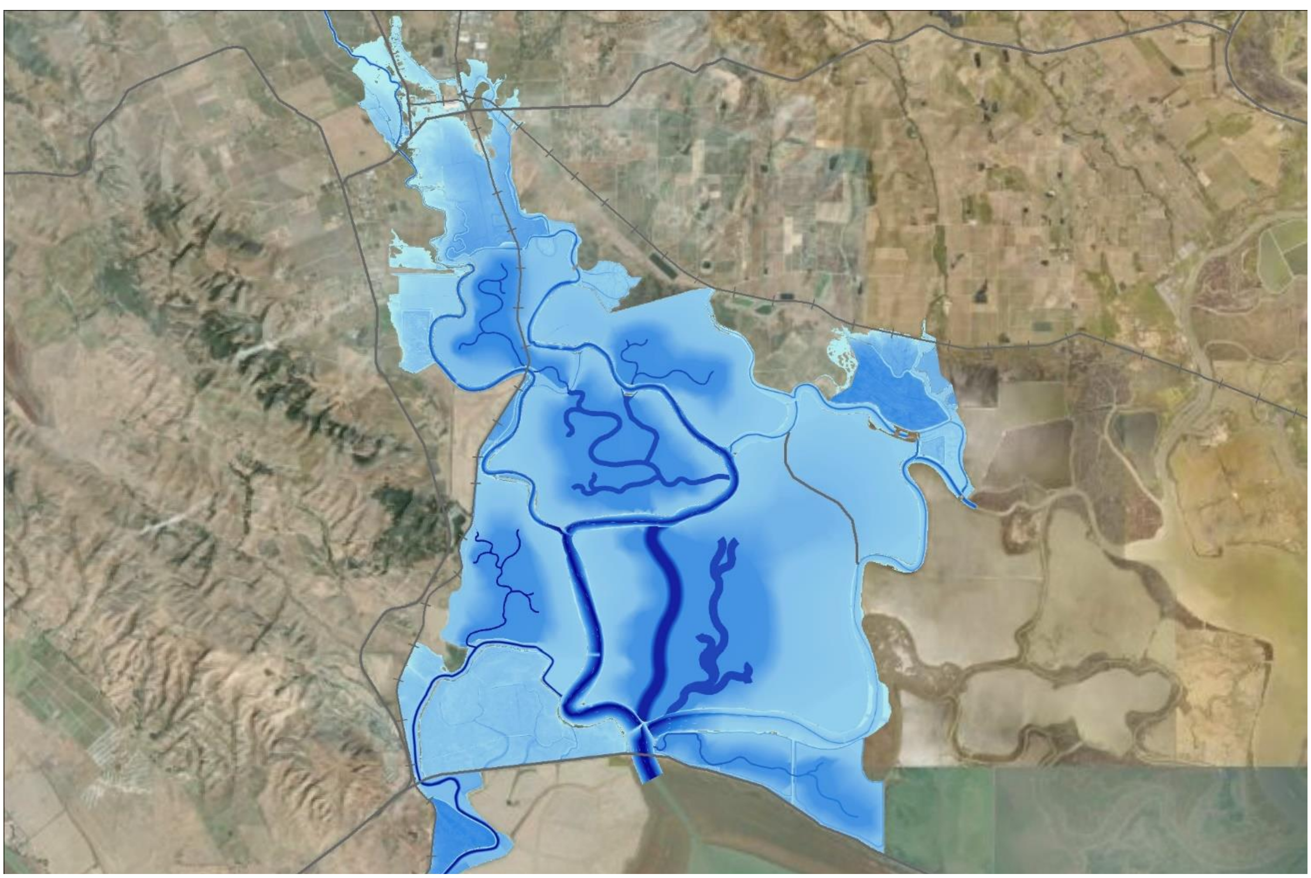
DRAFT

SONOMA CREEK BAYLANDS STRATEGY

Hydrodynamic modeling appendix

Prepared for
Sonoma Land Trust

January, 2020



DRAFT

SONOMA CREEK BAYLANDS STRATEGY

Hydrodynamic modeling appendix

Prepared for
Sonoma Land Trust

January, 2020

180 Grand Avenue
Suite 1050
Oakland, CA 94612
510.839.5066
www.esassoc.com

D180152.01

TABLE OF CONTENTS

SONOMA CREEK BAYLANDS STRATEGY

Page

List of Figures

Page

List of Tables

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.

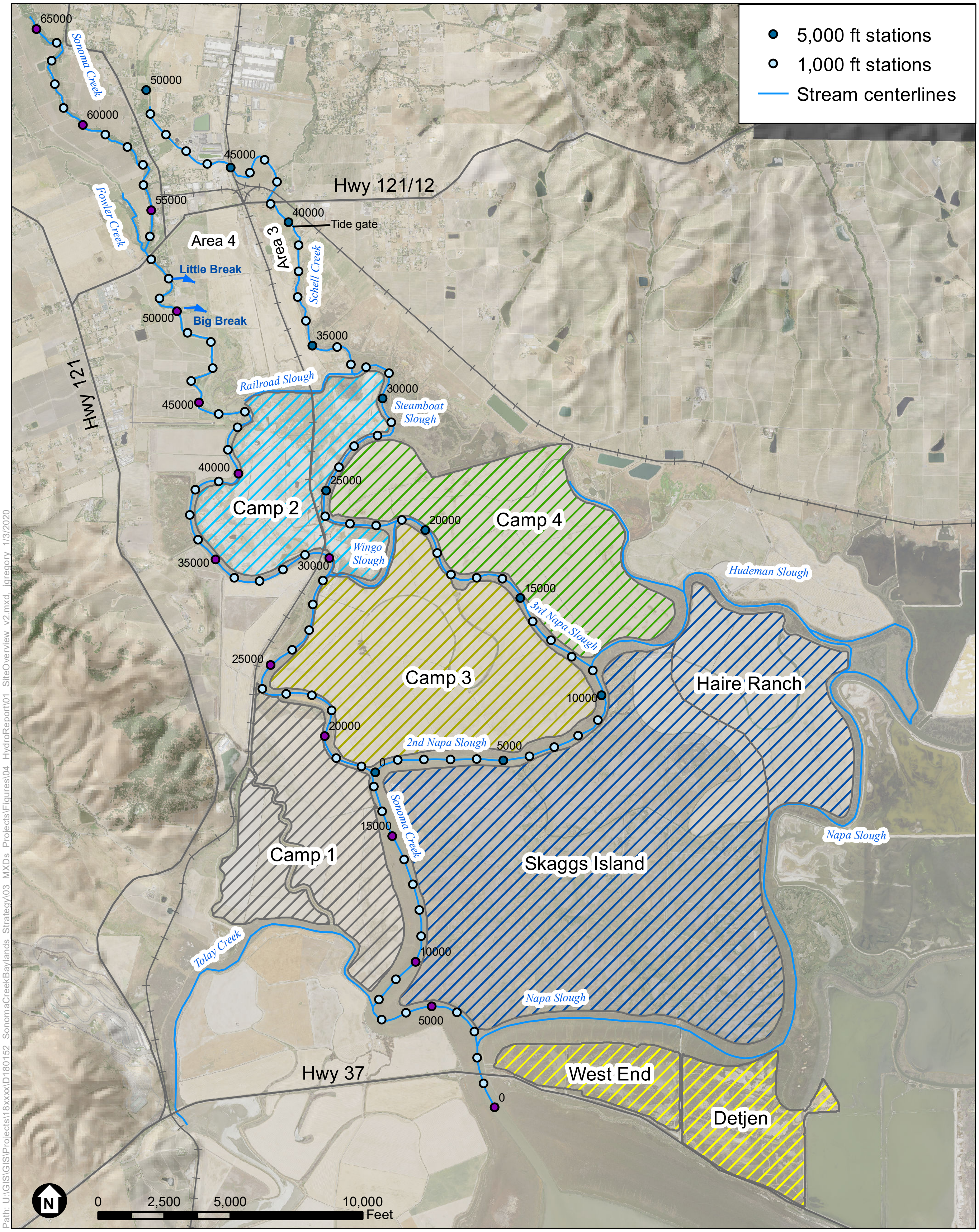
- Modeling of the No-action scenario suggests that for 2050 conditions, peak stage on Sonoma Creek increases by 0.9 ft at the north end of Camp 2 for a 1% chance flow with an elevated tide. Peak stage on Schell Creek increases by 1.0 ft at the tide gate and by 0.6 ft immediately upstream of Highway 121.

- 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.

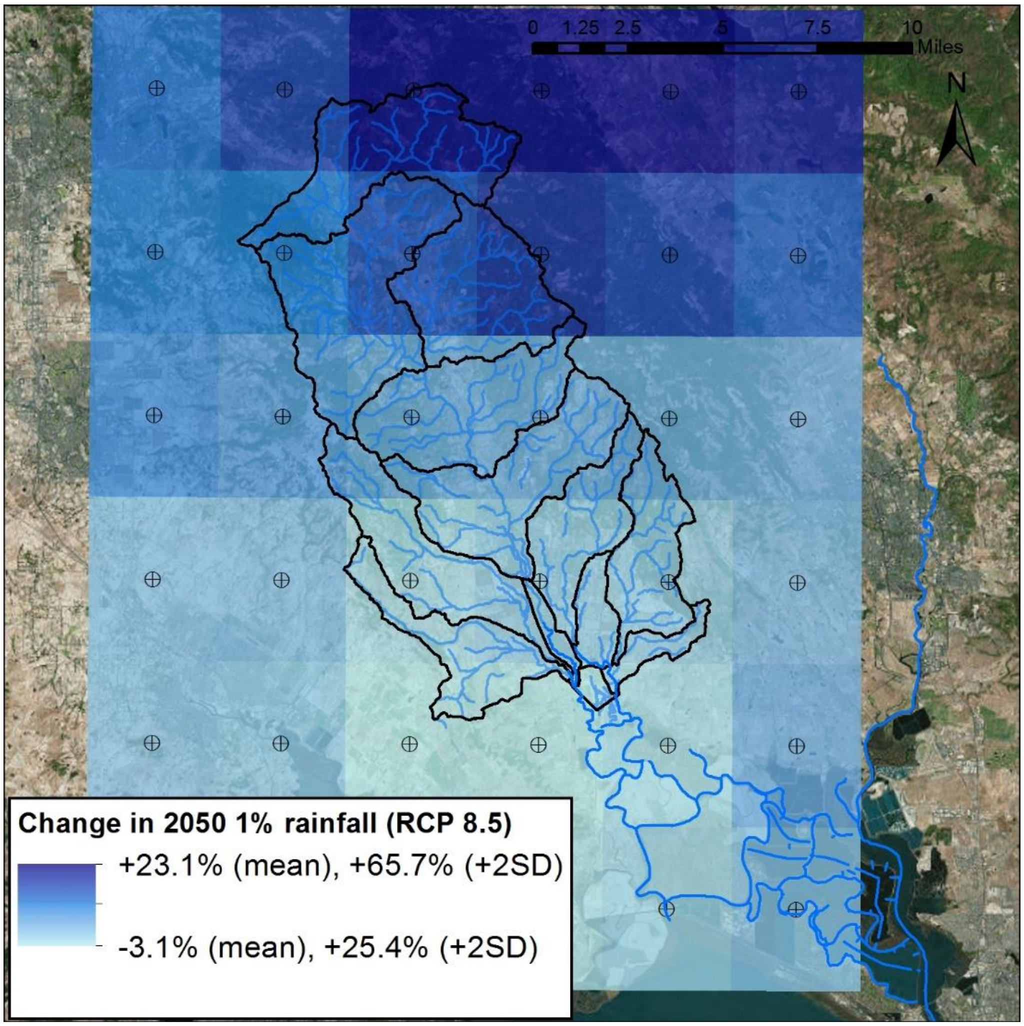


Figure 2. Map of climate change grid cells and hydrologic model subbasins

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).

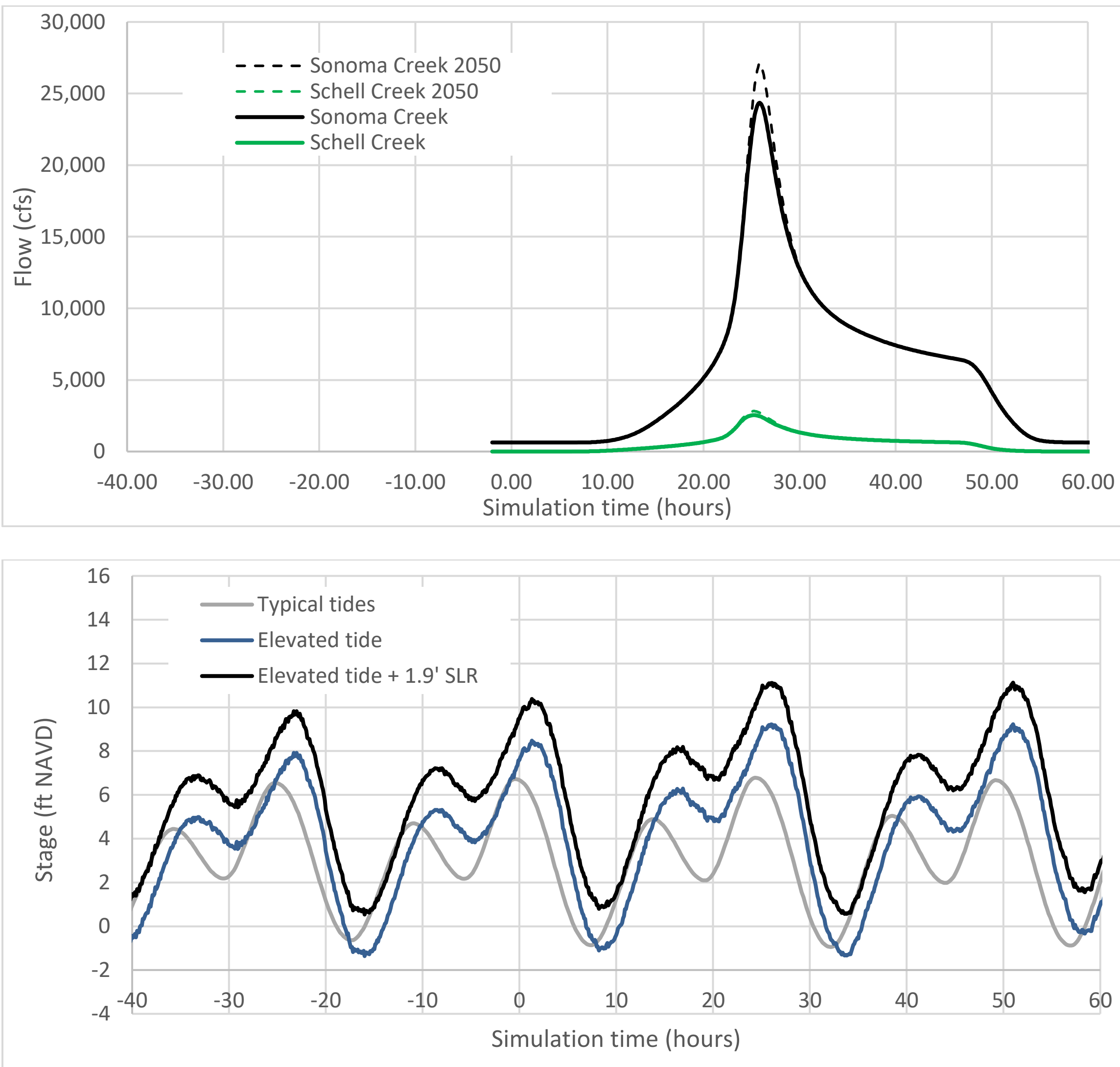


Figure 3. Discharge and tide boundary conditions for present and future hydrologic scenarios

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.

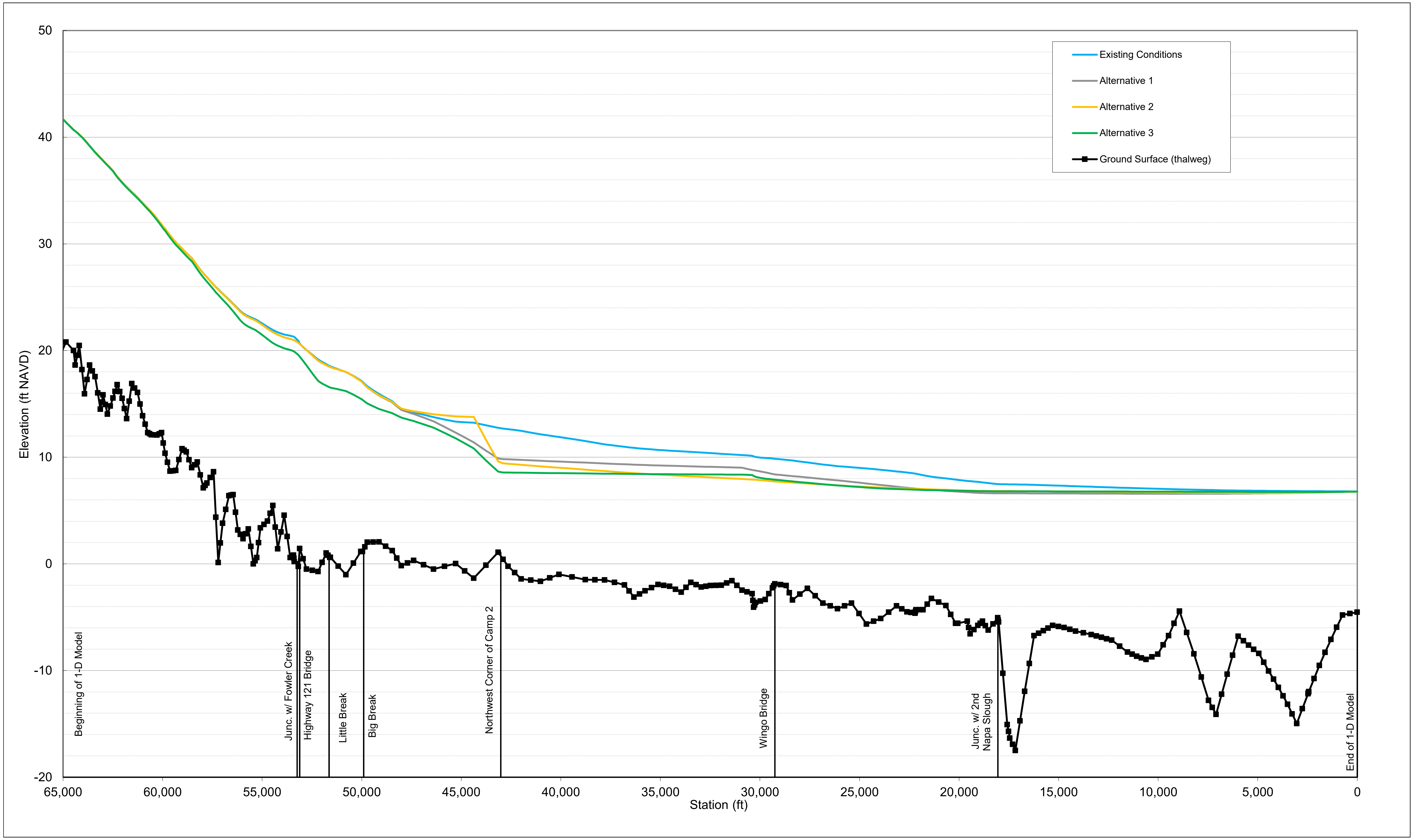


Figure 4

Sonoma Creek water surface profiles
1% flow, typical tide

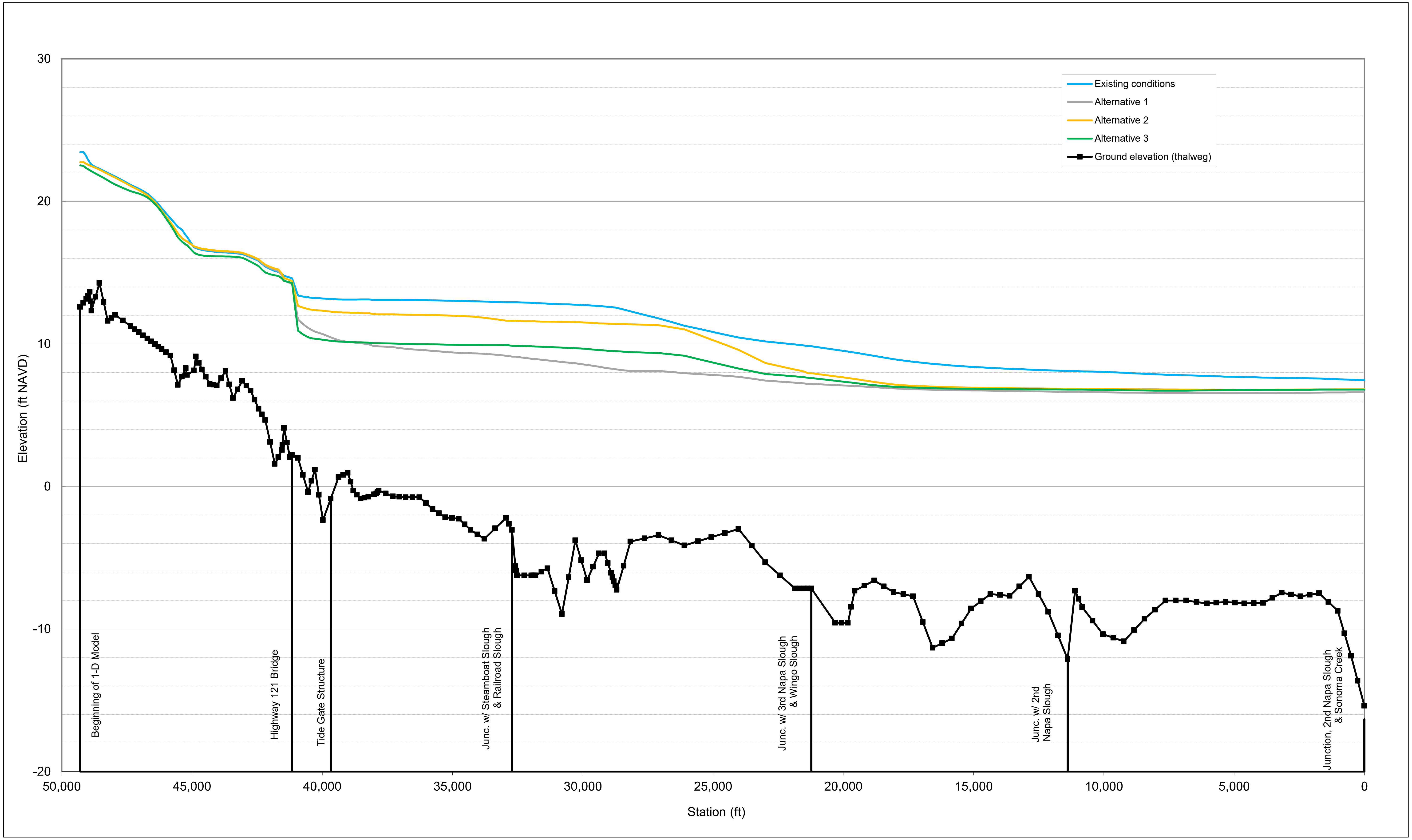


Figure 5
Schell Creek water surface profiles
1% flow, typical tide

ESA

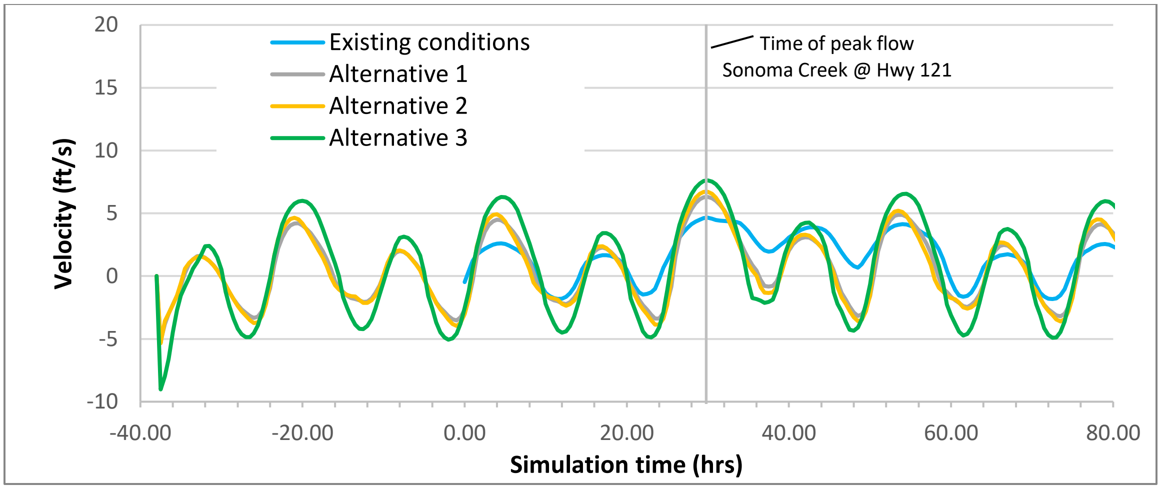


Figure 26. Velocity time series comparisons for all alternatives. 1% flow, typical tide.

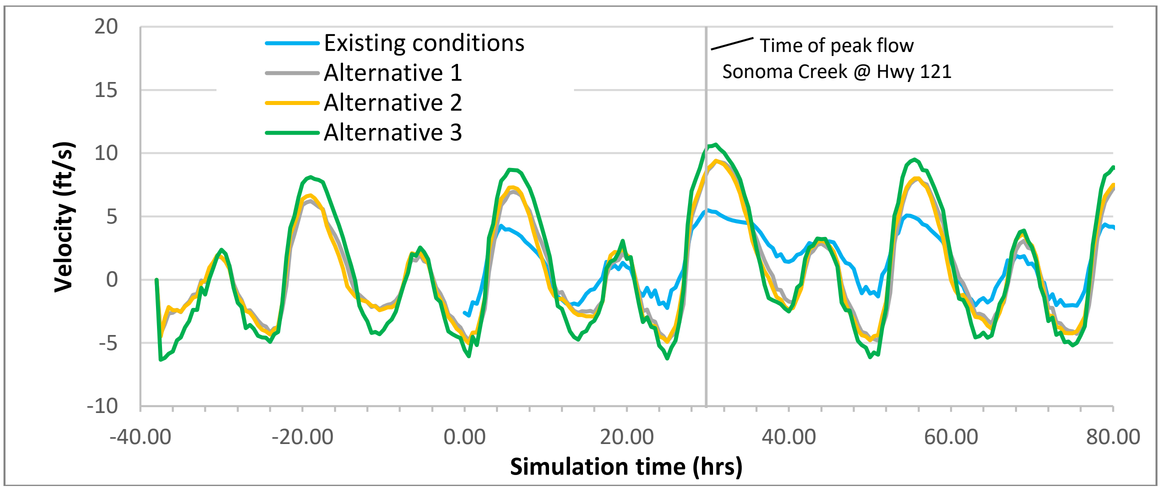


Figure 27. Velocity time series comparisons for all alternatives. 1% flow, elevated tide.

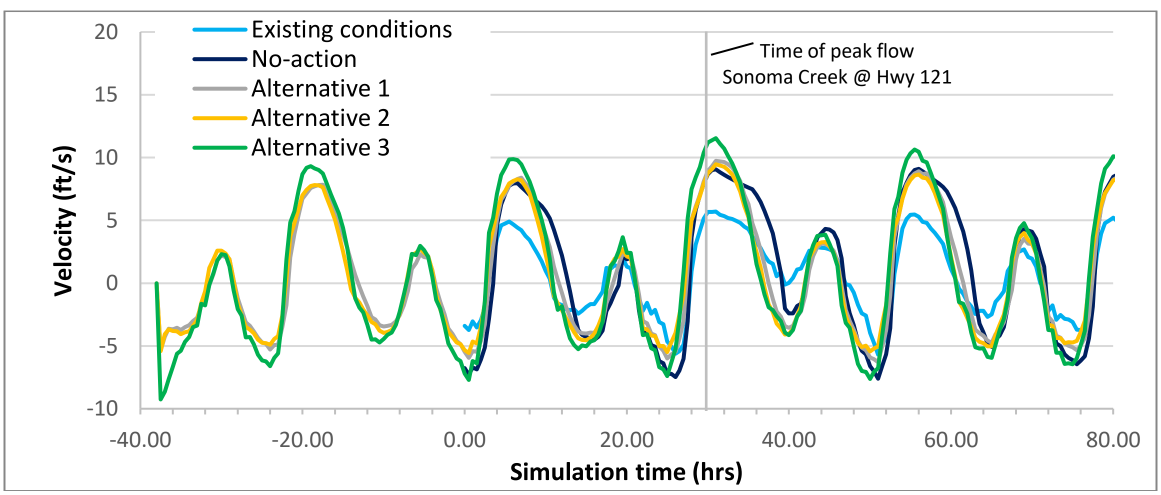


Figure 28. Velocity time series comparisons for all alternatives. 2050 1% flow, elevated tide w/SLR.

6 REFERENCES

Buffington, K.J., and Thorne, K.M., 2019, LEAN-corrected San Francisco Bay digital elevation model, 2018: U.S. Geological Survey data release, https://doi.org/10.5066/P97J9GU8.

DWR, 2015. Perspectives and Guidance for Climate Change Analysis.

ESA PWA, 2012. Lower Sonoma Creek Flood Management and Ecosystem Enhancement.

OPC, 2018. State of California, Sea-level Rise Guidance.

Pierce, David., 2014. Statistical Downscaling Using Localized Constructed Analogs (LOCA).

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu. 1981-2010 precipitation normals. Created July, 2012.

PWA, 2004. Sonoma Creek & Tributaries Basin Hydrologic Investigation. PWA Ref. #1411.21.

PWA, 2008. Sonoma Creek Flood Management and Enhancement Project. Hydraulic Model Development.

Williams, Philip B., Orr, Michelle K., Garrity, Nicholas J., 2002. Hydraulic Geometry: A Geomorphic Design Tool for Tidal Marsh Channel Evolution in Wetland Restoration Projects

7 PREPARERS

ESA Staff:

- James Gregory, P.E.
- Michelle Orr, PhD
- Nate Chesier, P.E.

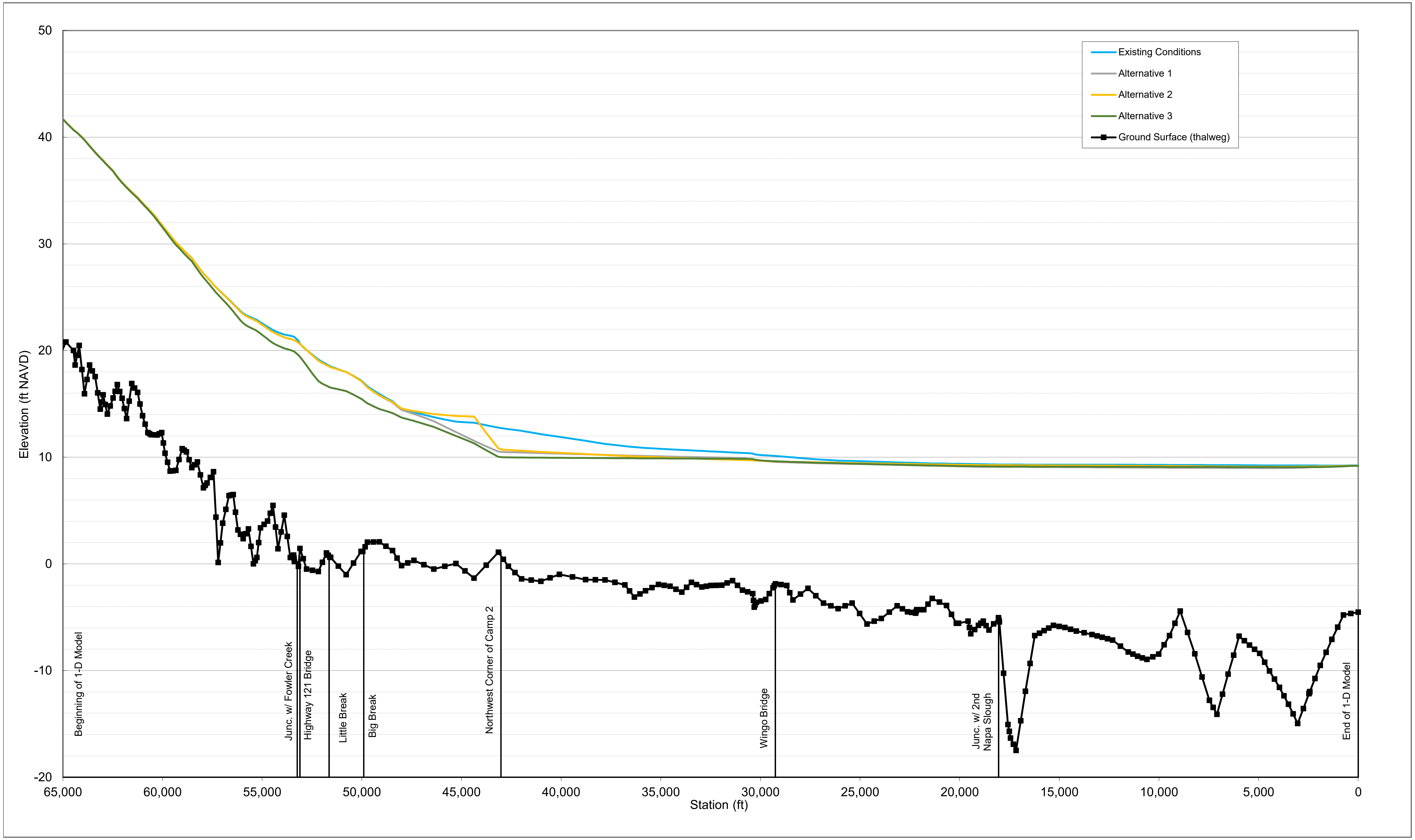


Figure 6
Sonoma Creek water surface profiles
1% flow, elevated tide

ESA

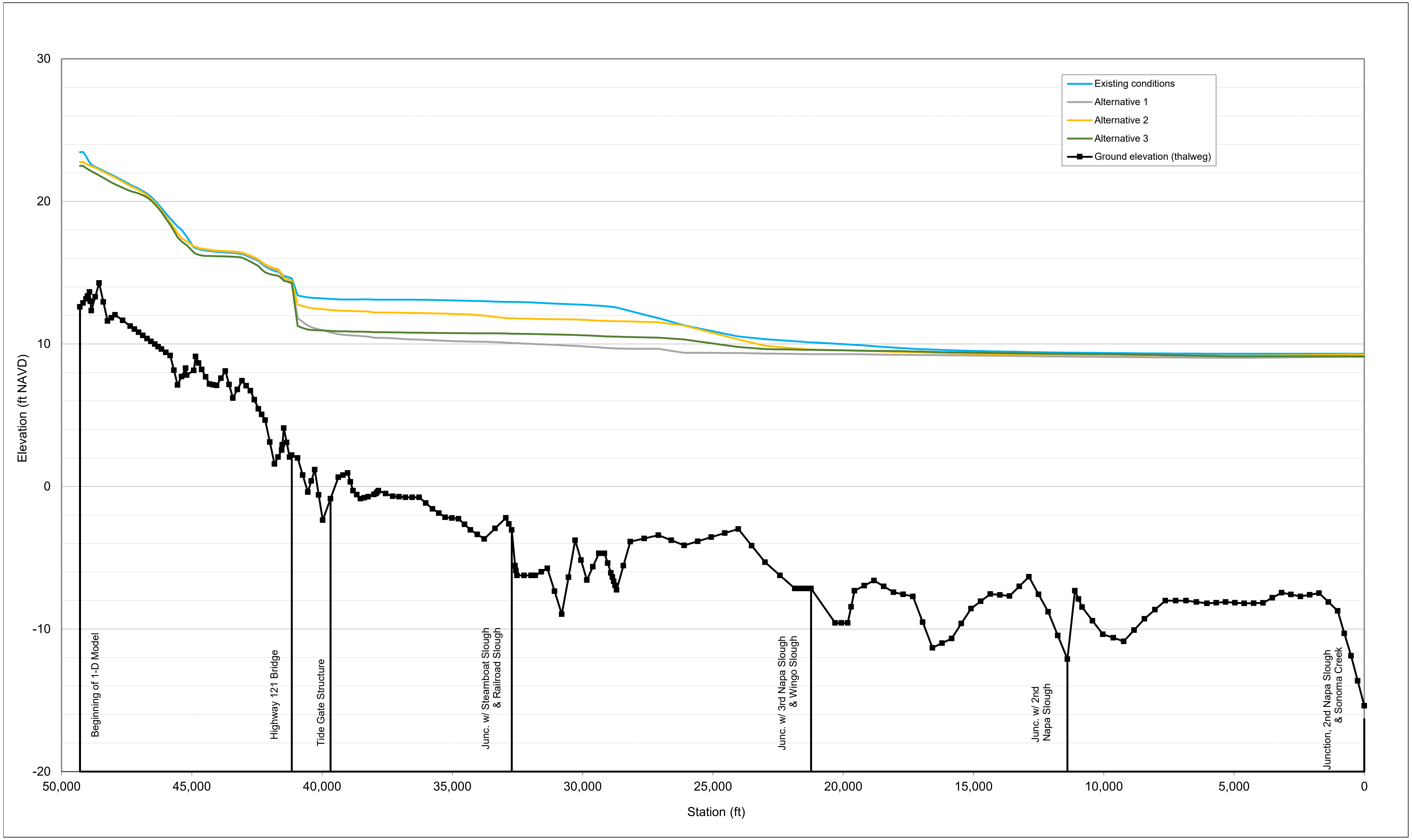


Figure 7

Schell Creek water surface profiles
1% flow, elevated tide

ESA

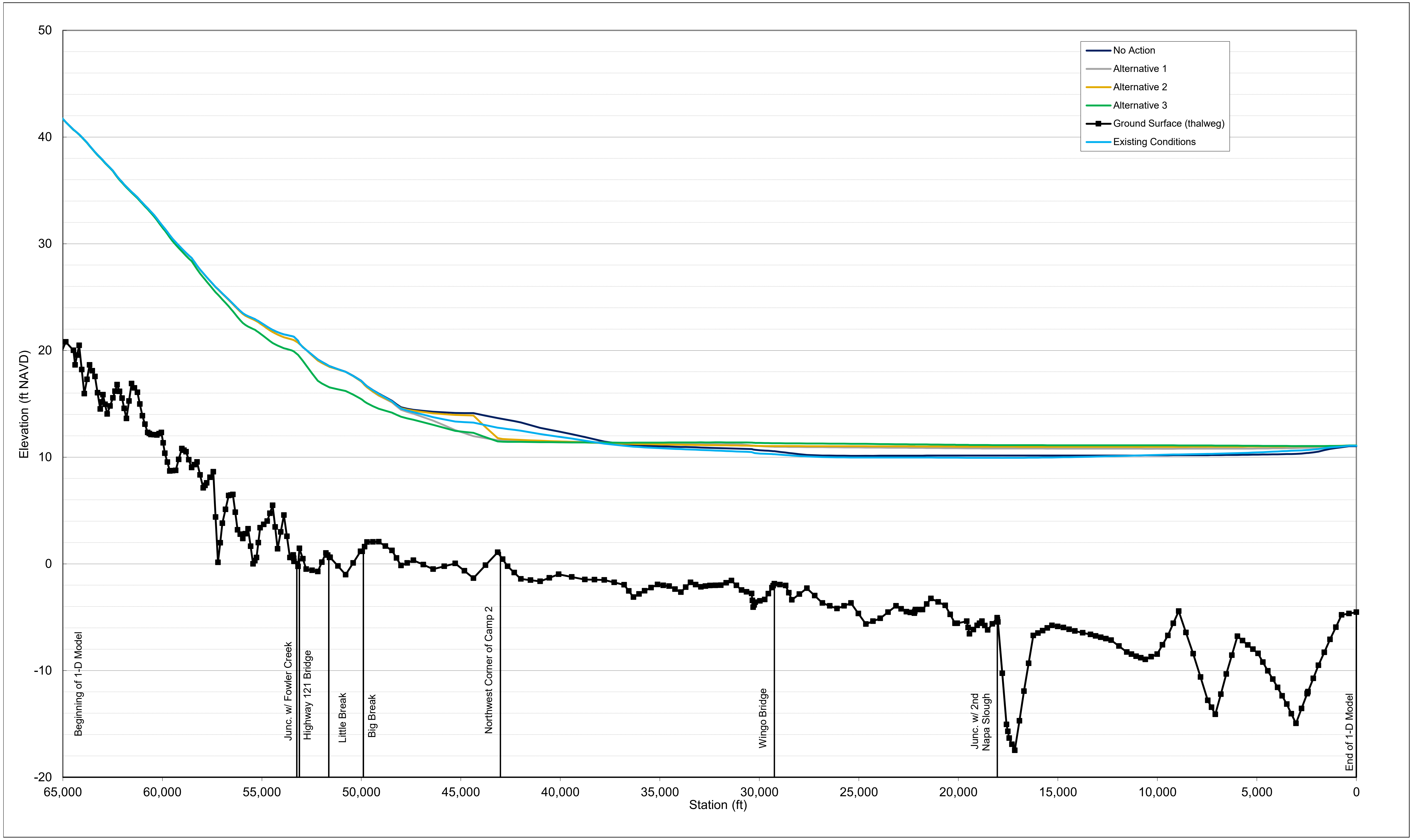
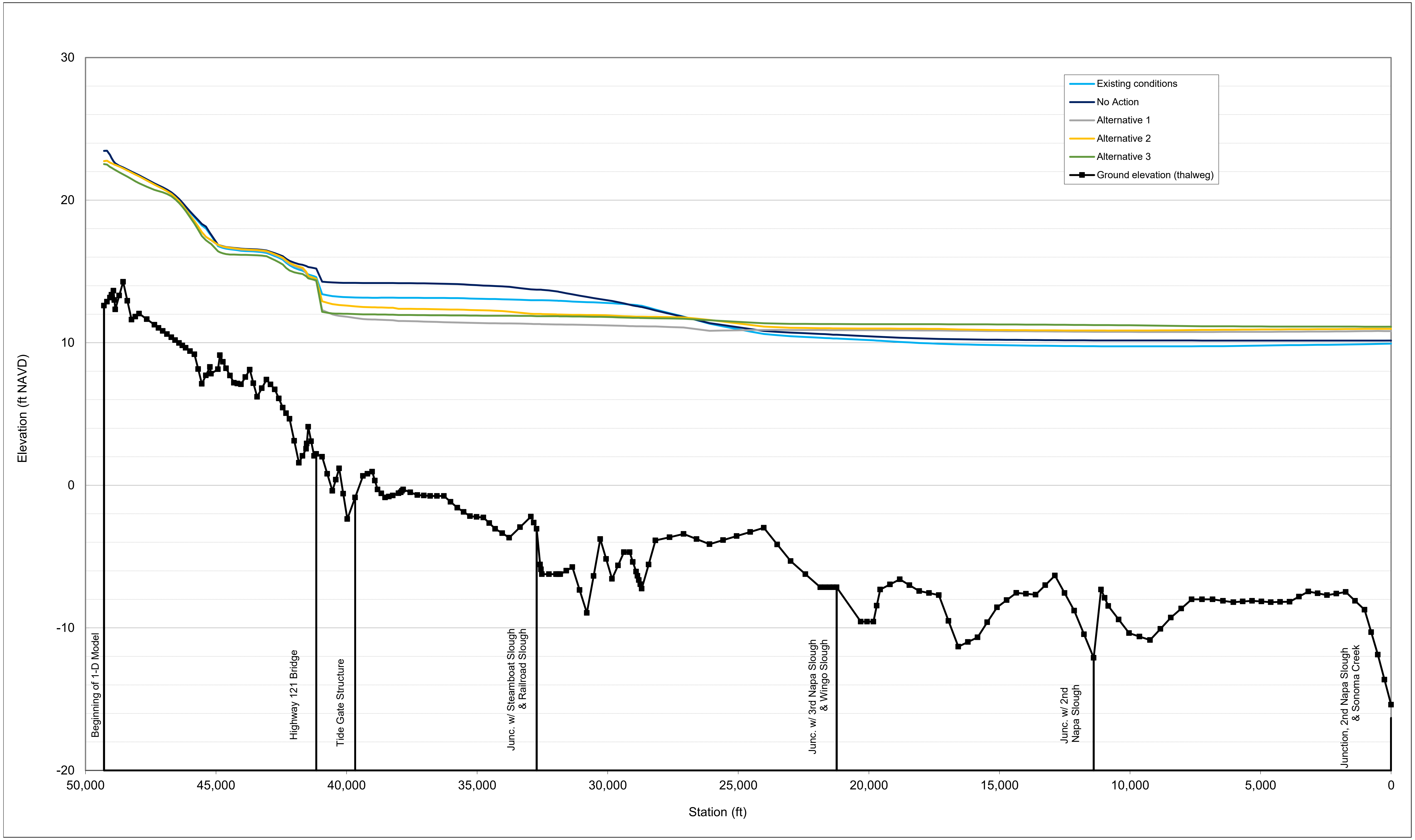


Figure 8

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

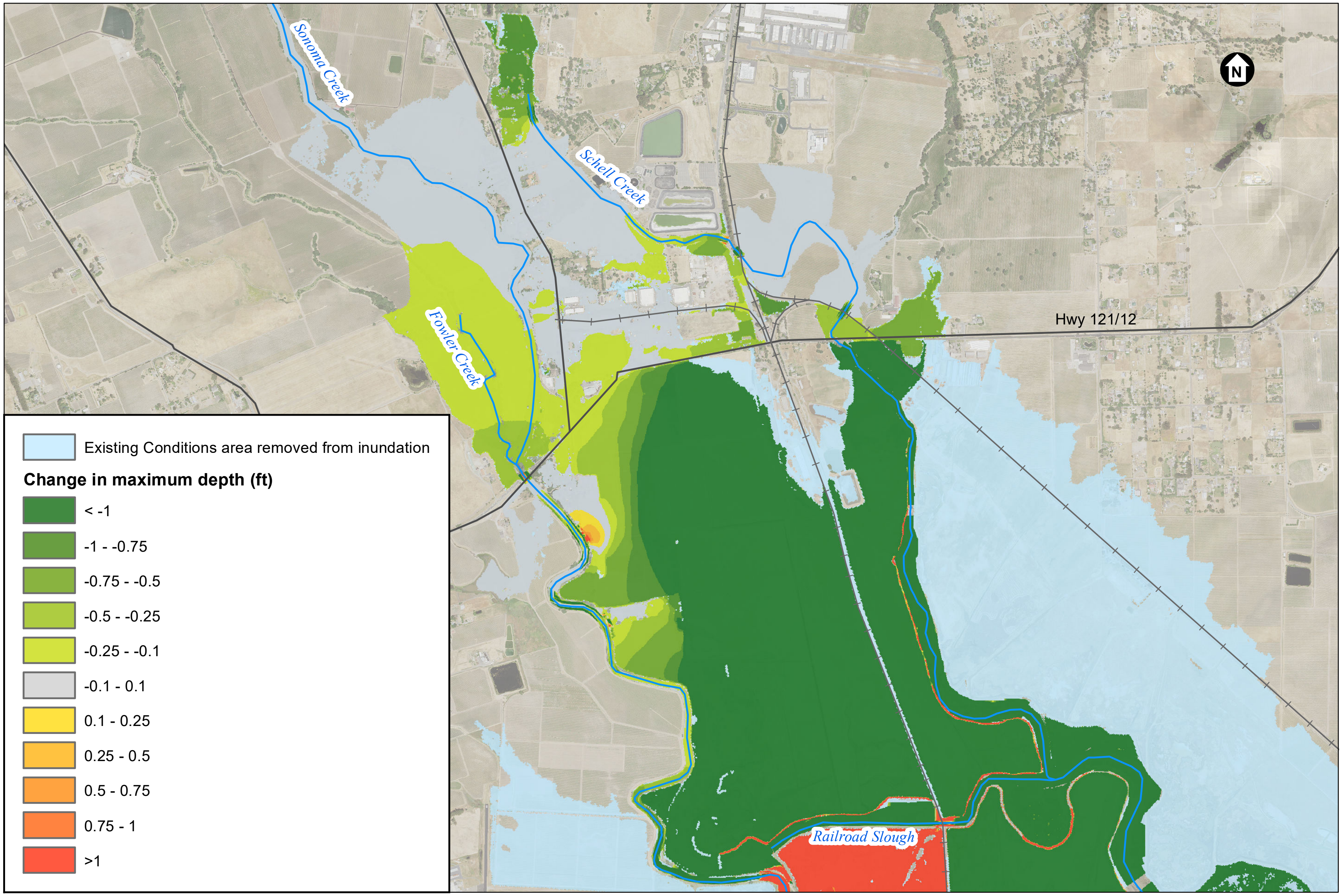


Lower Sonoma Creek Strategy. D180152.01

Figure 9

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

ESA

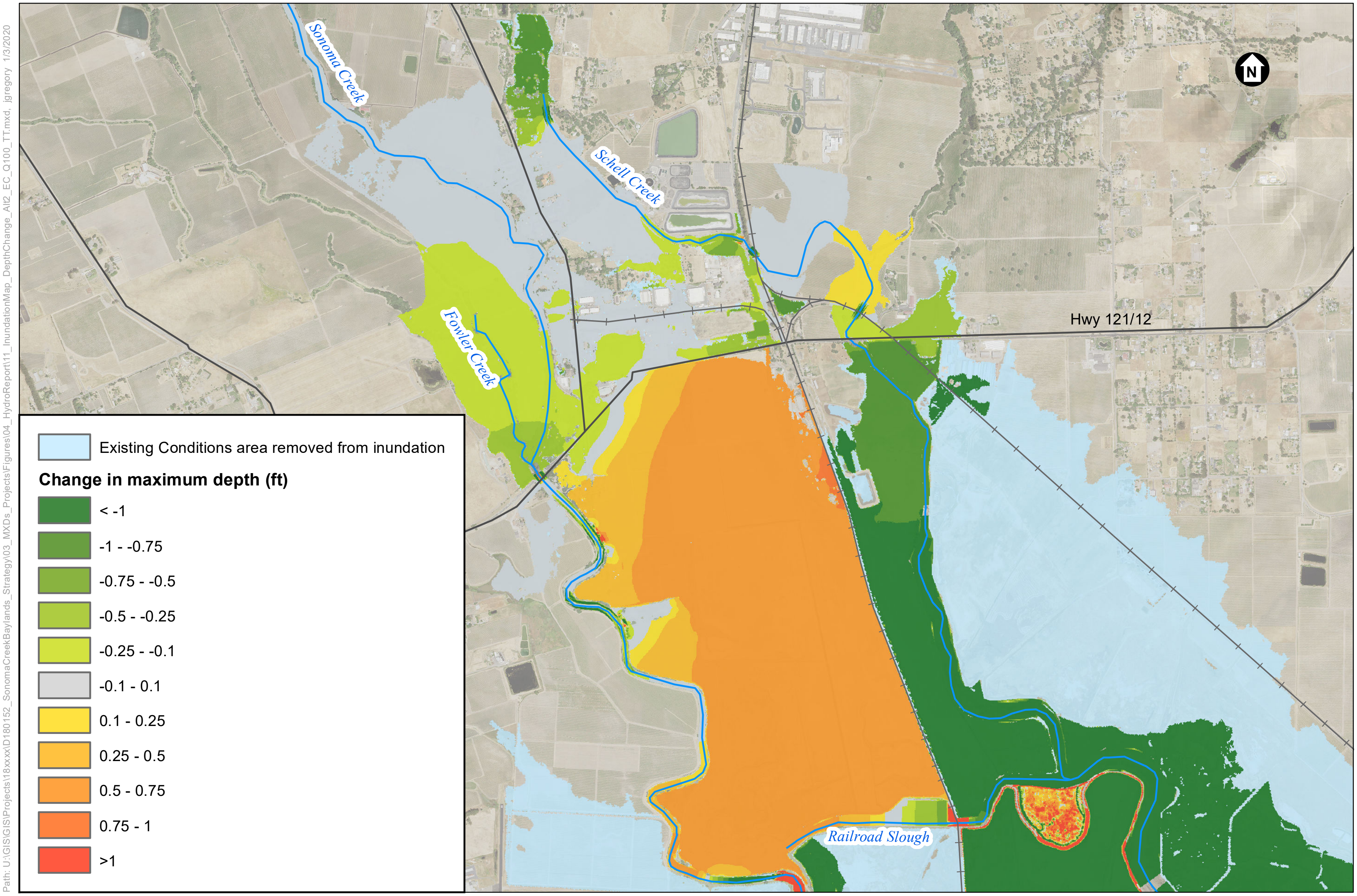


SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

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

ESA

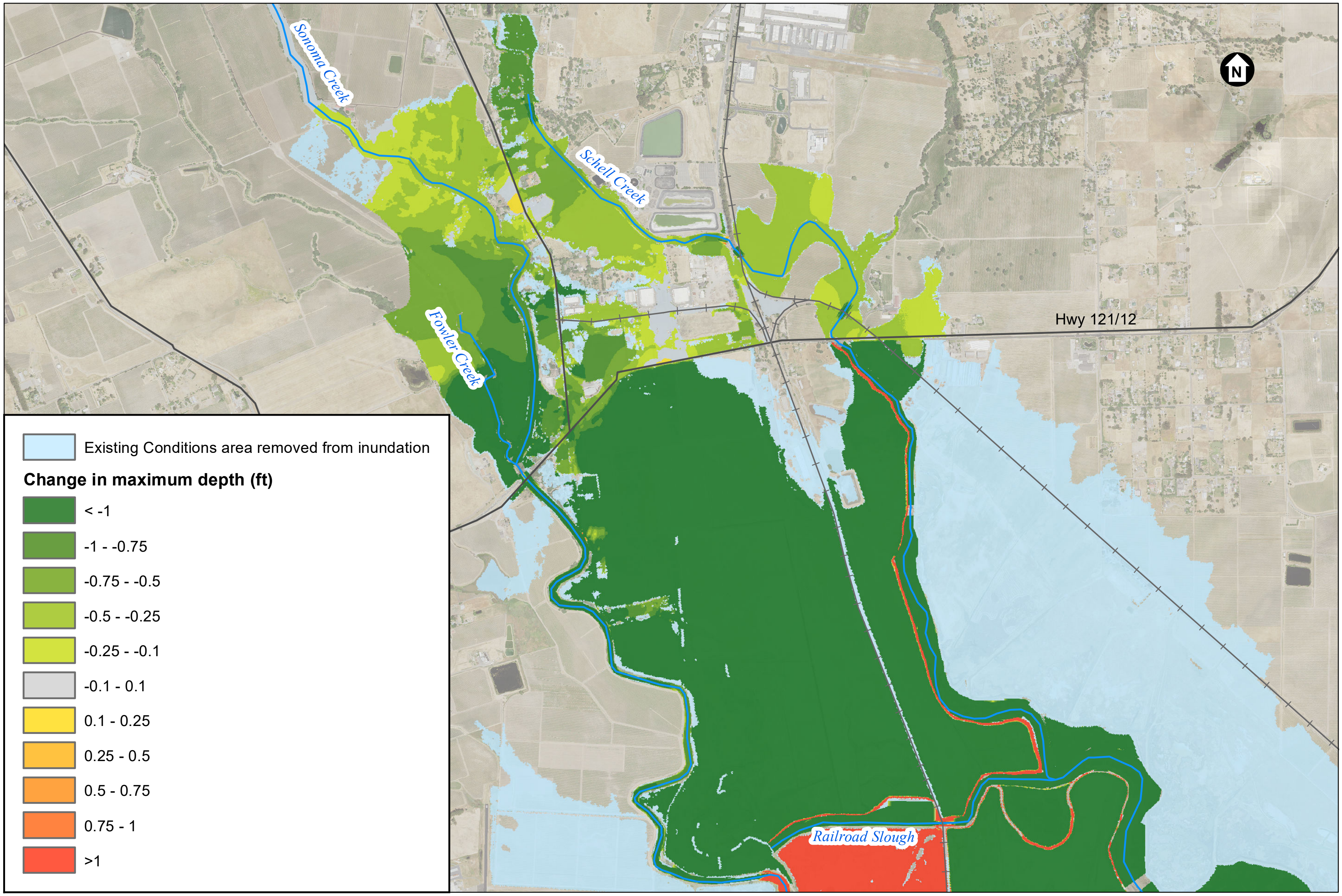


SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

ESA

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



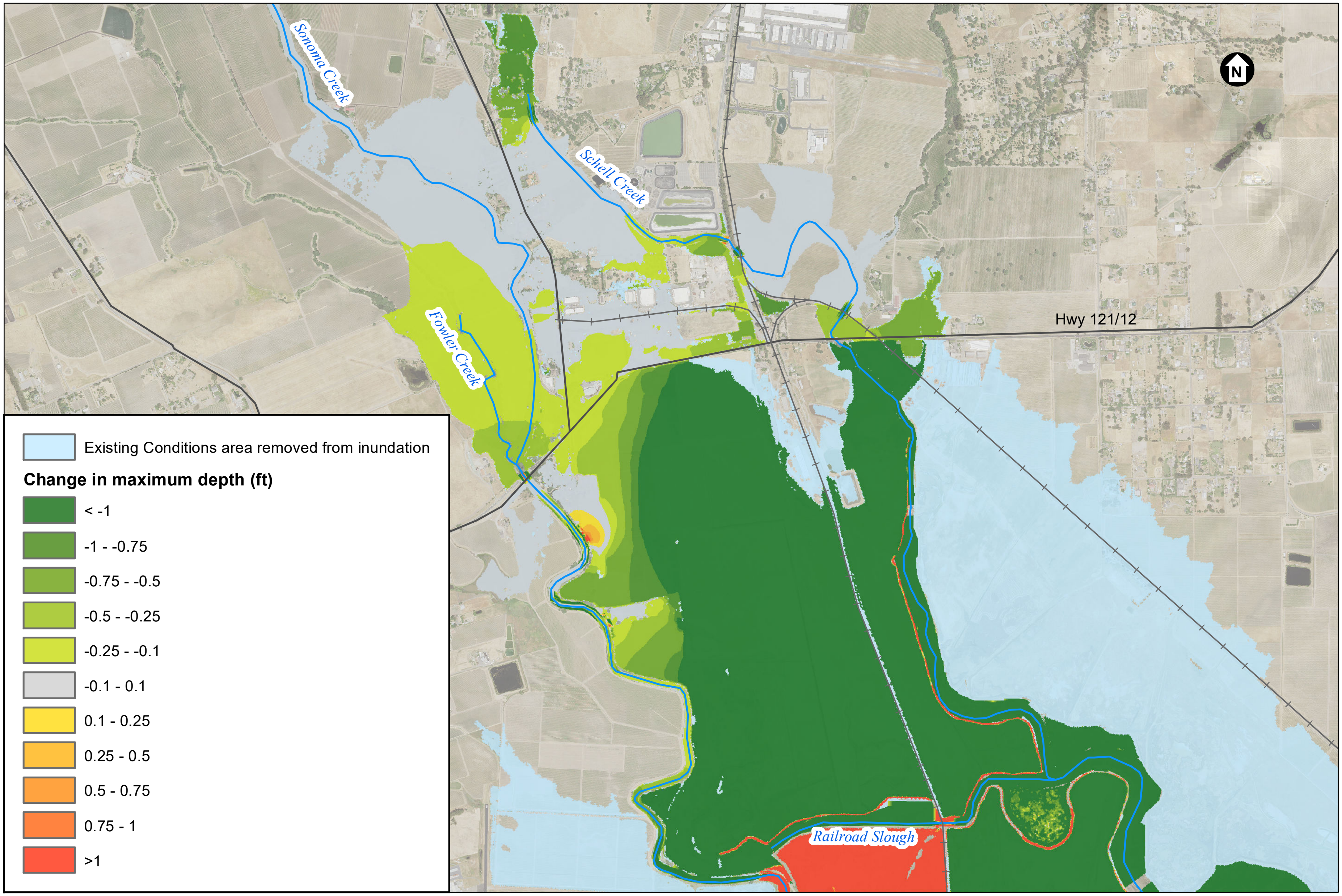
SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

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

ESA

Path: U:\GIS\GIS\Projects\18xxx\D180152_SonomaCreekBaylands_Strategy\03_MXDs_Projects\Figures\04_HydroReport\12_InundationMap_DepthChange_Alt3_EC_Q100_TT.mxd, jgregory 1/3/2020

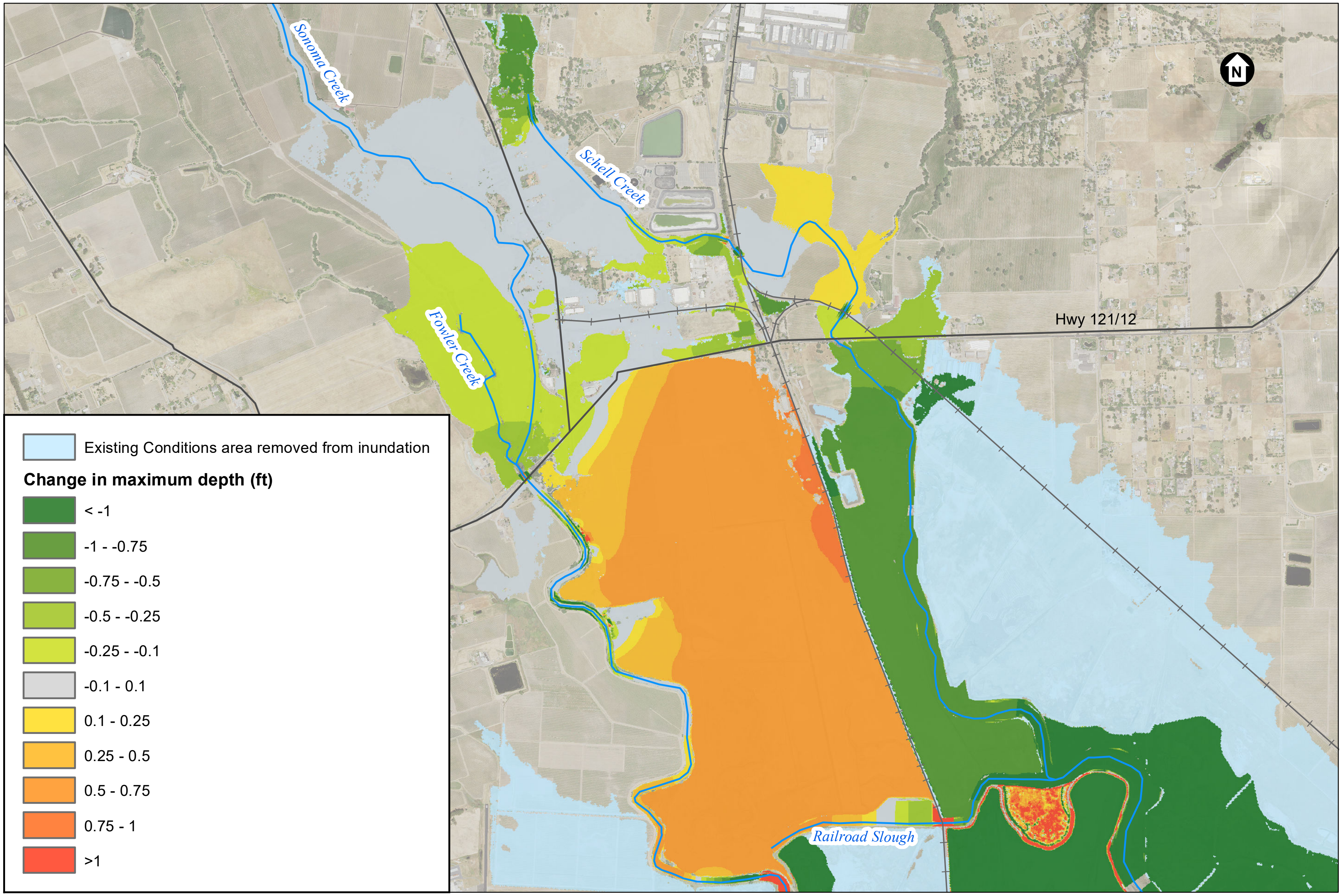


SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

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

ESA



SOURCE: NAIP (2014 aerial)

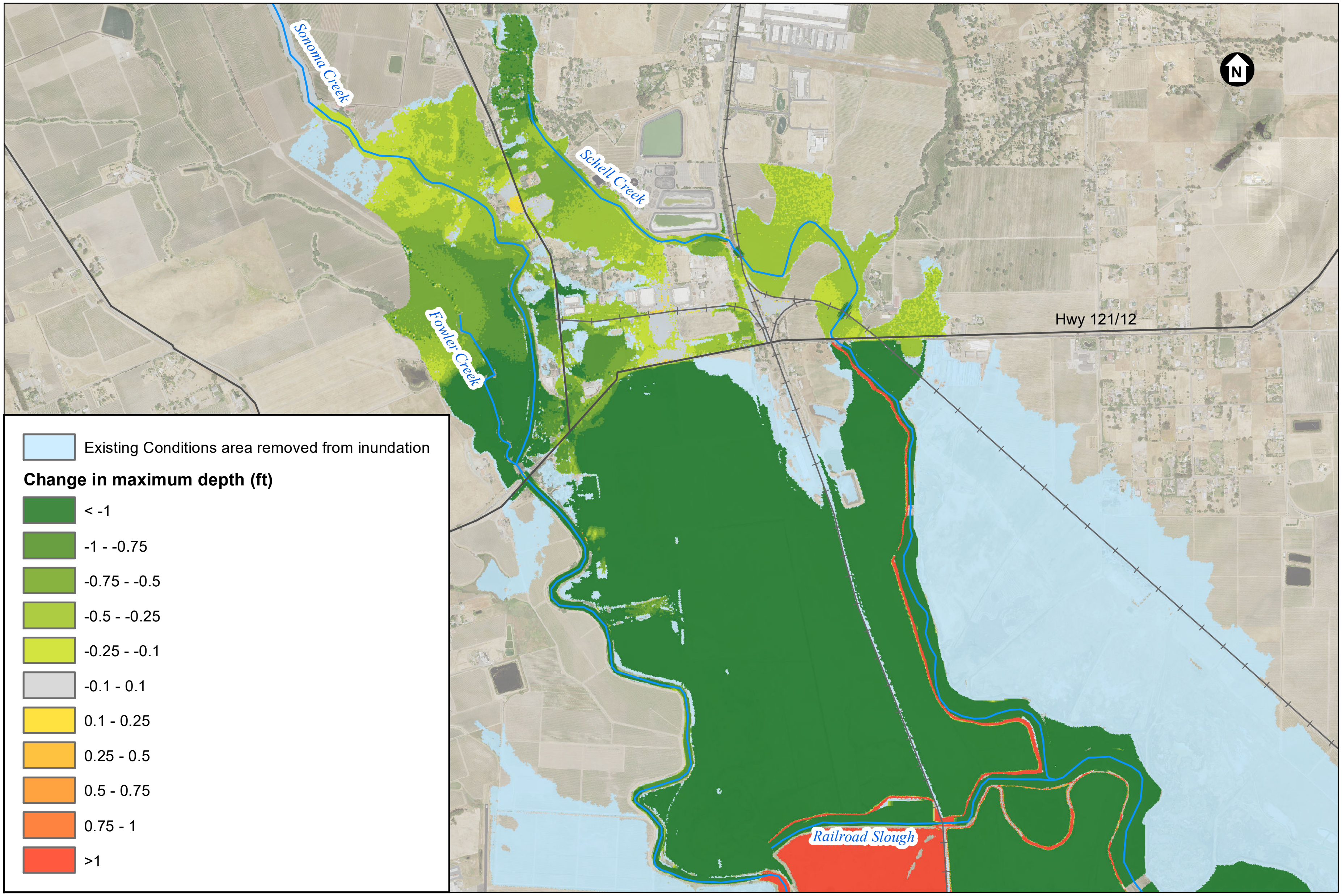
Lower Sonoma Creek Strategy

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

ESA

Path: U:\GIS\GIS\Projects\18xxx\D180152_SonomaCreekBaylands_Strategy\03_MXDs_Projects\Figures\04_HydroReport\14_InundationMap_DepthChange_Alt2_EC_Q100_NYEtide.mxd, jgregory 1/3/2020

Path: U:\GIS\GIS\Projects\18xxx\D180152_SonomaCreekBaylands_Strategy\03_MXDs_Projects\Figures\04_HydroReport\15_InundationMap_DepthChange_Alt3_EC_Q100_NYEtide.mxd, jgregory 1/3/2020

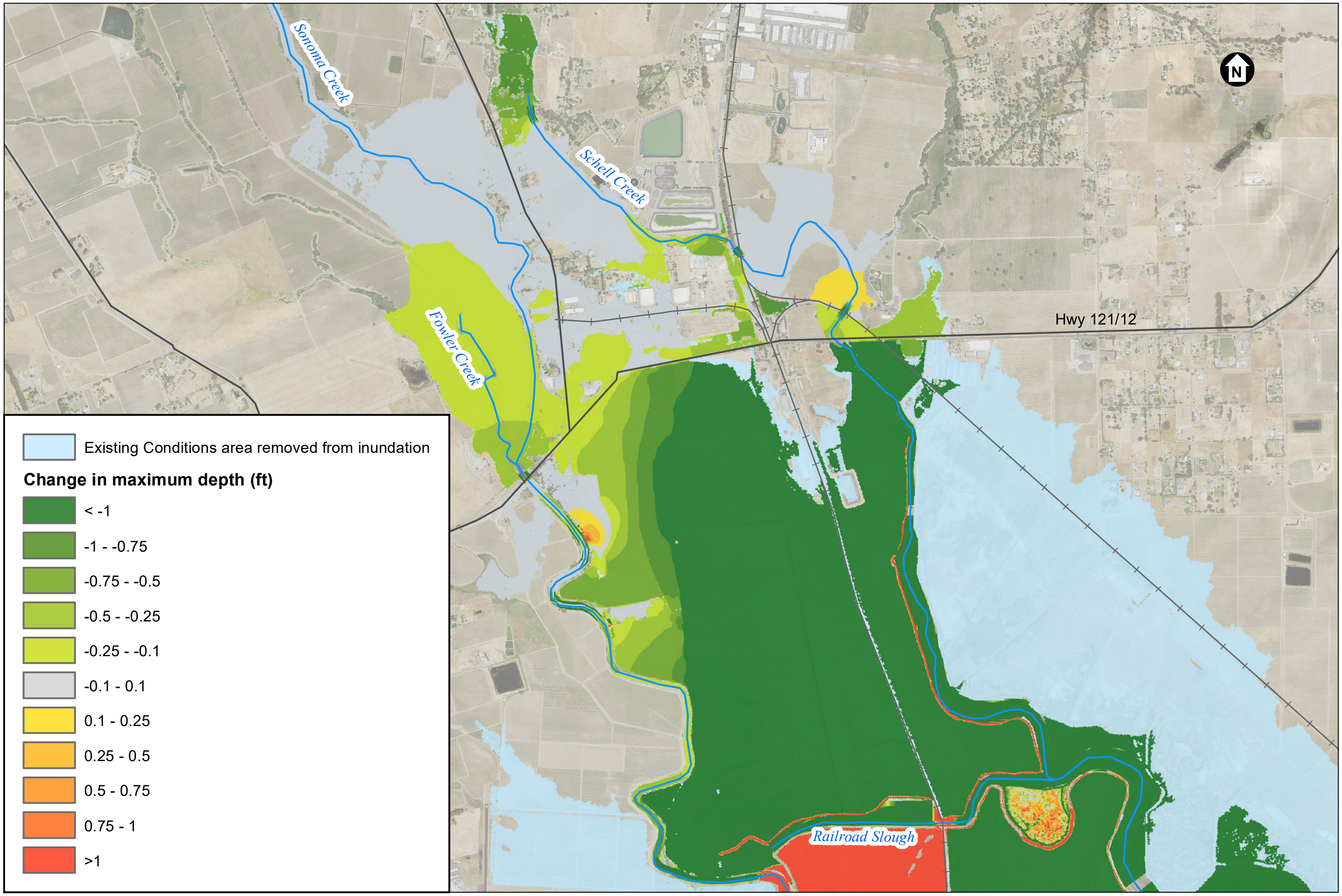


SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

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

ESA

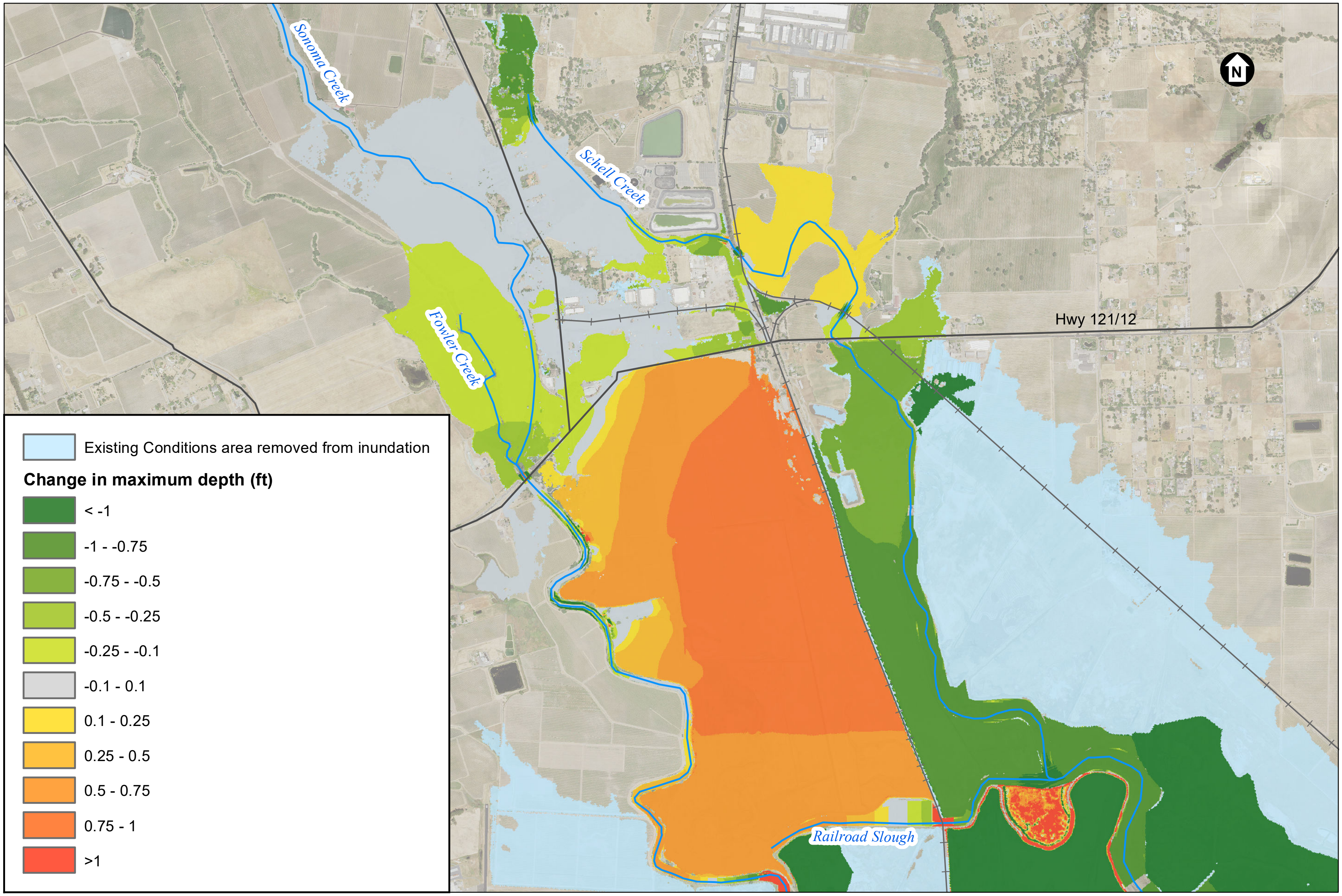


SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

ESA

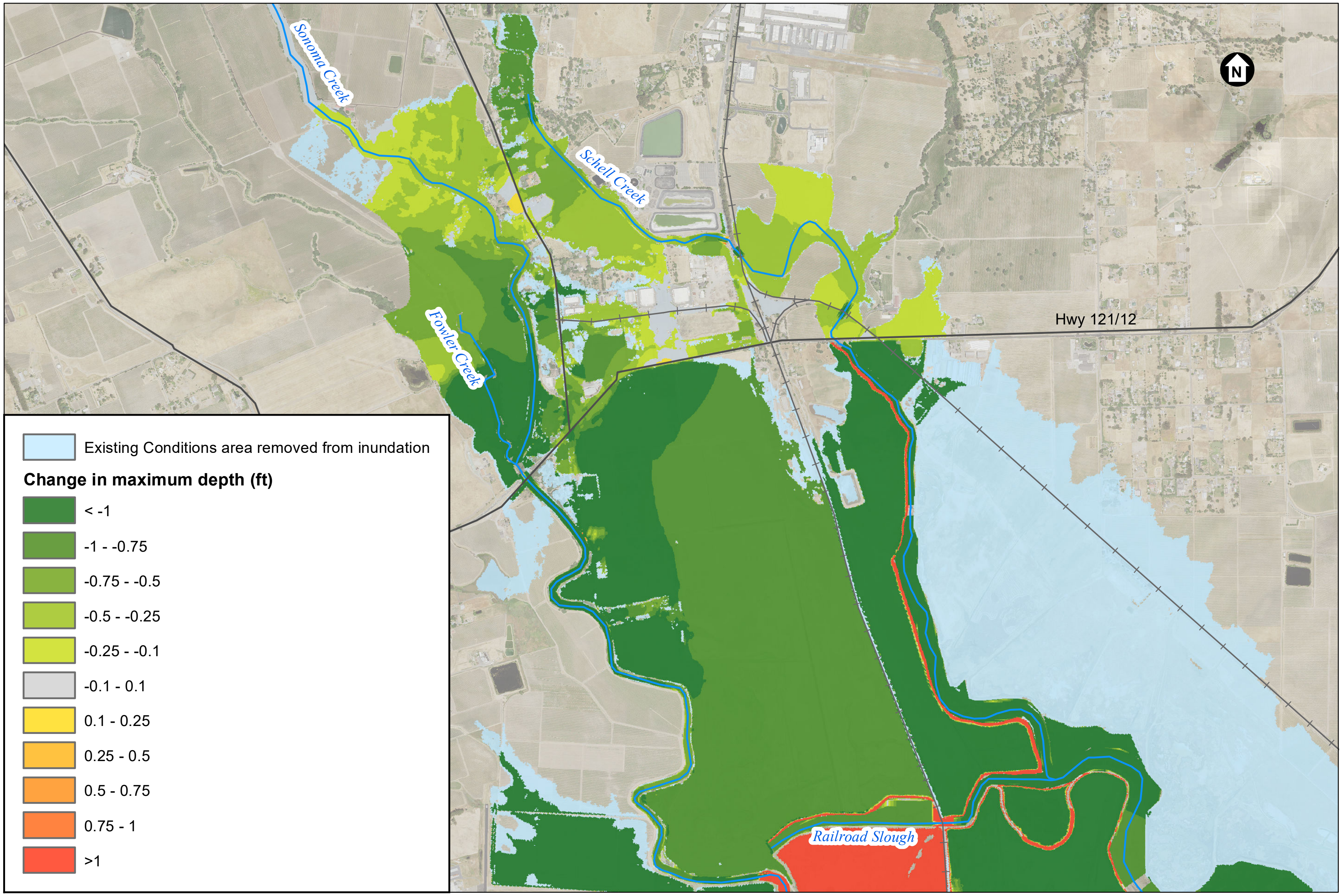
Figure 16
Change in maximum depth, 2050 1% flow, elevated tide w/SLR
Alternative 1 minus Existing Conditions



SOURCE: NAIP (2014 aerial)

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

ESA

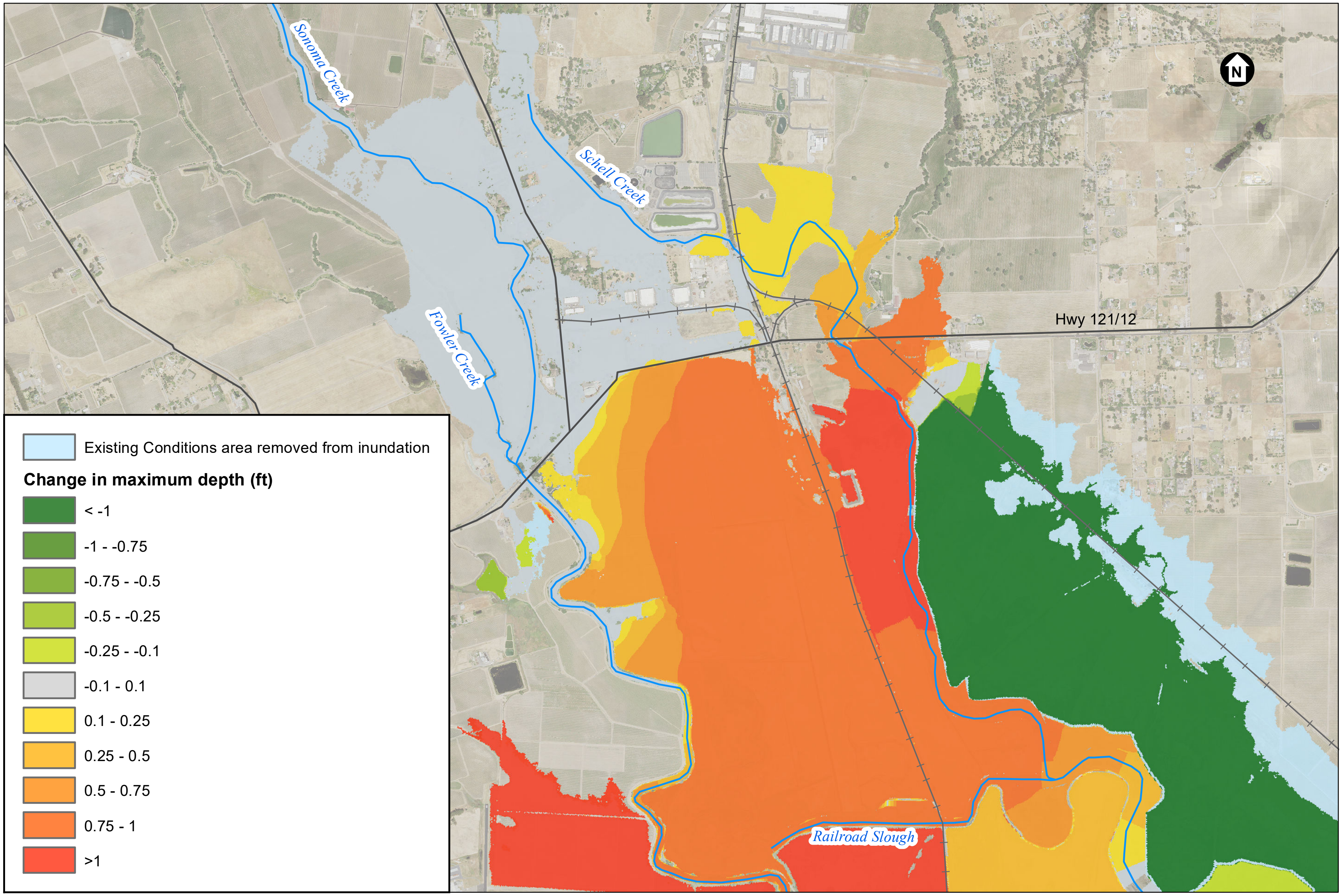


SOURCE: NAIP (2014 aerial)

Lower Sonoma Creek Strategy

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

ESA



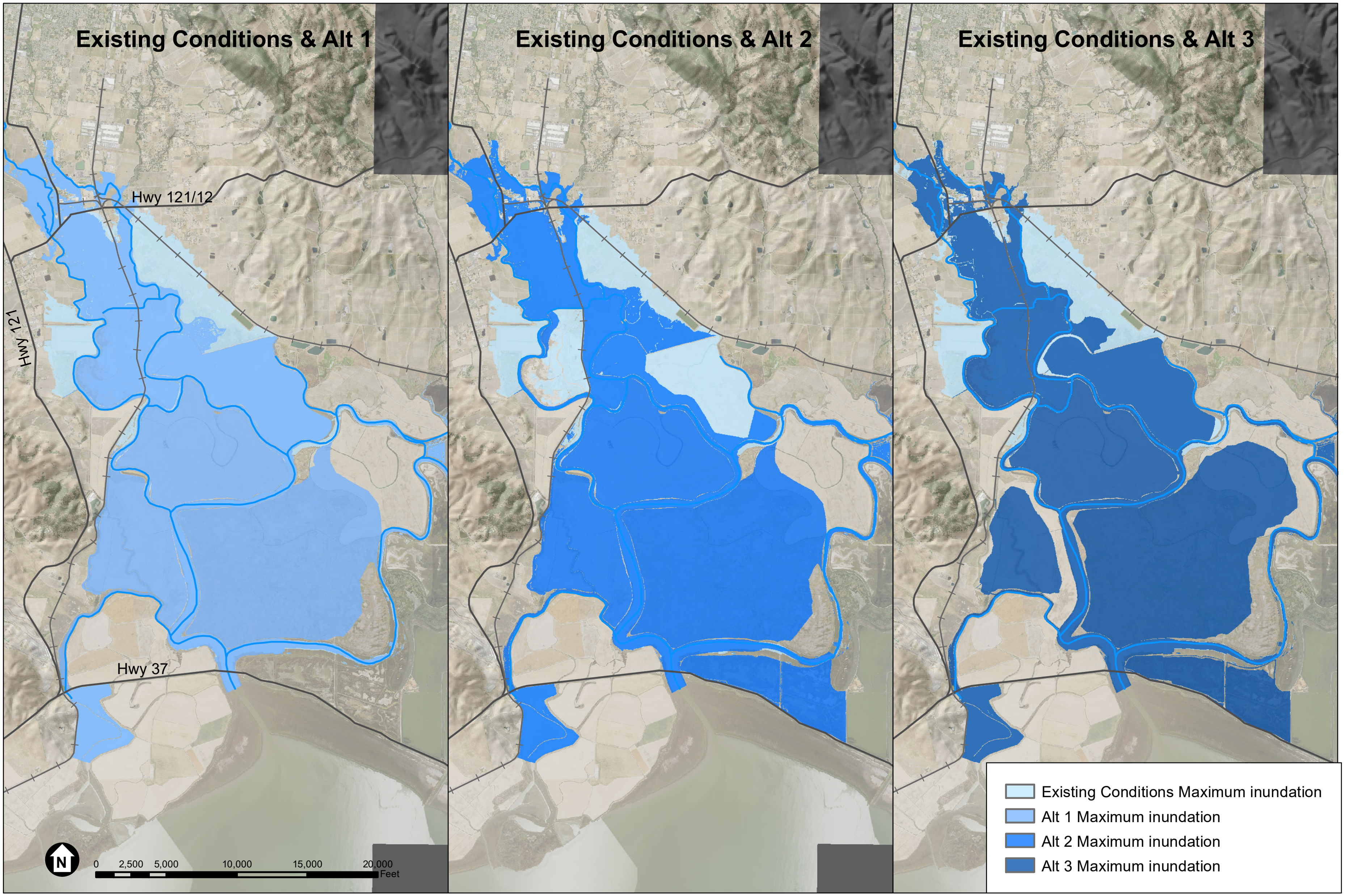
Path: U:\GIS\GIS\Projects\18xxx\D180152_SonomaCreekBaylands_Strategy\03_MXDs_Projects\Figures\04_HydroReport\19_InundationMap_DepthChange_Alt0_EC_2050Q100_NYEtide_wSLR.mxd, jgregory 1/5/2020

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



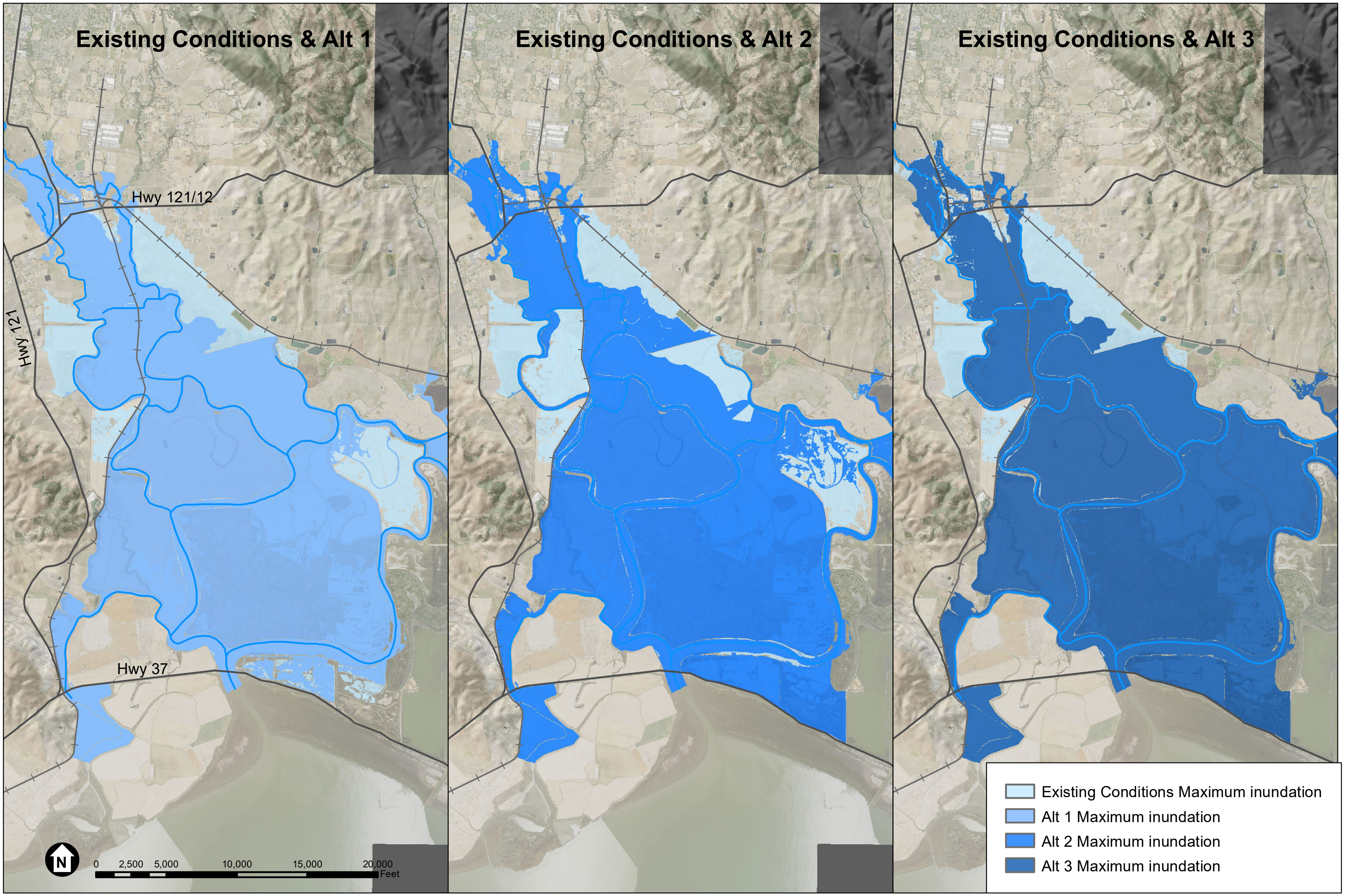
SOURCE: NAIP (2014 aerial)

Sonoma Creek Baylands Strategy

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

ESA

Path: U:\GIS\GIS\Projects\18xxxx\D180152_SonomaCreekBaylands_Strategy\03_MXDs_Projects\Figures\04_HydroReport\20_InundationMap_100yr_TT.mxd, jgregory 1/5/2020

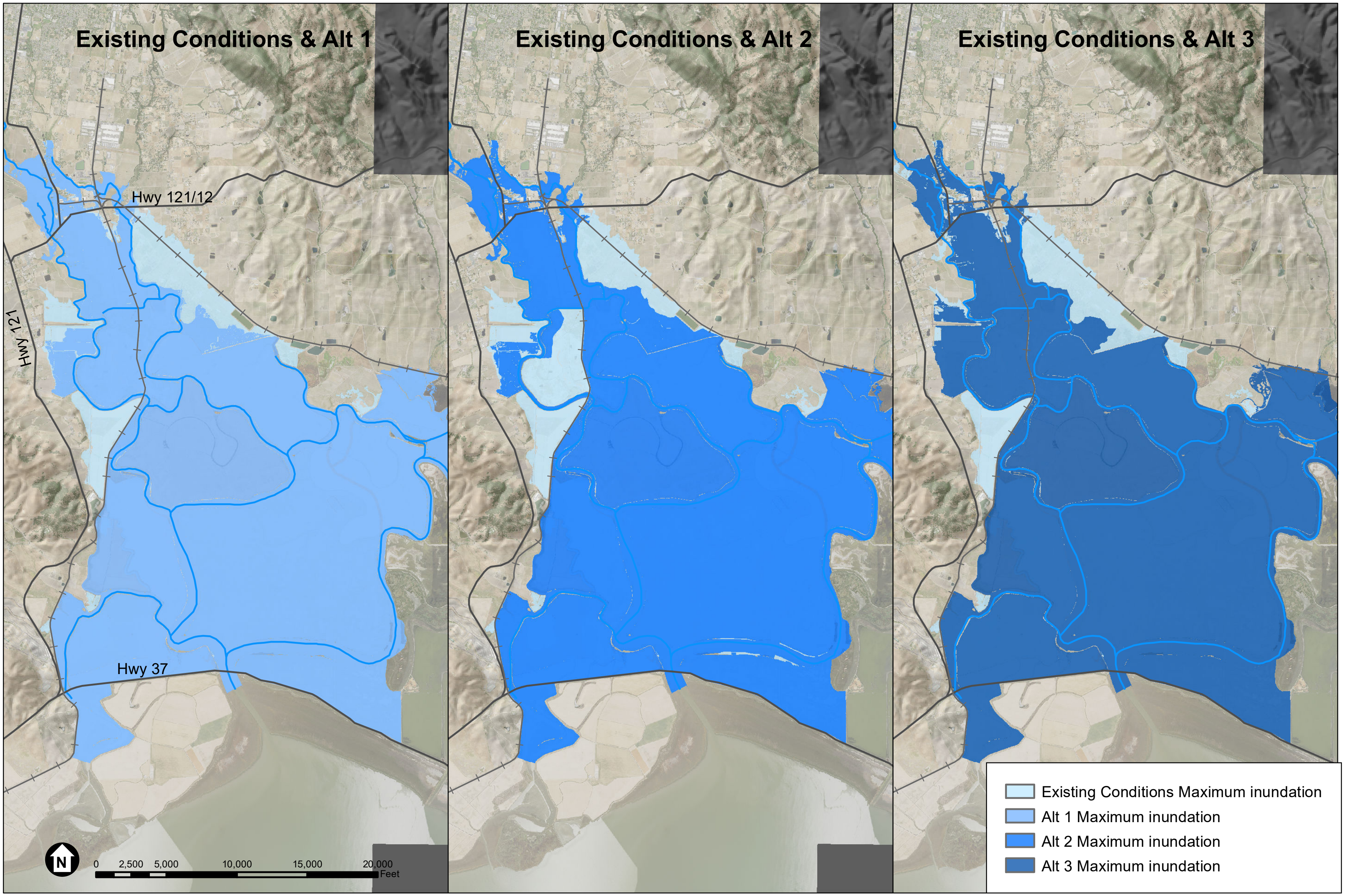


Path: U:\GIS\GIS\Projects\18xxxx\D180152_SonomaCreekBaylands_Strategy\03_MXDs_Projects\Figures\04_HydroReport\21_InundationMap_100yr_NYEtide.mxd, jgregory 12/15/2019

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



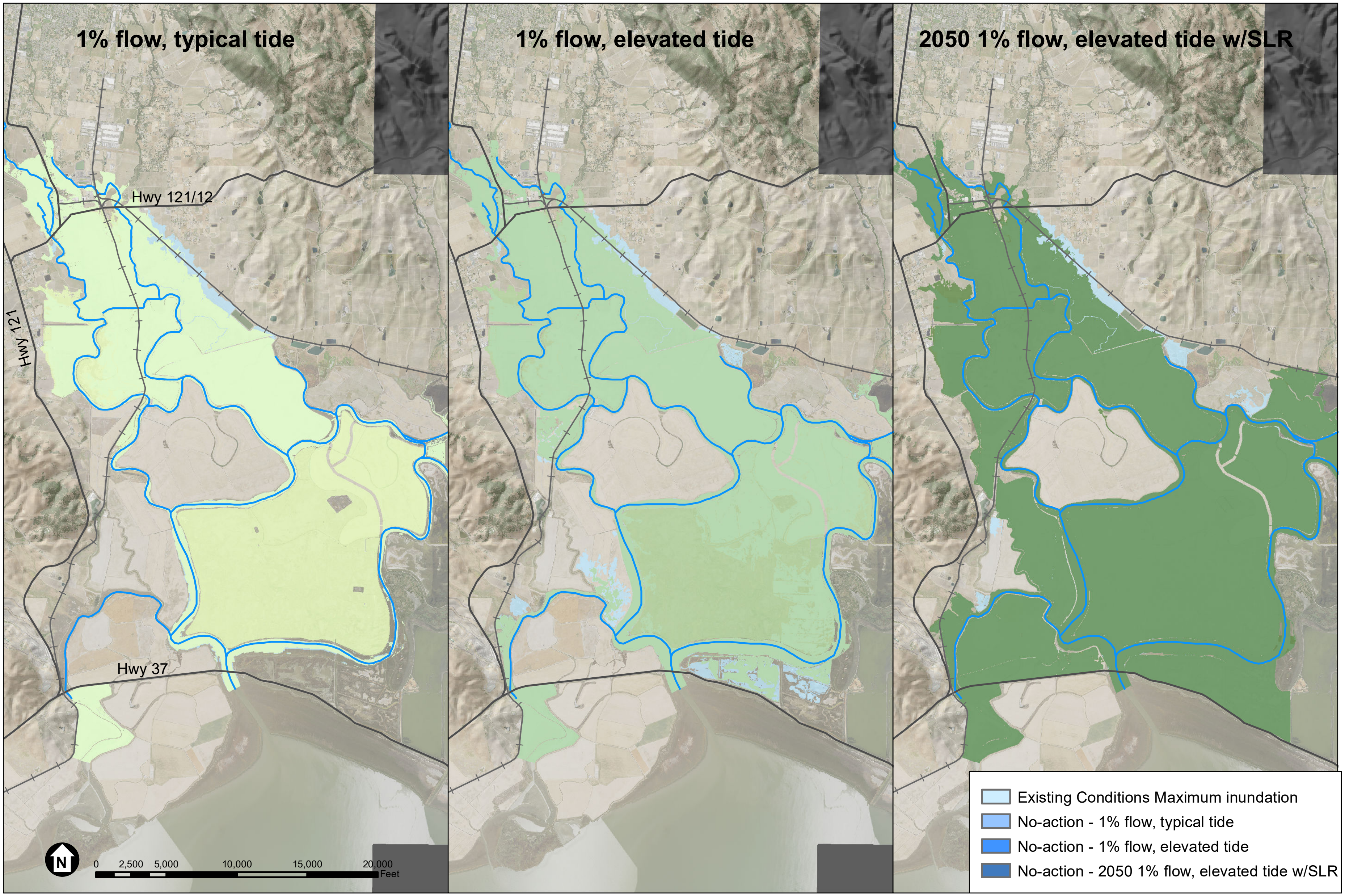
Path: U:\GIS\GIS\Projects\18xxxx\D180152_SonomaCreekBaylands_Strategy\03_MXDs_Projects\Figures\04_HydroReport\22_InundationMap_2050100yr_NYEtide_wSLR.mxd, jgregory 1/6/2020

SOURCE: NAIP (2014 aerial)

Sonoma Creek Baylands Strategy

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

ESA



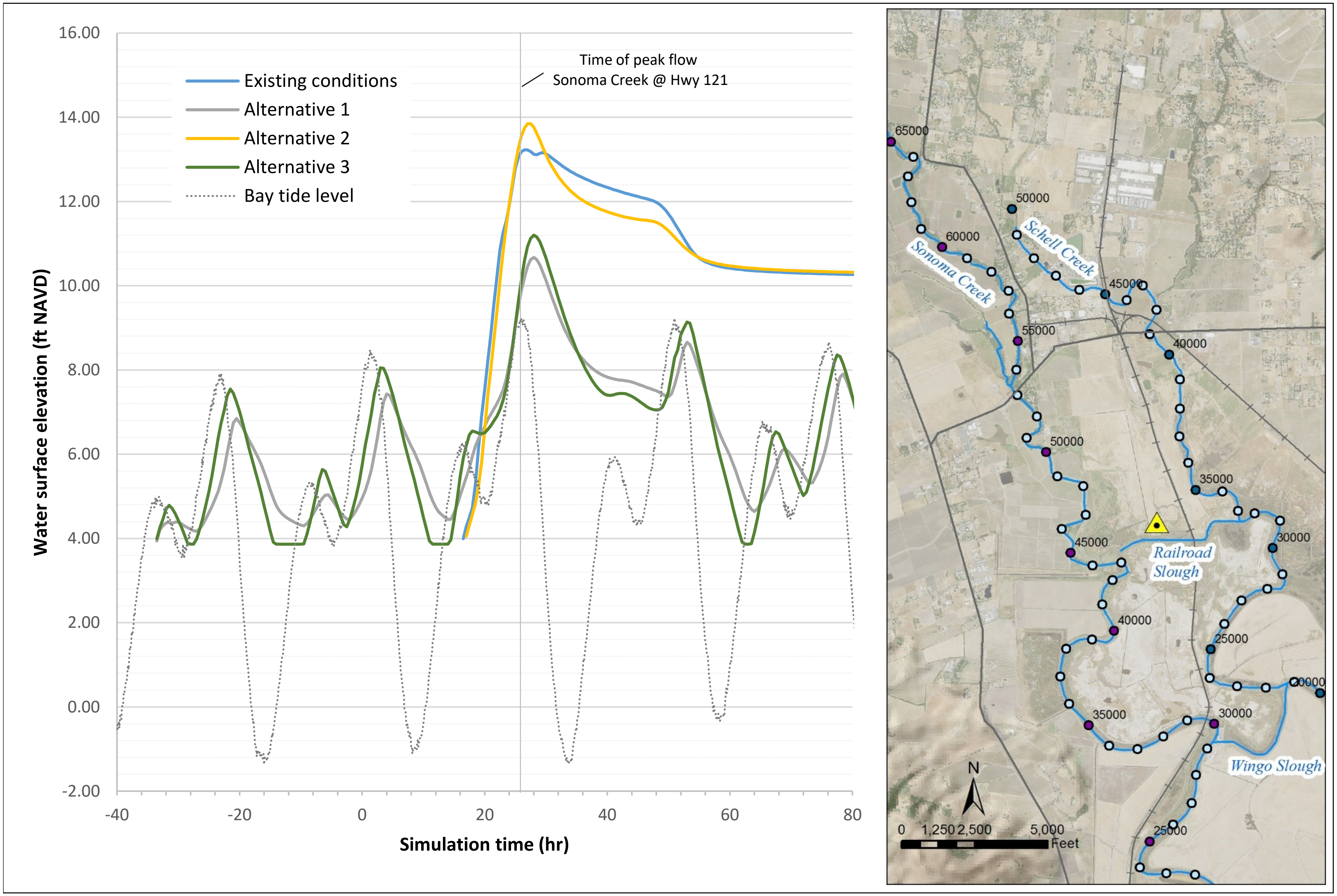
Path: U:\GIS\GIS\Projects\18xxx\D180152_SonomaCreekBaylands_Strategy\03_MXDs_Projects\Figures\04_HydroReport\23_EC-NoAction_InundationMap_AllScenarios.mxd, jgregory 1/6/2020

SOURCE: NAIP (2014 aerial)

Sonoma Creek Baylands Strategy

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

ESA

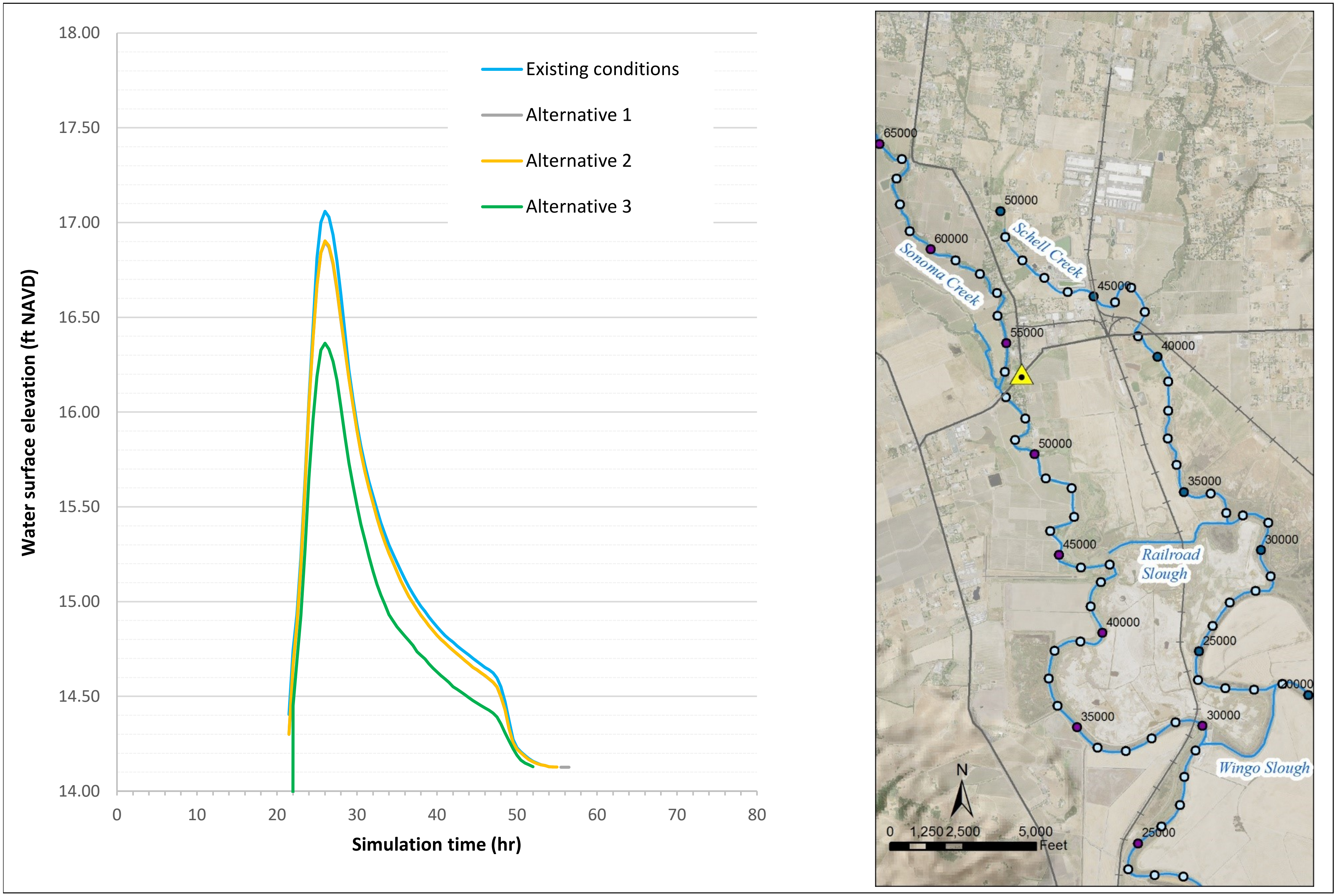


NOTE: Time series shown at yellow marker on righthand map panel

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.