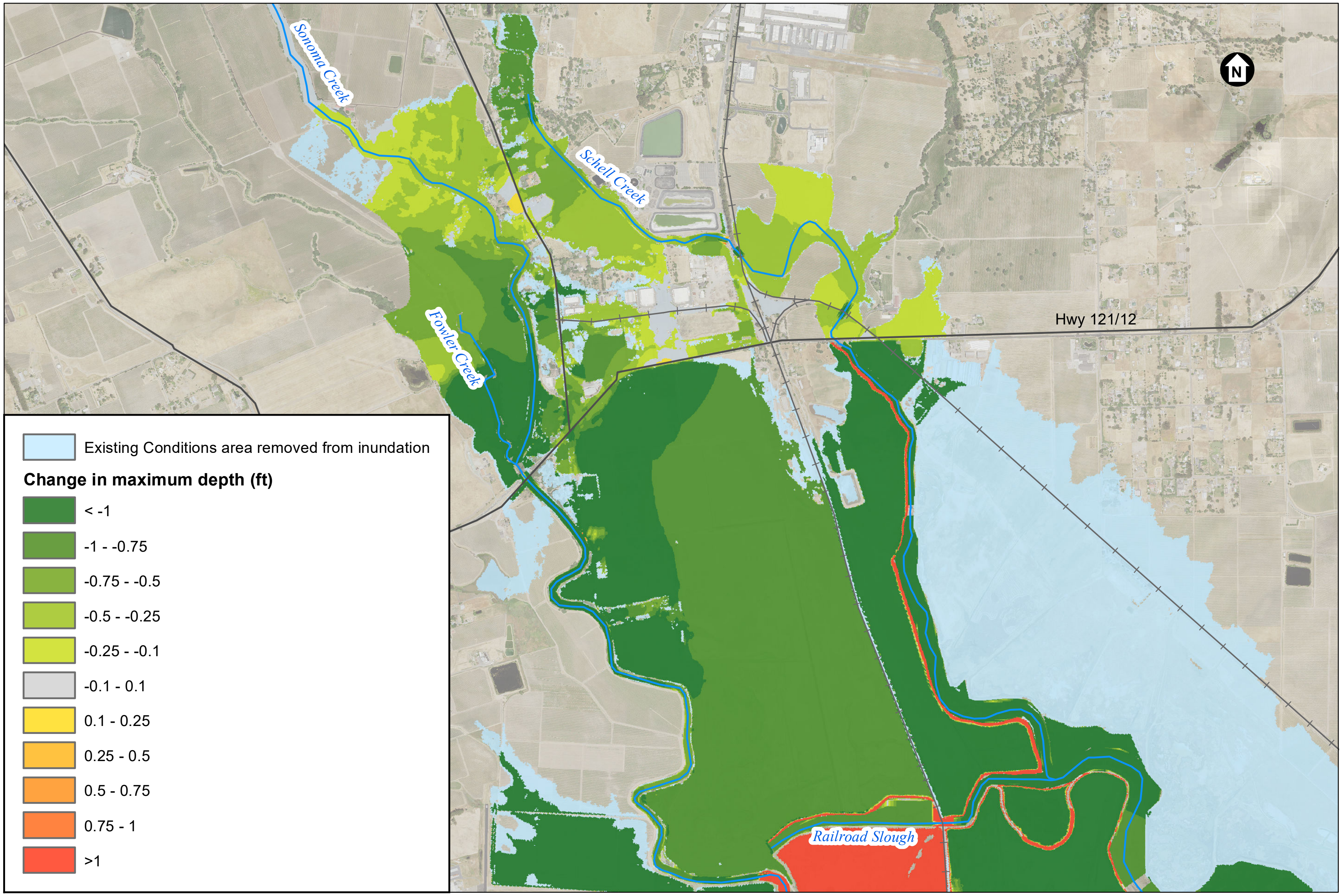
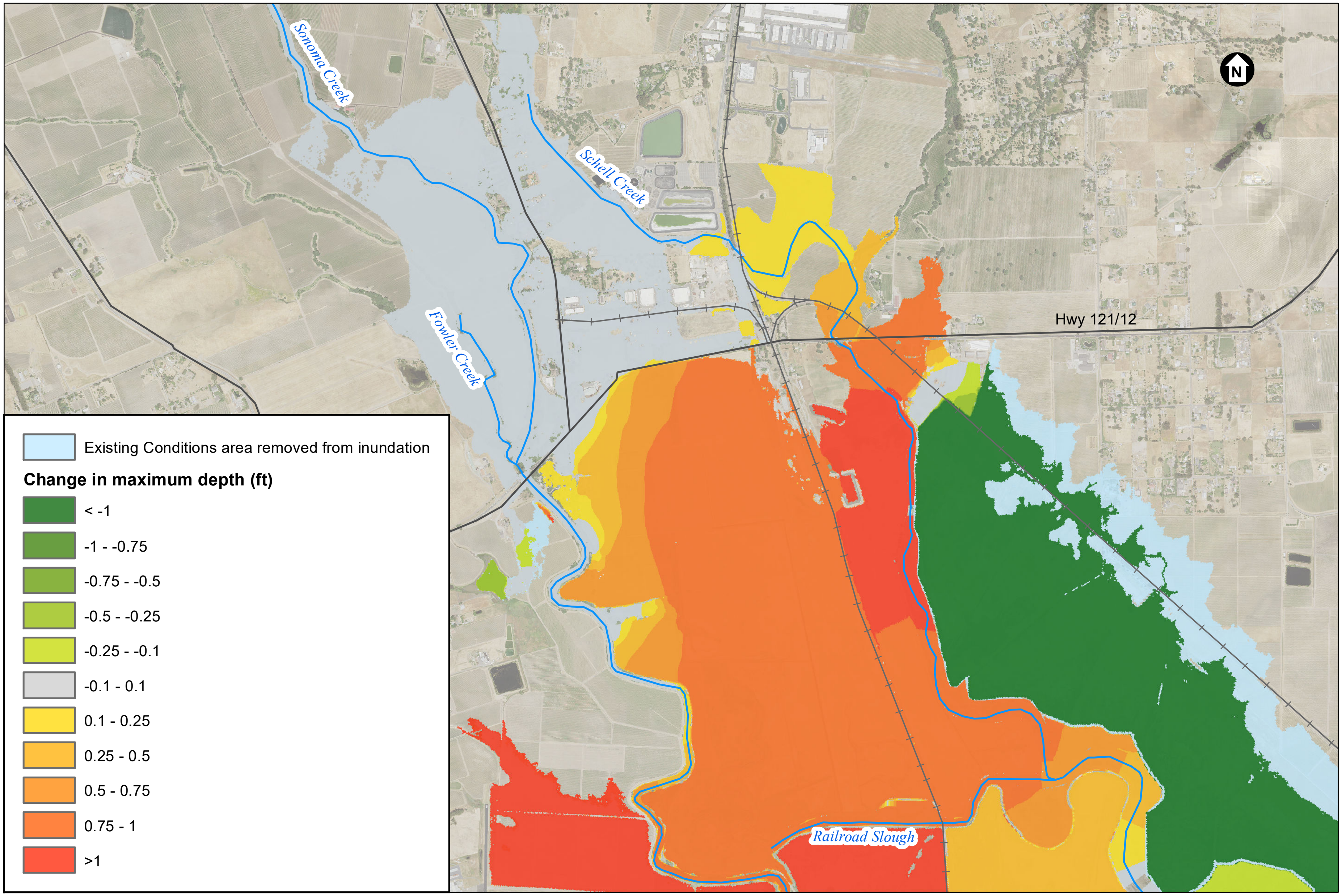


SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

Figure 18
Change in maximum depth, 2050 1% flow, elevated tide wSLR
Alternative 3 minus Existing Conditions

ESA

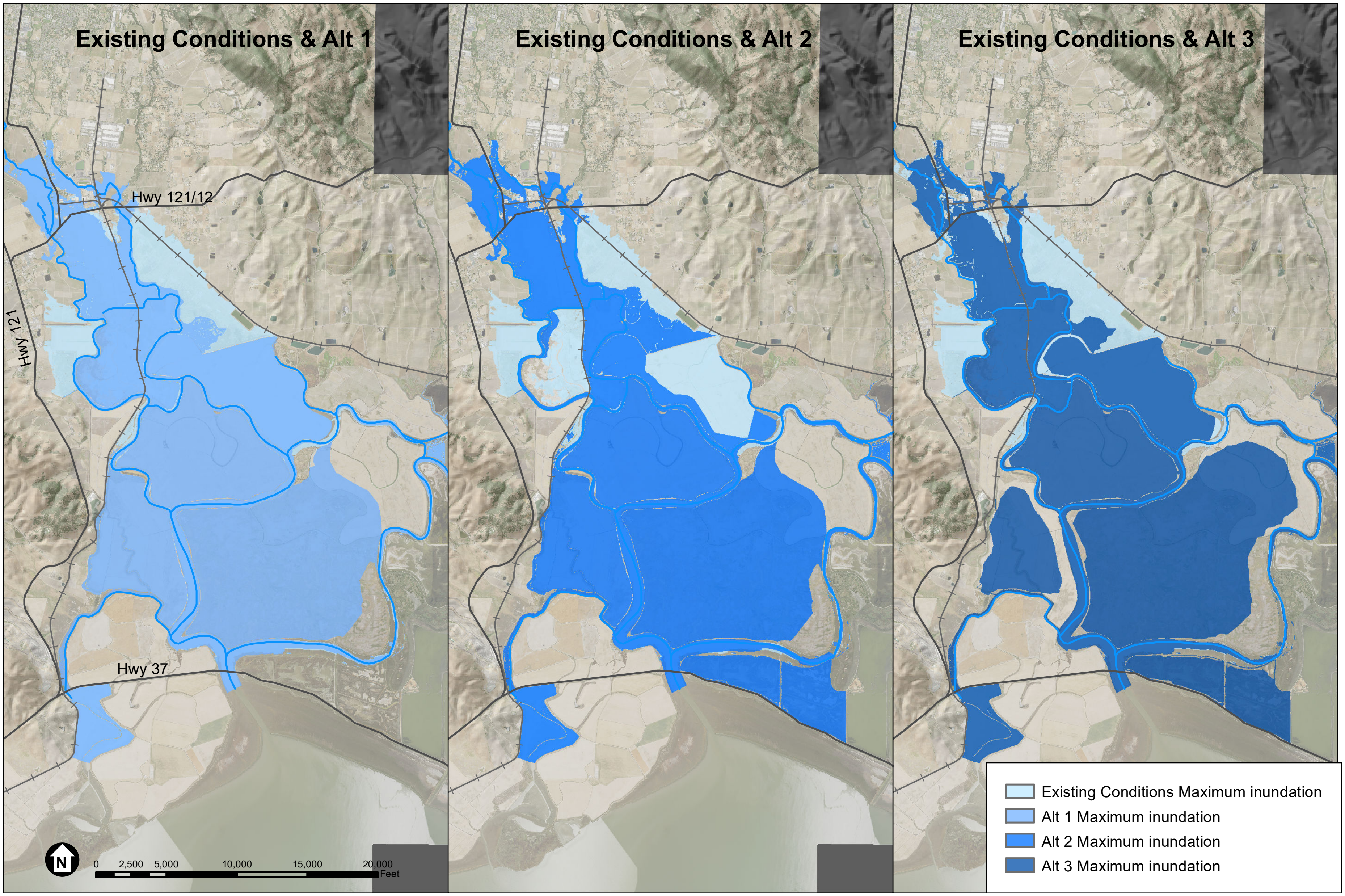


SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

Figure 19
Change in maximum depth, 2050 1% flow, elevated tide wSLR
No-action minus Existing Conditions

ESA

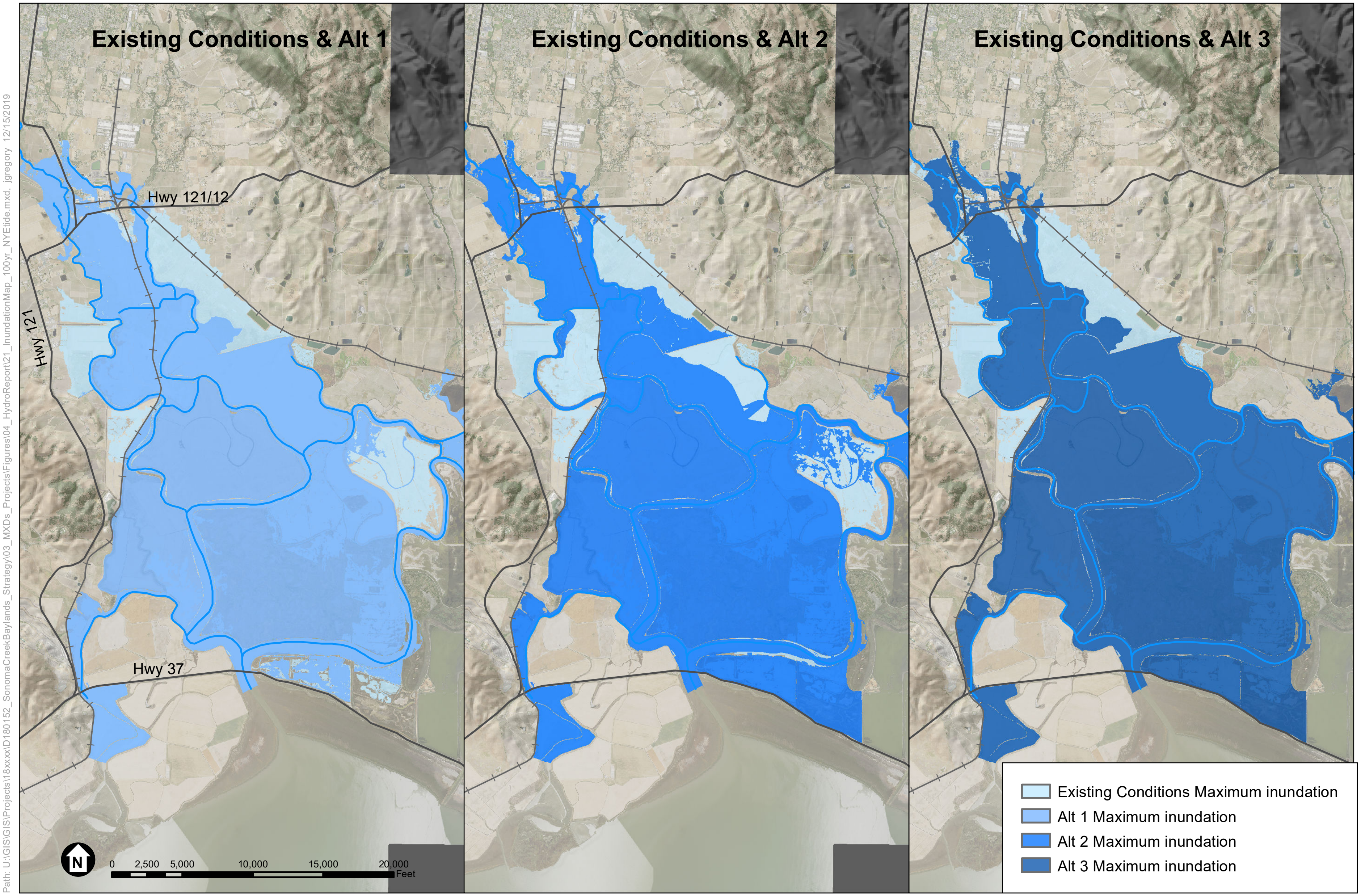


SOURCE: NAIP (2014 aerial)

Sonoma Creek Baylands Strategy

Figure 20
Maximum inundation extent for 1% flow, typical tide
Existing Conditions, Alternative 1, Alternative 2, and Alternative 3

ESA

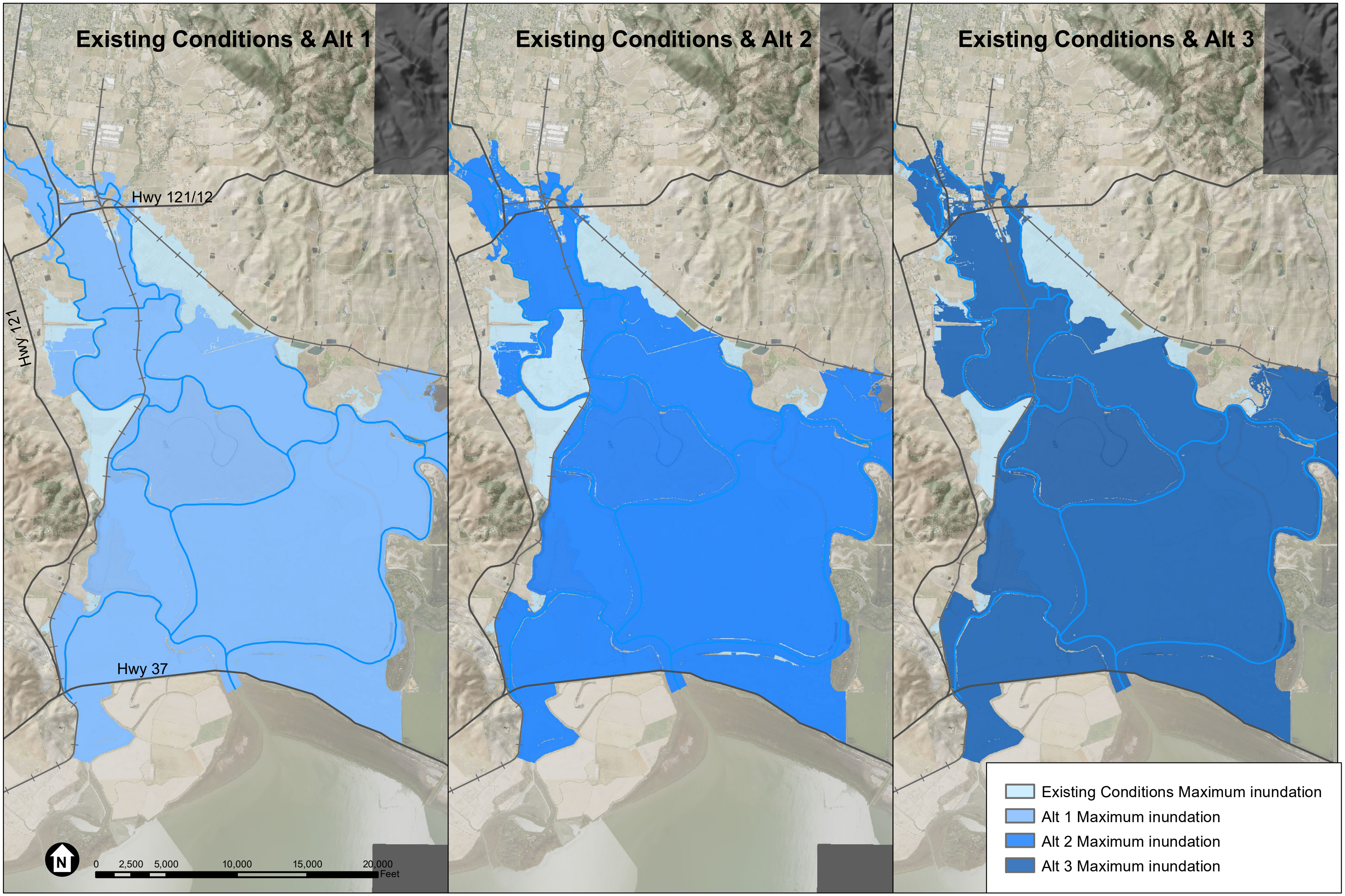


SOURCE: NAIP (2014 aerial)

Sonoma Creek Baylands Strategy

Figure 21
Maximum inundation extent for 1% flow, elevated tide
Existing Conditions, Alternative 1, Alternative 2, and Alternative 3

ESA



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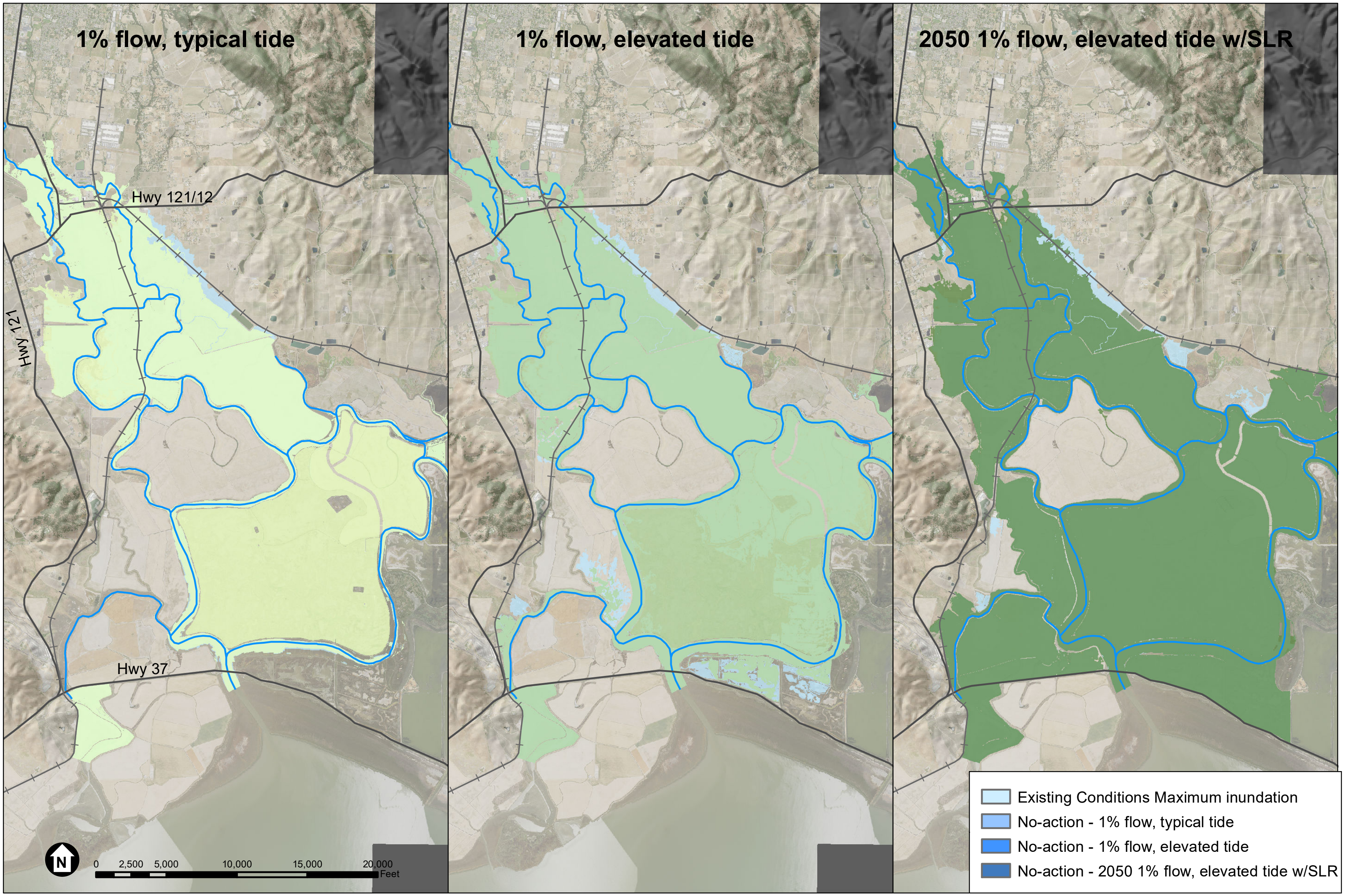
SOURCE: NAIP (2014 aerial)

Sonoma Creek Baylands Strategy

ESA

Figure 22
Maximum inundation extent for 2050 1% flow, elevated tide w/SLR
Existing Conditions, Alternative 1, Alternative 2, and Alternative 3



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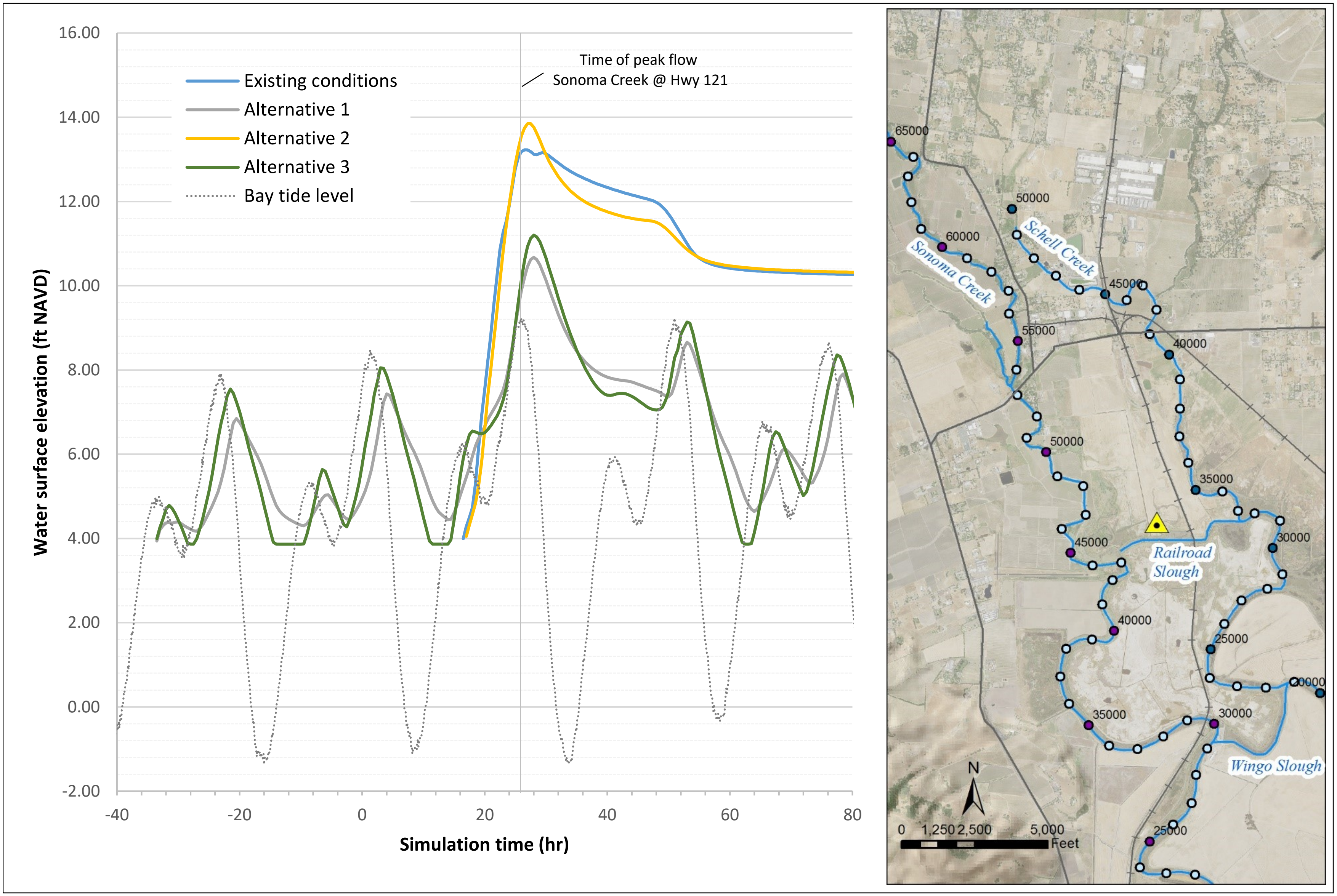
SOURCE: NAIP (2014 aerial)

Sonoma Creek Baylands Strategy

Figure 23
Maximum inundation extent for three hydrologic scenarios
Existing Conditions and No Action

ESA

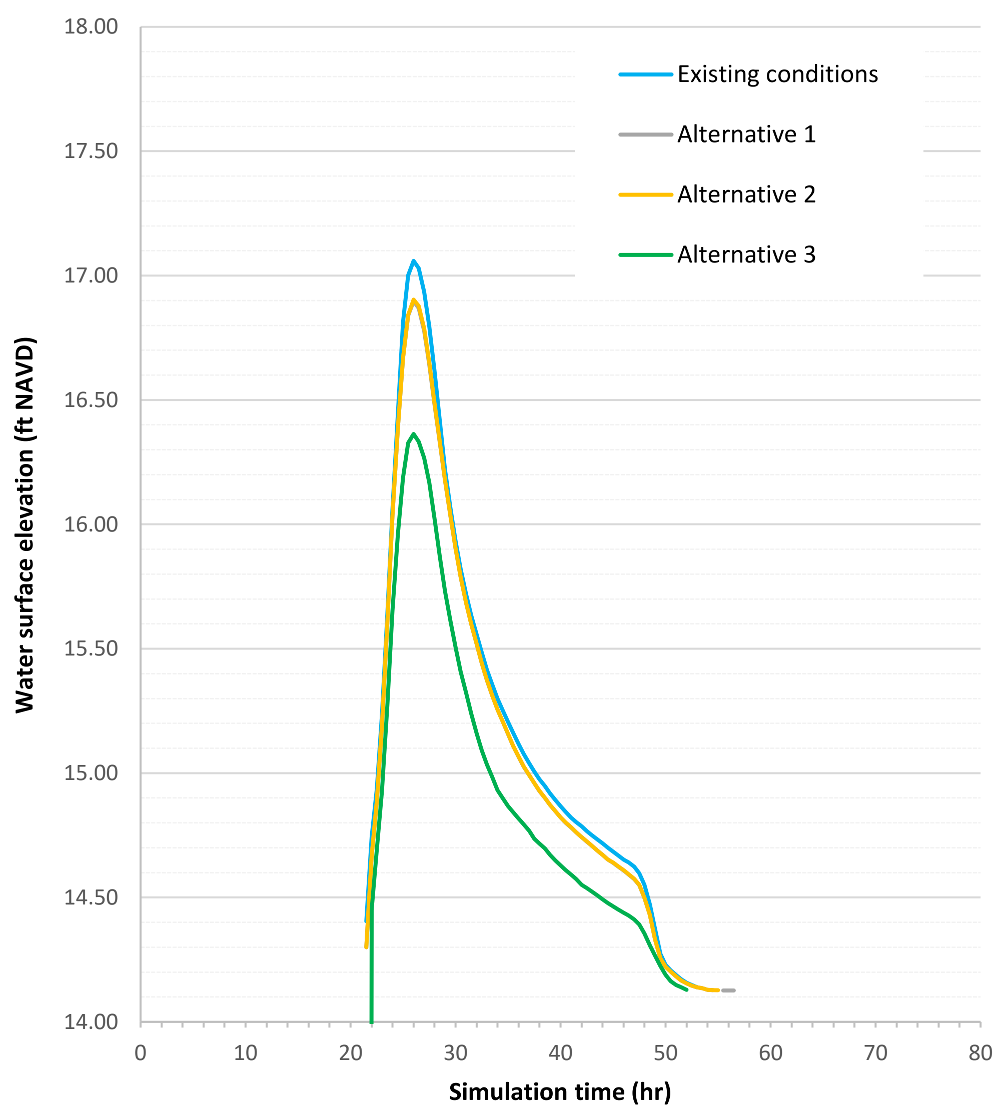


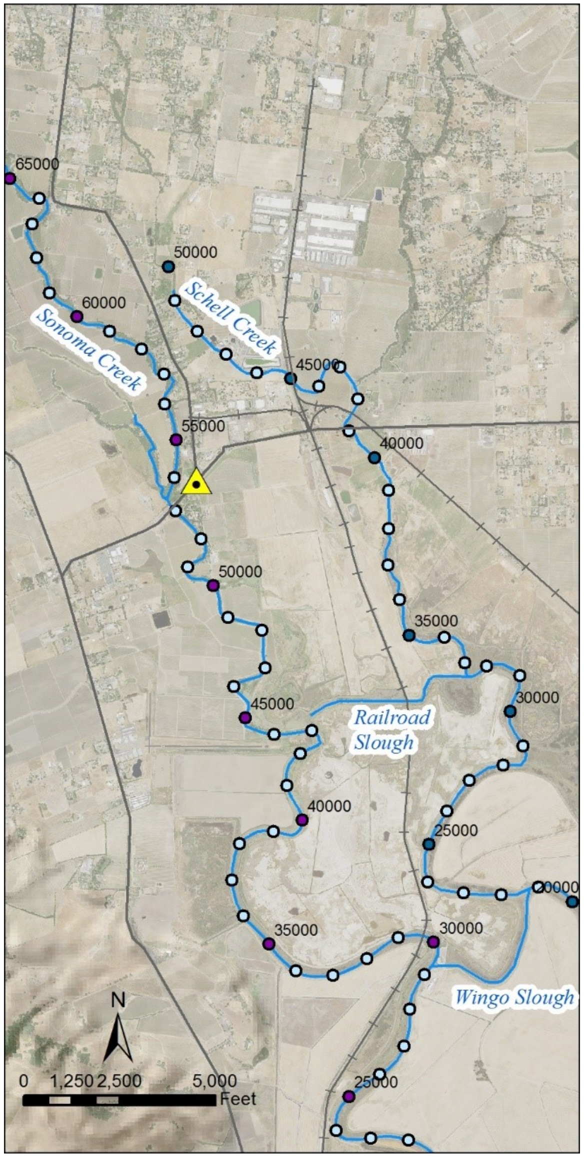
NOTE: Time series shown at yellow marker on righthand map panel

Sonoma Creek Baylands Strategy. D180152.01

Figure 24

Water surface elevation time series in Area 4 for all alternatives. 1% flow, elevated tides.





NOTE: Time series shown at yellow marker on righthand map panel

Sonoma Creek Baylands Strategy. D180152.01

Figure 25

Water surface elevation time series, Highway 12 at Highway 121 for all alternatives. 1% flow, elevated tides.

Appendix 2: Geomorphic Analysis

Jeremy Lowe, San Francisco Estuary Institute

Introduction

The restoration strategy and alternatives are designed to provide a mosaic of functional and resilient habitats in the Lower Sonoma and Tolay Creek watersheds. This section of the plan evaluates how well each of the alternatives succeeds at achieving this goal up to 2100 based on the designs of the alternatives and habitat evolution in response to sea level rise.

Of particular concern is the potential increase in flow rates along the tidal channels of Sonoma Creek as tidal action is restored to diked areas either by design through restoration projects, or by accident due to erosion and breaching of dikes. The presently diked parcels are very large areas of subsided land which, since they lie within the tidal range, will fill and empty on each tide. The volume of water that enters on the flood and leaves on the ebb is called the tidal prism and is conveyed to and from the marsh by the remaining tidal channels. The present tidal prism is relatively small, since most areas are protected by dikes, and many of the channels have been filling in with marshes. If the tidal prism increases, then these channels will erode to a size that allows them to convey the increased volume of water. Erosion of the channels to convey water may result in erosion of the existing fringing infill wetlands and dikes, and scouring around bridge piles. It is therefore essential to estimate the future widths of the main channels if tidal prism is increased.

Methods

The relationship between channel size at a particular cross-section of a channel and some measure of flow discharge (such as tidal prism) upstream of that cross-section is known as hydraulic geometry. The hydraulic geometry relationships for marshes in San Francisco Bay have been investigated by Williams et al. (2002) for marshes in San Francisco Bay. In that study, empirical correlations between channel cross-section morphology (width, depth, area) and tidal prism for a San Francisco Bay data set were used to predict equilibrium cross-section morphology for a given tidal prism. For each cross-section were characterized:

- Depth, D (m) - depth relative to MHHW at the deepest part of the cross-section, the thalweg;
- Width, W (m) - distance between the two banks at MHHW, or projected to MHHW if the banks were lower;
- Cross-sectional area, A (m^2) - area below MHHW for the part of the channel within the channel width;
- Diurnal Tidal prism, TP (m^3) - volume of water between MLLW and MHHW within the contributing tidal watershed area landward (upstream) of the cross-section, extending to the drainage divide between channel networks.

The dataset included the historical pre-diked Sonoma Creek, Petaluma River and Napa River, as well as modern channels within ancient marshes such as China Camp, Heerdt Marsh, Petaluma Marsh and Wildcat Marsh (**Figure 1**).

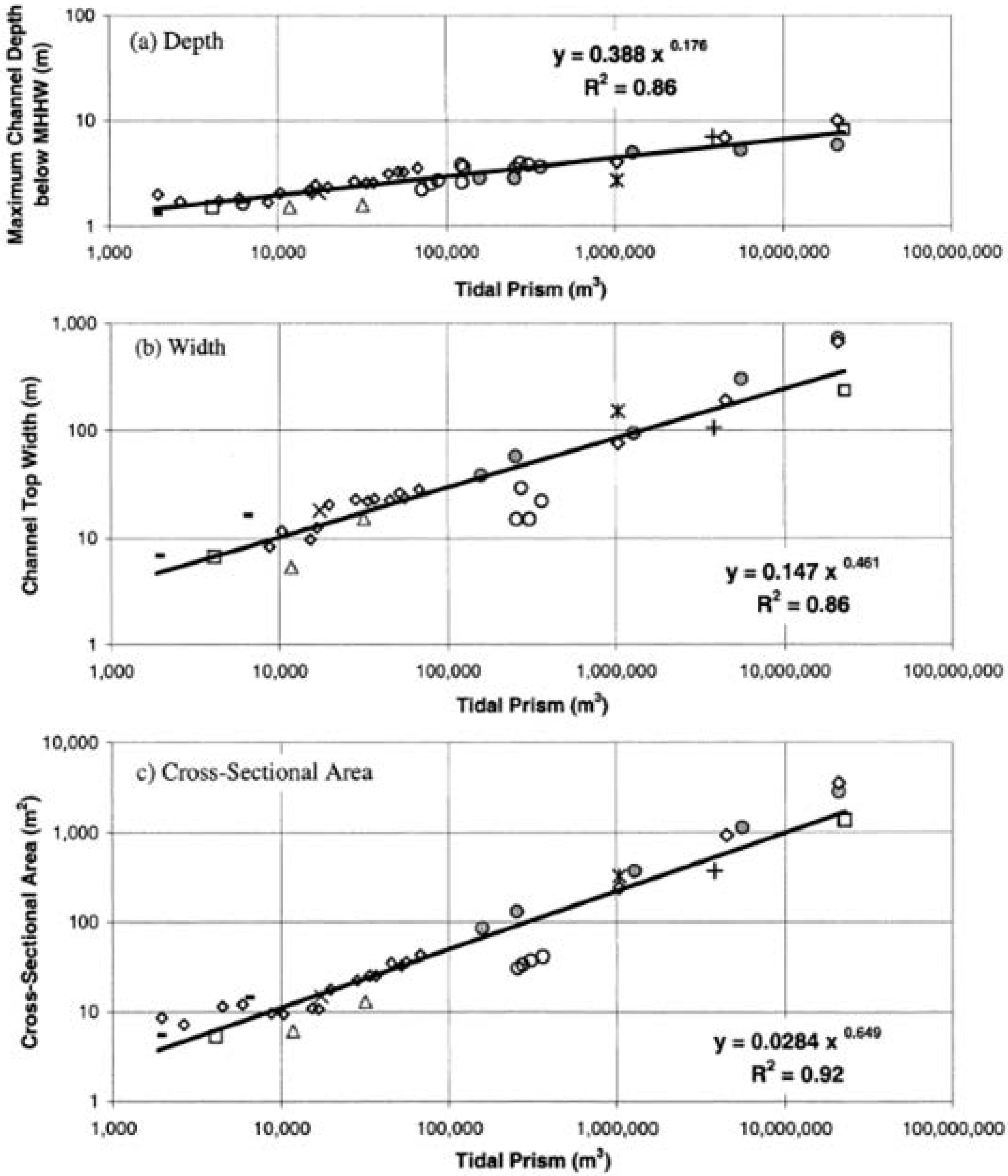


Figure 1. Depth, width, and cross-sectional area versus diurnal tidal prism for ancient marshes in San Francisco Bay (Figure 6 from Williams et al. 2002).

From the analysis of the historical and present-day marsh channels, Willams et al. determined the following hydraulic geometry relationships:

$$D = 0.388\,TP^{0.176};\; W = 0.147\,TP^{0.461};\; A = 0.0284\,TP^{0.649} \quad \text{Eq. 1-3}$$

Tidal prism was calculated. **Table 1** shows the tidal datum and extreme total water levels for Sonoma Creek calculated as part of their recent FEMA remapping of the Bay (AECOM 2016):

Table 1: Present (2000) tidal datum and extreme water surface elevations for Sonoma Creek.

		Elevation ft (m) NAVD88	
Extreme water levels	100-year total water level	9.74 (2.97)	100-year storm surge is 3.5ft (1.07m)
	10-year total water level	8.53 (2.60)	
	1-year total water level	7.48 (2.28)	
Daily Tides	Highest Astronomical Tide (HAT)	7.71 (2.35)	Tide range is 5.8ft (1.76m)
	Mean Higher High Water (MHHW)	6.23 (1.90)	
	Mean Sea Level (MSL)	3.48 (1.06)	
	Mean Lower Low Water (MLLW)	0.46 (0.14)	

The net effect of diking and draining was a dramatic loss of tidal marsh habitat, the creation of discrete diked bayland parcels, a significant reduction in tidal prism, and the creation of a significant sediment trap in the historical channels. The former marshes have subsided by several feet below MHHW , and the whole area is dependent upon levees and pumping to prevent flooding.

Elevations for all parcels except West End and Detjen were derived from Sonoma County Veg Map's 3ft bare earth LiDAR-derived DEM (2013). West End and Detjen elevations were derived from CA Ocean Protection Council's 3.3 feet (1 meter) LiDAR-derived DEM (2010). **Figure 2** shows that most of the diked baylands have subsided to an elevation at about MLLW (0.43 ft/0.13 m NAVD88). Camps 1-4 and Skaggs Island are all clustered around this elevation, with Camp 3 the lowest-lying parcel at a mean ground elevation of -0.05 ft /-0.01m NAVD88. The Ringstrom Bay, West End, and Detjen units have average elevations equivalent to low marsh (between 4.22 ft/1.29m and 5.04 ft/1.54m, according to Takekawa et al. 2013). On the alluvial fan, south of SR 121, Area 4 is at high marsh elevation, and Area 3 has an average elevation above the tidal range.

Average elevations for each parcel of interest are shown in **Figure 3** and reveal a north-south gradient from the alluvial fan south of SR 121 to the diked marshes further south.

Potential tidal prisms for each parcel are shown in **Figure 4**. These volumes were calculated for void space between the present ground surface and MHHW. The volumes were approximated based on hypsometric curves generated for each parcel using Sonoma County Veg Map's 3ft bare earth LiDAR-derived DEM (2013) (and OPC's 1m LiDAR-derived DEM (2010) for West End and Detjen) and are estimates only. Skaggs Island has the largest potential tidal prism, as a large area at relatively low existing elevation (an average of 0.99 ft/0.30m NAVD88). Camps 3 and 4, other large and low-lying parcels, also have large potential tidal prisms. In comparison, smaller and higher parcels like Camps 1-2, Detjen, and West End, have smaller potential tidal prisms. Tubbs Island is shown for comparison.

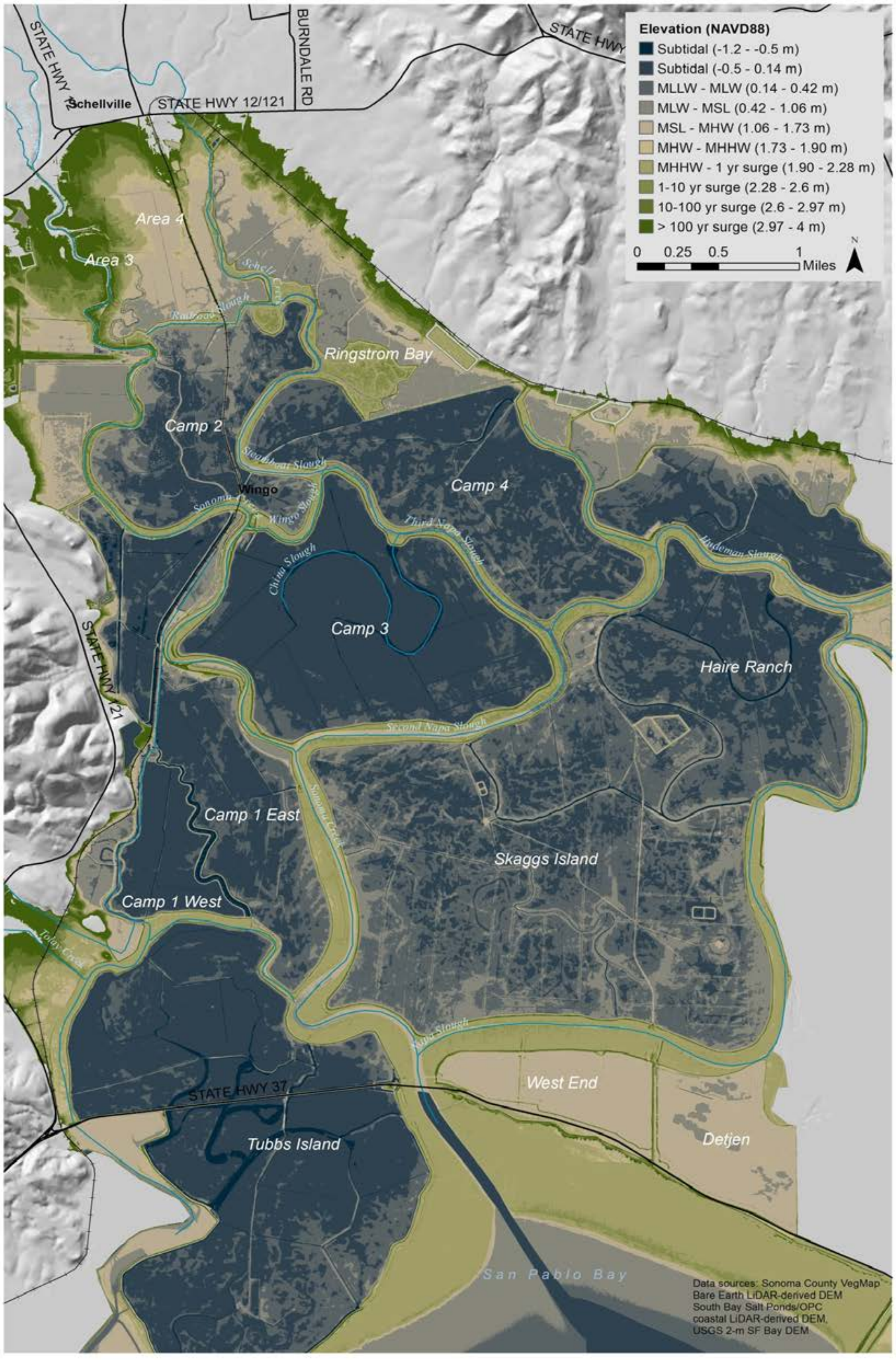


Figure 2. Present day topography of the broader Sonoma Creek area following diking. Digital elevation model sources: South Bay Salt Pond/OPC coastal Lidar-derived DEM, USGS 2-m SF Bay DEM.

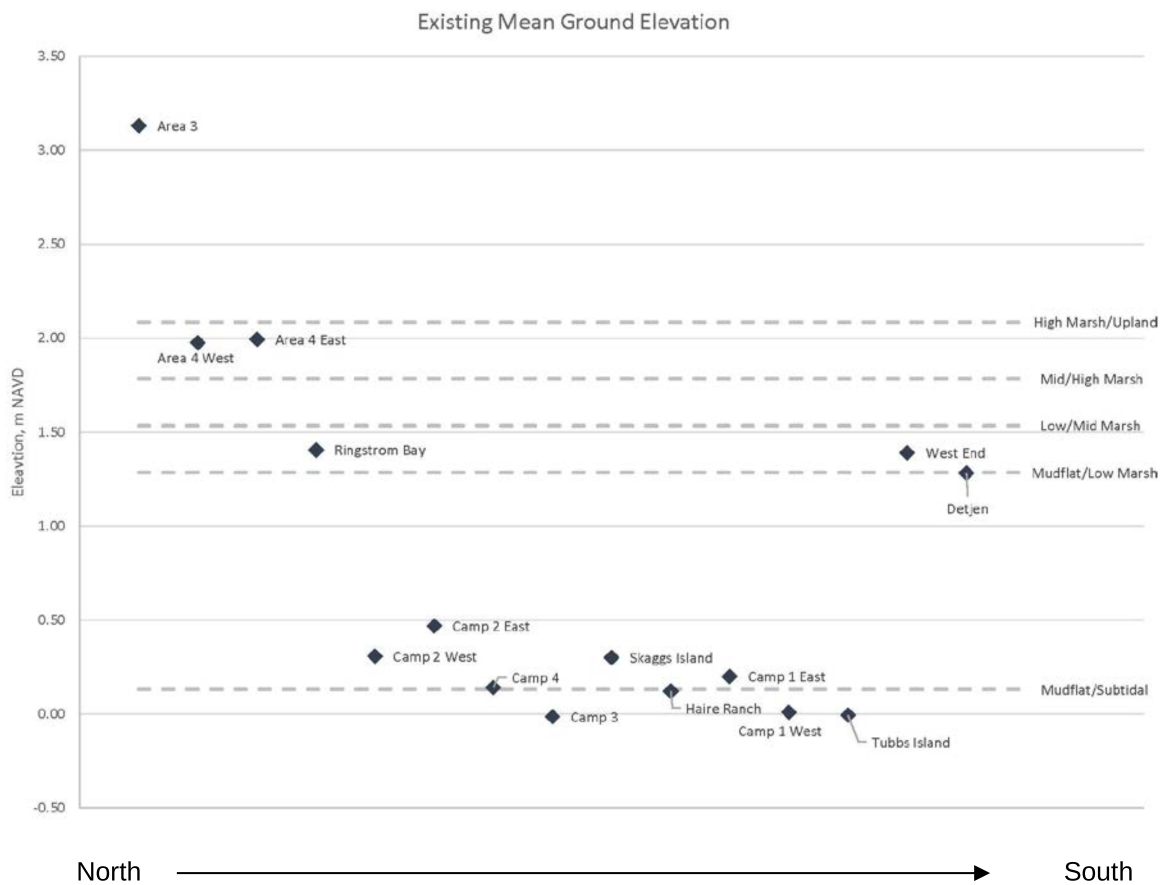


Figure 3. Existing mean ground elevations (data from Sonoma County Veg Map and CA OPC LiDAR-derived DEM).

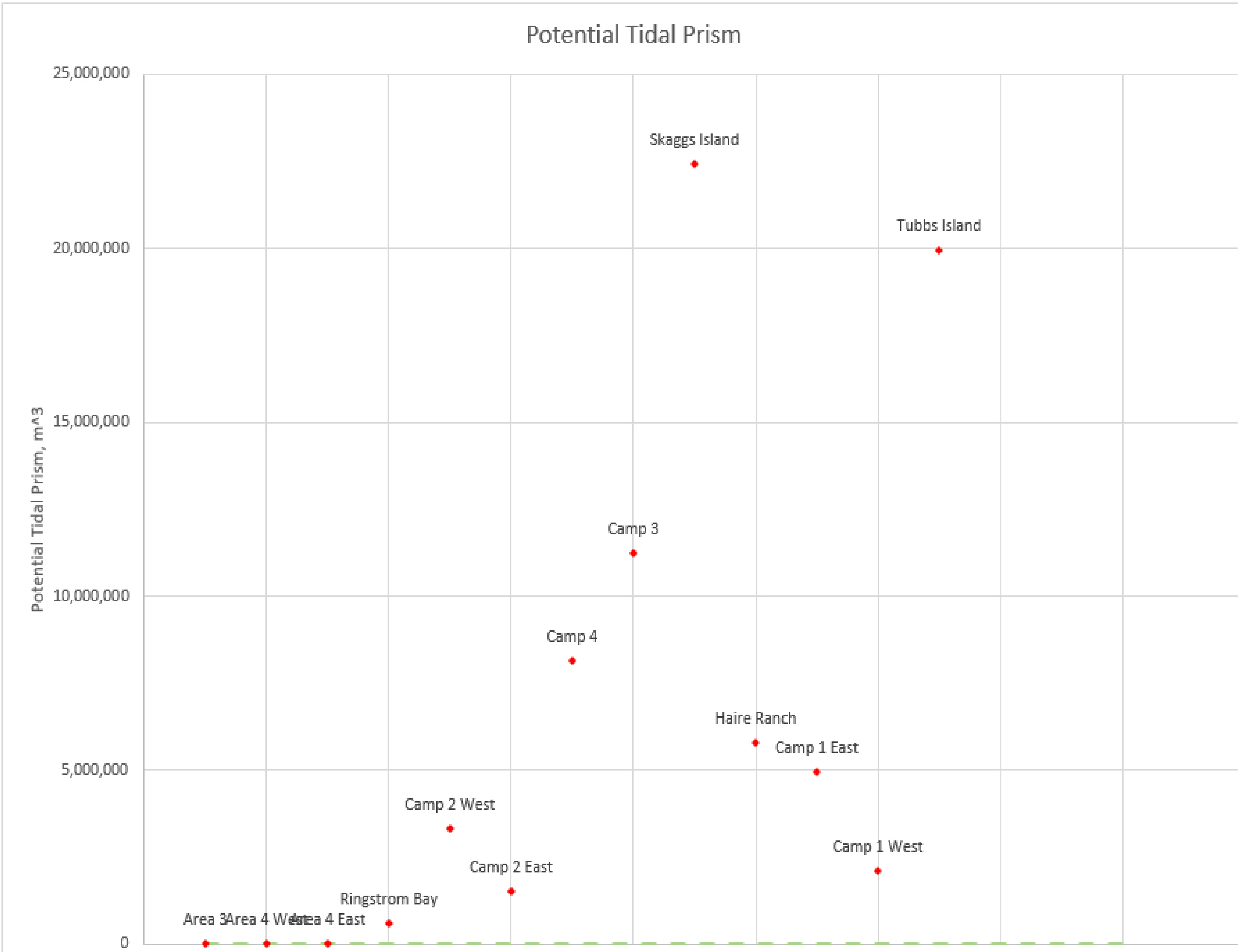


Figure 4. Potential tidal prisms of diked bayland, based on elevations from Sonoma County Veg Map and CA OPC LiDAR-derived DEM.

Historical Sonoma Creek

The historical width of Sonoma Creek prior to diking, measured from the earliest accurate surveys of these marshes taken in 1856 by the U.S. Coast and Geodetic Survey, was about 354m at the SR 37 bridge which corresponds to a tidal prism of approximately 25.2 million m^3 (Table 2). Subsequent diking and draining has reduced the channel at the bridge to its present width of about 118m for a tidal prism of about 2.0 million m^3.

Table 2. Historical, present, and potential Sonoma Creek width, depth, and cross-sectional area based on hydraulic geometry described in Williams et al. (2002).

	Historical	**Present**	**Potential**
Tidal Prism (Mm^3)	25.2	2.0	58.0
Width (m)	364	118	557
Depth (m)	7.9	4.9	9.1
Area (m^2)	1486	305	2694

In the future, an accidental breach on the east bank of the Sonoma Creek could inundate the whole of Skaggs Island including the former subtidal and mudflat areas. Such a breach at Skaggs Island could increase the tidal prism passing under the SR 37 bridge to as much as 21 million m^3 (more than it was historically due to the subsidence of former marshes) and increase the present width of 118m to about 357m. In the past, such breaches have been repaired relatively quickly, and the Sonoma Creek channel has not been significantly eroded. But in the future with rising sea levels, it may not be cost-effective to maintain these dikes, and the inundation could become permanent. In the extreme case, tidal action could be restored to all the former marshes either as planned marsh restoration projects or by accidental breaching. In this case, the maximum tidal prism of the Sonoma Creek is about 58 million m^3 giving a potential maximum width of about 557m. In addition to the channel to accommodate normal tidal flows, allowance would have to be made to maintain the adjacent creek marsh which at present is about 152m wide.

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Appendix 3: Landscape (Ecological) Analysis

Sam Veloz, Point Blue Conservation Science

Introduction

The restoration strategy and alternatives are designed to provide a mosaic of functional and resilient habitats in the Lower Sonoma and Tolay Creek watersheds. This section of the plan evaluates how well each of the alternatives succeeds at achieving this goal up to 2100 based on the designs of the alternatives and habitat evolution in response to sea level rise.

Methods

We are taking advantage of existing models of habitat and wildlife response to sea level rise to assess the performance of each of the alternatives. Stralberg et al. (2011) used a hybrid approach to marsh accretion modeling in which projections from a point-based accretion model were spatially interpolated across the San Francisco Estuary. Hayden et al. (2019) modified these models to incorporate more extreme sea level rise projections and to allow variation of timing of restoration within an evolving landscape. Here we applied these models to each of the alternatives developed for the project.

The Marsh98 accretion model applied in the study is briefly described here, although Stralberg et al. (2011) provides additional detail. Marsh98 models accretion (the vertical accumulation of organic material and inorganic sediment) as a function of the availability of suspended sediment, depth and periods of inundation by tides and the addition of organic material. For this analysis we used constant values of 150 mg/L of suspended sediment and 2 mm/year of contribution from organic material. The model does not include the effects of erosion that are likely to occur due to changes in tidal prism or from wind wave forces. We applied a “medium-high risk” sea level rise curve from the 2018 State of California sea level rise guidance which projects an increase of sea levels of 1.9 feet by 2050 and 6.9 feet by 2100 (California Ocean Protection Council 2018). The starting elevation of each model run was based on the SonomaVegMap 3-ft bare earth LiDAR-derived digital elevation model(DEM) (2013, http://sonomavegmap.org/data-downloads/) and the 3.3-ft OPC LiDAR-derived DEM for the Detjen and West End properties.

In all cases, the model begins accretion in 2010 for all areas that are currently open to tides and continues until 2100. To assess how the timing of restoration would affect results, we ran seven different runs of the accretion model in which potential restoration areas are restored in 2022, then in 5-year intervals from 2025 – 2050. For each model run, accretion begins at the specified restoration year and continues until 2100 in areas that are not currently open to full tidal exchange.

We used habitat classes from Takekawa et al. (2013) to categorize the marsh surface by habitat class and summed the acreage of each habitat class within each potential restoration area.

We used existing models of tidal marsh bird abundance (Veloz et al. 2013) to assess whether the habitat provided in each alternative could provide functional habitat for wildlife species. Observations of four species of tidal marsh birds were made from the entire San Francisco Estuary between 2000 and 2009: California black rail (*Laterallus jamaicensis,* CA state threatened), California Ridgway’s rail (*Rallus obsoletus obsoletus*, federally endangered), saltmarsh common yellowthroat (*Geothlypis trichas*, state species of special concern) and marsh wren (*Cistothorus palustris*). These species were selected as they represent a range of conservation concern from endangered to common and each species utilizes different aspects of marsh habitat thus serving as indicators for a range of marsh species. We used a statistical machine learning approach to correlate the abundance of individuals of each species to a suite of environmental variables such as elevation-based habitat metrics, salinity, channel density and distance to the bay and levees. Additional details on modeling are provided in Veloz et al. (2013). We used these existing models to project the abundance of individuals of each species to the evolved landscape at 20-year intervals (2020-2100) from the Marsh98 model results. We summarized the number of each species within each property in the study area to assess the response to the management alternatives.

We used observations of the relative abundance of fish at mature marshes and restoring marshes in the North Bay to estimate how the fish community will respond to habitat evolution and the management alternatives. We acquired data only from monitoring studies in which sampling was conducted within mature or restored marshes, thus excluding data from channels and sloughs. We evaluated data collected within the Green Island Unit of the Napa Sonoma Marshes Wildlife Area and Fagan Slough Ecological Reserve (Fagan SER) from 2009 - 2011 (URS 2012). Fish were sampled at three restoration sites and one mature marsh. We also included fish monitoring data from the Sears Point restoration project (Keegan and Lee, 2018). In all cases, marsh sites were attributed with the maximum observed relative abundance of each species at a site. We were not able to include all observations over years or months as the environmental variables (marsh elevation) of interest do not vary substantially on such a short time scale.

As sampling locations within the reports we investigated only provided the location at the resolution of the site, we summarized the mean elevation of each site where sampling occurred. We visually inspected scatter plots of the relative abundance of each species vs the mean elevation of the sites. We characterized species into groups that preferred relatively deeper water habitats (sub-tidal and mudflat habitats) and those that preferred higher elevations (mudflat to mid-marsh habitats). We included only native California species in our assessment. We were able to estimate a correlation between relative abundance and elevation for: Bay Goby (*Lepidogobius lepidus*), California halibut (*Paralichthys californicus*), Central California Coast steelhead (*Oncorhynchus mykiss*), Pacific herring (*Clupea pallasii*), staghorn sculpin (*Leptocottus armatus*) and Threespine stickleback (*Gasterosteus aculeatus*). We could not detect any clear correlation between relative abundance and elevation for any other species.

Results

Marsh accretion models

There is a general pattern of accretion across all alternative and restoration starting year scenarios. While mid and low marsh habitats can increase in acreage between 2030 and 2070, as rates of sea level rise increase towards the end of the century, the models consistently predict that marshes will drown with the landscape dominated by mudflat habitat (**Figure 1**). Additionally, starting restoration later results in a greater proportion of high marsh habitat but less mid marsh habitat at 2050 than starting restoration early, because elevations are raised to high marsh elevation prior to breaching in the restoration design and are thus at a higher elevation than when restoration begins earlier.

There tends to be more low marsh habitat remaining in the landscape at 2090 when restoration is initiated in 2022 vs 2050. By 2100, almost all models project very little marsh habitat remaining in the landscape with the exception of close to 2500 acres of low marsh persisting at 2100 in Alternative 3 when restoration starts at 2050. However, the potential benefits of delaying restoration must be contrasted with the loss of any habitat prior to 2050 in which species could be building populations.

For the remainder of the results we focus on model runs where restoration is initiated in 2022. Alternative 3 results in the greatest range of habitats persisting consistently throughout the study period with substantially more subtidal habitat than the other two alternatives. In addition to starting with substantially more subtidal habitat than the other alternatives, Alternative 3 also begins with more high marsh and upland habitat than the other two (**Figure 2**).

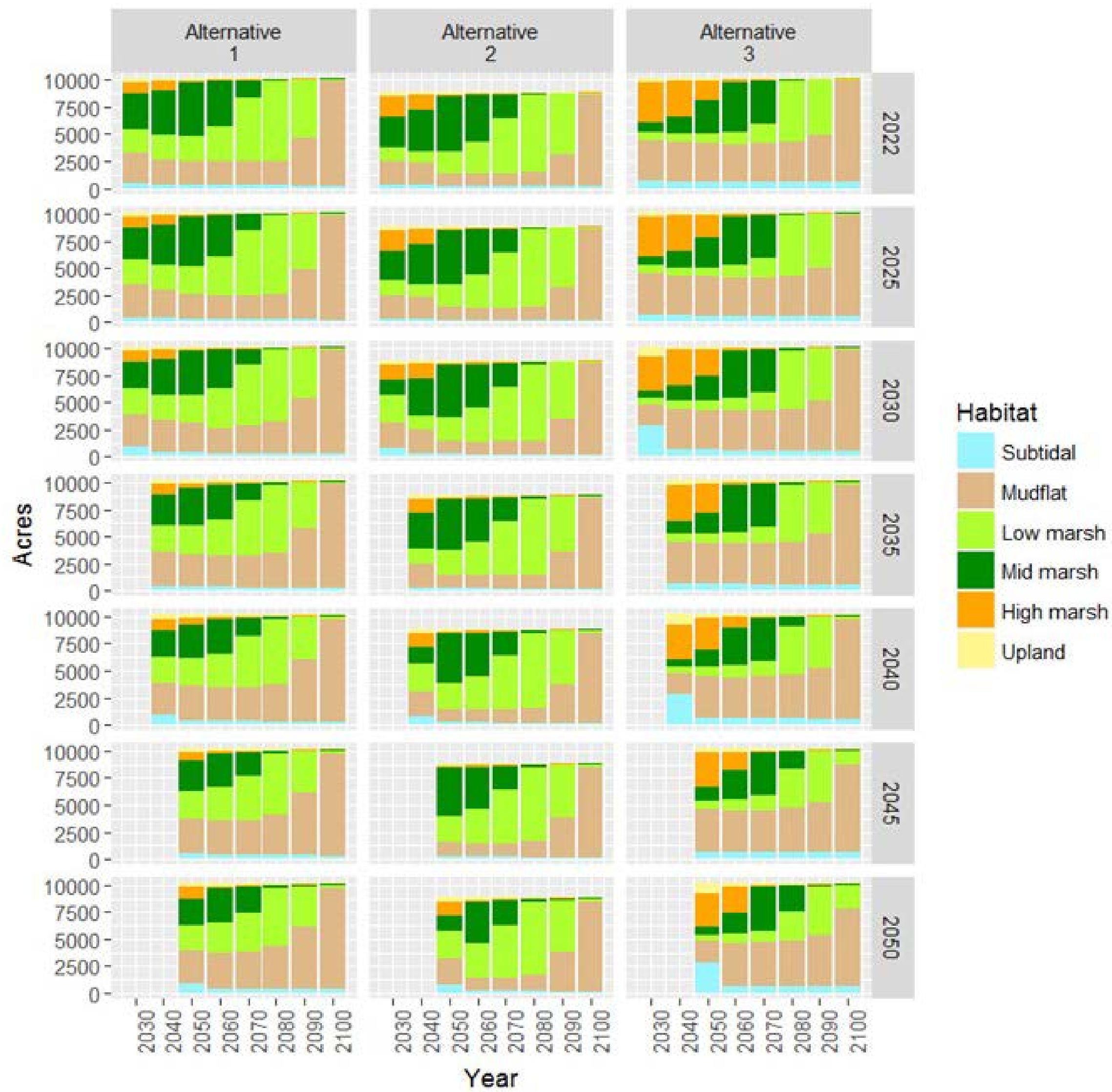

Figure 1. The acres of bayland habitats projected by the Marsh98 model in response to sea-level rise. The bars in each graph are colored by habitat type. The years along the x axis indicate the model year from the Marsh98 model. Each vertical panel represents the results from the management alternatives. Each horizontal panel indicates the year in which restoration was initiated in the model. Columns are left blank where the model year precedes the restoration year.

The high marsh habitat persists through 2050 in Alternative 3, whereas the high marsh habitat in Alternatives 1 & 2 is largely converted to mid-marsh by 2050 (**Figure 2**). Alternatives 1 & 2 achieve relatively more mid-marsh habitat than alternative 3 through 2050 but by 2060, Alternative 3 has more mid-marsh habitat than Alternatives 1 & 2. By 2080, very little mid-marsh habitat remains in any of the alternatives (**Figures 2 & 3**). Marsh98 projects that the amount of low marsh habitat substantially increases in 2070 in Alternatives 1 & 2 and by 2080 in Alternative 3, corresponding to decreases in the projections of mid-marsh habitat (Figure 2 & 3). Although there is less overall area restored in Alternative 2, Marsh98 projects similar acreage of low, mid, and high marsh habitat between Alternatives 1 & 2 (**Figure 2**).

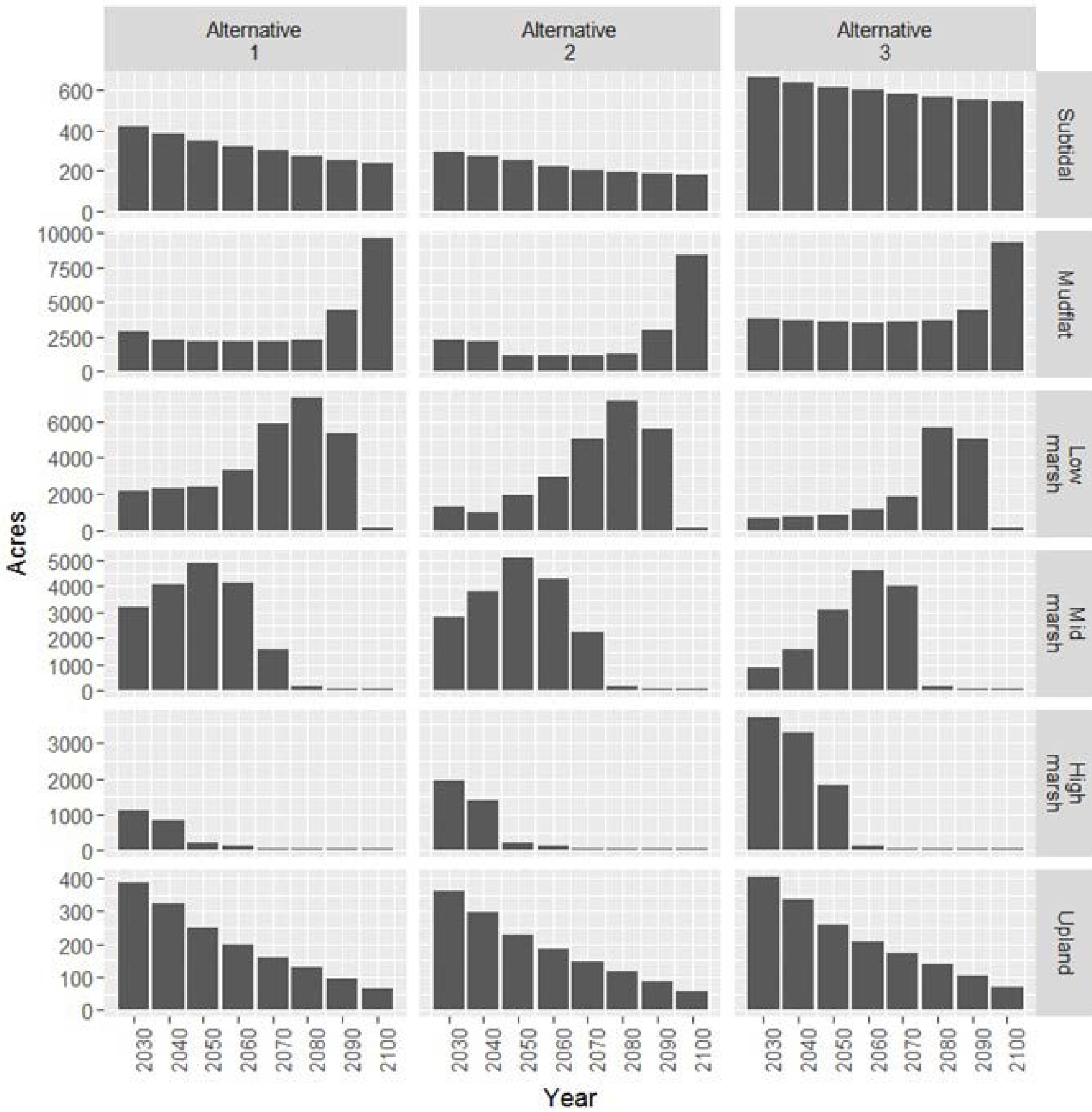

Figure 2. Acres of bayland habitat projected for each model year. Each vertical panel displays the results from each management alternative. Horizontal panels provide results by habitat classes. Restoration was initiated in 2022.

The design of each of the alternatives leads to varying spatial patterns in habitat availability across the alternatives. By 2080, Alternatives 1 & 2 result in large areas of low marsh habitat distributed fairly homogeneously across the landscape. In contrast, there is a mixture of habitats in many of the restored properties in Alternative 3, primarily mudflat and low marsh habitat by 2080 but also narrow patches of mid-marsh along the edges of properties (**Figure 3**). Detailed summaries of habitat present in each property for each alternative are available in Appendix 3A.

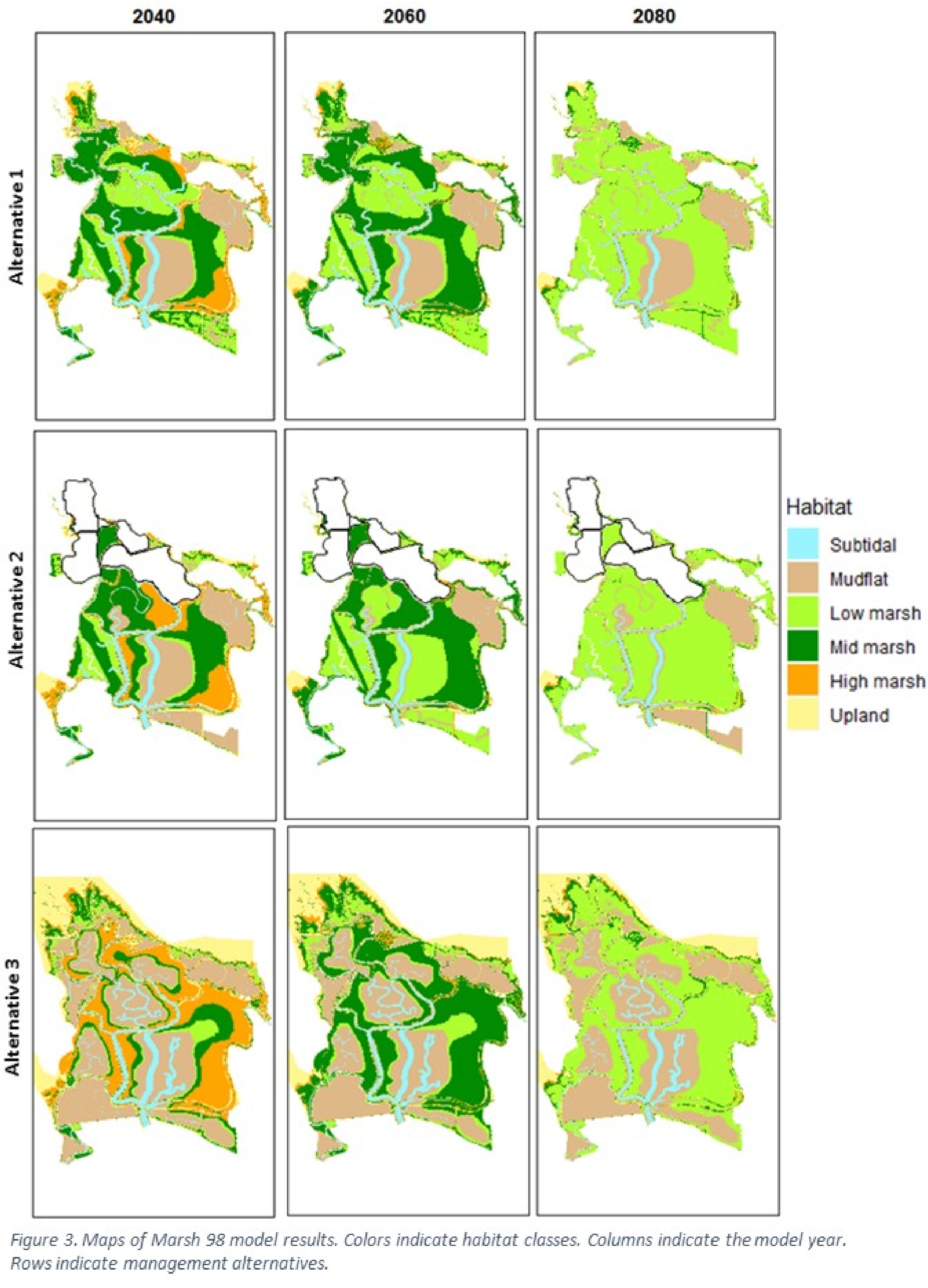

Figure 3. Maps of Marsh 98 model results. Colors indicate habitat classes. Columns indicate the model year. Rows indicate management alternatives.

Bird models
We found substantial differences in the projected abundance of each species within the study area across the three management alternatives. Which alternative resulted in the highest abundance of each species varied by when restoration was initiated and the species of interest. Across all species and models we found that birds respond fairly quickly to restoration as we project large increases in each species immediately following restoration (**Figure 4**). A peak in abundance for each species is projected around 2060 then declines in abundance as habitats begin to drown in the last half of the century. We also found a consistent pattern that starting restoration sooner results in greater numbers of each species, although this difference declines by 2080 as little marsh habitat remains irrespective of when restoration was initiated (**Figure 4**).

In general, we project decreased abundance of the four bird species in Alternative 3 versus Alternatives 1 & 2. The differences are likely due to the greater areas of non-tidal marsh habitat within Alternative 3. By 2080, where the landscapes become similar across the alternatives in terms of the amount of marsh habitat remaining (primarily low marsh, **Figure 1**), we project similar abundance of each species in each of the scenarios (Figure 4). The projected decline in abundance in each of the species between 2060 and 2080 is less pronounced in Alternative 3 versus Alternatives 1 & 2. As marshes drown by 2100, we project that all species will decline to near zero within the study properties within each of the alternatives (**Figure 4**).

The timing of restoration seems to have varying effects on the four tidal marsh species studied across management alternatives. When restoration is initiated in 2022, we almost always project greater numbers of each species in Alternative 1 versus Alternatives 2 & 3 (**Figure 4**). In contrast, when restoration is initiated in 2040, we project similar or higher abundance of each species in Alternative 2 versus Alternatives 1 & 3, with the greatest difference occurring at model year 2060.

Focusing on models in which restoration was initiated in 2022, we can see the upper limits of the abundance of each species across the alternatives. Restoration will result in dramatic increases in the numbers of each species within San Pablo Bay between 2040 and 2080 as compared to current populations. For example, we estimated approximately 300 Ridgway's rail occurred in San Pablo Bay in 2010 (Veloz et al. 2012), so restoration will result in a doubling or tripling of the 2010 population between 2040 and 2080, depending on which alternative is selected. We project similar population increases following restoration for the other three species as well (**Figure 5**). Although we project these population gains are essentially lost by 2100, the restoration can create habitat from which species can migrate to newly available habitats beyond the study region.

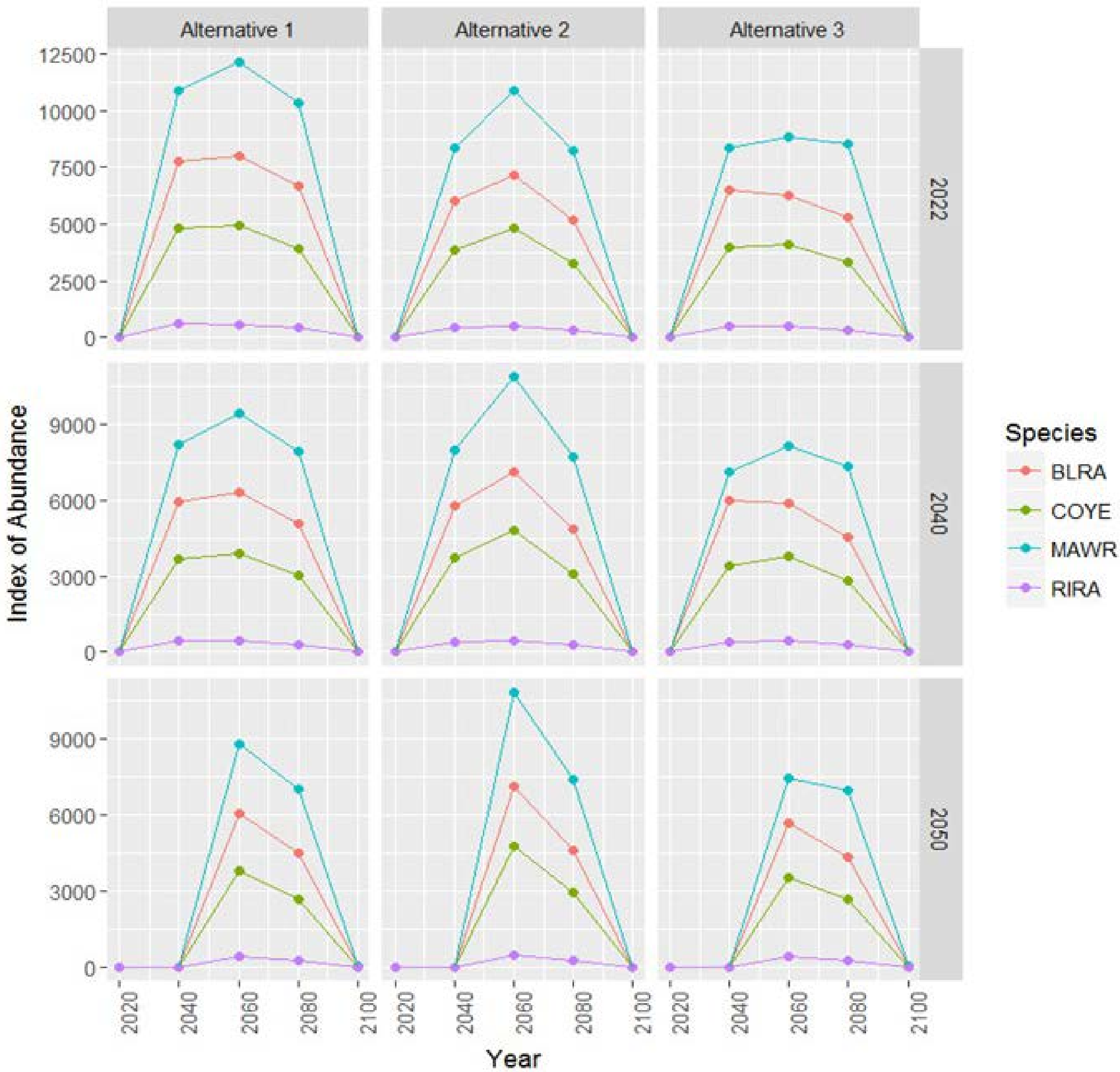

Figure 4. Index of the projected number of individuals of four species of tidal marsh birds; black rail (BLRA), common yellowthroat (COYE), marsh wren (MAWR) and Ridgway's rail (RIRA). The horizontal axis indicates the year of the model results. Each vertical panel represents a management alternative. Each horizontal row represents the year restoration was initiated in the model.

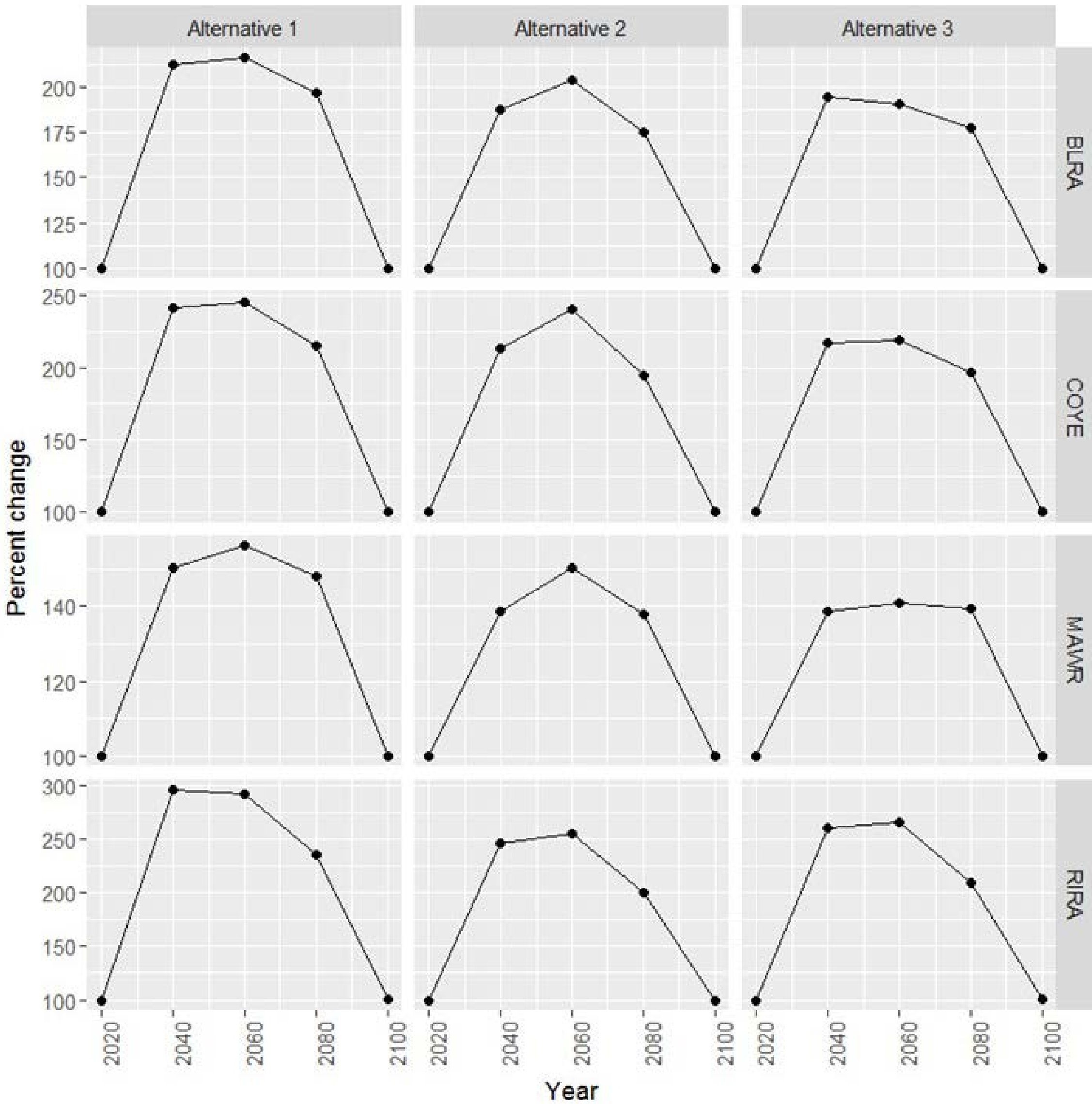

Figure 5. Percent change in the 2010 San Pablo Bay population for each of four species of tidal marsh birds; black rail (BLRA, 6,900), common yellowthroat (COYE, 3,400), marsh wren (MAWR, 21,700) and Ridgway's rail (RIRA, 300). Values following the acronym here are the 2010 population estimate in San Pablo Bay for each species from Veloz et al. (2012). Restoration was initiated in 2022 for these results.

Fish observations

With the limited observation data available for this assessment we were only able to coarsely characterize fish habitat into those that prefer deeper waters (subtidal - mudflat habitat) and those that prefer shallower habitats (mudflat - mid-marsh). Our assessment classified bay goby, California halibut and staghorn sculpin as species that prefer the deeper habitats within baylands with the highest relative abundance of these species found at sites with mean elevation < -0.6 m MHHW. Central California Coast steelhead, Pacific herring and threespine stickleback were all found at higher relative abundance at sites with mean elevation > -0.3 m MHHW.

Using these coarse classifications we can qualitatively ranking of the three management alternatives by how they affect fish species. Alternative 3 that results in the highest proportion of mudflat and subtidal habitat would provide the somewhat more preferred habitat. Similarly, as marshes lose elevation with increasing sea level rise, the increase of low elevation habitat should benefit the deeper habitat associated species. In contrast, the species more closely associated with lower marsh elevations will likely experience a decline in the quality of their habitats as the marshes drown with increasing sea level rise.
The assessment of fish habitat we provide here should be considered extremely preliminary as we had very limited data with which to estimate habitat preferences. Conducting surveys across more sites that better sample the range of marsh elevations would help enhance our assessment and allow quantitative predictions of fish response to restoration and marsh evolution.

Discussion

Our survey shows that restoration will substantially increase habitat that will result in increases in the populations of tidal marsh dependent species within the study area between 2020 and 2080. With high rates of sea level rise, we do project that by 2100 this habitat will largely be lost as marshes drown. However, with lower rates of sea level rise, previous surveys have shown that these habitat gains and subsequent population gains may be resilient beyond 2100 (Veloz et al. 2013). If rates of sea level rise are as high as assumed for this analysis, maintaining the population gains that follow restoration will require additional habitat restoration and space for marsh migration in currently upland areas.
The benefits of each of the alternatives relative to one another are assessed by focusing on the abundance of four representative tidal marsh species. However, there is no clear preferred alternative based on that metric alone as the results vary by when restoration is initiated and which species is used. Additionally, the other habitats not included in our assessment, subtidal and mudflat, will likely provide habitat for fish and wildlife such as shorebirds and waterfowl. It is possible that including a wider range of taxa in the assessment of benefits across alternatives would result in a different perspective of which alternative could provide the greatest benefits to biodiversity.

Creating higher habitat within restoration sites that provides migration space as sea levels rise seems to be the most resilient strategy for maintaining marsh habitat for the longest period of time. Starting elevations within alternative 3 are higher within some of the properties considered and these areas provide the most resilient habitat within the restoration areas. Additionally, we project that areas of fringing infill wetlands will develop in areas that are currently at upland elevations outside the planning area. If these areas were protected as open space, the habitat created through restoration in each of the alternatives could provide source populations in the future from which individuals could colonize newly evolving habitat outside the planning area.

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Appendix 4: Feasibility Level Opinion of Probable Cost

Steve Carroll, Ducks Unlimited and Jeremy Lowe, San Francisco Estuary Institute

Units Abbreviation Legend:

AC	acre
CY	cubic yard
EA	each
LF	linear foot
LS	lump sum
MI	mile
TN	ton

The Extended Price numbers have been rounded to the nearest $1,000.

Alternative 3

Line	Site	Line Item	Quantity	Units	Unit Price	Extended Price	Description of Actions
1	**Areas 3 & 4**	Mobilization & Demobilization	1	LS	$3,343,000	$3,343,000	Mobilizing & demobilizing forces, equipment, and facilities to needed to perform the work.
2		Site Preparation & Env. Compliance	1	LS	$2,026,000	$2,026,000	General site preparations, environmental compliance measures and BMP's
3	Levee Lowering	Remove Railroad Slough Levee	20,000	CY	$8.00	$160,000	Excavate and haul for onsite use as habitat fill.
4		Remove Schell Creek Levee	12,000	CY	$8.00	$96,000	Excavate and haul for onsite use as habitat fill.
5		Remove Stock Pond Levees	10,000	CY	$5.00	$50,000	Excavate and haul for onsite

							use as habitat fill.
6	Channel Excavation	Big Break Channel Expansion	19,000	CY	$7.50	$143,000	Expand Big Break channel to Area 4. Reuse material as habitat fill.
7	Levee Improvement	Area 4 West Levee	44,000	CY	$10.00	$440,000	Construct ~4,400 LF levee along west edge of Area 4 using onsite fill.
8	Railroad Infrastructure	Railroad Embankment	149,000	CY	$70.00	$10,430,000	Construct ~7,500 LF embankment along both sides of railroad using imported material.
9		Rock Slope Protection	60,000	TN	$100.00	$6,000,000	Armor new embankments on both sides of railroad.
10		Railroad Slough Bridge Flood Gate	1	EA	$100,000	$100,000	Construct flood gate at north side of Railroad slough bridge.
11	Other Infrastructure	Millerick Road Low Water Crossing	1,000	TN	$100.00	$100,000	Install a rocked low water crossing on Millerick Road at Big Break.
12		Power Line Installation	7,500	LF	$20.00	$150,000	Construct new powerline along railroad from SR121 to Camp 2.

13	Demolition	Millerick Road Demolition	3,000	LF	$10.00	$30,000	Demolish Millerick Road south of Vineyard to Camp 2.
14		Railroad Slough Tide Gate Demolition	1	EA	$25,000	$25,000	Demolish the existing concrete tide gate structure.
15		Power Line Demolition	3,000	LF	$10.00	$30,000	Remove the powerline along Millerick Road from the vineyard south to Camp 2.
16		House Demolition	3	EA	$200,000	$600,000	Demolish homes in the northern part of Area 4.
17		Septic System Demolition	3	EA	$10,000	$30,000	Demolish septic systems per county standards
18		Barn Demolition	12	EA	$100,000	$1,200,000	Demolish barns in the northern part of Area 4.
19		Fence demolition	2	MI	$5,000	$10,000	Remove fencing in Area 4.
20		Miscellaneous Demolition	40	AC	$10,000	$400,000	General debris, equipment, & structure removal and clean up.
21		General Ripping & Discing	40	AC	$1,000	$40,000	Rip and disc hardened lands in northern Area 4.

22		Road Demolition	11,000	LF	$132.80	$141,000	Demolish existing asphalt and rock surfaced areas (estimated equivalent of 3 acres).
23		Well Demolition	3	EA	$15,000	$45,000	Demolish wells per county standards.
24		Pump Demolition	2	EA	$20,000	$40,000	Remove existing pumps and appurtenances.
25	**Areas 3 & 4 Subtotal**					**$25,629,000**	
26	**Camp 2**	Mobilization & Demobilization	1	LS	$5,854,000	$5,854,000	Mobilizing & demobilizing forces, equipment, and facilities to needed to perform the work.
27		Site Preparation & Env. Compliance	1	LS	$3,548,000	$3,548,000	General site preparations, environmental compliance measures and BMP's
28	Levee lowering	Lower Sonoma Creek Levee	57,000	CY	$5.00	$285,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
29		Remove Railroad Slough Levee	111,000	CY	$8.00	$888,000	Excavate and haul for onsite use as habitat fill.

30		Remove Wingo Slough Levee	53,000	CY	$8.00	$424,000	Excavate and haul for onsite use as habitat fill.
31		Lower Steamboat Slough Levee	30,000	CY	$5.00	$150,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
32	Levee Breaching	SW Sonoma Creek Breach	14,000	CY	$12.00	$168,000	Excavate breach and sidecast material nearby.
33		SE Wingo Slough Breach	15,000	CY	$12.00	$180,000	Excavate breach and sidecast material nearby.
34	Channels Excavation	SW Sonoma Creek Channel	1,214,000	CY	$7.50	$9,105,000	Excavate channel and haul material for use as habitat fill onsite.
35		Wingo Slough Channel	161,000	CY	$7.50	$1,208,000	Excavate channel and haul material for use as habitat fill onsite.
36	Railroad Infrastructure	Railroad Embankment	253,000	CY	$70.00	$17,710,000	Construct ~6,000 LF embankment along both sides of railroad using imported material.

37		Rock Slope Protection	48,000	TN	$100.00	$4,800,000	Armor new embankments on both sides of railroad.
38		Railroad Slough Bridge Flood Gate	1	EA	$100,000	$100,000	Construct flood gate at south side of Railroad Slough bridge.
39		Wingo Slough Bridge Flood Gate	1	EA	$100,000	$100,000	Construct flood gate at north side of Wingo Slough bridge .
40	Other Infrastructure	Power Line Installation	6,000	LF	$20.00	$120,000	Install powerline along railroad alignment from railroad slough to wing slough.
41	Demolition	Millerick Road Demolition	7,800	LF	$10.00	$78,000	Demolish Millerick Road from Area 3 to Wingo Slough.
42		Power Line Demolition	7,800	LF	$10.00	$78,000	Remove powerline within west side of Camp 2.
43		Pump Station Demolition	11	EA	$40,000	$40,000	Demolish NW Pump station
44		Well Demolition	3	EA	$15,000	$45,000	Demolish wells per county standards.
45	**Camp 2 Subtotal**					**$44,881,000**	
46	**Camp 3**	Mobilization & Demobilization	1	LS	$4,264,000	$4,264,000	Mobilizing & demobilizing forces, equipment, and facilities to needed to

							perform the work.
47		Site Preparation & Env. Compliance	1	LS	$2,584,000	$2,584,000	General site preparations, environmental compliance measures and BMP's
48	Levee Lowering	Lower Sonoma Creek Levee	4,000	CY	$5.00	$20,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
49		Remove Wingo Slough Levee	43,000	CY	$8.00	$344,000	Excavate and haul for onsite use as habitat fill.
50		Lower Third Napa Slough Levee	11,000	CY	$5.00	$55,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
51		Lower Second Napa Slough Levee	1,000	CY	$5.00	$5,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
52		Remove Residential Levees	8,000	CY	$5.00	$40,000	Remove ~ 1,200 LF of levees around residence.

53	Levee Breaching	Second Napa Slough Breach	14,000	CY	$12.00	$168,000	Excavate breach and sidecast material nearby.
54		Wingo Slough Breach	14,000	CY	$20.00	$280,000	Excavate breach and sidecast material nearby.
55		Third Napa Slough Breach	15,000	CY	$12.00	$180,000	Excavate breach and sidecast material nearby.
56	Channel Excavation	Sonoma Creek Channel	819,000	CY	$7.50	$6,143,000	Excavate channel and haul material for use as habitat fill onsite.
57		China Slough Channel	409,000	CY	$7.50	$3,068,000	Excavate channel and haul material for use as habitat fill onsite.
58	Railroad Infrastructure	Railroad Embankment	157,000	CY	$70.00	$10,990,000	Construct ~5,300 LF embankment on east side of railroad from Wingo Slough to Camp 1 using import fill.
59		Rock Slope Protection	21,000	TN	$100.00	$2,100,000	Armor new embankment.
60		Wingo Slough Bridge Flood Gate	1	EA	$100,000	$100,000	Construct flood gate at south side of Wingo Slough bridge.

61	Demolition	Power Line Demolition	200	LF	$10.00	$2,000	Remove 2 poles at residence
62		House Demolition	7	EA	$200,000	$1,400,000	Remove homes around Camp 3
63		Septic System Demolition	7	EA	$10,000	$70,000	Demolish septic systems per county standards.
64		Barn Demolition	6	EA	$100,000	$600,000	Demolish barns.
65		General ripping/discing	6	AC	$1,000	$6,000	Loosen soil around barns and residences.
66		Road Demolition	2,500	LF	$1312.80	$32,000	Demolish ~2,500 LF of paved/heavily surfaced road.
67		Road Demolition	5,400	LF	$10.00	$54,000	Demolished ~5,400 LF of graveled road east of the railroad.
68		Well Demolition	3	EA	$15,000	$45,000	Demolish wells per county standards.
69		Pump Demolition	1	EA	$20,000	$20,000	Remove pump station
70		Miscellaneous Demolition	2	AC	$10,000	$20,000	General debris, equipment, & structure removal and clean up.
71		Miscellaneous Demolition	1	EA	$100,000	$100,000	Demolish bridge, ~50 ft length

72	**Camp 3 Subtotal**					**$32,690,000**	
73	**Camp 4**	Mobilization & Demobilization	1	LS	$881,000	$881,000	Mobilizing & demobilizing forces, equipment, and facilities to needed to perform the work.
74		Site Preparation & Env. Compliance	1	LS	$534,000	$534,000	General site preparations, environmental compliance measures and BMP's
75	Levee lowering	Lower Steamboat Slough Levee	149,000	CY	$6.50	$969,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
76		Lower Third Napa Slough Levee	12,000	CY	$6.50	$78,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
77		Lower Hudeman Slough Levee	7,000	CY	$6.50	$46,000	Selectively lower to MHHW levees south and east of property, sidecast material.
78		Lower Internal Berms	10,000	CY	$5.00	$50,000	Selectively lower ~3,600 LF of internal berms.

79	Levee Breaching	Third Napa Slough Breach	13,000	CY	$12.00	$156,000	Excavate breach and sidecast material nearby.
80	Channel Excavation	Third Napa Slough Channel	488,000	CY	$7.50	$3,660,000	Excavate and haul for onsite use as habitat fill.
81	Demolition	Power Line Demolition	900	LF	$10.00	$9,000	Remove powerlines.
82		Barn Demolition	3	EA	$100,000	$300,000	Remove barns.
83		General ripping/discing	7	AC	$1,000	$7,000	Loosen ~7 acres around barn areas
84		Road Demolition	4,400	LF	$10.00	$44,000	Demolish ~4,400 LF of internal rocked road
85		Pump Demolition	1	EA	$20,000	$20,000	Demolish pump stations and appurtenances
86	**Camp 4 Subtotal**					**$6,754,000**	
87	**Skaggs Island**	Mobilization & Demobilization	1	LS	$6,890,000	$6,890,000	Mobilizing & demobilizing forces, equipment, and facilities to needed to perform the work.
88		Site Preparation & Env. Compliance	1	LS	$4,176,000	$4,176,000	General site preparations, environmental compliance

							measures and BMP's
89	Levee Lowering	Lower Sonoma Creek Levee	35,000	CY	$5.00	$175,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
90		Lower Second Napa Slough Levee	12,000	CY	$5.00	$60,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
91		Lower Napa Slough Levee	69,000	CY	$5.00	$345,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
92		Remove Hair Ranch Internal Levee	112,000	CY	$6.50	$728,000	Excavate and haul for onsite use as habitat fill.
93	Levee Breaching	Breach at Napa Slough confluence	58,000	CY	$20.00	$1,160,000	Excavate breach and sidecast material nearby.
94		Second Napa Slough Beach	14,000	CY	$12.00	$168,000	Excavate breach and sidecast material nearby.

95	Channel Excavation	Napa Sl. - Second Napa Sl. Channel	2,997,000	CY	$7.50	$22,478,000	Excavate channel and haul material for use as habitat fill onsite.
96		Napa Slough - Haire Channel	1,605,000	CY	$7.50	$12,038,000	Excavate channel and haul material for use as habitat fill onsite.
97	VortacORTAC	Vortac Levee	267,000	CY	$10.00	$2,670,000	Construct a ring levee inside Skaggs around Vortac.
98		Grade Levee for Vortac Access	16,000	LF	$10.00	$160,000	Improve levee from Hudeman Slough bridge to Vortac for access.
99		Surface Levee for Vortac Access	2,000	CY	$150.00	$300,000	Surface levee from Hudeman Slough bridge to Vortac for access.
100		Vortac Pump Station	1	EA	$40,000	$40,000	Install a pump to keep Vortac dewatered, connect to existing electrical supply.
101	Demolition	Power Line Demolition	6,400	LF	$10.00	$64,000	Remove powerlines within the Haire Unit.
102		House Demolition	2	EA	$200,000	$400,000	Remove homes

103		Septic System Demolition	2	EA	$10,000	$20,000	Demolish septic systems per county standards
104		Barn Demolition	3	EA	$100,000	$300,000	Remove barns.
105		Misc. demolition	4	AC	$10,000	$40,000	Clearing debris, leveling land
106		General ripping/discing	8	AC	$1,000	$8,000	Loosen soil on ~8 acres at Haire Ranch
107		Road Demolition	29,000	LF	$132.80	$371,000	Demolish ~29,000 LF of asphalt roads (excludes road from 37 to vortex)
108		Well Demolition	1	EA	$15,000	$15,000	Demolish well per county standards.
109		Pump Demolition	3	EA	$20,000	$60,000	Demolish pump stations and appurtenances
110		Miscellaneous Demolition	1,000	LF	$10.00	$10,000	Demolish HDPE discharge to deep water unit
111		Miscellaneous Demolition	10,000	LF	$15.00	$150,000	Cut to grade steel sheet pile along Second Napa & Hudeman Sloughs
112	**Skaggs Island Subtotal**					**$52,826,000**	

113	**Camp 1 West & East**	Mobilization & Demobilization	1	LS	$3,627,000	$3,627,000	Mobilizing & demobilizing forces, equipment, and facilities to needed to perform the work.
114		Site Preparation & Env. Compliance	1	LS	$2,198,000	$2,198,000	General site preparations, environmental compliance measures and BMP's
115	Levee lowering	Sonoma Creek Levee	4,000	CY	$5.00	$20,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
116		Lower West Camp 1 Levee	4,000	CY	$5.00	$20,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
117		Lower Bush Slough Levees	26,000	CY	$6.50	$169,000	Excavate and haul for onsite use as habitat fill.
118		Lower Tolay Creek Levee	11,000	CY	$5.00	$55,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
119	Levee Breaching	Tolay Creek SW Breach	9,000	CY	$12.00	$108,000	Excavate breach and sidecast

							material nearby.
120		Tolay Creek - Bush Slough Breach	9,000	CY	$12.00	$108,000	Excavate breach and sidecast material nearby.
121	Channel Excavation	Tolay Creek SW Channel	256,000	CY	$87.50	$1,920,000	Excavate and haul for onsite use as habitat fill.
122		Tolay Creek - Sonoma Creek Channel	252,000	CY	$15.00	$3,780,000	Excavate from Bush Slough to Sonoma Creek and haul for onsite use as habitat fill.
123		Tolay Creek Pickleweed Clearing	28	AC	$25,0400	$712,000	Hand clear Tolay Creek channel footprint, place material in site.
124	Railroad Infrastructure	Railroad Embankment	160,000	CY	$70.00	$11,200,000	Construct ~9,400 LF embankment along east side of railroad using imported material. From Camp 3 to where ground elevation = 15 ft.
125		Rock Slope Protection	37,000	TN	$100.00	$3,700,000	Armor new embankment.
126	Demolition	Barn Demolition	1	EA	$100,000	$100,000	1Demolish barn

127		Miscellaneous Demolition	5	AC	$10,000	$50,000	General debris, equipment, & structure removal and clean up.
128		General ripping/discing	6	AC	$1,000	$6,000	Loosen soils on ~6 acres around the farm epicenter
129		Road Demolition	3,500	LF	$10.00	$35,000	Demolish ~3,500 LF gravel road along west side
130	**Camp 1 West & East Subtotal**					**$27,808,000**	
131	**West End & Detjen**	Mobilization & Demobilization	1	LS	$4,357,000	$4,357,000	Mobilizing & demobilizing forces, equipment, and facilities to needed to perform the work.
132		Site Preparation & Env. Compliance	1	LS	$2,641,000	$2,641,000	General site preparations, environmental compliance measures and BMP's
133	Levee Lowering	Lower Napa/South Slough Levee	18,000	CY	$5.00	$90,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
134		Lower Napa Slough Levee	28,000	CY	$5.00	$140,000	Selectively lower to MHHW. Sidecast material to

							flatten interior side slope.
135		Lower Detjen internal berms	28,889	CY	$5.00	$144,000	Selectively lower to MHHW. Sidecast material to flatten interior side slope.
136	Levee Breaching	West End Breach	8,000	CY	$20.00	$160,000	Excavate breach and sidecast material nearby.
137		Skaggs Island Road Culvert	1	EA	$150,000	$150,000	Install box culverts in Skaggs Is. Road to connect parcels
138	Channel Excavation	West End Channel	529,000	CY	$87.50	$3,968,000	Excavate and haul for onsite use as habitat fill.
139	Levee Improvement	Detjen East Levee	11,000	CY	$70.00	$770,000	Build up Detjen East Levee - imported materials
140		Detjen Hwy 37 Levee	117,000	CY	$70.00	$8,190,000	Build up existing south berm - imported materials
141		West End Hwy 37 Levee	149,000	CY	$70.00	$10,430,000	Build up south existing berm - imported materials

142	PG&E Infrastructure	Transmission Tower Improvement	25	EA	$60,000	$1,500,000	Raise concrete around tower footings
143		Boardwalk Improvement	6,200	LF	$38.00	$236,000	Raise existing boardwalks
144	Demolition	House Demolition	2	EA	$200,000	$400,000	Demolish houses
145		Septic System Demolition	1	EA	$10,000	$10,000	Demolish septic systems per county standards
146		Barn Demolition	2	EA	$100,000	$200,000	Demolish barns
147		Miscellaneous Demolition	2	AC	$10,000	$20,000	Demolish water tower, ditch boardwalks, etc.
148	**West End & Detjen Subtotal**					**$33,406,000**	
149	**Alluvial Fans, Riparian Corridors, Transition Zones**	Mobilization & Demobilization	1	LS	$1,980,000	$1,980,000	Mobilizing & demobilizing forces, equipment, and facilities to needed to perform the work.
150		Site Preparation & Env. Compliance	1	LS	$1,200,000	$1,200,000	General site preparations, environmental compliance measures and BMP's
151		Alluvial Fans	1	LS	$5,000,000	$5,000,000	Restoration (plug number)

152		Riparian Corridors	1	LS	$3,000,000	$3,000,000	Restoration (plug number)
153		Transition Zones	1	LS	$4,000,000	$4,000,000	Restoration (plug number)
154	**Alluvial Fans Subtotal**					**$15,180,000**	
155	**Alternative Subtotal**					**$239,174,000**	
158	**Construction Cost Contingency**					**$71,752,000**	**30%**
159	**Total Construction Costs**					**$310,926,000**	