Technical Memorandum

June 29, 2024

To	Morguine Sefcik	**Tel**	707.267.2275
Copy to	Greg Garrison PE, Mazen Idriss EIT	**Email**	brett.vivyan@ghd.com
From	Brett Vivyan PE	**Ref. No.**	12621644
Subject	Arcata Hydraulic Model Development		

1. Introduction

1.1 Overview

Previous studies, local, and global climate models have suggested that the shoreline and select landward regions of the City of Arcata (City) may be susceptible to sea level rise and climate impacts. Within these vulnerable areas exist critical infrastructure including utilities, transportation assets, and public facilities. The California Coastal Commission Local Coastal Program Local Assistance Grant Program has awarded funding to the City to pursue the *Arcata Sea Level Rise Vulnerability Assessment and Capital Improvement Project Adaptation Plan* (Project). The City is currently updating their Local Coastal Program (LCP) with updates to the Local Coastal Element. The Project will allow the City to quantify vulnerabilities and develop adaptation strategies for erosion and flooding in their Local Coastal Program. A detailed hydraulic model is required to understand where shoreline overtopping will occur and the extent of flooding and inundation under various water level, storm and rainfall events. This Memorandum outlines the development and results of such a model.

1.2 Scope of Study

The City has requested the Project Tasks outlined below. This Memorandum describes the process for completing Task 1.

1) Develop a two-dimensional hydrodynamic model of the region of interest. Using 2019 LiDAR data for topography/bathymetry, available stormwater infrastructure from GIS data, North Spit Tide Gage data, previously modeled water levels, and hydrological/streamflow estimates from StreamStats or other studies, the City requests the identification of five Coastal Scenarios. These Coastal Scenarios will be modeled to determine potential flooding pathways from the combined effects of riverine and tidal sources.
2) Based on the hydrodynamic model, a range of potential Planning Scenarios with varied simulated exposures will be considered in the development of adaptation concepts. Each Planning Scenario must include a map identifying locations of primary flood pathways, flood depth and duration on transportation infrastructure, and flood depth and duration on flood sensitive utilities. A Vulnerability Assessment section of the Capital Improvement Projects (CIP) Adaptation Concept Plan will be

developed based on exposure, sensitivity, and adaptive capacity of City assets. This Vulnerability Assessment Section will be reviewed by the Coastal Commission for review, and it will be revised to reflect CCC and stakeholder comments.

3) The City requests adaptation strategies to address vulnerabilities in Task 2 to inform the LCP and planned CIP's which include the Arcata Wastewater Treatment Facility upgrades. Strategies considered include nature-based adaptation, hybrid approaches, managed retreat, or improvement of current infrastructure. The appropriate strategy will be developed considering cost, location, engineering feasibility, environmental impacts, consistency with the Coastal Act, City LCP policy, State and Coastal Commission sea level rise planning guidance, the age of the asset, multi-benefit strategy opportunities, and other regulations. These strategies will be outlined in the CIP Adaptation Concept Plan with graphics of proposed improvements that include mapping layers for coastal resources and potential impacts to coastal resources based on the concept's footprint. The graphics must show planning intentions for the Arcata shoreline, including Zones 1 and 2, which are currently in the Local Coastal Element of the draft LCP. The CIP Adaptation Concept Plan will include descriptions and methods from the previous tasks. Public and stakeholder outreach will be conducted. The Coastal Commission will review the CIP Adaptation Concept Plan, and it will be revise to reflect CCC and stakeholder comments.

1.3 Study Area

The region of interest includes the Coastal Zone within the City of Arcata. This Study Area includes the City's shoreline, extending from McDaniel Slough to Washington Gulch (Brainard Slough), and inland sufficient to capture the extent of Coastal Zone flooding for the selected scenarios (Figure 1).

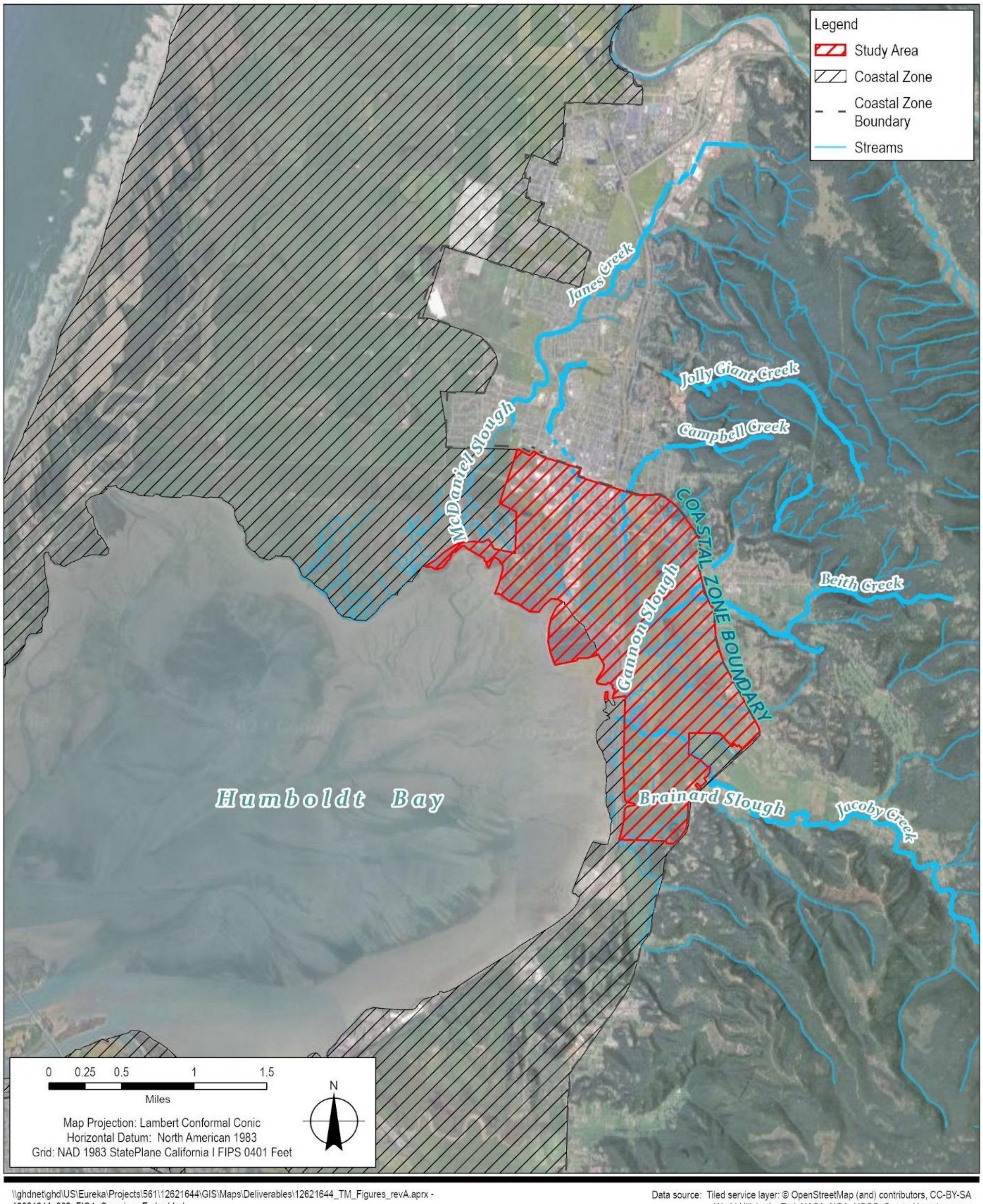


Figure 1 Study Area

2. Tidal Water Levels and Sea Level Rise

Astronomical tides are the primary influence on water levels within Humboldt Bay. Typical daily tides range from mean lower low water (MLLW) to mean higher high water (MHHW), a range of about 6.85 feet (NOAA Station 9418767). During spring tides, which occur twice per lunar month, the tide range increases due to the additive gravitational forces caused by alignment of the sun and moon. The largest spring tides of the year, which occur in the winter and summer, are sometimes referred to as “King” tides and result in water levels that exceed 8 feet.

Ocean water levels typically vary within predictable astronomical tide ranges; however, sea level anomalies caused by El Niño Southern Oscillation or storm surge events can increase the water levels above the predicted astronomical tide. These events in combination with high astronomical tides can result in extreme water levels. The highest water level on record at the North Spit tidal station occurred on December 31, 2005 when a water level of 9.6 feet was observed, which was roughly 1.5 feet higher than the predicted tide, as illustrated in Figure 2.

Note, this extreme water level was observed at the peak of the tide cycle, lasting a relatively short duration (e.g. several minutes), followed by the ebbing limb of the tide cycle and subsequent low tide. While topography and elevation are good indicators of flood potential, flood duration is also a key factor influencing the extent of coastal flooding, particularly where hydraulic connectivity is limited by a levee, berm or storm drain infrastructure, such as a tide gate.

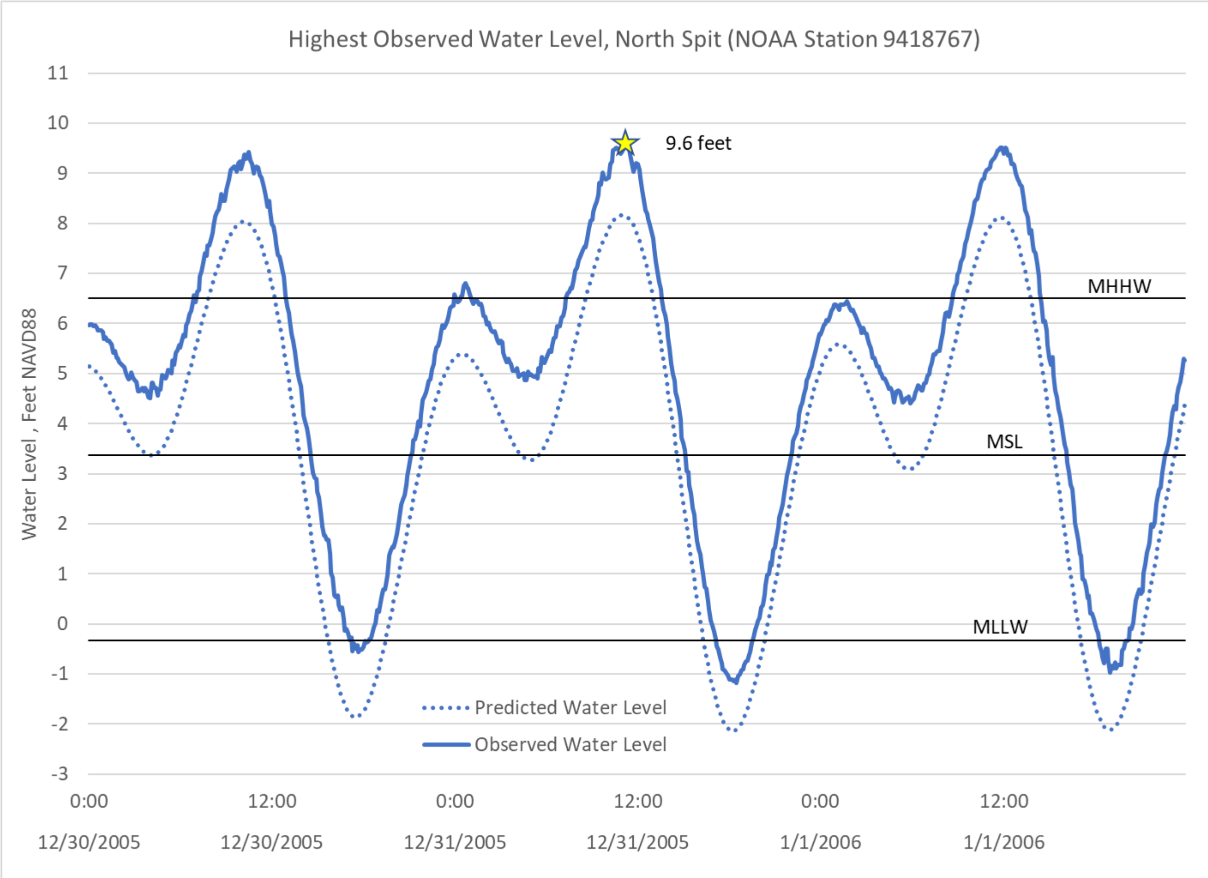


Figure 2 ***Highest Observed Water Level at North Spit (NOAA Sta 9418767)***

Water levels along the City of Arcata shoreline differ from those at the North Spit (NOAA Sta 9418767) due various hydrodynamic factors. A hydrodynamic model developed by Northern Hydrology and Engineering (NHE) was utilized in NHE's Humboldt Bay: Sea Level Rise, Hydrodynamic Modeling, and Inundation Vulnerability Mapping report model water levels throughout Humboldt Bay. The open ocean boundary condition for the model includes variability in sea levels due to astronomical tides and the effects of wind, sea-level pressure, and El Nino (NHE, 2015a). NHE also developed an Excel application to extract estimated average water levels and annual exceedance probabilities of extreme high-water levels for locations throughout Humboldt Bay (NHE, 2015b). Using the excel application and accounting for vertical land motion, NHE developed existing tidal datums and annual exceedance probabilities for this study, as shown in Table 1.

Table 1 ***2023 Tidal water levels and still water return periods for the study area provided by NHE.***

Tidal Datum and Annual Exceedance Probability (%)	Annual Expected Number of Occurrences (#/yr)	Annual Average Recurrence Interval (yr)	Year 2023 Value (m, NAVD 88)	Year 2023 Value (ft, NAVD 88)
Mean High Water (MHW)	-	-	2.0	6.4
Mean Higher High Water (MHHW)	-	-	2.2	7.1
Mean Monthly Maximum Water (MMMW)	-	-	2.6	8.5
Mean Annual Maximum Water (MAMW)	-	-	2.9	9.5

Tidal Datum and Annual Exceedance Probability (%)	Annual Expected Number of Occurrences (#/yr)	Annual Average Recurrence Interval (yr)	Year 2023 Value (m, NAVD 88)	Year 2023 Value (ft, NAVD 88)
99.0	0.99	1.01	2.8	9.3
95.0	0.95	1.05	2.8	9.3
90.9	0.91	1.10	2.8	9.3
80.0	0.80	1.25	2.9	9.4
66.7	0.67	1.5	2.9	9.5
50.0	0.50	2	2.9	9.6
20.0	0.20	5	3.0	9.9
10.0	0.10	10	3.1	10.1
5.0	0.05	20	3.1	10.3
4.0	0.04	25	3.2	10.4
2.0	0.02	50	3.2	10.5
1.0	0.01	100	3.3	10.7
0.5	0.005	200	3.3	10.8
0.2	0.002	500	3.3	11.0

2.1 Sea Level Rise

Sea level rise (SLR) is the primary issue of concern when considering how impacts from a changing climate could affect infrastructure and lands along Humboldt Bay. SLR is unique among other natural processes and episodic events because it will develop over the span of decades. Initially, SLR may be difficult to distinguish among the variable water levels of Humboldt Bay, but even small amounts of SLR may increase the risk of coastal flooding during extreme events, posing a threat to a variety of coastal resources.

Global mean sea level is rising, with acceleration in recent decades due to increasing rates of ice loss from the Greenland and Antarctic ice sheets, as well as continued glacier mass loss and ocean thermal expansion ((IPCC, 2019). The rate of global SLR for 2006-2016 of 3.6 mm/year is unprecedented over the last century and was 2.5 times higher than the rate for 1901-1990 of 1.4 mm/year (IPCC, 2019). SLR projections along the west coast of California are provided in the 2018 and latest 2024 Draft State of California Sea Level Rise Guidance document (OPC, 2024) for 12 active tide gauges. The California Coastal Commission (CCC) Sea Level Rise Policy Guidance, updated in 2018 to reflect the latest projections, refers to these as the “best available science” on SLR projections in California.

SLR projections for Humboldt Bay North Spit on (Station ID: 9418767), the nearest tide gauge to Arcata, are used for the study area. These projections are shown in Figure 3 for a range of probabilistic scenarios and time horizons through 2150. OPC 2024 identifies the Intermediate-Low scenario as the lower bound for the most likely sea level rise by 2100, the Intermediate as a reasonable upper bound for the most likely range of sea level rise by 2100, and the Intermediate-High as corresponding to other scientific estimates of plausible high-end projections. The High scenario is described as embedded with deep uncertainties and ambiguity framing the worst case beyond 2100 and estimating a likelihood is not possible. Future updates to the OPC and CCC guidance will continue to be updated using the best available predictions for SLR.

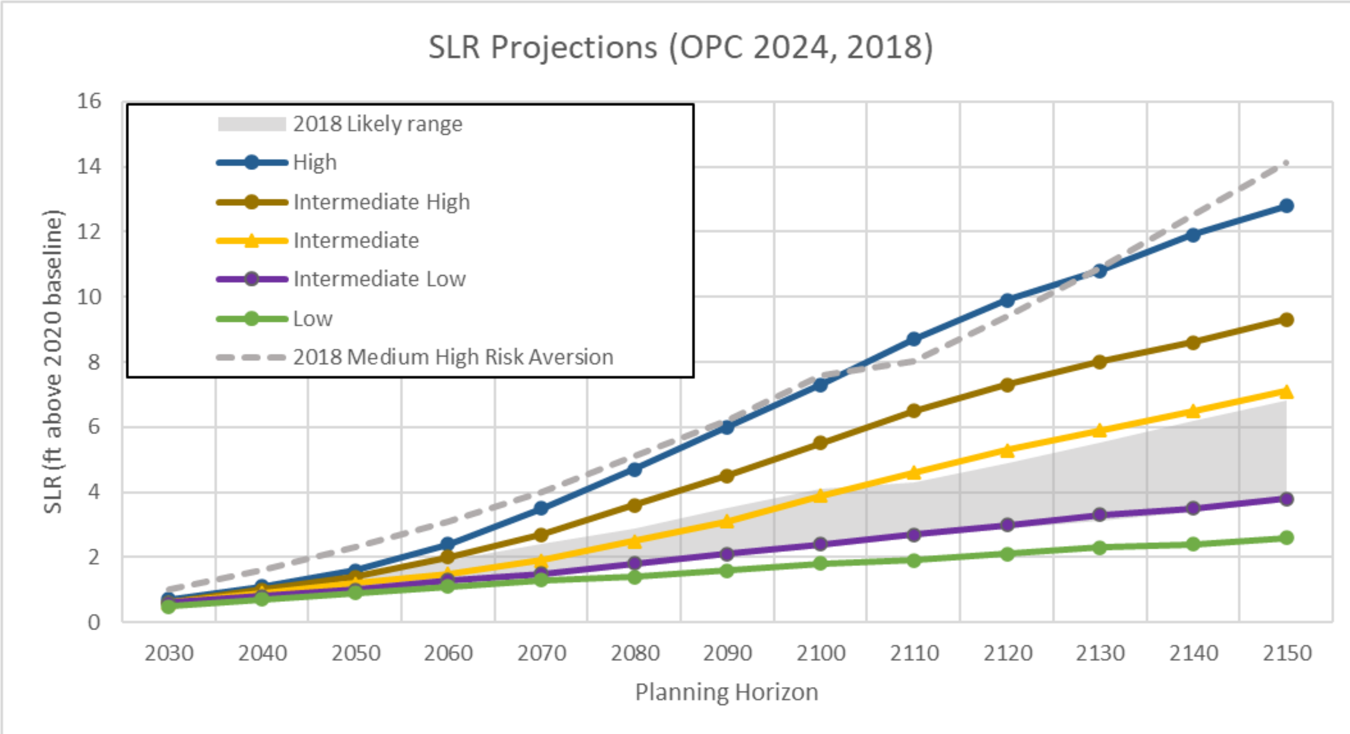


Figure 3 ***SLR projections from OPC 2024 and OPC 2018.***

Planning Horizon. The Local Coastal Element of the General Plan notes a 20-year planning horizon and CIPs are typically 20 to 30 years, with consideration of longer term infrastructure life span (typically up to 50 years). A CIP and LCP Planning Time Frame from 2025 to 2055 and an infrastructure lifespan of up to 50 years will be utilized for this study. Therefore sea level rise projections to 2105 will be considered.

Design Criteria. Infrastructure design commonly incorporates design likelihoods. For example, the 1% annual chance flood elevation is commonly used for critical infrastructure, such as levee protection systems or electrical facilities serving critical infrastructure. A factor of safety or freeboard is then added to accommodate additional uncertainties. For the purposes of this assessment, the Intermediate-Low, Intermediate, and Intermediate-High scenarios will be used for evaluating vulnerability and risk of critical assets as they represent estimates of plausible projections with a reasonable likelihood of occurrence.

Scenario definitions. As a part of this planning study, SLR projections are added to existing tidal datums and high-end extreme water levels to estimate likelihoods of event during the LCP and CIP planning period and typical infrastructure lifespan. The existing tidal datums and extreme high-water level probability estimates for Arcata Bay at the Arcata Marsh & Wildlife Sanctuary calculated by NHE with sea level rise estimates consistent with OPC 2024 Intermediate-Low, Intermediate, and Intermediate-High are provided in Figure 4 thru Figure 6.

The OPC 2024 High scenario has not been included as OPC 2024 that there is a less than 1% chance of exceeding the intermediate-High Scenario by 2100 and the High Scenarios is assumed to be a lower likelihood with deep uncertainties and ambiguity. This low probability projection in addition to the use of low likelihood design criteria would result in a likelihood significantly less than relevant design criteria. For example, assuming sea level rise and storm surge are independent events, a sea level rise likelihood of less than 1% in combination with the 1% annual chance water level would be the product of the two and result in a likelihood of 0.01%.

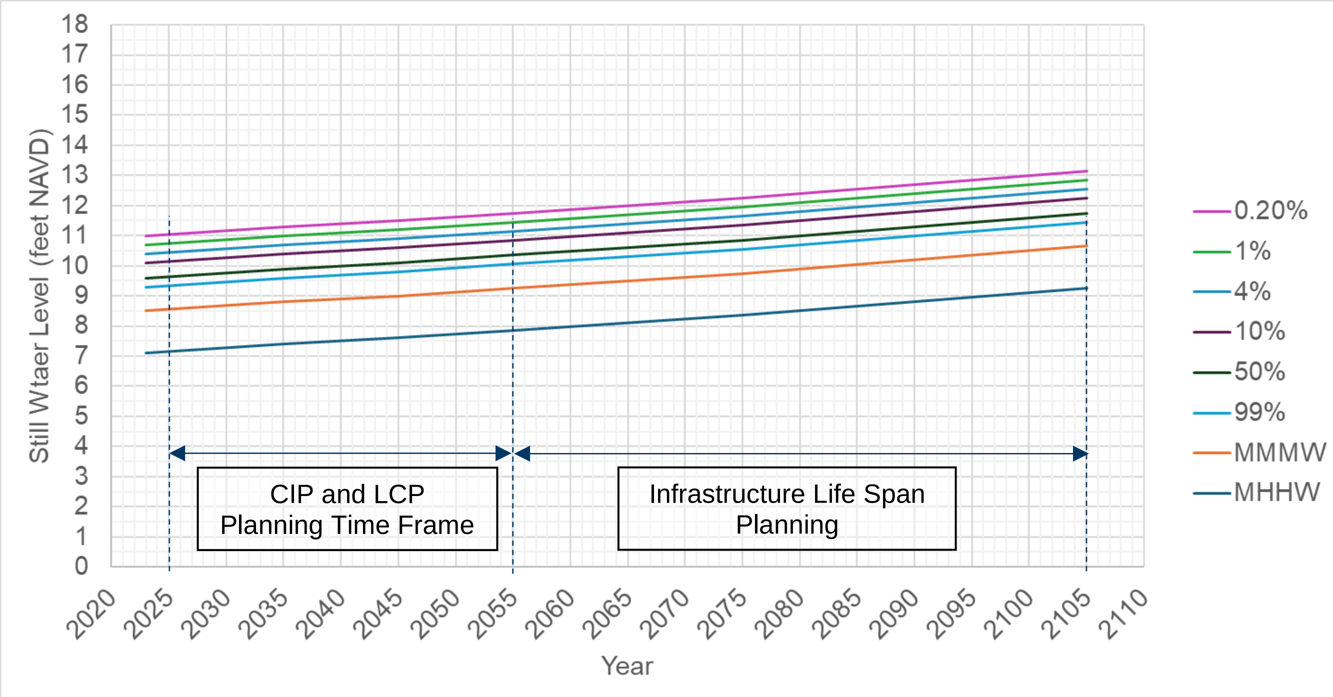


Figure 4 Still Water Datums and OPC Intermediate-Low Sea Level Rise Projection (Lower Bound of Most Likely Range of Sea Level Rise by 2100).

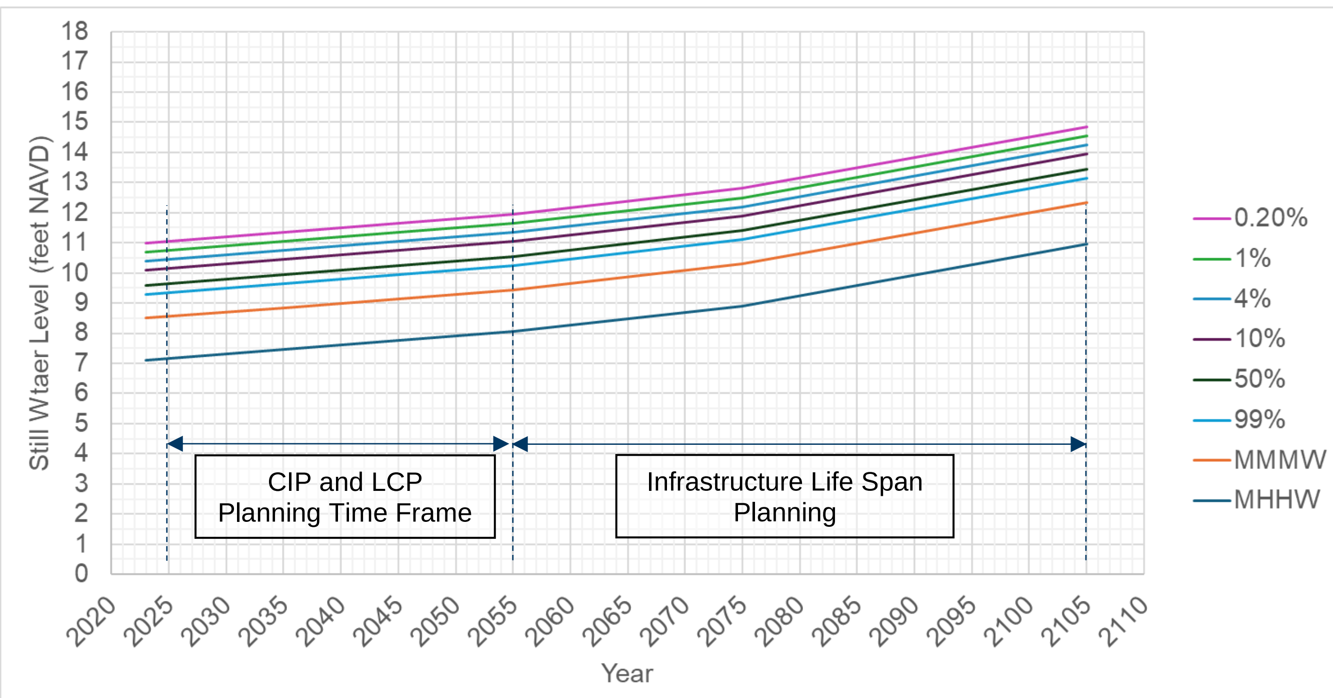


Figure 5 Still Water Datums and OPC Intermediate Sea Level Rise Projection (Upper Bound of Most Likely Range of Sea Level Rise by 2100).

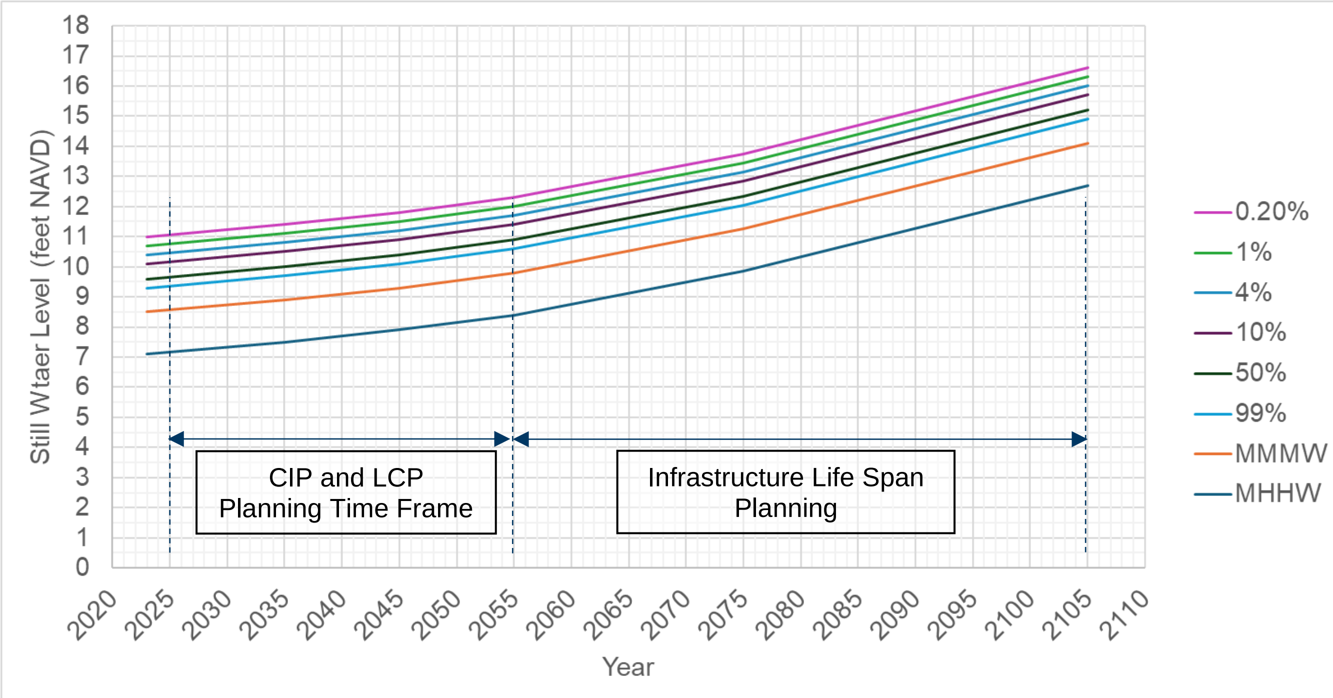


Figure 6 Still Water Datums and OPC Intermediate-High Sea Level Rise Projection (Plausible High-End Projection by 2100).

3. Precipitation and Peak Flows

Peak flows for given return periods were estimated for multiple locations within the study area using the USGS StreamStats online application (USGS, 2019). The application calculates contributing drainage area, mean annual precipitation, and return period peak flows using regional regression equations developed by Gotvald et al. (2012). Peak flows for the 2-year, 10-year and 100-year recurrence intervals for Campbell, Beith, Janes, Grotzman, Jolly Giant, and Jacoby Creeks are shown in Table 2.

Table 2 Peak flows for modeled creeks

Creek	2-year (peak cfs)	10-year (peak cfs)	100-year (peak cfs)
Jolly Giant	66	179	1,090
Janes	158	416	2,540
Jacoby	1,090	2,540	4,480
Campbell	63	172	332
Grotzman	68	183	348
Beith	99	261	495

3.1 Increased Precipitation

Cal-Adapt provides projections for increases in rainfall intensity for multiple emissions scenarios (Table 3). Projections indicate that the current 10-year recurrence will become the 2-year recurrence between 2069-2099 and that the current 100-year recurrence will become the 10-year recurrence between mid- and end-century.

Table 3 Cal-Adapt precipitation recurrences for the Arcata area.

Recurrence	Baseline (inches/day) 1960 – 1990	Mid-Century (inches/day) (% increase) 2034 – 2064	End-Century (inches/day) (% increase) 2069 – 2099
2-year	2.4	2.8 (17%)	3.0 (25%)
10-year	3.0	3.8 (27%)	4.8 (60%)
100-year	3.8	5.2 (37%)	8.2 (116%)
Projected changes in Estimated Intensity of Extreme Precipitation Events which are exceeded on average once every 2, 10 and 100 years under a Medium Emissions (RCP 4.5) Scenario. Cal-Adapt. Data: LOCA Downscaled CMIP5 Climate Projections (Scripps Institution of Oceanography), Gridded Observed Meteorological Data (University of Colorado Boulder), LOCA Derived Products (Geospatial Innovation Facility) for CanESM2 (Average)			

3.2 Compound Frequency

Along much of the U.S. Pacific Coast, which includes the Study Area, storm systems that produce extreme coastal surge events are not the same storm systems that produce extreme rainfall and resulting riverine flooding, and these events can generally be assumed to be independent (FEMA, 2005). As a part of the County of Humboldt's Sea Level Rise Adaptation Plan for Transportation Infrastructure and Other Critical Resources in the Eureka Slough Hydrographic Area, Humboldt Bay, NHE performed an analysis to verify this independence assumption using annual peak-flows for the Eel River and Little River and the coincident maximum daily tide level at Crescent City (NHE, 2021). Over the period of record for both river locations, coincident coastal and riverine events exceeding the 10-year recurrence have not occurred, while coincident events between the 2-year and 10-year recurrence did occur. NHE concluded from the analysis that coastal and riverine extreme events generally appear to be independent.

The State of California Department of Transportation (Caltrans) Highway Design Manual provides guidance for evaluating boundary conditions subject to both tides and fluvial storms. This guidance includes one-percent compound frequency curves for tidal tailwater elevations and flood return periods based for the NOAA # 9418767, North Spit, Humboldt buoy (Figure 7). This compound frequency curve does not account for future changes to water levels due to sea level rise or future changes to rainfall intensity. Assuming independence of the two parameters, future probabilities may be multiplied together to estimate future compound frequency.

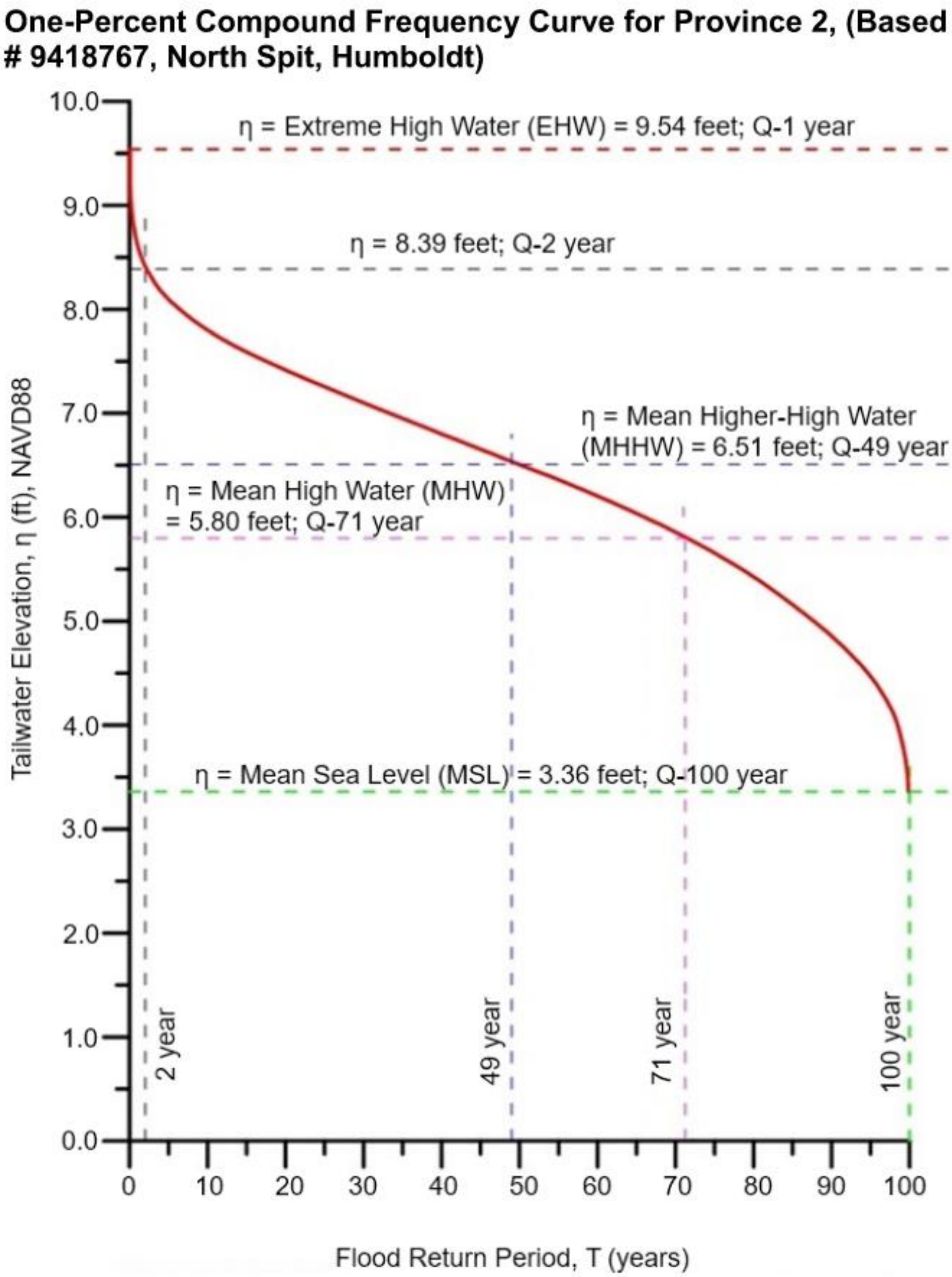


Figure 7 One-percent compound frequency curve for Humboldt Bay North Spit (Caltrans, 2020).

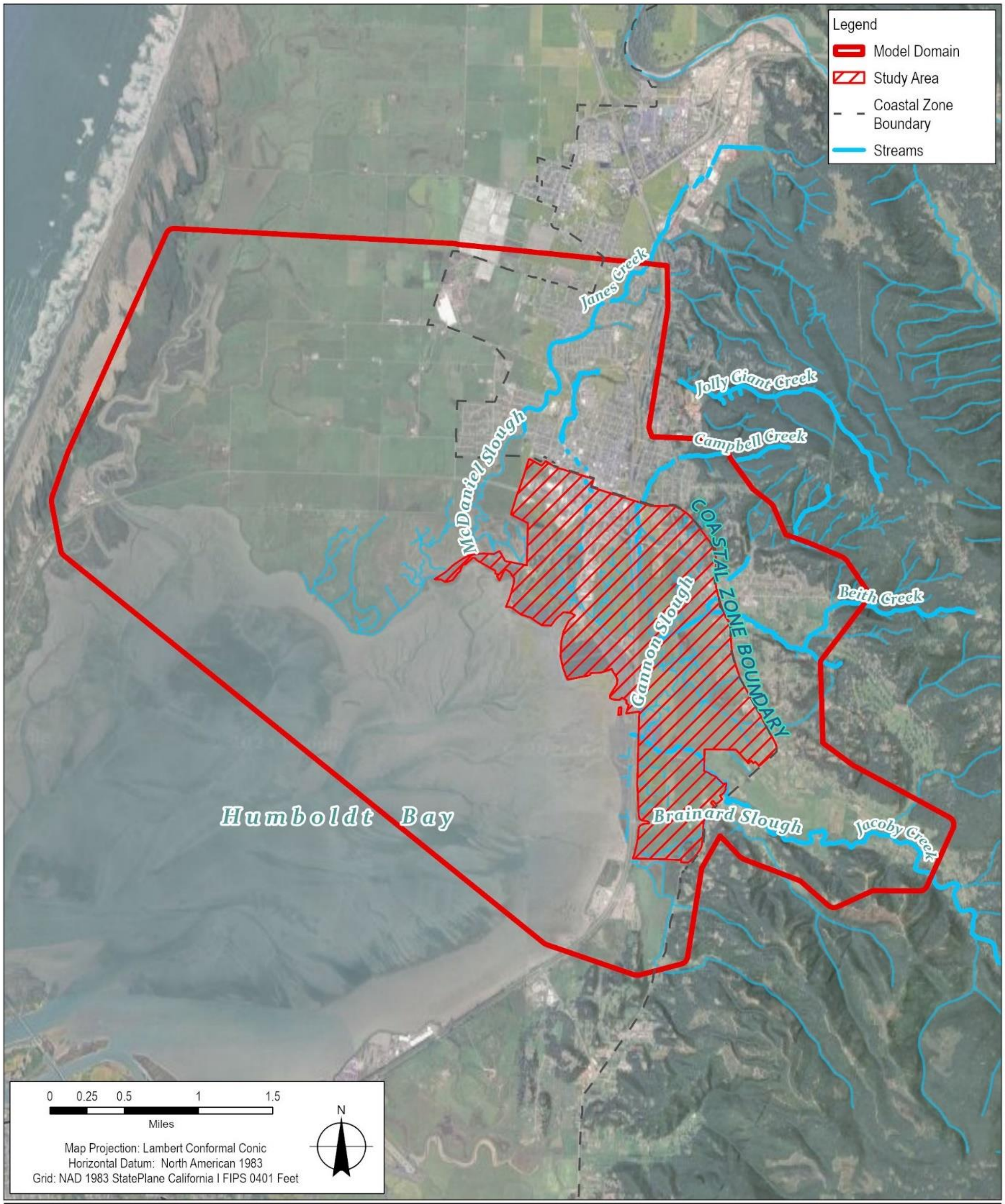
4. Hydraulic Model Development

4.1 HEC-RAS

HEC-RAS is a program deigned by the US Army Corps of Engineers. It is designed to perform one and two-dimensional hydraulic calculations on natural or constructed channels. The project hydraulic model was developed in the US Army Corps of Engineers HEC-RAS 2D, version 6.2.

4.2 Model Domain

The model domain was selected to encompass the Study Area and adjacent hydrographic areas, as shown in Figure 8.



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Data source: Tiled service layer: © OpenStreetMap (and) contributors, CC-BY-SA World Hillshade: Esri, NASA, NGA, USGS, FEMA Created by:mhargrave

Figure 8 Model Domain

4.3 Topography and Bathymetry

The model input used a topographic dataset from a LiDAR survey done for the Humboldt Bay Area. The data was collected on September 24th, 2019 with a Leica Hyperion LiDAR mapping unit and ground control by a California Certified Professional Land Surveyor (PLS). The dataset covered the study area, including Humboldt Bay. The LiDAR survey was conducted during a low tide to minimize inaccuracies due to hydro flattening (survey exhibits water surface instead of ground surface). A 1-foot resolution digital elevation model (DEM) bare earth (ground elevation with vegetation elevations removed) was developed from the classified point cloud and used as the foundation for the topographic inputs. The City of Arcata's impervious surface dataset was used to identify building footprints. Building footprints were raised 10ft higher than the original DEM elevation to account for the structure influence flow paths.

4.4 Grid Spacing and Mesh

The model's physical extent is defined in HEC-RAS as a user defined polygon, as shown in Figure 9. A mesh grid is assigned over the 2-D modeling domain with surface elevations and Manning's n values for surface roughness coefficient. The grid is defined with 40 ft. x 40 ft. cells covering the model domain. Refinement regions are added with larger representing the broader floodplain and areas with less topographic complexity, and smaller cells along levees and within the City limits to better capture the hydraulic behaviour of the channels and sloughs overtopping. Refinement regions allow for finer detail here needed while also minimizing computational time. The resulting mesh grid has the following characteristics:

- Number of cells: 168,218
- Average Cell Size: 2,420 ft^2
- Maximum Cell Size: 23,020 ft^2
- Minimum Cell Size: 31.9 ft^2

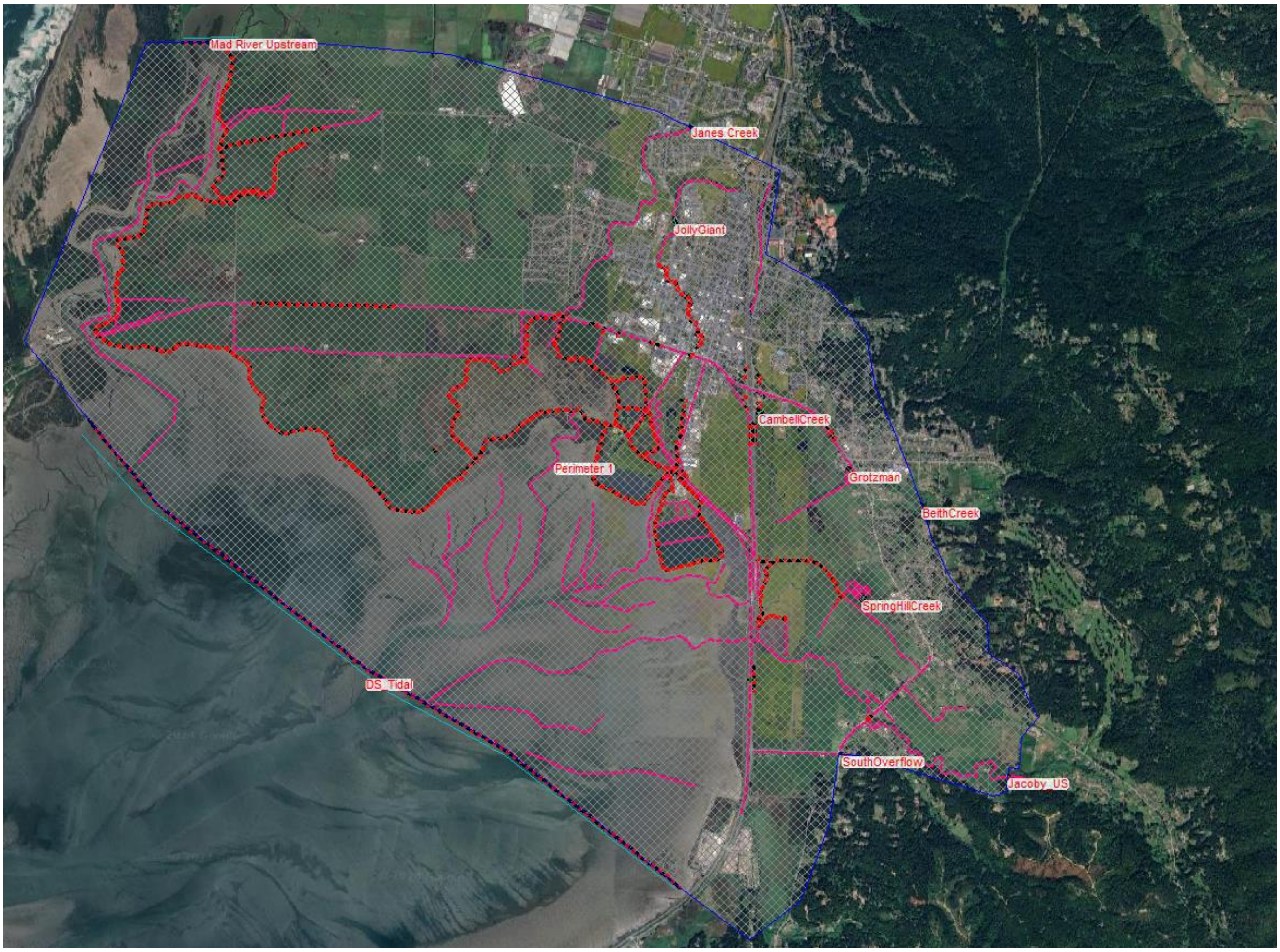


Figure 9. *HEC-RAS Model 2-D Domain.*

4.5 Breaklines and Connections

Breaklines are used to capture elevation boundaries within the model. Breaklines were used along features such as the top of existing levees, roadway centerlines, and creek alignments. Ares within the domain which contain critical topographic features such as levees, roadway fill prisms, and channel thalwegs, breaklines and 2D/SA connections are used to align mesh cell faces and ensure proper hydraulic connectivity (Figure 10). 2D/SA connections are also used for schematization of stormdrain infrastructure such as tide gates and culverts.

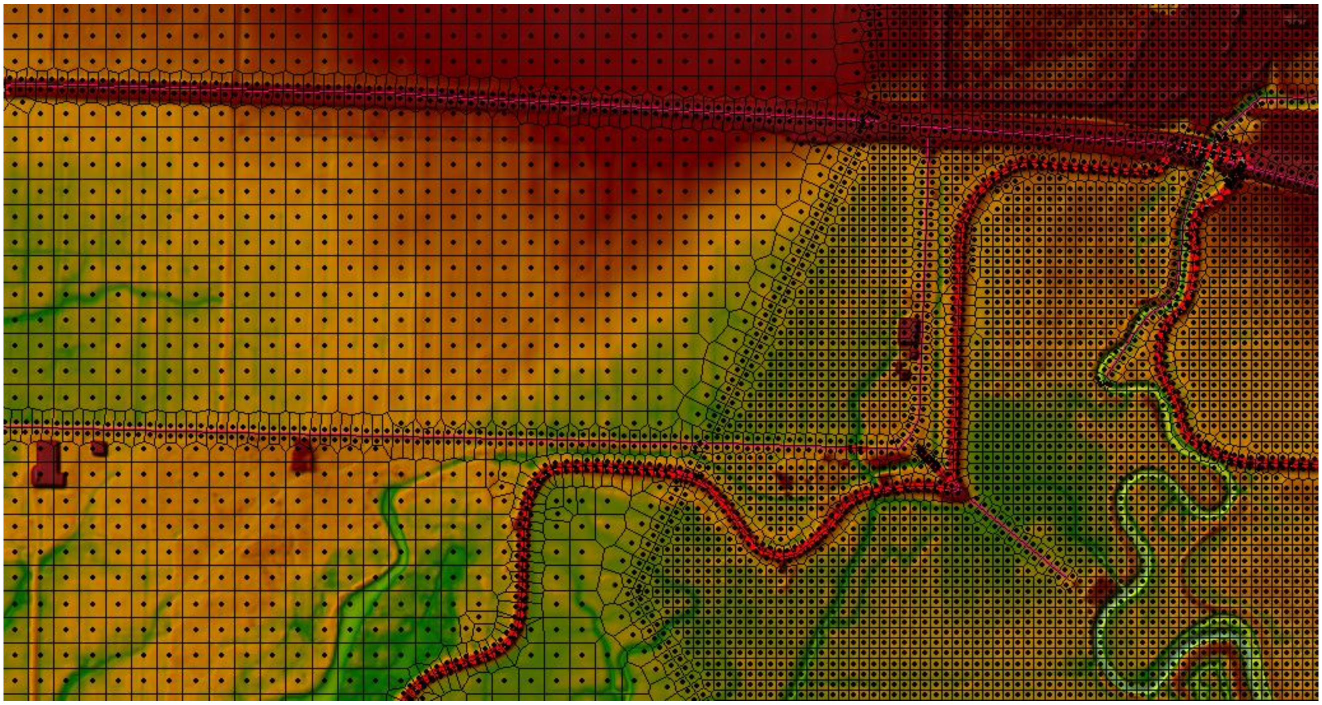


Figure 10 Example of breaklines and 2D/SA connections used to define critical topographic features such as top of l;eves and channel thalwegs

4.6 Surface Modifications

The validation of hydraulic connectivity is vital correctly predicting inundation and flow patterns within a fluvial/pluvial system. In addition, the use of LiDAR for the model topography and bathymetry can often contain artificial blockages due to vegetation or other visual obstructions. In order to maintain hydraulic connectivity the model terrain was modified in key areas to remove artificial obstructions. In addition, when culverts and tide gate invert elevations are known, the model terrain was modified to maintain consistent hydraulic connectivity. An example of a location where the terrain was modified is the underground segment of Jolly Giant Creek within the City. HEC-RAS does not include the ability to model long segments of pipe flow, therefore the terrain was modified to maintain flow through the City and connectivity to the day lighted segments of Jolly Giant Creek (Figure 11)

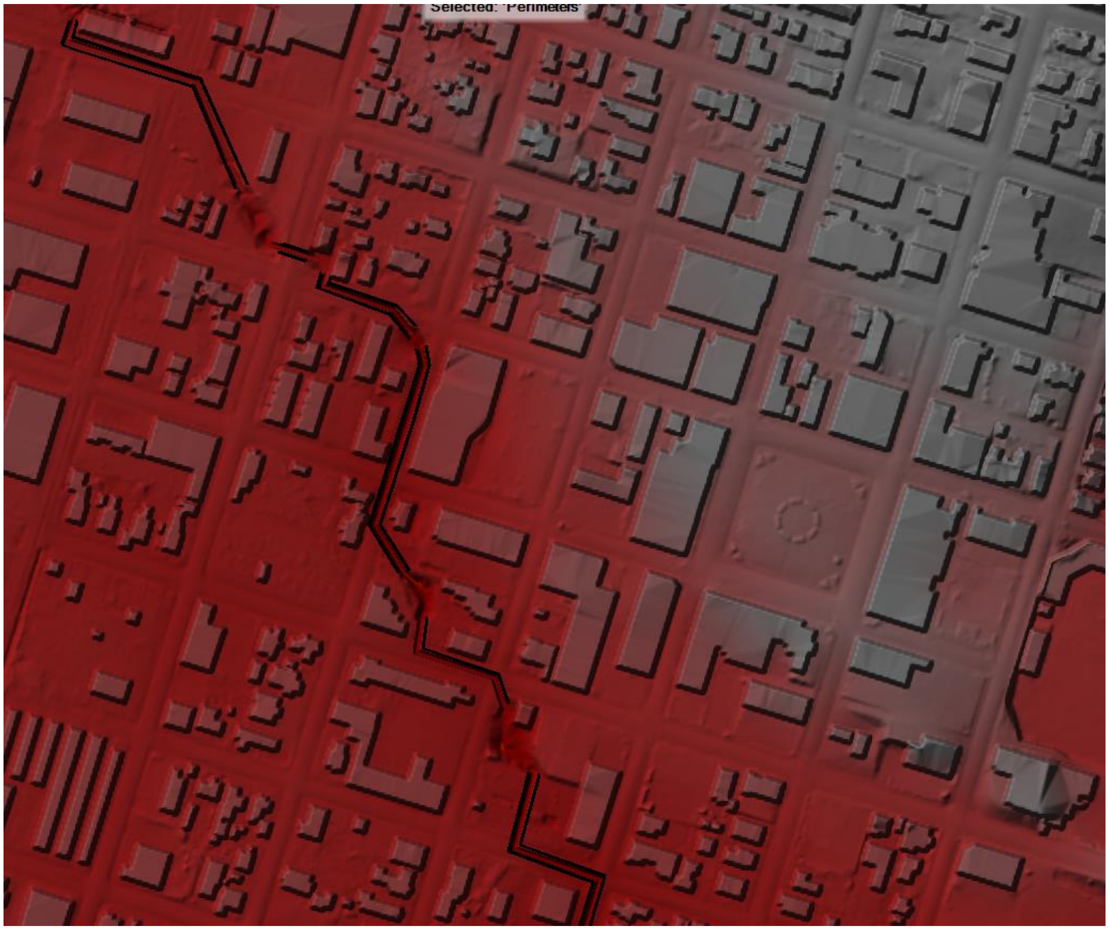


Figure 11 Terrain modification for hydraulic connectivity of Jolly Giant Creek

4.7 Model Parameter Values

The USGS GAP/LANDFIRE National Terrestrial Ecosystems 2011 data set provided land use data as 30 meter resolution raster. The impervious surface dataset from the City of Arcata supplied roads surface boundaries, which were merged with the USGS land use to improve the land use resolution.

4.8 Tidal Boundary Conditions

Tidal boundary conditions are defined as open boundaries at the downstream end of the model domain (along the model domain intersecting Humboldt Bay. Water surface elevation (WSE) time series developed by Northern Hydrology & Engineering's (NHE) Environmental Fluid Dynamic Code model were utilized. Model development is described in the Humboldt Bay: See Level Rise, Hydrodynamic Modeling, and Inundation Vulnerability Mapping report (NHE, 2015). Tidal water level time series were selected that include peak water levels including mean monthly maximum water (MMMW) and the 2-, 10-, 100- and 500-year recurrence water levels. Water depths were extracted from the 2015 2D Humboldt Bay model at 15-min resolution at 4 grid cell locations (see figure). These were converted to water surface elevation (m, NAVD88) by adding the grid cell bed elevation (m, NAVD88). Water surface elevations time series were adjusted by NHE from year 2012 to year 2023 using the information shown in Table 4. Two additional time series were developed by adding 1-foot and 2-feet to the 100-year recurrence time series to represent potential future water levels with sea level rise. Tidal boundary time series are shown on Figure 12 through Figure 18.

Table 4 Adjustment parameters

Correction Period	Year Span	Regional Sea Level Rise rate (mm/yr)	Delta WSE (mm)	Delta WSE (m)	Delta WSE (ft)
2012 to 1992	-20	2.28	-45.60	-0.0456	-0.1496
1992 to 2023	31	1.99	61.69	0.0617	0.2024
Net correction			16.09	0.0161	0.0528

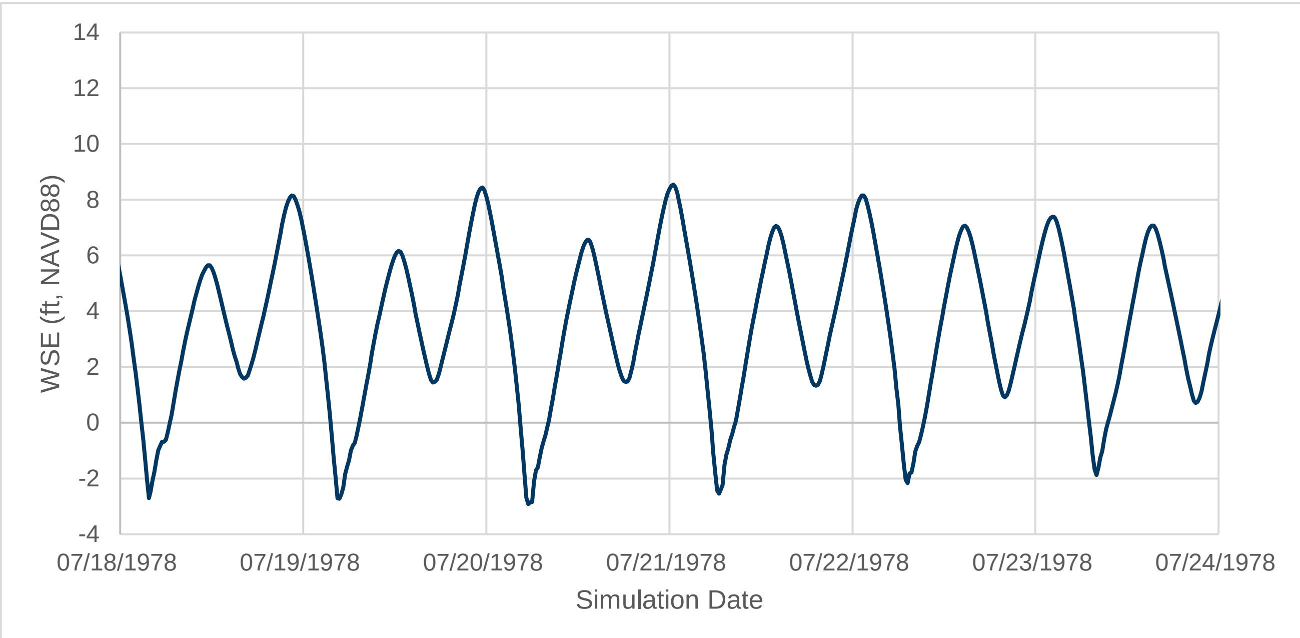


Figure 12. Mean Monthly Maximum Water Level (MMMW) tidal boundary condition

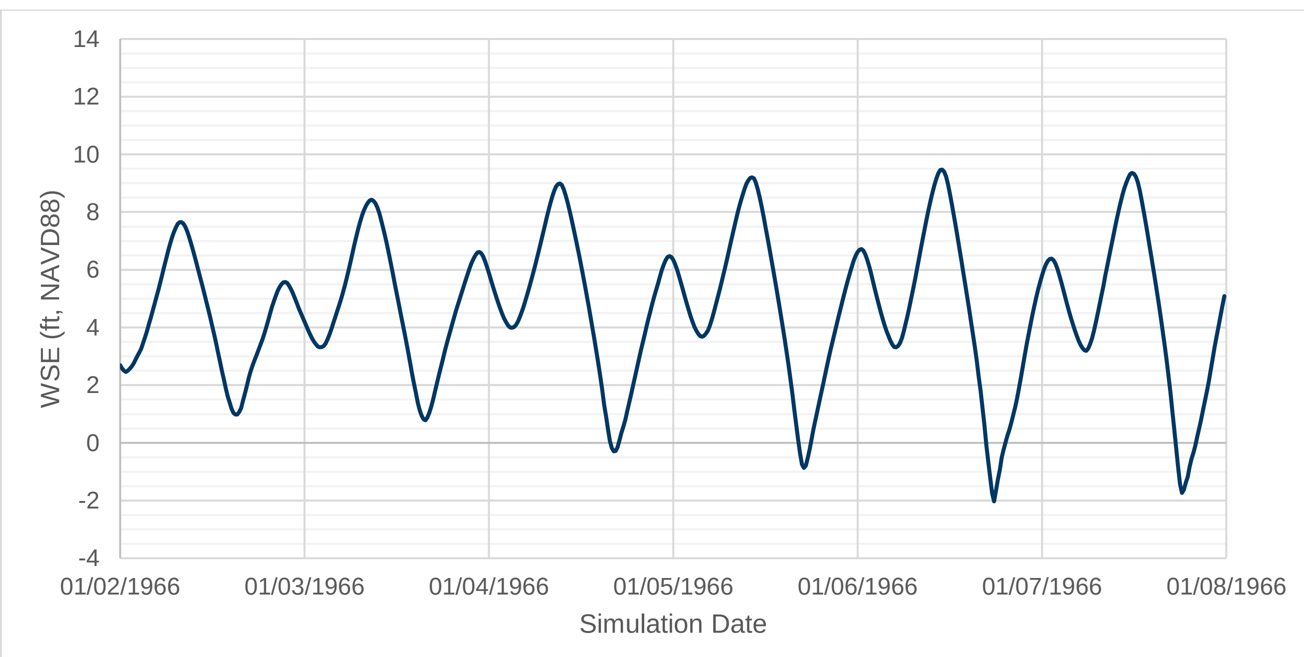


Figure 13. Tidal boundary condition with peak of 9.5 feet

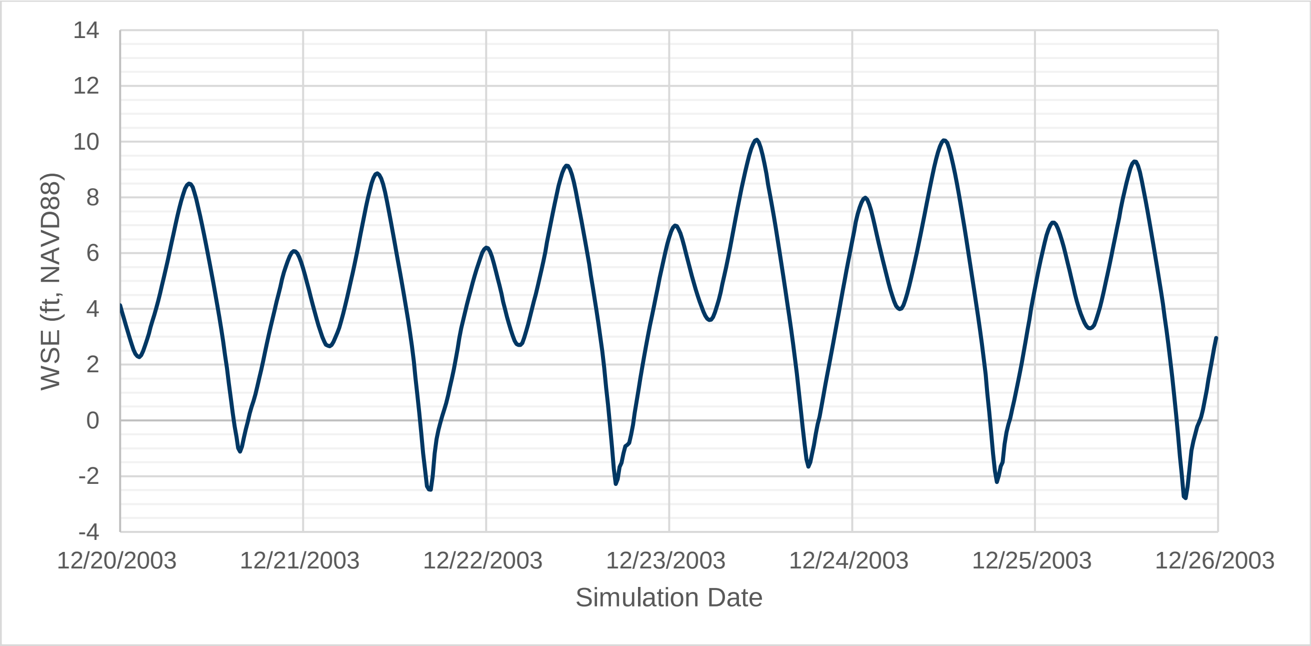


Figure 14. Tidal boundary condition with peak of 10.1 feet

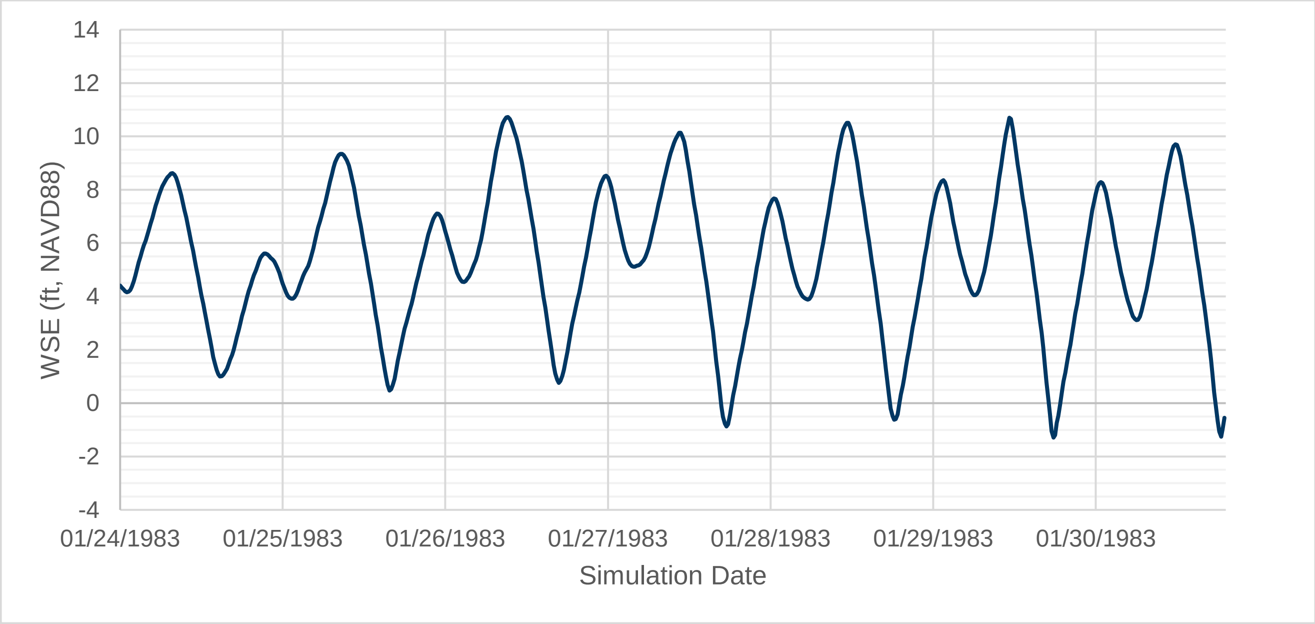


Figure 15. Tidal boundary condition with peak of 10.7 feet

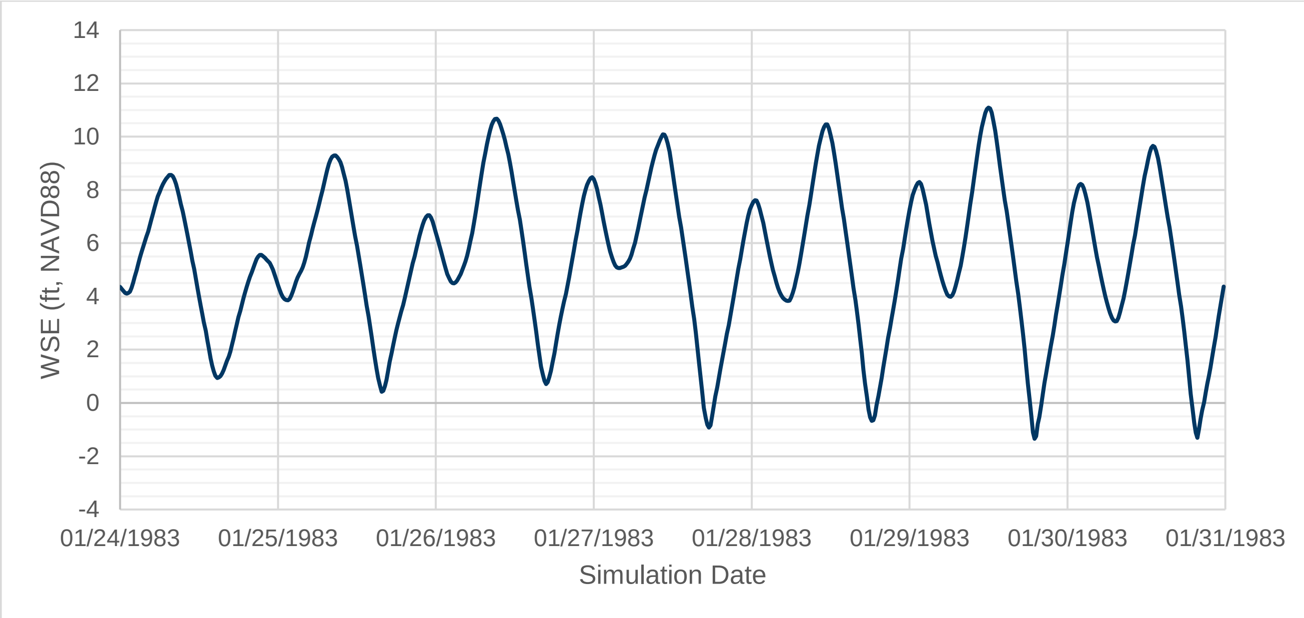


Figure 16. 1 Tidal boundary condition with peak of 11.1 feet

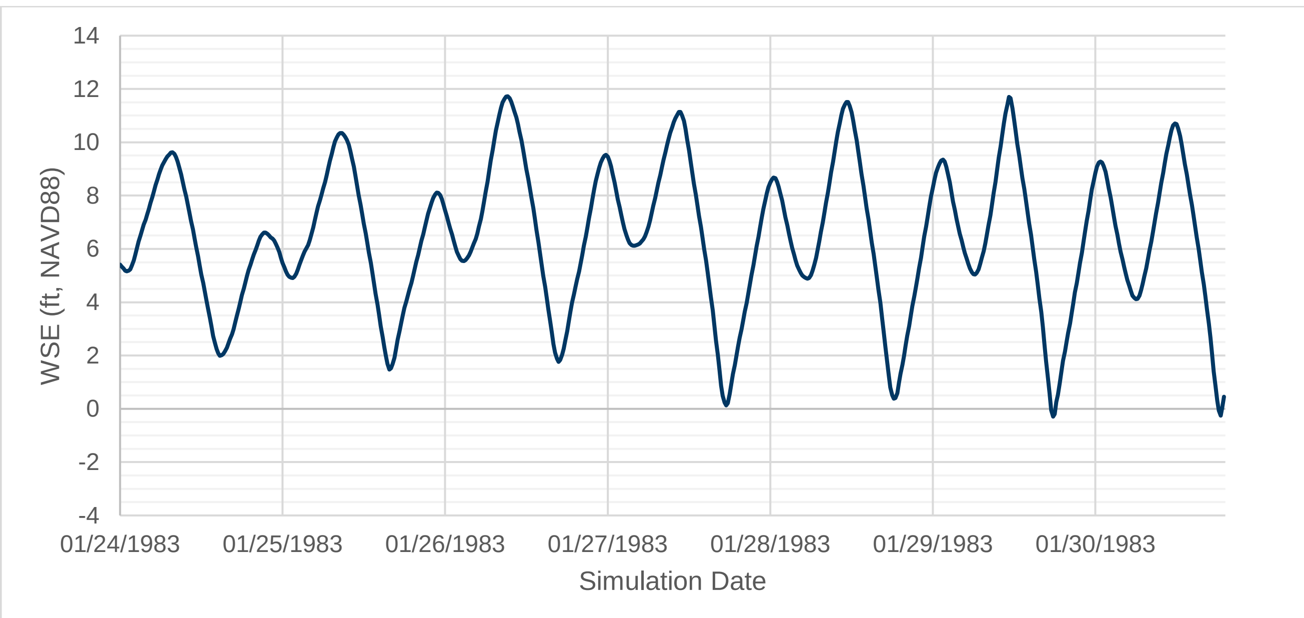


Figure 17. Tidal boundary condition with peak of 12.7 feet

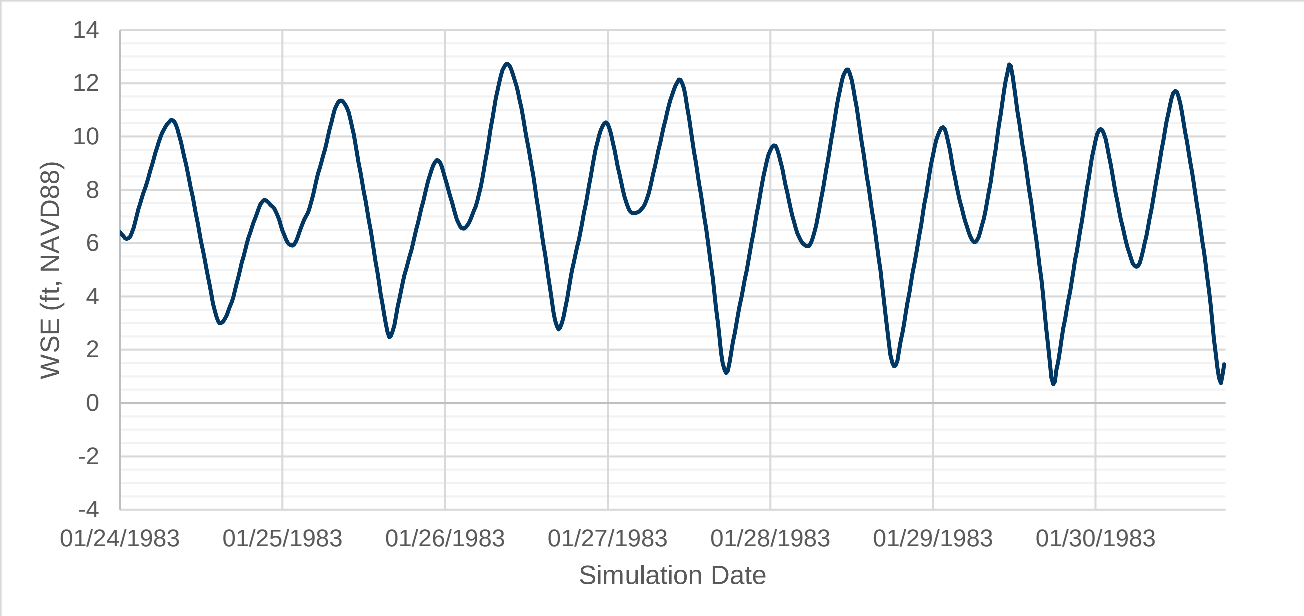


Figure 18. Tidal boundary condition with peak of 12.7 feet

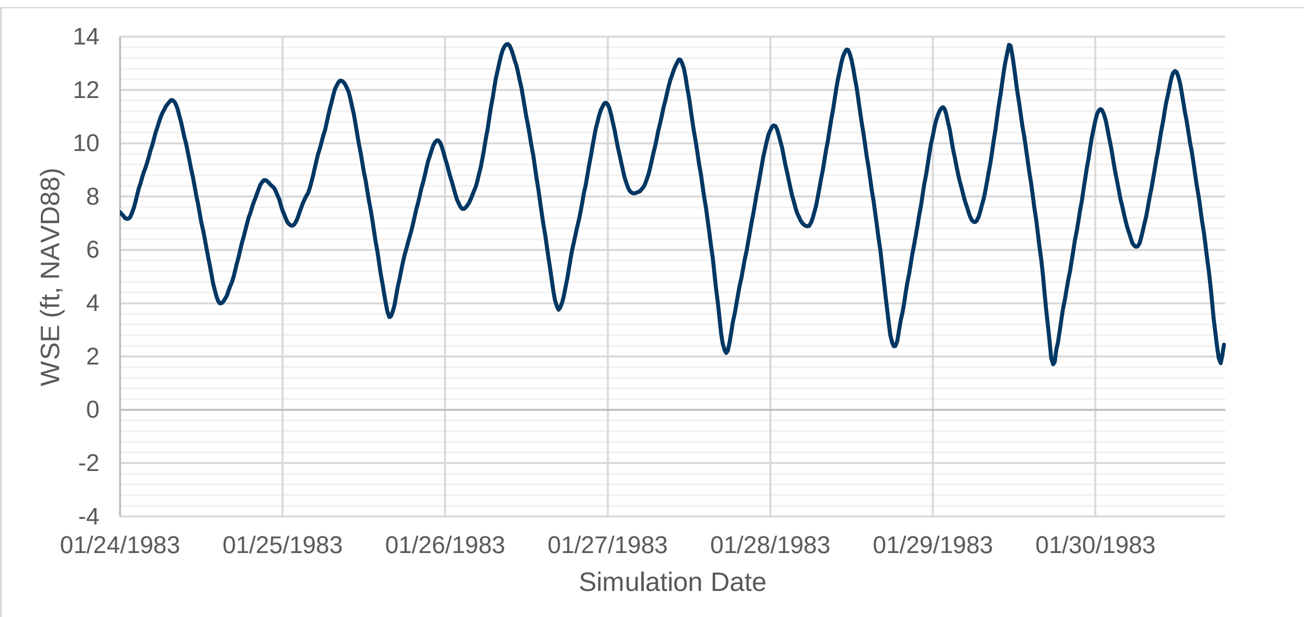


Figure 19. Tidal boundary condition with peak of 13.7 feet

4.9 Fluvial Boundary Conditions

Fluvial boundary conditions are defined as open boundaries at the free upstream ends of the model domain on each of the modeled creeks. Hydrographs utilize the peak flow from StreamStats and assume a linear increase and decrease, with the peak occurring 8 hours into the 24 hour event. The 2-, 10- and 100-year recurrence stream flows are shown in Figure 20, Figure 21 and Figure 22, respectively.

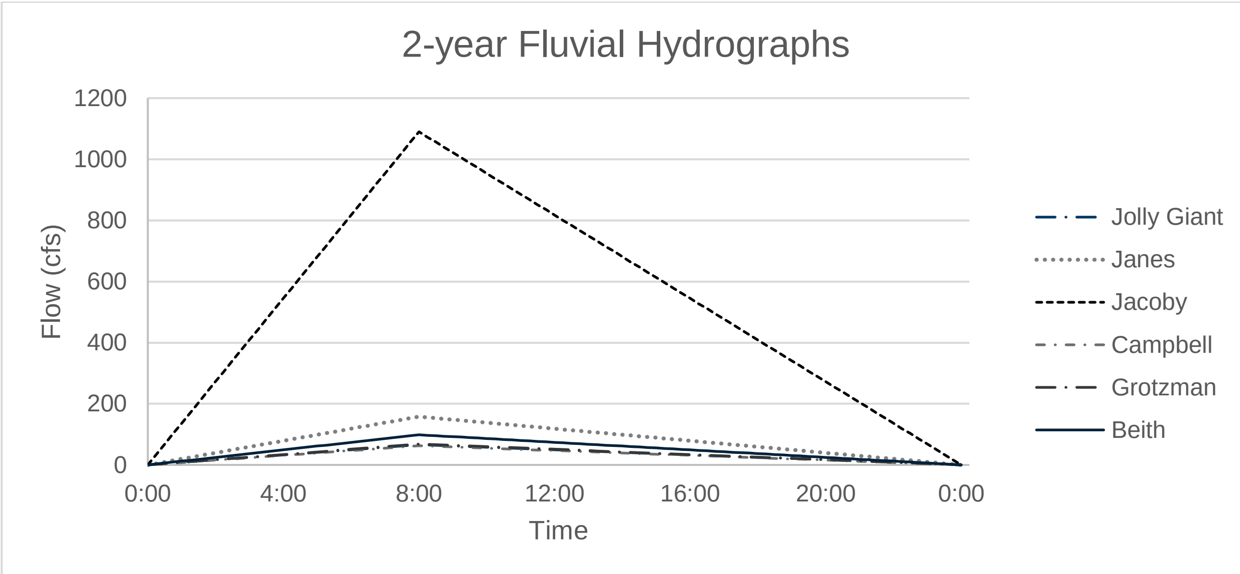


Figure 20. 2-year recurrence stream flows

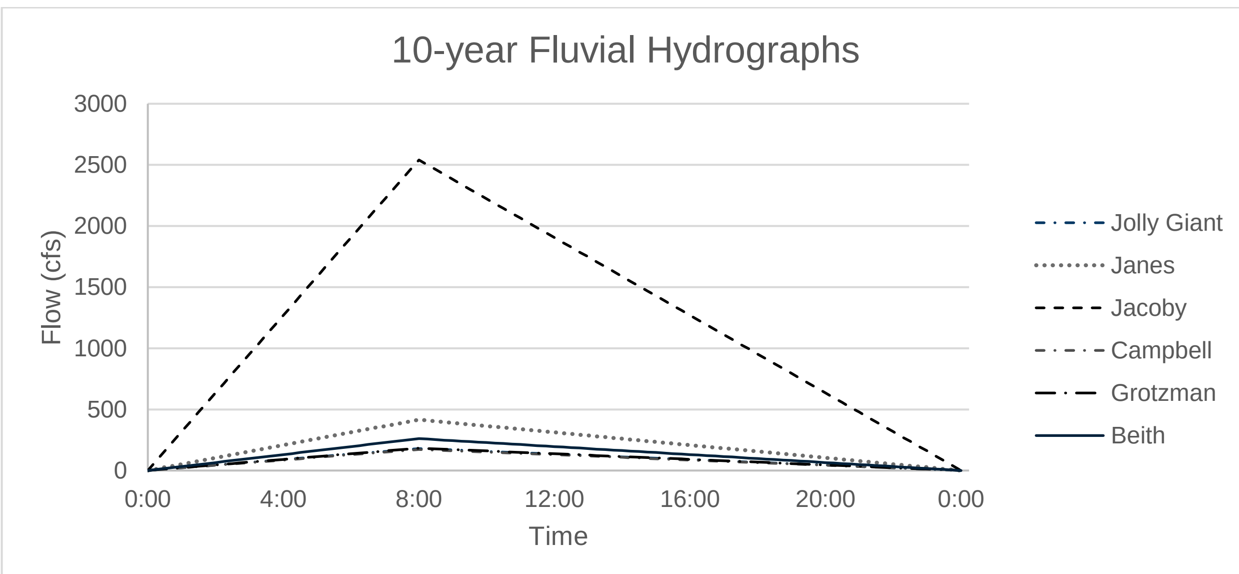


Figure 21. 10-year recurrence stream flows

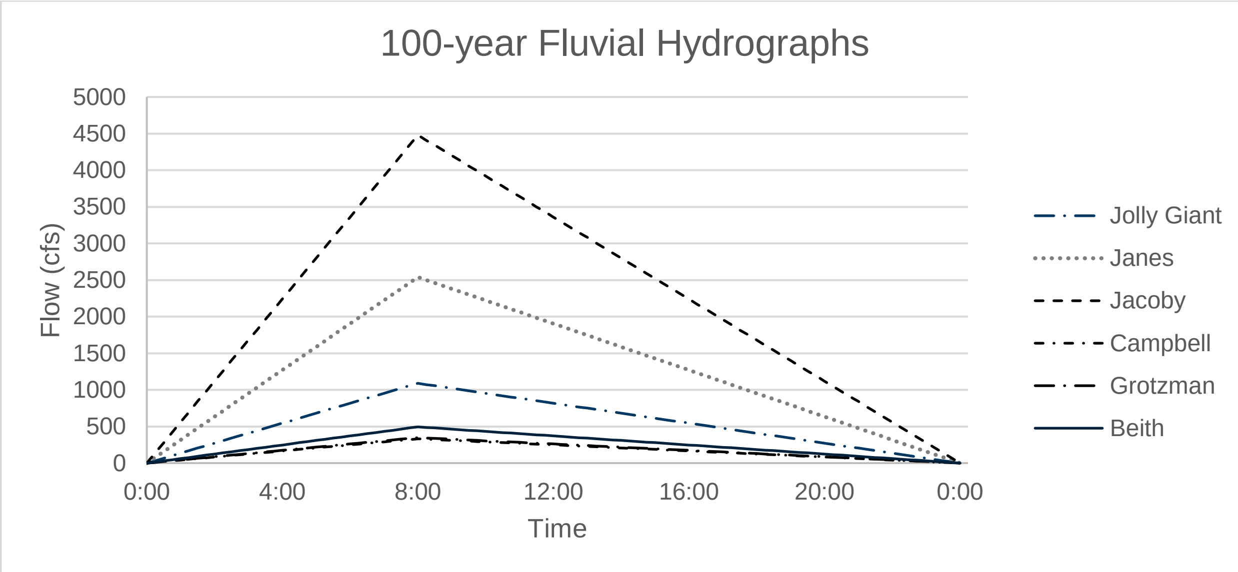


Figure 22. 100-year recurrence stream flows

4.10 Structures

Structures influencing hydraulic controls were included as connections in the HEC RAS model to represent linear infrastructure such as levees or roadways that separate 2-dimensional flow areas, or bridges and culverts that connect hydraulic conveyance channels, such as creeks and slough channels. Linear infrastructure was identified using topographic data and spillway top elevations defined by topographic data. Bridges and culverts were identified and dimensioned based on spatial storm water infrastructure data and associated attributes provided by the City. Upstream and downstream invert elevations were set based on ground elevations immediately upstream and downstream of the structures. Culverts and bridges were modeled as spillways with openings corresponding to the reported geometry and top elevations based on topography.

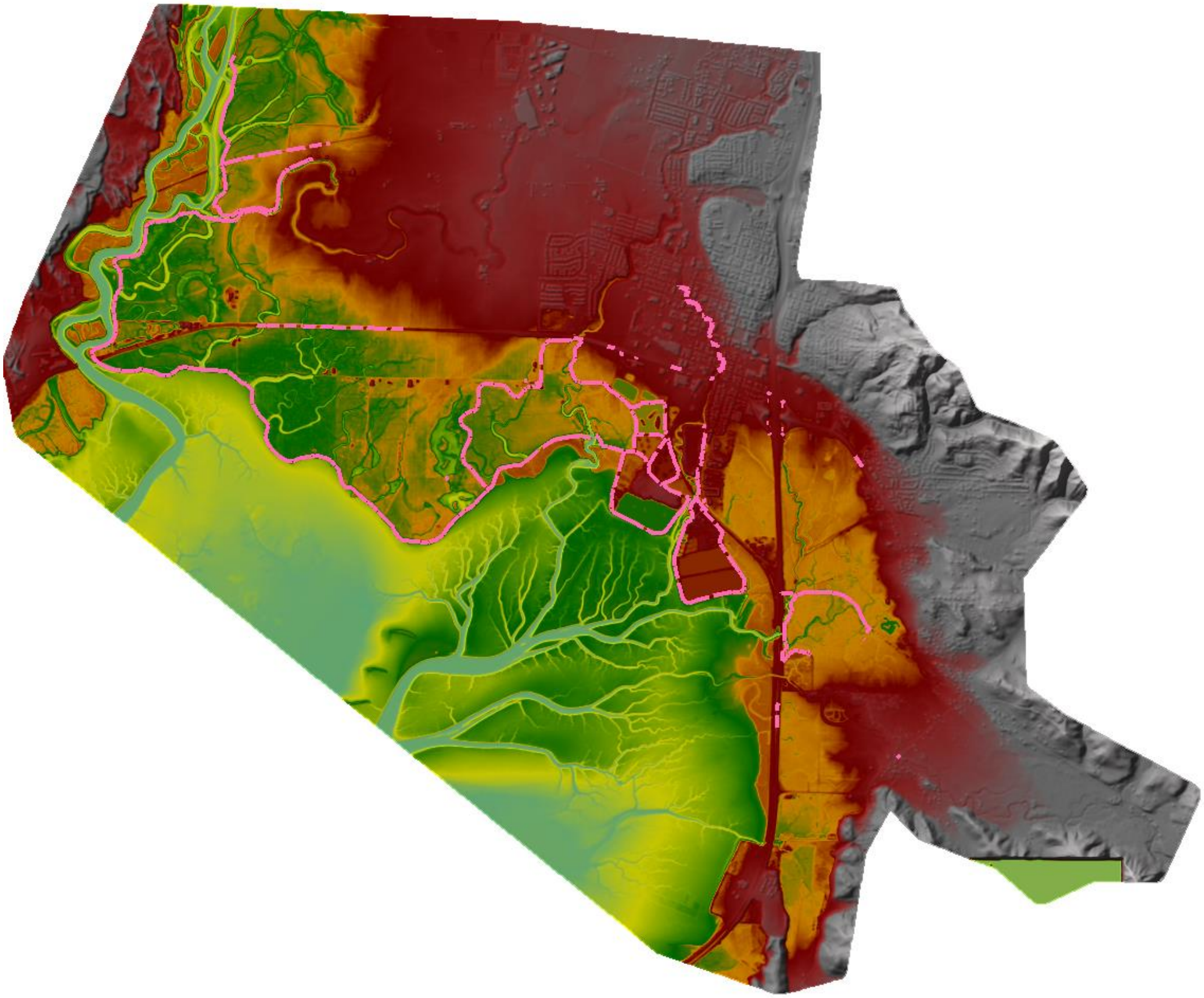


Figure 23 Locations of structures included in the model

4.11 Model Scenarios

Seven tidal and fluvial model scenarios were performed. Tidal scenarios consisted of the current 2-, 10-, and 100-year extreme events and the 100-year with 1-foot and 2-feet of sea level rise added. Fluvial boundary conditions for these runs consisted of a constant flow of 1 cfs. Fluvial scenarios consisted of the 2-, 10- and 100-year stream flows with a tidal boundary condition of MMMW time series. A combined event of the 10-year fluvial and 2-year tidal was also completed.

4.12 Simulation Period

The simulation period for each model was six days to capture multiple tidal cycles and assess the duration required to drain flooded areas.

4.13 Model Validation

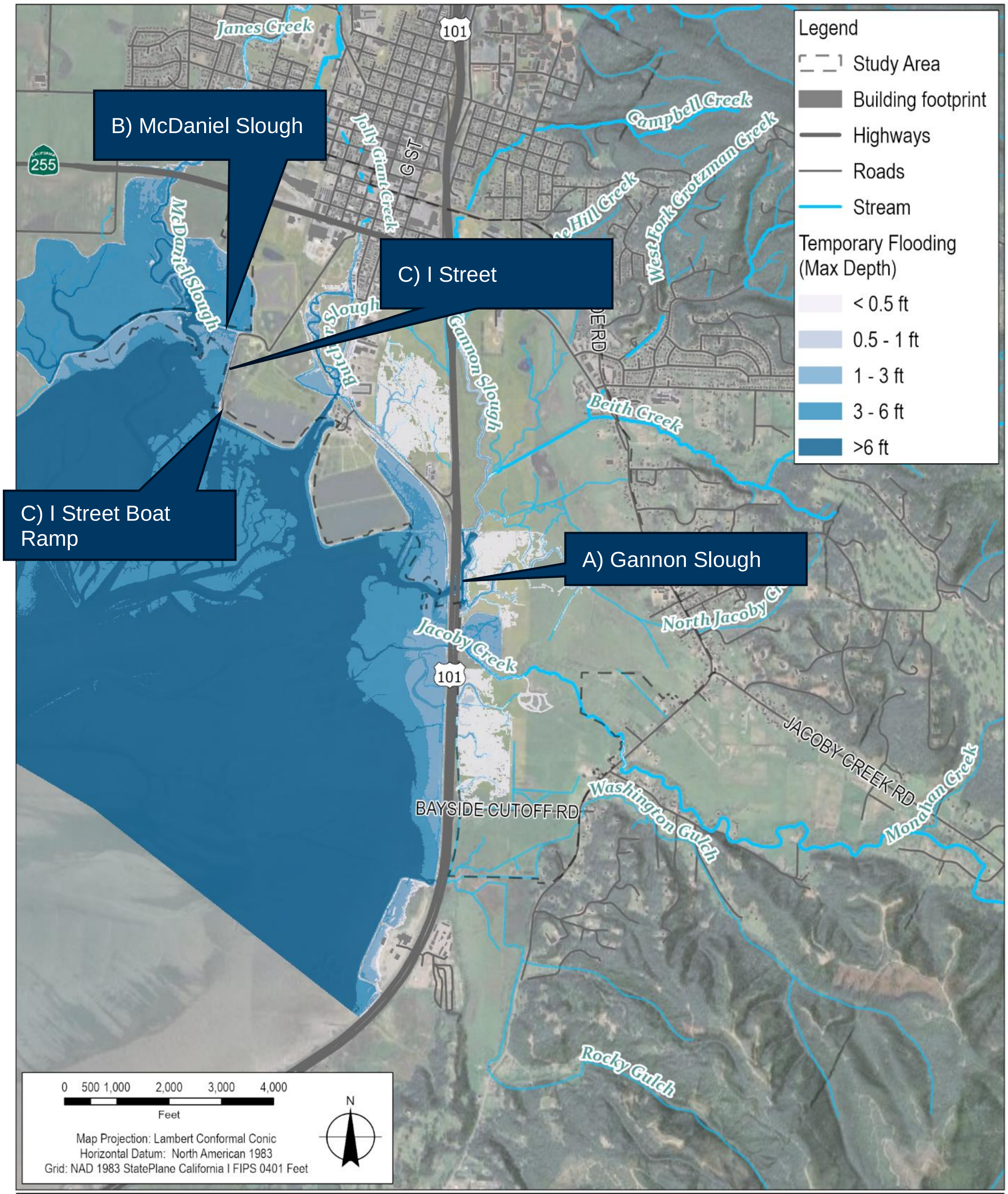
The intent of the model is to indicate locations of shoreline overtopping, flood pathways across the landscape, and whether or not various infrastructure is located within the flooding footprints. Approximate depth and duration will inform management actions and further detailed modeling and other studies will be required. The model scenarios were run and resulting flood extent and pattern reviewed by GHD, Northern Hydrology and Engineering, Michael Love & Associates, and City staff. These reviewers have knowledge of the Study Area, have implemented, observed and monitored projects pertaining to drainage and hydraulic structures, and modeled sub areas for other projects. Photographs of previous events were reviewed for general conformance with model results.

The highest water level on record at the North Spit tidal station occurred on December 31, 2005 when a water level of 9.6 feet was observed, therefore several of the model scenarios exhibit greater water levels. Available photos from this scenario were not located for the Study Area. For each scenario, shoreline elevations and tidal boundary conditions were compared to confirm that if water levels exceeded shoreline elevations, a hydraulic connection was shown in the model results. Recent photos of a King Tides event from January 11, 2024, when peak tides at the North Spit reached 8.4 feet, which would translate to approximately 8.9 feet in the Study Area, based on the difference of extreme water levels reported by NHE and those reported for Station 9418767, North Spit CA. Photos are shown in Figure 24 and model results for a tide elevation of 9.5 feet are shown in Figure 25. With an additional 0.6 feet of tidal water level, model results appear to be generally consistent with photo observations. Along Gannon Slough (Figure 24A) water levels in the photo near the top elevation of the levee separating the slough from the agricultural lands. Model results show that with an additional 0.6 feet of tidal elevation, overtopping would occur in select locations resulting in shallow flooding. The observations and model results are generally consistent with what would be expected and anecdotal evidence provided by the reviewers.

A) B)

C) D)

Figure 24 Photos from King Tide event of approximately 8.9 feet on January 11, 2024 A) Gannon Slough B) McDaniel Slough C) I Street Boat Ramp D) I Street (Photos provided by City of Arcata)



N:\US\Santa Rosa\General\US West GIS Testing\Workspace4\12621644\GIS\Maps\Deliverables\12621644_TM_Embedded_Figures_RevC.aprx - 12621644_007_FIG6_2yr_Tidal_Results_RevB

Data source: Tiled service layer: © OpenStreetMap (and) contributors, CC-BY-SA World Hillshade: Esri, NASA, NGA, USGS, FEMA Created by:jlopez4

Figure 25 Modeled results for peak tidal water level of 9.5 feet and approximate photo points of approximate water level 8.9 feet on January 11, 2024.

On January 13, 2024 a rainfall storm event, estimated to be between the 10- to 15-year flood recurrence occurred in the Study Area (McBain, 2024). Photos of event along primarily show flooding within parcels and shallow flooding of the adjacent roadway (Figure 26). Model results for the 10-year fluvial event generally agree with the photographs, showing limited flooding along Jolly Giant Creek, mostly within parcels containing daylighted creek segments and shallow flooding of the adjacent roadway (Figure 27).

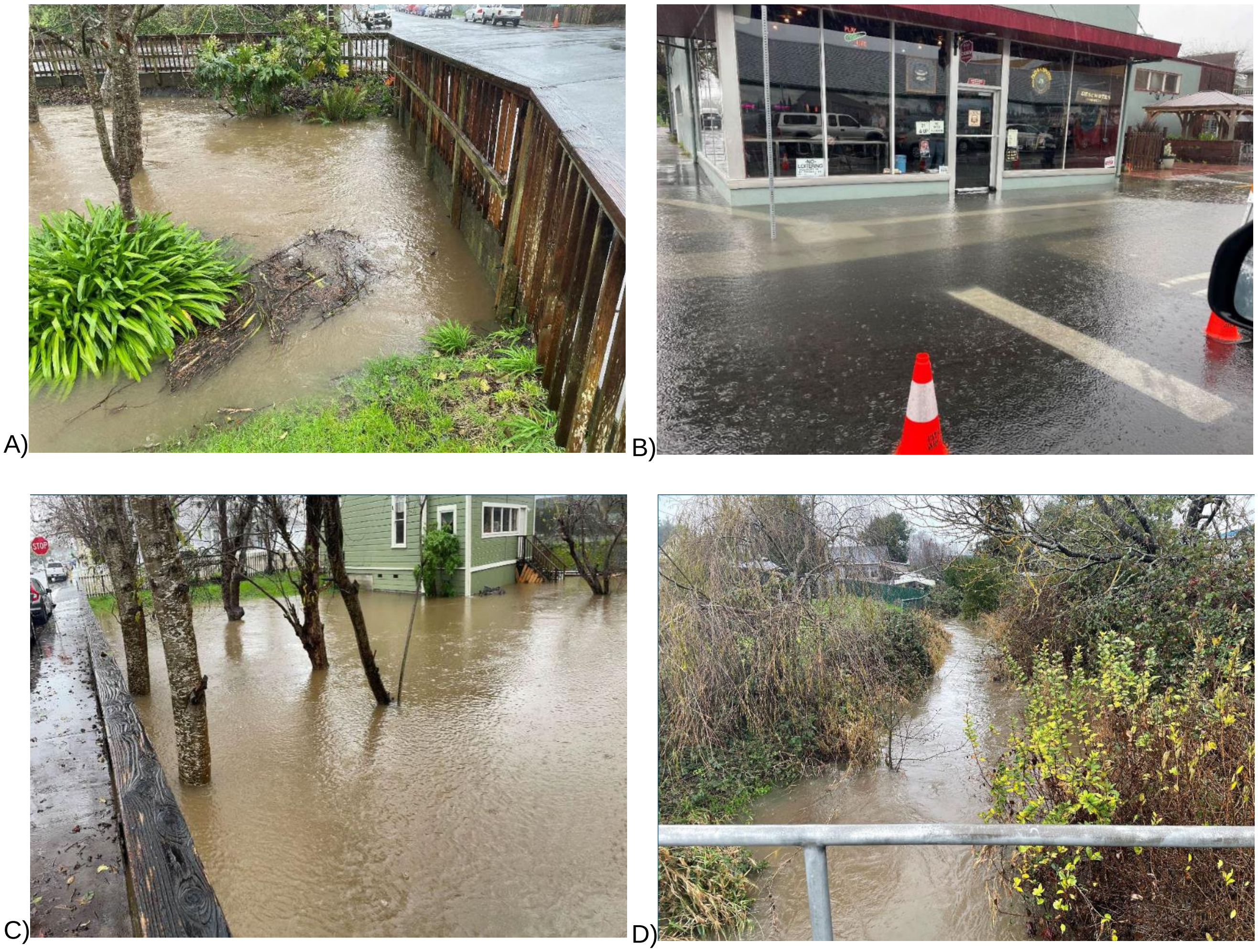
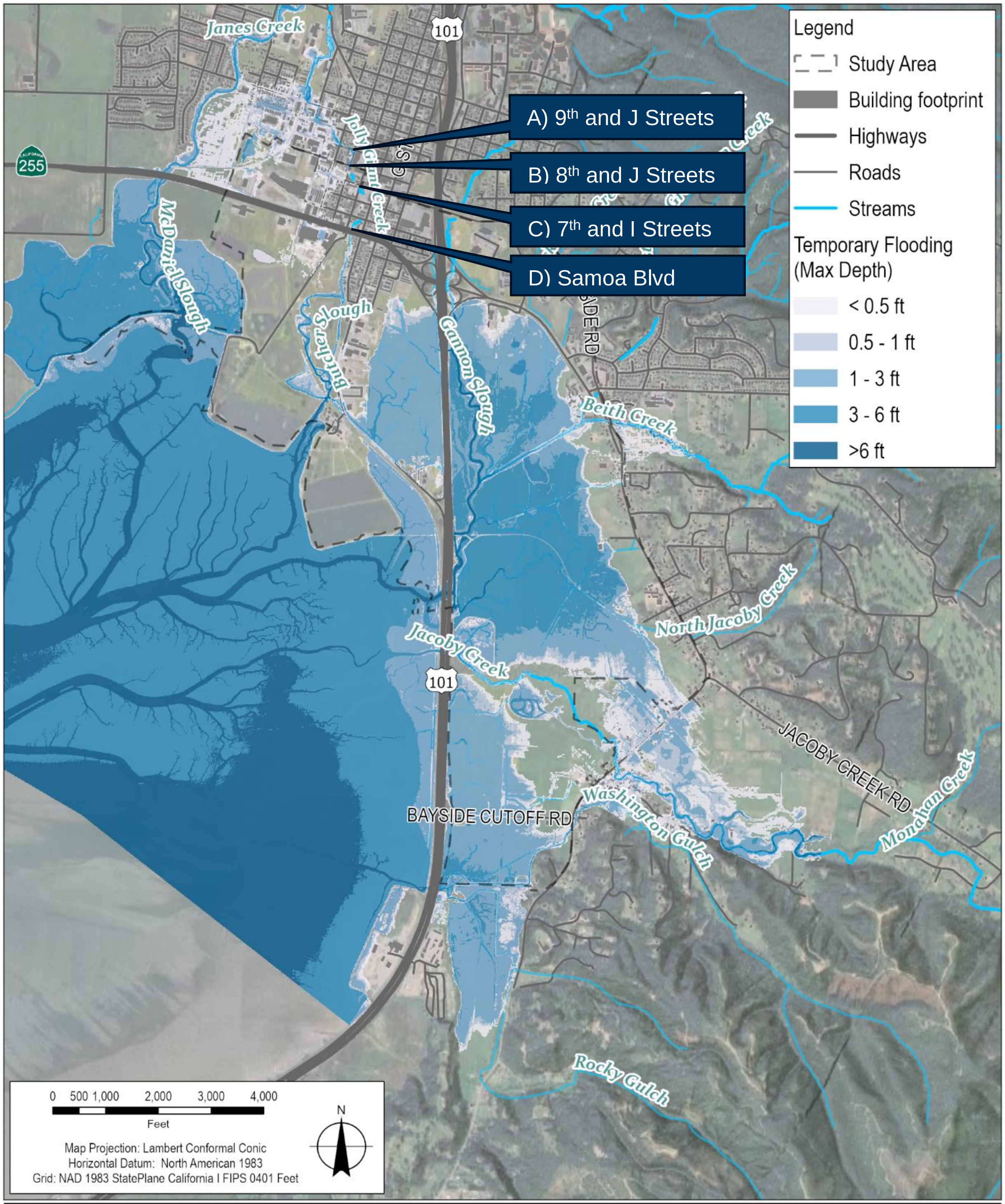


Figure 26 ***Flooding along Jolly Giant Creek on January 13. 2024 A) Corner of 9th and J Streets B) Corner of 8th and J Streets C) Corner of 7th and I Streets D) Samoa Blvd.***



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Data source: Tiled service layer: © OpenStreetMap (and) contributors, CC-BY-SA World Hillshade: Esri, NASA, NGA, USGS Created by:jlopez4

Figure 27 ***Model results of the 10-year fluvial event and photo points evaluated for model validation.***

5. Model Results

Model results for flooding depth are shown in Figure 35 through Figure 38. A summary of the figures and boundary conditions modeled are shown in Table 5. Interpretation and discussion of model results, with respect to flood pathways, overtopping locations, depth, duration and impacts to infrastructure are provided in the Vulnerability and Risk Assessment Technical Memorandum.

Table 5 List of model result figures and boundary conditions,

Figure	Fluvial Boundary Condition	Tidal Boundary Condition
Figure 28	1 cfs base flow	peak 9.4 feet (existing 2-year)
Figure 29	1 cfs base flow	peak 10.0 feet (existing 10-year)
Figure 30	1 cfs base flow	peak 10.7 feet (existing 100-year)
Figure 31	1 cfs base flow	peak 11.1 feet (existing 500-year)
Figure 32	1 cfs base flow	peak 11.7 feet (existing 100-year + 1 foot SLR)
Figure 33	1 cfs base flow	peak 12.7 feet (existing 100-year + 2 feet SLR)
Figure 34	1 cfs base flow	peak 13.7 feet (existing 100-year + 3 feet SLR)
Figure 35	2-year	MMMW
Figure 36	10-year	MMMW
Figure 37	100-year	MMMW
Figure 38	10-year	peak 9.4 feet (existing 2-year)

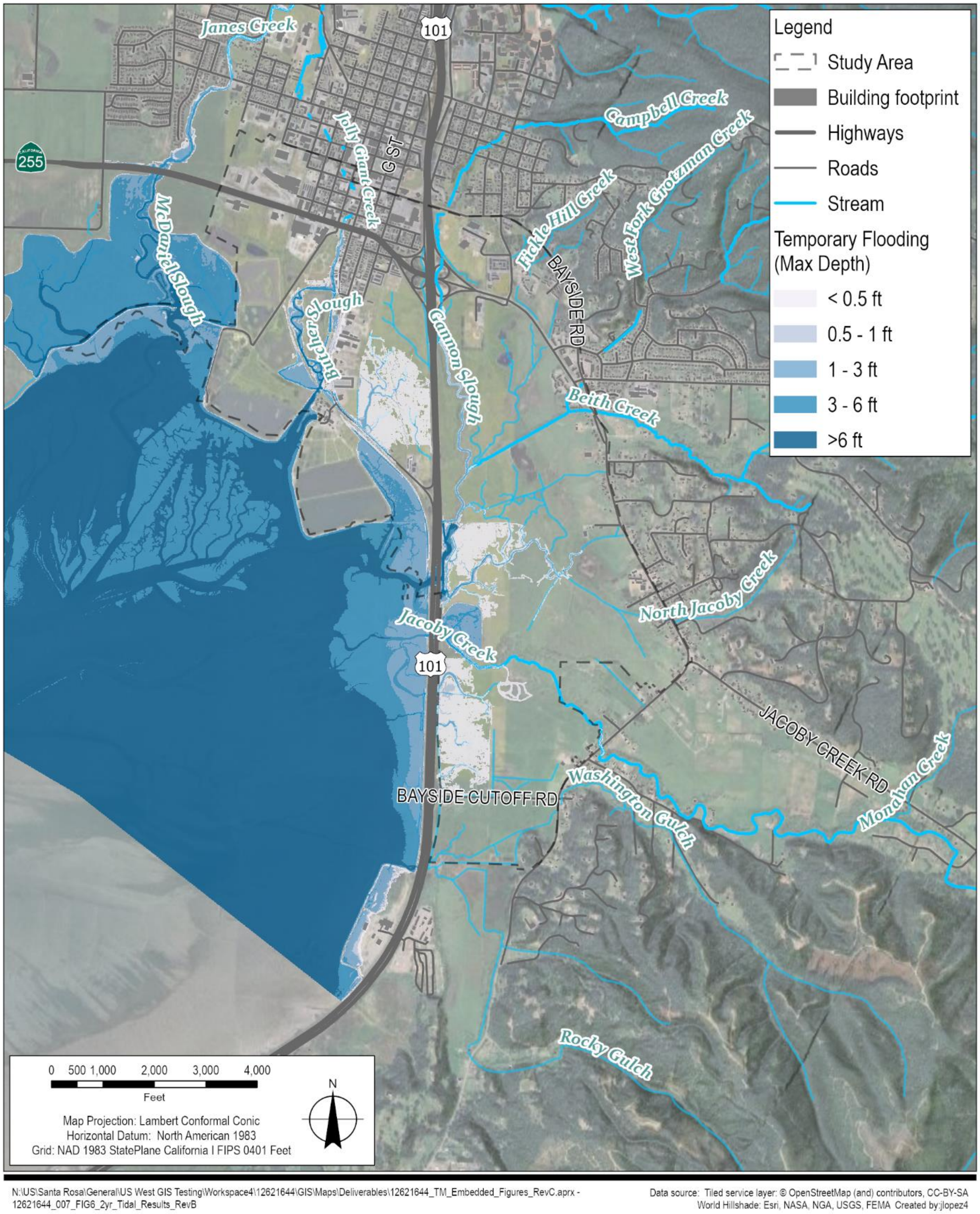


Figure 28 Model results for the peak 9.5 feet (existing 2-year) tidal boundary conditions.

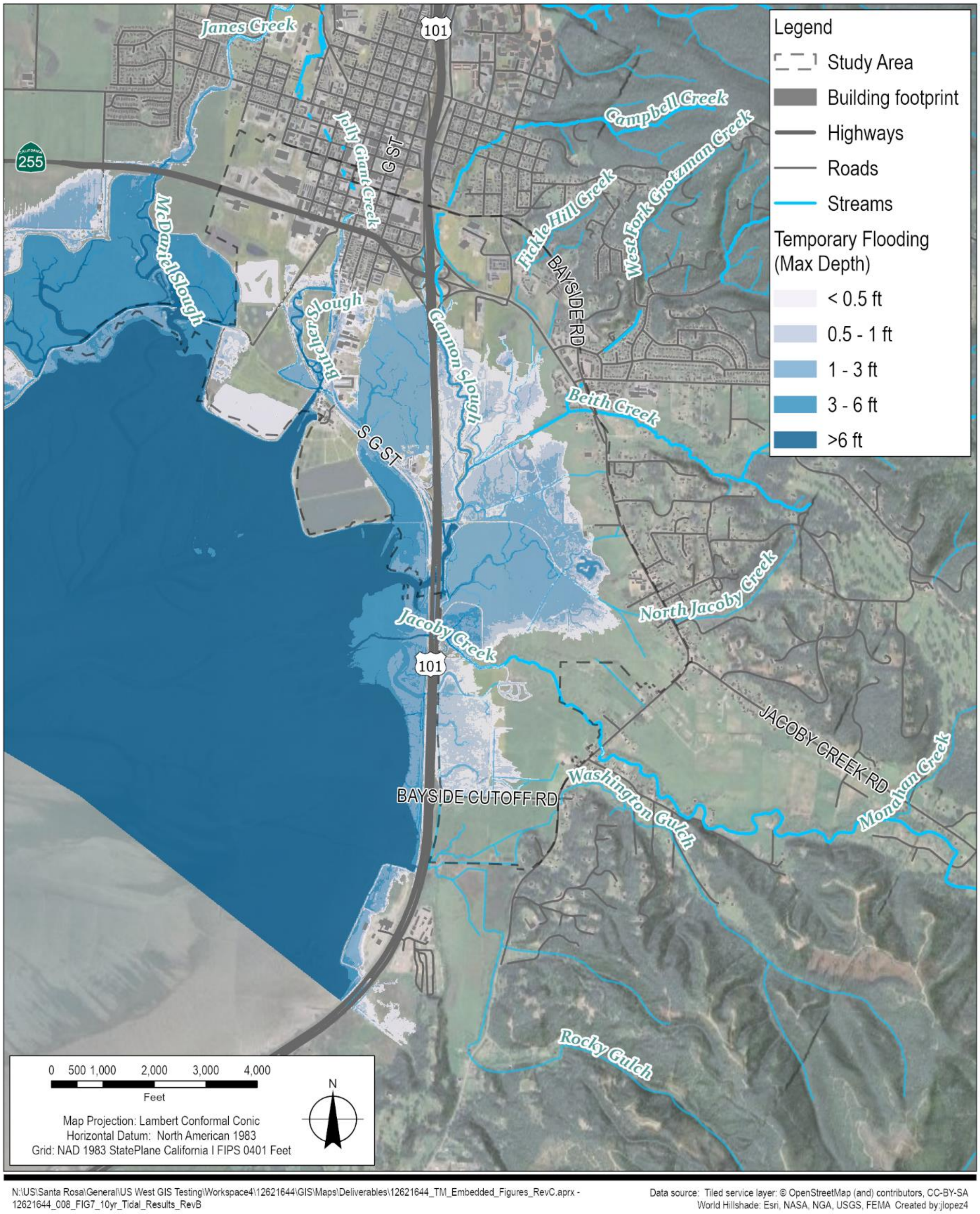


Figure 29 ***Model results for the peak 10.1 feet (existing 10-year) tidal boundary conditions.***

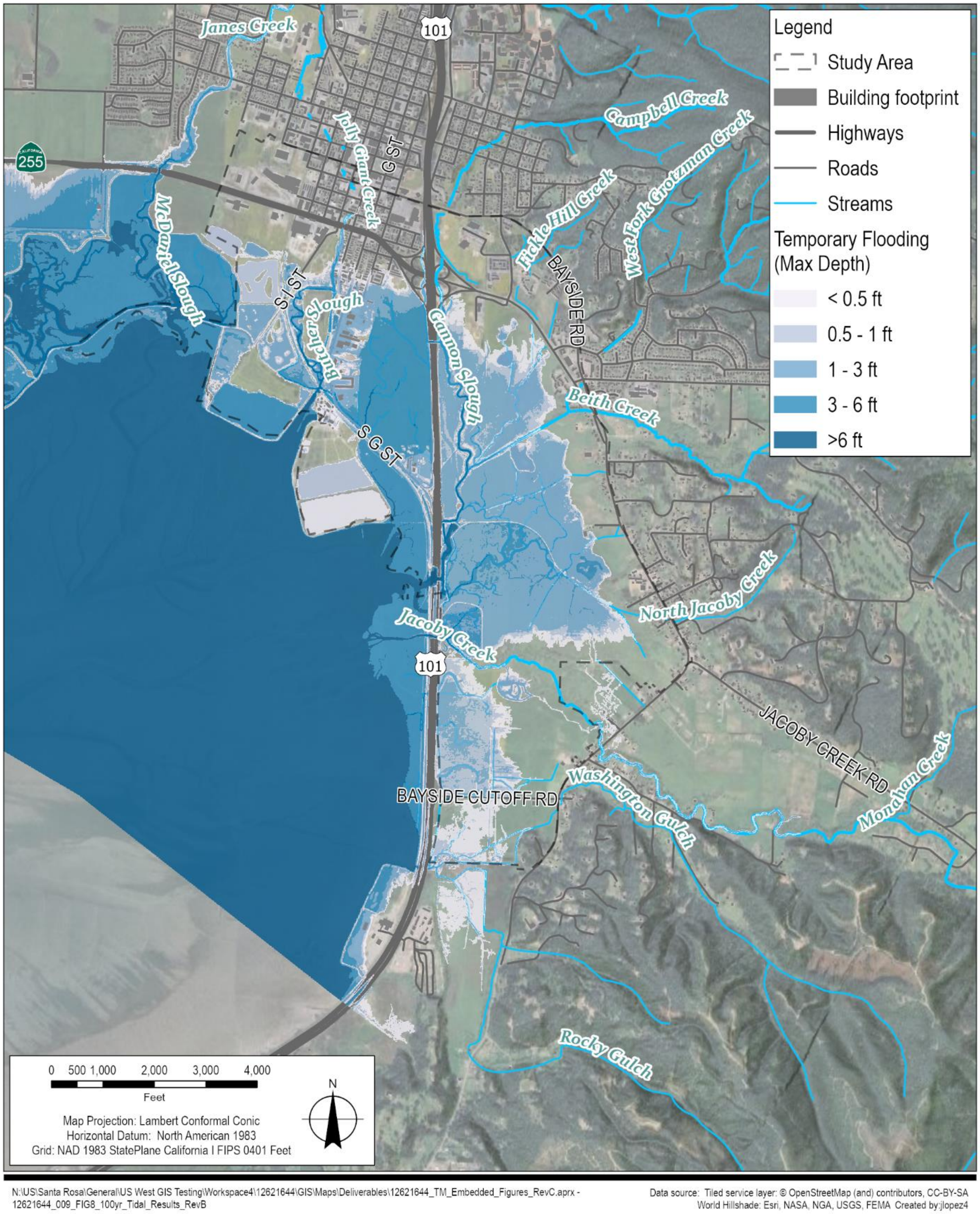


Figure 30 ***Model results for the peak 10.7 feet (existing 100-year) tidal boundary conditions.***

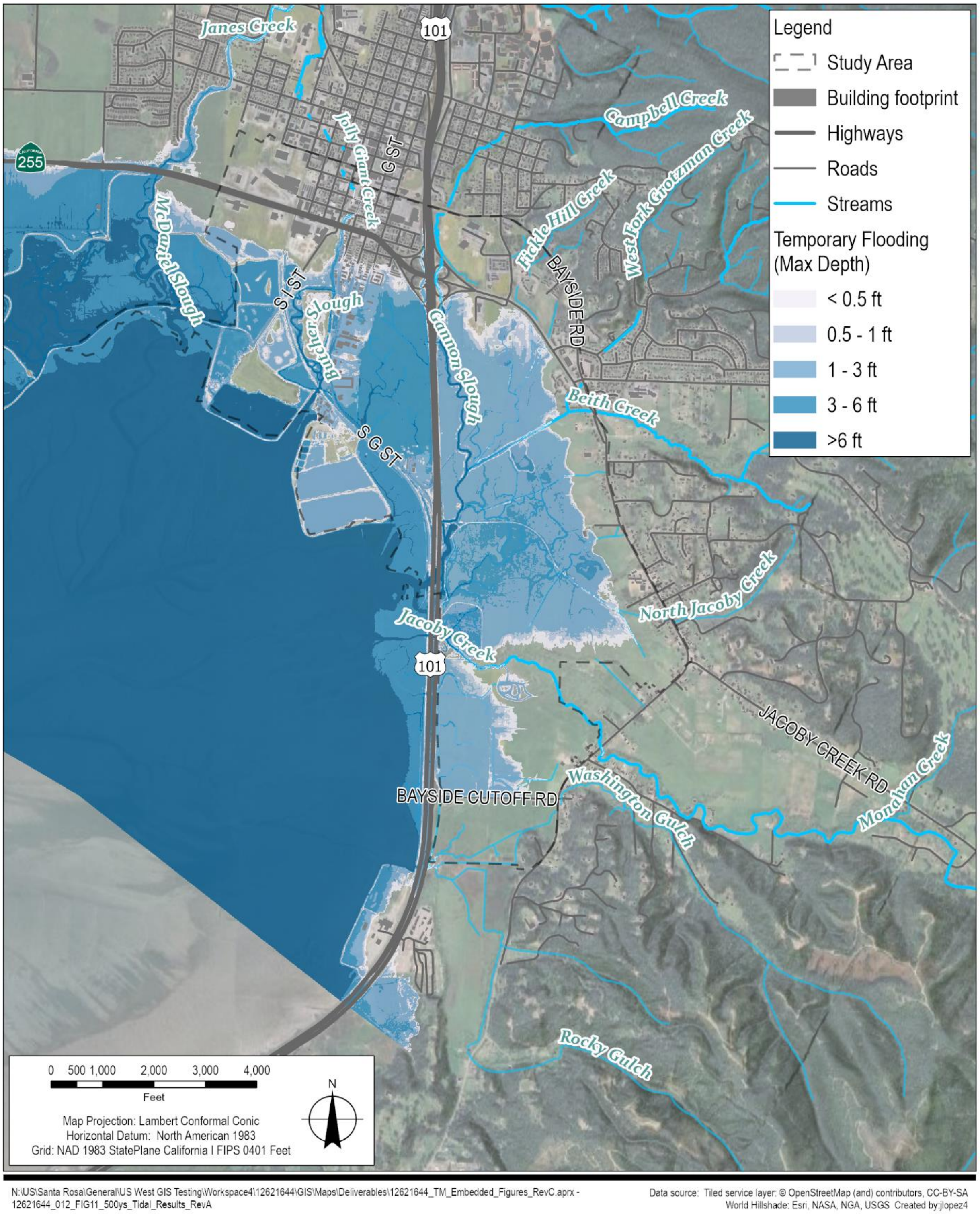


Figure 31 Model results for the peak 11.1 feet (existing 500-year) tidal boundary conditions.

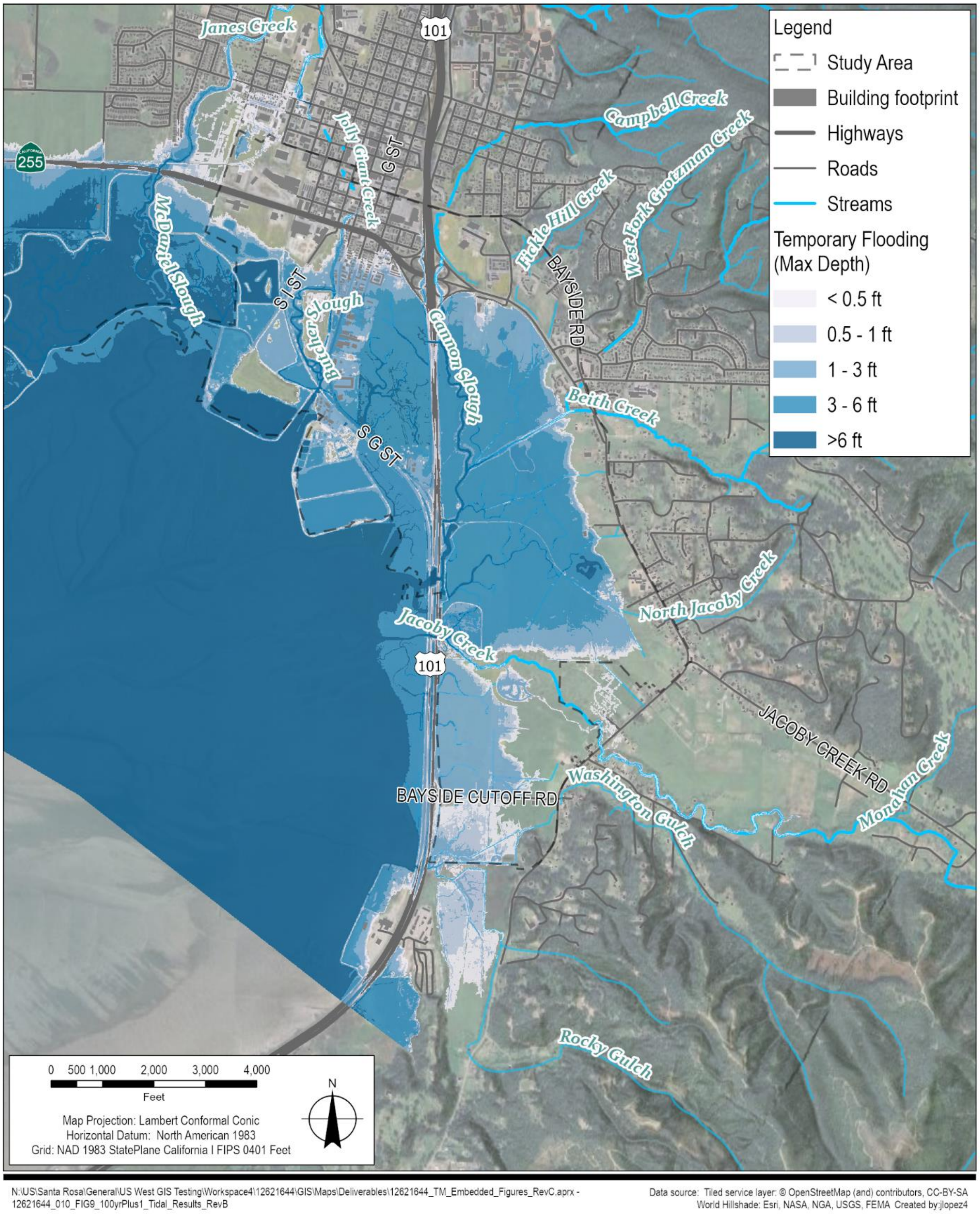
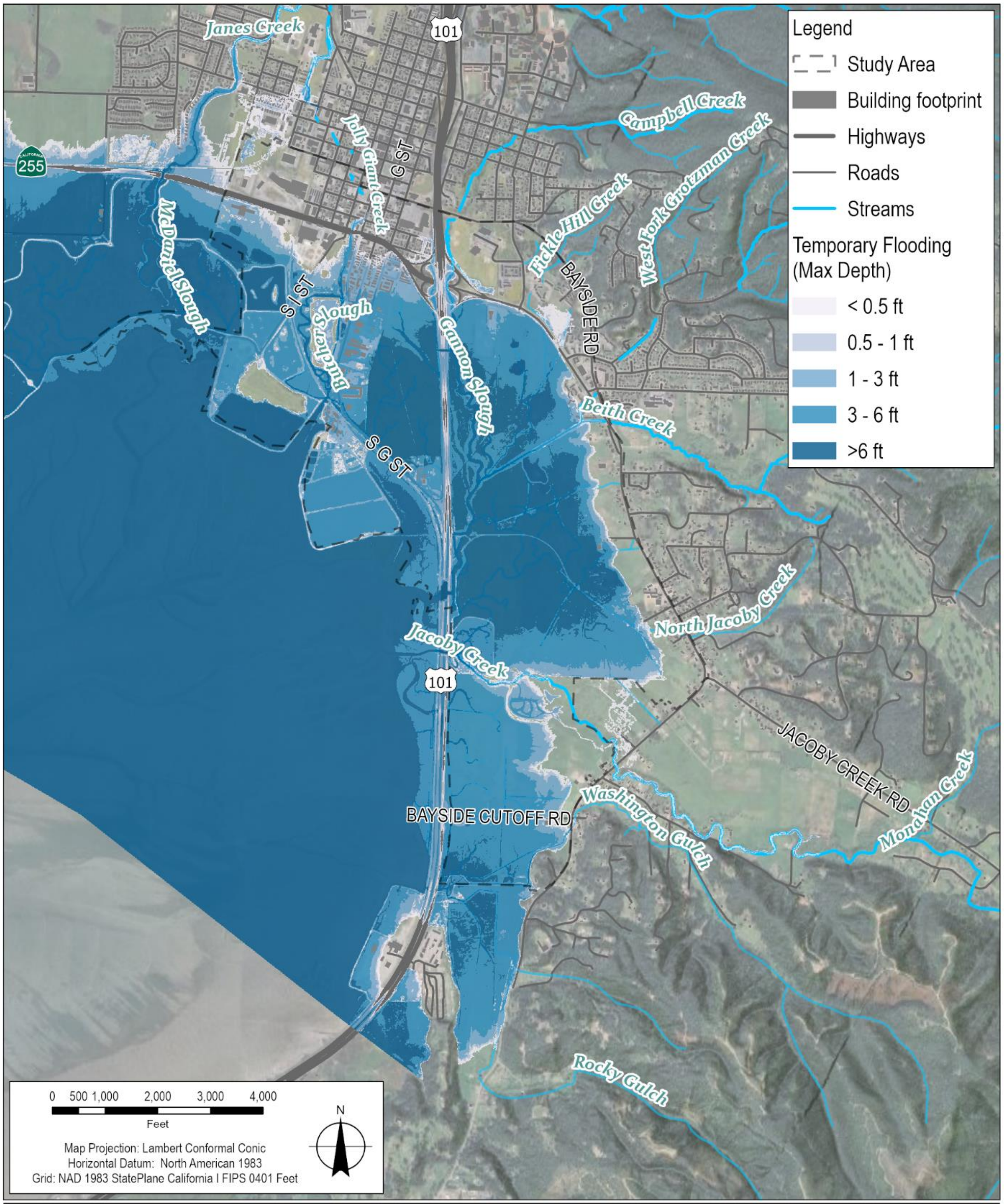


Figure 32 ***Model results for the peak 11.7 feet (existing 100-year + 1 foot SLR) tidal boundary conditions.***



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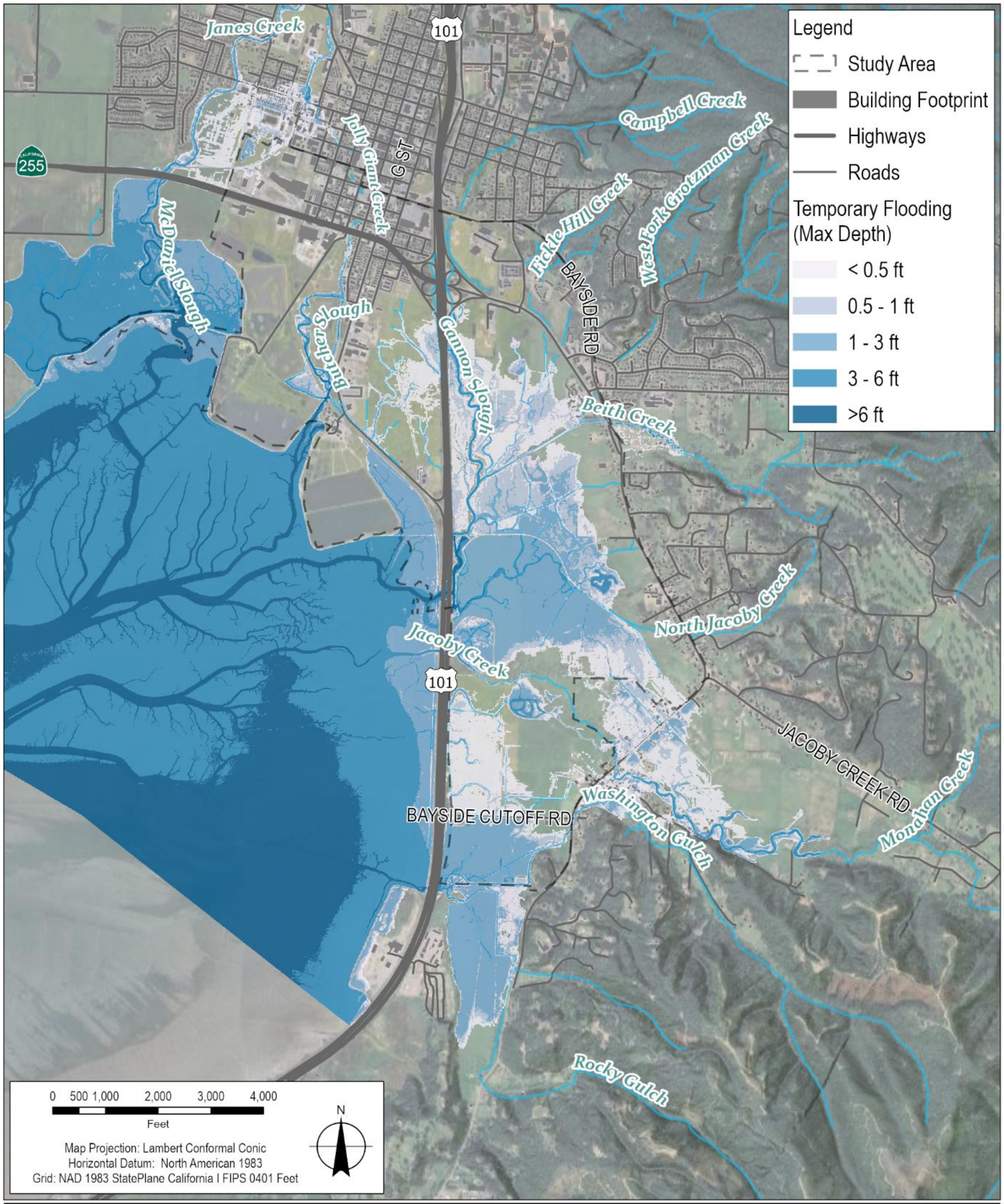
Data source: Tiled service layer: © OpenStreetMap (and) contributors, CC-BY-SA World Hillshade: Esri, NASA, NGA, USGS, FEMA Created by:jlopez4

Figure 33 Model results for the peak 12.7 feet (existing 100-year + 2 feet SLR) tidal boundary conditions.

To be inserted in final document. See Vulnerability and Risk Assessment Technical Memorandum

Figure 34 Model results for the peak 13.7 feet (existing 100-year + 3 feet SLR) tidal boundary conditions.



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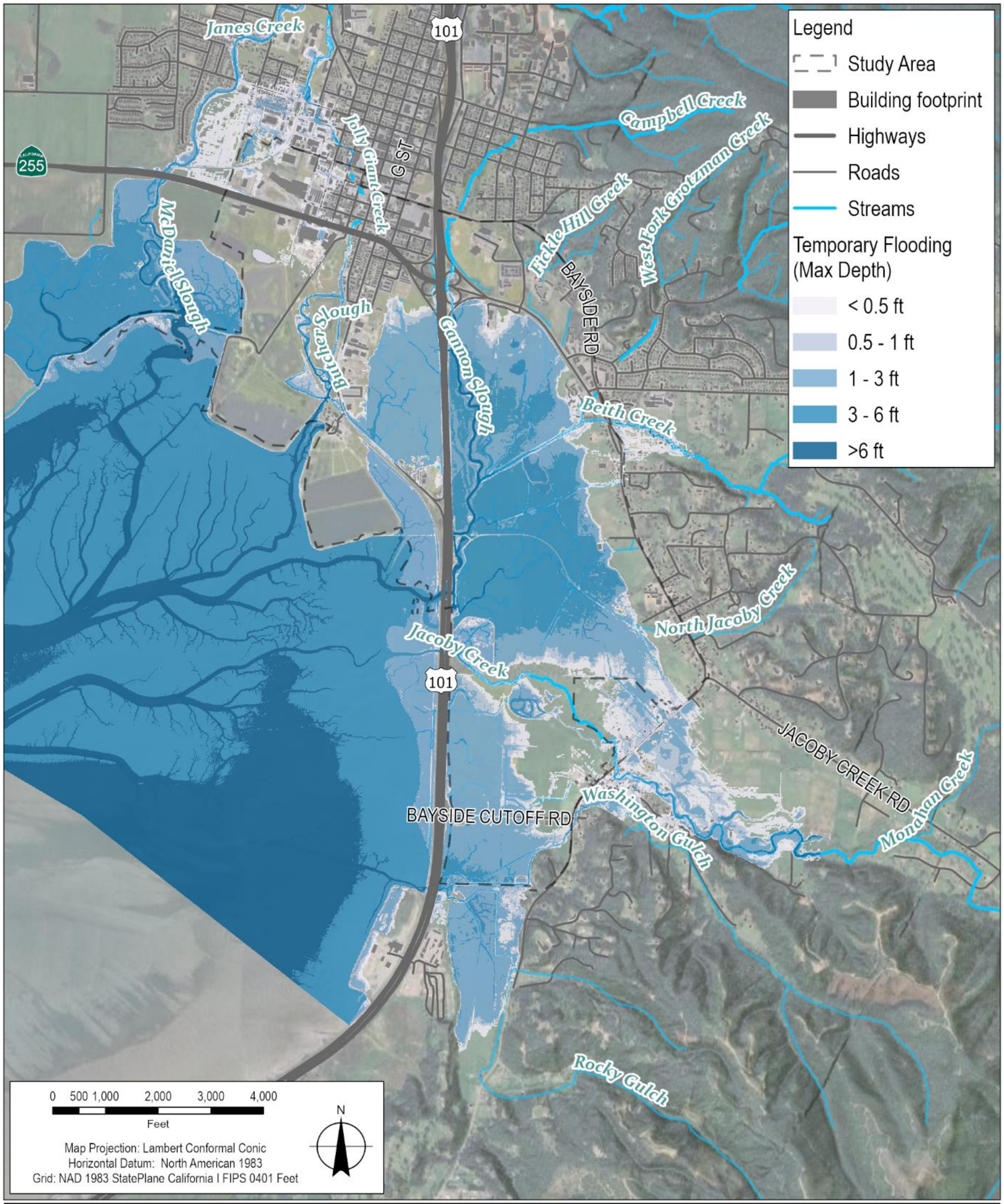
Data source: Tiled service layer: © OpenStreetMap (and) contributors, CC-BY-SA World Hillshade: Esri, NASA, NGA, USGS Created by:jlopez4

Figure 35 ***Model results for the 2-year fluvial and MMMW tidal boundary conditions.***



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Data source: Tiled service layer: © OpenStreetMap (and) contributors, CC-BY-SA World Hillshade: Esri, NASA, NGA, USGS Created by:jlopez4

Figure 36 ***Model results for the 10-year fluvial and MMMW tidal boundary conditions.***

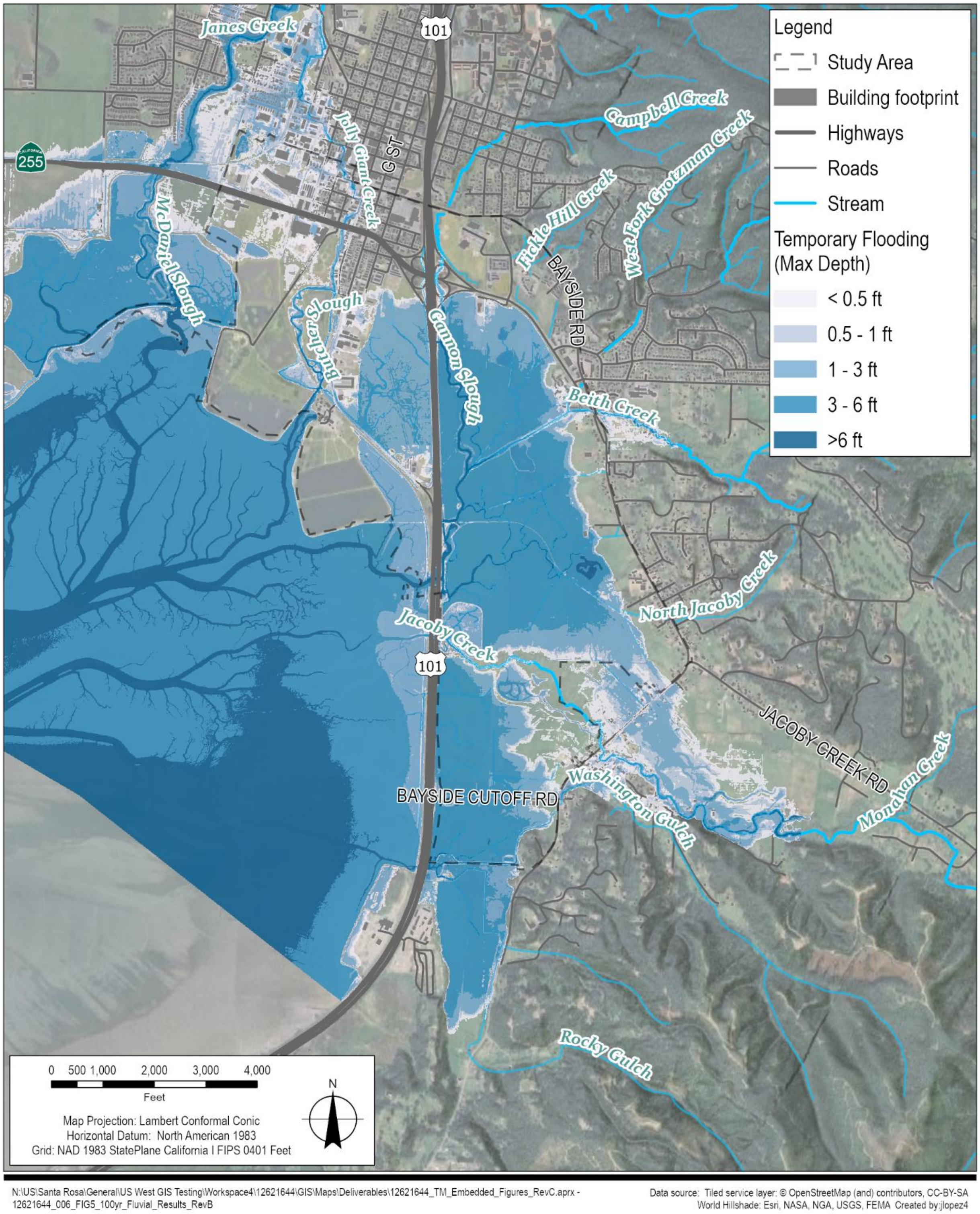
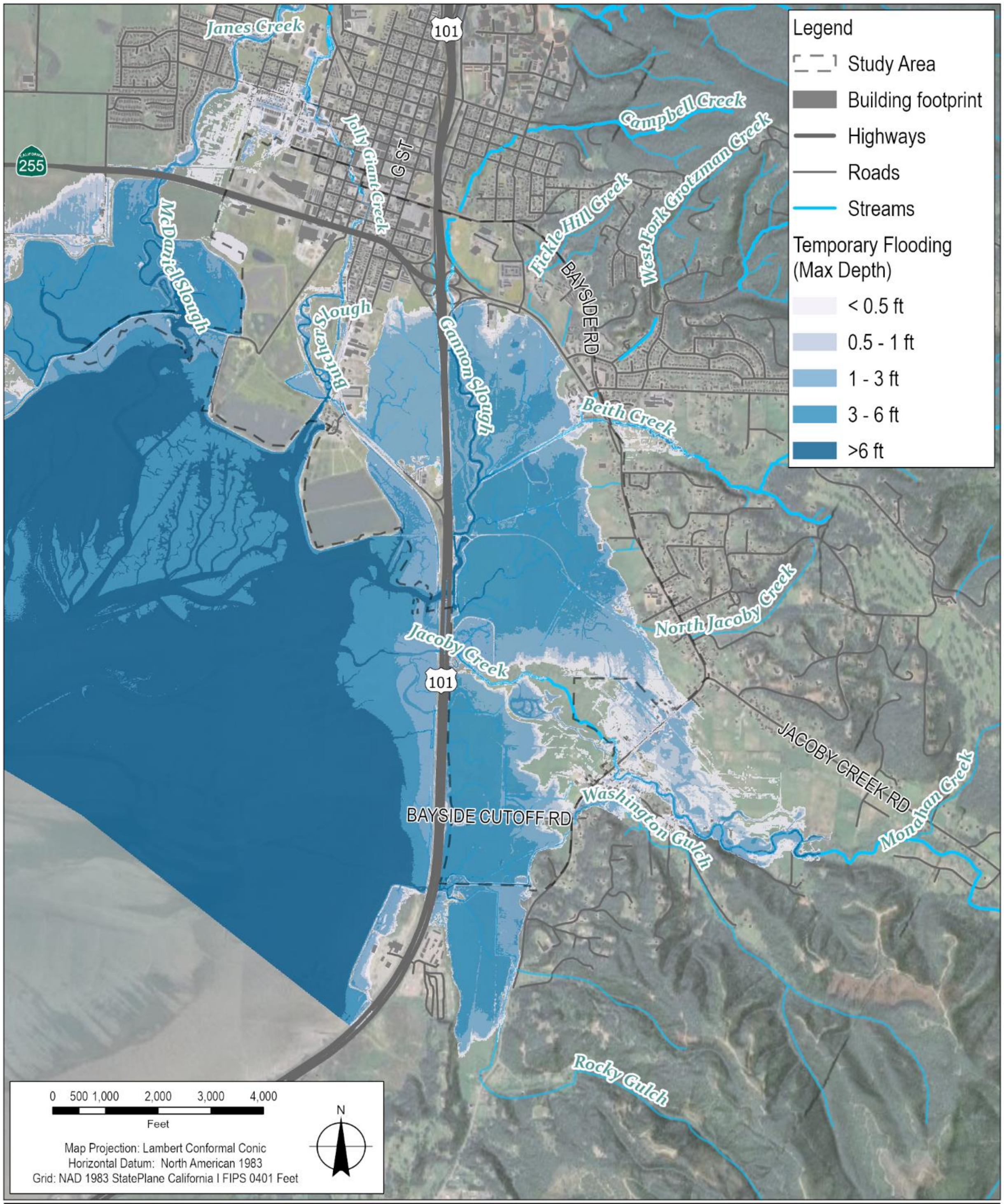


Figure 37 Model results for the 100-year fluvial and MMMW tidal boundary conditions.



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Data source: Tiled service layer: © OpenStreetMap (and) contributors, CC-BY-SA World Hillshade: Esri, NASA, NGA, USGS, FEMA Created by:jlopez4

Figure 38 ***Model results for the peak 9.4 feet (existing 2-year) tidal and 10-year fluvial boundary conditions.***

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