City of Sausalito

Gate 5 Road Vulnerability Assessment Memo Draft

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Abbreviations and Glossary

Abbreviations

Abbreviation	Description
AAL	Average Annual Loss
BCDC	San Francisco Bay Conservation and Development Commission
DEM	Digital Elevation Model
FFE	First-Floor Elevation
MHHW	Mean Higher High Water
OPC	California Ocean Protection Council
RSAP	Regional Shoreline Adaptation Plan
SLR	Sea Level Rise
SSP	Shared Socio-economic Pathways

Glossary of terms

Term	Explanation
Average Annual Loss (AAL)	The average expected economic loss from flooding in a given year, accounting for the probability and damages of a wide range of flood events. It is the integral of the loss-probability function.
Annual Exceedance Probability (AEP)	The probability that a flood of a given size or greater will occur in any single year. A 1% AEP event has a 1-in-100 chance of occurring in any given year.
Compound Flooding	Flooding caused by two or more drivers — such as storm surge and heavy rainfall — occurring simultaneously.
Depth-Damage Function	A curve that relates flood depth — measured from the top of the first finished floor — to damage expressed as a percentage of replacement cost. The output is a damage percentage that is then translated into a dollar loss estimate.
Discount Rate	A percentage used to convert future costs into their present-day value. A higher discount rate places less weight on future losses. This study uses 0% (undiscounted), 2%, and 7% discount rates.
First-Floor Elevation (FFE)	The elevation of the lowest finished floor of a building. A building is considered exposed to flooding when water depth exceeds its first-floor elevation.

Term	Explanation
Flood Risk	The likelihood and adverse consequences of flooding. Flood risk for assets and people for any location in a floodplain is a function of flood hazard at that location and their exposure and vulnerability to the flood hazard (USACE, 2015).
Hazus	Hazus, short for Hazards United States, is a geographic information system (GIS)-based software tool created and distributed by the Federal Emergency Management Agency (FEMA) to help communities assess and manage risks from natural hazards (floods, earthquakes, hurricanes, tsunamis). It provides standardized depth-damage curves for buildings and content losses based on building type and occupancy.
Land Subsidence	The gradual sinking of the ground surface over time due to natural or human-caused processes. In coastal areas, subsidence lowers land relative to sea level, compounding flood risk.
LiDAR (Light Detection and Ranging)	A remote sensing technology that uses laser pulses to measure the distance to the Earth's surface.
Mean Higher High Water (MHHW)	The average of the daily higher-high tide.
Pluvial Flooding	Flooding that results from rainfall in which water accumulates faster than it can dissipate, either through infiltration or drainage methods.
Present Value	The current value of future costs, calculated by applying a discount rate. Used in this study to express flood losses in today's dollars.
Return Period	A statistical expression of how often a flood event of a given size is expected to occur on average. A 100-year return period event has a 1% chance of occurring in any given year. Return period and AEP express the same concept in different ways.
Sea Level Rise (SLR)	The long-term increase in average ocean water levels resulting from climate change, driven by the thermal expansion of warming ocean waters and melting of glaciers and ice sheets.
SLR Scenarios	Planning scenarios defined in the *State of California Sea Level Rise Guidance: 2024 Science and Policy Update* (OPC, 2024) to represent a range of plausible future sea level conditions.
Shared Socio-economic Pathways (SSPs)	Shared Socioeconomic Pathways (SSPs) are climate change scenarios of projected socioeconomic global changes up to 2100 as defined in the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report on climate change in 2021.
Storm Surge (1-yr and 100-yr)	A sustained rise in sea level above the normal predicted tide as a result of a storm event. A 1- yr storm surge is expected to occur once per year while a 100-yr storm surge has a 1% chance of occurring in any given year.

Term	Explanation
Tidal Flooding or Inundation	Flooding that results from high tides encroaching along the shoreline or pushing water up a storm drain network.
XP-SWMM	XP-Stormwater Wastwater Management Model is an integrated 1D/2D modeling solution for stormwater and wastewater management supporting urban planning, growth, and flood mitigation efforts. It is a commercial software package building upon the open-source engine developed by the US Environmental Protection Agency.

Executive summary

The City of Sausalito faces increasing flood risk along Gate 5 Road and the surrounding area due to the combined effects of sea level rise, storm surge, rainfall-driven (pluvial) flooding, and land subsidence. This vulnerability assessment evaluates how flood exposure and risk are expected to evolve under current conditions and future planning horizons—2025, 2050, 2080, and 2100—to support informed decision-making on flood mitigation strategies and long-term adaptation planning.

Flood hazard conditions were evaluated using integrated hydrologic and hydraulic modeling that combines pluvial flooding, tidal influence, storm surge, sea level rise, and subsidence. Modeling scenarios were developed in accordance with California state and regional guidance and reflect best available science. Results show that flooding along Gate 5 Road is already occurring under relatively frequent events and is projected to worsen substantially over time, with increases in flood depth, spatial extent, and duration driven primarily by storm surge, rising sea levels, and land subsidence.

Subsidence analysis indicates that ground elevations in the project area are lowering at rates between approximately 0.2 and 0.6 inches per year, compounding future flood hazard by reducing effective freeboard over time. By 2050, cumulative subsidence may reach up to approximately 1.25 feet, increasing to as much as 3.75 feet by 2100. While these estimates are consistent with prior studies, uncertainty increases for longer-term projections, highlighting the need for continued monitoring and future refinement.

Model results show that under present-day conditions, localized flooding of Gate 5 Road occurs during relatively frequent storm events, with shallow depths and moderate durations. By mid-century, flooding expands to affect most of the roadway, with inundation lasting up to 18 hours. By late-century, projected flooding becomes severe, with durations approaching a full day. Flooding is predominantly driven by storm surge and overland flow from Richardson Bay, with rainfall playing a secondary and decreasing role over time. By 2080 and 2100, overland flooding is the primary source of inundation even in the absence of a high storm surge event, and most of the area from the coast up to Gate 5 Road will be under water during a typical tidal cycle.

Building exposure and risk increase markedly across all future scenarios. Undiscounted Average Annual Loss (AAL) estimates indicate that expected flood damages from storm surge will likely rise from approximately $17.6 million in a year in 2025 to nearly $50 million by 2050 and over $110 million by 2080, with building contents accounting for the majority of these losses. Lifecycle “do-nothing” risk analysis, which quantifies cumulative flood damages over the 2025–2080 period, estimates total undiscounted losses of approximately $2.37 billion. Even when discounted to present value, projected damages remain substantial (approximately $466 million with 7% discount rate), underscoring the long-term economic consequences of inaction. A chronic inundation threshold was applied to identify when buildings are expected to become functionally unusable; results indicate that nearly 90 buildings in the study may reach this condition by 2100.

A compound flooding stress test confirms that storm surge is the dominant driver of risk in the project area. While precipitation can modestly increase losses—particularly in early planning horizons—its relative contribution declines over time as sea level rise and subsidence increasingly govern flood behavior.

Overall, this assessment demonstrates that flood risks along Gate 5 Road will escalate significantly over the coming decades without intervention. The findings provide a critical technical foundation to support the development and evaluation of adaptation, mitigation, and infrastructure strategies aimed at reducing flood impacts, improving resilience, and protecting the economic vitality of the Gate 5 corridor and surrounding community.

1. Introduction

This document summarizes the vulnerability assessment for Gate 5 Road and the surrounding low-lying shoreline area in the City of Sausalito. The purpose of the assessment is to evaluate existing and future flood hazards and to characterize how exposure and risk may change over time due to sea level rise (SLR), storm surge, rainfall-driven (pluvial) flooding, and land subsidence. Flood scenarios were developed using available state and regional guidance and were evaluated for multiple planning horizons to support near-term decision making and longer-term adaptation planning.

This document is organized to provide a clear basis for planning decisions. Section 2 summarizes the hazard conditions and scenarios evaluated, including present-day and future planning horizons. Section 3 summarizes exposure and risk results, including building exposure and key risk metrics. Appendices provide supporting technical information, assumptions, and reference material used to develop the assessment.

2. Hazard Assessment

2.1 Hazard Overview

Several hazard sources exist in the study area that can lead to significant flooding and associated damage and disruption. Key hazard sources include SLR, tidal inundation, storm surge, pluvial flooding and land subsidence.

Sea levels are rising at accelerating rates, leading to increased risk to coastal communities. As sea levels rise, the likelihood of inundation increases chronically during regular tidal patterns and acutely during storm events.

Storm surge is the amount of temporary increase in sea level above the predicted astronomic tide due to changes in the atmospheric and meteorologic conditions. This leads to elevated water levels during storm conditions that contribute to coastal flooding.

Pluvial flooding is flooding that results from rainfall in which water accumulates faster than it can dissipate, either through infiltration or drainage methods. While pluvial flooding can occur independently of coastal processes, its effects in coastal settings are often influenced by elevated baseline water levels, shallow groundwater, and limited drainage capacity associated with tidal conditions.

Subsidence is the downward vertical movement of the Earth's surface, which may include both natural and man-made reasons such as natural compaction or mining. This is a particularly hazardous phenomenon in coastal areas as it lowers the land surface relative to sea level, exacerbating the other hazards mentioned above. Accordingly, subsidence is incorporated in all future-year hazard modeling to reflect relative sea-level change compared to land elevations.

2.2 Flood Scenario Selection and Rationale

Flood scenarios were selected using guidance from state and regional adaptation planning frameworks to ensure consistency with best available science and alignment with regional decision-making practices. Scenario selection was informed by the State of California Sea Level Rise Guidance: 2024 Science & Policy Update published by the California Ocean Protection Council (OPC), and by the Regional Shoreline Adaptation Plan (RSAP) Data Sources and Analytical Methodology Report prepared by the San Francisco Bay Conservation and Development Commission (BCDC).

The OPC guidance provides location-specific sea level rise projections for coastal California, including distinct values for the San Francisco Bay, which were used to define time- and scenario-specific SLR inputs for the study area. The BCDC RSAP methodology provides regional recommendations for flood scenario design in adaptation planning, including guidance on appropriate combinations of tides, storm surge return periods, and planning horizons.

Consistent with this guidance, projected sea level rise was incorporated into the flood scenarios developed for the considered time horizons using time- and scenario-specific SLR projections. This was done to reflect the continually increasing rates of SLR. Storm surge was evaluated using 1-year and 100-year return periods, reflecting both frequent nuisance flooding and extreme coastal flooding conditions recommended for adaptation planning. In addition, a no-surge condition was evaluated to allow isolation and interpretation of non-surge flood mechanisms, such as precipitation-driven and baseline tidal flooding, where appropriate.

The SLR scenarios evaluated include present-day conditions, and future, Intermediate planning scenarios for 2050, 2080, and 2100, as well as a High planning scenario for the 2100 horizon, consistent with the State of California Sea Level Rise Guidance (OPC,2024). For the San Francisco Bay region, the OPC guidance identifies 0.8 ft of sea level rise by 2050 under the Intermediate scenario, increasing to 3.1 ft by 2100, values that are also reflected in the RSAP.

The emphasis on the Intermediate scenario for mid-century horizons is consistent with recommendations in the RSAP, which identifies 0.8 ft of sea level rise by 2050 as a required minimum coastal flood hazard condition for vulnerability assessment and adaptation planning, and recommends inclusion of higher scenarios primarily at the end-of-century horizon. This approach is further aligned with the Sausalito Shoreline Adaptation Plan (2025), which evaluates 2050 conditions using 0.8 ft of sea level rise and focuses end-of-century analysis on Intermediate and High sea level rise planning scenarios in combination with extreme tide conditions.

Accordingly, the Intermediate SLR scenario was used to represent plausible future conditions for mid-century risk assessment, while both Intermediate and High scenarios were included at the 2100 horizon to support long-term adaptation planning. The set of scenarios for 2025 without SLR was included to characterize present-day or near-term events where future SLR is not a dominant factor in the flooding of Gate 5 Road.

Pluvial flooding was evaluated using 10-, 25-, 50-, and 100-year precipitation return periods. This range of return periods were considered to provide a comprehensive view of events that represent the present and future conditions that may affect the City of Sausalito. These are common return periods used in hazard assessments and can help to prepare an area against flooding under such conditions. Additionally, these return periods are commonly used for sizing infrastructure to future flood events and therefore will aid any conceptual design based on this study.

Future precipitation projections were evaluated using a single emissions pathway, the Shared Socio-economic Pathway (SSP) 2-4.5, which represents a moderate emissions trajectory and is slightly more conservative than the higher-emissions SSP 3-7.0 pathway, further supporting its selection as a planning scenario This pathway was selected to maintain consistency with the Intermediate SLR planning scenario and to avoid combining incompatible climate assumptions across hazards. Precipitation projections were therefore not paired with multiple emissions pathways, as the objective of the analysis was to assess flood sensitivity and relative exposure under plausible future conditions rather than to bracket the full range of global emissions uncertainty. This means that if the actual emissions differ from this assumed trajectory, it could result in increased pluvial flooding risk than what is shown in this analysis. Projected changes in extreme precipitation under various SSPs are summarized in Appendix B.

Flood hazard conditions were evaluated using four time horizons including 2025 (present conditions), 2050, 2080, and 2100. Precipitation-driven and compound flooding scenarios were evaluated through 2080, reflecting limitations and increasing uncertainty in precipitation projections at longer horizons. The 2100 horizon was included to support long-term planning and shoreline adaptation considerations related to SLR but was not used in the quantitative risk calculations presented in Section 3.

To fully analyze future flood risk and conditions in the project area, using this framework, a total of 36 scenarios combining pluvial, tidal, SLR and subsidence conditions were defined and analyzed using XP-Stormwater Wastewater Management Model (XP-SWMM) 2026 software from Autodesk (Section 2.4).

2.3 Subsidence

Subsidence is the downward vertical movement of the Earth's surface and can generally be described as a rate that is length over time, such as inches per year (in/yr) or feet per year (ft/yr). There are several types of subsidence with different mechanisms such as local-scale settlements in subsurface materials due to changes in surface loading or groundwater use, or tectonic-scale plate thinning that results in massive inland basins. For this vulnerability assessment, the mechanism of subsidence was not investigated, but it is likely that both local-scale and tectonic-scale factors are contributing to the subsidence in the Gate 5 project area. The following sections will outline and describe how our team determined a subsidence rate for the project area based on publicly available historical ground surface elevation datasets. Recommendations on how to utilize the subsidence rate and future work to help determine a more project specific subsidence rate are also discussed.

2.3.1 Datasets Used and References

Our team utilized ground surface elevation datasets from three locations:

- United States Geological Survey (USGS) National Map (USGS, 2026)
  - Datasets from 2004 and 2010 were available as LiDAR (Light Detection and Ranging) point cloud data (LPC) as .laz files that were decompressed into .las files that were then converted to digital elevation model (DEMs) in ArcGIS Pro (ESRI, 2025)
  - Dataset from 2018 was readily available as a DEM
- NORCE Maps (NORCE, 2026)
- The NORCE Maps service contains modified Copernicus Sentinel InSAR (Interferometric Synthetic Aperture Radar) data. For the project area, the two data sets utilized were from January 2018 and April 2023. Datasets were viewed directly on the NORCE Maps site.
- Terrain Elevation Difference Analysis 1968-2007 Report (Towill, 2009)
  - Datasets were not directly referenced, but the final elevation difference heat map was utilized

2.3.2 Methods and Assumptions

Data from the three different sources were viewed and analyzed independently from one another.

The three USGS datasets were pulled into GIS as DEMs, and three rasters were made by subtracting the elevation values between the different years: a 2004-2010 raster, a 2010-2018 raster, and a 2004-2018 raster. All datasets utilized a vertical datum of NAVD88 and a horizontal datum of NAD 1983 2011 StatePlane California III FIPS 0403, both in US feet. Ground surface elevation changes were determined by cutting profiles along seven areas of interest on the three elevation change rasters: 1) Gate 5 Rd, 2) Coloma St, 3) Harbor Dr, 4) Bridgeway, 5) Varda Landing Rd, 6) the northernmost Clipper Yacht Harbor point, and 7) the southernmost Clipper Yacht Harbor point (Figure 1).

The two NORCE datasets were similarly analyzed for ground surface elevation changes by cutting the same seven profiles on the NORCE Maps site. The vertical change was presented in millimeters but converted into US inches and feet.

The seven profiles used for subsidence analysis were chosen because of the project's focus on the roadways and stormwater systems that will likely run under the roads in the project area. It was also advantageous to look at the center of roads because it minimizes noise from movable objects (like boats, cars, or buildings).

Note that any spikes in elevation that were not linear (meaning that they are only present in one location along the profile) or any spikes that are anomalous to the rest of the profile (meaning a singular spike of 2 ft when the rest of the profile had a maximum of 0.5 ft) were ignored because they were assumed that it represented a moved object.

Note that positive changes in elevation were largely ignored because they were assumed to represent placement of fill. If the entire profile showed positive elevation change or no change, then a subsidence rate of 0 ft/yr would be assumed.

A rate of subsidence was visually determined for each profile by placing a horizontal line of best fit that ignored spikes in elevation and positive change.

The 2009 Towill report was not used other than to compare the results of the USGS and NORCE data analysis to the Towill heat map. Note that very large and anomalous elevation changes around certain buildings or the coast line were ignored on the heat map; these changes were assumed to be due to construction, specific building settlements, or coastal erosion.

Figure 1 The Seven (7) Profiles of Interest Utilized for Subsidence Analysis.

2.3.3 Data Analysis

Appendix A presents Figure 29 through Figure 35 that represent the elevation changes seen in the seven profiles of interest in the USGS datasets. Note that the vertical axis is elevation change in feet, and the horizontal axis is distance along the select profile. A rate was determined by taking the elevation change in feet and dividing it by the number of years that each raster represented.

Figure 36 through Figure 42 in the Appendix show the elevation changes in the NORCE Maps site. Note that the vertical axis in the bottom graph is the rate of subsidence in mm/yr and the horizontal axis is distance along the select profile. The subsidence rate was then converted into in/yr.

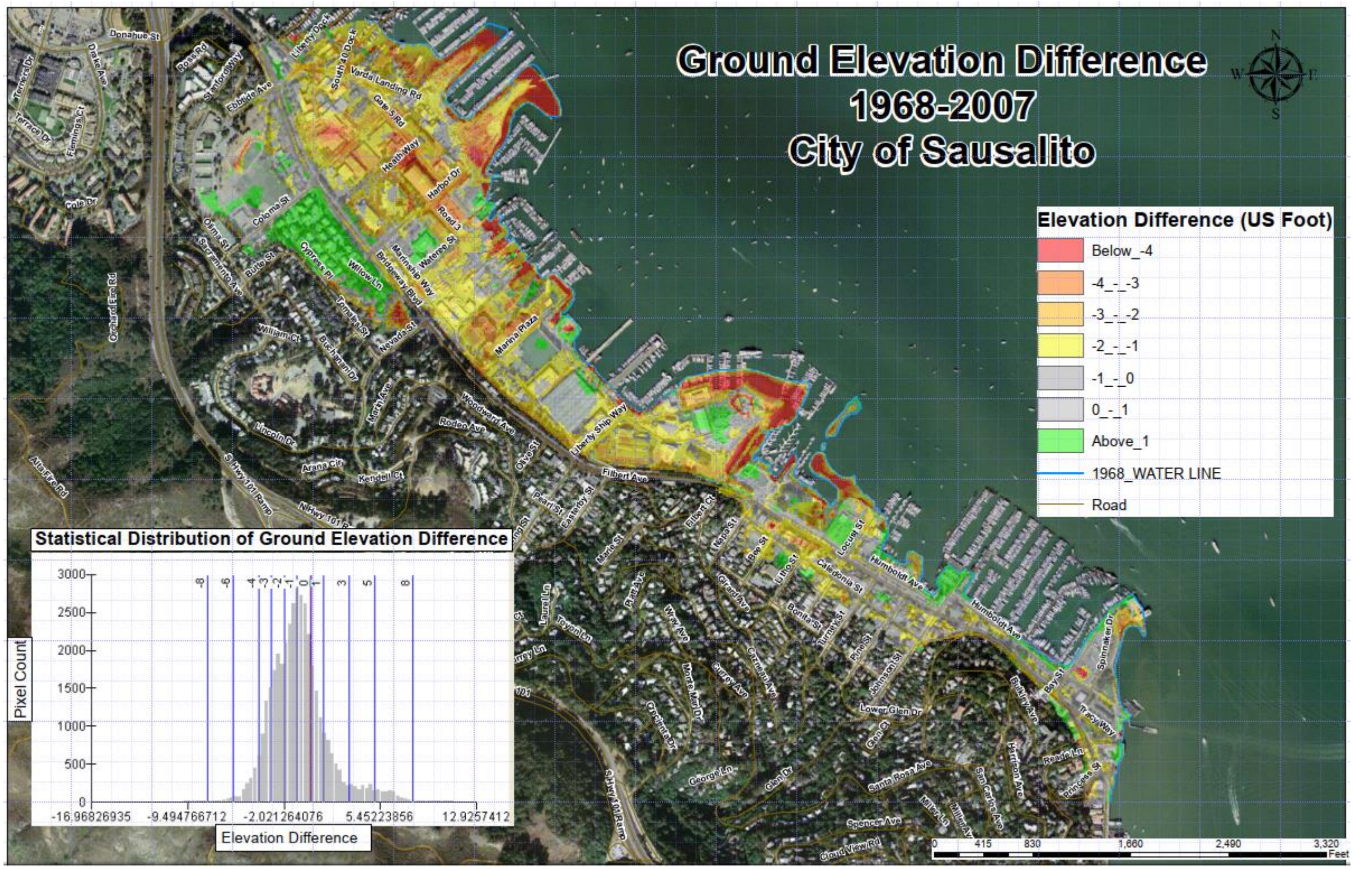


Figure 2 The Towill 2009 Heat Map of Elevation Changes Provided in the Request for Proposals (RFP) for City of Sausalito Gate 5 Area Drainage Management Study (2025).

2.3.4 Conclusions

The USGS datasets and the NORCE Maps datasets are consistent and on average show a range of subsidence values between 0.2 in/yr to 0.6 in/yr. This upper range of 0.6 ft/yr is also largely consistent with the 2009 Towill heat map shown in Figure 2 when we ignore the larger more anomalous settlements seen around some of the buildings and on the coastline. This range of rates for subsidence implies:

- 0.42 ft to 1.25 ft of subsidence in 25 years (2050)
- 0.83 ft to 2.5 ft of subsidence in 50 years (2075)
- 1.25 ft to 3.75 ft of subsidence in 75 years (2100)

While there is a range in the subsidence values, there is not a clear spatial pattern to this range along any of the seven profiles of interest, so this study assumed a single rate of subsidence across the site.

Note that as we go out 75+ years from present, our confidence in the subsidence rate goes down. This is because our analysis is based on historical data mostly constrained in the last 20 years with some data that goes back about 50 years. In the case that subsidence rates or a value is needed to project ground elevations 75+ years out from present, the model should note it is likely the subsidence rate is conservative, especially if the upper values of the range are utilized. This is because subsidence should slow down as time goes on, especially if groundwater and land use are not significantly changed. An example of a significant change in groundwater or land use would be if a large structure is built in this area that requires a deep foundation and local dewatering.

2.3.5 Future Work

For future stormwater system design, it is recommended that a geotechnical desktop study and exploration be conducted to characterize the upper 80ft of subsurface materials to help with final design, construction recommendations, and determine future infrastructure-related settlements.

2.4 Flood Modeling

To model flooding in the Gate 5 Road area, WSP utilized the XP-SWMM software. WSP utilized this software to combine expected pluvial, tidal, SLR, storm surge and subsidence conditions to assess the potential for flooding in the project area. Additionally, this software allows for the interaction of such conditions with a modeled pipe network that mimics the existing storm drain system in the area. The following sections will detail the model inputs, important assumptions and considerations specific to the XP-SWMM model, and the results that were obtained from it.

2.4.1 Datasets

To locate the topography for the XP-SWMM model, WSP utilized USGS LiDAR Explorer (USGS, 2020). The DEMs were sourced from the CA_NorCal_Wildfires_b5b project, published in 2020 (collected in 2018), which provided the underlying .laz files that were merged to be the base elevation data. The original grid resolution of 3.28 feet was retained. To account for projected land subsidence, three additional DEMs were generated to reflect estimated land elevations for the years 2050, 2080, and 2100. For each scenario, the DEM elevations were lowered by the high end of the corresponding range of estimated subsidence values in Section 2.3.4 to conduct a conservative analysis.

As mentioned previously, the SLR values used in this study were selected from the State of California Sea Level Rise Guidance (OPC, 2024). Location-specific median SLR projections for San Francisco Bay were applied to represent relative sea level change at the project site. As shown in Table 1, the analysis incorporates the Intermediate SLR scenario for mid-century and late-century planning horizons (0.8 ft by 2050, 1.8 ft by 2080, and 3.1 ft by 2100), as well as the High SLR scenario for the 2100 horizon (6.5 ft) to support long-term adaptation planning.

Table 1 Sea Level Scenarios for San Francisco Used in This Study (OPC, 2024)

Year	Sea Level Scenario / Median values of Sea Level Scenarios in feet				
	Low	Int-Low	**Intermediate**	Int-High	High
2050	0.5	0.6	**0.8**	1.0	1.3
2080	0.8	1.2	**1.8**	3.0	4.1
2100	1.0	1.6	**3.1**	4.8	**6.5**

Note: Sea Level Scenarios and values used in this study are indicated in bold.

To inform the modeled pipe network of Sausalito's storm drain system, WSP used the CSW-ST2 Technical Assessment Report (CSW-ST2, 2025). The CSW-ST2 Technical Assessment Report was completed in 2025. This report included the evaluation of conditions across the 15 miles of existing storm drain infrastructure in the city of Sausalito. The storm drain system included catch basins, inlets, outlets, and vaults. This assessment evaluated deficiencies, mostly due to degrading material, and recorded their findings using field forms and closed-circuit television footage. This study represented the most complete and recent record of the storm drain system and its condition. The other recent stormwater and flood analysis completed by West and Yost Associates in 2011 (West Yost Associates, 2011) was based on documents and as-builts that originated from the 1970s and 1980s, which were missing critical information, and did not include any field verification of stormwater infrastructure. There were large numbers of discrepancies between the CSW findings and the West and Yost findings. Therefore, one of the two studies had to be selected as the basis for the pipe network modeled within XP-SWMM. The CSW study was selected because it contained more recent data and included field verification of significant portions of the pipe network.

While the CSW survey contained field verified data, the study still lacked sufficient detail for certain elements of the pipe network. As the aim of the CSW assessment was to evaluate condition, several measurements relevant to stormwater modeling, like grate elevations and pipe invert elevations, were missing. General details regarding sizing and location of the system were a component of this report, however WSP had to make some assumptions about the infrastructure sizing based on the surrounding infrastructure. Additionally, there were several missing connections between nodes of the network. WSP therefore did not include portions of the CSW study within the XP-SWMM model.

The tidal inputs used in the model were derived from the updated tidal datums and extreme tide elevations for San Francisco Bay (AECOM, 2016). The study estimated extreme tide elevations based on regionally modeled hydrodynamic conditions. For this project, the tidal datums and extreme tide elevations from Point 15, one of 50 reference points along the Marin County coastline and closest to the project location, was used as a guide. Table 2 shows this information.

Table 2 Tidal Datum and Extreme Tide Elevations Pulled from AECOM Report.

Location		***Tidal Datum***						***Extreme Tide Elevation***							
		FEET-NAVD88						**FEET-NAVD88**							
County	*Point ID*	*MLLW*	*MLW*	*MSL*	*MTL*	*MHW*	*MHHW*	*1-YR*	*2-YR*	*5-YR*	*10-YR*	*25-YR*	*50-YR*	*100-YR*	*500-YR*
Marin	15	0.07	1.09	3.28	3.28	5.47	6.02	7.20	7.55	7.96	8.28	8.76	9.17	9.63	10.94

Land use inputs for the XP-SWMM model were developed using the 2021 National Land Cover Database (NLCD) (USGS, 2021). The NLCD dataset covering the project area was imported into GIS, where land-cover–specific polygons were extracted for the model. These polygons were then imported into the XP-SWMM land use layer and assigned Manning's N values corresponding to each cover type. A total of 12 distinct land-cover classifications were identified within the project area and incorporated into the model. These values are reported in Table 3.

Table 3 Landcover Types and Corresponding Manning N Values.

NLCD Landcover Type	**Mannings N**
Deciduous Forest	0.1
Mixed Forest	0.12
Evergreen Forest	0.15
Developed, Open Space	0.035
Developed, Low Intensity	0.08
Developed, Medium Intensity	0.12
Developed, High Intensity	0.15
Grasslands and Herbaceous	0.04
Open Water	0.035
Barren Land	0.03
Shrub Scrub	0.08
Woody Wetlands	0.08

2.4.2 Methods

The XP-SWMM model was developed using both 1D and 2D components. The 1D component of the model represents the storm drain network in the project area. The 1D captures both tide and rainfall inputs into the system through the nodes and then models its movement through the network. The 2D component of the model represents the topography of the area and models overland flow from the same tide and rainfall inputs. Additionally, the 2D component of the model captures the water that "leaves" the 1D network by spilling out of a catch basin, manhole, etc. when water in the 1D component overruns the system. Establishing proper connectivity between the 1D and 2D components was vital to producing realistic system behavior.

Four model versions were created to represent the 2025, 2050, 2080, and 2100 subsidence scenarios; the only differences among these models were the subsidence-adjusted DEMs and corresponding adjustments to node and link elevations. This included lowering the ground elevation and invert elevations at each node because it was assumed that subsidence would cause the stormwater node and link elevations to lower by the same amount as the overall subsidence amount. The 1D network configuration was based strictly on the CSW survey as mentioned above, and very few assumptions were made regarding pipe connectivity.

A 10 ft grid size with sub-grid sampling was used in the 2D domain to improve spatial resolution and enhance model accuracy. Sub-grid sampling was implemented to better utilize the underlying terrain data by generating a stage–storage relationship for each grid cell based on all elevation values within that cell. This approach provides a more accurate representation of local topography compared to applying a single elevation to the entire 10 ft cell.

Model scenarios were developed to evaluate a range of combined rainfall and tidal conditions for the Sausalito area. Future conditions—including extreme tide levels, projected SLR, and increased storm intensity—were incorporated into the scenarios. Rainfall inputs included no rainfall as well as 10-year, 25-year, 50-year, and 100-year, 24-hour storm events for both present conditions and projected years 2050 and 2080. Tide conditions included no surge (Mean Higher High Water [MHHW]), a 1-year, and a 100-year extreme tide surge event with SLR level rise applied (Section 2.4.1). All scenarios are summarized in Table 4. For the 2100 scenarios, both Intermediate and High SLR projections were evaluated.

Table 4 Model Scenario Summary.

Scenario #	Climate Scenario	Year	Sea Level Rise (ft)	Extreme Tide	Still Water Level (ft) NAVD88	Pluvial
1	N/A	2025	0	1-Year	7.2	N/A
2	N/A	2025	0	100-Year	9.6	N/A
3	N/A	2025	0	N/A	6.0	10-Year
4	N/A	2025	0	N/A	6.0	25-Year
5	N/A	2025	0	N/A	6.0	50-Year
6	N/A	2025	0	N/A	6.0	100-Year
7	N/A	2025	0	1-Year	7.2	10-Year
8	N/A	2025	0	1-Year	7.2	25-Year
9	N/A	2025	0	1-Year	7.2	50-Year
10	N/A	2025	0	1-Year	7.2	100-Year

Scenario #	Climate Scenario	Year	Sea Level Rise (ft)	Extreme Tide	Still Water Level (ft) NAVD88	Pluvial
11	N/A	2025	0	100-Year	9.6	10-Year
12	N/A	2025	0	100-Year	9.6	100-Year
13	Intermediate	2050	0.8	1-Year	8.0	N/A
14	Intermediate	2050	0.8	100-Year	10.4	N/A
15	Intermediate	2050	0.8	N/A	6.8	10-Year
16	Intermediate	2050	0.8	N/A	6.8	25-Year
17	Intermediate	2050	0.8	N/A	6.8	50-Year
18	Intermediate	2050	0.8	N/A	6.8	100-Year
19	Intermediate	2050	0.8	1-Year	8.0	10-Year
20	Intermediate	2050	0.8	1-Year	8.0	100-Year
21	Intermediate	2050	0.8	100-Year	10.4	10-Year
22	Intermediate	2050	0.8	100-Year	10.4	100-Year
23	Intermediate	2080	1.8	1-year	9.0	N/A
24	Intermediate	2080	1.8	100-Year	11.4	N/A
25	Intermediate	2080	1.8	N/A	7.8	10-Year
26	Intermediate	2080	1.8	N/A	7.8	100-Year
27	Intermediate	2080	1.8	1-Year	9.0	10-Year
28	Intermediate	2080	1.8	1-Year	9.0	100-Year
29	Intermediate	2080	1.8	100-Year	11.4	10-Year
30	Intermediate	2080	1.8	100-Year	11.4	100-Year
31	Intermediate	2100	3.1	N/A	9.1	N/A
32	Intermediate	2100	3.1	1-year	10.3	N/A
33	Intermediate	2100	3.1	100-Year	12.7	N/A
34	High	2100	6.5	N/A	12.5	N/A
35	High	2100	6.5	1-year	13.7	N/A
36	High	2100	6.5	100-Year	16.1	N/A

The NRCS (SCS) 24-Hour Design Storm Type IA, most common for this part of California (USDA/NRCS, 1986), was used for the rainfall distributions input into the model. The distributions were in 6-minute increments and for each rainfall event, they were adjusted using a multiplier that was determined from

NOAA Atlas 14 24-HR precipitation frequency data in the project area (USDC/NOAA, 2014). For the future precipitation predictions in 2050 and 2080, the NOAA multiplier values were adjusted using the predicted percent change from current values (See Appendix B).

To determine the catchment basins for the nodes throughout the stormwater network, WSP used the terrain data to delineate the overland flow paths and the boundaries of each catchment basin. WSP then measured key features within each catchment basin, such as the longest flow path length and average slope. The NLCD land cover data was used to determine a composite curve number for each catchment basin. With this information, the time of concentration for each catchment basin was found by utilizing the SCS Lag Time Method. Table 5 below shows key characteristics of the catchment basins along with the time of concentration calculated for each of them.

Table 5 Catchment Basin Characteristics and Time of Concentrations.

Outlet Node / Watershed Name	Longest Flow Path Length (ft)	Avg Slope (%)	Composite Curve Number	S	Lag Time (hours)	Time of Concertation (minutes)
CB 381	584	3.4	98	0.20	0.05	5
CB 383	235	4.2	98	0.20	0.02	2
CB 386	287	3.3	98	0.20	0.03	3
CB 388	786	3.9	97	0.28	0.07	7
CB 362	1030	15.4	87	1.48	0.07	7
CB 365	547	2.1	90	1.12	0.10	10
CB 374	733	3.6	98	0.20	0.06	6
CB 370	946	4.3	94	0.61	0.08	8
CB 369	938	5.1	86	1.68	0.11	11
MH 73	1294	6.9	87	1.52	0.12	12
MH 76	1319	11.4	85	1.77	0.10	10
MH 77	948	15.4	85	1.79	0.07	7
MH 104	790	5.3	88	1.34	0.09	9
MH 75	704	8.7	87	1.49	0.06	6
CB 314	704	24.1	89	1.28	0.04	4

2.4.3 Assumptions and Limitations

Some key assumptions and limitations of this XP-SWMM model and its analysis include:

- The input data used for model development, such as stormwater network information and climate projections, are based on the best available data at the time of model development in January 2026. Climate projections for future conditions are inherently uncertain despite also being based on available data and best practices.
- Model performance is constrained by the solvers and methods within the software. While they are advanced in their capabilities; there is no perfect model of physical hydrodynamics or surface

water processes or their interactions with each other. Therefore, there is inherent uncertainty in the model results no matter the quality of the input data.

- Spatial resolution is limited to available LiDAR and processing software. Even if a finer resolution were available, it is not always feasible due to the increase of model run time and decrease of model efficiency.
- The 1D pipe network in the model is based on incomplete survey data. While generally detailed, significant measurements and connections were missing from the technical assessment report (CSW-ST2, 2025). More specifically, the missing measurements and data from the report were concentrated along Gate 5 Road where the focus of the model results is located. Field survey and verification of these nodes and links could significantly alter model results.
- There was no consideration of private storm water systems or flood mitigation measures on private property. For example, if individual property owners have installed pumps, they were not reflected in the models. As this data was not available in a comprehensive manner and was beyond the scope of this project, it was not included.
- The model results may not convey the worst-case scenario as the peak of the tidal oscillation for the various conditions was not aligned with the peak of the design storm hydrographs. This represents a natural variation but not the ultimate peak flooding that could occur within the reality of the flooding scenarios considered. Simulating all the combinations of how a peak rainfall event and a peak storm surge event could align was outside the scope of this analysis.
- This analysis is limited to the project area and its watershed, which is bound by the northbound lane of Highway 101.

2.4.4 Results

From the XP-SWMM model, several data rasters, such as water depth, duration of inundation and water surface elevation, were generated and used to evaluate the scenarios listed in Table 6. These rasters included Maximum Depth (ft), Maximum Water Surface Elevation (ft) and Duration of Inundation (hr). Together, these outputs were used to assess the extent and characteristics of flooding along Gate 5 Road and the greater project area.

To illustrate the flooding extents and drivers for the various scenarios, a comparison was made for the simultaneous 10-yr rainfall and 1 yr surge events across the four-time horizons. Flooding for this scenario across time horizons is illustrated in Figure 3. Under existing conditions (2025 time horizon), a 10-yr rainfall event and 1-yr surge causes flooding by surcharge from the storm drain system. Approximately 480 ft of Gate 5 Road would be inundated with about 0.5 ft of water in this scenario. This figure is centered on Heath Way running along the STG Beaverton LLC and Modernist Factory LLC properties. The adjacent ditches and parking lots in the surrounding area experience greater water depths reaching 1.6 ft near Heath Way. This area is estimated to remain inundated on average between 4-7 hours with the other areas remaining flooded for up to 16 hours. In this scenario, flooding is also occurring along Varda Landing Road and in the parking lot of Clipper Yacht Harbor. The flooding in these two areas is directly driven by the 1-yr surge because of the lack of storm infrastructure, such as tide gates, in these areas and their proximity to Richardson Bay. These areas are estimated to remain flooded between 1 and 6 hours, varying by specific location. Along Coloma Street the flooding is approximately 0.4 ft in depth. Another location of flooding is seen on the edge of the intersection of Bridgeway Boulevard and Ebbtide Avenue where there is about 1 ft of water. In this scenario, those catch basins are flooded for less than hour.

Under the same rainfall and surge conditions in the 2050 time horizon, the extent of Gate 5 Road extending from Harbor Drive to roughly 60 ft south of Varda Landing would be inundated. This represents over half of Gate 5 Road that would be flooded, and the flooding is estimated to last anywhere from 3 hours to18 hours in the lower parts of the road, particularly around Heath Way. The water depths seen for this event, like in 2025, vary by location, but can be as deep as 2 ft directly on the road. In this case, most of the project area to the east of Gate 5 Road toward the coastline is inundated with water.

For the 2080 time horizon, Gate 5 Road up to about 500 ft away from Bridgeway Boulevard would be inundated. The water depths along the road in this scenario are deeper than the previous time horizons, ranging from 3 to 6 feet on the road and in the surrounding area, while it remains inundated between 13 and 20 hours along the road. Similar depths and duration of inundation are seen between Gate 5 Road and the coastline.

While no rainfall scenarios were considered for the 2100-time horizon, the 1-yr surge conditions (both Intermediate and High) are severe enough that a 10-yr rainfall event would have little impact on the flood depths seen in this scenario. In both the Intermediate and High case for 2100, the entirety of Gate 5 Road is flooded with water. The flood depths in the Intermediate-risk case range from 4 to 8 ft along Gate 5 Road with it being inundated between 16 and 24 hours. In the High-risk scenario, flood depths range from 5 to 12 ft along the road, and most of which is inundated for 24 hours. Additionally, in both cases, flooding extends up to and beyond Bridgeway Boulevard. This results in flooding most of MLK Park and much of the neighborhood between Bridgeway Boulevard and Tomales Street in the High-risk scenario. In this area, flood depths range from 2 to 9 ft and can last anywhere between 2 and 20 hours.

Flooding in the project area is primarily driven by storm surge influence from Richardson Bay. This is particularly true in the future time horizons of 2050, 2080 and 2100, but is also true for parts of the project area under existing conditions. Under existing conditions, most of the surge impacts are due to backflow through the stormwater network. In the future scenarios, overland flow is substantially more significant due to higher water surface elevations and lower ground levels caused by subsidence. Surges are mostly impacting the areas closest to the coastline such as along Varda Landing Road and along the Clipper Yacht Harbor. The flooding that is seen at higher elevations, along Coloma Street, west of Bridgeway Boulevard and parallel to MLK Park, only occurs during 25-yr, 50-yr and 100-yr rainfall events across surge conditions.

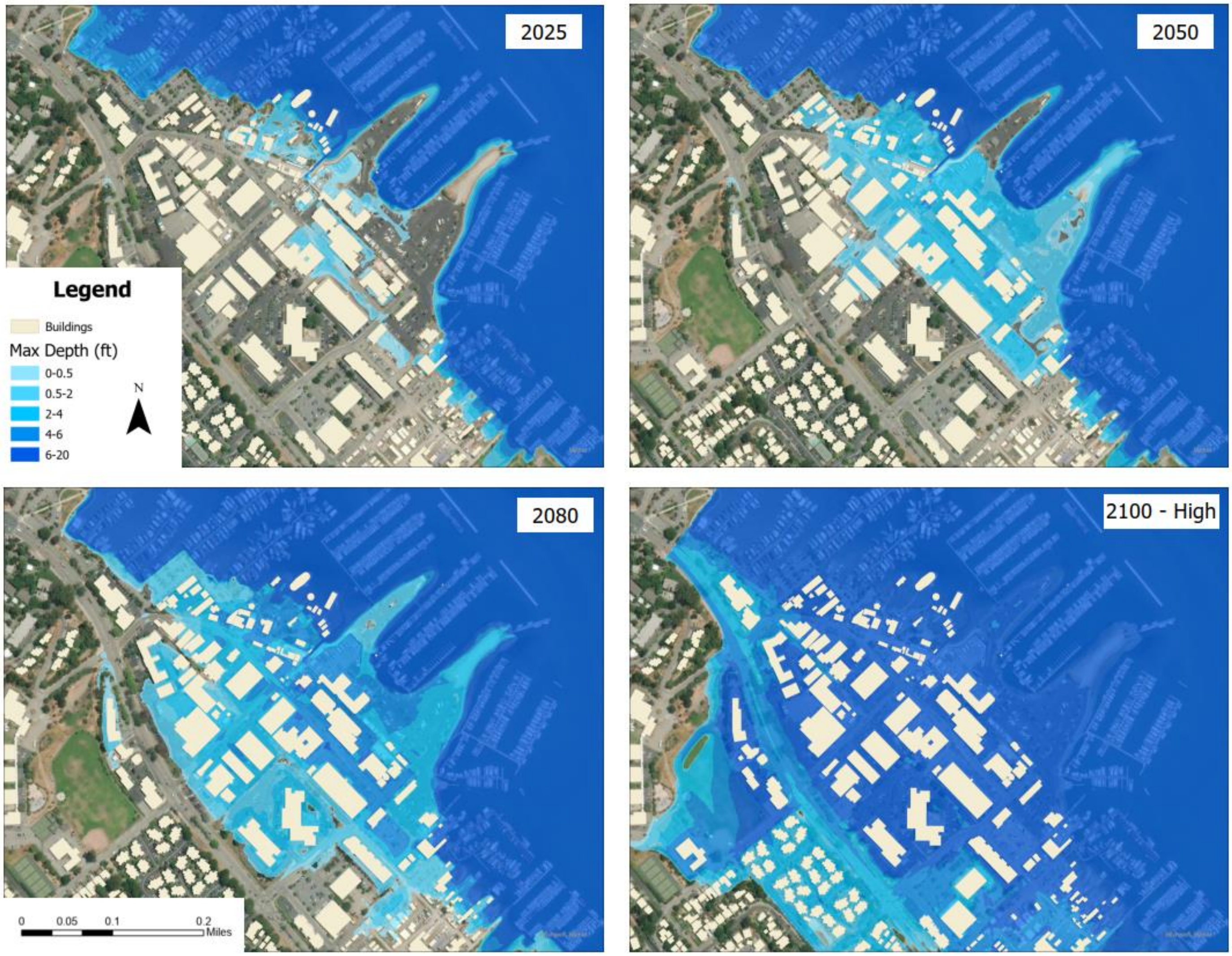


Figure 3 10-yr Rainfall and 1-yr Surge Conditions for all Time Horizons.

At certain tidal surge conditions, overland flow from Richardson Bay becomes the driving force of the flooding seen in the area. This means that flooding becomes independent of the storm drain system along Gate 5 Road and floods as a direct result of tide or storm surge elevations increasing above the land elevations. Under 2025 sea level and subsidence conditions, overland flooding becomes the primary source of flooding during a 100-yr surge event. The effects of rainfall during this surge event are minimal as water covers the project area. Overland flooding leads to flooding along the coast and upland of Gate 5 Road. The flood depths range from 0.5 to 4 ft and can last up to 16 hours. While some overland flooding occurs close to the coastline for the 1-yr surge event in 2025 conditions, flooding in most of the project area is a result of the storm drain system flooding. For the 2050-time horizon, the overland flooding does not become the primary source of flooding until the 1-yr surge event. This results in flood depths of 0.5 to 4.5 ft from the coast up to Gate 5 Road that last up to 18 hours. Under a normal tide cycle (MHHW) in 2050 conditions, the flooding in the project area is a result of both overland flooding and flooding of the storm drain system. This is not the case for 2080 or 2100 when SLR and land subsidence are greater. In these time horizons, overland flooding is the primary source of inundation, even in the absence of a high storm surge event. In 2080 and 2100, the project area will be inundated with water during a typical tidal cycle (MHHW) where most of the area from the coast up to Gate 5 Road will be under water between 18 and 24 hours of the day.

Figure 4 shows the difference between the areas of rainfall-driven flooding and storm surge-driven flooding for the 100-yr rainfall event under current conditions. To show that rainfall has a less significant impact on flooding than tide conditions, the MHHW tide and 100-yr surge conditions are shown. The depth in blue is flooding as a result of the tide/surge while the orange and red depths are a result of rainfall. As shown in the figure, the rainfall-driven depths are rather minimal once overland flow becomes the driving force of flooding.

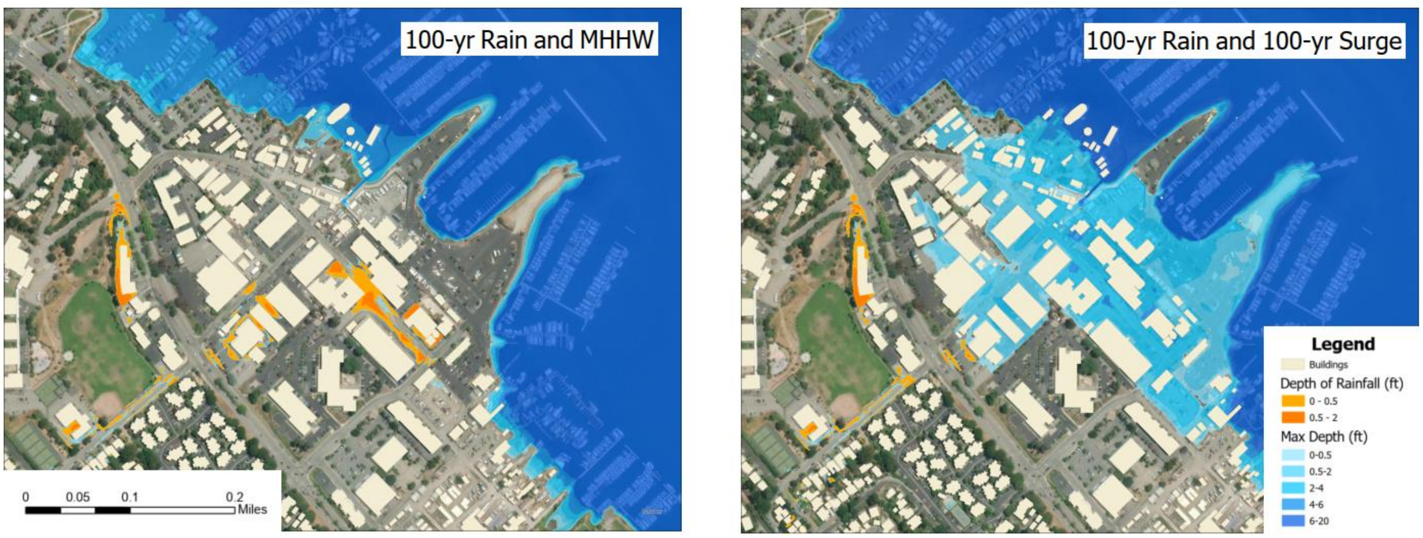


Figure 4 Rainfall Driven Flooding Versus Tidal Driven Flooding in the 2025-Time Horizon.

A comparison across time horizons was also made during MHHW and no rainfall event, which are shown in Figure 5. During a typical tide in 2025 when the MHHW is 6.02 ft and there is no rainfall, the areas with flooding include a small portion of Gate 5 Road centered around the storm water infrastructure at Heath Way. The maximum water depth in this area is minimal at less than 0.5 ft and stays flooded between 1 and 4 hours. For a typical tide in the 2050-time horizon when MHHW is 6.9 ft and there is no rainfall, there is flooding on the majority of Gate 5 Road extending from Harbor Drive to about Varda Landing Road. The maximum flood depths seen across the road in this scenario range from 0.2 ft to 2.5 ft. The duration of flooding along Gate 5 increases to about 1 to 5 hours. Under these 2050 conditions, the extent of flooding is greater and much of the land between Gate 5 Road and the coast and along Varda Landing is flooded with depths up to 3 ft that lasts around 4 to 14 hours. Looking at these conditions in 2080 when the MHHW increases to 7.9 ft, flooding is more extensive. The flooding extends from below Harbor Drive to approximately 200 ft past Varda Landing Road. Like in 2050, the area east towards the coast is mostly flooded, but also continues up Coloma Street towards Bridgeway Boulevard. The flood depths in this scenario get as high as 5 or 6 ft along the roadways and remain flooded for 8 to 21 hours depending on location. For both the Intermediate and High-risk 2100 typical tide with MHHW values of 9.2 and 12.6 ft respectively, the flooding is extensive. Under the Intermediate-risk scenario, flooding occurs in most of the area between Bridgeway Blvd and the coast, including Gate 5 road. Under the High-risk scenario, the flooding extends beyond Bridgeway Boulevard and up Coloma Street, inundating most of MLK park and the neighborhood. The flood depths for the 2100 scenario range from 2 to 10 ft and the flooding lasts between 12 and 24 hours.

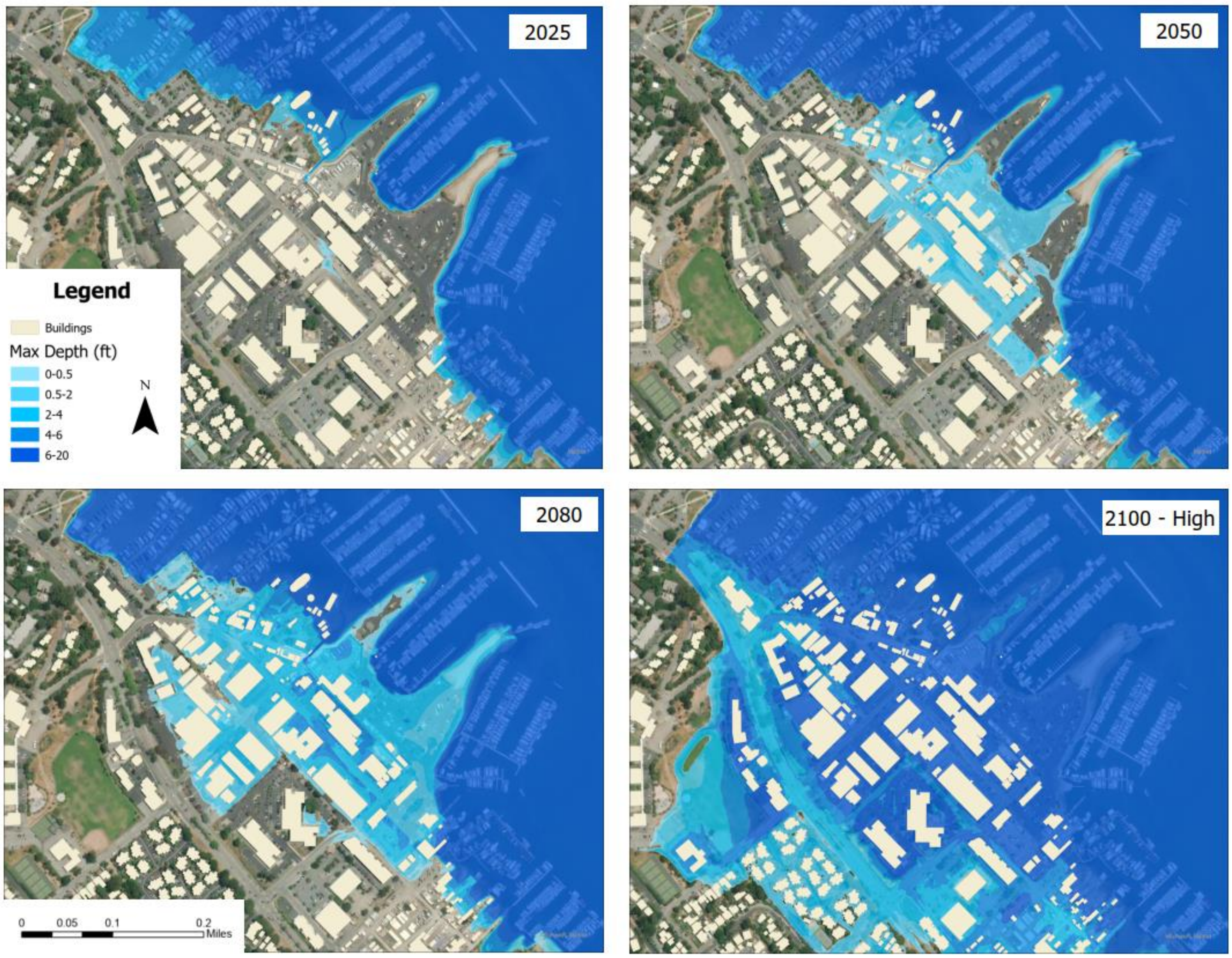


Figure 5 MHHW with No Rainfall for All Time Horizons.

The modeling conducted for this analysis indicates that future flooding in the study area will be driven primarily by overland flow due to SLR and land subsidence. Figures 6 and 7, presented below, show the results of a 1-yr surge and 100-yr surge event across all time horizons respectively. These results illustrate the anticipated flood extents and depths in the absence of mitigation measures and can be referenced when considering future flooding conditions that the Gate 5 Road area will face.

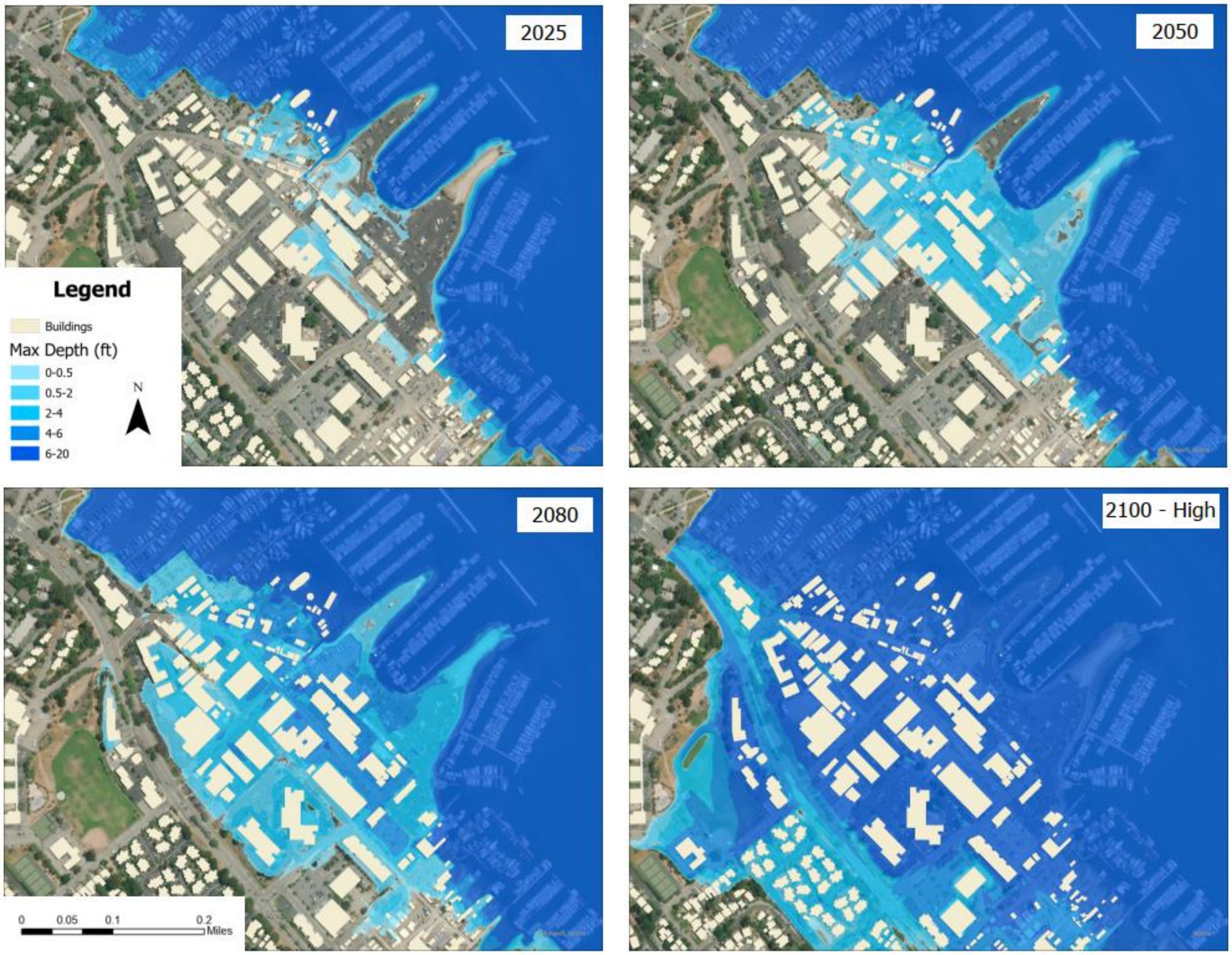


Figure 6 No Rainfall and 1-yr Surge Conditions Across All Time Horizons.

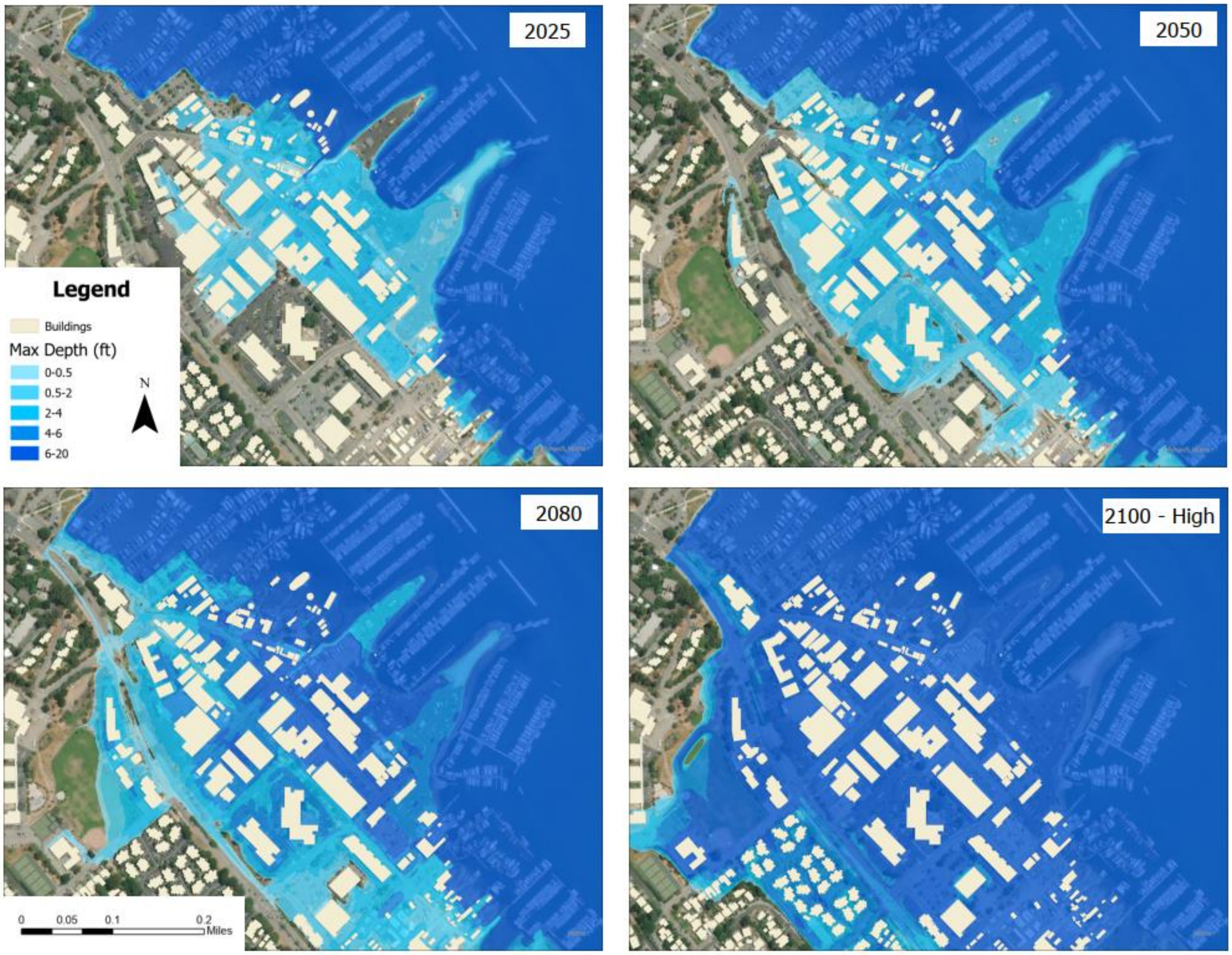


Figure 7 No Rainfall and 100-yr Surge Conditions Across All Time Horizons.

3. Risk Assessment

This section presents the flood risk assessment for the study area, including both exposure and risk analysis. The first part introduces the methodology used and the second part summarizes the results of the analysis.

3.1 Methodology

This section describes the methodological framework used to assess flood exposure and risk. It outlines the data preparation steps, exposure analysis procedures, and risk quantification methods applied to estimate average annual losses, lifecycle risk, chronic inundation triggers, and the sensitivity of results to compound flooding assumptions.

3.1.1 Building Data Preparation and Development

Building-level datasets were assembled and processed to develop a consistent inventory of structures and attributes used in the exposure and risk analyses. The following datasets were used to develop the building inventory for the flood risk assessment:

Marin County

1. Assessor Data:
    a. Land Value
    b. Improvement Value
2. Parcel Boundaries: Used to spatially join assessor data to the building footprints
3. Building Footprints: Used as unit of analysis and for building type to gap fill missing information.

National Structure Inventory (NSI) (USACE)

1. Structure
2. Foundation height (first floor elevation)
3. Number of stories
4. Structure value
5. Contents value

City of Sausalito

1. Critical Infrastructure: Includes Lycee Francais de San Francisco-Private Elementary School and Willow Creek Academy Charter Elementary School within the study area.

An initial total of 439 buildings were developed as part of the study area. Buildings located seaward of the shoreline were excluded from the analysis, as the flood control interventions evaluated in this study are not expected to affect structures outside the coastal boundary. Some of the features are inconsistently represented in the source dataset, further supporting their exclusion from the building-level analysis. This resulted in a total of 427 buildings included in the risk analysis.

Due to data constraints, assessor data at the parcel level was used as the primary value assigned to each building. If more than one building sat on a parcel, the assessed values were allocated proportionally to each building by area. When a single building intersected more than one parcel, they were manually reviewed to assign the appropriate assessor data whether that be a single parcel or more than one parcel. If a building legitimately spans multiple parcels, assessed values from all intersecting parcels were summed to represent the total value available for allocation.

NSI points were spatially joined to building footprints to supplement missing assessor values and or structural information. Multiple NSI points sometimes overlapped with the same building footprint but contained conflicting attributes. If that was the case the value fields were summed, the maximum number of stories was used, and the minimum foundation height was retained.

For each building, the maximum value between assessor-derived and NSI-derived values was retained for use in the risk analysis. Consistent with FEMA's Hazards United States (HAZUS) methodology, building content value is represented as a percentage of the building replacement value and varies by occupancy type. HAZUS assumes that the value of contents in residential buildings is approximately 50% of the structure value, while content values for non-residential buildings can range from 50% to 150% depending on the occupancy and intensity of use (FEMA, 2009). For this analysis, content value was assumed to be 50% of building value for residential buildings and 100% of building value for non-residential buildings, representing a mid-range estimate commonly applied in flood loss assessments.

3.1.2 Exposure Analysis

A GIS model was used to identify buildings in the study area that would be inundated by flood waters under the different flood scenarios. For each building, the maximum water depth was calculated for each modeled flood simulation raster.

3.1.3 Risk Quantification

3.1.3.1 Building-Level Loss Estimation

The analysis focused on flood damages to building structures and their contents in the study area. Losses were estimated for each building under each modeled flood scenario and analysis year using building-level exposure outputs (projected flood depths by horizon year and return period at each building's location). Flood damages were evaluated for the 2025–2080 period.

Depth–damage functions from the FEMA HAZUS flood methodology were used to translate inundation depth into percent damage for structures and contents. HAZUS provides standardized depth–damage relationships for multiple occupancy types and building characteristics, enabling estimation of building and contents losses for a given flood depth. Occupancy classifications from the NSI were used to assign each building an appropriate HAZUS damage function.

3.1.3.2 Average Annual Loss

AAL represents the long-term expected value of flood losses in a given analysis year by combining the likelihood of flood events with their consequences. For each analysis year and building, event losses were estimated across a set of return periods. Each return period T was converted to an annual exceedance probability (AEP) using the standard approximation P=1/T. AAL was then computed via trapezoidal numerical integration over the exceedance probability domain, consistent with common graphical risk-integration approaches (i.e., computing the area under a loss–exceedance curve using discrete probability–loss points). AAL for a given analysis year was calculated as follows:

$$\mathbf{AAL = \Sigma_{i=1}^{n}\ 0.5 \times (L_i + L_{i+1}) \times (P_i - P_{i+1})}$$

Where:

- $\mathbf{L_i}$ = Loss for event i
- $\mathbf{P_i}$ = Annual exceedance probability for event i
- **n** = Number of modeled events/return periods

3.1.3.3 Cross-Horizon Return-Period Mapping for AAL Estimation

To support AAL estimation, losses are evaluated across a set of modeled storm surge scenarios representing key benchmark return periods at discrete horizon years (e.g., 2025, 2050, 2080, and 2100). To further enhance the resolution of the probability–loss relationship used in AAL integration—without requiring additional hydrodynamic simulations—the analysis applied a cross-horizon return-period mapping approach to reuse modeled water levels as additional probability points in other analysis years.

A storm surge frequency relationship was derived from stillwater elevation–return period pairs provided in the AECOM (2016) report for the study area (Table 2). Using this relationship, each modeled total water level (including SLR and subsidence adjustments) was assigned an equivalent return period relative to the storm surge frequency curve of a given reference year. This allowed modeled scenarios from one horizon year to be interpreted as representing additional return periods in another horizon year (i.e., “equivalent return periods”), thereby expanding the loss–exceedance curve used to compute AAL.

For example, the 2050 1-year storm surge water level corresponds to an estimated ~54-year return period under the 2025 storm surge frequency relationship. In this way, the 2050 1-year scenario was used as an additional probability–loss point when estimating 2025 AAL. Similar cross-horizon mappings were developed to supplement the probability–loss curves for the 2050 and 2080 AAL calculations using modeled scenarios from adjacent time horizons. The mapping approach and supporting calculations are summarized in Appendix B. The Log-Pearson Type III fitting procedure and parameters used to perform the return-period mapping are provided in the Appendix.

3.1.3.4 Present Value of Expected Losses

Lifecycle “do-nothing” risk was computed by projecting annual losses over the analysis period (2025–2080) and converting them to present value using selected discount rates. Discounting reduces the weight assigned to losses occurring later in the analysis period and allows comparison of long-term risk on a consistent economic basis. The analysis reports the present value of expected losses as undiscounted totals and discounted totals using 2% and 7% discount rates.

To represent the transition from intermittent flooding to chronic flooding under rising sea levels, the lifecycle analysis incorporates a trigger-year assumption based on a planning threshold (in Section 3.1.4). Buildings are considered to enter chronic inundation when projected water levels reach at least 0.5 ft above first-floor elevation (FFE), a condition intended to reflect frequent, persistent flooding that would disrupt functionality and make continued occupation or repeated repair impractical under a no-action scenario. The first year a building reaches this threshold is defined as its trigger year.

In the lifecycle cost time series, buildings that reach the chronic inundation threshold are assigned a one-time total loss in the trigger year. After that point, additional annual losses for those buildings are not accumulated under the do-nothing condition, reflecting that the building is treated as functionally lost once chronic inundation occurs.

To support lifecycle analysis, AAL estimates computed at milestone years (2025, 2050, 2080) were converted into an annual loss time series across the 2025–2080 analysis period. Because flood modeling results were produced for discrete horizon years, annual losses for intermediate years were estimated by interpolating AAL at the building level between milestone years. For each building and loss component (structure and contents), AAL was computed at the available milestone years and then converted into an annual time series over the 2025–2080 analysis period using piecewise linear interpolation. This produces a continuous annual loss series that reflects gradual changes in surge-driven flood depths under SLR assumptions, while preserving the modeled AAL values at the milestone years.

3.1.4 Chronic Inundation Trigger

To represent the onset of chronic tidal flooding, the analysis defines a planning threshold of 0.5 ft above FFE. When this threshold is reached, a building is assumed to transition into a condition where flooding becomes frequent and persistent enough to disrupt functionality and make continued occupation or repeated repair impractical under a no-action scenario. The timing of this transition is estimated using projected mean water levels driven by SLR and subsidence, evaluated at milestone years and interpolated to identify the first year the threshold is reached.

FFE values are provided as height above local ground (above grade) (see Section 3.1.1). To compute a building-specific trigger in a consistent vertical reference frame, the first floor is converted to an absolute elevation by combining (i) building-level ground elevation in the project vertical datum and (ii) the provided first-floor height above grade. Subsidence projections are provided as cumulative downward land motion relative to 2025. For reporting purposes, subsidence is treated as lowering the effective first-floor elevation over time, reducing freeboard between the first floor and tidal water levels. A depth threshold of 0.5 ft above the first floor is then applied to define a building-specific trigger elevation.

Mean water levels are evaluated at milestone years (2025, 2050, 2080, and 2100) using MHHW in 2025 as the baseline, with SLR increments applied at future milestone years. The threshold exceedance year is computed as the earliest year when the projected mean water level reaches or exceeds the building's trigger elevation. Because projections are available at milestone years, exceedance timing is estimated using piecewise linear interpolation between milestones (2025–2050, 2050–2080, and 2080–2100). If the threshold is not reached by the end of the analysis horizon, the exceedance year is recorded as not exceeded within the study period.

This mean water-level exceedance year is used as a planning trigger representing when baseline tidal levels (inclusive of SLR and subsidence effects) would be expected to reach a defined depth above the first floor. It does not represent event-driven inundation, and it is not intended to substitute for modeled flood depths that incorporate storm surge, precipitation, stormwater system performance, and other transient or nonlinear processes.

3.1.5 Compound Flooding Stress Test Methodology

Results from the flood modeling analysis (see Section 2.4.4) indicate that storm surge is the dominant driver of coastal flooding in the study area, particularly under future SLR and land subsidence conditions. As mean sea level increases and the land subsides, inundation becomes increasingly controlled by elevated coastal water levels, while the relative contribution of precipitation decreases once widespread overland flooding from the coast is established. Based on this understanding, precipitation was not treated as a co-equal probabilistic driver in the baseline risk analysis. Instead, precipitation effects were evaluated using a stress-test framework to assess potential sensitivity to rainfall conditions.

Compound flooding can occur when multiple flood drivers—such as storm surge and intense rainfall—co-occur or occur in close succession, potentially increasing flood impacts relative to assessments that consider drivers independently. In this study, detailed joint probabilities of coincident storm surge and precipitation events were not available; therefore, compound influences were evaluated using a stress-test framework rather than a fully probabilistic joint-occurrence model. This approach is intended to bound potential impacts and test the sensitivity of flood losses to precipitation conditions, while maintaining transparency regarding uncertainties in event dependence.

The stress test estimates conditional AAL under two rainfall conditions (10-year and 100-year precipitation return periods), paired with the coastal surge conditions used in the baseline analysis. Results are reported as “AAL given precipitation scenario,” meaning they represent expected annual losses under the assumed precipitation condition. These results should not be interpreted as unconditional long-term AAL unless the probability of the precipitation condition and its dependence with storm surge are explicitly characterized.

Conditional AAL estimates are intended to provide context on the potential sensitivity of flood losses to precipitation effects and are not summed with, or interpreted as replacing, the surge-only baseline risk results.

3.1.6 Assumptions and Limitations

- The analysis assumes that the building footprint polygons when used in conjunction with the data on the number of stories provides an accurate proxy for the square footage of the buildings themselves. The building footprints were not checked against aerial imagery.
- The USACE NSI dataset was developed using a generalized statistical approach rather than locally verified data. The FFE and number of stories values are likely inaccurate in some cases.
- The selection of FEMA HAZUS damage functions is not an exact science. Choosing an appropriate damage function for each building relies on accurate information about the type and purpose of the building. It was assumed that the NSI data correctly documented this information as it was beyond the scope of the project to ground-truth it.
- HAZUS depth-damage functions for contents assume that contents are fully present and unprotected at the time of flooding. In areas subject to frequent or recurring flood exposure, such as portions of the Gate 5 Road corridor, property owners may have adapted by relocating or protecting movable assets prior to flood events, which would result in lower actual content losses than those estimated by the damage functions. As such, content loss estimates may represent an upper bound in locations where adaptive behavior is likely.
- The analysis focuses only on costs associated with flooding damage to buildings and contents. A broader analysis could consider other potential sources of flood-related costs, including flooding damage to infrastructure, land values, lost state and local tax revenue, and social and environmental impacts, aside from buildings.
- The analysis focuses only on direct economic impacts. Quantitative impacts assessed in this study are limited to direct flood damages to buildings and their contents. The analysis does not account for broader economic ripple effects, including indirect impacts on state and local tax revenues, businesses, induced impacts on households, or other secondary consequences. In addition, the analysis does not quantify costs associated with transportation disruptions (e.g., lost travel time or roadway closures); lost sales or business interruption; or costs related to injuries or fatalities during flood events.

3.2 Exposure Analysis Results

This section presents the results of the exposure analysis, focusing on the number and spatial distribution of buildings exposed to flooding under the modeled scenarios and time horizons. In addition to building-level exposure, flood exposure was also evaluated in terms of inundation duration, with a focused assessment of effects along Gate 5 Road.

3.2.1 Building Exposure Analysis

Table 8 summarizes the number of buildings exposed to flooding under each modeled scenario. Exposure is defined as flood depth exceeding the FFE, such that buildings counted as “exposed” experience positive depth above the first floor in the modeled scenario. Figure 8 summarizes the number of buildings exposed to flooding through time (2025, 2050, 2080).

Overall, the results show that storm surge drives the majority of building exposure, with exposed building counts increasing substantially over time under SLR. Under surge-only conditions, the number of exposed buildings increases from 10 buildings for the 2025 1-year surge event to 55 in 2050 and 77 in 2080. For the more severe surge event, exposed building counts increase from 64 buildings under the 2025 100year surge to 77 in 2050 and 110 in 2080, indicating expanding inundation extent and increasing numbers of affected assets over time.

In contrast, pluvial-only (no surge) scenarios show limited exposure in 2025 (3–6 exposed buildings). By 2050 and 2080, exposed-building counts increase (approximately 38–39 buildings in 2050 and 68–74 in 2080); however, the relatively small change across precipitation return periods within each horizon year suggests that this increase is driven primarily by higher baseline water levels under SLR (and associated overland/coastal influence) rather than precipitation severity alone.

Table 6 Number of Exposed Buildings by Scenario and Analysis Year (Exposed = Flood Depth > 0 ft Relative to First Floor Elevation)

Scenario #	Scenario	Exposed Buildings (Count)
1	2025 - No Rain, 1-YR Surge	10
2	2025 - No Rain, 100-YR Surge	64
4	2025 - 10-YR Pluvial, No Surge	3
5	2025 - 25-YR Pluvial, No Surge	3
6	2025 - 50-YR Pluvial, No Surge	4
7	2025 - 100-YR Pluvial, No Surge	6
8	2025 - 10-YR Rain, 1-YR Surge	12
9	2025 - 25-YR Rain, 1-YR Surge	12
10	2025 - 50-YR Rain, 1-YR Surge	13
11	2025 - 100-YR Rain, 1-YR Surge	16
12	2025 - 10-YR Rain, 100-YR Surge	64
13	2025 - 100-YR Rain, 100-YR Surge	66
14	2050 - No Rain, 1-YR Surge - Int	55
15	2050 - No Rain, 100-YR Surge - Int	77
16	2050 - 10-YR Pluvial, No Surge - Int	38

Scenario #	Scenario	Exposed Buildings (Count)
17	2050 - 25-YR Pluvial, No Surge - Int	38
18	2050 - 50-YR Pluvial, No Surge - Int	39
19	2050 - 100-YR Pluvial, No Surge - Int	39
20	2050 - 10-YR Rain, 1-YR Surge - Int	55
21	2050 - 100-YR Rain, 1-YR Surge - Int	56
22	2050 - 10-YR Rain, 100-YR Surge - Int	77
23	2050 - 100-YR Rain, 100-YR Surge - Int	77
24	2080 - No Rain, 1-YR Surge - Int	77
25	2080 - No Rain, 100-YR Surge - Int	110
26	2080 - 10-YR Pluvial, No Surge - Int	68
27	2080 - 100-YR Pluvial, No Surge - Int	74
28	2080 - 10-YR Rain, 1-YR Surge - Int	77
29	2080 - 100-YR Rain, 1-YR Surge - Int	83
30	2080 - 10-YR Rain, 100-YR Surge - Int	110
31	2080 - 100-YR Rain, 100-YR Surge - Int	113

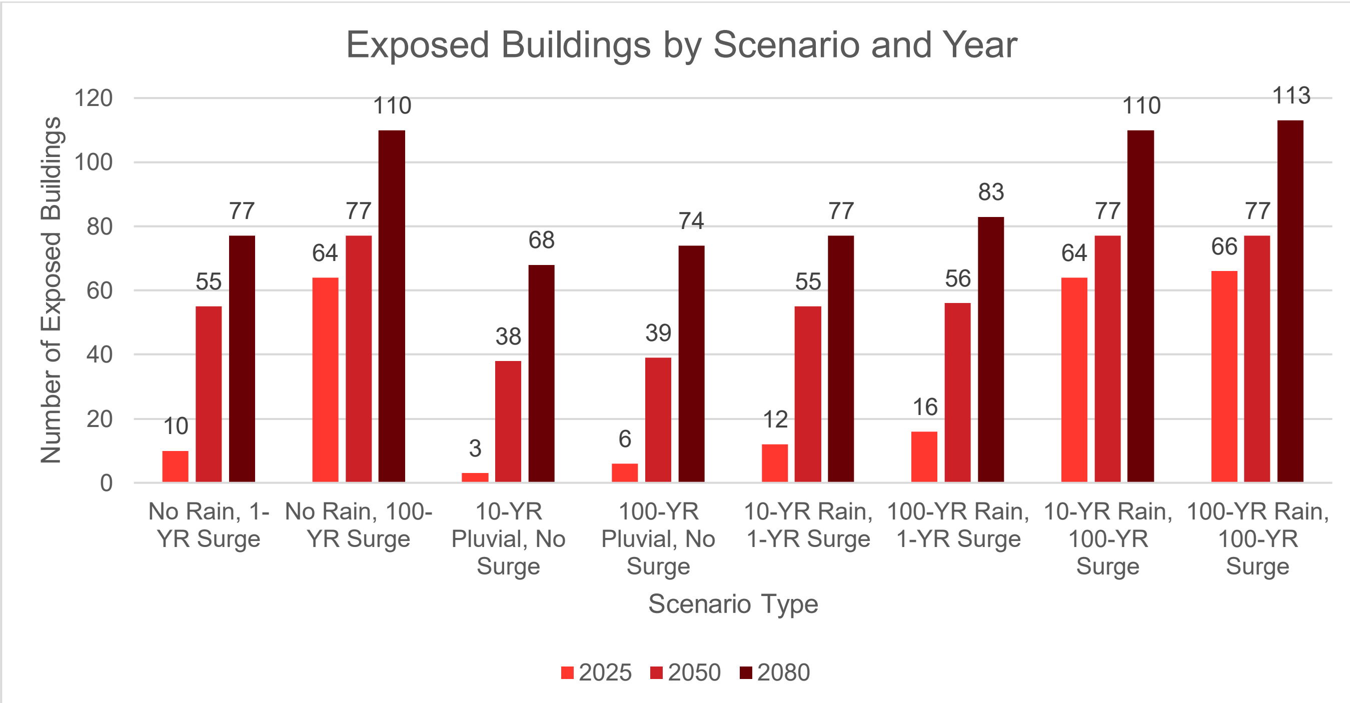


Figure 8 Exposed Buildings by Scenario and Year.

Compound scenarios (surge and precipitation) show that precipitation can increase exposure above surge-only conditions, but the incremental effect is modest relative to surge. For example, in 2025 the 1-year surge exposure increases from 10 buildings (no rain) to 12–16 buildings with rainfall, depending on precipitation return period. Under the 100-year surge in 2025, exposure increases slightly from 64 buildings (no rain) to 66 buildings under the 100-year precipitation condition. In 2050, exposure under the 1-year surge changes minimally with precipitation (55 to 56 buildings), and under the 100-year surge remains unchanged (77 buildings with or without precipitation). In 2080, precipitation increases exposure under the 1-year surge from 77 buildings to 83 buildings under the 100-year precipitation condition, while exposure under the 100-year surge increases from 110 to 113 buildings.

The following maps illustrate building-level flood depths relative to FFE for storm-surge flooding at two event severities (1-year and 100-year surge) and across multiple horizon years (2025, 2050, 2080, and 2100). Buildings are symbolized by depth bins (in feet) above the finished floor, so warmer colors indicate deeper inundation within the structure.

Across both event severities, the maps show a clear expansion in the number of exposed buildings and an increase in depth above FFE over time, consistent with rising sea levels elevating surge-driven water levels. In the 1-year surge sequence, exposure grows from a small cluster in 2025 to broader, deeper impacts by 2050 and 2080, with additional intensification by 2100. In the 100-year surge sequence, the exposed footprint is larger in every year, and higher-depth categories become more prevalent over time—highlighting not only more widespread exposure, but also a shift toward more severe inundation.

Figure 9 Flood Depth Above First Floor Elevation (ft) for 2025 1-year Storm Surge (Left), and 2050 Intermediate Scenario, 1-year Storm Surge (Right).

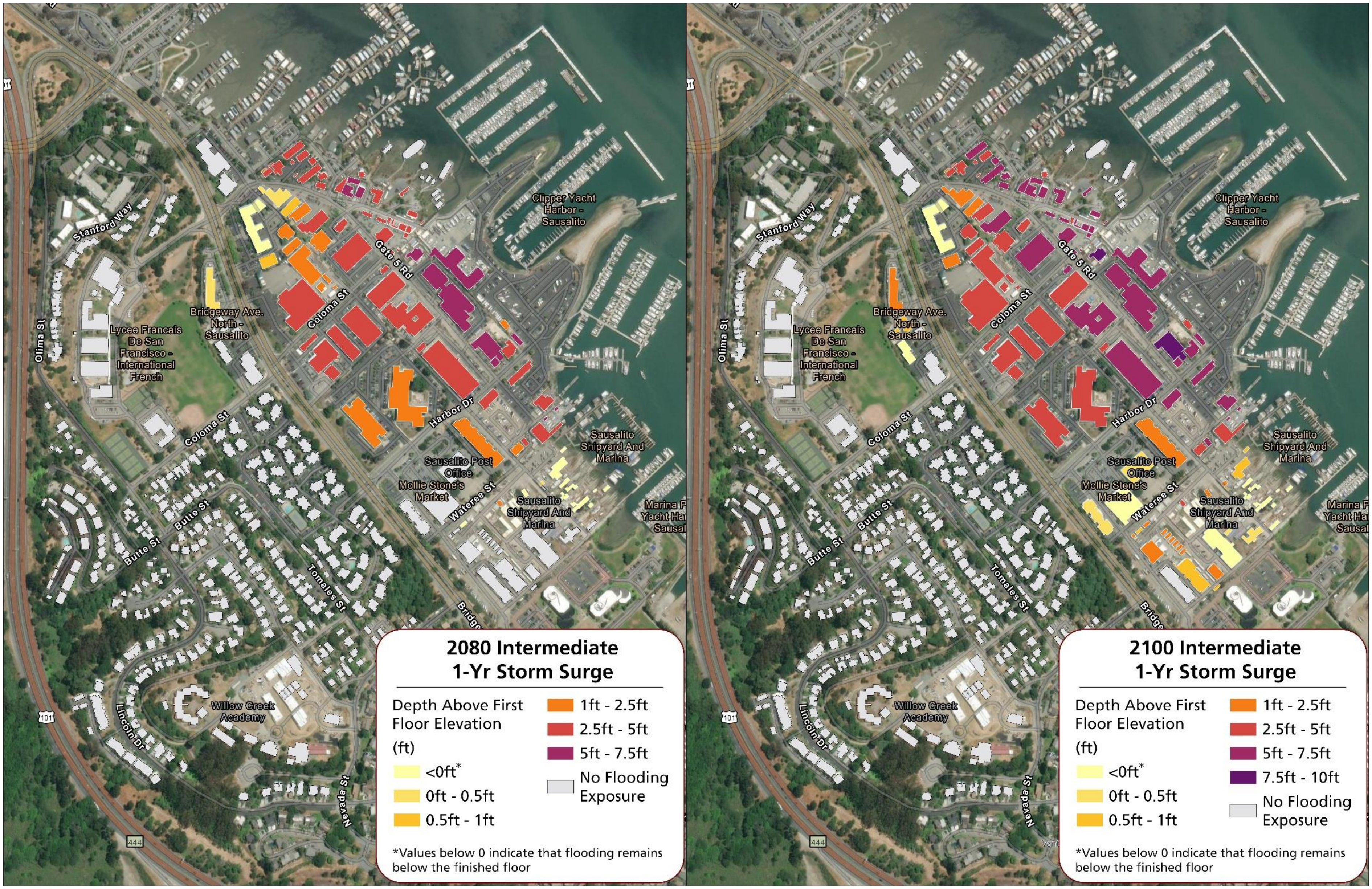


Figure 10 Flood Depth Above First Floor Elevation (ft) for 2080 Intermediate Scenario, 1-year Storm Surge (Left), and 2100 Intermediate Scenario, 1-year Storm Surge (Right).

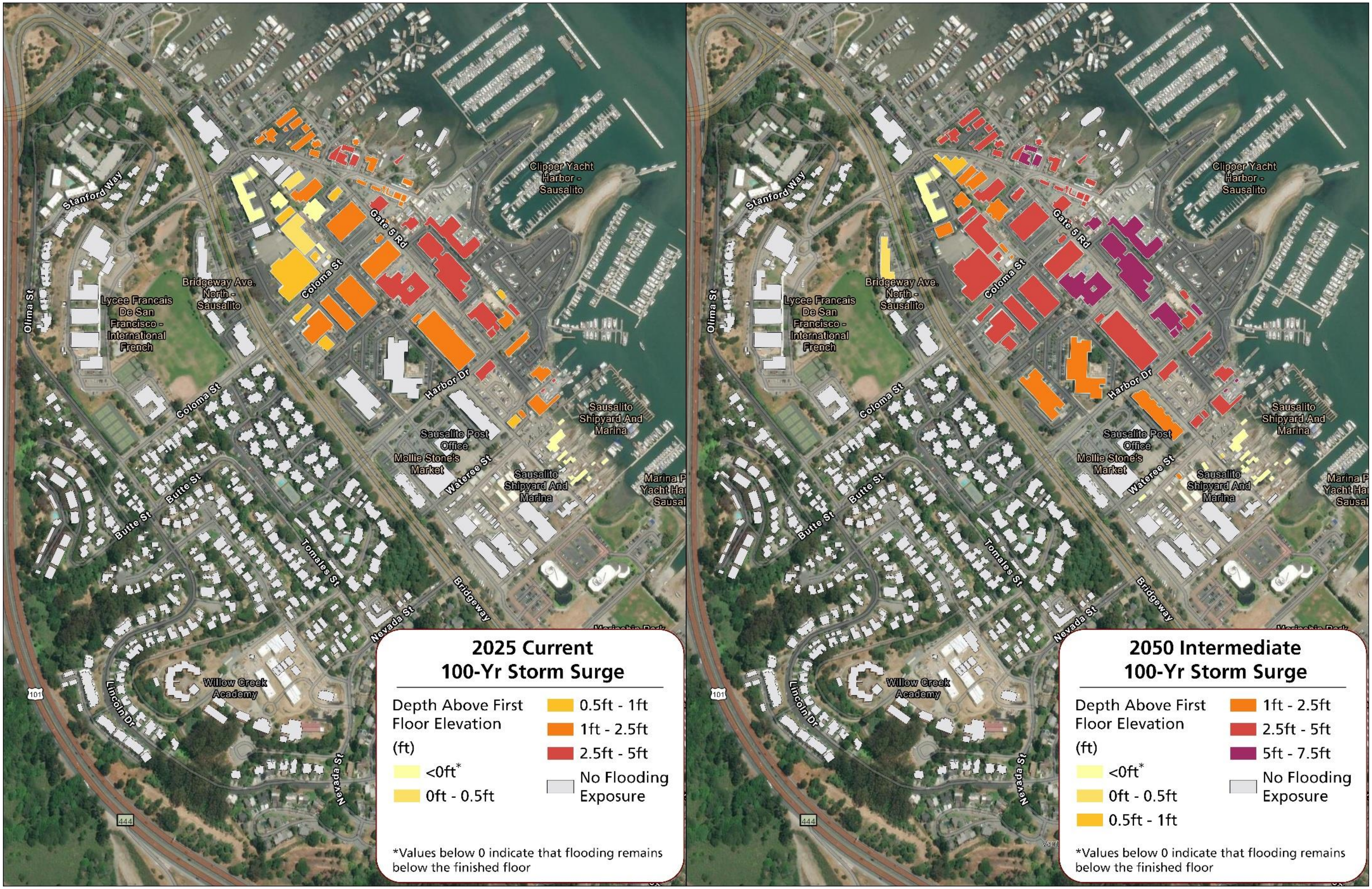


Figure 11 Flood Depth Above First Floor Elevation (ft) for 2025 100-year Storm Surge (Left), and 2050 Intermediate Scenario, 100-year Storm Surge (Right).

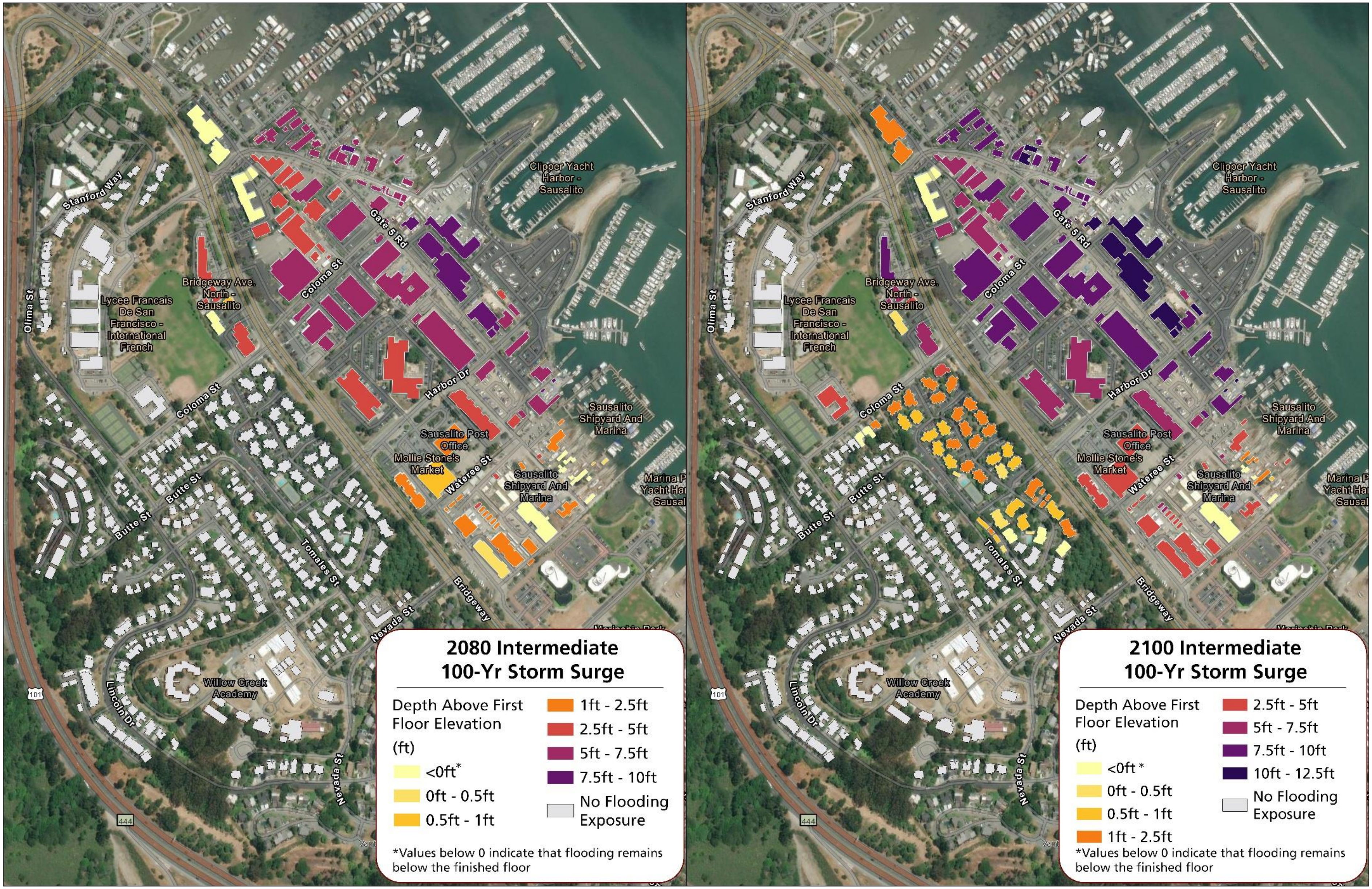


Figure 12 Flood Depth Above First Floor Elevation (ft) for 2080 Intermediate Scenario, 100-year Storm Surge (Left), and 2100 Intermediate Scenario, 100-year Storm Surge (Right).

3.2.2 Exposure of Gate 5 Road to 1-year Surge Flooding

Results from the XP-SWMM model allowed WSP to evaluate the duration of inundation across the project area and focus on Gate 5 Road. For each scenario run, as detailed in Table 4, a duration of inundation raster was produced. This recorded how much time the flooding in the area was greater than 0 ft over the 24-hour simulation period. Additionally, WSP drew a profile line, shown in orange in Figure 13 along Gate 5 Road to illustrate ground elevation, water elevation and duration of flooding. The data pulled from this section are shown in Figure 14 to Figure 17, showing the scenarios with No Rainfall and a 1-yr surge across all four time-horizons. As shown in these figures, the increasing water level across time horizons is in part due to the subsidence that is estimated to occur. As the ground elevation lowers, the flood depths and duration of inundation increases. The lowest point along Gate 5 Road is at the intersection with Heath Way, where Heath Ceramics is located, and this is the point where the longest flood durations along the road occur.

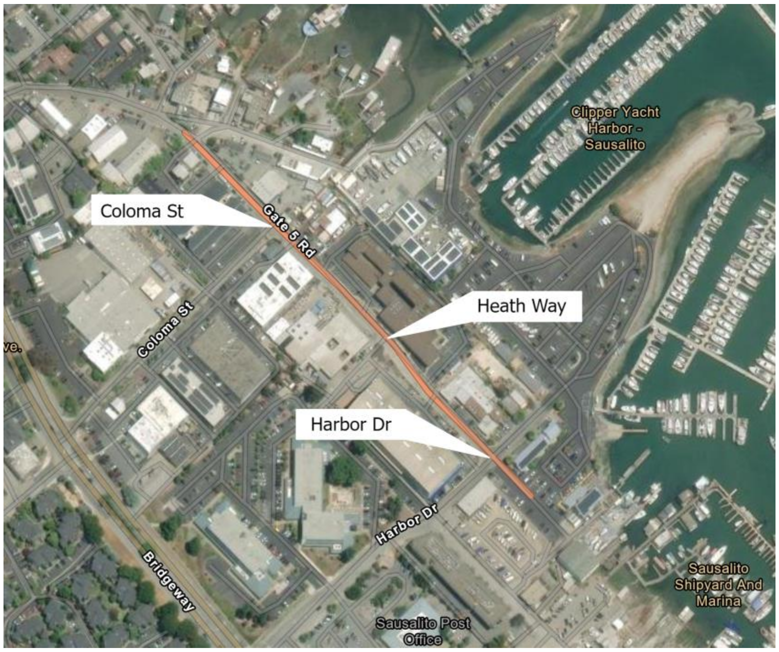


Figure 13 Profile on Gate 5 Road.

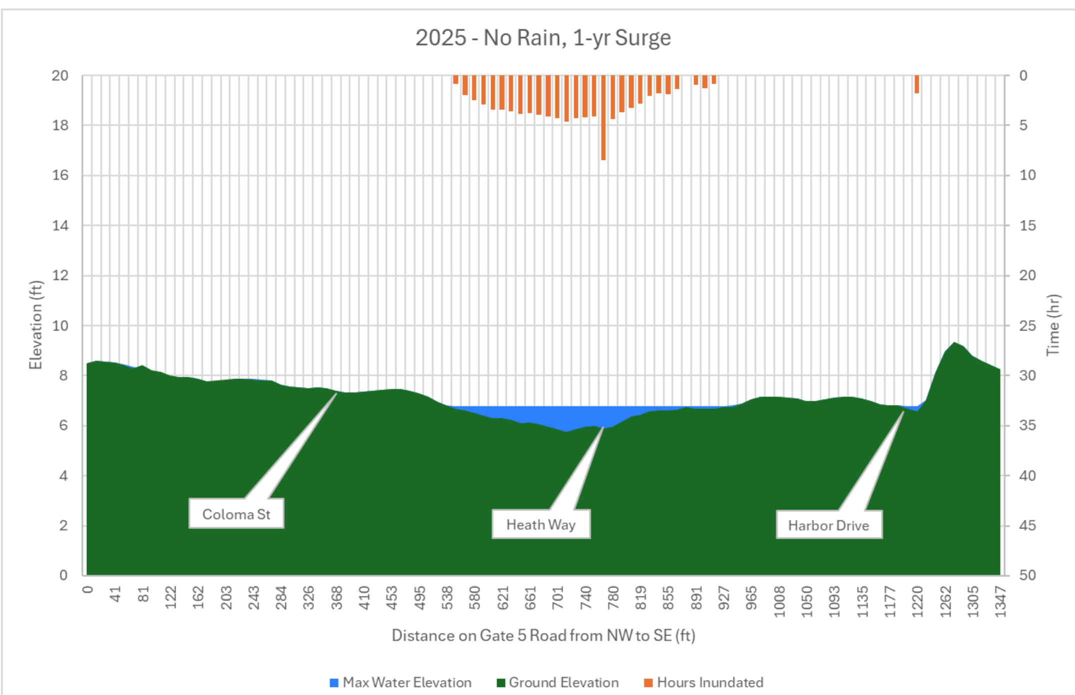


Figure 14 2025 Water Elevation and Inundation Duration Along Gate 5 Road Profile for No Rain and 1-yr Surge Event.

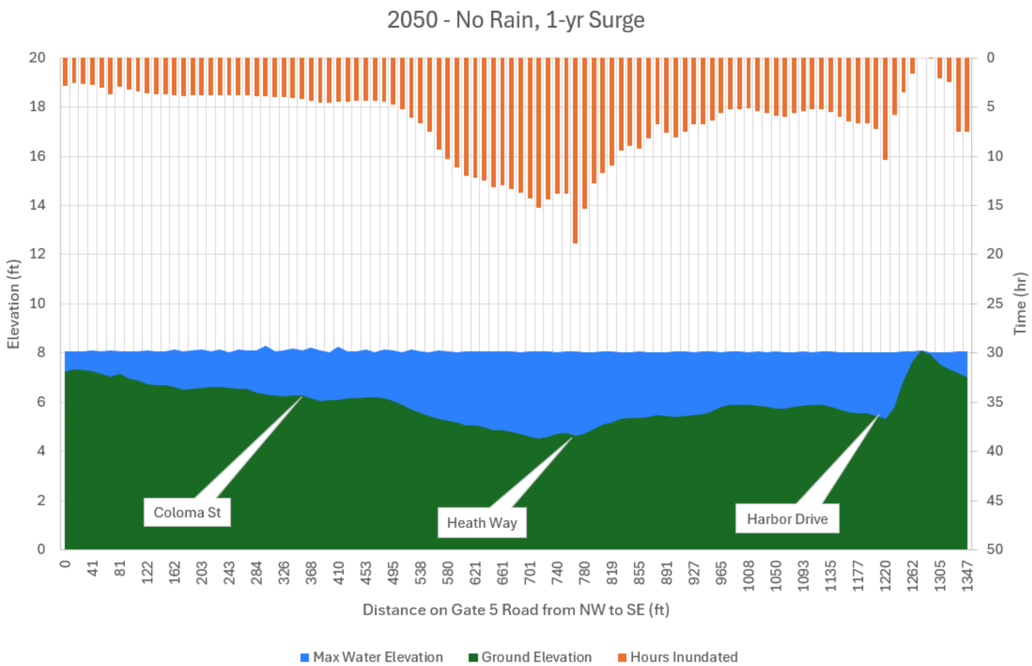


Figure 15 2050 Water Elevation and Inundation Duration Along Gate 5 Road Profile for No Rain and 1-Yr Surge Event.

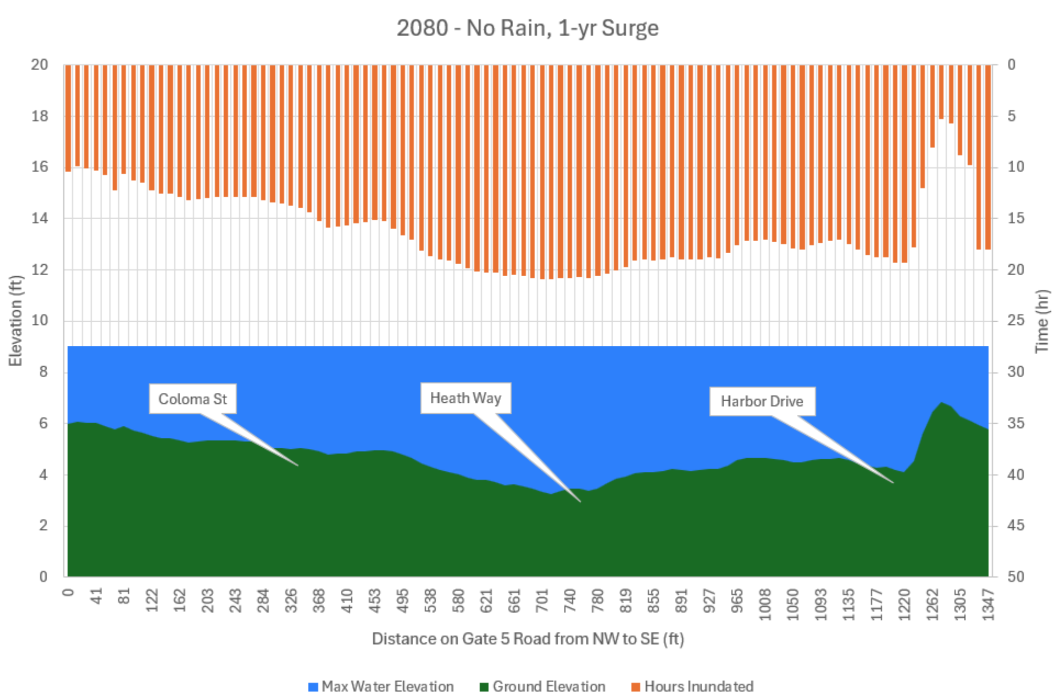


Figure 16 2080 Water Elevation and Inundation Duration Along Gate 5 Road Profile For No Rain And 1-Yr Surge Event.

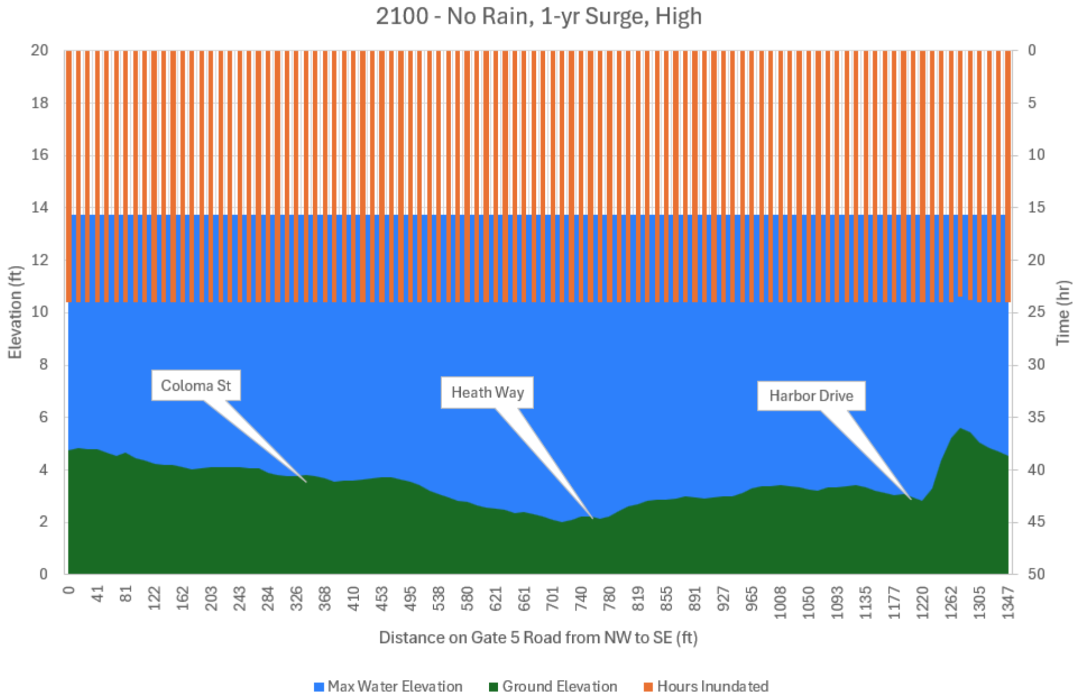


Figure 17 2100 Water Elevation and Inundation Duration Along Gate 5 Road Profile for No Rain and 1-yr Surge Event.

The maximum duration of flooding within the project area for the no rain,1-yr scenarios, is summarized in Table 7. Additionally, the duration of inundations at the intersections of Gate 5 Road with Coloma Street, Heath Way and Harbor Drive is shown in Table 8. Both illustrate that future conditions will lead to more severe flood impacts in the area.

Table 7 Maximum Duration of Inundation for the No Rain and 1-yr Surge Scenarios Across Time-Horizons.

Scenario	Maximum Duration of Inundation (hr)
2025	8.5
2050	18.9
2080	20.9
2100-Int	23.9
2100-High	24.0

Table 8 Duration of Inundation at Intersections on Gate 5 Road for No Rain and 1-yr Surge Scenarios.

Intersection	2025	2050	2080	2100-Int	2100-High
Coloma Street	0	4.1	13.9	19.5	24
Heath Way	8.5	18.9	20.8	23.7	24
Harbor Drive	0	6.6	18.7	21.3	24

Figure 18 shows a 100-yr surge event to show both the extent of a 100-yr surge and the increasing durations along Gate 5 Road with increasing condition of severity beyond a 1-yr surge event.

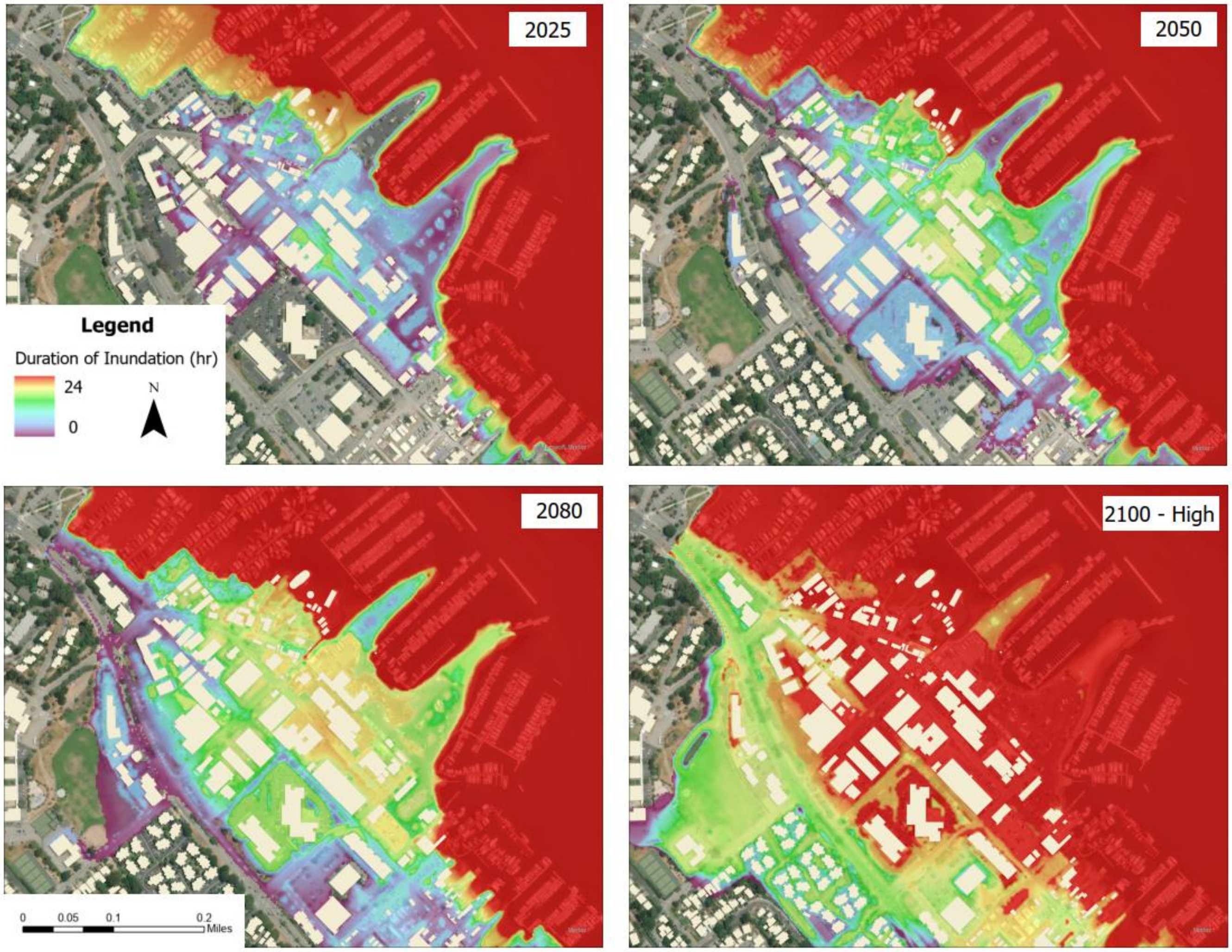


Figure 18 Duration of Inundation in Project Area for No Rain and 100-yr Surge Events Across Time-Horizons.

3.3 Risk Assessment Results

This section describes the results of the risk analysis. Results are presented first for the surge-only baseline, using AAL by analysis year and maps of building-level AAL. The section then evaluates lifecycle "do-nothing" risk through discounted expected losses over the analysis period and identifies buildings projected to experience chronic inundation based on a threshold exceedance criterion. Finally, a compound-flood stress test is presented to examine how plausible precipitation conditions could influence losses when joint probabilities of surge and rainfall events are uncertain.

3.3.1 Surge-Only Coastal Flood Risk

This section summarizes the results of the flood risk assessment considering storm surge flooding only, excluding precipitation and other flood mechanisms. This surge-only analysis provides a baseline characterization of coastal flood risk under existing and future SLR conditions. Risk is expressed as AAL and evaluated across multiple analysis years, as well as lifecycle risk.

3.3.1.1 Average Annual Loss and Spatial Distribution of Risk

The surge-only flood risk analysis indicates a substantial increase in AAL over time for buildings in the analysis area, driven by storm surge exposure under progressively higher sea levels. As shown in Table 9 and Figure 19, total AAL is estimated at approximately $17.6 million in 2025, increasing to $49.8 million by 2050, and $113.7 million by 2080. Losses are dominated by contents damage across all analysis years, reflecting the sensitivity of building contents and inventory to flooding.

Table 9 Total Average Annual Loss due to Coastal Flooding (Storm Surge and Sea Level Rise) by Type of Loss (Buildings, Contents, Total – Buildings and Contents).

Year	AAL Buildings	AAL Contents	AAL Total
2025	$4,919,895	$12,720,247	$17,640,142
2050	$12,992,490	$36,840,224	$49,832,714
2080	$29,980,442	$83,723,229	$113,703,670

The growth in AAL over time reflects rising sea levels that elevate surge-driven water levels and expand the extent and depth of inundation at exposed buildings. Between 2025 and 2050, total AAL nearly triples, with continued acceleration through 2080 as larger portions of the building inventory become exposed to damaging flood depths. Maps of building-level AAL further illustrate the spatial concentration of surge-related flood risk, identifying clusters of higher-loss assets that drive a disproportionate share of total damages.

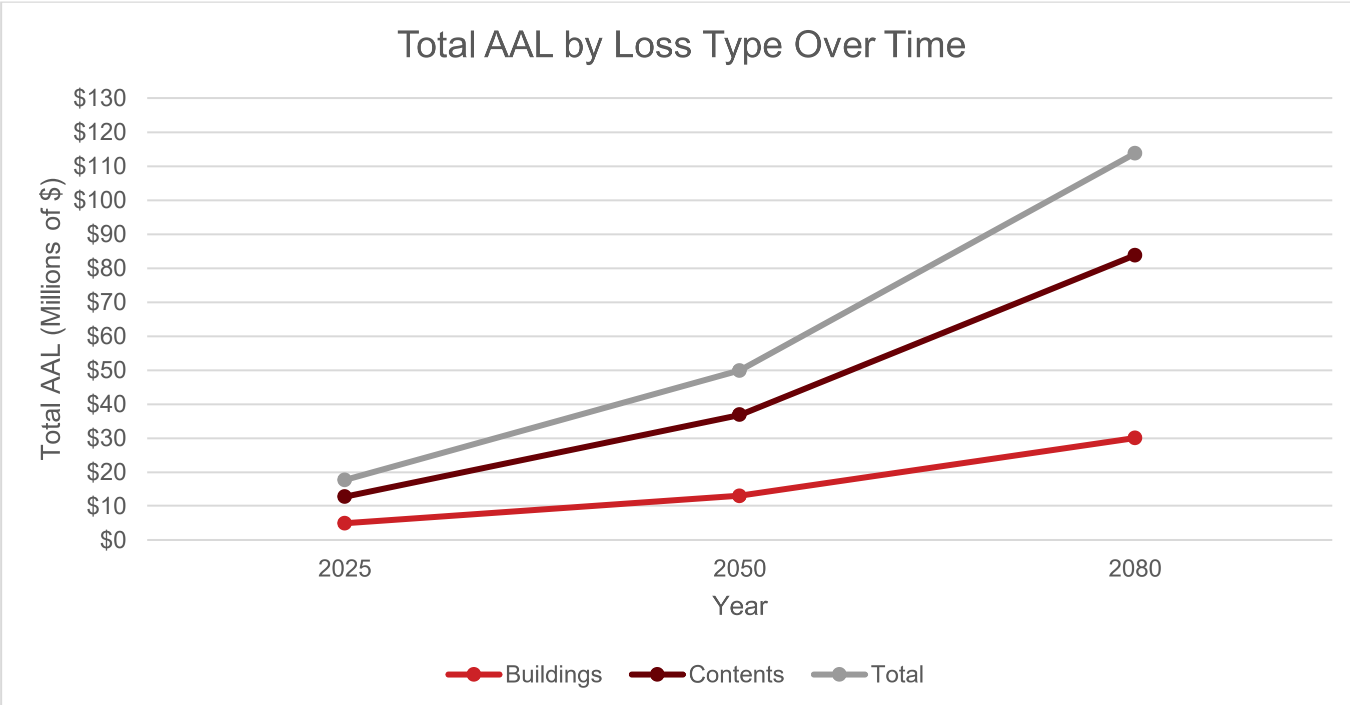


Figure 19 Total Average Annual Loss (AAL) Due To Coastal Flooding (Storm Surge and Sea Level Rise) Over Time by Type of Loss (Buildings, Contents, Total – Buildings and Contents).

Across all mapped years, the building-level AAL maps show that surge-related flood risk is spatially concentrated, with higher losses clustered in low-lying areas closest to the shoreline and tidal channels, as well as along primary access corridors and waterfront parcels. In 2025, higher-loss buildings are limited to a smaller set of assets; however, by 2050 and 2080 these clusters expand both in extent and magnitude, reflecting increased surge depths and higher expected damages under SLR.

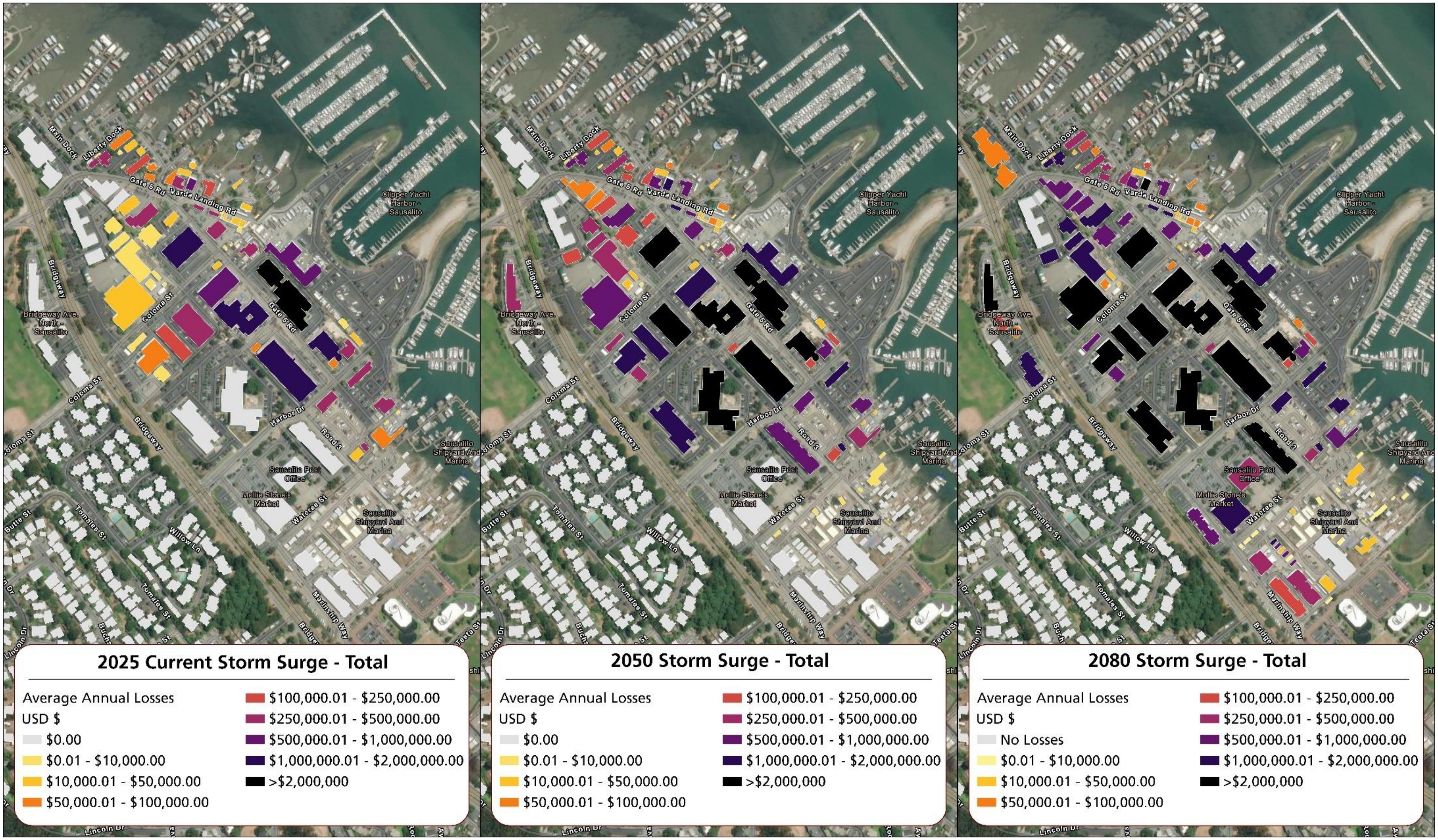


Figure 20 Average Annual Losses for Storm Surge (Undiscounted) for 2025, 2050, and 2080, Accounting for Total Losses (Buildings and Contents).

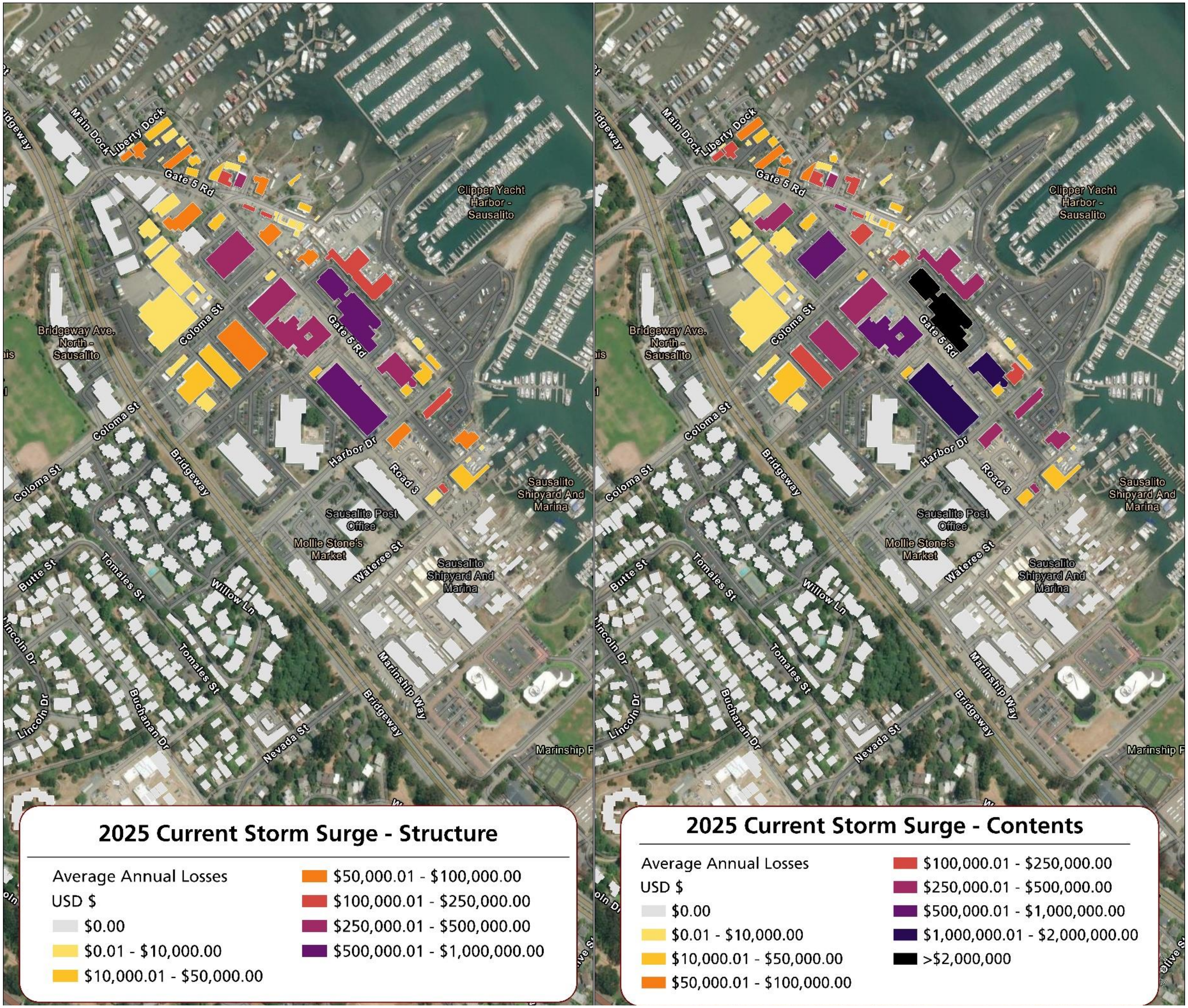


Figure 21 Average Annual Losses for Storm Surge for 2025 (undiscounted) Accounting for Losses to Buildings (Left) and Contents (Right).

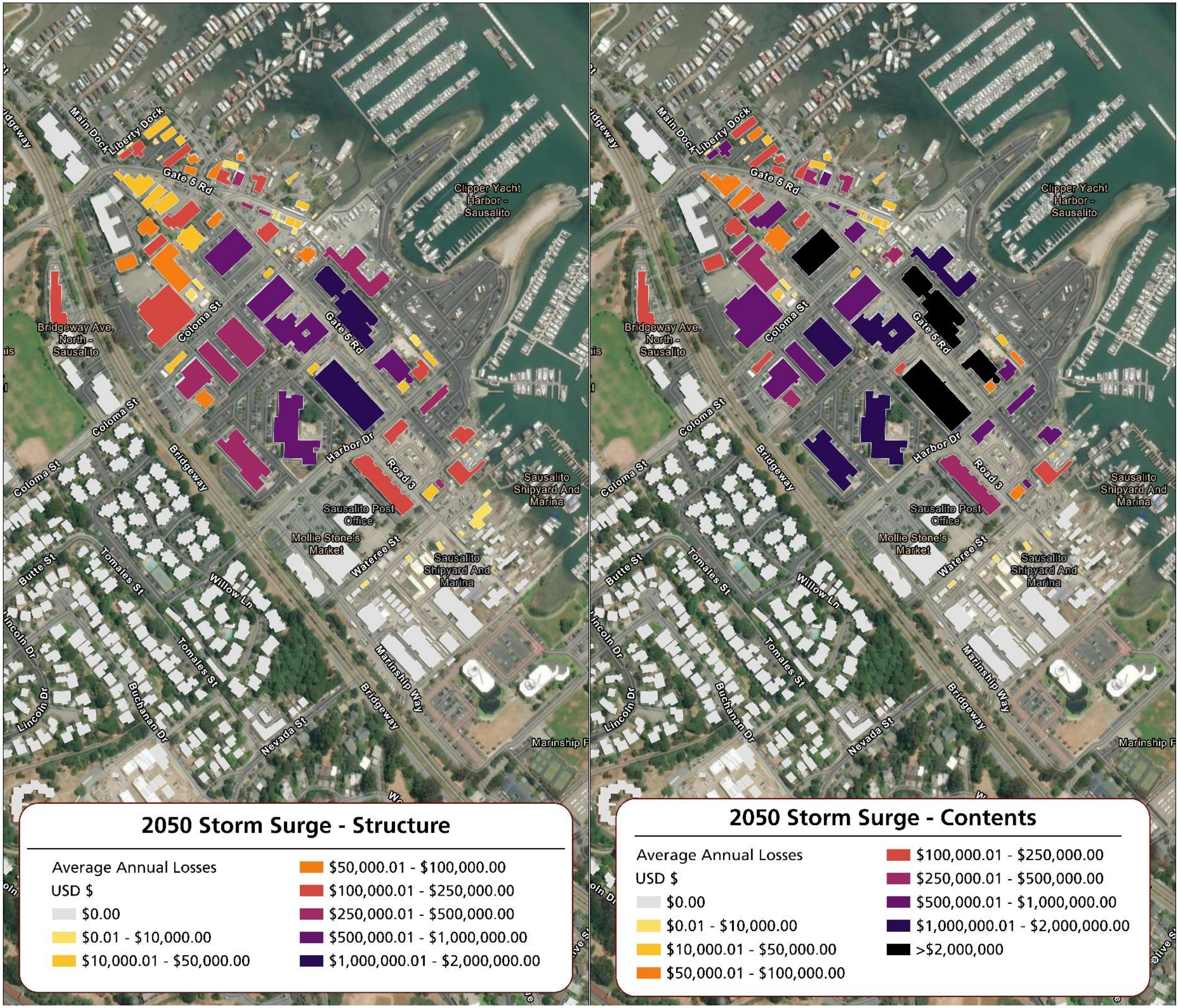


Figure 22 Average Annual Losses for Storm Surge for 2050 (undiscounted) Accounting for Losses to Buildings (Left) and Contents (Right).

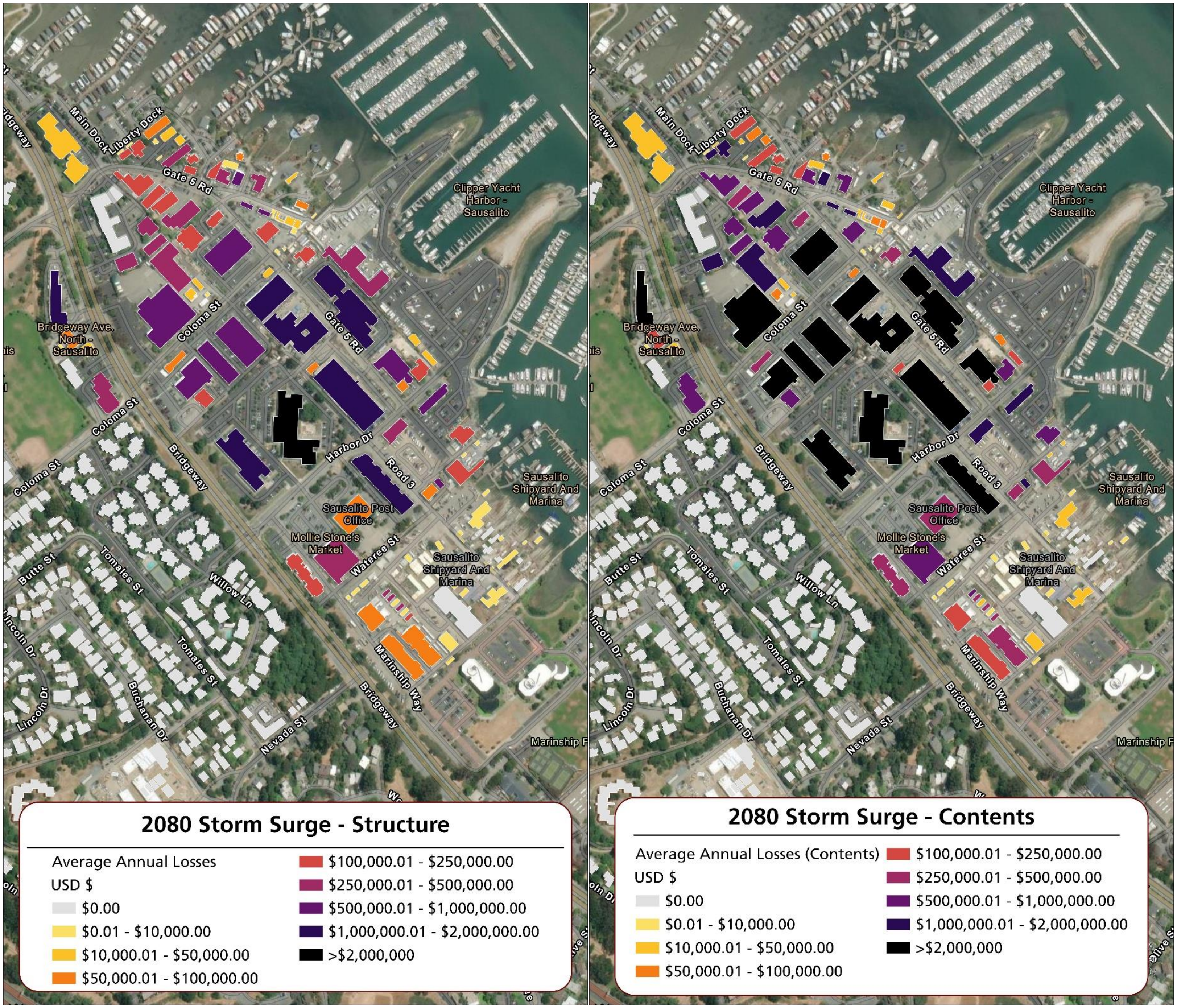


Figure 23 Average Annual Losses for Storm Surge for 2080 (undiscounted) Accounting for Losses to Buildings (Left) and Contents (Right).

3.3.1.2 Lifecycle Risk (Do-Nothing Costs)

This section extends the surge-only AAL results by evaluating expected flood damages over the full analysis period under a no-action (“do-nothing”) scenario. Annual losses are projected through time and converted to present-value terms using selected discount rates, allowing comparison of long-term flood risk on a consistent economic basis.

3.3.1.2.1 Chronic Inundation and Trigger-Year Summary

This subsection summarizes when buildings are projected to transition into chronic inundation. Chronic inundation is defined as reaching at least 0.5 ft of flood depth above FFE during MHHW. The first year in which a building meets or exceeds this threshold is referred to as the building’s trigger year. Results are presented as (1) the number of buildings entering chronic flooding in each year and (2) the cumulative number of buildings under chronic flooding over time. These outputs provide context for the lifecycle cost results by explaining years in which one-time total losses are concentrated when multiple buildings cross the threshold in the same year.

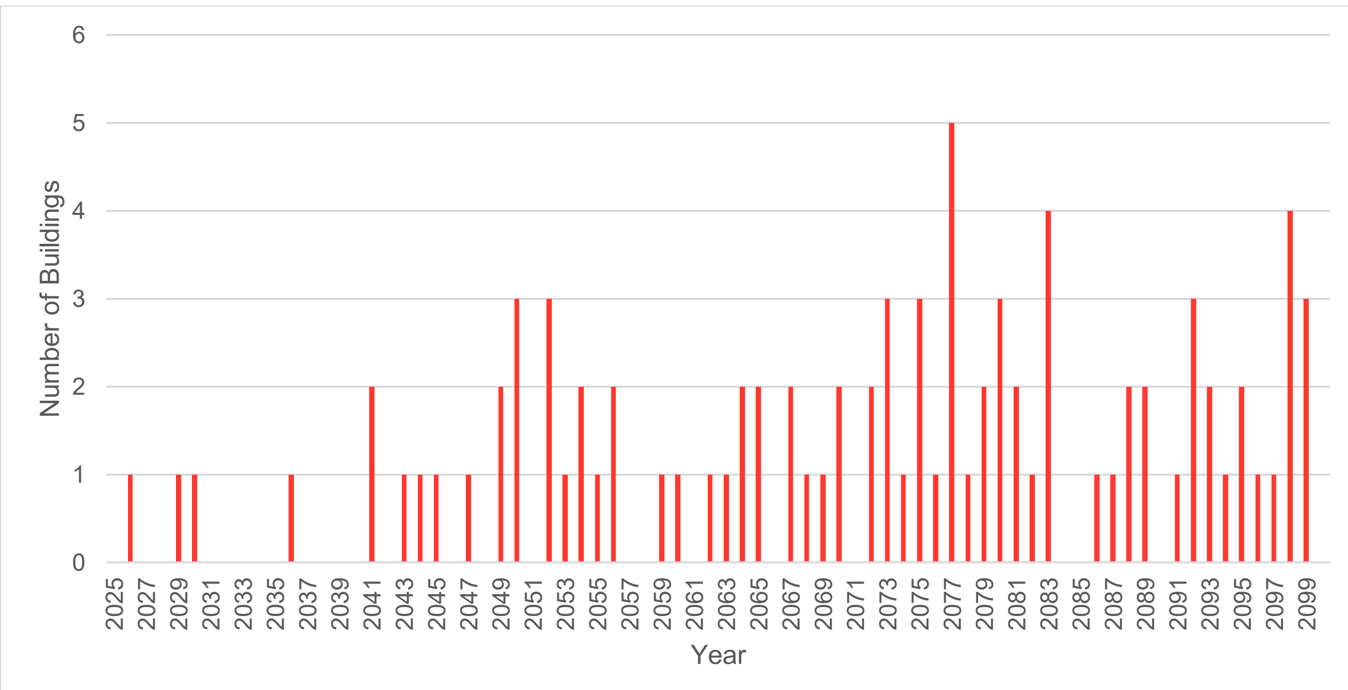


Figure 24 Buildings Entering Chronic Flooding by Year.

The annual trigger-year results show that buildings enter chronic flooding intermittently, with most years affecting a small number of buildings and occasional years in which several buildings cross the threshold (Figure 24, bars show the number of buildings that first reach ≥0.5 ft of flood depth above FFE in each year). The cumulative results show a steady increase in the number of buildings under chronic flooding over the analysis period, indicating that chronic inundation becomes progressively more widespread.

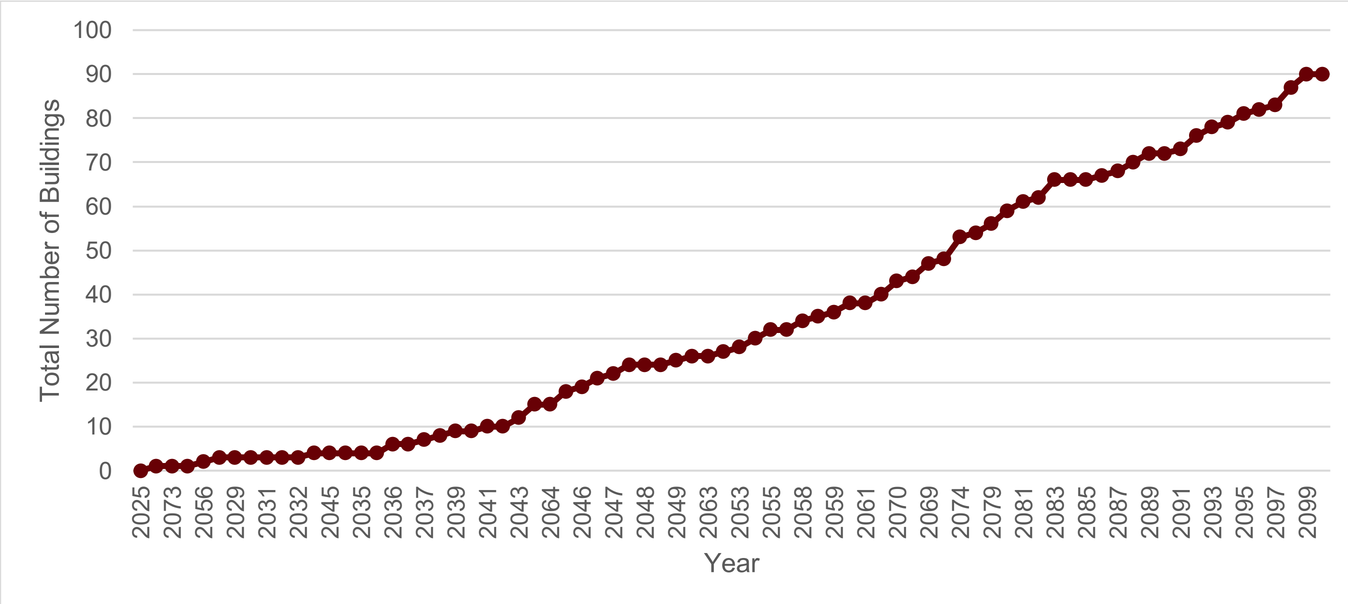


Figure 25 Cumulative Buildings Under Chronic Flooding. Cumulative count of buildings that have reached the chronic inundation threshold (≥0.5 ft above FFE).

To summarize when buildings are projected to enter chronic flooding, trigger years were grouped into multi-year intervals. The table below reports the number of buildings that first reach the chronic inundation threshold (≥0.5 ft above FFE) within each interval and the cumulative total by the end of the interval.

Table 10 Buildings Entering Chronic Flooding by Time Interval (≥0.5 ft above FFE), with Cumulative Total (Screened through 2100).

Year Interval	Buildings Entering Chronic Flooding	Cumulative at End of Interval
2025-2034	3	3
2035-2044	5	8
2045-2054	13	21
2055-2064	9	30
2065-2074	14	44
2075-2084	22	66
2085-2094	13	79
2095-2100	11	90
TOTAL	**90**	**-**

3.3.1.2.2 Lifecycle Risk

This section summarizes lifecycle "do-nothing" risk as the present value of expected flood losses over the 2025–2080 analysis period. Table 11 and Figure 24 show results for three discount-rate cases: undiscounted (simple sum of annual losses), 2%, and 7%.

Table 11 Present Value of Expected Flood Losses by Discount Rate.

Discount Rate	PV of Expected Building Losses	PV of Expected Contents Losses	PV of Total Expected Losses
Undiscounted	$660,621,977	$1,706,553,241	$2,367,175,219
2%	$368,416,739	$952,048,181	$1,320,464,920
7%	$129,569,200	$336,545,625	$466,114,824

Over 2025-2080, undiscounted lifecycle losses total approximately $2.37 billion, consisting of $660.6 million in building (structure) losses and $1.71 billion in contents losses. Applying discounting reduces the present value of future losses, with total lifecycle losses decreasing to approximately $1.32 billion at a 2% discount rate and $466.1 million at a 7% discount rate. Across all discount-rate cases, contents losses account for approximately 72% of total lifecycle losses, indicating that contents remain the dominant contributor to expected flood damages.

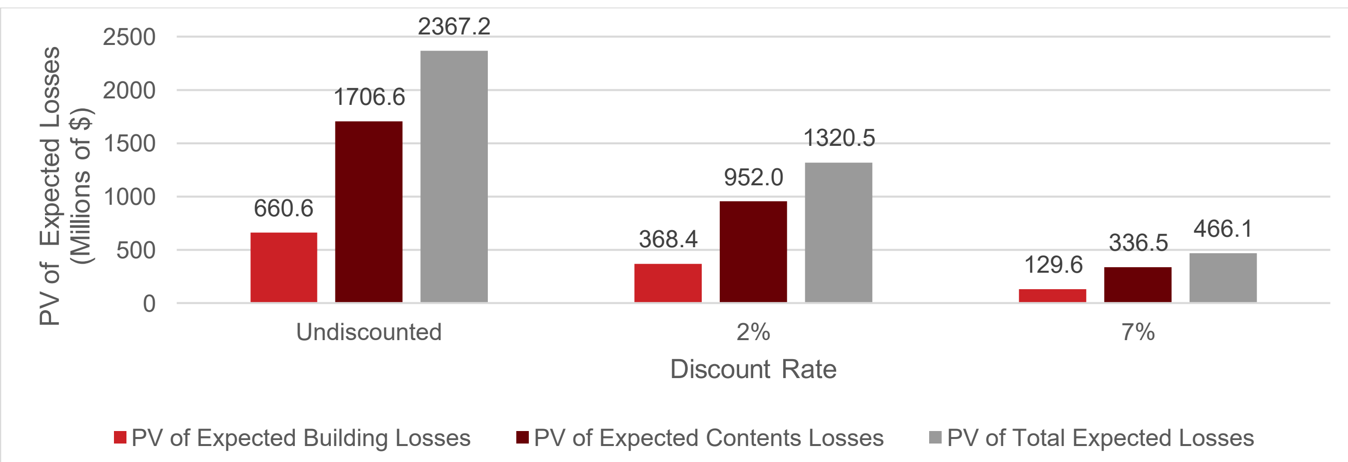


Figure 26 Present Value of Expected Flood Losses (No Action) by Discount Rate.

Figure 27 shows the estimated annual "do-nothing" costs (expected annual losses) from 2025–2080 for the undiscounted series and discounted cases (2% and 7%) for comparison. Discounting reduces the contribution of later-year damages to lifecycle present value totals and therefore lowers the discounted time series relative to the undiscounted series, particularly in the later decades.

The time series includes intermittent peaks associated with the chronic inundation trigger-year assumption: when a building first exceeds 0.5 ft above FFE, a one-time total loss is applied in that year and the building is excluded from subsequent annual loss calculations under the “do-nothing” condition. Years in which a larger number of buildings become chronically inundated show temporary spikes in annual losses, because a one-time total loss is applied when each building first crosses the threshold.

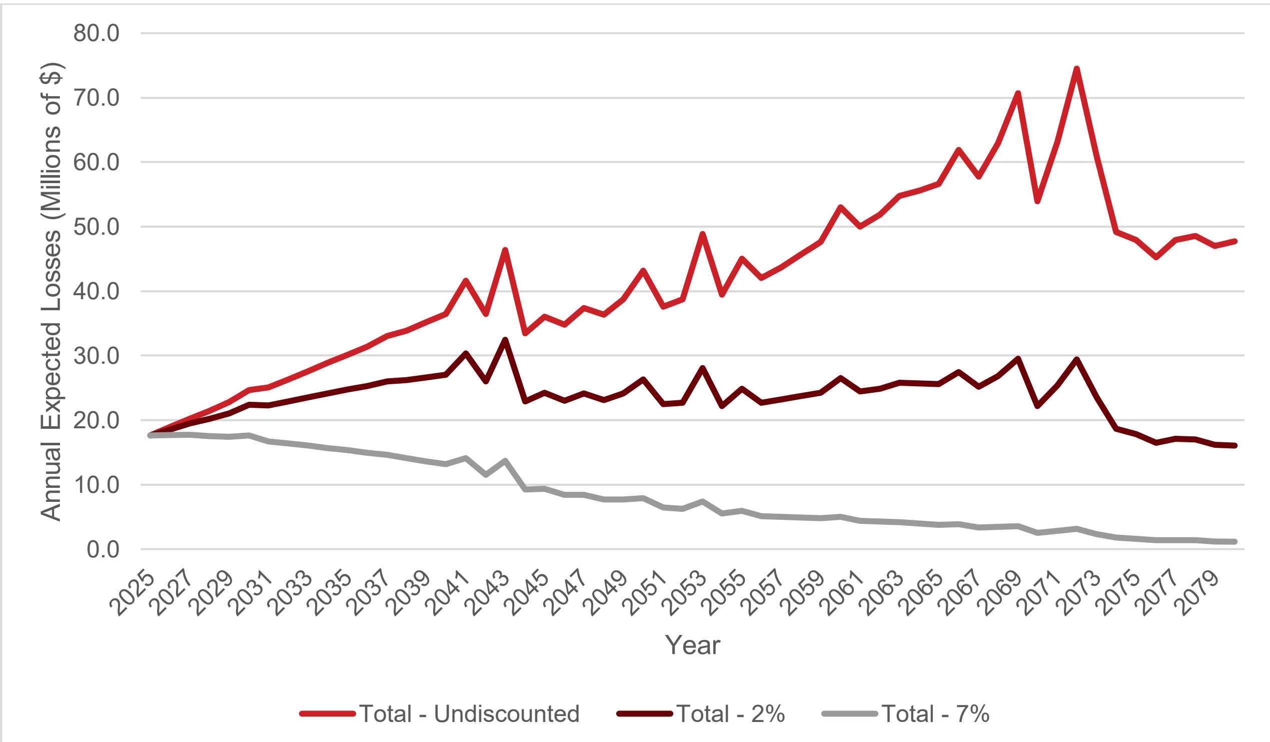


Figure 27 Do-Nothing Annual Expected Losses by Discount Rate, 2025–2080.

Discount rates are used to convert future losses to present value for lifecycle totals. Peaks reflect the chronic inundation trigger-year assumption (0.5 ft above FFE), where buildings are assigned a one-time total loss in the trigger year and excluded from subsequent annual loss calculations

3.3.2 Compound Flooding Stress Test

Results from the compound flooding stress test are summarized in Table 12 and Figure 28, which compare the surge-only baseline to conditional AAL estimates under 10-year and 100-year precipitation conditions. Conditional AAL values represent expected losses under the assumed precipitation return-period condition and are shown in Figure 28 for comparison to the surge-only baseline.

Across all analysis years, total conditional AAL remains close to the surge-only baseline, indicating that storm surge continues to drive the majority of estimated losses, with precipitation contributing an incremental increase under the stress-test assumptions.

Table 12 Total Average Annual Loss — Surge-Only Baseline vs. Compound Flooding Stress-Test (Conditional AAL).

Year	Total Average Annual Loss		
	Surge-only (baseline)	**Surge + 10-yr precip (conditional)**	**Surge + 100-yr precip (conditional)**
2025	$17,640,142	$18,636,480	$20,592,813
2050	$49,832,714	$50,407,835	$52,520,032
2080	$113,703,670	$114,381,594	$116,833,822

In 2025, total AAL increases from $17.6M (surge-only) to $18.6M under the 10-year precipitation condition (+5.7%) and to $20.6M under the 100-year condition (+16.7%). By 2050, the incremental effect is smaller in relative terms, with total AAL increasing from $49.8M (surge-only) to $50.4M (+1.2%) for the 10-year condition and $52.5M (+5.4%) for the 100-year condition. In 2080, conditional total AAL increases from $113.7M to $114.4M (+0.6%) for the 10-year condition and to $116.8M (+2.8%) for the 100-year condition.

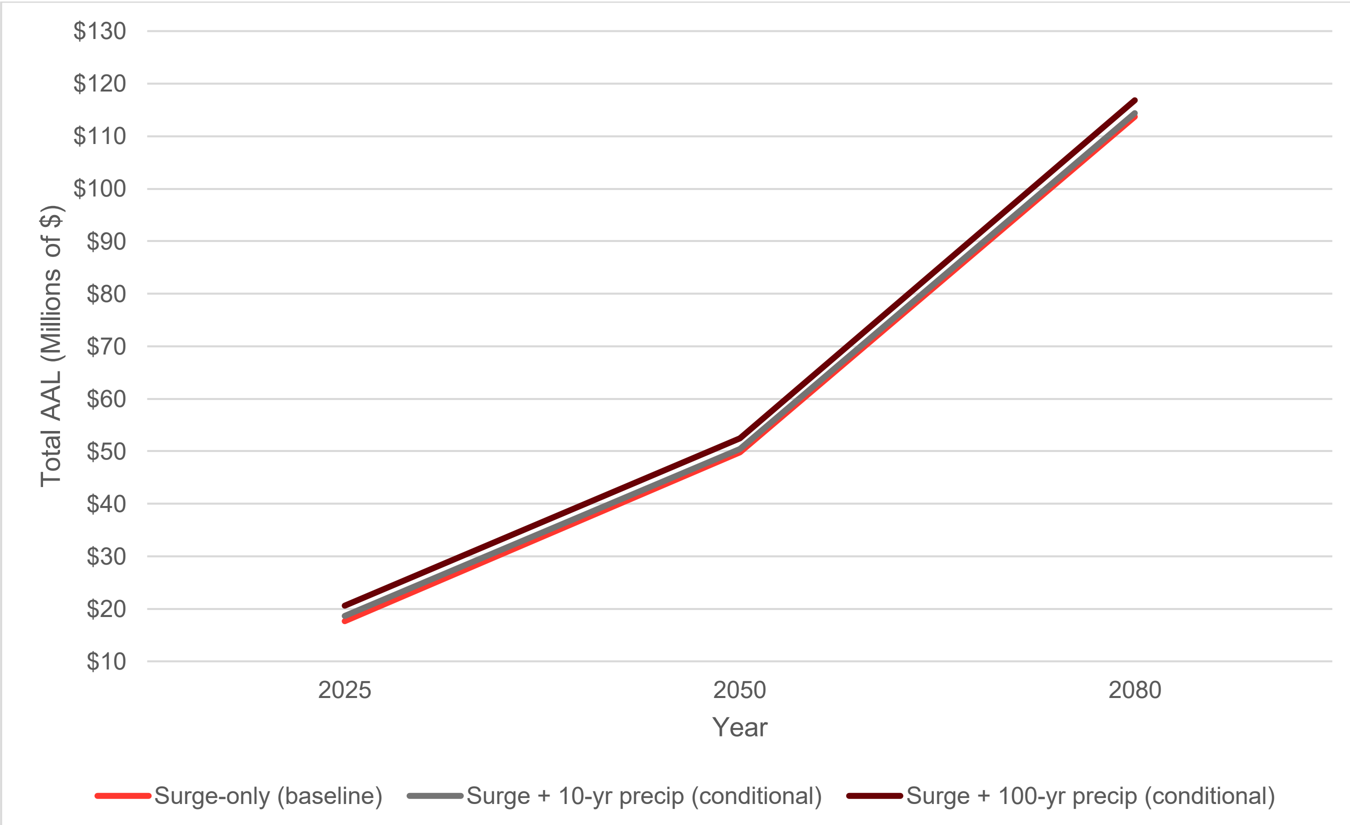


Figure 28 Total Average Annual Loss by Year — Surge-Only Baseline vs. Precipitation Stress-Test (Conditional AAL).

Losses remain dominated by contents across all scenarios and years (Table 13). Under the stress test, both buildings and contents AAL increase relative to the surge-only baseline, but the proportional increase is generally larger in earlier years and under the 100-year precipitation condition. Overall, the results suggest that while precipitation can increase losses under plausible compound conditions, the relative influence of precipitation diminishes over time as rising sea levels elevate surge-driven coastal water levels and expand surge-controlled inundation.

Table 13 Average Annual Loss by Loss Type — Surge-Only Baseline vs. Compound Flooding Stress-Test (Conditional AAL)

Year	Loss Type	Average Annual Loss		
		Surge-only (baseline)	Surge + 10-yr precip (conditional)	Surge + 100-yr precip (conditional)
2025	Buildings	$4,919,895	$5,209,044	$5,990,356
	Contents	$12,720,247	$13,427,436	$14,602,457
	Total	$17,640,142	$18,636,480	$20,592,813
2050	Buildings	$12,992,490	$13,226,455	$14,129,457
	Contents	$36,840,224	$37,181,380	$38,390,576
	Total	$49,832,714	$50,407,835	$52,520,032
2080	Buildings	$29,980,442	$30,237,344	$31,314,297
	Contents	$83,723,229	$84,144,250	$85,519,525
	Total	$113,703,670	$114,381,594	$116,833,822

4. Discussion and Key Takeaways

Key takeaways from the analysis include the following:

- Coastal flood hazards account for a large majority of the flooding impacts in the study area. The projected worsening of flood conditions over time reflects the compounding effects of sea level rise and ongoing land subsidence, which lowers ground elevations and reduces freeboard over time.
- By 2050, a majority of Gate 5 Road (from Harbor Drive to about Varda Landing Road) will be inundated on a daily or near daily basis, with shallow inundation of properties on the shoreward side and directly inland from the road.
- While overland flow from Richardson Bay is not the primary source of flooding during most events under current conditions, it becomes the primary source during the 2050 1-year event and events of greater magnitude. In 2080 and 2100, overland flow occurs regularly, and most of Gate 5 Road is expected to be under water for 18 to 24 hours a day. Under the 2100 High scenario, Bridgeway Boulevard and some properties inland of Bridgeway will be inundated on a daily or near daily basis.
- In terms of building exposure, the analysis shows 10 buildings with flooding during the 1-year event under current conditions. This increases to 55 buildings during the 1-year event during 2050, with many buildings on both sides of Gate 5 Road exposed. This increases to 77 buildings during the 2080 1-year event. For the 100-year event, the number of exposed buildings is 64 under current conditions, 77 in 2050, and 110 in 2080.
- According to the analysis, there is already almost $5 million in flood-related average annual losses to building structures in 2025 conditions. This more than doubles to almost $13 million in 2050 and more than doubles again to almost $30 million in 2080. Losses are much higher when building contents are considered, though content losses may be overestimated to the extent that property owners in frequently flooded areas have adapted by relocating or protecting contents prior to flood events. There are significant losses during all three timeframes on either side of Gate 5 Road. The shoreward side of the road is primarily exposed to direct overland flow from Richardson Bay as surge-driven water levels overtop low-lying coastal areas, while the inland side is primarily affected by storm drain surcharge and backflow through the stormwater network. These expected losses suggest a major potential benefit in investing in flood protection measures that would mitigate flooding on both sides of Gate 5 Road.
- Over the next 10 years (by 2035), it's expected that 3 buildings will experience over half a foot of flooding during MHHW. By 2045, that total will reach 8, and by 2055, it will reach 21. It's expected to reach 66 by 2085 and 90 by 2100.
- In aggregate, do-nothing costs from flooding are substantial, with total undiscounted losses of approximately $2.37 billion (structures and contents), of which $660 million correspond to building (structure) losses. Even when future losses are heavily discounted at a 7% annual discount rate, do-

nothing costs for structures are roughly $130 million. This figure is over $368 million with a 2% discount rate. Costs are much higher when building contents are included. Costs are slightly higher when heavy precipitation is combined with storm surge, but coastal flooding accounts for the large majority of damages.

- The high do-nothing costs point to the clear need for coordinated flood protection measures in the study area and large potential benefits of investing in this protection. Annual expected losses are projected to double around 2040. The results underscore the need for both a near-term solution that addresses sources of flooding now, but also the relatively frequent overland flooding that will occur soon in the future.
- It is important to note that the quantitative economic impacts assessed in this study are limited to direct flood damages to building structures and their contents. The analysis does not account for broader economic consequences, including lost time due to roadway disruption and closures, lost sales revenue and business interruption, indirect impacts on state and local tax revenues, or costs associated with injuries and fatalities during flood events. These unquantified impacts would further increase the total economic burden of flooding in the study area, reinforcing the case for investment in flood protection measures.

5. Appendix A: Subsidence

Figure 29 through Figure 35 that represent the elevation changes seen in the seven profiles of interest in the USGS datasets. Note that the vertical axis is elevation change in feet, and the horizontal axis is distance along the select profile.

Figure 36 through Figure 42 show the elevation changes in the NORCE Maps site. Note that the vertical axis in the bottom graph is the rate of subsidence in mm/yr and the horizontal axis is distance along the select profile.

Figure 29 Gate 5 Elevation Changes with USGS Datasets.

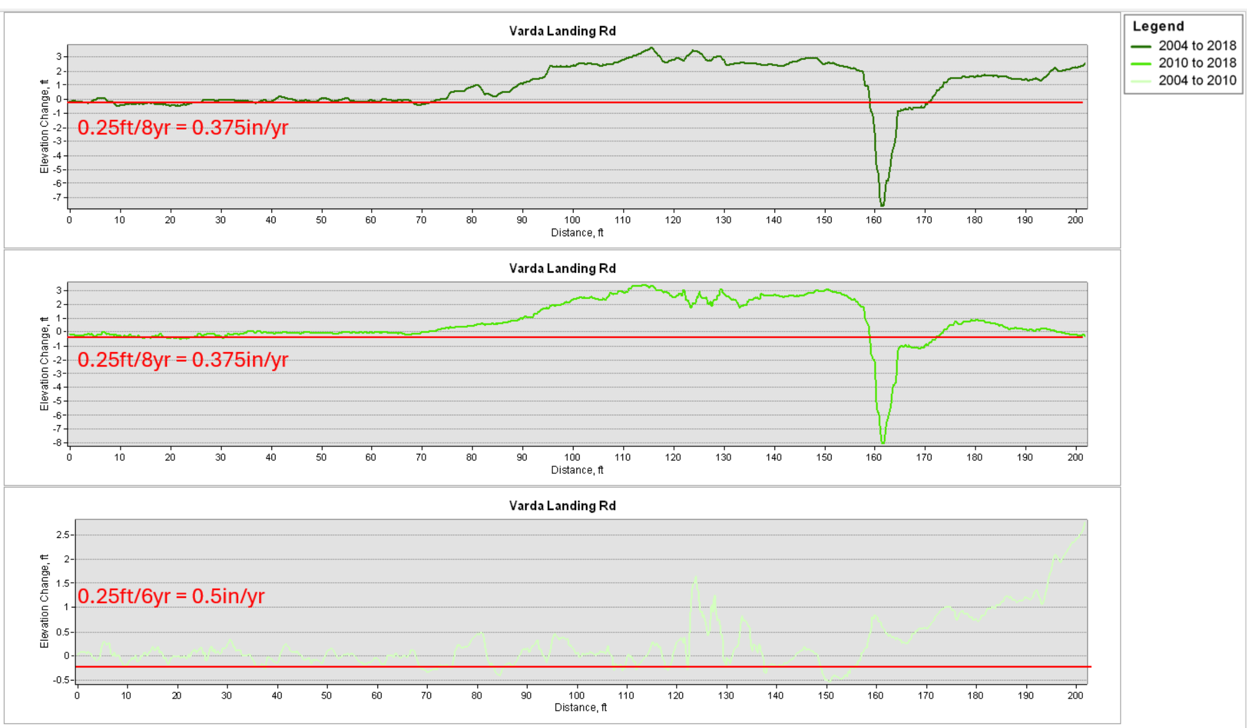


Figure 30 Varda Landing Rd Elevation Changes with USGS Datasets.

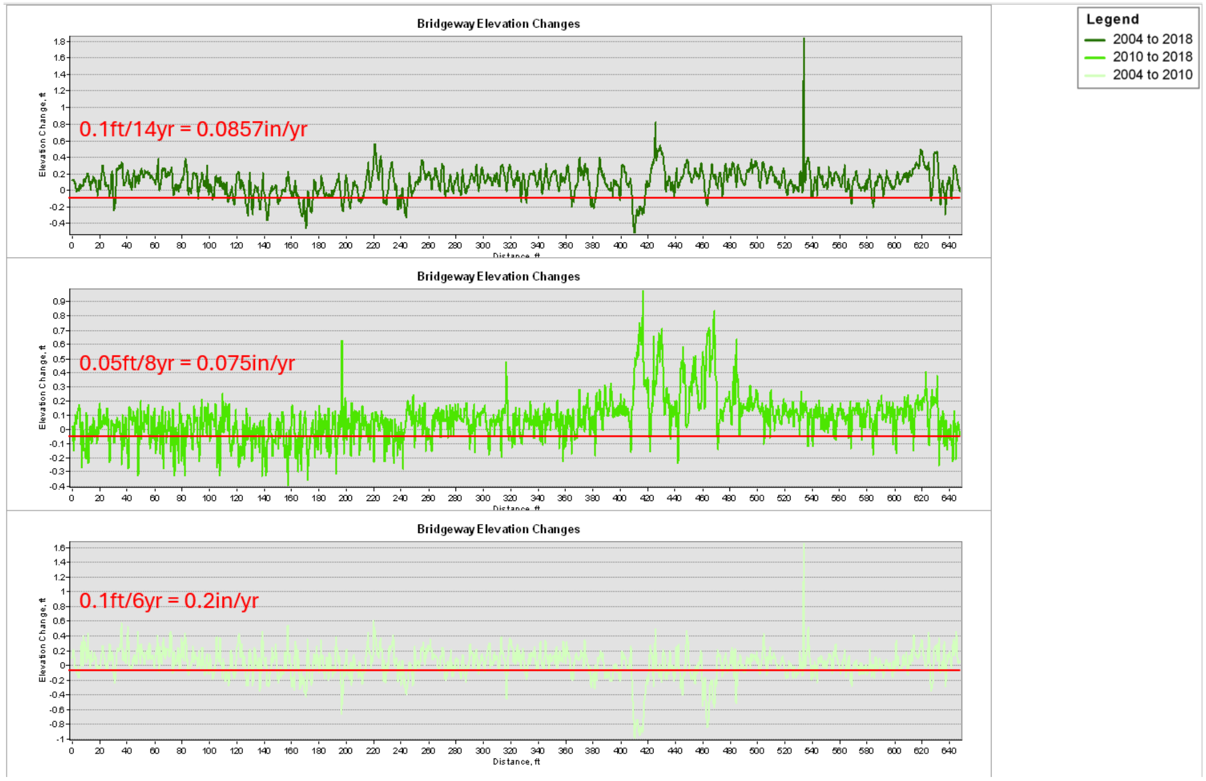


Figure 31 Bridgeway Elevation Changes with USGS Datasets.

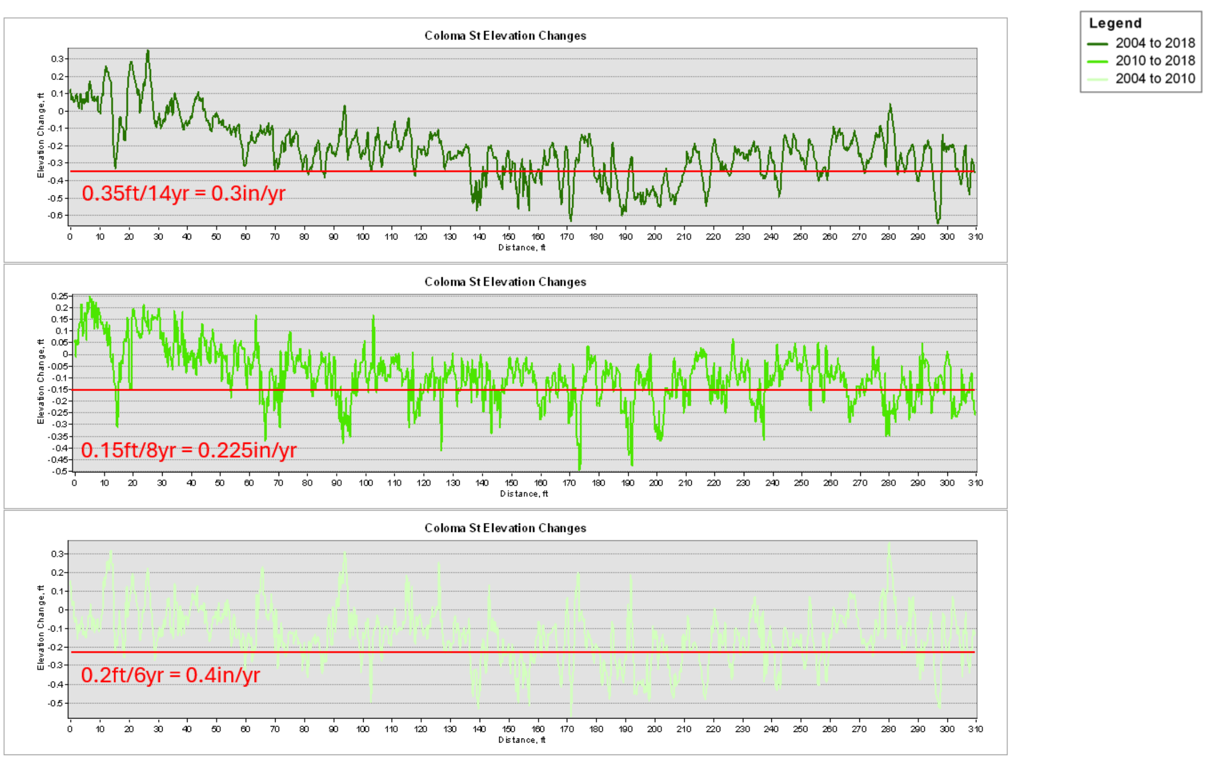


Figure 32 Coloma St Elevation Changes with USGS Datasets.

Figure 33 Harbor Dr Elevation Changes with USGS Datasets.

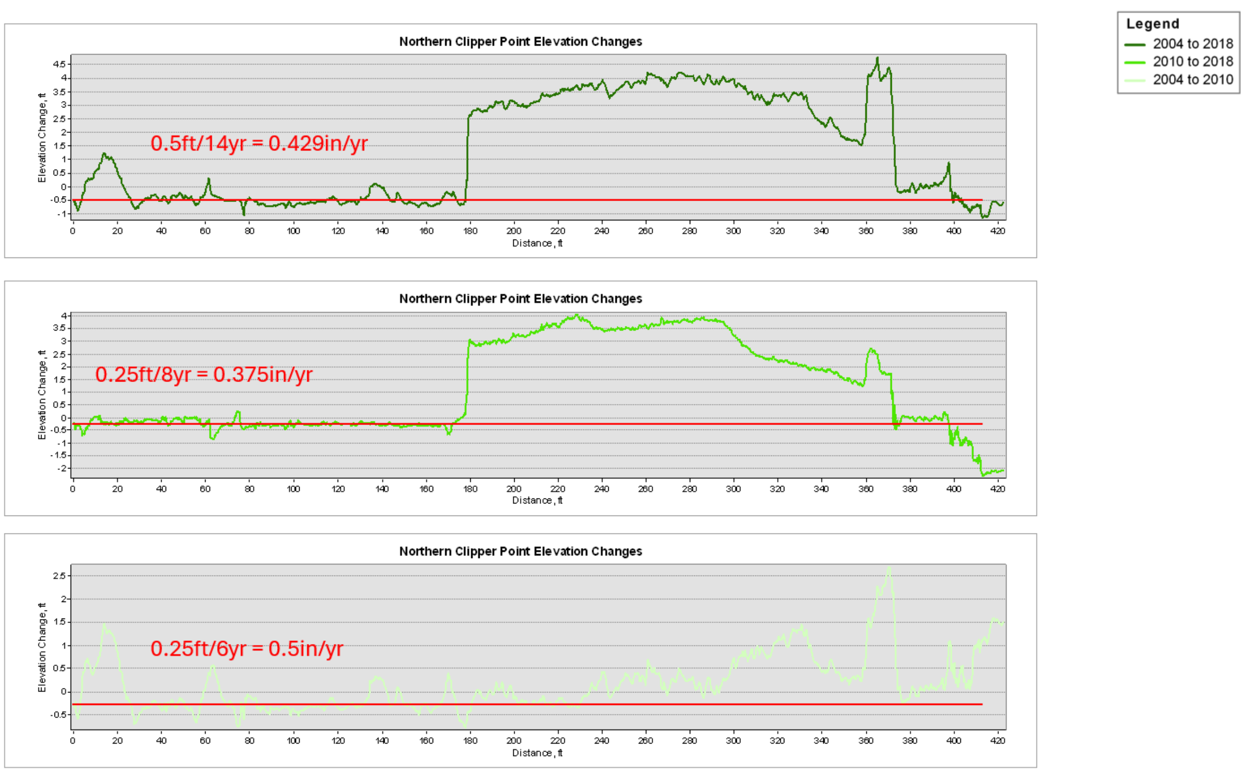


Figure 34 Northern Clipper Point Elevation Changes with USGS Datasets.

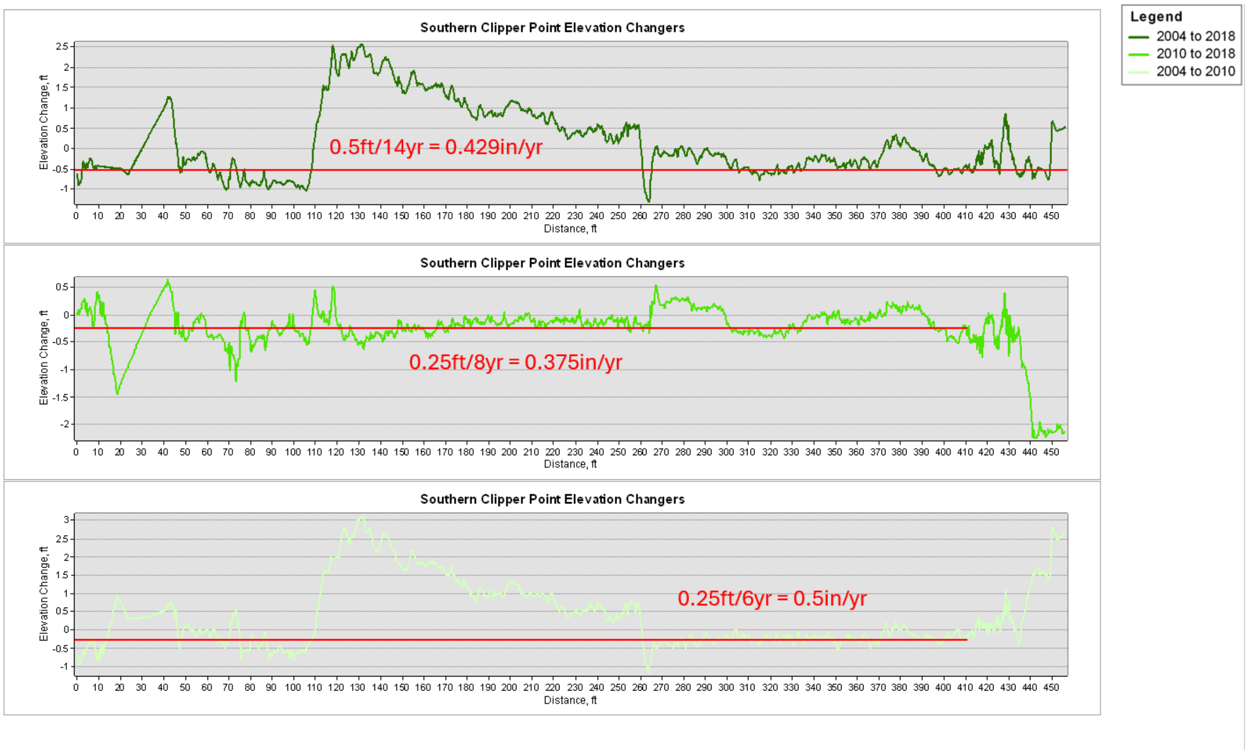


Figure 35 Southern Clipper Point Elevation Changes with USGS Datasets.

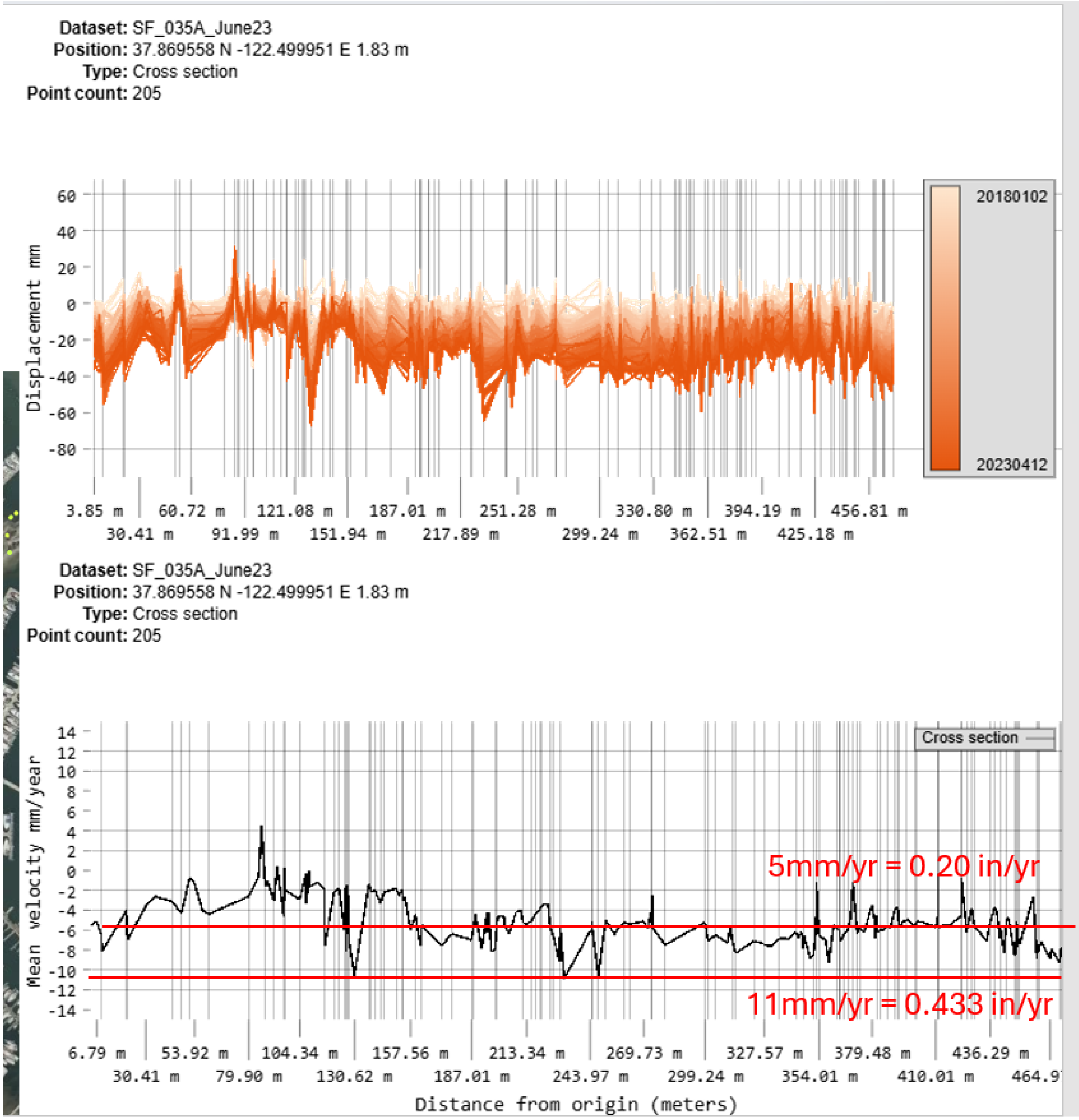


Figure 36 Gate 5 Rd Elevation Changes in NORCE Maps.

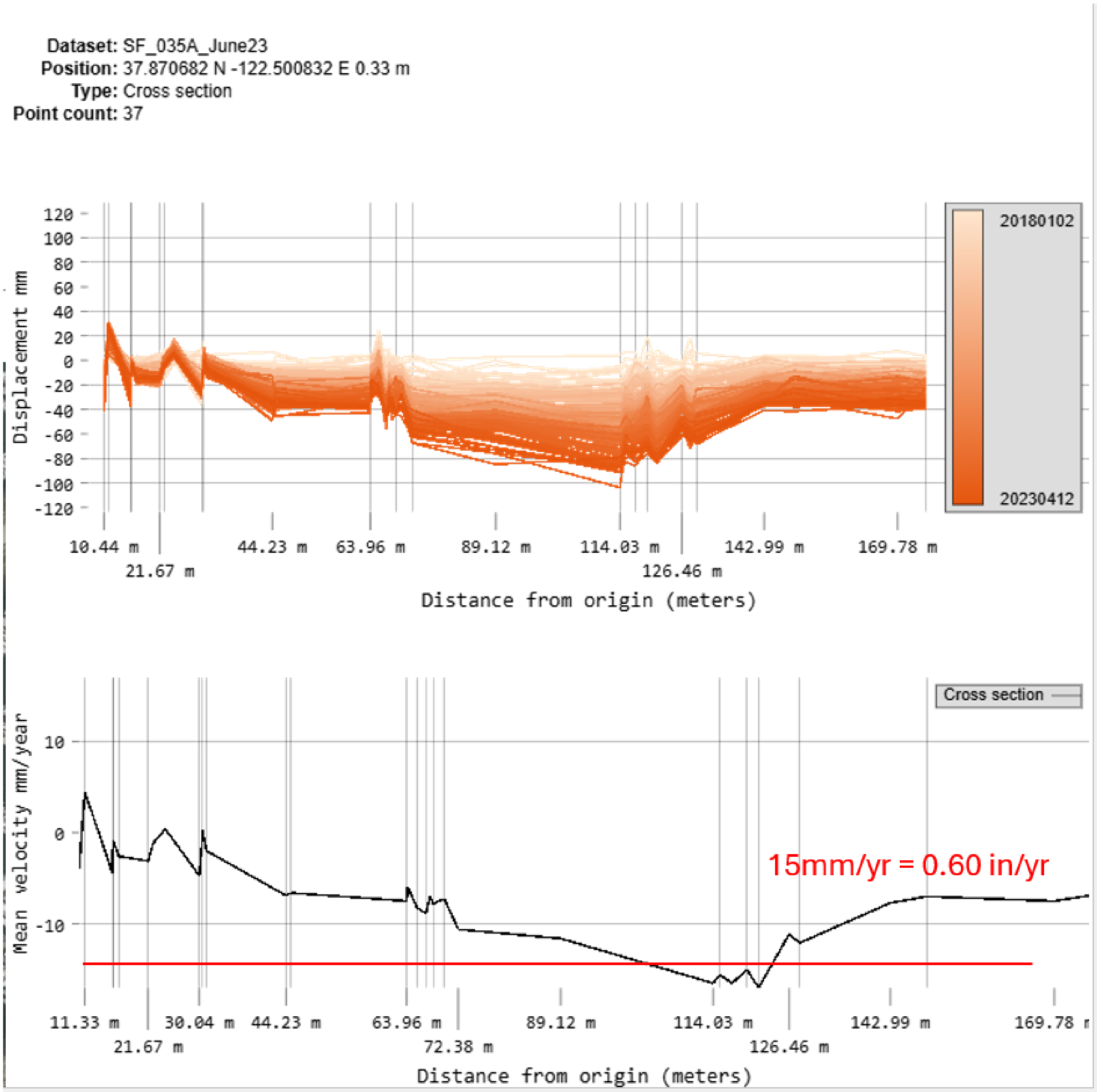


Figure 37 Varda Landing Rd Elevation Changes in NORCE Maps.

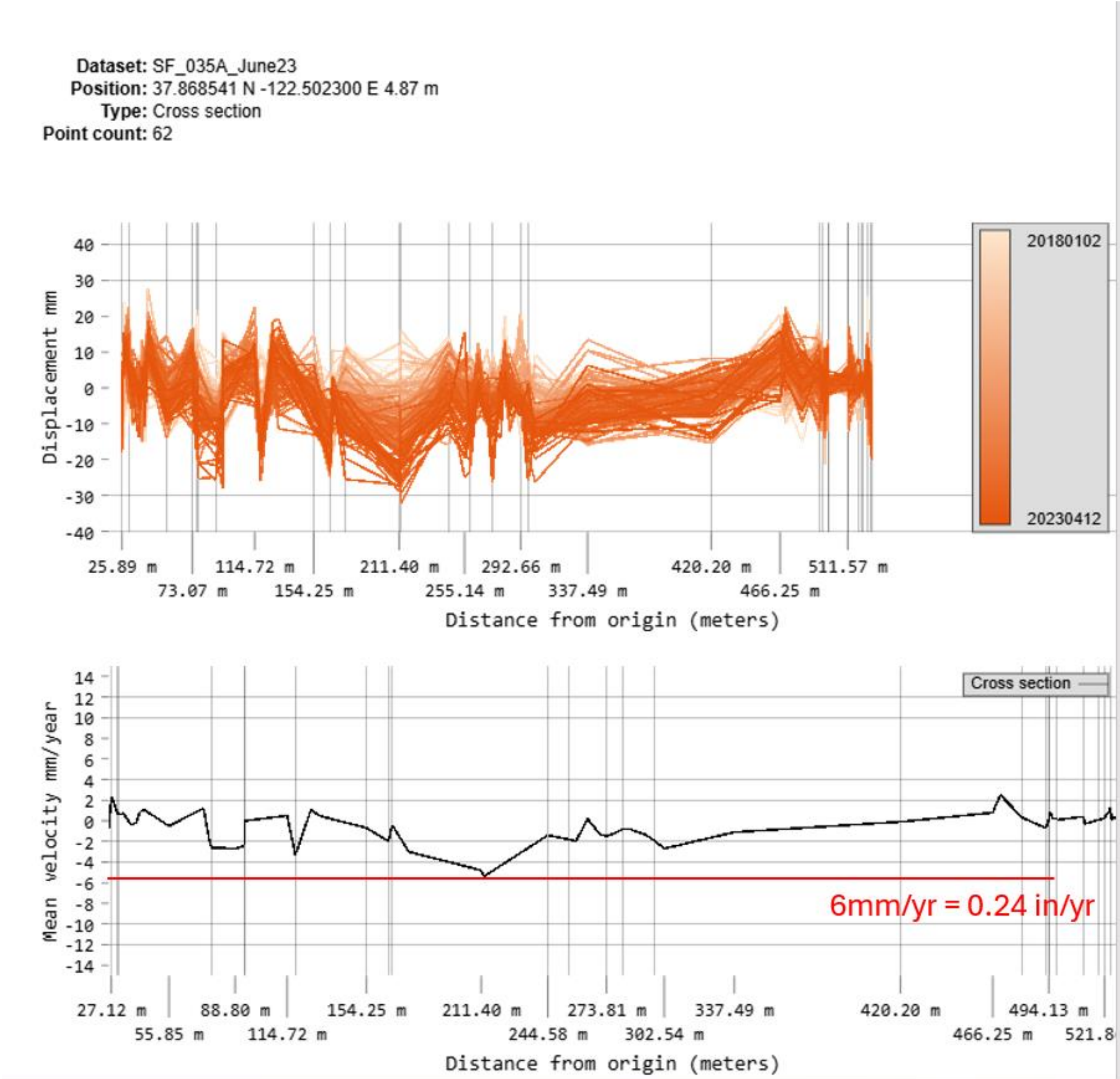


Figure 38 Bridgeway Elevation Changes in NORCE Maps.

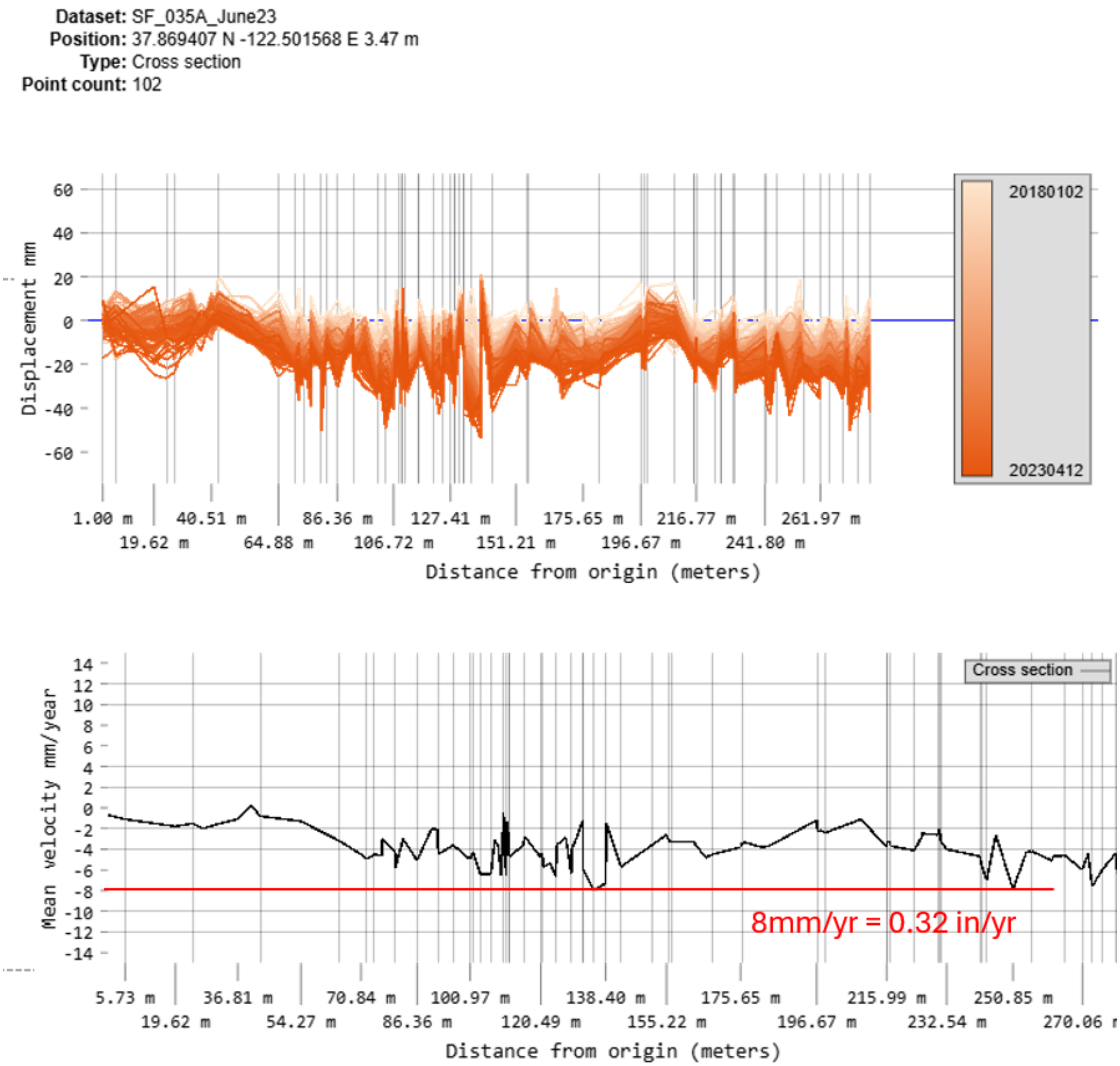
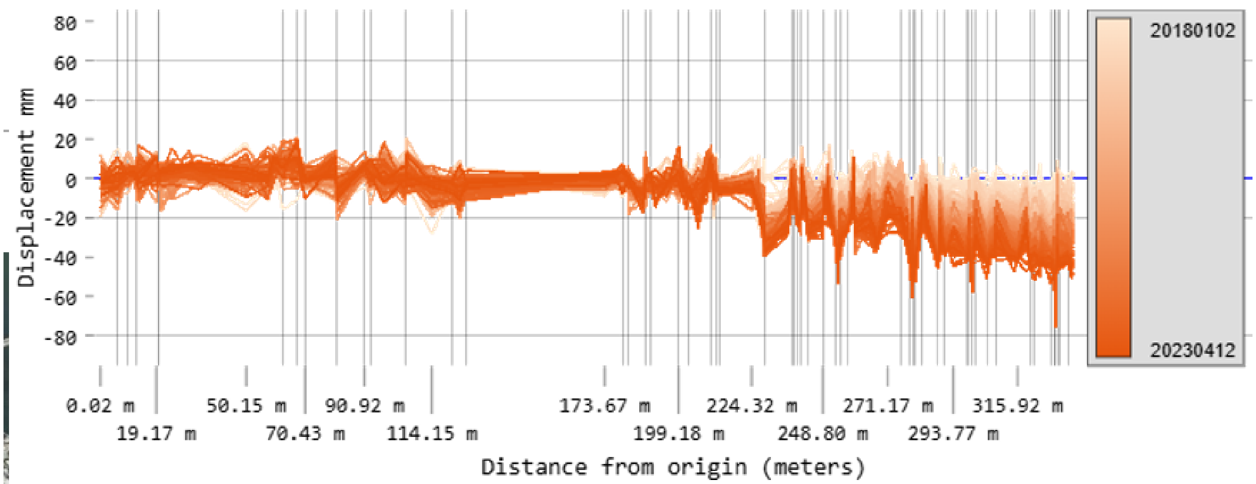


Figure 39 Coloma St Elevation Changes in NORCE Maps.

Dataset: SF_035A_June23
Position: 37.868065 N -122.499086 E 2.83 m
Type: Cross section
Point count: 120



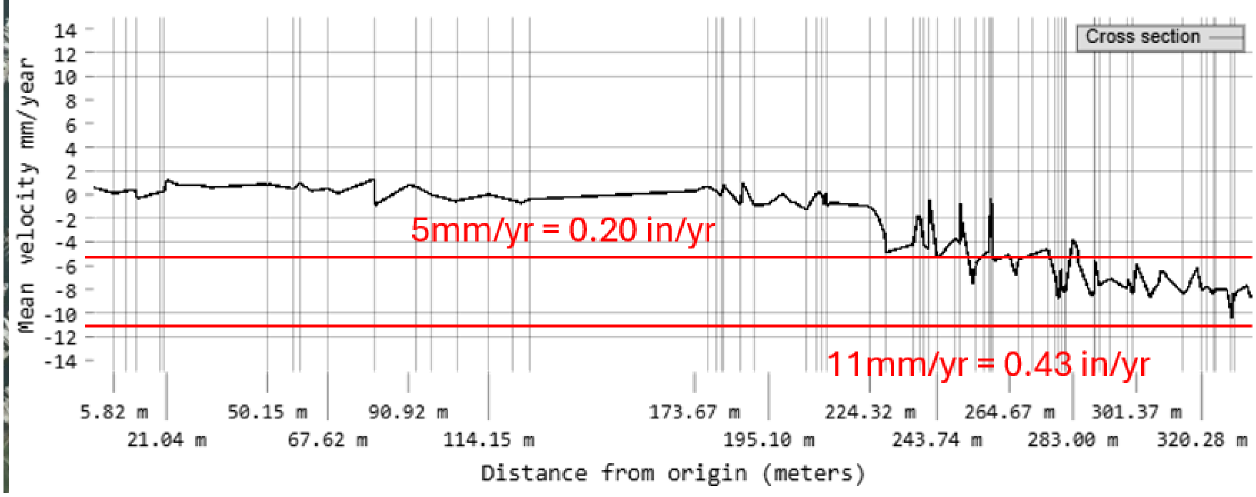


Figure 40 Harbor Rd Elevation Changes in NORCE Maps.

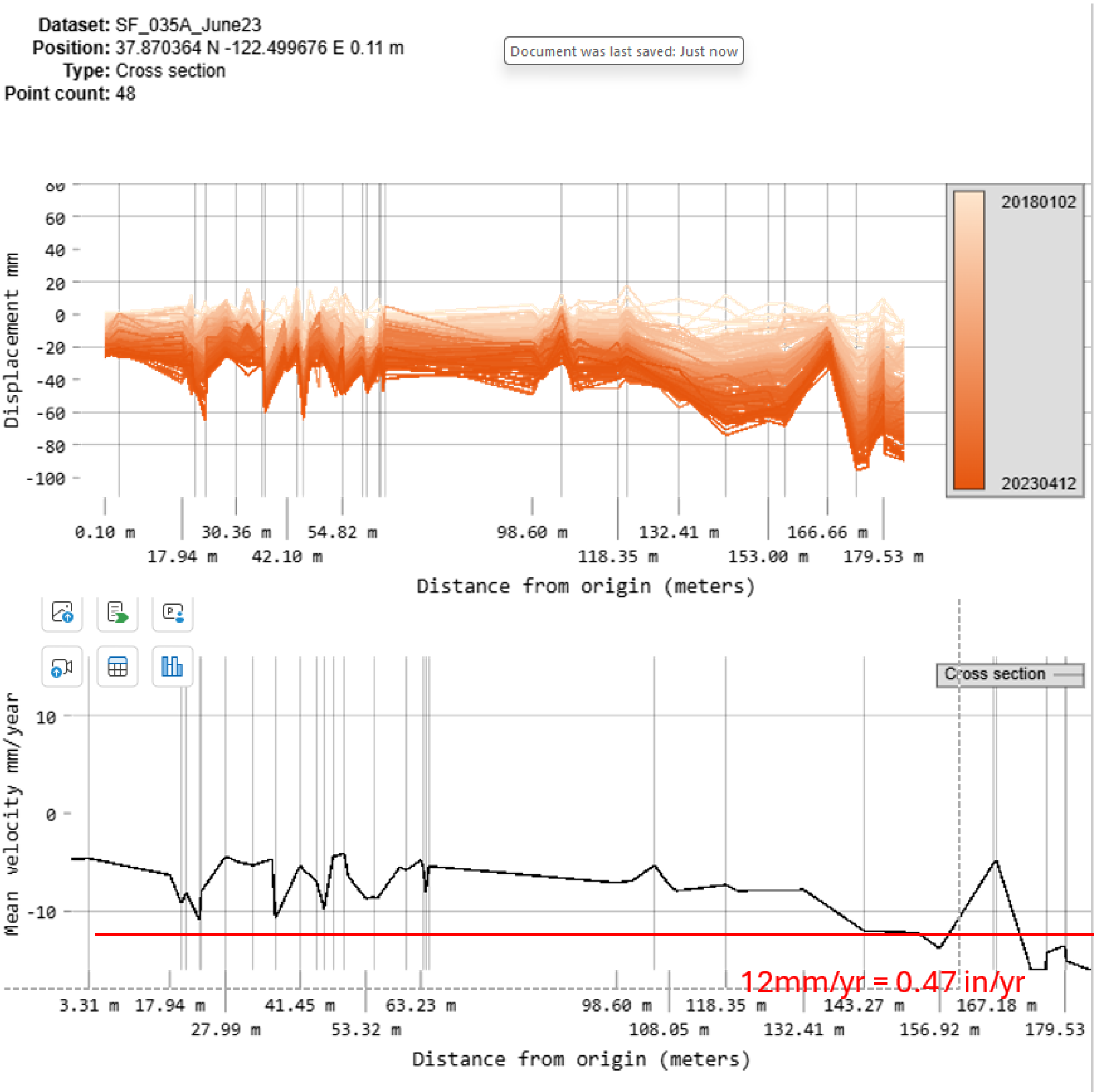


Figure 41 Northern Clipper Point Elevation Changes in NORCE Maps.

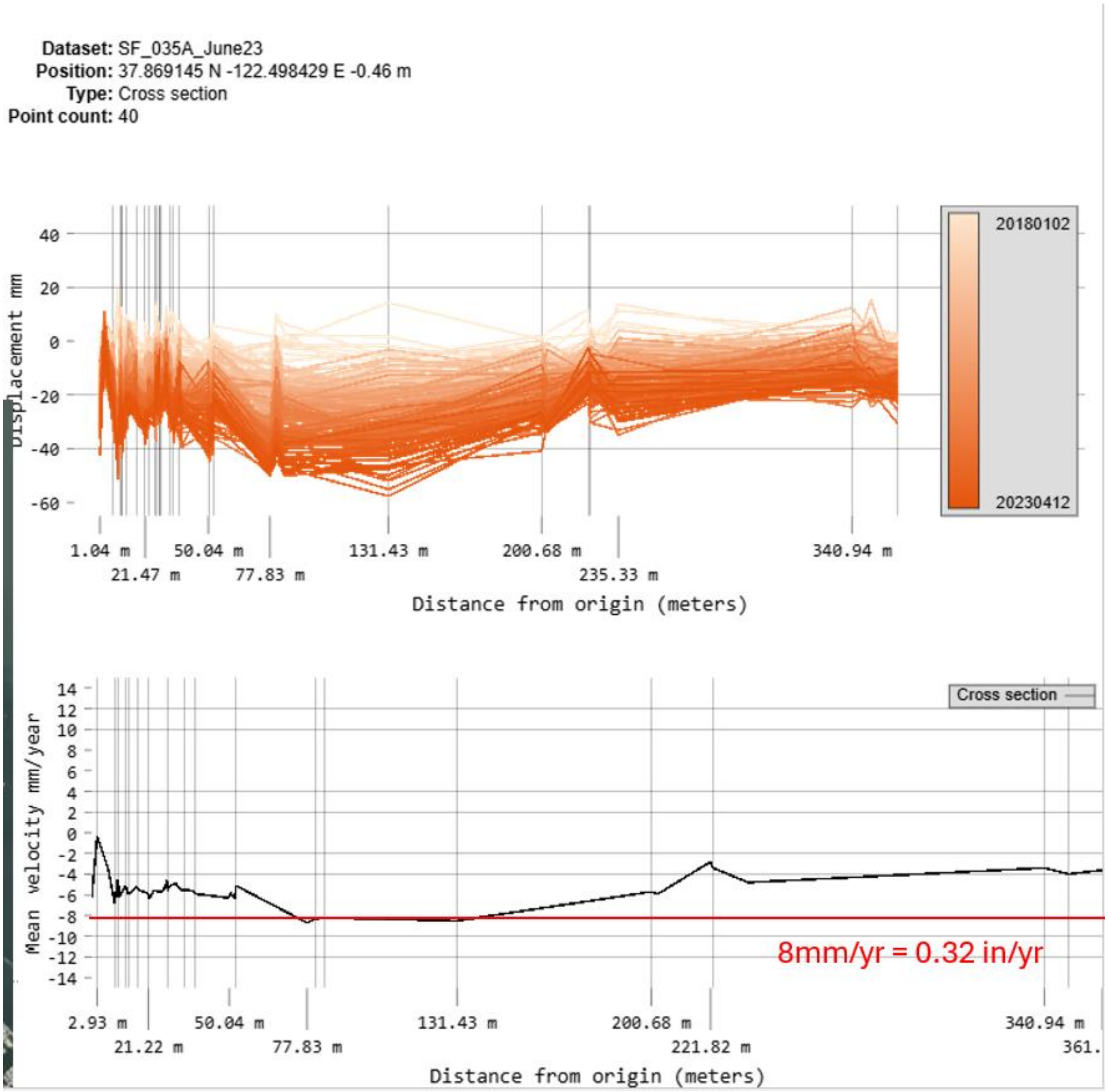


Figure 42 Southern Clipper Point Elevation Changes in NORCE Maps.

6. Appendix B: Future Changes in Extreme Precipitation

The data was obtained from the second iteration of the Localized Constructed Analogs (LOCA2) dataset, downloaded from the Cal-Adapt Analytics Engine using Python. The 3km hybrid dataset for California was used. This is the newest generation of climate data from the 6th Coupled Model Intercomparison Project (CMIP6). The data has been averaged over a 30-year period for both the historical and future periods. Climate model projections are taken from 13 global climate models (GCMs).

The recommended correction factor noted in the NOAA Atlas-14 methodology of 1.13 was applied to the precipitation data to transfer it from daily to 24-hour to match the Atlas-14 outputs. Bias correction to NOAA Atlas-14 was conducted to account for extremes.

Future changes in extreme precipitation were calculated using the following steps:

1. The annual maxima for 30-year time periods centered on future decades were retrieved for the model grid cell containing the project area [-122.50, -122.48 ;   37.85, 37.87].

2. The Generalized Extreme Value (GEV) distribution was fit to the annual maximums using L-moments for the future periods, 2040-2069 and 2070-2099, and the model baseline period of 1985-2014.

3. A ratio of the modeled baseline to modeled future was established for each model, return period, and future greenhouse gas emissions scenario (SSP 2-4.5, SSP 3-7.0, and SSP5-8.5). For instance, if a model shows a 100-year precipitation of 5.0 inches for the baseline period 1985-2014 and a value of 6.0 inches for the future period of the 2050s (2040-2069), the ratio is 1.2 or a 20% increase.

4. The ratios are aggregated by each future greenhouse gas emissions scenario.

5. The NOAA Atlas-14 precipitation Intensity-Duration-Frequency (IDF) curve was retrieved for the 24-hour event.

6. The aggregated ratios were applied to the current NOAA Atlas-14 24-hour depth curve to create an “adjusted” future curve.

The results in Table 14 show the adjusted return periods obtained from the analysis.

Table 14 Future Changes in Extreme Precipitation (% Change from Baseline Time Period).

Return Period (years)	**Atlas-14 24-hr Precipitation-Frequency**			**2050s % Change**			**2080s % Change**			
	Depth (in)	**10th percentile (in)**	**90th percentile (in)**	**SSP 2-4.5**	**SSP 3-7.0**	**SSP 5-8.5**	**SSP 2-4.5**	**SSP 3-7.0**	**SSP 5-8.5**	
10	5.04	4.49	5.78	**-2%**	-8%		1%	**22%**	18%	30%
25	6.18	5.34	7.3	**-6%**	-14%		-2%	**32%**	22%	41%
50	7.09	6.02	8.54	**-9%**	-18%		-4%	**43%**	26%	52%
100	8.05	6.68	9.91	**-12%**	-22%		-6%	**59%**	30%	66%
	The above are historical values from NOAA Atlas-14.			The above are the ratio of change expected.						

Note: Values in bold, corresponding to SSP2-4.5, were used in this study.

Baseline Time Period: 1985-2014

Mid-Century Time Period 2050s: 2040-2069

End-of-Century Time Period 2080s: 2070-2099

"Climate models from LOCA2 hybrid: ""ACCESS-CM2"", ""CESM2-LENS"", ""EC-Earth3"", ""EC-Earth3-Veg"", ""FGOALS-g3"", ""GFDL-ESM4"", ""INM-CM5-0"", ""IPSL-CM6A-LR"", ""KACE-1-0-G"", ""MIROC6"", ""MPI-ESM1-2-HR"", ""MRI-ESM2-0"", ""TaiESM1"""

7. Appendix C: Cross-Horizon Return-Period Mapping

This appendix provides supporting information for the cross-horizon return period mapping approach described in Section 3.1.3.3. The materials included here document how modeled storm surge water levels from different horizon years were assigned equivalent return periods for use in AAL estimation.

Storm surge stillwater elevation–return period pairs were obtained from the AECOM (2016) study for the project area and represent storm surge–only conditions referenced to present-day Mean Higher High Water (MHHW). These values were used solely to define a frequency relationship for return-period interpretation.

A Log-Pearson Type III (LP3) relationship was fitted in natural-log space to the available storm surge points. The LP3 distribution was selected as a standard frequency-analysis form for representing extreme water levels and was used here to establish a smooth, monotonic relationship between stillwater elevation and annual exceedance probability.

The fitted relationship was applied in two ways:

- Forward mapping, to evaluate water levels for reference return periods, and
- Inverse mapping, to estimate the equivalent return period associated with a modeled total water level from a different horizon year.

Table 15 lists the fitted LP3 parameters used for the storm surge frequency relationship and Figure 8 shows the fitted LPS function and the storm surge points from AECOM (2016).

Table 15 Log-Pearson Type III Parameters for Storm Surge Stillwater Elevation.

Parameter	Value
Mean, μ (log space)	2.0465
Standard deviation, σ (log space)	0.0548
Skew, g	3.038

Note: Parameters are expressed in natural-log space and correspond to stillwater elevation in feet. These values apply only to the storm surge frequency relationship used for return-period mapping.

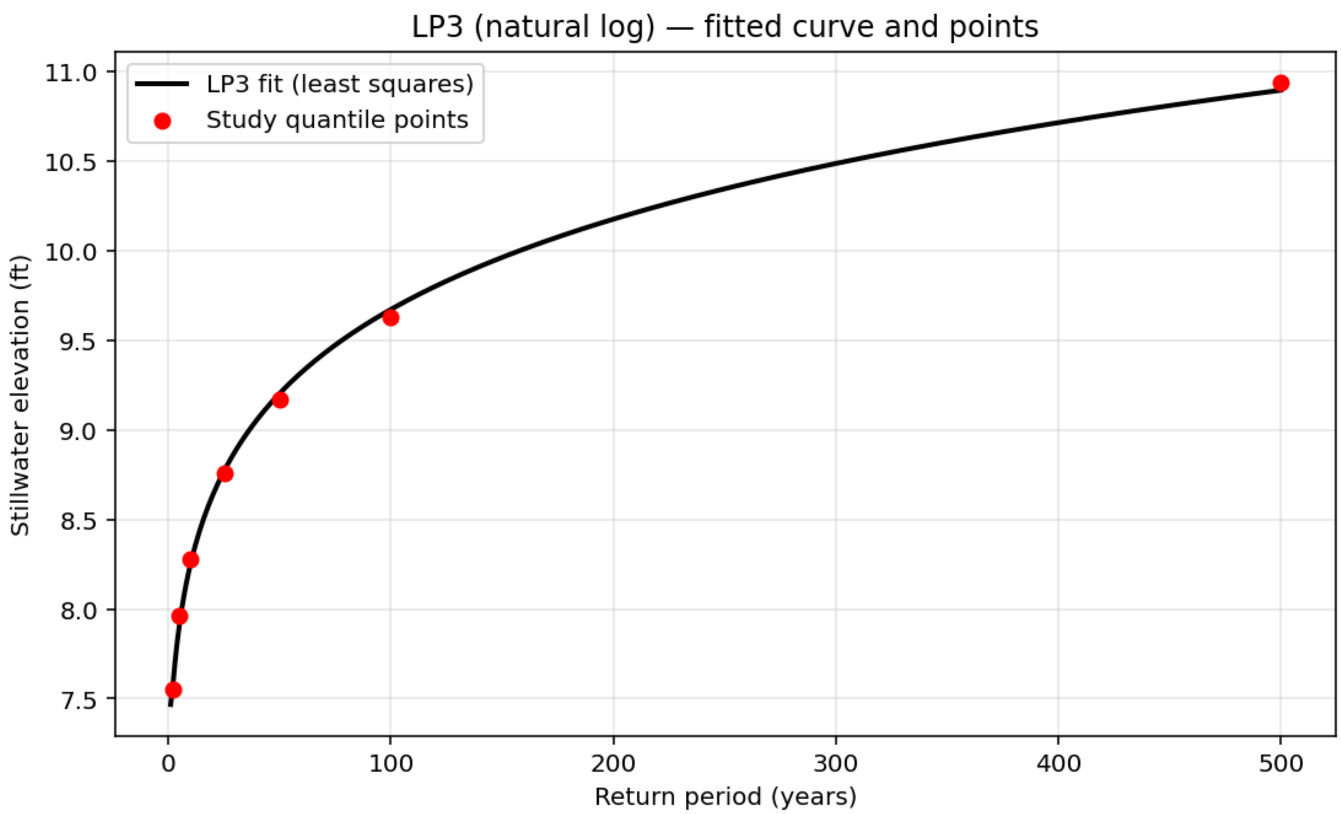


Figure 43 Log-Pearson Type III Distribution (Black, Line) and AECOM Study Values (Red, Points).

To increase the resolution of probability–loss curves used in AAL estimation without additional hydrodynamic simulations, modeled total water levels from one horizon year were interpreted as equivalent return periods relative to the storm surge frequency relationship of another analysis year. Equivalent return periods were used only to supplement AAL integration points and do not represent changes to modeled hydrodynamic forcing. Total water levels include storm surge, SLR, and subsidence adjustments consistent with the associated horizon year. Equivalent return periods were used only where inferred values fell within the calibrated range of the storm surge frequency relationship based on the source AECOM quantile points.

Table 16 Modeled Storm Surge Water Levels and Equivalent Return Periods.

Year	Climate Scenario	Storm Surge Case	Total water level used for RP equivalence (2025 ref.) (ft)	Equivalent RP (2025)	Total water level used for RP equivalence (2050 ref.) (ft)	Equivalent RP (2050)	Total water level used for RP equivalence (2080 ref.) (ft)	Equivalent RP (2080)
2025	N/A	1-yr	7.2	1	5.15	-	2.9	-
2025	N/A	100-yr	9.63	94	7.58	2	5.33	-
2050	Intermediate	1-yr	9.25	54	7.20	1	4.95	-
2050	Intermediate	100-yr	11.68	1250	9.63	94	7.38	-
2080	Intermediate	1-yr	11.5	1020	9.45	72	7.2	1
2080	Intermediate	100-yr	13.93	12255	11.88	1562	9.63	94
2100	Intermediate	No Surge	12.87	4422	10.82	455	8.57	18
2100	Intermediate	1-yr	14.05	-	12.00	-	9.75	112

Note: "Total water level" values include storm surge (if applicable), sea level rise, and subsidence adjustments from the source scenario year. These values are shown relative to different reference-year storm surge frequency curves to estimate equivalent return periods for AAL integration. Cells marked "–" indicate cases where equivalent return periods fall outside the calibrated range of the fitted storm surge frequency relationship.

Although equivalent return periods were derived for multiple modeled scenarios, only a limited subset of cross-horizon mappings was used in the final AAL calculations (Table 17). This selection was made to maintain consistency between the storm surge–only analysis and the stress test (surge + precipitation) analysis. Specifically, precipitation projections were available only through the 2080 horizon, therefore, to ensure comparability across hazard sets, cross-horizon mappings involving 2100-derived water levels were not used in AAL calculations, even where equivalent return periods could be computed. The subset of reused scenarios applied in the AAL computation is summarized in Table. This approach preserved internal consistency across hazard evaluations while still improving the resolution of AAL integration.

Table 17 Cross Horizon Scenario Reuse Applied in AAL Estimation

Analysis Year	Source Scenario	Equivalent Return Period
2025	2050, 1-year storm surge, Intermediate	54
2050	2025, 100-year storm surge	2
2050	2080, 1-year storm surge, Intermediate	72

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