Sea Level Rise Vulnerability Assessment and Capital Improvement Project Adaptation Plan

Vulnerability & Risk Assessment

City Of Arcata

June 05, 2025

The Power of Commitment

Project name	Arcata Sea Level Rise and Adaptation Plan
Document title	Sea Level Rise Vulnerability Assessment and Capital Improvement Project Adaptation Plan | Vulnerability & Risk Assessment
Project number	12621644
File name	CityofArcata_SLR_Vulnerability and Risk Assessment.docx

Status Code	**Revision**	**Author**	**Reviewer**		**Approved for issue**		
			Name	**Signature**	**Name**	**Signature**	**Date**
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Executive Summary

Project Overview

Previous studies along with local and global climate models have indicated that the shoreline and select lower elevation landward regions of the City of Arcata (City) are susceptible to increased inundation and flooding from sea level rise (SLR) and storm events. Within these vulnerable areas exist critical infrastructure including City utilities, transportation assets, and other public facilities that warrant study and adaptation planning. The California Coastal Commission's Local Coastal Program (LCP) Local Assistance Grant Program has awarded the City funding to pursue the *Arcata Sea Level Rise Vulnerability Assessment and Capital Improvement Project Adaptation Plan* (Project). The City is currently revising their LCP with updates to the Local Coastal Element that reflect the most up to date understanding of the implications of projected SLR and precipitation.

To better understand potential impacts of coastal, fluvial and groundwater flooding on City assets and inform the design and development of capital improvement program (CIP) projects, a vulnerability and risk assessment was completed. The assessment was conducted utilizing hydrodynamic modeling of current and future tidal water levels, precipitation events and groundwater levels to identify flood pathways, extent, depth and duration for a range of flooding scenarios. The vulnerability assessment addresses the questions: *What City assets may be adversely affected by flooding and when?* The risk assessment accounts for the likelihood that an asset will be impacted, the types of impacts, and the consequence of those impacts. The risk assessment is used to inform the temporal and spatial prioritization of adapting assets for future conditions. The framework for these assessments is presented in Figure ES-1. Adaptation strategies will be developed and presented in a subsequent report.

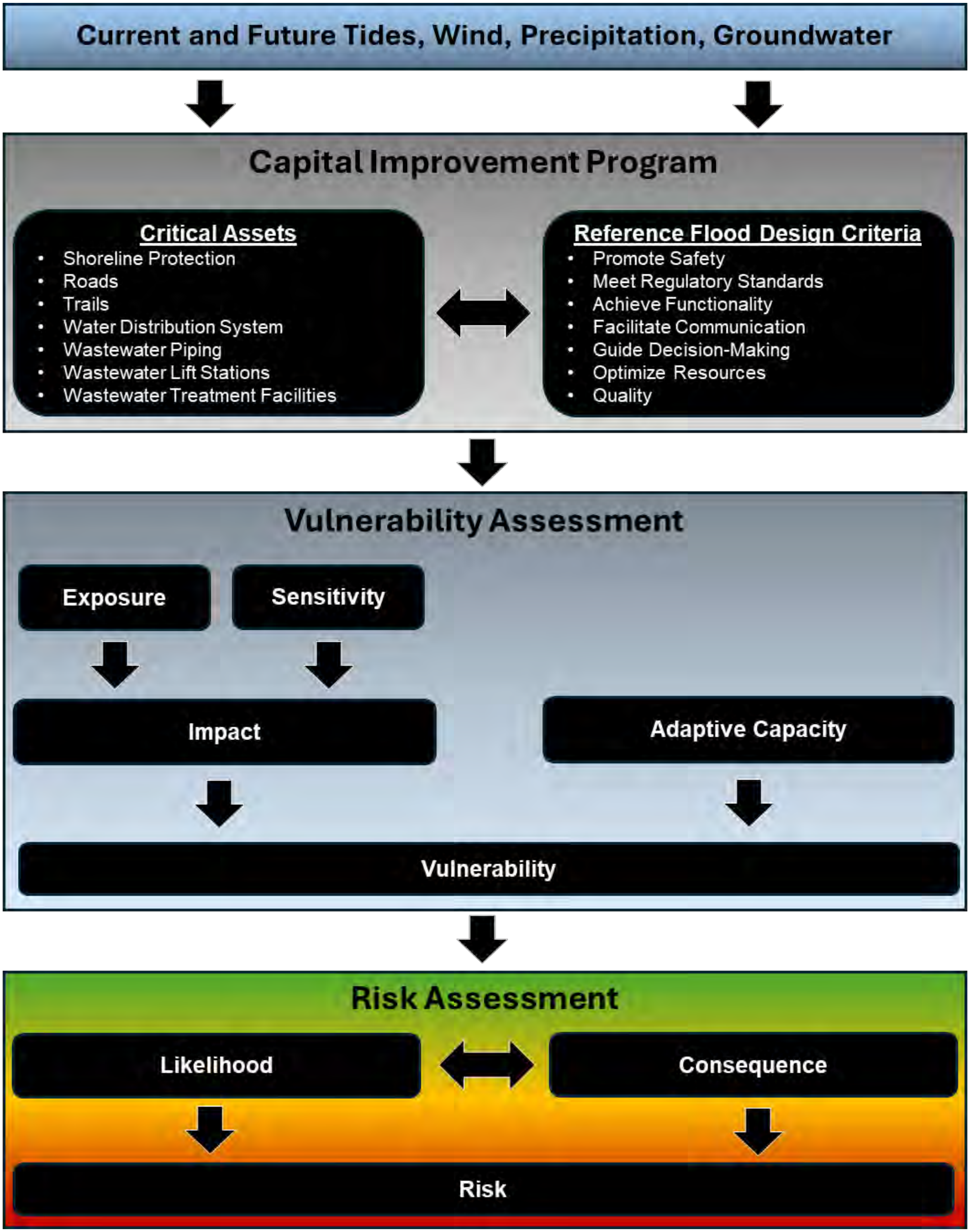

Figure ES-1 Capital Improvement Program Vulnerability and Risk Assessment Framework

Study Area Current and Future Tides, Wind, Precipitation, and Groundwater

The Project Study Area was delineated to encompass areas of the City within the Coastal Zone that are potentially vulnerable to coastal and fluvial flooding. This Study Area was selected to inform updates to the City's Local Coastal Program and Capital Improvement Program. The Study Area includes critical infrastructure such as shoreline protection structures and the City's wastewater collection and treatment facilities, water distribution, roadways, and trails.

For this study, NHE built upon their previous modeling of Humboldt Bay and developed water level datums and annual exceedance probabilities of extreme events along the Study Area shoreline, within Humboldt Bay. Modeling conducted by NHE provided tidal water level time series in Humboldt Bay influenced by astronomical tides and storm surge events with additional modeling providing wind setup and wave runup effects on water levels along the shoreline.

SLR scenarios were developed based vertical land motion for the Study Area and the latest 2024 State of California Sea Level Rise Guidance. These SLR scenarios were used to describe changes to water level datums and annual exceedance probabilities over the course of the planning horizon, to 2105.

Tidal time series from the NHE model and stream flow hydrographs developed from the USGS StreamStats were used to develop model scenarios representing a range of existing and future conditions. A hydrodynamic model of the Study Area shoreline and landward areas was developed to evaluate flooding pathways, extent, depth and duration of each model scenario.

The United States Geological Survey (USGS) Coastal Storm Modeling System (CoSMoS) Our Coast Our Future web tool was utilized to estimate existing and future groundwater conditions.

Capital Improvement Program and Flood Design Criteria

The purpose of the assessment is to inform the City's Capital Improvement Program (CIP). The CIP is a long-term, multi-year planning tool that identifies the construction, repair, and replacement of major City assets. The planning period for CIPs is typically 20 to 30 years, with consideration of longer-term infrastructure life span (typically up to 50 years). A CIP planning time frame from 2025 to 2055 and an infrastructure lifespan of up to 50 years was utilized for this assessment, resulting in SLR and precipitation scenarios to 2105. This assessment will be used to inform the identification and prioritization of future project needs to allow enough time to fund, plan, permit, design and implement projects. The City's assets and infrastructure within the Study Area are the focus of the vulnerability analysis. Critical assets include the following City infrastructure:

- **Shoreline Protection**
- **Roads**
- **Trails**
- **Water Distribution System**
- **Wastewater Collection Piping**
- **Wastewater Lift Stations**
- **Wastewater Treatment Facilities**

Engineering design criteria serve as guidelines and benchmarks for developing and evaluating engineering projects. Some key purposes include:

- **Promote Safety:** Help identify and mitigate potential hazards, protecting users and the environment.
- **Meet Regulatory Standards:** Design criteria align projects with local, national, and international regulations and standards.
- **Achieve Functionality:** Define the necessary functions and performance requirements
- **Facilitate Communication:** Clear criteria help communicate expectations and requirements.
- **Guiding Decision-Making:** Provide a framework for making informed decisions throughout the design process.

– **Optimize Resources:** Criteria help in the efficient use of materials, time, and budget, leading to cost-effective solutions.
– **Quality:** Help meet the desired quality and reliability standards.

Reference flood design criteria are typically based on the likelihood or recurrence of a given event. Reference criteria from the City, Federal Emergency Management Agency (FEMA), Natural Resources Conservation Service (NRCS), American Society of Civil Engineers (ASCE), and other municipalities was compiled and reviewed. This reference criteria were utilized in the evaluation of existing and future vulnerability of each critical asset where applicable.

Vulnerability Assessment

The focus of the vulnerability assessment in this report is to characterize adverse effects to City-owned infrastructure, resulting from a range of existing and future tidal and groundwater levels and stream flows. The vulnerability of City assets was assessed based on the framework described in the 2024 State of California Sea Level Rise Guidance document that includes an evaluation of the impacts to infrastructure due to exposure and sensitivity of an asset flooding and due to erosion, and the ability to moderate damages due to future conditions (adaptive capacity). Additional consideration in the vulnerability assessment was given to flood design criteria and associated likelihoods described previously.

The vulnerability assessment focused on the following factors:

– **Asset sensitivity:** characterized how service may or may not be affected if exposed to flood waters
– **Exposure:** identified if flooding associated with a given water level or storm event would interact with the asset
– **Impacts:** were described based on the asset sensitivities and flood exposure to identify thresholds, characterized by marked changes to operations (i.e. typical wet conditions, maintenance, and damage following an event). Reference design criteria was identified, intended to inform typical avoidance or mitigation measures.
– **Adaptive Capacity**: characterized the asset and City staff's ability to moderate potential damages.
– **Vulnerability:** utilized the results of the steps above and projected changes to the recurrence and magnitude of hazards to characterize the likelihood of impacts over the course of the planning horizon. The exposure and likelihood of an event was compared to reference design criteria to understand if and when an asset meets or will no longer meet typical design criteria.

Vulnerability as a function of impacts and changing likelihoods affecting each asset was evaluated for 2024 (current), 2055, 2075, and 2105 to capture the planning horizon comprised of the City's CIP planning time frame (2025 to 2055) and typical design infrastructure lifespan of 50 years.

Risk Assessment and Summary of Findings

While the vulnerability assessment identified what and how assets will be impacted, the risk assessment was used to determine the scale and severity of impacts. Characterizing risk allows the City to make informed decisions regarding the allocation of resources and development of an adaptation strategy in the CIP, based on the temporal and spatial distribution of risk. Risk accounts for how likely an asset is to experience flood impacts (likelihood), and how those impacts affect the City's ability to manage and maintain operations (consequence). The combination of the likelihood (almost unprecedented to almost certain) and consequence (insignificant to catastrophic) of a given event was used to apply a qualitative risk rating (very low to very high) for each asset using a risk matrix evaluation for each of the dates of interest within the planning horizon.

The risk assessment indicates that the assets within the area south of Samoa Boulevard (SR 255) and west of Hwy 101 exhibit the greatest escalation of risk during the planning horizon, as shown in Figure ES-2. Under existing conditions, a portion of South G, South F, South I and South H Streets all exhibit medium risk due to likely flooding resulting in moderate to major consequences associated with the road becoming inaccessible. All other assets in this area exhibit a low to very low risk rating due to likelihood ranging from unlikely to almost unprecedented or consequences ranging from insignificant to moderate. By 2055, a significant portion of roadways south of SR 255 exhibit medium risk, with a portion of South G and South F streets progressing to high risk. Shoreline protection, AWTF facilities, and trails increase to medium risk due to the increased likelihood of flooding, erosion and associated disruption to services and the City's ability to manage impacts. By 2075 and beyond, the increased likelihood of major consequences occurring, such as damage to assets and increased duration of disruption to services results in the majority of assets evaluated exhibiting high risk.

Given the increasing levels of risks over time, the importance of adapting and protecting these assets as a part of the City's CIP increases. Based on the temporal and spatial distribution of risk ratings, identification and sequencing of strategies for adaptation will be presented in a subsequent report update. Adaptation projects will be developed to reduce current and future risk and inform the LCP and CIP projects. Strategies considered will include nature-based adaptation, hybrid approaches, managed retreat, and improvement of current infrastructure.

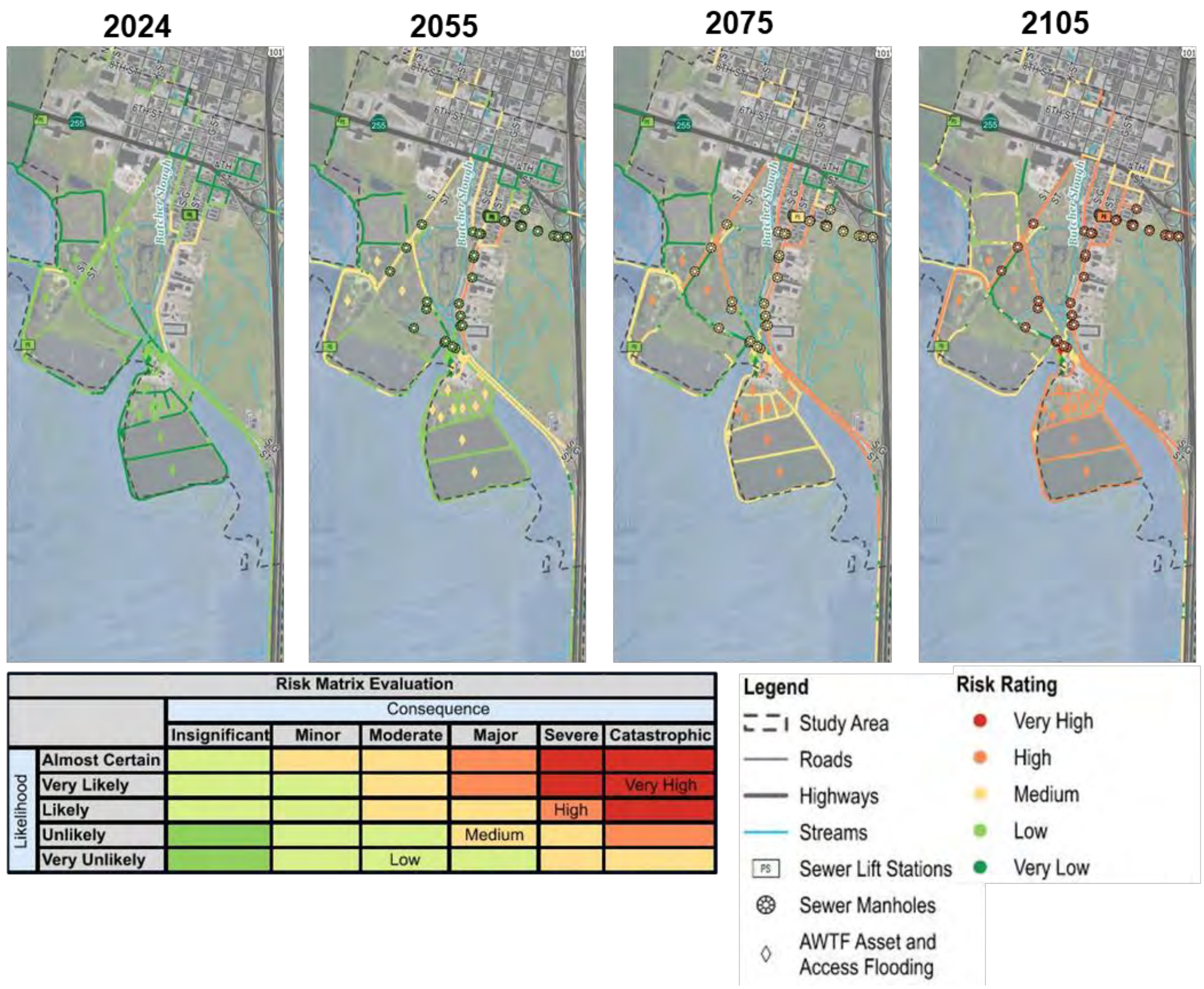

Figure ES-2 Risk Ratings of City Assets Based Likelihood and Consequence During the Planning Horizon (OPC Intermediate Scenario)

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1. Introduction and Purpose

Previous studies along with local and global climate models have indicated that the shoreline and select lower elevation landward regions of the City of Arcata (City) are susceptible to increased inundation and flooding from sea level rise (SLR) and storm events. Within these vulnerable areas exist critical infrastructure including City utilities, transportation assets, and other public facilities that warrant study and adaptation planning.

The California Coastal Commission's Local Coastal Program (LCP) Local Assistance Grant Program has awarded the City funding to pursue the *Arcata Sea Level Rise Vulnerability Assessment and Capital Improvement Project Adaptation Plan* (Project). The City is currently revising their LCP with updates to the Local Coastal Element that reflect the most up to date understanding of the implications of projected SLR.

The focus of this study is to build on previous vulnerability assessments and inform updates to the City's LCP. This is done by characterizing and assessing vulnerabilities of City infrastructure to SLR including consideration of risk (likelihood and consequences) and developing adaptation strategies for City infrastructure.

All elevations referenced in this Study are reported in North America Vertical Datum of 1988 (NAVD88). Ground elevations utilize the 2019 Humboldt Bay LiDAR data set.

2. Vulnerability and Risk Assessment Process

To better understand the impacts of flooding caused by SLR and storm events on City assets, a vulnerability and risk assessment was completed as part of this report. The assessment was conducted within a set study area, utilizing hydrodynamic modeling of current and future water levels affecting the study area to identify flooding and flow paths for specific SLR and climate change scenarios. The vulnerability assessment addresses the questions: *What is vulnerable to flooding?* and *When will it be vulnerable?*

While the vulnerability assessment identifies what, when and how assets will be impacted, the risk assessment evaluates the likelihood that an asset with be impacted by a flood event, the types of impacts, and the consequence of those impacts to the specific asset. Identifying risk of flooding impacts allows the City to make informed decisions for future development projects as well as planning for adaptation strategies to protect, modify or relocate assets to help protect them from the impacts of future flooding.

3. Study Area

The region of interest (Study Area) includes the City of Arcata shoreline, extending from McDaniel Slough to the north, to Washington Gulch (Brainard Slough) to the south, and inland to the Coastal Zone boundary as shown in Figure 1. The Study Area was delineated to encompass areas of the City within the Coastal Zone that are potentially vulnerable to coastal and fluvial flooding. Areas of the City within the coastal zone are managed as part of the Coastal Commission's Local Coastal Program (LCP), which requires the City to plan future development in the coastal zone with SLR in mind. The Study Area includes critical infrastructure such as shoreline protection structures and the City's wastewater collection and treatment facilities, water distribution, roadways, and trails in addition to other public and private facilities and development.

The Study Area water courses, zoning, and topography are all relevant to the evaluation of the flooding and inundation vulnerability and risks to the area resulting from SLR and increased storm intensity.

3.1 Study Area Water Courses

The primary water courses within the study area include Humboldt Bay, slough channels, and creeks. Slough channels of interest include Brainard, Butcher, McDaniel, and Gannon. Gated culverts exist on Brainard and Gannon Sloughs, restricting the propagation of tidal flows to inland areas while Butcher and McDaniel Slough are ungated and hence otherwise unrestricted to tidal flows. Creeks of interest include Beith, Campbell, Grotzman, Jacoby, Janes, and Jolly Giant.

Aerial images of select relevant locations along the Arcata shoreline are shown in Figure 2, Figure 3, and Figure 4.

The historical extent of the Humboldt Bay tidal range reached further inland than present day. The extent of tidal reach has been reduced by the placement of fill for linear features, such as dikes or levees, roadways and rail lines, as well as fill for areas of development. Development in former tidal areas, south of Samoa Boulevard, is largely located along South G Street, where the Arcata Wastewater Treatment Facility (AWTF) is also located.

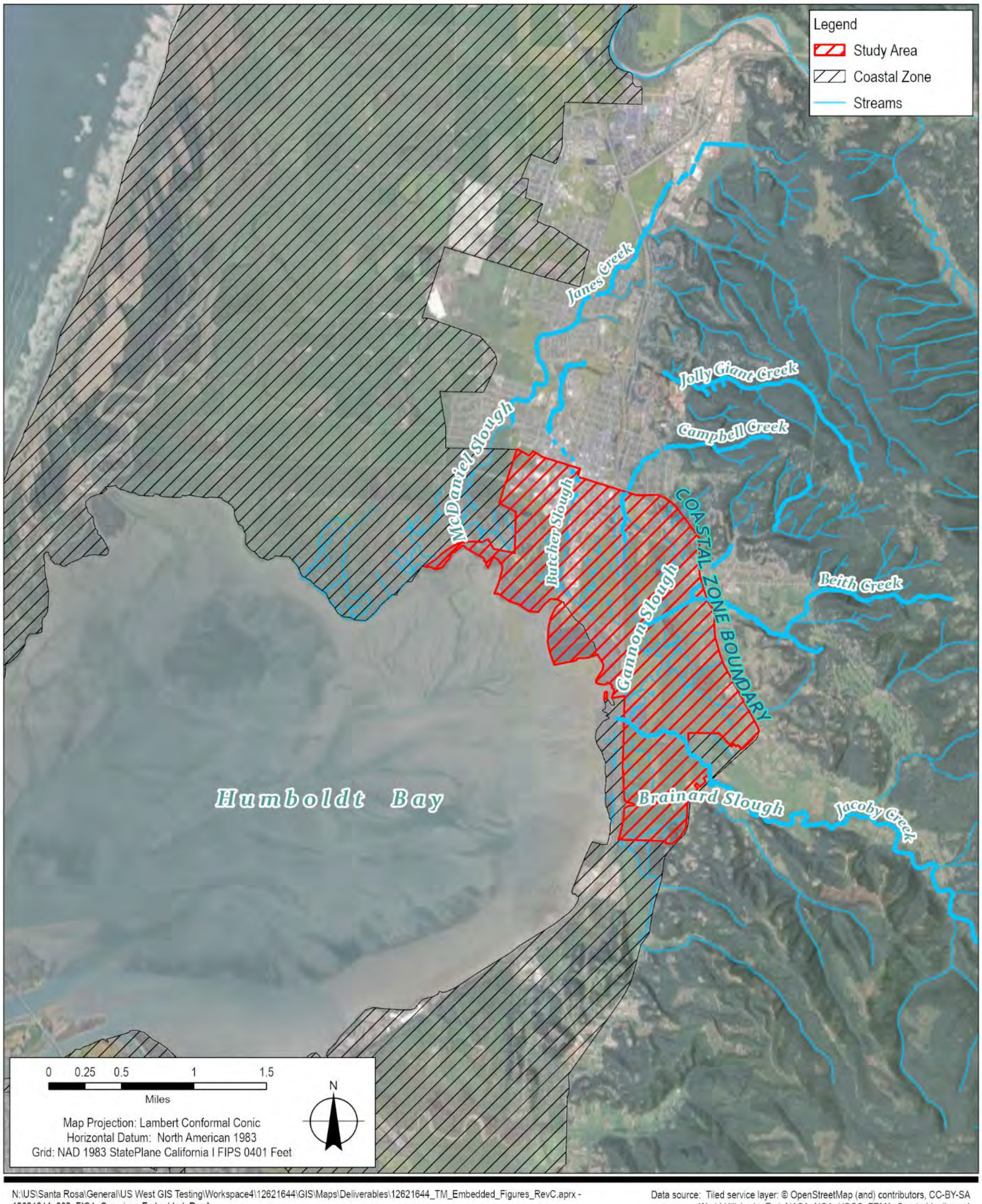


Figure 1 ***Project Study Area and the Coastal Zone in the Vicinity of the City of Arcata.***

Figure 2 ***View of South G Street and AWTF looking northeast from Humboldt Bay***

Figure 3 ***View of South I Street and Humboldt Bay looking West***

Figure 4 *View of South I and South G Streets looking South*

3.2 Study Area Zoning

The Study Area and City of Arcata's LCP planning area is comprised of six land use types quantified in Table 1 and shown in Figure 5. The AWTF is located within Public Facility and Natural Resource zoned areas adjacent to Humboldt Bay with access from South G Street. The Arcata Marsh and Wildlife Sanctuary (AMWS) is located within zoned Natural Resource areas adjacent to South I Street. Developed areas are present within zoned industrial, residential, and commercial areas. Much of the Study Area is zoned Agriculture Exclusive and is primarily located east of Highway 101.

Table 1 *Land use types and area according to the City of Arcata's LCP planning area (Trinity Associates, 2018).*

Zoning	Total Acres	Total %
Agriculture Exclusive	875	57%
Natural Resources	296	19%
Residential	141	9%
Industrial	136	9%
Public Facility	78	5%
Commercial	17	1%
Total	1,542	100%

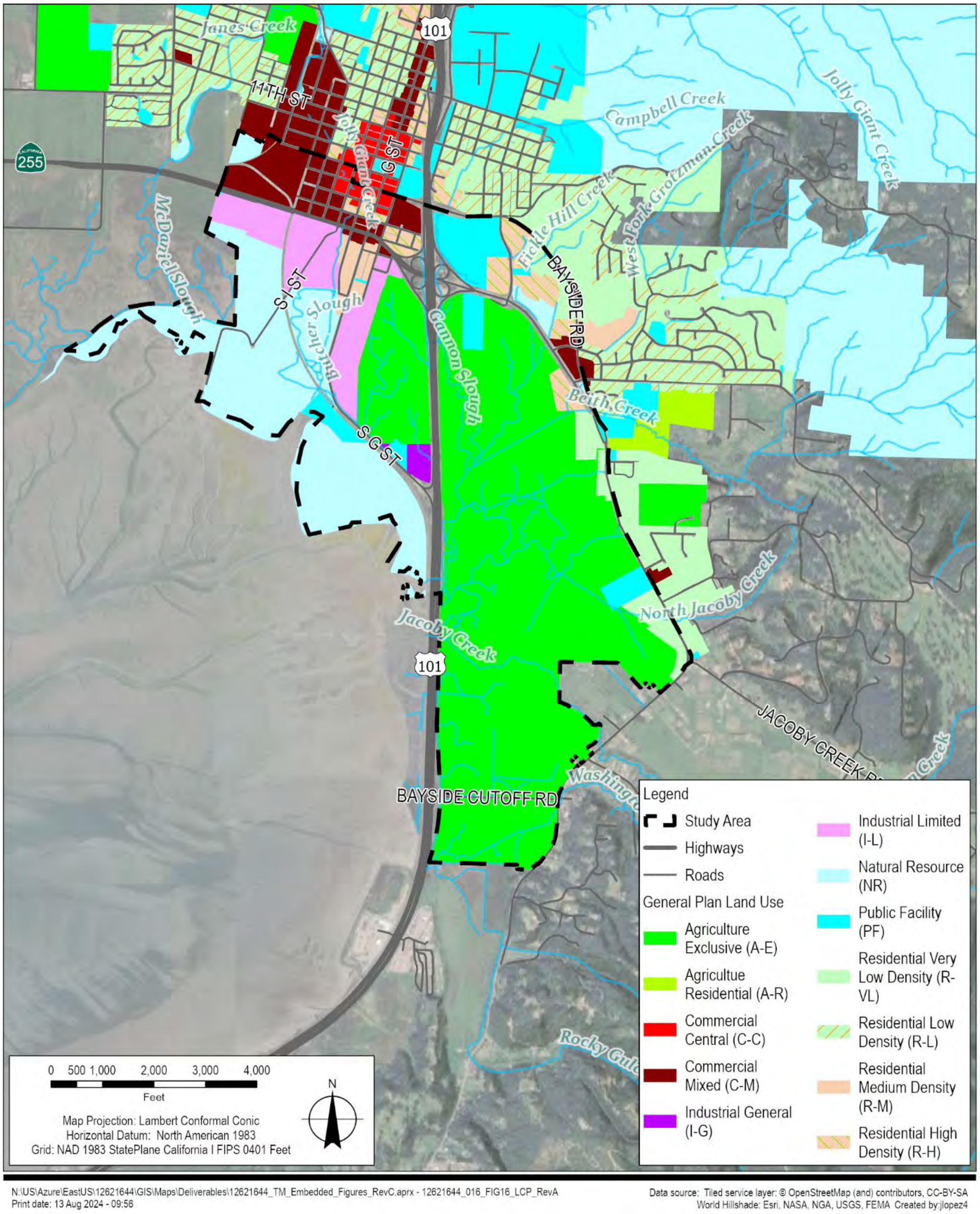


Figure 5 ***Land use zoning with the City of Arcata and Study Area***

3.3 Study Area Topography

The topography of the study area is characterized by low lying floodplain and marshland that has been diked, drained and filled for the uses presented in Section 3.2. The overall topography of the area is presented in Figure 6. All elevations referenced in this Study are reported in North America Vertical Datum of 1988 (NAVD88). Ground elevations utilize the 2019 Humboldt Bay LiDAR data set.

Developed areas south of Highway 255 (Samoa Boulevard), along South G Street and South I Street typically exhibit ground elevations between 8 feet and 11 feet because of historically placed fill. Agricultural and Natural Resource zoned areas typically exhibit lower ground elevations, between 5 feet and 7 feet.

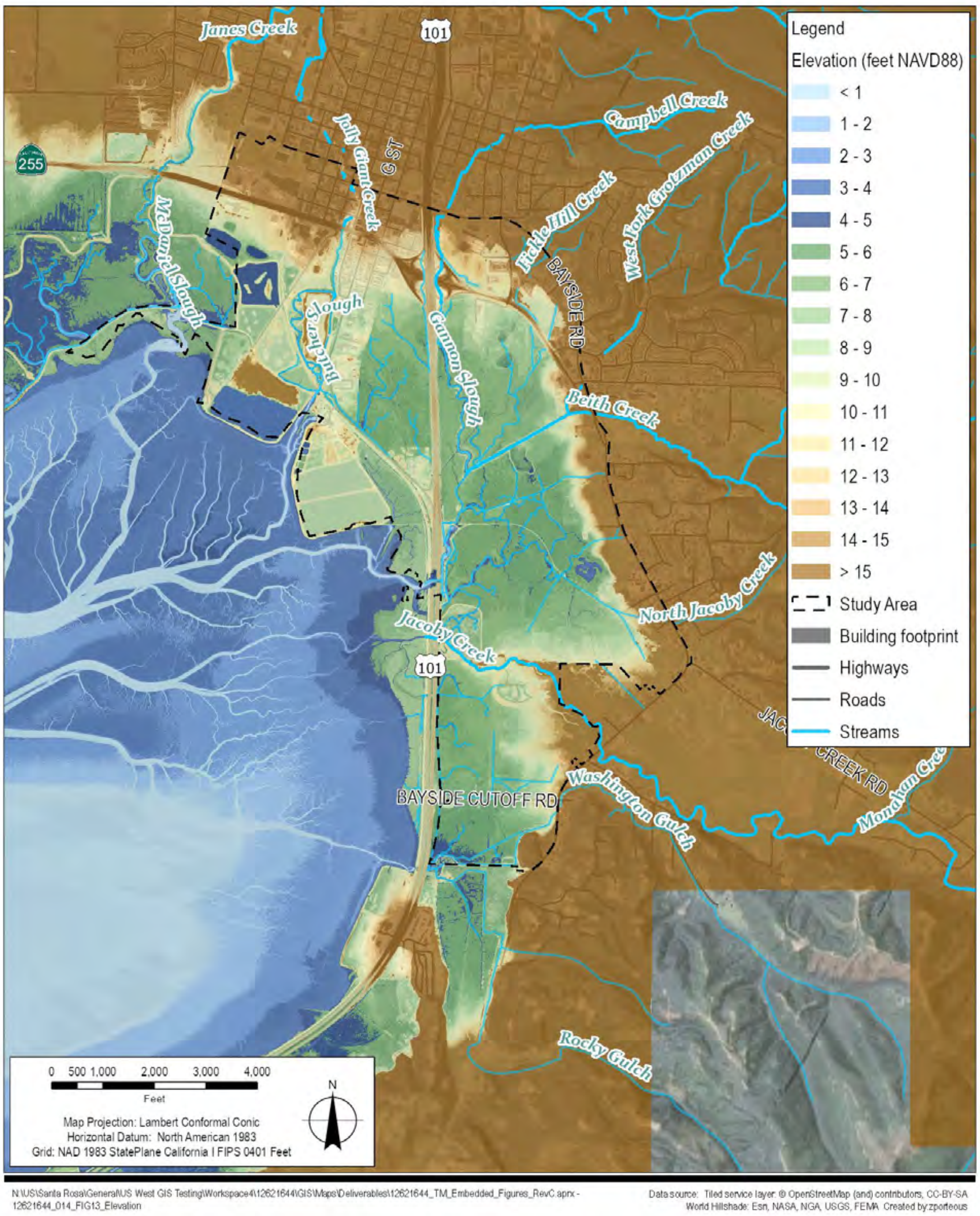


Figure 6 ***Ground elevations within the Study Area.***

Due to the low-lying nature of the study area, it is vulnerable to the effects of SLR. Risks to assets within the Study Area are significantly affected by water levels as discussed in the next section.

4. Planning Horizon

The planning horizon is used in this study for the consideration of the effects of SLR and increased precipitation. 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, resulting in consideration of tidal water levels, precipitation and groundwater levels to 2105.

Infrastructure design commonly incorporates design likelihoods. For the purposes of this assessment, a range of SLR scenarios (Intermediate-Low to High) will be considered in the vulnerability assessment. The risk assessment will include a primary focus on the reasonable estimate of the upper bound of the most likely SLR in 2100 (Intermediate).

As a part of this study, SLR and precipitation projections are added to existing datums and high-end extreme events to estimate future likelihoods of events during the LCP and CIP planning period and typical infrastructure lifespan to 2105. Local effects of wind, wind waves and wave runup will be incorporated as applicable.

5. Tidal Water Levels, Precipitation, and Groundwater

The Study Area is affected by tidal water levels in Humboldt Bay, precipitation within the contributing watersheds, and groundwater levels. The following sections describe the range of factors contributing to water levels and flows to inform the development of flooding scenarios used to evaluate vulnerability and risk to City assets.

5.1 Tidal Water Levels

Water levels along the City of Arcata shoreline differ from those along other parts of Humboldt Bay due to various hydrodynamic factors. To address relevant factors and forecast tidal water levels, a hydrodynamic model was developed by Northern Hydrology and Engineering (NHE) and the results were summarized in the report, Humboldt Bay: Sea Level Rise, Hydrodynamic Modeling, and Inundation Vulnerability Mapping, 2015. The open ocean boundary condition for the model included variability in sea levels due to astronomical tides and the effects of wind, sea-level pressure, and El Niño (NHE, 2015). These still water levels exclude local variations caused by wind effects within Humboldt Bay.

For this study, NHE built upon previous modeling and developed water levels and annual exceedance probabilities of extreme high-water levels for the Study Area, presented in Table 2, with additional detail provided in Appendix A (NHE, 2024).

Table 2 2023 Tidal water levels and still water return periods for the study area (NHE, 2024).

Tidal Datum and Annual Exceedance Probability (%)	Annual Expected Number of Occurrences (#/yr)	Annual Average Recurrence Interval (yr)	Year 2023 Value (ft, NAVD 88)
Mean High Water (MHW)	-	-	6.4
Mean Higher High Water (MHHW)	-	-	7.1
Mean Monthly Maximum Water (MMMW)	-	-	8.5
Mean Annual Maximum Water (MAMW)	-	-	9.5
99.0	0.99	1.01	9.3

Tidal Datum and Annual Exceedance Probability (%)	Annual Expected Number of Occurrences (#/yr)	Annual Average Recurrence Interval (yr)	Year 2023 Value (ft, NAVD 88)
95.0	0.95	1.05	9.3
90.9	0.91	1.10	9.3
80.0	0.80	1.25	9.4
66.7	0.67	1.5	9.5
50.0	0.50	2	9.6
20.0	0.20	5	9.9
10.0	0.10	10	10.1
5.0	0.05	20	10.3
4.0	0.04	25	10.4
2.0	0.02	50	10.5
1.0	0.01	100	10.7
0.5	0.005	200	10.8
0.2	0.002	500	11.1

5.2 Wind Effects on Tidal Water Levels

Water levels in Humboldt Bay are based on tidal elevations which can be significantly influenced by local wind effects. Water levels are influenced by both wind setup and wave runup which result in total water level (TWL). Wind setup is the increase in still water level of the Bay caused by wind generally pushing the water from one end of the Bay to the other. Wave Runup is the result of the interaction between wind waves and the shoreline, resulting in temporary spray or surge of water up the shoreline slope or feature. Total water levels (TWL) at a given shoreline location are estimated by combining still water levels (tide levels plus storm surge), wind setup, and wave runup from locally generated waves (Figure 7). NHE analyzed local wind characteristics and performed a wind wave analysis using data from local NOAA weather stations (Appendix A). A summary of these effects is provided below.

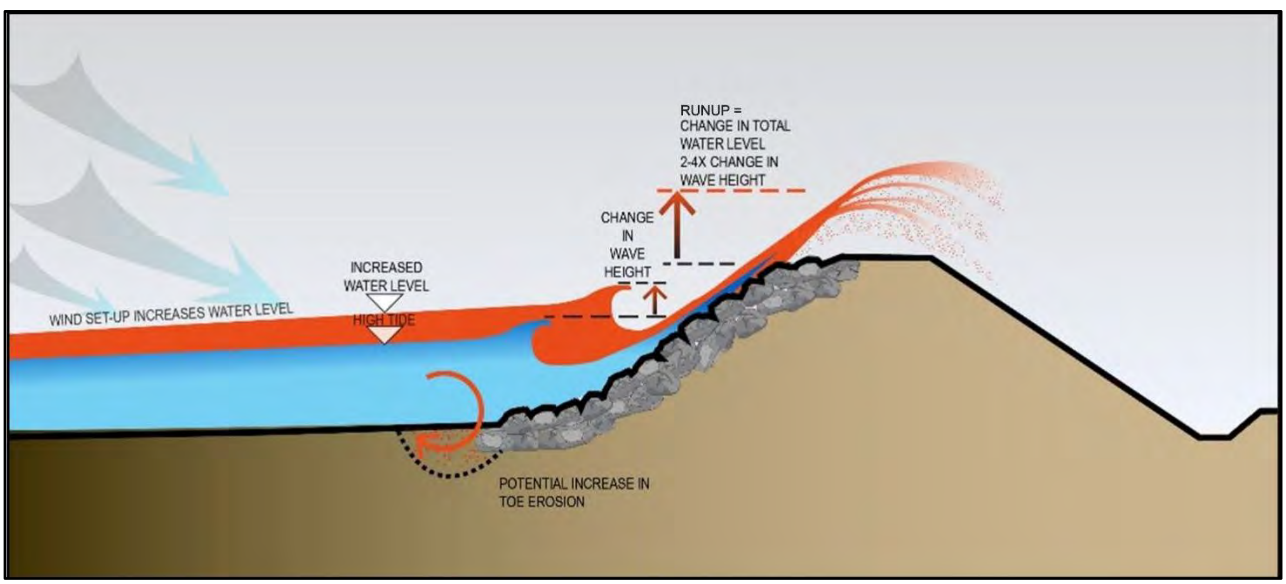


Figure 7 ***Conceptual representation of wind, wind waves and wave runup resulting in total water level (TWL).***

5.2.1 Wind Setup

The tidal water levels in the Humboldt Bay are influenced by wind setup that is dictated by local wind characteristics. As wind blows over the surface of the bay a shear stress is applied to the water surface which pushes water in the direction of the wind. The wind stress effects can magnify or suppress tidal water levels along the bay shoreline depending on the location and the prevailing wind direction and magnitude. At the study area, wind blowing from south to north (south winds) tend to increase water levels in the northern part of the bay and tend to decrease water levels in the south part of the bay. Conversely north winds tend to increase water levels in the southern part of the bay and tend to decrease water levels in the northern part of the bay.

NHE (2024) utilized a hydrodynamic model of Humboldt Bay to estimate wind setup at the project site for various wind speeds and directions. As expected, the modelling results indicated that the largest wind wave setup occurred at a wind direction aligned to the longest wind fetch (the longest unobstructed wind path across the Bay's water surface, which is 240.3 degrees relative to the project shoreline, Figure 8). The resulting wind setup in feet at the study area shoreline is presented below in Table 3.

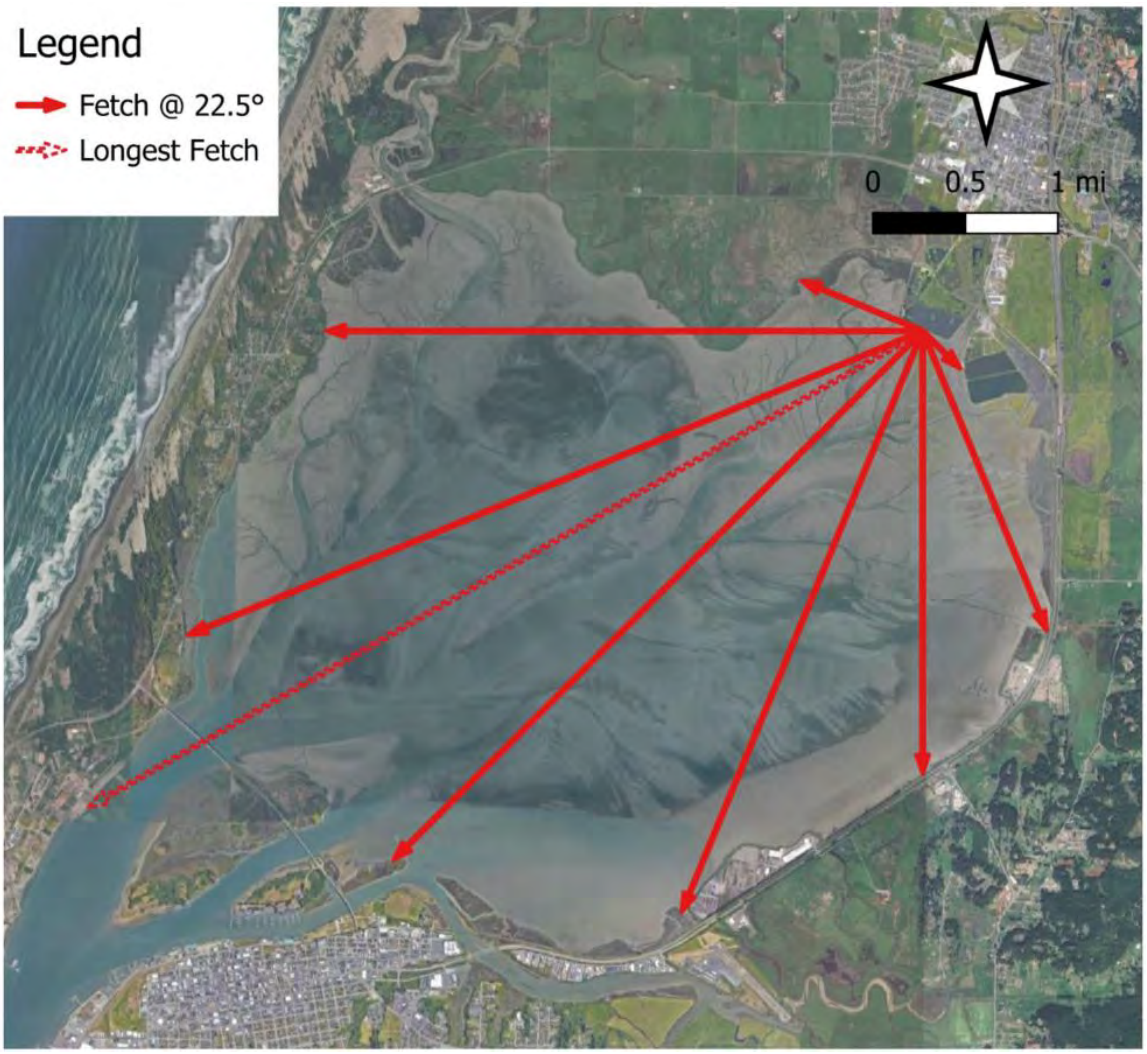


Figure 8 Fetch directions relative to the Project shoreline adjacent to Klopp Lake in North Bay (NHE, 2024).

Table 3 Estimated wind setup at project shoreline (NHE, 2024)

Annual Exceedance Probability (%)	Wind Setup (ft)
95	0.59
66.7	0.64
50	0.68
20	0.79
10	0.86
4	0.95
2	1.00
1	1.04

The wind setup elevations presented in Table 3 are the increase in still water level in the Study Area caused by south wind events (typically winter storms). The 95% or approximately yearly wind event increases still water levels by 0.59 feet, while the 1% or 100-year wind event increases still water levels by 1.04 feet. In addition to wind setup, wind wave conditions and wave runup can result in temporary increases in water levels along the shoreline as waves interact with the Bay shoreline.

5.2.2 Wind Wave Conditions and Runup

Despite being largely sheltered from the open coast, the north bay in the vicinity of the Study Area has sufficient fetch (wind exposure) such that locally generated wind waves have the potential to contribute to flood hazards along the shoreline of the Study Area. Depending on specific shoreline feature height and shape as well as the still water level, the addition of wind waves and the magnitude of wave runup can result in temporary overtopping of the shoreline feature.

The relationship between wind speed and the creation of wind wave heights and periods were estimated along the longest fetch direction for eight extreme wind speeds (95, 66.7, 50, 20, 10, 4, 2 and 1% exceedance probability). The corresponding peak wave heights and periods were calculated using procedures outlined in the US Army Corps of Engineers 2015 Coastal Engineering Manual and used to then calculate the wave runup as the wind waves interact with an armored shoreline as shown in Table 4, using the Technical Advisory Committee for Water Retaining Structures (TAW). Wave runup may be added to the stillwater level at a given location to estimate the peak of the temporary spray or surge of water in the immediate vicinity of the shoreline.

Table 4 Peak wave heights/period and wave runup at project location (NHE, 2024).

Annual Exceedance Probability (%)	Adjusted Wind Speed (mph)	Peak Wave Height (ft)	Peak Wave Period (s)	Wave Runup $R_{2\%}$ (ft)
95	37.6	2.35	2.66	4.14
66.7	38.9	2.45	2.70	4.29
50	39.9	2.53	2.73	4.40
20	42.6	2.74	2.80	4.70
10	44.2	2.87	2.85	4.89
4	45.9	3.01	2.90	5.09
2	47.0	3.09	2.92	5.21
1	47.9	3.17	2.95	5.32

5.3 Sea Level Rise & Vertical Land Motion

SLR is an issue of concern when considering how a changing climate could affect infrastructure and lands within the Humboldt Bay region. SLR, like many other natural processes, is continually evolving over time. In the short term, SLR may be appear to be minimal in comparison to other factors that affect water levels of Humboldt Bay. However, even a small amount of SLR may increase the risk of coastal flooding during extreme events, posing an increased threat to a variety of coastal resources.

The potential rate of SLR is forecasted by considering scenarios based on various sets of assumptions. SLR scenarios along the west coast of California are provided in the latest 2024 State of California Sea Level Rise Guidance document (OPC, 2024). The California Coastal Commission (CCC) Sea Level Rise Policy Guidance refers to these as the “best available science.” These scenarios, as described in OPC’s guidance are as follows:

- **Low**: the scenario is on the lower bounding edge of plausibility given current warming and sea level trajectories, and current societal and policy momentum.
- **Intermediate-low**: a reasonable estimate of the lower bound of most likely SLR in 2100
- **Intermediate**: Based on sea level observations and current estimates of future warming, a reasonable estimate of the upper bound of most likely SLR in 2100.
- **Intermediate-high**: Intermediate-to-high future emissions and high warming; this scenario is heavily reflective of a world where rapid ice sheet loss processes are contributing to SLR.
- **High**: high future emissions and high warming with large potential contributions from rapid ice-sheet loss processes; given the reliance on sea level contributions for processes in which there is currently low confidence in their understanding, a statement on the likelihood of reaching this scenario is not possible.

The magnitude of SLR for these scenarios based on OPC’s guidance is presented in Table 5.

Table 5 ***Median values for Sea Level Scenarios for California, in feet, relative to a year 2000 baseline. These statewide values all incorporate an average value of vertical land motion corresponding to a negligible rate of 0.1 mm (0.0003 ft) per year uplift (OPC, 2024).***

Year	Low	Int-Low	Intermediate	Int-High	High
2000	0.0	0.0	0.0	0.0	0.0
2020	0.2	0.2	0.2	0.2	0.3
2030	0.3	0.4	0.4	0.4	0.4
2040	0.4	0.5	0.6	0.7	0.8
2050	0.5	0.6	0.8	1.0	1.2
2060	0.6	0.8	1.1	1.5	2.0
2070	0.7	1.0	1.4	2.2	3.0
2080	0.8	1.2	1.8	3.0	4.1
2090	0.9	1.4	2.4	3.9	5.4
2100	1.0	1.6	3.1	4.9	6.6
2110	1.1	1.8	3.8	5.7	8.0
2120	1.1	2.0	4.5	6.4	9.1
2130	1.2	2.2	5.0	7.1	10.0
2140	1.3	2.4	5.6	7.7	11.0
2150	1.3	2.6	6.1	8.3	11.9

How SLR affects actual water elevations is influenced by a variety of factors. For the Humboldt Bay region, one of the most significant factors is vertical land motion. Vertical land motion results from movement of the earth's crustal plates, as well as other local factors. The Humboldt Bay is subject to a multitude of factors causing the ground surface to slowly subside. The rate of vertical motion is not uniform around the bay and hence varies by location.

OPC provides adjusted scenarios for 13 NOAA tide gauge locations that include local vertical land motion. The closest gauge location to the Study Area, for which SLR scenarios are provided is Humboldt Bay North Spit (Station ID: 9418767), approximately nine miles south of the Arcata shoreline. Greater amounts vertical land motion occurs at the North Spit tide gauge (-3.21 mm/yr) compared to the Mad River Slough (-0.54 mm/yr) along the northern extent of the bay, approximately 3 miles west of the AWTF, at a similar latitude (Patton, et al., 2023). Rates of SLR using the OPC SLR scenarios along the west coast of California and vertical land motion for Mad River Slough are shown in Figure 9.

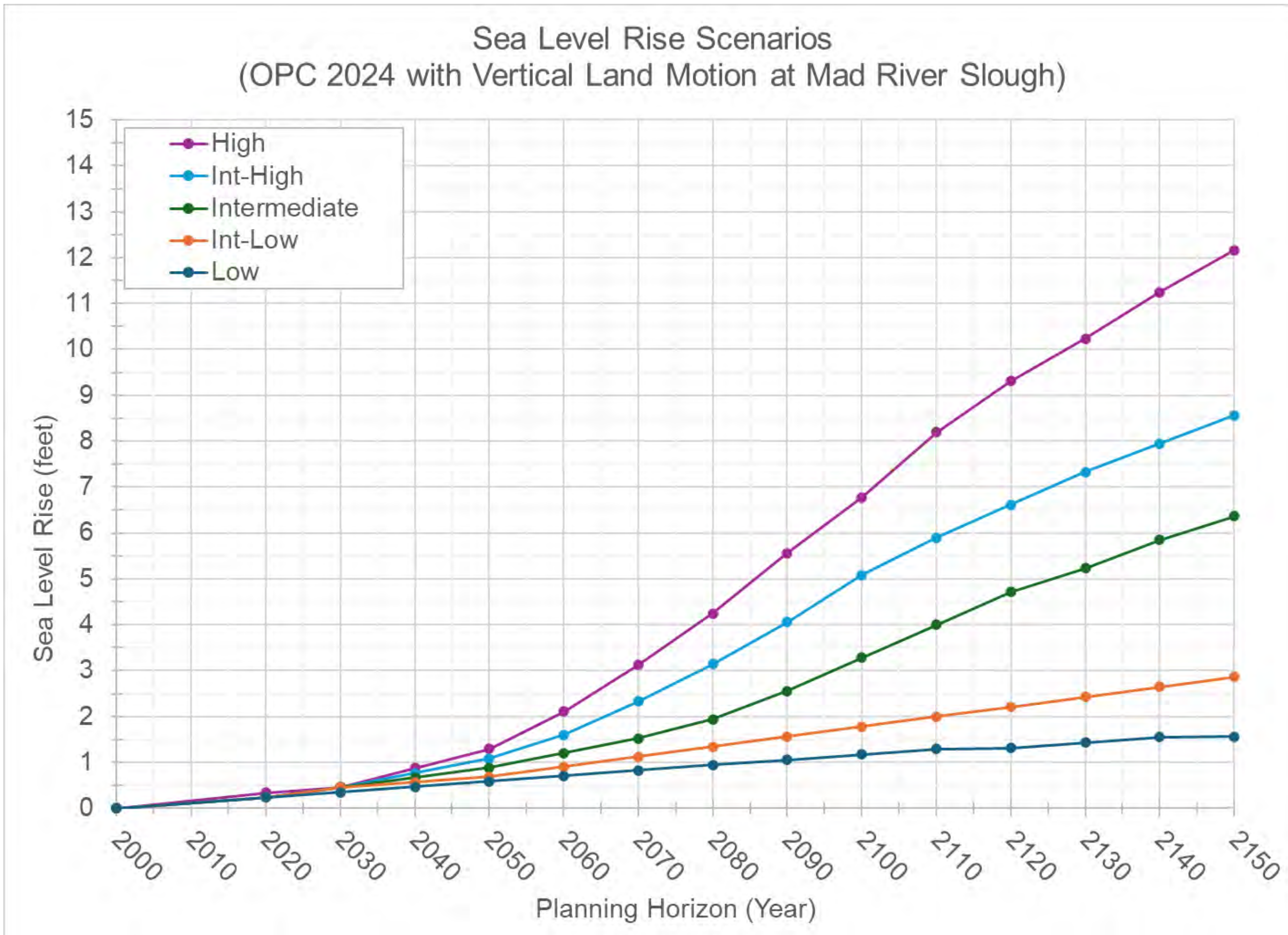


Figure 9   ***SLR scenarios from OPC 2024 with vertical land motion for northern Humboldt Bay.***

The SLR scenarios presented in Figure 9 result from modeling that is in part based on surface air temperature of the planet. Surface air temperatures have been rising distinctly since the industrial revolution and may continue to rise into the future. As the surface temperature continues to rise, the likelihood that the sea level scenario projection will be exceeded increases. Exceedance probabilities for the SLR scenarios based on the Intergovernmental Panel on Climate Change (IPCC) warming-level based Global Mean Sea level projections were provided in the SLR guidance and are summarized in Table 6.

Table 6 *Exceedance probabilities for the SLR Scenarios based on IPCC warming level– based GMSL projections (OPC, 2024).*

Global Mean Surface Air Temperature 2081-2100	1.5° C	2.0° C	3° C	4.0° C	5.0° C
Low Scenario	92%	98%	99.50%	99.90%	>99.9%
Intermediate-Low Scenario	97%	50%	82%	97%	99.50%
Intermediate Scenario	0.50%	2%	5%	10%	23%
Intermediate-High Scenario	0.10%	0.10%	0.10%	1%	2%
High Scenario	<0.1%	<0.1%	<0.1%	<0.1%	0.1%

As present in Table 6, as surface temperature rise, the probability of reaching and exceeding each SLR scenario also increases. If Global surface temperatures reach 3.0°C above pre-industrial levels by 2100, there is near certainty that the Low SLR Scenario will be exceeded, and 5% chance that the intermediate Scenario will be exceeded. The High SLR Scenario is a highly improbable scenario for all presented warming levels, having 0.1% chance of occurring for the maximum 5.0°C of warming scenario.

5.3.1 Sea Level Rise and Planning Horizon

As a part of this planning study, SLR projections are added to existing tidal datums and high-end extreme water levels to estimate future likelihoods of events during the LCP and CIP planning period and typical infrastructure lifespan to 2105. The existing still water tidal datums and extreme water level probability estimates by NHE, described in Section 5.1, for the Study Area with the addition of OPC 2024 SLR scenarios and vertical land motion will be used as a baseline for vulnerability and risk analyses, and are shown in Figure 10Figure 9 through Figure 13. Local effects of wind, wind waves and wave runup on total water levels will be incorporated as applicable.

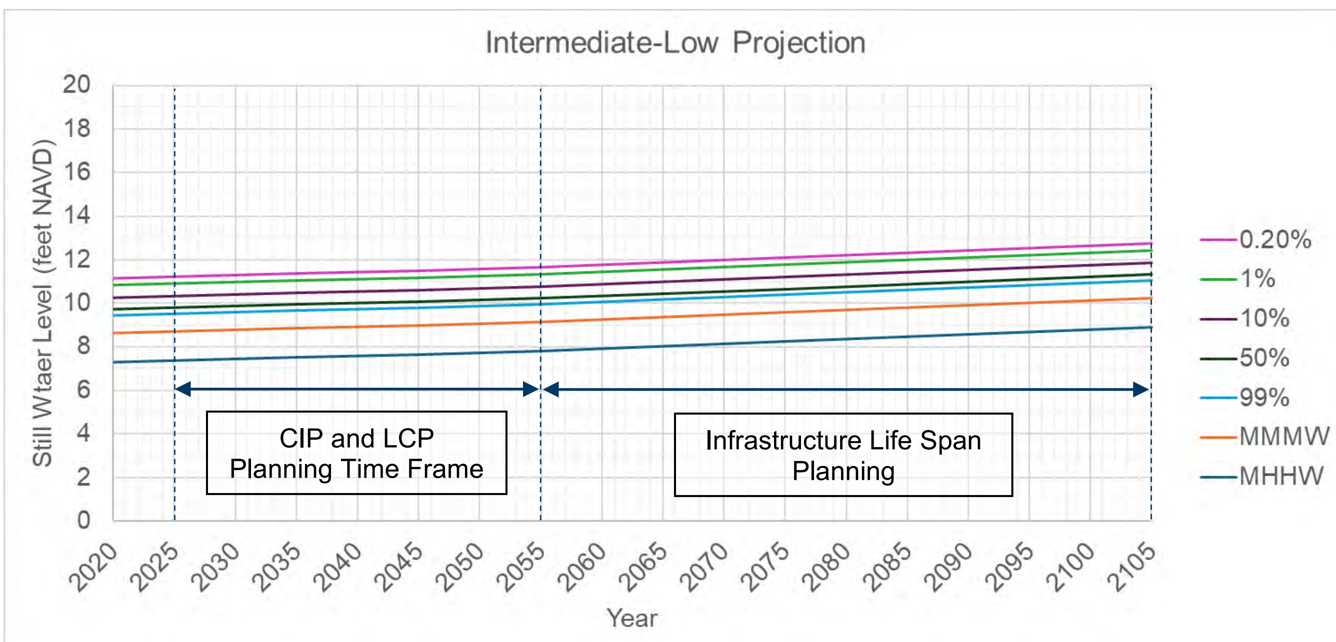


Figure 10 *Still Water Datums and OPC Intermediate SLR Projection (Lower Bound of Most Likely Range of SLR by 2100).*

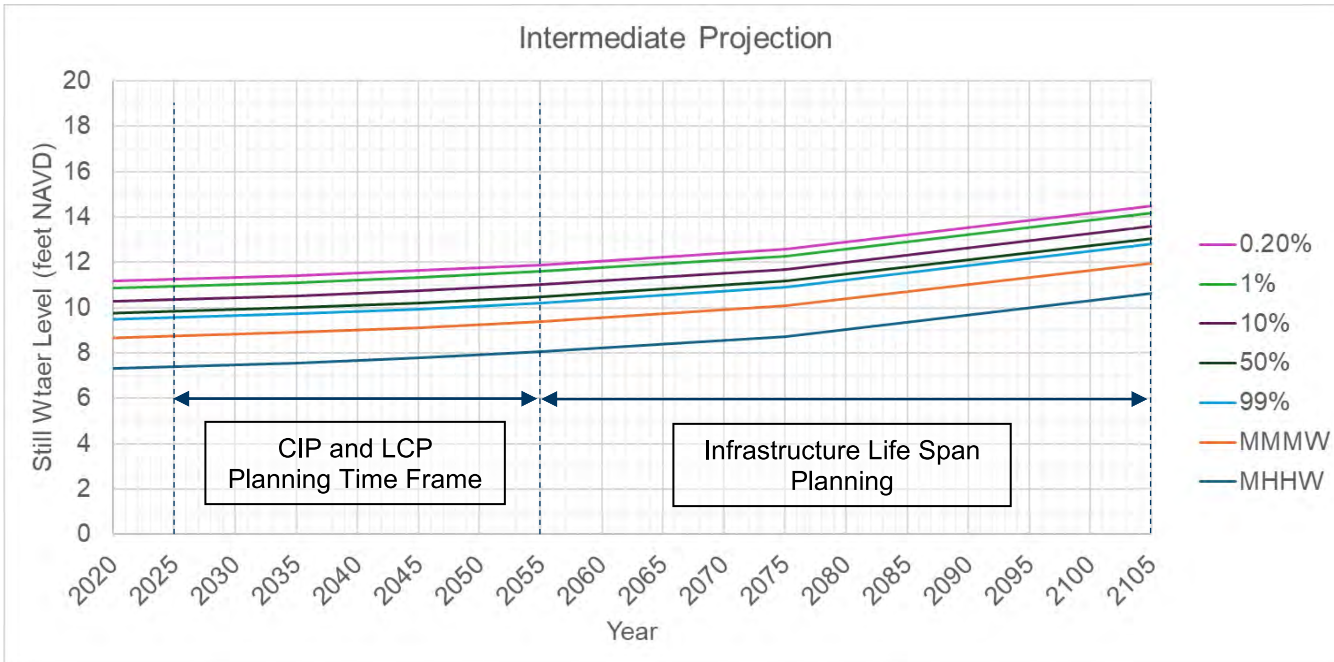


Figure 11 ***Still Water Datums and OPC Intermediate SLR Projection (Upper Bound of Most Likely Range of SLR by 2100).***

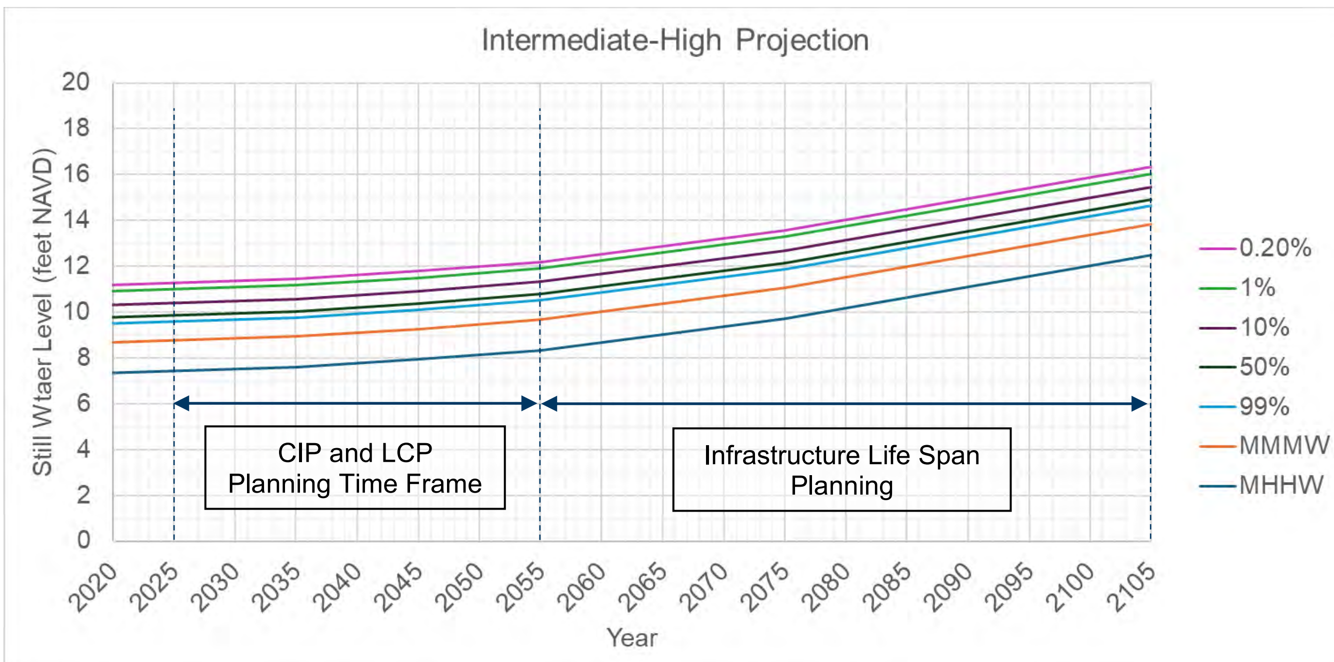


Figure 12 ***Still Water Datums and OPC Intermediate-High SLR Projection (Plausible High-End Projection by 2100).***

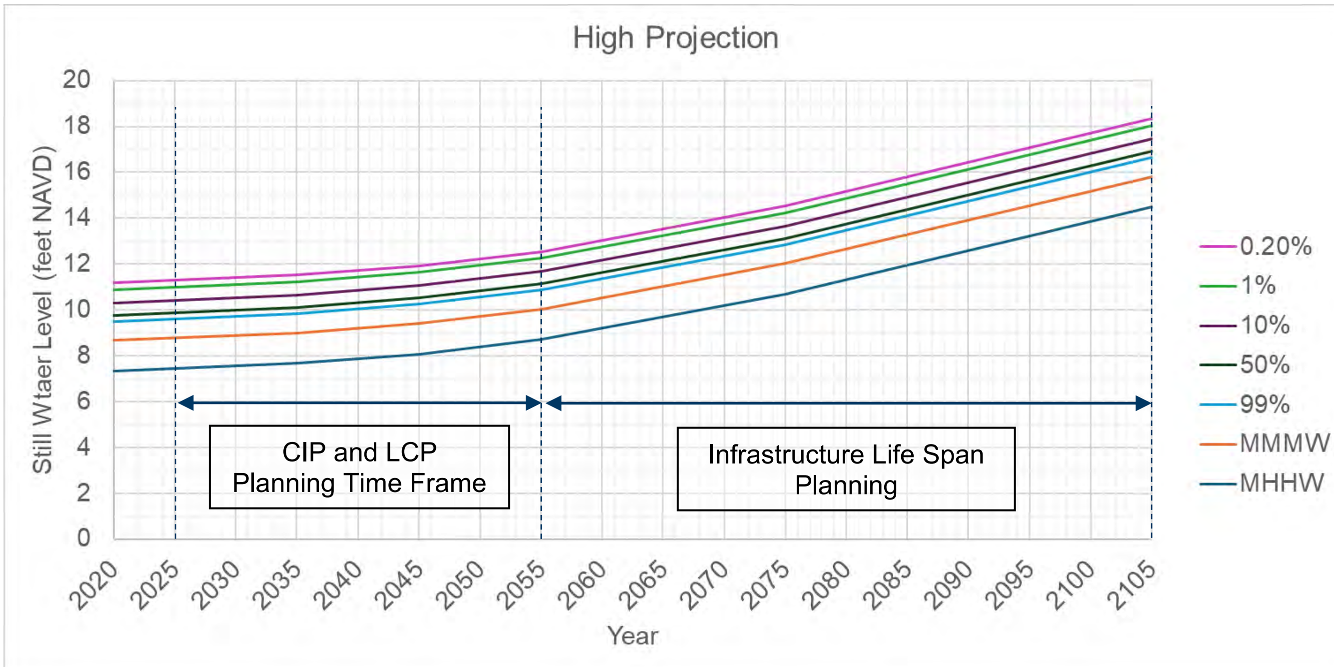


Figure 13 Still Water Datums and OPC High SLR Projection (the likelihood of reaching this scenario is highly implausible by 2015).

As presented in Figure 9 through Figure 13, for each SLR scenario, there is a corresponding range of still water levels that may occur due tidal and storm surge events. The events presented vary from the expected 1-year high water level (99% probability estimate) up to the 500-year high water level event (0.2% probability estimate). When planning and designing new infrastructure facilities, design standards created by governing agencies often identify a flood event that the new facility must be designed around for flood resiliency. For example, the 1% annual chance (100-year return event) flood elevation is commonly used for critical infrastructure, such as levee protection systems or electrical facilities serving critical infrastructure. A factor of safety by providing additional freeboard is then incorporated to accommodate uncertainties and contingencies. Further discussion of design standards and impacts of high-water events on specific facilities can be found in Section 8.5.

5.4 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 (U.S. Geological Survey, 2019). The application is used to calculate 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 Beith, Campbell, Grotzman, Jacoby, Janes, and Jolly Giant Creeks and are shown in Table 7. The peak flow events were then used to develop hydrographs to model fluvial flood events.

Table 7 Peak flows for creeks of interest

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

The Streamstats Application is used to calculate the current peak flow event for a watershed based on previously recorded precipitation events. However, future precipitation events are expected to become more frequent and severe due to climate change, potentially changing the recurrence interval peak flow events for the watersheds in the Study Area, and hence Streamstats may underestimate future peak flow events if precipitation events used in the analysis are not adjusted.

5.5 Increased Precipitation Due to Climate Change

To account for the impact of climate change on peak flow events, Cal-Adapt climate change modeling scenarios were used to adjust the 2-year, 10-year and 100-year precipitation events. Cal-Adapt provides peer-reviewed data that portrays how climate change might affect California at the state and local level. The adjusted precipitation events were then used a proxy to estimate the increase in peak flow events. Projections for increases in rainfall intensity for multiple emissions scenarios are described below:

– RCP 4.5 (medium emissions scenario): a scenario where greenhouse gas (GHG) emissions peak by 2040 and then decline.
– RCP 8.5 (high emissions scenario): a scenario where global GHG emissions continue to rise throughout the 21st century.

Each scenario also includes four global climate model conditions, as described below:

– A “warmer/drier” simulation (HadGEM2-ES)
– A “cooler/wetter” simulation (CNRM-CM5)
– A “dissimilar” simulation that is most unlike the other three, to produce maximal coverage of possible future climate conditions (MIROC5)
– An “average” simulation (CanESM2)

The “average” simulations under each scenario were selected to evaluate a potential range of potential future increases to precipitation, as shown in Table 8. 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. These relative changes in recurrence probabilities, are used in this study to estimate changes in likelihood of peak flows, as an estimate of future conditions.

Table 8 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	2.7 - 2.8 (13% – 17%)	3 - 3.2 (25% - 33%)
10-year	3.0	3.6 - 3.8 (20% - 27%)	4.8 - 5 (60% - 67%)
100-year	3.8	4.9 - 5.2 (29% - 37%)	8.2 - 8.5 (116% - 124%)
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) to High Emissions (RCP 8.5) Scenarios. 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)			

5.6 Compound Frequency

Along much of the U.S. Pacific Coast, which includes the Study Area, storm systems that produce extreme coastal surge events are typically different from the 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 investigate 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 14).

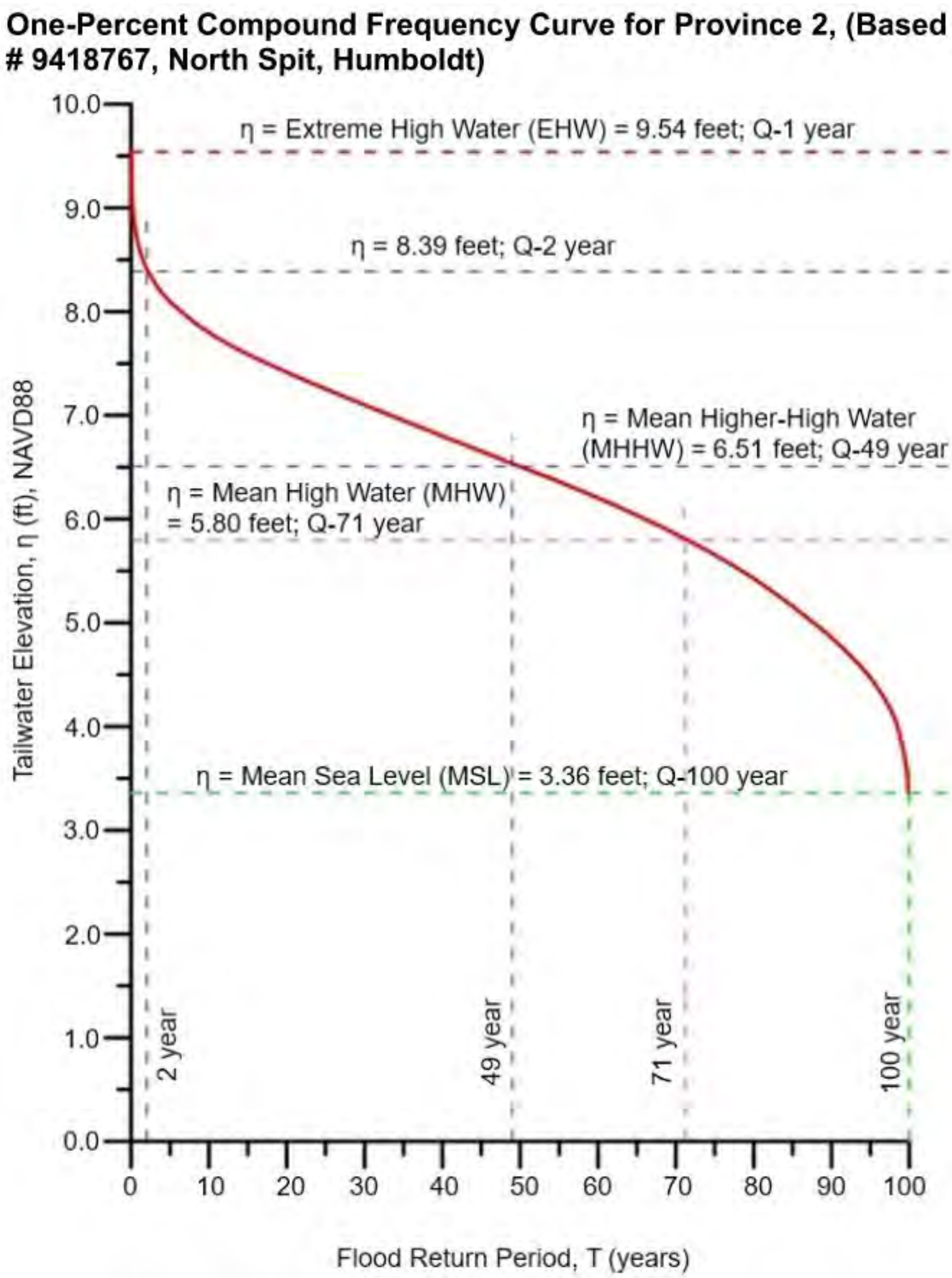


Figure 14 One-percent compound frequency curve for Humboldt Bay North Spit (Caltrans, 2020).

This compound frequency curve is the result of the product of each independent probability at the time of curve development. Assuming the general independence of the two parameters will persist into the future, for the purposes of this study, future probabilities previously described may be multiplied together to estimate future compound frequency within the Study Area.

5.7 Groundwater

The groundwater level in a coastal aquifer system fluctuates with the tide periodically (Guo, Liu, Zhu, & Dai, 2024). Increases in groundwater elevation within the Study Area are expected due to gradual SLR and changes of coastal processes such as erosion and shoreline retreat impacting inflows into the unconfined aquifer beneath the Study Area (Jiao & Post, 2019). Groundwater rise is the vertical movement of groundwater due to SLR (Bosserelle, Morgan, & Hughes, 2022). Groundwater rise depends on several factors, including the rate of SLR, connectivity to shallow groundwater through geological and geomorphological settings, topographic/hydrographic context, and infrastructure systems that affect the urban environment (Bosserelle, Morgan, & Hughes, 2022). The United States Geological Survey (USGS) Coastal Storm Modeling System (CoSMoS) reports estimated existing and future groundwater conditions in their Our Coast Our Future web tool (Hazard Map – Our Coast, Our Future (wpengine.com)). Existing groundwater in the Study Area is shown to generally be within 3.3 feet (one meter) of the ground surface. The model utilizes a range of steady-state conditions to bracket the range of likely groundwater levels with lower bound of local mean sea level (LMSL) and upper bound of MHHW (Befus, Hoover, Barnard, & Erickson, 2020). The rate of groundwater rise as a result of SLR can be influenced by several factors, such as local topography, soil composition, and the presence of rivers and streams (May, 2020). Our Coast Our Future web tool provides estimated areas of depth to groundwater based on groundwater geology and SLR increments (Figure 15 through Figure 17). The "Moderate" groundwater geology was selected based on the documentation to use this as a starting point to screen for potential groundwater hazards.

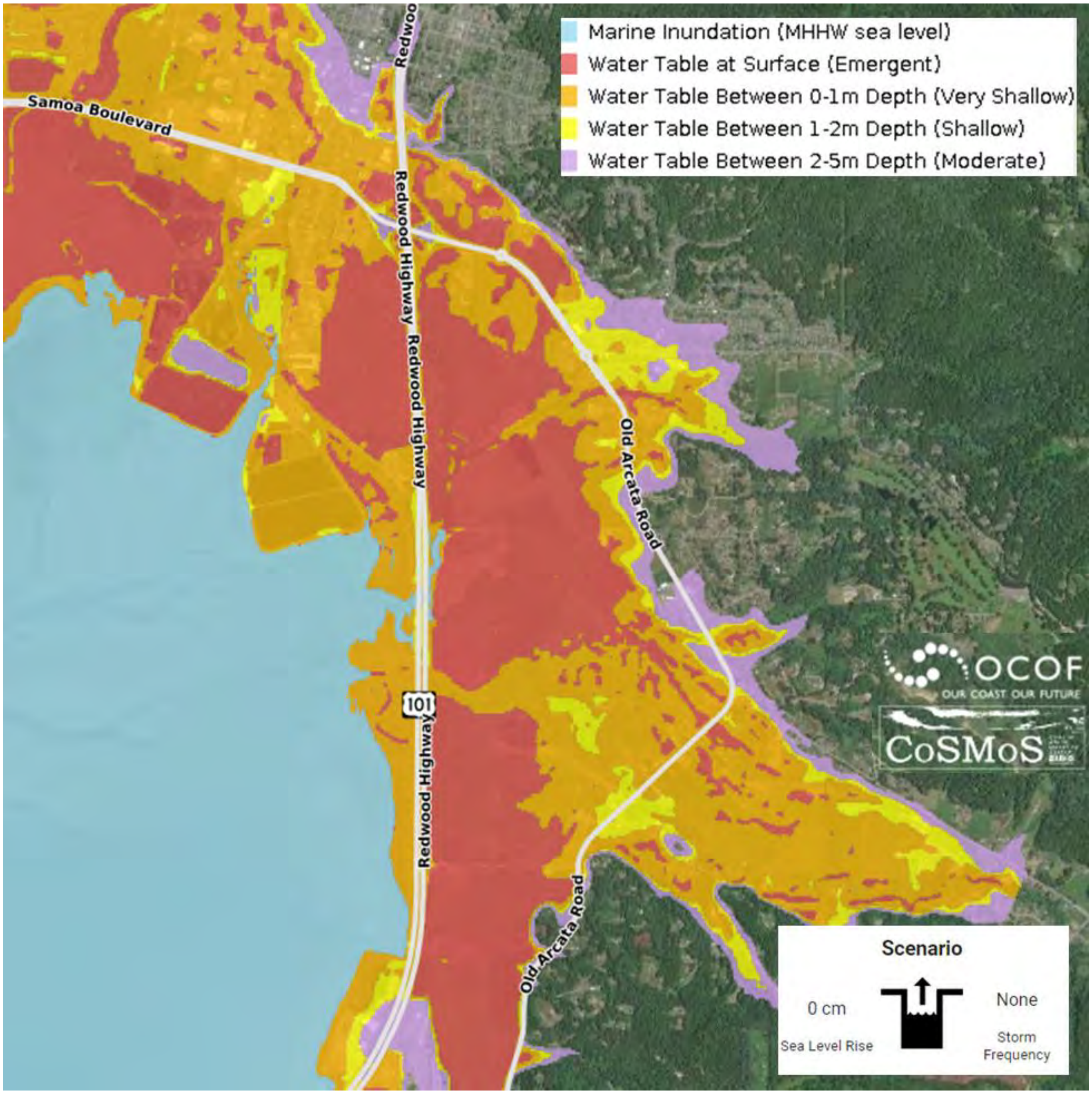


Figure 15 ***Estimated groundwater depth shown in Our Coast Our Future web tool (Hazard Map – Our Coast, Our Future (wpengine.com)) for "Moderate" groundwater geology, 0 cm of SLR and no storm conditions.***

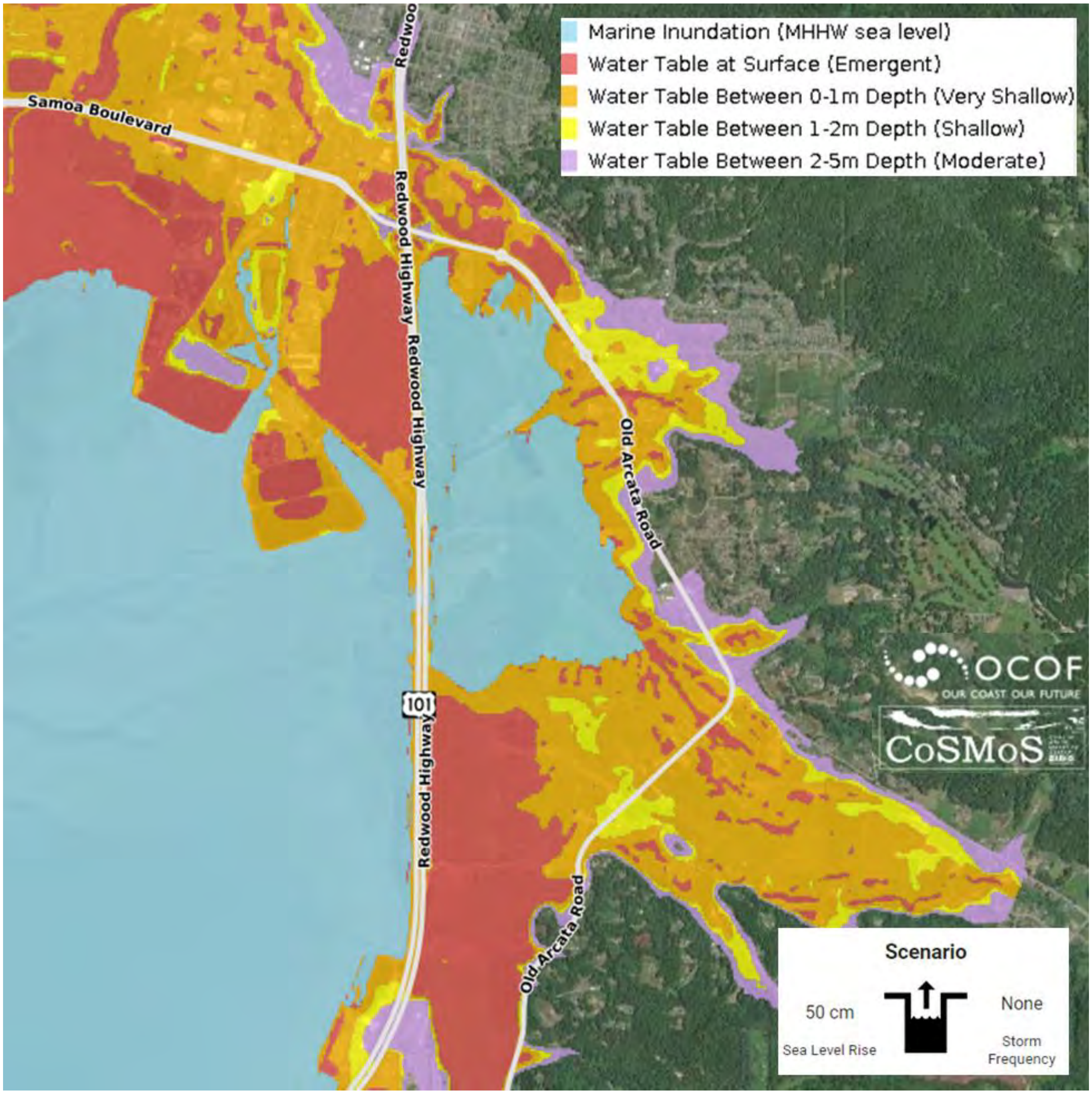


Figure 16 ***Estimated groundwater depth shown in Our Coast Our Future web tool ([Hazard Map – Our Coast, Our Future (wpengine.com)]) for "Moderate" groundwater geology, 50 cm of SLR and no storm conditions.***

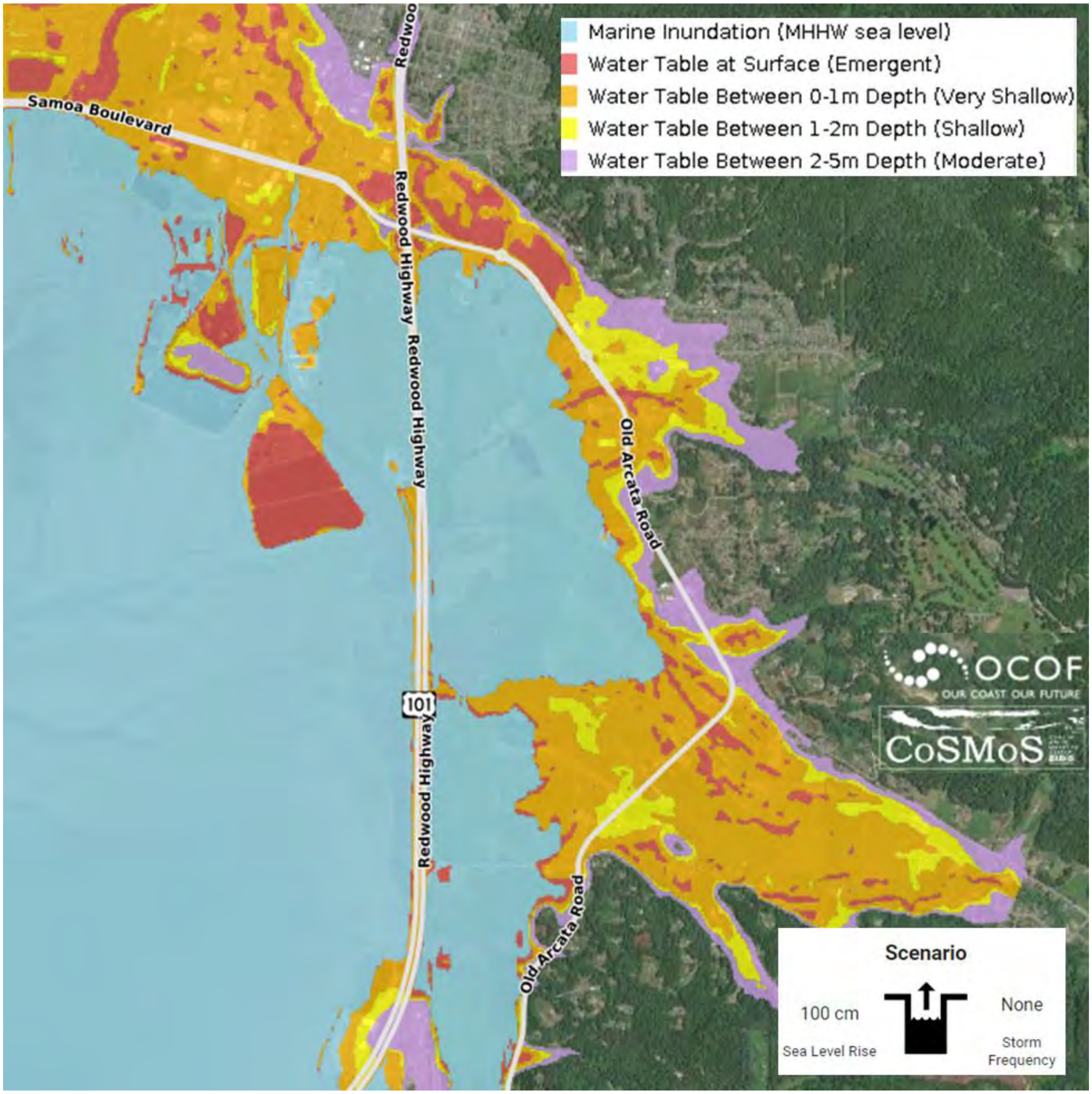


Figure 17 ***Estimated groundwater depth shown in Our Coast Our Future web tool ([Hazard Map – Our Coast, Our Future (wpengine.com)]) for "Moderate" groundwater geology, 100 cm of SLR and no storm conditions.***

As presented in Figure 15 through Figure 17, emergent and high groundwater levels are currently found throughout the Study Area. Projected SLR will not significantly impact the groundwater design parameters for future infrastructure as assets in the Study Area are currently impacted by high groundwater. However, emergent groundwater and tidal inundation will reduce overall drainage in the Study Area. Future discussion of the impacts of groundwater on the vulnerability of assets can be found in Section 8.7.8.

6. Modeled Coastal Flood Scenarios

The interaction between fluvial flows and tidal water levels is a complex and dynamic process. Tides cause regular fluctuations in water levels within the Bay and slough channels. Fluvial flows are conveyed by creeks to slough channels and the Bay. The combination of tidal water level and fluvial flow can result in varying effects on channel conveyance capacity, flood patterns, and flood elevations. Coastal flood scenarios were developed to evaluate a range of hydraulic conditions consisting of tidal water levels and fluvial flows combinations that could reasonably affect the Study Area. This segment of the memorandum is based upon the coastal scenario modeling described in the *Hydraulic Model Technical Memorandum*, provided as Appendix B of this report.

HEC-RAS is a computer simulation program designed 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.

Seven tidal, three fluvial, and one combined extreme tidal and fluvial model scenarios were performed. Tidal scenarios consisted of peak water levels between 9.5 feet and 13.7 feet, representing the current approximate 2-, 10-, 100-, and 500-year extreme events and potential future events resulting from multiple feet of SLR. Fluvial boundary conditions for these scenarios consisted of a constant flow of 1 cfs. Fluvial scenarios consisted of the existing approximate 2-, 10- and 100-year stream flows with a tidal boundary condition with a peak of 8.5 feet (MMMW) coincident with the peak fluvial flow. A combined event of the coincident 10-year fluvial and tidal peak of 9.5 feet (2-year tidal) was also completed (Table 9). Likelihoods of the scenarios are reported for existing and three planning horizons for the OPC Intermediate SLR projection and Cal-Adapt Medium Emissions (RCP 4.5 and RCP 8.5) Scenario.

The number of scenarios and range of water levels were increased from those originally scoped to evaluate incremental increases in flooding and likelihood to inform the identification of thresholds for which flooding progresses from more typical wet winter conditions, to reduced service of a given asset, to damage and the potential need for replacement.

Table 9 Modeled scenarios utilized in analysis.

Scenario	Fluvial Boundary Condition	Tidal Boundary Condition	Likelihood (Chance of Occurrence per Year)			
			2024	2055	2075	2105
1	1 cfs base flow	peak 9.5 feet	2-in-3	1-6/year	>1/Month	Daily
2	1 cfs base flow	peak 10.1 feet	1-in-10	1-6/year	6/year	Daily
3	1 cfs base flow	peak 10.7 feet	1-in-100	1-in-3	1-6/year	Daily
4	1 cfs base flow	peak 11.1 feet	1-in-500	1-in-10	2-in-3	Daily
5	1 cfs base flow	peak 11.7 feet	<1-in-500	1-in-125	1-in-10	Daily
6	1 cfs base flow	peak 12.7 feet	<1-in-500	<1-in-500	<1-in-500	Daily
7	1 cfs base flow	peak 13.7 feet	<1-in-500	<1-in-500	<1-in-500	Daily
8	2-year	MMMW	1-in-2	>1-in-2	>1-in-2	>1-in-2
9	10-year	MMMW	1-in-10	1-in-6	1-in-4	1-in-2
10	100-year	MMMW	1-in-100	1-in-10	1-in-6	1-in-3
11**	10-year	peak 9.5 feet	1-in-7	1-6/year	>1/Month	Daily
*Likelihood based on existing likelihood and OPC 2024 Intermediate SLR projection and Cal-Adapt Medium Emissions (RCP 4.5) Scenarios **Compound frequency estimated based on product of fluvial and tidal likelihood						

7. Capital Improvement Program

7.1 Critical Assets

The CIP is a long-term, multi-year planning tool that identifies the construction, repair, and replacement of major City assets. The planning period for CIPs is typically 20 to 30 years, with consideration of longer-term infrastructure life span (typically up to 50 years). A CIP planning time frame from 2025 to 2055 and an infrastructure lifespan of up to 50 years was utilized for this assessment, resulting in SLR and precipitation scenarios to 2105. This assessment will be used to inform the identification and prioritization of future project needs to allow enough time to fund, plan, permit, design and implement projects. The City's assets and infrastructure within the Study Area are the focus of the vulnerability and risk analyses. Critical infrastructure includes the following City infrastructure:

- Shoreline Protection
- Roads
- Trails
- Water Distribution System
- Wastewater Collection Piping
- Wastewater Lift Stations
- Wastewater Treatment Facilities

Private utilities such as gas, electricity, communications, as well as privately owned lands, structures, and facilities, were not included in the analysis. State and Federal roads and highways such as Highway 101 and State Route 255 (not under City jurisdiction) were also not included in the analysis. City infrastructure within the Study Area that is potentially vulnerable to existing and future tidal and fluvial flooding is further discussed in the sections below.

7.1.1 Shoreline Protection

The Study Area just inland of the shoreline is protected by linear features such as levees (earthen fill, old railroad prisms), roads, and other miscellaneous fill prisms which create elevation barriers to tides in Humboldt Bay and along slough channels. Additional elevation barriers exist inland of the shoreline and provide additional barriers to overland flow. Primary elevation barriers, generally categorized as levees (any linear fill feature) are shown in Exhibit 1.1 in Appendix C. Trinity Associates mapped and quantified shoreline infrastructure along Humboldt Bay and slough channels within the Study Area, as shown in Table 10. Shoreline structures generally vary in elevation from 9 to 12 feet as shown in Exhibit 1.1 through Exhibit 1.7 in Appendix C. The lowest lengths of shoreline structures are overtopped by a water level of 9.5 feet, and nearly all shoreline structures are overtopped by a water level of 12.7 feet.

Table 10 Shoreline infrastructure in the Study Area (Trinity Associates, 2018).

Shoreline Protection Structure	Length of Shoreline (miles)
Wastewater Pond/Marsh Dikes	1.9
Fill	1.8
Railroad Grade	1.1
Dike	1.0
Roads	0.8
Total	6.6

7.1.2 Roads

Roads within the Study Area and under the City of Arcata jurisdiction include multiple road function classifications based on the type of service the road provides (Federal Highway Administration, 2000). Table 11 provides descriptions of each classification, example roadways and the total length of roadway by classification which are included in the Vulnerability Assessment.

Table 11 Roadway Classifications and Length within Study Area.

Road Classification	Examples	Length (miles)
Arterials - freeways, multilane highways, and other important roadways that supplement the Interstate System	Samoa Blvd	1.8
Collectors - major and minor roads that connect local roads and streets with arterials	Old Arcata Rd Samoa Blvd	6.5
Local Roads - Limited mobility and are the primary access to residential areas, businesses, farms, and other local areas.	S. G St 2nd St Front St	7.1
	Total	15.4

7.1.3 Trails

Trails are used for recreation and active transportation within the Study Area. The seven trails in the Study Area which cover a total length of 7.7 miles are presented in Table 12. The trail system within the Arcata Marsh and Wildlife Sanctuary typically exhibits a “soft surface” such as gravel or soil for pedestrian foot-traffic, while the other trails are paved and support a wider range of mobility such as foot-traffic and bicyclists.

Table 12 Trails within the Study Area.

<table>
<tr><th>Trail Name</th><th>Length (Miles)</th><th>Trail Type</th></tr>
<tr><td>Arcata Marsh and Wildlife Sanctuary</td><td>3.8</td><td>Soft Surface (Gravel/Earthen)</td></tr>
<tr><td>Community Center to 7th Street</td><td>0.1</td><td rowspan="6">Hard Surface (pavement)</td></tr>
<tr><td>Dr Martin Luther King Jr Parkway to Samoa Blvd</td><td>0.1</td></tr>
<tr><td>Humboldt Bay Trail - North</td><td>1.8</td></tr>
<tr><td>Rail With Trails - Phase 1</td><td>0.2</td></tr>
<tr><td>Samoa Blvd Path-North Side</td><td>0.5</td></tr>
<tr><td>Samoa Blvd Path-South Side</td><td>1.2</td></tr>
<tr><td>Total</td><td>7.7</td><td></td></tr>
</table>

7.1.4 Water Distribution System

The water distribution system with the Study Area is comprised of main service lines, laterals, and associated valves and fire hydrants. Water distribution lines and components are primarily located within the roadway right of way. The distribution system within the Study Area consists of approximately 12.6 miles of water lines Table 13. Water distribution pipes are typically buried a minimum of 2.5 feet below ground surface (City of Arcata, 2023).

Table 13 Water distribution lines within the Study Area.

Water Line Type	Total Length (Miles)
Fire Hydrant Lateral	0.3
Fire Line	<0.1

Water Line Type	Total Length (Miles)
Main Line	11.4
Service Lateral	0.7
Total	12.6

7.1.5 Wastewater Collection Piping

The wastewater collection system piping is comprised of gravity mains and manholes, pressure mains and reclaimed water distribution lines with total lengths in the Study Area shown in Table 14. Manholes are located throughout the system to provide access for maintenance. A total of 168 manholes are located within the Study Area, as tabulated in Table 15. Similar to the water distribution system, wastewater collection pipes and manholes are primarily located within the roadway right-of-way. Wastewater collection system pipes are typically buried a minimum of 2 feet below ground surface (City of Arcata, 2023).

Table 14 Wastewater collection pipes within the Study Area.

Wastewater Collection System Pipes	Total Length (Miles)
Gravity Main	9.8
Pressure Main	3.5
Reclaimed Water Distribution	1.7

Table 15 Wastewater collection manholes within the Study Area

Wastewater Collection System Component	Total Number
Manholes	168

7.1.6 Wastewater Lift Stations

Seven lift stations are located within the Study Area and are generally comprised of a concrete slab, enclosures or buildings, pumps in a wet well, electrical components, and some stations are equipped with backup power supply generators. Lift station are located at a range of elevations within the Study Area. Electrical equipment is typically located one to three feet above adjacent ground elevations, as shown in Table 16.

Table 16 Wastewater lift stations within the Study Area.

Lift Station Name	Adjacent Ground Elevation (feet)	Electrical Equipment Elevation (feet)
Samoa Lift Station	14.1	15.3
First St Lift Station	10.3	13.3 (Electrical) 11.8 (Backup Generator)
Meadowbrook Lift Station 1	13.3	14.9
Bayside Gables Lift Station	21.5	22.3
Bayside Lift Station #1	35.6	36.1
Bayside Lift Station #2	35.2	36.7

7.1.7 Wastewater Treatment Facilities

The City of Arcata is currently constructing Phase One of the Arcata Wastewater Treatment Plant (AWTF) Improvement Project that is replacing aging infrastructure, reconfiguring to a single pass flow through the treatment facility and enhancement marshes, upgrading the disinfection system to ultraviolet light and developing a new treated effluent outfall location. As a part of the Phase One Improvements, electrical equipment, backup power supplies and other critical facilities are being elevated as shown in Table 17. Elevations of existing facilities that are related to treatment and operation are listed in Table 18.

Table 17 Wastewater treatment essential facilities.

Essential Facilities	Grade Elevation (feet)	Top of Slab Elevation (feet)	Electrical Equipment Elevation (feet)
Perimeter Levee	Lowest 10-11 Typical 11-14	NA	NA
Headworks	10-11	11.0	NA
Top Deck	-	22.4	24.0
Lower Grit Pump Area	-	6.8	14.0
Primary Clarifier No. 2	10	16.7	14.0
Pond Pump Station & Pump Station No. 1	11	11.4	14.0
Emergency Pond Pump Station	11	11.9	14.0
UV & Chlorine Contact Basins	11	15.7	14.0
Enhancement Wetlands Pump Station	14.4	14.9	14.0
Generator Building	10	10.4	12.4
Electrical Building	13	13.3	14.0
Oxidation Ponds	10.5 – 13.0	NA	NA
Treatment Wetlands	10.0 -12.5	NA	NA
Enhancement Marshes	10.0 -12.5	NA	NA

Table 18 Wastewater treatment and operations facilities.

Other Treatment and Operations Facilities	Feature	Grade Elevation (feet)
Interior Site and Facility Access	Various Driving Paths/Roads	~9.5-10.5
Office Facilities	Adjacent Grade	~9.8
Sludge Drying Beds	Adjacent Grade	~10.2

7.2 Reference Flood Design Criteria

Engineering design criteria serve as guidelines and benchmarks for developing and evaluating engineering projects. Some key purposes include:

- **Promote Safety:** Help identify and mitigate potential hazards, protecting users and the environment.
- **Meet Regulatory Standards:** Design criteria align projects with local, national, and international regulations and standards.
- **Achieve Functionality:** Define the necessary functions and performance requirements
- **Facilitate Communication:** Clear criteria help communicate expectations and requirements.
- **Guiding Decision-Making:** Provide a framework for making informed decisions throughout the design process.
- **Optimize Resources:** Criteria help in the efficient use of materials, time, and budget, leading to cost-effective solutions.
- **Quality:** Help meet the desired quality and reliability standards.

The City of Arcata Title VIII Building Regulations Chapter 4, Flood Hazard Mitigation Standards guide development in flood prone areas of the City jurisdiction. City guidance requires any development to be designed around a Base Flood Elevation (BFE), a Federal Emergency Management Agency (FEMA) term referencing the elevation of surface water resulting from a flood that has a 1% chance of equaling or exceeding that level in any given year (FEMA, 2024). For example, all new construction of residential and commercial buildings in the City must be elevated a minimum of 1-foot above the FEMA BFE (City of Arcata, 2016). The BFE may or may not be applied to other assets, such as roadways and piping systems. This section provides reference design criteria for each asset type listed below are summarized in Table 19 and described in the following subsections.

Table 19 Reference Design Standards for Critical Assets

Asset	Reference Flood Design Criteria
Shoreline Protection	< 1% Annual Chance of Overtopping + Minimum Freeboard 0.3-2 foot (Levee or Dike height 0-6 feet) (USDA, 2022) 2 feet (Levee or Dike height 6-12 feet) (USDA, 2022) 3 feet Minimum Freeboard (FEMA Accredited) (FEMA, 2021)
Roads	Drainage Design (Winzler & Kelly, 1994) <10% Annual Chance of Stormdrain Surcharge < 4% Annual Chance of Flooding Outside of Roadway <1% Annual Chance of Flood Damage to Adjacent Structures
Trails	No reference design criteria found. Assume: < 4% Annual Chance of closure associated with 6 inches or more of Flooding Depth
Water Distribution System	No references for flood design. Based on asset sensitivity, many of these pipes exist in areas of high seasonal groundwater and flooding would not significantly affect the operation of these facilities. Consideration may be given to corrosivity of subsurface environment.
Wastewater Collection Piping	No references for flood design of pressure mains. No references for flood design of gravity pipes and manholes.
Wastewater Lift Stations	Minimum Lowest Floor Elevation (ASCE, 2015): <1% Annual Chance + 1 ft Freeboard Minimum Elevation of Utilities and Equipment (ASCE, 2015):: <1% Annual Chance + 1 to 2 ft Freeboard
Wastewater Treatment Facilities	Minimum Lowest Floor Elevation (ASCE, 2015): <1% Annual Chance + 1 ft Freeboard Minimum Elevation of Utilities and Equipment (ASCE, 2015):: <1% Annual Chance + 1 to 2 ft Freeboard Minimum Elevation of Shoreline Protection < 1% Annual Chance of Overtopping + Minimum Freeboard 2 feet (Levee or Dike height 6-12 feet) (USDA, 2022)

7.2.1 Shoreline Protection

The Natural Resources Conservation Service (NRCS) provides design standards for determining dike and levee classification include purpose; potential hazard to life; design high water height; value of the protected land, crops, and property; and land use changes likely to occur over the life of the dike or levee (USDA, 2022). FEMA provides design criteria as a part of obtaining accreditation that is recognized in Flood Insurance Rate Maps (FEMA, 2021).

7.2.2 Roads

The City of Arcata does not have specific design criteria related to the flooding of roadways. The nearby City of Eureka, which is in a similar hydrologic setting as Arcata, has an informal policy reported in the Stormdrain Master Plan that requires stormwater facilities to pass a 10-year (10% annual chance) storm with no surcharge or flooding of any portion of the travel lanes (Winzler & Kelly, 1994). A 25-year (4% annual chance) storm should be contained within the street with no overtopping of curbs. A 100-year (1% annual chance) storm should not cause major flood damage to any structures.

7.2.3 Trails

Specific design criteria for acceptable trail flood likelihood could not be found. An estimation of flooding that renders a trail unpassable, is six inches. A likelihood of a 25-year (4% annual chance) storm will be used for this analysis.

7.2.4 Water Distribution System

Specific design criteria for acceptable flood likelihood for mains is not common. Given the sensitivity of these assets to flooding is very low, no reference design criteria was selected in the evaluation of these assets and flood likelihood.

7.2.5 Wastewater Collection Piping

Specific design criteria for acceptable flood likelihood for mains and manholes is not common. Given the sensitivity of these assets to flooding is very low, no reference design criteria was selected in the evaluation of these assets and flood likelihood.

7.2.6 Wastewater Lift Stations:

ASCE 24-14 Flood Resistant Design and Construction provides standards for the elevation and freeboard (additional height above the National Flood Insurance Program’s base flood elevation) of minimum elevation of lowest floor (ASCE, 2015).

ASCE 24-14 Flood Resistant Design and Construction provides standards for the elevation and freeboard (additional height above the National Flood Insurance Program’s base flood elevation) of minimum elevation of utilities and equipment (ASCE, 2015). Utilities and equipment included in this study include electrical equipment.

7.2.7 Wastewater Treatment Facilities

ASCE 24-14 Flood Resistant Design and Construction provides standards for the elevation and freeboard (additional height above the National Flood Insurance Program’s base flood elevation) of minimum elevation of lowest floor (ASCE, 2015). Buildings included in this study include Lift Stations, Pump Stations, Electrical Buildings, Generator Buildings, and Office Buildings.

ASCE 24-14 Flood Resistant Design and Construction provides standards for the elevation and freeboard (additional height above the National Flood Insurance Program’s base flood elevation) of minimum elevation of utilities and equipment (ASCE, 2015). Utilities and equipment included in this study include electrical equipment for buildings (Pump Stations, Electrical Building, Office Building), in addition to treatment facilities including Headworks, Clarifiers, UV & Chlorine Contact Basins, Sludge Drying Beds.

Specific design criteria for acceptable flood likelihood for Oxidation Ponds, Treatment Wetlands, and Enhancement Marshes are not available. For the purposes of this study, evaluation of the protection of these treatment-related facilities will utilize levee and dike design standards, as these facilities are typically protected by these shoreline structures in the Study Area.

8. Vulnerability Assessment

The vulnerability assessment in this report builds on the findings of the 2018 City of Arcata Local Coastal Program Sea Level Rise Vulnerability Assessment (Trinity Associates, 2018), to provide additional detail to inform the Capital Improvement Projects (CIP) Adaptation Concept Plan. This updated vulnerability assessment provides additional detail on the likelihood, consequence, and duration of flooding to provide a more refined assessment to inform a risk assessment for critical infrastructure. The vulnerability assessment in this section is followed by the risk assessment in Section 7.

Vulnerability assessments are intended to help understand the potential impacts to people, natural resources and infrastructure due to drivers such as flooding and erosion. The main focus of this vulnerability assessment is the potential impacts to City-owned infrastructure resulting from a range of existing and future tidal and groundwater levels and stream flows. Impacts to people, natural resources, and other infrastructure can be inferred through the typical use of this infrastructure and hence are not specifically evaluated in this study. This part of the assessment answers the questions: *What is vulnerable to flooding?* and *When will it be vulnerable?* Applying the spatial and temporal components to the analysis is intended to inform planning of the City's capital improvement program to effectively plan infrastructure investments where and when they are most needed.

8.1 Framework

The vulnerability assessment framework follows the industry standard, as illustrated in Figure 18, from the Intergovernmental Panel of Climate Change's *Sensitivity, Adaptive Capacity, and Vulnerability* (IPCC, 2007) and described in the 2024 State of California Sea Level Rise Guidance document (OPC, 2024). The definitions of general key terms are shown in the box to the right.

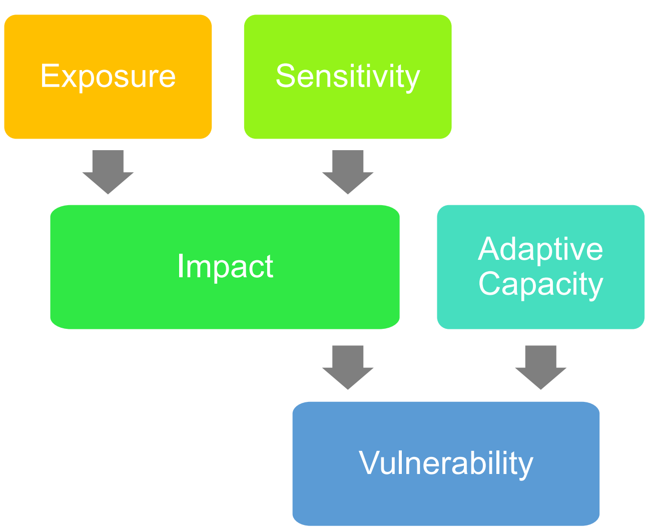


Figure 18 Vulnerability Assessment Framework (UNESCWA, 2014)

Key Terms

Critical Asset - A critical asset is an asset whose absence or unavailability would significantly degrade the ability of a utility to carry out its mission or would have unacceptable consequence for the owner or community (AWWA, 2010).

Exposure refers to the presence (location) of resources, infrastructure, or assets in places that could be adversely affected by physical events and which, thereby, are subject to potential future harm, loss, or damage (Lavell, 2012).

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise) (Lavell, 2012).

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Lavell, 2012; US EPA, 2017).

Vulnerability is the propensity or predisposition to be adversely affected. (Lavell, 2012).

8.2 Methodology

The vulnerability assessment was completed as follows:

- **Collect and model relevant hydroclimatic data**. This step is described in Section 1 of this memorandum.
- **Inventory of critical assets**. This information was provided by the City of Arcata and is comprised of shoreline protection structures and utility and transportation infrastructure. Additional information was obtained from previous studies; it was the starting point for this assessment.
- **Consideration of design criteria.** Information was collected from City of Arcata policies and standards, and other organizations that provide guidance on the development and evaluation of engineering projects**.**
- **Conduct a sensitivity analysis**. Site visits, observations from previous flood events, and engineering judgement were used to determine critical thresholds for the various asset types (or individually, as applicable). Critical thresholds represent the point at which there is a high potential for damage or need for closure of an asset.
- **Conduct an exposure analysis**. Utilize the results of a range of hydrodynamic modeling and available groundwater information to identify the extent, depth and duration of flooding to which critical assets are exposed.
- **Determine adaptive capacity**. Identify the existing and future flood event likelihoods, actions to moderate potential damages or cope with the consequences associated, and critical thresholds that limit these actions.
- **Determine vulnerability.** Identify the projected timing and frequency that impacts to assets may occur based on OPC SLR and CalAdapt precipitation projections.

8.3 Asset Sensitivity

Sensitivity is the degree to which the City owned infrastructure assets summarized above are impacted by increased water levels and flooding. The purpose of the sensitivity evaluation is to identify critical thresholds that differentiate the impact of varying flood depths or elevations on a given asset. Asset sensitivity thresholds were developed based on general observations during wet-weather conditions, historical flood events, and engineering judgment. Brief descriptions of each of the assets are provided below.

8.3.1 Shoreline Protection

Linear fill features have provided elevation barriers between the water bodies and low-lying lands of the Study Area for more than a century. The stability of these features is dependent on site-specific parameters such as composition of the fill material, geometry, presence of erosion protection (e.g., rip rap) and general condition, among others. Overtopping of a fill feature can result in erosion as water flows over the top of the feature and down a steepened slope as shown in Figure 19.

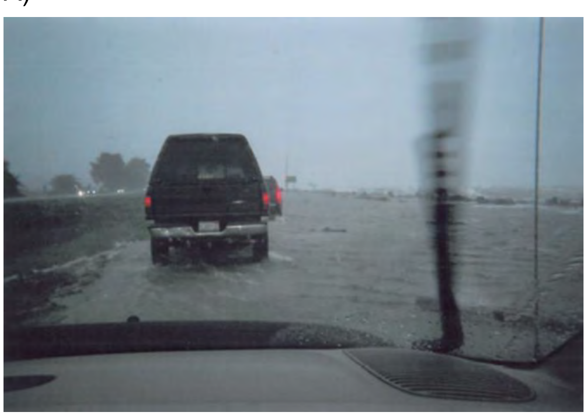
Figure 19 Observed erosion due to overtopping of fill prism.

Screening-level guidance is provided in the US Army Corps of Engineers, US Bureau of Reclamation, Federal Energy Regulatory Commission, Tennessee Valley Authority in their Overtopping Failure: Best Practices in Dam and Levee Safety Risk Analysis Part D – Embankments and Foundations Chapter D-3 presentation (USACE, USBR, FERC, TVA, 2017). This guidance suggests that overtopping of greater than 1 foot for greater than 2 hours has the potential to result in failure of the structure. Overtopping not meeting these conditions (less than 1 foot of overtopping depth or less than 2-hour duration) would be expected to potentially cause rill erosion, as observed in multiple locations around Humboldt Bay but with a lower likelihood of substantial damage compromising the integrity of the structure.

8.3.2 Roads

Flooding can affect roadways in multiple ways. Significant erosion and damage resulting from flooding have not been observed in reference areas. The December 31st, 2005 event that flooded Highway 101 along the eastern shore of Humboldt Bay and the January 13th, 2024 event that flooded several locations in Arcata along Jolly Giant and Janes Creeks as shown in Figure 20 below and were reviewed to estimate effects of roadway flooding.

A)



B)

Figure 20 Roadway flooding references A) December 31st, 2005 and B) January 13th, 2024.

The December 31st, 2005 event had an estimated 10.3 feet tidal water surface elevation within the Study Area that was a result of a combined tide of 9.5 feet and northwesterly winds with 2 to 5 foot wind waves. Based on photographs of the flooding of Highway 101, flood depths appear to be less than one foot, and vehicles were able to travel through, although at significantly reduced speed and the roadway was eventually closed to traffic. A review of Caltrans Damage Request forms provided by Caltrans did not indicate any funding requests associated with damage to the roadway, only for the cleanup of tree and vegetative debris.

The January 13th, 2024 event was the result of a combined high tide (observed peak water level of 8.5 feet at station 9418767, North Spit CA) and 10- to 15-year fluvial flow (McBain, 2024). The event resulted in several discrete areas of roadway flooding as a result of creek flows overtopping the channel banks. Based on photos of the event, flooding depths may have been as deep as approximately one foot, limiting access in some locations for lower clearance vehicles. No significant damage was noted by the City following the event, but staff time and cleanup were required to set signage and other features to limit access to certain areas and restore roadway access after flood water receded.

Based on the storm events reviewed above, the primary effects of flooding result in reduced access, roadway closure and impassable conditions. The City Streets Supervisor closes City streets when the roadway has water fully across the width. For the Vulnerability Assessment, roads are considered inaccessible when flooding exceeds one foot.

8.3.3 Trails

Similar to roadways, damage of paved trails due to flooding is not anticipated based on the response of the highway paved surface in the 2005 and the lack of observed damage to trails in the 2024 event. Depending on the location and characteristics of trail flooding, dangerous conditions could arise for pedestrians and bicyclists if high velocity flows across the trails are encountered. Flooding depth on trails greater than six inches is assumed to create dangerous conditions requiring closure of the trail. Flooding depth between three and six inches would be expected to significantly reduce access for users. Less than three inches of flooding is assumed to have limited effects.

8.3.4 Water Distribution System

Pressure mains are located subsurface throughout the Study Area. Many of these pipes exist in areas of high seasonal groundwater and flooding would not significantly affect the operation of these facilities. Increases in salinity may result in increased corrosion of ductile iron and other metal components resulting in reduced service life and increased frequency of maintenance and replacement. These facilities are not considered to be sensitive to flooding.

8.3.5 Wastewater Collection Piping

Similar to the water distribution system, pressure sewer mains are located subsurface in multiple locations of the Study Area. Many of these pipes exist in areas of high seasonal groundwater and flooding would not significantly affect the operation of these facilities. Increases in salinity may result in increased corrosion of ductile iron and other metal components resulting in reduced service life and increased frequency of maintenance and replacement. These facilities are not considered to be sensitive to flooding.

Similar to wastewater and water pressure mains, gravity wastewater mains and manholes are located subsurface throughout the Study Area. Many of these facilities are also located in areas of high seasonal groundwater resulting in increased wastewater flows and decreased capacity. The primary concern related to flooding of these facilities is sanitary wastewater overflows (SSOs) that diminish available conveyance in the system and could result in the discharge of untreated wastewater to the surrounding environment and regulatory fines. It is assumed that occasional flooding would be similar to existing larger storm events for which the City does not regularly experience SSOs. However, it was determined that if these occasional flood events were to occur more frequently (more than once per month), the continuous inundation of manholes would require action to seal, replace and / or relocate facilities and attend to any potential SSOs.

8.3.6 Wastewater Lift Stations

GHD conducted field inspections of wastewater lift stations to evaluate the sensitivity of these facilities to flooding. Lift stations may have a structure/building to house components or be a locking cabinet. Examples of lift station exteriors are shown in Figure 21 A and B. Lift station exteriors are located on concrete slabs. Flooding in and around these structures poses a risk to the functioning of the station if floodwaters come in contact with electrical panels or flood into conduits (Figure 21 C and D). Flooding below these components would result in cleanup and pose challenges to access during the flood event but would not be expected to result in damage or significant disruptions to service.

A)

B)

C)

D)

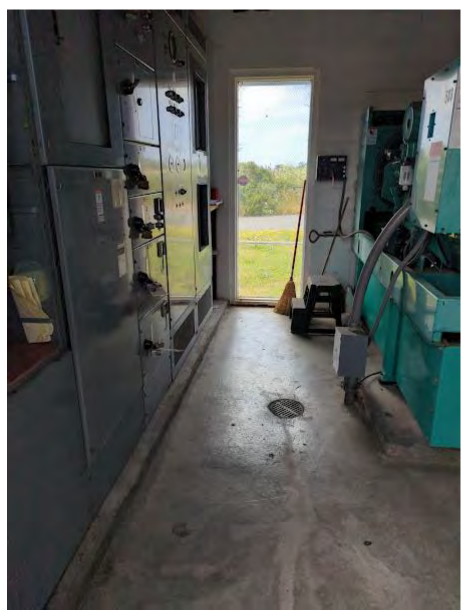


Figure 21 ***Typical lift station components consisting of A) lift station building on concrete slab B) lift station cabinet on concrete slab C) electrical panels and D) electrical panels and backup generators.***

8.3.7 Wastewater Treatment Facilities

GHD conducted field inspections of essential facilities listed previously in Section 7.1.7, Table 17 and other treatment and operations facilities listed Table 18, to evaluate the sensitivity of these facilities to flooding.

Essential Facilities

Essential facilities include the headworks, clarifiers, oxidation ponds, treatment wetlands, UV and chlorine contact basins, buildings housing generators, electrical equipment, oxidation ponds, treatment wetlands, and enhancement marshes. These facilities are protected by the perimeter levee (a shoreline protection feature described previously). Overtopping or flanking of the perimeter levee resulting flooding in and around these facilities poses a risk to the functioning of the treatment facility if floodwaters come in contact with electrical components or mix with active treatment processes (flooding into the headworks lower grit pump area, UV and chloring contact basin, or clarifiers) and discharges of inadequately treated wastewater to surface waters. Flooding below these components would result in cleanup and pose challenges to access during the flood event but would not be expected to result in significant damage or significant disruptions to service and treatment capabilities.

Tidal overtopping entering the oxidation ponds, treatment wetlands, or enhancement marshes would have the potential to reduce treatment effectiveness and the City's ability to meet discharge requirements in addition to the potential for causing the discharge of inadequately treated wastewater to surface waters. The oxidation ponds have potential additional exposure to wind waves and associated overtopping. However, given the size of the oxidation ponds (approximate 25 acres each) and the relatively small amount of discharge making it over the perimeter levee in temporary surges and into the oxidation ponds, significant impacts to treatment effectiveness would not be anticipated compared to that of still water overtopping.

Other Treatment and Operations Facilities

Other treatment and operations facilities include the interior access roads, office facilities and sludge drying beds. Flooding of the office building and access roads within the treatment facility grounds would reduce the City's ability to maintain normal operations and access and require clean up following flooding. Flooding of the sludge drying beds could result in improper discharge to surface waters.

8.4 Exposure Analysis

For this study, exposure characterizes the disposition of critical assets to coastal flooding scenarios extent, depth, and duration. Exposure accounts for existing topography and hydraulic structures that affect the conveyance and overland flow. Its purpose is to inform the evaluation of impacts to critical assets for a given coastal flooding scenario. The exposure analysis considers the following:

– Flooding Pathways, Depth and Duration
– Wind Setup and Wind Waves
– Groundwater

The results of the hydrodynamic modeling of coastal flood scenarios were used to identify flood pathways, depth and duration, locations of shoreline overtopping, and exposed transportation and utility infrastructure. The model results are shown in a series of Exhibits in Appendix C and general trends are discussed below:

– **Exhibits 1.1 through 1.11 Flooding Pathways:** show the locations of shoreline overtopping and associated depth and duration that may result in erosion or potential failure of the shoreline structure, maximum depth and extent of flooding, and flood pathways for each scenario.
– **Exhibits 2.1 through 2.11 Affected Transportation:** show the extent and depth of flooding with road and trail locations affected by flooding.
– **Exhibits 3.1 through 3.11 Affected Utilities:** show the extent and depth of flooding with water and wastewater lines, lift stations, and affected wastewater manholes.

8.4.1 Flooding Pathways, Depth and Duration

Flooding pathways are based on modeling of a range of tidal water levels and fluvial flows described previously. These water levels and flows represent current extreme (low likelihood) events that will become more frequent (increasing likelihood) in the future, based on OPC SLR and CalAdapt precipitation scenarios.

Flooding pathways and depths in Exhibits 1.1 through 1.11, show that initial tidal overtopping of the existing shoreline infrastructure will first occur along South G Street and Gannon Slough. Tidal water levels will propagate up Butcher Slough where low elevation pathways can result in flooding of additional areas of South G Street. As tidal water levels increase the extent of overtopping in these three locations expands. Isolated locations of the AWTF, Arcata Marsh and Wildlife Sanctuary, and interior levees in the agricultural fields east of Highway 101 begin to overtop when water levels exceed elevation 10.7 feet. Tidal overtopping along South G Street and Butcher Slough will result in flooding of South G Street, G Street and South I Street from multiple directions and flood depths in developed areas will begin to exceed 1 foot depth. When tidal water levels reach 11.7 feet, the majority of shoreline infrastructure adjacent to developed areas along South G Street and South I Street is overtopped, and flood depths will increase to one to three feet deep. Large areas of the agricultural fields will be flooded with three to six feet of tidal flow. As tidal water levels increase to 12.7 feet, the majority of the Study Area will be flooded.

Fluvial flooding events within the Study Area will primarily affect the agricultural lands east of Highway 101 and a culvert under the highway will convey flood water to the west, to the undeveloped areas near South G Street. Flooding from Janes Creek will primarily affect locations outside the Study Area while flooding from Jolly Giant Creek will result in flooding of developed areas near Highway 255/Samoa Boulevard. Fluvial flooding does not result in significant flooding (greater than 1 foot) of developed areas along South G Street, the AWTF or Arcata Marsh and Wildlife Sanctuary.

The combined event with a peak tidal water level of 9.5 feet and current 10-year fluvial flows results in similar flood patterns as each of the individual, independent events with moderate increases in flood depth along Butcher Slough and in the agricultural fields east of Highway 101. This scenario was selected for analysis based on similarities to the 2024 event and the reasonable likelihood of higher tidal events coinciding with storms that bring increased precipitation. The moderate increases are due to the reduced storage volume and conveyance area available within the stream channels and low elevation areas.

Flood duration was evaluated at four locations for each scenario for the duration of the model simulation period of 150 hours (Figure 22). These locations include South G Street where tidal flooding first occurs, the AWTF, South G Street near the First Street Wastewater Lift Station, and within the agricultural fields east of Highway 101. Flood duration for each of these locations, for each scenario is shown in Table 20. The flood duration is the total number of hours flooded during the event simulation period. The occurrence of multiple high tides similar to the peak elevation shown on the days preceding and following the peak and extreme low tides in between result in cycles of flooding and draining throughout the event simulation. As SLR increases the peak extreme tidal water level in addition to the low tide, draining capabilities are diminished, resulting in longer durations to flooding, as shown in water levels meeting and exceeding 12.7 feet.

Exhibits 2.1 through 2.11 show the roads and trails that are affected by flooding described above and Exhibits 3.1 through 3.11 show the water and wastewater utilities. Flooding impacts to these facilities are described in Section 8.7.

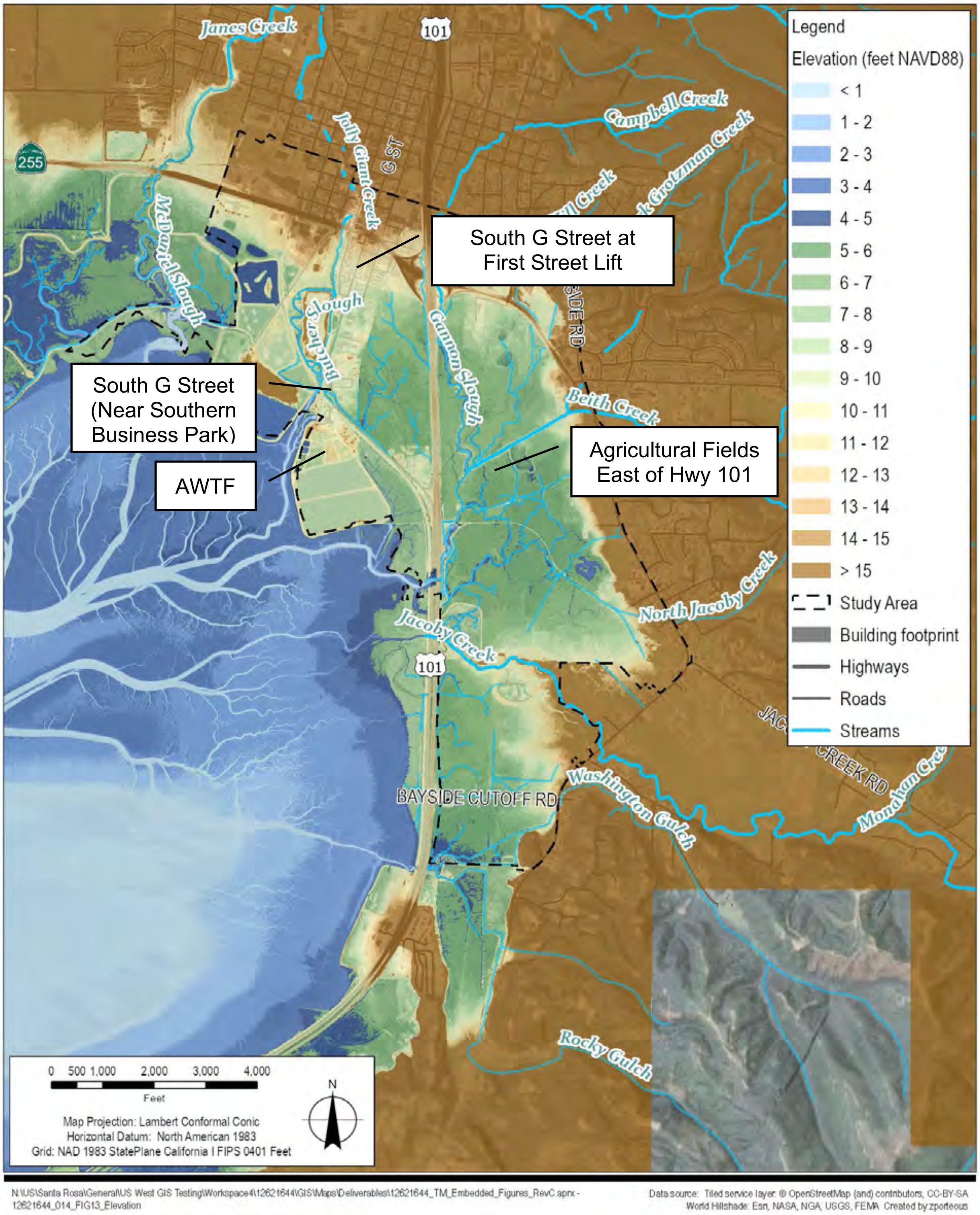


Figure 22 Locations evaluated for flood duration and ground elevations within the Study Area.

Table 20 Flood event duration during model simulation for each scenario.

Scenario	Fluvial Boundary Condition	Tidal Boundary Condition	Flood Event Duration (hrs)			
			Agricultural Lands East of Hwy 101	AWTF	South G Street (Near Southern Business Park)	South G Street (at First Street Lift Station)
1	1 cfs base flow	peak 9.5 feet	0	0	2	0
2	1 cfs base flow	peak 10.0 feet	4	0	6	0
3	1 cfs base flow	peak 10.7 feet	63	0	31	3
4	1 cfs base flow	peak 11.1 feet	91	31	33	7
5	1 cfs base flow	peak 11.7 feet	129	107	67	17
6	1 cfs base flow	peak 12.7 feet	131	131	115	39
7	1 cfs base flow	peak 13.7 feet	132	132	134	65
8	2-year	MMMW	17	0	0	0
9	10-year	MMMW	33	0	0	0
10	100-year	MMMW	34	0	11	0
11	10-year	peak 9.5 feet	34	0	5	0

8.4.2 Wind Setup and Wind Waves

The entirety of the shoreline within the Study Area is exposed to the effects of wind setup and wind waves. Wind setup, resulting in changes to the water levels due to local wind characteristics can be included in the tidal water levels and assumed to moderately change the likelihood of a given water level occurring. For example, the tidal water level of 10.7 feet could be a result of the current 50% annual chance water level of 9.6 feet and 1% annual chance wind setup event of 1.04 feet. However, the likelihood of both of these events coinciding cannot be determined without additional study.

The shoreline along the Study Area is also exposed to wind waves that have varying effects on the total water level and resulting overtopping. Total water level and wave runup has the greatest effect at the shoreline, resulting in temporary, intermittent splashing and effects are greatly reduced as facilities or observers are located farther from the immediate shoreline. For example, a vehicle traveling on the AWTF perimeter levee near the oxidation ponds during an extreme wind wave event may be exposed to the splashing forces of waves, but vehicles traveling on South G Street would not. Wind waves would be expected to cause regular erosion of unprotected shoreline features.

8.4.3 Groundwater

The estimated depth to groundwater in the Our Coast Our Future web tool, shown previously in Figure 15 through Figure 17, shows much of the areas developed on fill within the Study Area exhibiting groundwater within 0 to 3.3 feet (0 to 1 meter) of the ground surface. Lower-lying, undeveloped agricultural areas along Highway 101 exhibit emergent groundwater. With 1.6 feet (0.5 meters) of SLR, the lowest-lying undeveloped agricultural areas along Highway 101 exhibit marine inundation and emergent groundwater begins to encroach on developed areas. With 3.3 feet (1 meter) of SLR, the developed areas are projected to be exposed to marine inundation. The model does not account for the topography and influence of natural drainage features such as slough channels. The model also does not include drainage infrastructure such as stormdrain pipes and culverts. Additionally, the model assumes a homogeneous subsurface. All of these factors would affect groundwater elevations.

8.5 Impacts

Based on the sensitivities described above, water level or flood depth thresholds that result in marked changes to the characteristics of impacts are summarized in Table 21. For this Study, impacts to infrastructure are generally categorized and described as follows:

- **Wet Conditions:** flooding or wet conditions similar to typical wet-weather months that maintain typical maintenance and operations.
- **Additional Maintenance/Change to Typical Service of Operation:** temporary flooding that may result in diminished service or access and increased maintenance.
- **Damage/Replacement/Inaccessible:** flooding that results in damage, significant disruption to the service, loss of access to respond to an emergency, or potential loss requiring replacement of the facility.

Table 21 Critical Asset Impact Thresholds Due to Flooding

Asset	Physical Process	Asset Impacts		
		Wet Conditions	Additional Maintenance/ Change to Typical Service or Operation	Damage/ Replacement/ Significant Disruption to Service
Shoreline Protection [1]	Overtopping	No Overtopping, Water-side Erosion	>1ft for <2hrs, or <1ft for >0hrs Minor Erosion/Repairs	>1ft for >2hrs Breach/Reconstruction
Roads	Flood Depth/ Duration	No Flooding Typical Maintenance	Flooding of Centerline Road Closure/Reduced Access Signage, Clean-Up	>12 inch depth No Access, Clean-Up
Trails	Flood Depth/ Duration	<3 inch depth Usability Disturbance with Minor Clean-up	< 6 inch depth Reduced Access, Signage, Clean-Up	>6 inch depth Closure, Signage, Clean-Up
Water Distribution System (Pressure Mains)	Surface Flooding and Groundwater	Wet weather conditions, high ground water	Flooding preventing access	Replace at end of useful life
Wastewater Collection Piping (Pressure Mains)	Surface Flooding and Groundwater	Wet weather conditions, high ground water	Flooding preventing access	Replace at end of useful life
Wastewater Collection Piping (Gravity Main and Manholes)	Surface Flooding and Groundwater	Wet weather conditions, high ground water	Flooding < 1/Month	Inundation (Monthly flooding) elevation exceeds manhole lid elevation.
Wastewater Lift Stations	Surface Flooding	Flooding near facility (roadways)	Flooding enters/interacts with structures	Flooding at elevation of electrical panel or generators

Asset	Physical Process	Asset Impacts		
		Wet Conditions	Additional Maintenance/ Change to Typical Service or Operation	Damage/ Replacement/ Significant Disruption to Service
Wastewater Treatment Facilities (Pump Stations, Electrical Building, Generator Building, Office Building)	Surface Flooding	Flooding near facility (roadways)	Flooding enters/interacts with structures	Flooding at elevation of electrical panel or generators
Wastewater Treatment Facilities (Headworks, Clarifiers, UV & Chlorine Contact Basins)	Surface Flooding	Flooding near facility (roadways)	Flooding enters/interacts with structures	Flooding at elevation of electrical facilities or flooding enters treatment process
Wastewater Treatment Facilities (Oxidation Ponds, Treatment Wetlands, Enhancement Marshes, Sludge Drying Beds)	Surface Flooding	Flooding near facility (roadways)	Wind wave overtopping enters facility and limited access to facility	Still water flooding enters facility
Wastewater Treatment Facilities (Sludge Drying Beds)	Surface Flooding	Flooding near facility (roadways)	Flooding enters/interacts with structures	Still water flooding enters facility
References: [1] (USACE, USBR, FERC, TVA, 2017)				

8.6 Adaptive Capacity

As defined previously, adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Lavell, 2012; US EPA, 2017). Existing adaptive capacity of the infrastructure evaluated in this Study are described below and common options to improve adaptive capacity are identified.

8.6.1 Shoreline Protection

The ability of shoreline protection structures to moderate potential damages is influenced by their geometry and type of cover (bare earth, vegetation, rock, paving). Shoreline structures can reduce wave runup elevations with flatter, vegetated slopes facing the direction of wind wave approach. Conversely, steeper, hardened slopes can increase wave runup magnitude and elevations. Erosion and deterioration of the level of flood reduction provided by the shoreline structure depends on the type of cover, water level exposure, depth of overtopping (water surface elevation and shoreline structure elevation) and resulting overtopping flow rate. As shown in Exhibits 1.1 through 1.11, the ability of shoreline structures to withstand overtopping is maintained up to a tidal elevation of 11.7 feet. However, the ability to prevent flooding becomes limited at tidal elevations between 10.1 feet to 10.7 feet. Depending on the flooding impacts, likelihood and adaptive capacity of the infrastructure these shoreline structures protect, coping with shoreline overtopping (allow overtopping or remove structure) or enhancing adaptive capacity with intervention to provide a greater level of flood protection (reconstruction, realignment, elevating) may be identified.

8.6.2 Roads

As described previously, roadways in the reference areas have not experienced significant erosion and damage due to flooding. However, flooding has resulted in unsafe or limited access conditions and temporary closure of roadway use. As flooding becomes more frequent, while the roadway may not experience damage, coping with temporary closure or reduced access would be required. Longer-term saturation due to groundwater or regular flooding would result in reduction of the roadway lifespan, requiring more frequent maintenance and replacement. Depending on the depth and frequency flooding, the roadway access may become severely reduced, requiring permanent closure. Adaptive capacity could be increased by operational changes to the use of the road, enhancing drainage facilities (passive such as gravity flow stormdrain infrastructure or active such as pump stations), or various approaches to increase the elevation of the roadway.

8.6.3 Trails

Flooding of trials may result in unsafe or limited access conditions and temporary closure of trail use. As flooding becomes more frequent, while the trail may not experience damage, coping with temporary closure or reduced access would be required. Longer-term saturation due to groundwater or regular flooding would result in reduction of the trail lifespan, requiring more frequent maintenance and replacement. Depending on the depth and frequency flooding, the trail access may become severely reduced, requiring permanent closure. Adaptive capacity could be increased by operational changes to the use of the trail, enhancing drainage facilities (passive such as gravity flow stormdrain infrastructure or active such as pump stations), or various approaches to increase the elevation of the trail.

8.6.4 Water Distribution System

Many of these pipes exist in areas of high seasonal groundwater and therefore have the ability to moderate damages due to flooding. Increases in salinity may result in increased corrosion of ductile iron and other metal components resulting in reduced service life, which can be combated with cathodic protection or acceptance of increased frequency of maintenance and replacement. If facilities are located in highly erosive areas or access for maintenance becomes overly burdensome, realignment may be required.

8.6.5 Wastewater Collection Piping

Pressure mains exhibit a similar adaptive capacity as the water distribution system. Gravity wastewater mains and manholes throughout the Study Area are also located in areas of high season groundwater resulting in increased wastewater flows and decreased capacity. Adaptive capacity of these features is dependent on their storage and conveyance capacity to withstand flooding and prevent sanitary wastewater overflows (SSOs) that could result in the discharge of untreated wastewater to the surrounding environment. If facilities are located in highly erosive areas or access for maintenance becomes overly burdensome, realignment may be required. Replacing aging pipes and manholes and implementing water-tight features, such as the ability to bolt and seal manhole lids may be implemented to reduce inflows and reduction of capacity.

8.6.6 Wastewater Lift Stations

The ability of lift and pump stations to moderate potential damages is a result of the elevation at which components are located and the characteristics of the building. Temporary flooding in or around the facility that does not reach the elevation of electrical components could be prevented with temporary flood reduction practices such as placing and stacking sandbags around the facility and coping with the potential flooding of the facility and related cleanup. Adaptive capacity could be enhanced by implementing floodproofing measures such as wet floodproofing (allowing flooding inside the building by elevating components and using materials that that can withstand soaking), constructing more permanent flood walls around the facility, dry floodproofing (create a watertight building).

8.6.7 Wastewater Treatment Facilities

Essential Facilities

Perimeter Levee

The existing perimeter levee provides the first line of defense to moderate potential damages by preventing tidal water from entering the AWTF. Protected facilities may cope with a limited amount of overtopping and resulting flooding, described below, before measures to enhance adaptive capacity are needed. The City is already in the process of increasing adaptive capacity measures to elevate essential facilities as a part of the Phase One of the Arcata Wastewater Treatment Plant (AWTF) Improvement Project while measures to improve the levee's adaptive capacity are planned and permitted. Temporary flood reduction measures, such as water-filled dams placed on top of the perimeter levee could be implemented to prevent overtopping of isolated lower elevation locations.

Headworks

The lower grit pump area of the headworks is one of the lowest facilities in the AWTF treatment process. Inflow of tidal flood waters to the headworks could be mitigated with temporary flood reduction practices such as placing and stacking sandbags around the facility and coping with the potential flooding of the facility and related cleanup. Adaptive capacity could be enhanced by implementing floodproofing measures such as constructing more permanent flood walls around the facility.

Primary Clarifier No. 2, UV & Chlorine Contact Basins

The ability of the Primary Clarifier No. 2, UV & Chlorine Contact Basins to moderate potential damages or cope with flooding are limited. Still water overtopping would likely result in diminished treatment and potential discharges to surface water. Temporary flood reduction measures, such as temporary flood protection structures placed on top of the basin walls could be implemented to prevent still water overtopping. Adaptive capacity could be enhanced by implementing floodproofing measures such as constructing more permanent flood walls around the facility.

Pump Stations (Pond Pump Station, Pump Station No. 1, Enhancement Wetlands Pump Station)

Similar to lift stations in the community, the ability of pump stations at AWTF to moderate potential damages is a result of the elevation at which components are located and the characteristics of the building. Temporary flooding in or around the facility that does not reach the elevation of electrical components could be coped with if electrical facilities are not affected and the related cleanup is acceptable. The electrical facilities for these pump stations are located at an elevation that currently provides freeboard well above existing and anticipated future extreme events.

Generator and Electrical Buildings

Similar to lift stations and pump stations, the ability of critical facility buildings at AWTF to moderate potential damages is a result of the elevation at which components are located and the characteristics of the building. Temporary flooding in or around the facility that does not reach the elevation of electrical components and generators could be coped with if these components are not affected and the related cleanup is acceptable. The grade of the electrical building was increased above existing extreme event water levels and electrical facilities include additional freeboard. The generator building requires temporary flood reduction practices such as placing and stacking sandbags around the facility and coping with the potential flooding of the facility and related cleanup for existing extreme event water levels. Electrical equipment elevation provides freeboard for existing extreme events.

Oxidation Ponds, Treatment Wetlands and Enhancement Marshes

The oxidation ponds, treatment wetlands and enhancement marshes could accommodate some tidal flow into them without disruption to wastewater treatment effectiveness. Short duration, occasional overtopping associated with wind waves is considered to be within a reasonable buffer to not significantly diminish treatment. However, still water overtopping would likely result in diminished treatment and potential discharges to surface water. Temporary flood reduction measures, such as water-filled dams placed on top of the perimeter could be implemented to prevent still water overtopping.

Other Facilities

Site and Facility Access

The ability to maintain access to and within the AWTF is most significantly affected by the depth of flooding. Similar to roads and trails, temporary flooding of the access roads would not be anticipated to result in significant erosion and damage of the facility grounds. The use of high clearance vehicles could be used to access the AWTF facilities when flood depth is less than 1 foot. Access would be severely limited when flood depth increases above 1 foot. Adaptive capacity could be increased by enhancing drainage facilities (passive such as gravity flow stormdrain infrastructure or active systems such as pump stations) with the consideration that ground elevations may be lower than tidal elevations at certain times during the event.

Office Facilities

The ability of the office facilities to moderate potential damages is a result of the elevation at which components are located and the characteristics of the building. Temporary flooding in or around the facilities that does not reach the elevation of electrical or other components that could be damaged by flood waters could be prevented with temporary flood reduction practices such as placing and stacking sandbags around the facility and coping with the potential flooding of the facility and related cleanup. Adaptive capacity could be enhanced by implementing floodproofing measures such as wet floodproofing (allowing flooding inside the building by elevating components and using materials that that can withstand soaking), constructing more permanent flood walls around the facility, dry floodproofing (create a watertight building) or elevating the buildings.

Sludge Drying Beds

The ability of the sludge during beds to moderate potential damages or cope with flooding are limited, as flooding of these facilities would likely result in overland conveyance of sludge to other locations in and around the AWTF. Impacts to the sludge drying beds could be moderated with the implementation of temporary flood reduction practices such as placing and stacking sandbags around the facility or longer-term solutions such as a flood wall that also provide equipment access.

8.7 Vulnerability

The section below summarizes (1) the critical thresholds for tidal water levels and fluvial flows and (2) the existing and future likelihood (chance of occurrence per year) of that critical threshold. The likelihoods for critical threshold affecting each asset are evaluated for 2024 (current), 2055, 2075, and 2105 to capture the end of the CIP and LCP planning time frame (current to 2055) and desired design infrastructure lifespan of 50 years from the beginning (2025) and end of the planning time frame (2075 and 2105). The OPC Intermediate SLR scenario is presented followed by consideration of the Intermediate-High and High scenario. All scenarios include relevant changes in precipitation based on Cal-Adapt. The higher likelihood event between tidal flooding or fluvial flooding is shown. Each asset is evaluated against reference flood design criteria, where applicable, as an indication of overall vulnerability. An asset meeting reference design criteria (i.e. likelihood of event, water level, freeboard) is considered to have a very low or acceptable level of vulnerability. However, as sea levels rise and storm intensity increases, these assets may no longer meet reference design criteria and vulnerability will increase as the likelihood of exposure and impacts increase. The existing likelihood or frequency of events and increases over time, under multiple scenarios, are shown to inform the risk assessment. For example, multiple assets do not currently meet reference design criteria, and some amount of flooding or likelihood of flooding may be acceptable depending on the consequences resulting. Consequences are described in the risk assessment section.

8.7.1 Shoreline Protection

Linear landforms created for and or providing shoreline protection, provide an elevation barrier between water bodies and low-lying areas. These landforms are subject to erosion from short, shallow overtopping and potential failure for longer durations or deeper overtopping. Four stretches of shoreline were selected that protect low-lying areas. These stretches are generally referred to as South G Street, Agricultural Areas East of Highway 101, Arcata Marsh and Wildlife Sanctuary, and AWTF. Table 22 shows the threshold and likelihoods for the initiation of shoreline structure overtopping that would result in erosion and flooding as well as the thresholds and likelihoods for potential shoreline structure failure. Thresholds are associated with the lowest point in these linear features. Given many of these landforms, such as the railroad prism and other features that were not constructed for the purposes of flood control, as well as dikes that were constructed prior to modern FEMA and NRCS design standards, none of these stretches meet current design standards for crest elevation above design events with the additional required freeboard.

Shoreline protection along South G Street and the agricultural lands east of Highway 101 exhibit the lowest elevation structures in the Study Area and currently exhibit a 2-in-3 likelihood (1.5-yr return interval) of overtopping, with less than 1-in-500 likelihood of failure. In 2055, these areas will likely overtop up to six times per year and have a 1-in-10 annual chance of potential failure. Overtopping in these locations contribute a significant portion of flooding to low-lying areas they protect. Overtopping and flooding of the AWTF perimeter levee without temporary sandbag placement has an existing chance of occurrence of 1-in-100 and is expected to occur multiple times in a given year by the end of the century. With anticipated 3.3 feet of SLR (OPC Intermediate Scenario), the repeated overtopping of the levee by the end of the century will potentially lead to failure of lower elevation stretches of the levee.

Table 22 Likelihood of shoreline protection overtopping resulting in erosion and maintenance (OPC Intermediate Scenario).

Shoreline Protection Overtopping (Erosion and Maintenance)	Threshold	Chance of Occurrence per Year			
		2024	2055	2075	2105
OPC Intermediate Scenario					
South G Street Agricultural Areas East of Hwy 101	9.5 ft Tide	2-in-3	1-6/year	>1/Month	Daily
Arcata Marsh and Wildlife Sanctuary/ South I Street	10.1 ft Tide	1-in-10	1-6/year	6/year	Daily
AWTF	10.7 ft Tide	1-in-100	1-in-3	1-6/year	Daily
(Potential Failure)					
South G Street Agricultural Areas East of Hwy 101 Arcata Marsh and Wildlife Sanctuary/ South I Street	11.1 ft Tide	1-in-500	1-in-10	2-in-3	>1/Month
AWTF	11.7 ft Tide	<1-in-500	1-in-100	1-in-10	>1/Month
(light green)	Meets Reference Design Criteria <1-in-100 annual likelihood of overtopping and freeboard				
(tan)	Does Not Meet Reference Design Criteria. >1-in-100 annual likelihood of overtopping and freeboard				

Under the OPC Intermediate-High and High Scenarios, in 2055 overtopping results in flooding of South G Street, the agricultural areas and Arcata Marsh and Wildlife Sanctuary, and would likely occur multiple times per year (Table 23). Potential failure of these linear landforms would be projected to occur in 2075. The AWTF would experience intermittent overtopping and erosion between 2055 and 2075 and potential failure of the shoreline structures in 2075.

Table 23 Likelihood of shoreline protection overtopping resulting in erosion and maintenance (OPC Intermediate-High and High Scenario).

Shoreline Protection Overtopping (Erosion and Maintenance)	Threshold	Chance of Occurrence per Year						
		2024	2055		2075		2105	
OPC SLR Scenario			Int-High	High	Int-High	High	Int-High	High
South G Street Agricultural Areas East of Hwy 101	9.5 ft Tide 9.5 ft Tide	2-in-3	>1/Month	>1/Month	Daily	Daily	Daily	Daily
Arcata Marsh and Wildlife Sanctuary/ South I Street	10.1 ft Tide	1-in-10	1-6/year	6/year	>1/Month	Daily	Daily	Daily
AWTF	10.7 ft Tide	1-in-100	2-in-3	1-6/year	>1/Month	Daily	Daily	Daily
(Potential Failure)								
South G Street Agricultural Areas East of Hwy 101 Arcata Marsh and Wildlife Sanctuary/ South I Street	11.1 ft Tide	<1-in-500	1-in-4	2-in-3	6/year	>1/Month	Daily	Daily
AWTF	11.7 ft Tide	<1-in-500	1-in-33	1-in-10	1-6/year	>1/Month	Daily	Daily

(light green)	Meets Reference Design Criteria <1-in-100 annual likelihood of overtopping and freeboard
(tan)	Does Not Meet Reference Design Criteria. >1-in-100 annual likelihood of overtopping and freeboard

8.7.2 Roads

A wide range of likelihoods for roadway flooding resulting in roadway closure are exhibited in the Study Area (Table 24). This flooding may be shallow but extends across the centerline and requires signage and closure. Roadways evaluated are limited to those pertaining to the City of Arcata's jurisdiction and therefore does not include private roads or Highway 101. Likelihoods reported are for the lowest elevations of the roadways and length of roadway affected may be limited to small sections or the entirety of the roadway, depending on elevations. Several local roads exhibit an existing 1-in-10 annual chance of flooding resulting in closure due to tidal or fluvial events. South G Street exhibits a higher likelihood. Roadways affected by tidal flooding are expected to experience closure due to flooding multiple time a year by 2055. By 2075, roadway flooding for access to the AWTF occurs multiple times per year. These locations do not meet current reference design standards for drainage infrastructure to achieve less than 1-in-25 annual chance of flooding. Other roads exhibit less vulnerability, but nearly all roads listed would experience some degree of tidal flooding multiple times per year by 2105.

Table 24 Likelihood of roadway flooding resulting in road closure (OPC Intermediate Scenario).

Flooded Roadway (Centerline Flooding/Closure)	Threshold	Chance of Occurrence per Year			
		2024	2055	2075	2105
OPC Intermediate SLR Scenario					
Local Roads					
S G St	9.5 ft Tide	2-in-3	1-6/year	>1/Month	Daily
5th St, Front St H St S F St S H St S I St	10.1 ft Tide	1-in-10	1-6/year	6/year	Daily
8th St Anderson Ln K St L St N St Old Arcata Rd	10yr Fluvial	1-in-10	1-in-3	1-in-2	1-in-2
2nd St AWTF Site Access	10.7 ft Tide	1-in-100	1-in-3	1-6/year	Daily
6th St E St	11.1 ft Tide	1-in-500	1-in-10	2-in-3	>1/Month
3rd St 7th St I St J St S Union St	11.7 ft Tide	<1-in-500	1-in-125	1-in-10	>1/Month
4th St D St	12.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	1-6/year
Bayside Ct Community Park Way Union St	13.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	1-in-10
Major Collectors					
Samoa Blvd	10.7 ft Tide	1-in-100	1-in-3	1-6/year	Daily
Minor Collectors					
Bayside Cutoff Rd	11.7 ft Tide	<1-in-500	1-in-125	1-in-10	>1/Month
(green)	Meets Reference Design Criteria of <1-in-4 annual likelihood of flooding				
(tan)	Does Not Meet Reference Design Criteria. >=1-in-4 annual likelihood of flooding				

Fewer locations would result in greater than one foot of flooding that would result in limited to no access (Table 25). The reference design standard for more extreme flooding, that avoids likely damage to adjacent areas is to achieve less than 1-in-100 likelihood. Sections of roadway experiencing this depth of flooding on a daily basis by 2105 will likely no longer be able to be used. Between 2055 and 2075, these areas, including access to the AWTF, will begin to experience multiple events per year that will limit access for multiple days at a time. Other roads exhibit less vulnerability, but nearly all roads listed would experience regular (daily to monthly) access limitations by 2105.

Table 25 Likelihood of flooding more than one foot depth resulting in no access (OPC Intermediate Scenario).

Flooded Roadway (1ft Flooding No Access)	Threshold	Chance of Occurrence per Year 2024	2055	2075	2105
OPC Intermediate SLR Scenario					
Local Roads					
Front St S F St S G St	10.1 ft Tide	1-in-10	1-6/year	6/year	Daily
AWTF Site Access S G ST - South of AWTF S H St S I St	10.7 ft Tide	1-in-100	1-in-3	1-6/year	Daily
5th St	100yr Fluvial 11.1 ft Tide	1-in-100	1-in-10	2-in-3	>1/Month
H St	11.1 ft Tide	1-in-500			
2nd St 6th St 7th St E St I St J St S Union St	11.7 ft Tide	<1-in-500	1-in-100	1-in-10	>1/Month
3rd St	12.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	1-6/year
4th St Bayside Ct Community Park Way D St	13.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	1-in-10
Major Collectors					
Samoa Blvd	10.7 ft Tide	1-in-100	1-in-3	1-6/year	Daily
Minor Collectors					
Bayside Cutoff Rd	12.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	1-6/year
(green)	Meets Reference Design Criteria of <1-in-100 annual likelihood of flooding				
(tan)	Does Not Meet Reference Design Criteria. >1-in-100 annual likelihood of flooding				

Under the OPC Intermediate-High and High Scenarios, in 2055 the lowest elevation roads will experience closure and or no access multiple times per year, as shown in Table 26 and Table 27. This expands to most of the roadways by 2075.

Table 26 Likelihood of roadway flooding resulting in road closure (OPC Intermediate-High and High Scenario)

Flooded Roadway (Centerline Flooding/Closure)	Threshold	Chance of Occurrence per Year						
		2024	2055		2075		2105	
OPC SLR Scenario			Int-High	High	Int-High	High	Int-High	High
Local Roads								
S G St	9.5 ft Tide	2-in-3	>1/Month	>1/Month	Daily	Daily	Daily	Daily
5th St Front St H St S F St S H St S I St	10.1 ft Tide	1-in-10	1-6/year	6/year	>1/Month	Daily	Daily	Daily
8th St Anderson Ln K St L St N St Old Arcata Rd	10yr Fluvial	1-in-10	1-in-3	1-in-3	1-in-2	1-in-2	50%	50%
2nd St AWTF Site Access	10.7 ft Tide	1-in-100	2-in-3	1-6/year	>1/Month	Daily	Daily	Daily
6th St E St	11.1 ft Tide	1-in-500	1-in-4	2-in-3	6/year	>1/Month	Daily	Daily
3rd St 7th St I St J St S Union St	11.7 ft Tide	<1-in-500	1-in-33	1-in-10	1-6/year	>1/Month	Daily	Daily
4th St D St	12.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	1-in-10	1-6/year	>1/Month	Daily
Bayside Ct Community Park Way Union St	13.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500	1-in-10	>1/Month	Daily
Major Collectors								
Samoa Blvd	10.7 ft Tide	1-in-100	2-in-3	1-6/year	>1/Month	Daily	Daily	Daily
Minor Collectors								
Bayside Cutoff Rd	11.7 ft Tide	<1-in-500	1-in-33	1-in-10	1-6/year	>1/Month	Daily	Daily
(green)	Meets Reference Design Criteria of <1-in-25 annual likelihood of flooding							
(tan)	Does Not Meet Reference Design Criteria. >=1-in-25 annual likelihood of flooding							

Table 27 Likelihood of flooding more than one foot depth resulting in no access (OPC Intermediate-High and High Scenario).

Flooded Roadway (1ft Flooding No Access)	Threshold	Chance of Occurrence per Year						
		2024	2055		2075		2105	
OPC SLR Scenario			Int-High	High	Int-High	High	Int-High	High
Local Roads								
Front St S F St S G St	10.1 ft Tide	1-in-10	1-6/year	6/year	>1/Month	Daily	Daily	Daily
AWTF Site Access S G St - South of AWTF S H St S I St	10.7 ft Tide	1-in-100	2-in-3	1-6/year	>1/Month	Daily	Daily	Daily
5th St	100yr Fluvial 11.1 ft Tide	1-in-100	1-in-4	2-in-3	6/year	>1/Month	Daily	Daily
H St	11.1 ft Tide	1-in-500						
2nd St 6th St 7th St E St I St J St S Union St	11.7 ft Tide	<1-in-500	1-in-33	1-in-10	1-6/year	>1/Month	Daily	Daily
3rd St	12.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	1-in-10	1-6/year	1-in-10	Daily
4th St Bayside Ct Community Park Way D St	13.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500	1-in-10	<1-in-500	Daily
Major Collectors								
Samoa Blvd	10.7 ft Tide	1-in-100	2-in-3	1-6/year	>1/Month	Daily	Daily	Daily
Minor Collectors								
Bayside Cutoff Rd	12.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	1-in-10	1-6/year	1-in-10	Daily

(light green)	Meets Reference Design Criteria of <1-in-100 annual likelihood of flooding
(tan)	Does Not Meet Reference Design Criteria. >=1-in-100 annual likelihood of flooding

8.7.3 Trails

The likelihood of trail flooding and closure are shown in Table 28 with reference design criteria similar to those of roadways (less than 1-in-25 annual chance resulting in closure). Locations within the Arcata Marsh and Wildlife Sanctuary trail system exhibit elevations between MMMW and MAMW and are exposed to potential flooding multiple times per year. Humboldt Bay Trail – North along highway 101 exhibits a likelihood of 1-in-7. By 2055 sections of these trails would be expected to be closed multiple times per year and regular closure expected near the end of the century. Paths on Samoa Boulevard have a relatively low likelihood of closure through 2055 and would likely experience flooding near the end of the century.

Table 28 Likelihood of flooding in excess of one foot depth resulting in trail being impassable and closure of sections is required (OPC Intermediate Scenario).

Flooded Trail (Greater than Six Inch Deep)	Threshold	Chance of Occurrence per Year			
		2024	2055	2075	2105
OPC Intermediate SLR Scenario					
Arcata Marsh and Wildlife Sanctuary	9.2 ft Tide	1-6/year	>1/Month	>1/Month	Daily
Humboldt Bay Trail - North	10 ft Tide	1-in-7	1-6/year	>1/Month	Daily
Samoa Blvd Path-South Side	11.7 ft Tide	<1-in-500	1-in-100	1-in-10	>1/Month
Samoa Blvd Path-North Side Dr Martin Luther King Jr Parkway to Samoa Blvd	12.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	1-6/year
(green)	Meets Reference Design Criteria of <1-in-25 annual likelihood of flooding				
(orange)	Does Not Meet Reference Design Criteria. >=1-in-25 annual likelihood of flooding				

Under the OPC Intermediate-High and High Scenarios, regular (monthly) flooding could begin to occur in locations within the Arcata Marsh and Wildlife Sanctuary trail system and Humboldt Bay Trail – North by 2055 and progress to daily late century (Table 29). Paths on Samoa Boulevard have a relatively low likelihood of closure through 2055 and would likely experience flooding in the latter half of this century.

Table 29 Likelihood of flooding in excess of six inches depth resulting in trail being impassable and closure of sections is required (OPC Intermediate-High and High Scenario).

Flooded Trail (Greater than Six Inch Deep)	Threshold	Chance of Occurrence per Year						
		2024	2055		2075		2105	
OPC SLR Scenario			Int-High	High	Int-High	High	Int-High	High
Arcata Marsh and Wildlife Sanctuary	9.2 ft Tide	1-6/year	>1/Month	>1/Month	Daily	Daily	Daily	Daily
Humboldt Bay Trail - North	10 ft Tide	1-in-7	1-6/year	>1/Month	>1/Month	Daily	Daily	Daily
Samoa Blvd Path-South Side	11.7 ft Tide	<1-in-500	1-in-33	1-in-10	1-6/year	>1/Month	Daily	Daily
Samoa Blvd Path-North Side Dr Martin Luther King Jr Parkway to Samoa Blvd	12.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	1-in-10	1-6/year	>1/Month	Daily

(green)	Meets Reference Design Criteria of <1-in-25 annual likelihood of flooding
(orange)	Does Not Meet Reference Design Criteria. >=1-in-25 annual likelihood of flooding

8.7.4 Water Distribution System

Many of these pipes exist in areas of high seasonal groundwater and therefore are not considered vulnerable to flooding.

8.7.5 Wastewater Piping

The number of wastewater manholes becoming regularly flooded (six or more times per year corresponding to MMMW) under the OPC Intermediate Scenario are presented in Table 30. Tidal flooding of sewer manholes will reduce capacity of the system and could lead to sanitary sewer overflows in addition to changing the chemistry of the wastewater, altering treatment capabilities. The City has not experienced significant flooding of sewer manholes by freshwater sources resulting in reduced treatment or overflows. By 2055, nine wastewater manholes, located in low elevation areas, will likely experience flooding multiple times per year. By 2075, this increases to 14 or more, and by 2105, this increases to 40 or more. The number of submerged manholes could result in sanitary wastewater overflows in addition to treatment capacity and quality challenges.

Table 30 Number of wastewater manholes experiencing flooding greater than 6 times per year (MMMW) that will need to be relocated or replaced.

Sewer Manhole Flooding	Number of Manholes Affected by MMMW			
	2024	2055	2075	2105
OPC Intermediate Scenario	**(8.5 ft)**	**(9.4 ft)**	**(10.1 ft)**	**(12.0 ft)**
Outside of Roadway (Janes Creek Drainage, Agricultural Fields, Arcata Marsh)		6	6	27
S G St		3	5	9
S I St	-		1	5
H St			2	4
F St		-		2
2nd St				2
OPC Intermediate-High Scenario	**(8.5 ft)**	**(9.7 ft)**	**(11.1 ft)**	**(13.8 ft)**
Outside of Roadway (Janes Creek Drainage, Agricultural Fields, Arcata Marsh)		6	23	40
S G St		5	9	9
S I St		1	4	5
H St		2	4	6
F St			2	2
2nd St	-		2	2
Samoa Blvd				4
3rd St				5
5th St		-		2
4th St			-	3
Community Park Way				3
Union St				1
OPC High Scenario	**(8.5 ft)**	**(10.0 ft)**	**(12.0 ft)**	**(15.8 ft)**
Outside of Roadway (Janes Creek Drainage, Agricultural Fields, Arcata Marsh)		6	23	48
S G St		5	9	9
S I St		1	4	6
H St		2	4	6
F St			2	3
2nd St			2	2
Samoa Blvd	-	-		10
3rd St				5
5th St			-	4
4th St				3
Community Park Way				3
Union St				3
6th St				1

8.7.6 Wastewater Lift Stations

The likelihood of lift station flooding under the OPC Intermediate Scenario are outlined in Table 31. Multiple flood conditions are considered that include when flooding will enter or interact with the building or foundation, the backup power supply (if present), and the electrical equipment. Reference design criteria uses the 1-in-100 annual chance water level and one foot of freeboard for the building or foundation and two feet for the backup power and electrical equipment. The generator and electrical facilities in the First Street Lift Station exhibit clearance above the foundation while the other pump station exhibit electrical facilities at foundation elevation. All lift station components, with the exception of the First Street Lift Station building floor elevation, currently meet reference design criteria. By 2075, the First Street Lift Station building is expected to be exposed to flooding multiple times per year and the backup power supply and electrical equipment will no longer meet reference freeboard criteria. The Meadowbrook, Wetlands and Samoa Lift Stations all exhibit elevations above the 1-in-100 annual chance water level through 2105, but do not meet freeboard criteria at the end of the century.

Table 31 ***Likelihood of flooding resulting in damage / failure / replacement of lift station facilities (OPC Intermediate Scenario).***

Lift Station Flooding	Threshold	Chance of Occurrence per Year			
		2024	2055	2075	2105
OPC Intermediate Scenario					
First St Lift Station					
Building Floor Flooding	10.7 ft Tide	1-in-100	31.8%	1-6/year	Daily
Generator (Backup Power)	11.7 ft Tide	<1-in-500	0.8%	1-in-10	>1/Month
Electrical Equipment	13.3 ft Tide	<1-in-500	<1-in-500	<1-in-500*	1-in-3
Meadowbrook Lift Station					
Foundation and Electrical Equipment	100-yr Fluvial	<1-in-500	<1-in-500	1-in-500*	<1-in-500*
Wetlands Lift Station					
Foundation and Electrical Equipment	14.9 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500*
Samoa Lift Station					
Foundation and Electrical Equipment	15.3 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500*
(green)	Meets Reference Design Criteria of <1-in-100 annual likelihood of flooding and freeboard				
(orange)	Does Not Meet Reference Design. >=1-in-100 annual likelihood of flooding and freeboard * = asset not flooded, but does not meet freeboard requirements				

Under the OPC Intermediate-High and High Scenarios, the likelihood of First Street Lift Station flooding becomes more regular between 2055 to 2075 (Table 31). The other three lift stations no longer meet reference freeboard criteria in 2075 and are exposed to regular flooding at the end of the century.

Table 32 Likelihood of flooding resulting in damage / failure / replacement of lift station facilities (OPC Intermediate-High and High Scenario)

Lift Station Flooding	Threshold	Chance of Occurrence per Year						
		2024	2055		2075		2105	
OPC SLR Scenario			**Int-High**	**High**	**Int-High**	**High**	**Int-High**	**High**
First St Lift Station								
Building Flooding	10.7 ft Tide	1-in-100	2-in-3	1-6/year	>1/Month	Daily	Daily	Daily
Generator (Backup Power)	11.7 ft Tide	<1-in-500	1-in-33	1-in-10	1-6/year	>1/Month	Daily	Daily
Electrical Equipment	13.3 ft Tide	<1-in-500	<1-in-500	<1-in-500	1-in-100	3-in-7	>1/Month	Daily
Meadowbrook Lift Station								
Foundation and Electrical Equipment	14.9 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500*	<1-in-500*	2-in-3	>1/Month
Wetlands Lift Station								
Foundation and Electrical Equipment	14.9 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500*	<1-in-500*	2-in-3	>1/Month
Samoa Lift Station								
Foundation and Electrical Equipment	15.3 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500	<1-in-500*	1-in-5	>1/Month
(green)	Meets Reference Design Criteria of <1-in-100 annual likelihood of flooding and freeboard							
(orange)	Does Not Meet Reference Design. >=1-in-100 annual likelihood of flooding and freeboard * = asset not flooded, but does not meet freeboard requirements							

8.7.7 Wastewater Treatment Facilities

The AWTF is comprised of multiple components at varying elevations and likelihood of exposure to flooding impacts (Table 33). The City's Phase 1 project locates most essential facilities at an elevation that meets or exceeds reference design criteria of the 1-in-100 annual chance water and freeboard. However, some essential facilities, such as building floor elevations and the headworks lower grit pump area, are limited in their ability to achieve these higher elevations without additional projects and do not meet the freeboard criteria. The Headworks Lower Grit Pump Area and Generator building are projected to be exposed to flooding multiple times per year by 2075. The backup power supply (Generator Building Electrical Equipment) will begin to see flooding multiple time per year at the end of the century. The Enhancement Marshes will likely see multiple tidal flooding events per year in the latter part of the century. Office facilities will see a similar number of flooding events.

Table 33 Likelihood of flooding resulting in damage / failure / replacement of AWTF facilities (OPC Intermediate Scenario).

AWTF Asset and Access Flooding	Threshold	Chance of Occurrence per Year			
		2024	2055	2075	2105
OPC Intermediate Scenario					
Essential Facilities					
Headworks Lower Grit Pump Area Generator Building Enhancement Marshes	10.7 ft Tide	1-in-100	1-in-3	1-6/year	Daily
Oxidation Ponds Treatment Wetlands	11.1 ft Tide	1-in-500*	1-in-10	2-in-3	>1/Month
Pond Pump Station and Pump Station No. 1	11.4 ft Tide	<1-in-500*	1-in-33	1-in-3	>1/Month
Emergency Pond Pump Station	11.9 ft Tide	<1-in-500	1-in-500*	1-in-20	>1/Month
Generator Building Electrical Equipment	12.4 ft Tide	<1-in-500*	<1-in-500*	1-in-100	1-6/year
Electrical Building	13.3 ft Tide	<1-in-500	<1-in-500*	<1-in-500*	1-in-3
Electrical Equipment for Essential Facilities[1]	14.0 ft Tide	<1-in-500	<1-in-500	<1-in-500*	1-in-33
Enhancement Wetlands Pump Station	14.9 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500*
UV & Chlorine Contact Basins	15.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500*
Primary Clarifier No. 2	16.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500
Headworks Top Deck	22.4 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500
Headworks Electrical Equipment	24.0 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500
Other AWTF Facilities					
Office Facilities	10.7 ft Tide	1-in-100	1-in-3	1-6/year	Daily
Sludge Drying Beds Site and Facility Access	11.1 ft Tide	1-in-500*	1-in-10	2-in-3	>1/Month
(green)	Meets Reference Design Criteria of <1-in-100 annual likelihood of flooding and freeboard				
(orange)	Does Not Meet Reference Design. >=1-in-100 annual likelihood of flooding and freeboard * = asset not flooded, but does not meet freeboard requirements				

[1]Electrical Equipment for Grit Pump, Primary Clarifier No. 2, Pond Pump Station, Pump Station No. 1, Emergency Pond Pump Station, UV & Chlorine Contact Basins, Enhancement Wetland Pump Station, Electrical Building)

Under the OPC Intermediate-High and High Scenarios, multiple flooding events per year affecting the lower-elevation facilities will begin to occur in 2055 to 2075, compared to 2075 to 2105 (Table 33). Additionally, the duration for which facilities meet reference design criteria occurs 20 to 30 years earlier.

Table 34 Likelihood of flooding resulting in damage / failure / replacement of AWTF facilities (OPC Intermediate-High and High Scenarios).

AWTF Asset and Access Flooding	Threshold	Chance of Occurrence per Year						
		2024	2055		2075		2105	
OPC SLR Scenario			Int-High	High	Int-High	High	Int-High	High
Essential Facilities								
Headworks Lower Grit Pump Area	10.7 ft Tide	1-in-100	2-in-3	1-6/year	>1/Month	Daily	Daily	Daily
Enhancement Marshes	10.7 ft Tide							
Generator Building	10.7 ft Tide							
Oxidation Ponds Treatment Wetlands	11.1 ft Tide	1-in-500*	1-in-4	2-in-3	6/year	>1/Month	Daily	Daily
Pond Pump Station and Pump Station No. 1	11.4 ft Tide	<1-in-500*	1-in-10	1-in-3	1-6/year	>1/Month	Daily	Daily
Emergency Pond Pump Station	11.9 ft Tide	<1-in-500	1-in-100	1-in-20	Yearly	>1/Month	Daily	Daily
Generator Building Electrical Equipment	12.4 ft Tide	<1-in-500*	<1-in-500*	1-in-100	1-in-3	1-6/year	Daily	Daily
Electrical Building	13.3 ft Tide	<1-in-500	<1-in-500*	<1-in-500*	1-in-100	3-in-7	>1/Month	Daily
Electrical Equipment for Essential Facilities[1]	14 ft Tide	<1-in-500	<1-in-500	<1-in-500*	<1-in-500*	1-in-25	1-6/year	Daily
Enhancement Wetlands Pump Station	14.9 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500*	<1-in-500*	2-in-3	>1/Month
UV & Chlorine Contact Basins	15.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500	<1-in-500*	1-in-20	>1/Month
Primary Clarifier No. 2	16.7 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500	<1-in-500	<1-in-500*	1-6/year
Headworks Top Deck	22.4 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500	<1-in-500	<1-in-500*	<1-in-500*
Headworks Electrical Equipment	24 ft Tide	<1-in-500	<1-in-500	<1-in-500	<1-in-500	<1-in-500	<1-in-500*	<1-in-500*
Other AWTF Facilities								
Office Facilities	10.7 ft Tide	1-in-100	2-in-3	1-6/year	>1/Month	Daily	Daily	Daily
Sludge Drying Beds Site and Facility Access	11.1 ft Tide	1-in-500*	1-in-4	2-in-3	6/year	>1/Month	Daily	Daily

(green)	Meets Reference Design Criteria of <1-in-100 annual likelihood of flooding and freeboard
(orange)	Does Not Meet Reference Design. >=1-in-100 annual likelihood of flooding and freeboard * = asset not flooded, but does not meet freeboard requirements

[1]Electrical Equipment for Grit Pump, Primary Clarifier No. 2, Pond Pump Station, Pump Station No. 1, Emergency Pond Pump Station, UV & Chlorine Contact Basins, Enhancement Wetland Pump Station, Electrical Building)

8.7.8 Drainage - Groundwater and Sea Level Range

Increases in groundwater elevations and a higher elevation tidal range as a result of SLR will impact favorable drainage conditions. Increased groundwater levels may result in some areas experiencing emergent groundwater on the surface and reduced capacity of drainage and wastewater collection infrastructure, as groundwater flows into the systems. As shown in previous sections, The USGS CoSMoS estimates that developed areas within the Study Area will begin to see emergent ground water between 50 to 100 cm (1.6 to 3.3 feet) of SLR. The timing of these SLR amounts are shown on Table 35, within the context of planning periods.

Table 35 SLR amounts resulting in emergent groundwater in developed areas.

OPC SLR Scenario	2055 (ft)	2075 (ft)	2105 (ft)
Intermediate	1.0	1.7	3.6
Intermediate-High	1.3	2.7	5.5
High	1.7	3.7	7.5
(green)	Groundwater Below Surface in Developed Areas		
(orange)	Emergent Groundwater Projected in Developed Areas		

The tidal range affects the conveyance of stormwater, groundwater, and fluvial flows (runoff and base flows) within channels and stormwater infrastructure (drainage system). When tidal water levels are above the flow line or invert elevation of channels or infrastructure conveying runoff or baseflow, conveyance capacity is reduced. As tidal water levels increase above water surface elevations of runoff or baseflow, the drainage system is no longer able to convey flows to Humboldt Bay.

Each day Humboldt Bay experiences two high tides and two low tides, with each of the four tides reaching different elevations (referred to as a mixed semi-diurnal tide cycle). During full and new moons, the sun and the moon are aligned with respect to the earth and the combined gravitational effects cause a larger than average tidal range, so differences between the high and low tides are greatest ("spring tides"). During quarter moons, when the gravitational effects of the sun and the moon are opposed, a smaller than average tidal range occurs ("neap tides"). The average height of the lowest tides, known as Mean Lower Low Water (MLLW) is used in this study to infer when drainage channels may be significantly reduced and drainage infrastructure ineffective. Mean Sea Level (MSL) is the average hourly heights observed at a given location and is used in this study to indicate when the window of favorable drainage conditions is limited. Existing MLLW and MSL at Station 9418767, North Spit, CA are -0.34 ft and 3.36 ft, respectively. The lowest elevations of developed areas within the Study Area exhibit and elevation of 6 ft. Table 36 below presents vulnerabilities associated with favorable drainage conditions.

Table 36 Changes to tidal datums resulting in limited windows or gradients favorable to drain flooded areas.

OPC SLR Scenario	Datum	2055 (ft NAVD)	2075 (ft NAVD)	2105 (ft NAVD)
Intermediate	MLLW	0.7	1.4	3.3
	MSL	4.4	5.1	7.0
Intermediate-High	MLLW	1.0	2.4	5.1
	MSL	4.7	6.1	8.8
High	MLLW	1.4	3.3	7.1
	MSL	5.1	7.0	10.8
(green)	Favorable Windows or Elevation Gradients for Drainage (both MLLW and MSL below 6 feet)			
(orange)	Limited Windows or Gradients of Favorable to Drain Flooded Areas			

9. Risk Assessment Approach

While the vulnerability assessment identifies what and how assets will be impacted, a risk assessment is intended to inform the scale and severity of impacts. Characterizing risk can inform prioritization of actions.

9.1 Framework

The Army Corps of Engineers provides a Risk Assessment Methodology as a part of their Hydrologic Engineering Center Flood Damage Reduction Analysis (HEC-FDA). The risk assessment methodology is intended to support an understanding of flood risks and measure and describe them (USACE, 2023). This framework, in addition to the International Organization for Standardization (ISO) 3100 risk assessment guidelines have been reviewed and adapted to develop the framework described below and build upon the vulnerability assessment.

The vulnerability assessment characterized several factors that will inform the risk analysis:

– Asset sensitivity characterized how service may or may not be affected if exposed to flood waters
– Exposure identified if flooding associated with a given water level or storm event would interact with the asset
– Impacts were then described based on the asset sensitivities and flood exposure to identify thresholds, characterized by marked changes to operations (i.e. typical wet conditions, maintenance, and damage following an event). Reference design criteria was identified, intended to inform typical avoidance or mitigation measures.
– Adaptive capacity characterized the asset and City staff’s ability to moderate potential damages.
– Vulnerability utilized the results of the steps above and projected changes to the recurrence and magnitude of hazards to characterize the likelihood of impacts over the course of the planning period. The exposure and likelihood of an event was compared to reference design criteria to understand if and when an asset meets or will no longer meet typical design criteria.

The Risk Assessment includes consideration of the likelihood and consequence of an event (USACE, 2023):

– Event likelihood is based on existing recurrence intervals and future projections using OPC and Cal Adapt scenarios and described in the scale below (Table 37).

Table 37 Likelihood Scale providing qualitative terms for numerical likelihoods for use in Risk Analysis

Likelihood Scale	Description
Almost Certain	Multiple times per year
Very Likely	1-in-2 to yearly Annual Chance (2- to 1-yr recurrence)
Likely	1-in-25 to 1-in-2 Annual Chance (25- to 2-yr recurrence)
Unlikely	1-in-50 to 1-in-25 Annual Chance (50- to 25-yr recurrence)
Very Unlikely	1-in-500 to 1-in-50 Annual Chance (500- to 50-yr recurrence)
Almost Unprecedented	1-in-500 or Less Annual Chance (greater than 500-yr recurrence)

– Consequences utilize the components of the vulnerability assessment to qualitatively or quantitatively describe how impacts affect the City’s ability to manage and maintain operations. Consequences are described on a relative scale of severity. A consequence scale is a tool used to evaluate and categorize the potential outcomes or impacts of an event. The proposed risk scale for this study is provided in Table *38*.

Table 38 Consequence Scale providing qualitative consequence terms, definitions and examples for use in Risk Analysis

Consequence Scale	Description	Examples
Insignificant	Easily manageable within typical operations and maintenance	No change to typical operations and maintenance Within typical budgeted costs
Minor	Minimal impact, easily manageable with some additional maintenance/staff time required	Small additional operations and maintenance Additional costs within typical annual contingency
Moderate	Manageable impact, some effort required to address.	Short (hours) delays in service Increased costs not typically budgeted Limited additional resources required
Major	Noticeable impact, requires significant effort to manage	Temporary (1+ days) delays to service Requires repair of facilities or parts Additional resource required
Severe	Significant impact, challenging to manage, requiring additional resources	Extended (multiple days to one week) service disruption. Significant financial cost not typically budgeted Requires replacement of limited facilities or parts Substantial outside resources required to address
Catastrophic	Severe impact, potentially unmanageable even with additional resources	Long term (multiple weeks) service disruption Massive financial loss, failure and replacement of assets required Requires extensive replacement, repair, and or reconstruction of facilities

– The combination of the likelihood (almost certain to almost unprecedented) and consequence of a given event (insignificant to catastrophic) can then be used to apply a qualitative risk rating using a risk matrix evaluation (Table 39).

Table 39 Risk Matrix Evaluation combining Consequence Scale and Likelihood Scale to assign a qualitative risk rating.

Risk Matrix Evaluation							
		Consequence					
		Insignificant	**Minor**	**Moderate**	**Major**	**Severe**	**Catastrophic**
Likelihood	**Almost Certain**						
	Very Likely						Very High
	Likely					High	
	Unlikely				Medium		
	Very Unlikely			Low			
	Almost Unprecedented	Very Low					

9.2 Qualitative Risk Analysis

For this study, qualitative risk analysis focus is on flooding and impacts to operations, maintenance and continual service of City infrastructure. A similar process could be applied to evaluate effects on public health, habitats, or other assets of interest. A qualitative evaluation of consequences of impacts to critical assets is presented in Table 40. The consequences are then combined with the likelihood of the event causing the impact, as presented previously, for each asset and type of impact described in the vulnerability assessment to inform an overall risk rating for assets over time. Risk ratings associated with the OPC Intermediate Scenario are reported in the following sections as a baseline for evaluating risk. Review of the previously discussed increases in likelihood associated with the Intermediate-High and High Scenarios may be reviewed to inform the potential for earlier onset of increased risk ratings.

Table 40 Assignment of Risk Consequence Scale to asset exposure based on anticipated impacts.

Asset	Exposure	Asset Impact Consequence					
		Insignificant	**Minor**	**Moderate**	**Major**	**Severe**	**Catastrophic**
Shoreline Protection	Overtopping	No Overtopping	Erosion And Maintenance	Potential Failure Protecting Agricultural Areas		Potential Failure Protecting Developed Areas	
Roads	Surface Flooding			Centerline Flooding / Closure	1ft Flooding No Access		
Trails	Surface Flooding			> 6 inches flooding			
Lift Stations	Surface Flooding	Flooding Near Lift Station (Roadways)	Flooding Enters Structure	-	Flooding At Elevation of Generators	Flooding at Elevation of Electrical Panel	-
AWTF	Surface Flooding			Disruption of Access, Flooding Enters Structure, Potential Overflows to Sensitive Areas	Flooding Disrupting Operations / Treatment Effectiveness	Flooding Damaging Backup Power and Treatment	Flooding Damaging Electrical Infrastructure
Wastewater Gravity Main and Manholes	Monthly Submergence	1-5 Manholes Submerged	6-10 Manholes Submerged	11-15 Manholes Submerged	> 15 Manholes Submerged		
Drainage	Emergent Groundwater or Tide			Emergent Groundwater in Developed Areas	MSL at Developed Ground Elevation	MLLW at Developed Ground Elevation	
Asset impact consequences are specific to the Study Area, asset consequences descriptions are provided for threshold values of consequences to assets. Description left blank if no further damage or change in damage due to increased flood depth is expected.							

Additionally, Exhibits of risk to assets in 2024, 2055, 2075 and 2105 are presented in Appendix D. the exhibits provide a combined overview of the risks to the asset types presented below for the OPC Intermediate Scenario. Specific discussion of the risks to the assets depicted in Appendix D are presented in the following sections.

9.2.1 Shoreline Protection

Shallow overtopping of shoreline protection may result in erosion and maintenance needs to maintain crest elevations and function while deeper, prolonged overtopping may result in failure of the shoreline structure. Consequences associated with overtopping vary from minor to major. Minor consequences are associated with minor erosion occurs and maintenance or minor repair is required and can be completed by City staff. Consequences escalate to moderate and major depending on the location of the shoreline protection and the land and facilities they protect. Potential failure of shoreline protection affecting undeveloped, agricultural areas or the AMWS is moderate, where the impact can be managed with City resources in additional to limited additional resources and implement repairs, if needed. If developed areas are affected by failure of the shoreline protection, consequences are major, where significant effort is required to manage the impacts, significant repair is needed, and additional resources to respond to and manage the impacts is required.

The risk rating associated with these consequences and the likelihood of the threshold water level occurring are presented in Table 41. Minor erosion and maintenance of shoreline infrastructure received a low risk rating, for current and future sea levels. Potential failure of shoreline protection resulting in flooding of undeveloped areas currently exhibits a low risk rating and increases to medium risk mid-century. In developed areas, the risk rating escalates to a high in late century.

Table 41 Risk rating for shoreline overtopping resulting in erosion and maintenance and potential failure. Graphical representation of risk to shoreline locations can be found in Appendix D.

Shoreline Protection Overtopping (OPC Intermediate SLR Scenario)			Year | Risk Rating			
Impact: Erosion and Maintenance	**Threshold**	**Consequence**	**2024**	**2055**	**2075**	**2105**
South G Street	9.5 ft Tide	Minor: minimal impact, some additional maintenance/staff time required for minor repair	Low	Low	Low	Low
Agricultural Areas East of Hwy 101	9.5 ft Tide		Low	Low	Low	Low
AMWS/ South I Street	10.1 ft Tide		Low	Low	Low	Low
AWTF	10.7 ft Tide		Low	Low	Low	Low
Impact: Potential Failure						
Agricultural Areas East of Hwy 101	11.1 ft Tide	Moderate: Manageable impact, potential repair, limited additional resources required	Low	Medium	Medium	Medium
AMWS/ South I Street	11.1 ft Tide		Low	Medium	Medium	Medium
South G Street	11.1 ft Tide	Major: Noticeable impact, requires significant effort to manage, requires significant repair, additional resource required	Low	Medium	High	High
AWTF	11.7 ft Tide		Very Low	Low	Medium	High

Risk Rating
Very High
High
Medium
Low
Very Low

9.2.2 Roads

Flooding to the centerline of a roadway requires City staff to post signage and light barriers to close the road. Consequences of road closure are moderate, with short (hours) delays in service and relatively small costs not typically budgeted for additional staff time and resources. Local traffic may still be able to travel through these areas if needed but is not advised.

The risk rating associated with these consequences and the likelihood of the threshold water level occurring are presented in Table 42. Roads currently subject to closure due to tidal water levels up to 10.1 feet or the 10-year fluvial event exhibit a medium risk rating. Higher elevation roads achieve a low to very low risk rating but eventually exhibit a medium risk rating by mid to late century.

Table 42 Risk rating for roadway flooding resulting in road closure. Graphical representation of risk to roads can be found in Appendix D.

Roadway Flooding (OPC Intermediate SLR Scenario)						
Impact: Centerline Flooding	**Threshold**	**Consequence**	**Year | Risk Rating**			
			2024	**2055**	**2075**	**2105**
Local Roads						
S G St	9.5 ft Tide	Moderate: Closure, short (hours) delays in service, increased costs not typically budgeted, limited additional resources required	Medium	Medium	Medium	Medium
5th St | Front St | H St | S F St | S H St | S I St	10.1 ft Tide		Medium	Medium	Medium	Medium
8th St | Anderson Ln | K St | L St N St | Old Arcata Rd	10yr Fluvial		Medium	Medium	Medium	Medium
2nd St | AWTF Site Access	10.7 ft Tide		Low	Medium	Medium	Medium
6th St | E St	11.1 ft Tide		Low	Medium	Medium	Medium
3rd St | 7th St | I St | J St | S Union St	11.7 ft Tide		Very Low	Low	Medium	Medium
4th St | D St	12.7 ft Tide		Very Low	Very Low	Very Low	Medium
Bayside Ct | Community Park Way | Union St	13.7 ft Tide		Very Low	Very Low	Very Low	Medium
Major Collectors						
Samoa Blvd	10.7 ft Tide	Moderate: Closure, short (hours) delays in service, increased costs not typically budgeted, limited additional resources required	Low	Medium	Medium	Medium
Minor Collectors						
Bayside Cutoff Rd	11.7 ft Tide	Moderate: Closure, short (hours) delays in service, increased costs not typically budgeted, limited additional resources required	Very Low	Low	Medium	Medium

Risk Rating
Very High
High
Medium
Low
Very Low

Flooding of a roadway that meets or exceeds one foot poses additional consequences. Deeper flooding would result in longer delays in service (1+ days), increased costs and resources not typically budgeted or readily available under normal operations. Local traffic and other services will not likely be able to get through due to lack of vehicle clearance and potentially dangerous conditions. For these reasons, the consequence of this type of flooding in major.

The risk rating associated with these consequences and the likelihood of the threshold water level occurring are presented in Table 43. The lowest elevation roads subject to excessive depth resulting from tidal water levels up to 10.1 feet exhibit a medium risk rating under current conditions and progress to high risk mid-century. Higher elevation roads achieve a low to very low risk rating but progress to a medium risk rating by mid-century and nearly all roads are high risk by late century.

Table 43 Risk rating for flooding of 1 ft depth or more resulting in no access.

Roadway Flooding (OPC Intermediate SLR Scenario)						
Impact: 1 ft Flooding	**Threshold**	**Consequence**	**Year | Risk Rating**			
			2024	**2055**	**2075**	**2105**
Local Roads						
Front St | S F St | S G St	10.1 ft Tide	Major: No Access, requires significant effort to manage, Temporary (1+ days) delays to service, Additional resource required	Medium	High	High	High
AWTF Site Access| S H St | S I St S G ST - South of AWTF	10.7 ft Tide		Low	Medium	High	High
5th St	100yr Fluvial 11.1 ft Tide		Low	Medium	High	High
H St	11.1 ft Tide		Low	Medium	High	High
2nd St | 6th St | 7th St | E St | I St | J St | S Union St	11.7 ft Tide		Very Low	Low	Medium	High
3rd St	12.7 ft Tide		Very Low	Very Low	Very Low	High
4th St | Bayside Ct | Community Park Way | D St	13.7 ft Tide		Very Low	Very Low	Very Low	Medium
Major Collectors						
Samoa Blvd	10.7 ft Tide	Major: No Access, requires significant effort to manage, Temporary (1+ days) delays to service, additional resource required	Low	Medium	High	High
Minor Collectors						
Bayside Cutoff Rd	12.7 ft Tide	Major: No Access, requires significant effort to manage, Temporary (1+ days) delays to service, additional resource required	Very Low	Very Low	Very Low	High

Risk Rating
Very High
High
Medium
Low
Very Low

9.2.3 Trails

Flooding of trails to a depth of six inches or more may require City staff to post signage and light barriers to close sections of the trail. Consequences of trail closure are moderate, with short (hours) delays in service and relatively small costs not typically budgeted for additional staff time and resources. Trail users may be able to find alternative routes or decide to use other means of transportation and recreation.

The risk rating associated with these consequences and the likelihood of the threshold water level occurring are presented in Table 44. Trails currently subject to closure due to tidal water levels up to 10 feet exhibit a medium risk rating. Higher elevation trails achieve a low to very low risk rating but eventually exhibit a medium risk rating by mid to late century.

Table 44 Risk rating for trail flooding greater than 6 inches resulting in closure.

Trail Flooding (OPC Intermediate SLR Scenario)						
Impact: > 6 inches flooding	Threshold	Consequence	Year | Risk Rating			
			2024	2055	2075	2105
Arcata Marsh and Wildlife Sanctuary	9.2 ft Tide	Moderate: Trail Closure, manageable impact with limited additional resources required				
Humboldt Bay Trail - North	10 ft Tide					
Samoa Blvd Path-South Side	11.7 ft Tide					
Samoa Blvd Path-North Side	12.7 ft Tide					
Dr Martin Luther King Jr Parkway to Samoa Blvd	12.7 ft Tide					

Risk Rating
Very High
High
Medium
Low
Very Low

9.2.4 Water Distribution System

Many of these pipes exist in areas of high seasonal groundwater and already exhibit high likelihood of flooding but minimal impacts and are therefore considered to be very low risk.

9.2.5 Wastewater Collection Piping

Consequences associated with the flooding of wastewater manholes vary depending on the number of manholes submerged and anticipated impacts to treatment effectiveness and the ability of the City to respond to overflows. The threshold of flooding that results in impacts is when flooding becomes regular, exceeding 6 times per year. The threshold for this is associated with water levels corresponding to MMMW. Flooding of less than ten manholes results in insignificant to minor consequences as overflows may be limited to isolated areas and the treatment plant can likely accommodate this amount of salt water into the system. As regular flooding begins to affect 11 or more manholes, consequences progress to moderate and major as the City's ability to respond to all locations to contain overflows requires additional resources and impacts to the ability to effectively treat sewer flows with higher saltwater concentration decrease.

The risk rating associated with these consequences and the likelihood of the threshold water level occurring are presented in Table 45. Currently, a low risk rating is achieved, but when considered in aggregate at all impacted locations, the risk rating increased to medium late century and high at the end of the century due to challenges responding to the extent of potential overflows and impacts to treatment capabilities.

Table 45 ***Risk rating for flooding of sewer manholes resulting in sanitary sewer overflows and reduced treatment capabilities. Graphical representation of risk to manholes can be found in Appendix D.***

Sewer Manhole Flooding (OPC Intermediate SLR Scenario)				
Impact: Sewer Overflows, Reduced Treatment	**Consequence**	**Year | Risk Rating**		
		2055	**2075**	**2105**
Outside of Roadway	Minor to Major: Sanitary sewer overflows, reduced treatment effectiveness with saltwater entering system.			
S G St				
S I St				
H St				
F St				
2nd St				
	Overall Risk			

Risk Rating
Very High
High
Medium
Low
Very Low

9.2.6 Wastewater Lift Stations

Flooding of wastewater lift stations result in escalating consequences as flooding first affects access and foundation-level equipment and components, then may progress to impact the backup power supply and electrical equipment that would result in failure of lift station's ability to maintain service. Minor consequences result from flooding entering the building that only affects access and requires cleanup. Major consequences are associated with flooding and failure of the backup power system and requires replacement of the backup system, but does not disrupt longer-term service. Consequences are severe when the electrical panel is exposed to flooding and failure of the lift station occurs that requires replacement and or reconstruction of facilities.

The risk rating associated with these consequences and the likelihood of the threshold water level occurring are presented in Table 46. The First Street Lift Station is located at the lowest elevation and backup power and electrical facilities are located 1.0 to 2.5 feet above the floor elevation. While this lift station currently achieves a low risk rating, the low ground and floor elevation results in a risk rating that progresses to medium and then high late century. All other lift stations are located at higher elevations and achieve a low risk rating throughout.

Table 46 Risk rating for flooding of lift stations that affect the building access, backup power and electrical equipment. Graphical representation of risk to Lift Stations can be found in Appendix D.

Lift Station Flooding (OPC Intermediate SLR Scenario)						
Impact: Operations, Service	**Threshold**	**Consequence**	**Year | Risk Rating**			
			2024	**2055**	**2075**	**2105**
First St Lift Station						
Building Flooding	10.7 ft Tide	Minor: Flooding enters structure, cleanup required				
Generator (Backup Power)	11.7 ft Tide	Major: Flooding at elevation of generators, failure of backup power, replacement of generator required				
Electrical Equipment	13.3 ft Tide	Severe: Flooding at elevation of electrical panel, failure of Lift Station, replacement / reconstruction				
Meadowbrook Lift Station						
Foundation and Electrical Equipment	100-yr Fluvial	Severe: Flooding at elevation of electrical panel, failure of Lift Station, replacement / reconstruction				
Wetlands Lift Station						
Foundation and Electrical Equipment	14.9 ft Tide	Severe: Flooding at elevation of electrical panel, failure of Lift Station, replacement / reconstruction				
Samoa Lift Station						
Foundation and Electrical Equipment	15.3 ft Tide	Severe: Flooding at elevation of electrical panel, failure of Lift Station, replacement / reconstruction				

Risk Rating
Very High
High
Medium
Low
Very Low

9.2.7 Wastewater Treatment Facilities

The AWTF is comprised of multiple components that exhibit a range of consequences due to the impacts on treatment, operations and the ability to maintain wastewater services, in addition to potential overflow to sensitive areas. Moderate consequences result from impacts to buildings, lift station and storage facilities that disrupt access or have potential to result in overflows. Major consequences are associated with a disruption of operations and reduced treatment effectiveness due to saltwater entering treatment facilities. Consequences are severe when flooding damages backup power, repair and replacement of equipment is needed. Catastrophic consequences are a result of damage to the electrical infrastructure that results in a failure of treatment capabilities and reconstruction and replacement of facilities and equipment.

The risk rating associated with these consequences and the likelihood of the threshold water level occurring are presented in Table 47 for essential facilities and Table 48 for other facilities. Currently, AWTF facilities exhibit a very low to low risk rating. Although the consequence of impacts can be severe to catastrophic, the likelihood of those impacts is very low (below 1-in-500 annual chance) as a result of the City's Phase One project that elevates several essential facilities. Risk ratings for building facilities and some treatment facilities (ponds and marshes) escalate to medium mid-century. High to very high risk ratings are associated with late century impacts to the headworks and lower grit pump area, backup power supply, and pond and marsh treatment facilities.

Table 47 Risk rating for AWTF facilities affecting treatment, operations and service. Graphical representation of risk to AWTF assets can be found in Appendix D.

AWTF Flooding (OPC Intermediate SLR Scenario)						
Impact: Treatment, Operations, Service, Overflows	**Threshold**	**Consequence**	**Year | Risk Rating**			
			2024	**2055**	**2075**	**2105**
Essential Facilities						
Generator Building	10.7 ft Tide	Moderate: Disruption of access, flooding enters structure, potential overflows to sensitive areas				
Pond Pump Station and Pump Station No.1	11.4 ft Tide					
Emergency Pond Pump Station	11.9 ft Tide					
Electrical Building	13.3 ft Tide					
Enhancement Wetlands Pump Station	14.9 ft Tide					
Headworks Lower Grit Pump Area	10.7 ft Tide	Major: Flooding disrupting operations, reduced treatment effectiveness				
Enhancement Marshes	10.7 ft Tide					
Oxidation Ponds	11.1 ft Tide					
Treatment Wetlands	11.1 ft Tide					
UV & Chlorine Contact Basins	15.7 ft Tide					
Primary Clarifier No.2	16.7 ft Tide					
Headworks Top Deck	22.4 ft Tide					
Generator Building Electrical Equipment	12.4 ft Tide	Severe: Flooding damaging backup power, replacement required				
Electrical Equipment for Essential Facilities[1]	14 ft Tide	Catastrophic: Flooding damaging electrical Infrastructure, failure of treatment capabilities reconstruction required				
Headworks Electrical Equipment	24 ft Tide					
[1]Electrical Equipment for Grit Pump, Primary Clarifier No. 2, Pond Pump Station, Pump Station No. 1, Emergency Pond Pump Station, UV & Chlorine Contact Basins, Enhancement Wetland Pump Station, Electrical Building)						

Risk Rating
Very High
High
Medium
Low
Very Low

Table 48 Risk rating for AWTF facilities affecting treatment and access.

AWTF Flooding (OPC Intermediate SLR Scenario)						
Impact: Treatment, Access	Threshold	Consequence	Year | Risk Rating			
			2024	2055	2075	2105
Other AWTF Facilities						
Office Facilities	10.7 ft Tide	Moderate: Disruption of access and operations, flooding enters structure, potential overflows to sensitive areas				
Sludge Drying Beds	11.1 ft Tide					
Site and Facility Access	11.1 ft Tide					

Risk Rating
Very High
High
Medium
Low
Very Low

9.2.8 Drainage - Groundwater and Sea Level Range

Consequences associated with the emergent groundwater and increases in the lower elevations of the tidal range will vary. A shallow groundwater surface is common in the area and measures to manage it are insignificant to minor, under typical operations. As groundwater becomes emergent in developed areas, the consequence becomes moderate, as additional measures and resources will be required to manage it, such as more frequent maintenance and the implementation of new infrastructure or pumps.

Consequences associated with reduced windows of gravity drainage or the complete lack of ability to provide gravity drainage exhibit greater consequences, from major to severe as new infrastructure or relocation / modification of existing infrastructure may be required.

The risk rating associated with these consequences and the likelihood of the threshold water level occurring are presented in Table 45. A low-risk rating is achieved through mid-century that increases to medium risk by end of century, due to the resources that will be required to manage emergent groundwater and drainage systems.

Table 49 Risk rating for emergent groundwater and increased low tide elevations.

Groundwater and Sea Level Range (OPC Intermediate SLR Scenario)				
Impact: Emergent Groundwater	**Consequence**	**Year | Risk Rating**		
		2055	**2075**	**2105**
Developed Areas	Moderate: Emergent Groundwater requires additional resources and increased maintenance and replacement			
Impact: Increased Elevation of Low Tide				
Developed Areas: Limited Drainage Windows with MSL at Ground Elevation	Major: Shortened windows of favorable drainage conditions. May require additional infrastructure to manage.			
Developed Areas: Gravity Drainage Not Feasible with MLLW at Ground Elevation	Severe Gravity drainage no longer feasible. Requires additional infrastructure and maintenance.			

10. Vulnerability and Risk Analysis Summary and Next Steps

This vulnerability and risk analysis is intended to build upon the previous vulnerability assessment to further detail impacts to assets, the projected timing of impacts, the likelihood of impacts for a given planning horizon, and communicate the risk to a given asset to inform adaptation and prioritization.

Based on the existing likelihood of events and consequences of impacts, assets exhibiting a risk rating of medium to very high are summarized in the tables below for the planning horizons 2024 (Table 50), 2055 (Table 51), 2075 (Table 52), and 2105 (Table 53).

Table 50 Risk Assessment summary of Medium to Very High Risk Ratings for the 2024 OPC Intermediate Scenario

Risk Assessment – 2024 (OPC Intermediate Scenario)		
Asset	**Impact**	**Consequence**
Very High Risk: Likely and Catastrophic to Very Likely and Severe Consequences		
None		
High Risk: Unlikely but Catastrophic to Very Likely and Major Consequences		
None		
Medium Risk: Very Unlikely but Catastrophic to Almost Certain and Minor Consequences		
Roads: S G St | 5th St | Front St | H St | S F St | S H St | S I St | 8th St | Anderson Ln | K St | L St N St | Old Arcata Rd	Flooding of centerline roadway	Moderate: Closure, short (hours) delays in service, increased costs not typically budgeted, limited additional resources required
Roads: Front St | S F St | S G St	1 ft or greater of flooding	Major: No Access, requires significant effort to manage, Temporary (1+ days) delays to service, Additional resource required
Trails: Arcata Marsh and Wildlife Sanctuary Humboldt Bay Trail - North	6 inches flooding	Moderate: Trail Closure, manageable impact with limited additional resources required

Table 51 Risk Assessment summary of Medium to Very High Risk Ratings for the 2055 OPC Intermediate Scenario

Risk Assessment – 2055 (OPC Intermediate Scenario)		
Asset	**Impact**	**Consequence**
Very High Risk: Likely and Catastrophic to Very Likely and Severe Consequences		
None		
High Risk: Unlikely but Catastrophic to Very Likely and Major Consequences		
Roads: Front St | S F St | S G St	1 ft or greater of flooding	Major: No Access, requires significant effort to manage, Temporary (1+ days) delays to service, Additional resource required
Medium Risk: Very Unlikely but Catastrophic to Almost Certain and Minor Consequences		
Shoreline Protection: Agricultural Areas East of Hwy 101 AMWS/ South I Street	Overtopping resulting in potential failure	Moderate: Manageable impact, potential repair, limited additional resources required
Shoreline Protection: South G Street	Overtopping resulting in potential failure	Major: Noticeable impact, requires significant effort to manage, requires significant repair, additional resource required
Roads: S G St | 5th St | Front St | H St | S F St | S H St | S I St | 8th St | Anderson Ln | K St | L St N St | Old Arcata Rd | 2nd St | AWTF Site Access | 6th St | E St	Flooding of centerline roadway	Moderate: Closure, short (hours) delays in service, increased costs not typically budgeted, limited additional resources required
Roads: AWTF Site Access S H St | S I St S G ST - South of WWTF | 5th St | H St | Samoa Blvd	1 ft or greater of flooding	Major: No Access, requires significant effort to manage, Temporary (1+ days) delays to service, Additional resource required
Trails: Arcata Marsh and Wildlife Sanctuary Humboldt Bay Trail - North	6 inches flooding	Moderate: Trail Closure, manageable impact with limited additional resources required
AWTF: Generator Building Headworks Lower Grit Pump Area	Treatment, operations, service, overflows	Moderate: Disruption of access, flooding enters structure, potential overflows to sensitive areas
AWTF: Headworks Lower Grit Pump Area	Treatment, operations, service, overflows	Major: Flooding disrupting operations, reduced treatment effectiveness
AWTF: Office Facilities Sludge Drying Beds Site and Facility Access	Treatment, access	Moderate: Disruption of access and operations, flooding enters structure, potential overflows to sensitive areas
AWTF: Enhancement Marshes Oxidation Ponds Treatment Wetlands	Treatment, access	Major: Flooding disrupting operations, reduced treatment effectiveness, potential overflows to sensitive areas

Table 52 Risk Assessment summary of Medium to Very High Risk Ratings for the 2075 OPC Intermediate Scenario

Risk Assessment – 2075 (OPC Intermediate Scenario)		
Asset	**Impact**	**Consequence**
Very High Risk: Likely and Catastrophic to Very Likely and Severe Consequences		
None		
High Risk: Unlikely but Catastrophic to Very Likely and Major Consequences		
Shoreline Protection: South G Street	Overtopping resulting in potential failure	Major: Noticeable impact, requires significant effort to manage, requires significant repair, additional resource required
Roads: Front St | S F St | S G St | AWTF Site Access| S H St | S I St | Samoa Blvd S G ST - South of WWTF | 5th St | H St	1 ft or Greater of Flooding	Major: No Access, requires significant effort to manage, Temporary (1+ days) delays to service, Additional resource required
AWTF: Headworks Lower Grit Pump Area	Treatment, operations, service, overflows	Major: Flooding disrupting operations, reduced treatment effectiveness
AWTF: Enhancement Marshes Oxidation Ponds Treatment Wetlands	Treatment, access	Major: Flooding disrupting operations, reduced treatment effectiveness, potential overflows to sensitive areas
Medium Risk: Very Unlikely but Catastrophic to Almost Certain and Minor Consequences		
Shoreline Protection: Agricultural Areas East of Hwy 101 AMWS/ South I Street	Overtopping resulting in potential failure	Moderate: Manageable impact, potential repair, limited additional resources required
Roads: S G St | 5th St | Front St | H St | S F St | S H St | S I St | 8th St | Anderson Ln | K St | L St N St | Old Arcata Rd | 2nd St | AWTF Site Access | 6th St | E St | 3rd St | 7th St | I St | J St | S Union St	Flooding of Centerline Roadway	Moderate: Closure, short (hours) delays in service, increased costs not typically budgeted, limited additional resources required
Roads: 2nd St | 6th St | 7th St | E St | I St | J St | S Union St	1 ft or Greater of Flooding	Major: No Access, requires significant effort to manage, Temporary (1+ days) delays to service, Additional resource required
Trails: Arcata Marsh and Wildlife Sanctuary Humboldt Bay Trail – North Samoa Blvd Path-South Side	6 inches Flooding	Moderate: Trail Closure, manageable impact with limited additional resources required
Lift Stations: First Street – Generator (Backup Power)	Flooding Affecting Operations, Service	Major: Flooding at elevation of electrical equipment, generators, failure of backup power, replacement of generator required
Lift Stations: Meadowbrook – Electrical Equipment	Flooding Affecting Operations, Service	Severe: Flooding at elevation of electrical panel, failure of Lift Station, replacement / reconstruction
AWTF: Generator Building Headworks Lower Grit Pump Area Emergency Pond Pump Station	Treatment, Operations, Service, Overflows	Moderate: Disruption of access, flooding enters structure, potential overflows to sensitive areas
AWTF: Generator Building Electrical Equipment	Treatment, Operations, Service, Overflows	Severe: Flooding damaging backup power, replacement required
AWTF: Office Facilities Sludge Drying Beds Site and Facility Access	Treatment, Access	Moderate: Disruption of access and operations, flooding enters structure, potential overflows to sensitive areas

Table 53 Risk Assessment summary of Medium to Very High Risk Ratings for the 2105 OPC Intermediate Scenario

Risk Assessment – 2105 (OPC Intermediate Scenario)		
Asset	**Impact**	**Consequence**
Very High Risk: Likely and Catastrophic to Very Likely and Severe Consequences		
AWTF: Generator Building Electrical Equipment	Treatment, Operations, Service, Overflows	Severe: Flooding damaging backup power, replacement required
High Risk: Unlikely but Catastrophic to Very Likely and Major Consequences		
Shoreline Protection: South G Street AWTF	Overtopping resulting in potential failure	Major: Noticeable impact, requires significant effort to manage, requires significant repair, additional resource required
Roads: Front St | S F St | S G St | AWTF Site Access| S H St | S I St | Samoa Blvd S G ST - South of AWTF | 5th St | H St | 2nd St | 6th St | 7th St | E St | I St | J St | S Union St | 3rd St | Bayside Cutoff Rd	1 ft or Greater of Flooding	Major: No Access, requires significant effort to manage, Temporary (1+ days) delays to service, Additional resource required
Lift Stations: First Street – Generator (Backup Power) and Electrical Panels	Flooding Affecting Operations, Service	Severe: Flooding at elevation of electrical panel, failure of Lift Station, replacement / reconstruction
AWTF: Headworks Lower Grit Pump Area	Treatment, Operations, Service, Overflows	Major: Flooding disrupting operations, reduced treatment effectiveness
AWTF: Enhancement Marshes Oxidation Ponds Treatment Wetlands	Treatment, Access	Major: Flooding disrupting operations, reduced treatment effectiveness, potential overflows to sensitive areas
Medium Risk: Very Unlikely but Catastrophic to Almost Certain and Minor Consequences		
Roads: S G St | 5th St | Front St | H St | S F St | S H St | S I St | 8th St | Anderson Ln | K St | L St N St | Old Arcata Rd | 2nd St | AWTF Site Access | 6th St | E St | 3rd St | 7th St | I St | J St | S Union St | 4th St | D St | Bayside Ct | Community Park Way | Union St	Flooding of Centerline Roadway	Moderate: Closure, short (hours) delays in service, increased costs not typically budgeted, limited additional resources required
Roads: 2nd St | 6th St | 7th St | E St | I St | J St | S Union St	1 ft or Greater of Flooding	Major: No Access, requires significant effort to manage, Temporary (1+ days) delays to service, Additional resource required
Trails: Arcata Marsh and Wildlife Sanctuary Humboldt Bay Trail – North Samoa Blvd Path-South Side Samoa Blvd Path-North Side Dr Martin Luther King Jr Parkway to Samoa Blvd	6 inches Flooding	Moderate: Trail Closure, manageable impact with limited additional resources required
Lift Stations: Meadowbrook – Electrical Equipment	Flooding Affecting Operations, Service	Severe: Flooding at elevation of electrical panel, failure of Lift Station, replacement / reconstruction
AWTF: Generator Building Headworks Lower Grit Pump Area Emergency Pond Pump Station Electrical Building	Treatment, Operations, Service, Overflows	Moderate: Disruption of access, flooding enters structure, potential overflows to sensitive areas
AWTF: Electrical Equipment for Essential Facilities	Treatment, Access	Catastrophic: Flooding damaging electrical Infrastructure, failure of treatment capabilities reconstruction required
AWTF: Office Facilities Sludge Drying Beds Site and Facility Access	Treatment, Access	Moderate: Disruption of access and operations, flooding enters structure, potential overflows to sensitive areas

Based on the vulnerability and risk assessments presented in this report, GHD will work with City staff to identify priority locations and strategies for adaptation. Adaptation projects will be developed to address identified vulnerabilities to inform the LCP and planned CIP projects which include the Arcata Wastewater Treatment Facility upgrades and presented in a separate report. Strategies considered will include nature-based adaptation, hybrid approaches, managed retreat, or improvement of current infrastructure. The adaptation strategies chosen will consider a variety of options depending on the exposure and the most appropriate techniques to address those exposures. The adaptation strategies will consider the location, engineering feasibility, costs, environmental impacts, as well as consistency with the Coastal Act, City LCP Policy, current State and Coastal Commission sea level rise planning guidance, and other relevant guidance and regulations as necessary. The adaptation strategies will consider both the location of assets, as well as the condition and age (where known) and proximity to other natural and built landscapes at risk to determine if there are opportunities for multi-benefit adaptation strategies that address both climate adaptation, as well as long term capital planning.

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Appendices

Appendix A

Northern Hydrology & Engineering
Shoreline Coastal Flood Assessment

Northern Hydrology and Engineering

P.O. Box 2515, McKinleyville, CA 95519
Telephone: (707) 839-2195; email: jeff@northernhydrology.com

Engineering – Hydrology – Stream Restoration – Water Resources

TECHNICAL MEMORANDUM

Date: 07 July 2024

To: Brett Vivyan, P.E.
Project Manager/Technical Director
GHD Inc.
713 3rd Street
Eureka, CA 95501

From: Jeffrey K. Anderson, P.E., M.S.

Re: Existing Condition Coastal Flood Assessment for the City of Arcata Sea Level Rise Vulnerability and Adaptation Planning Services Project, City of Arcata, Humboldt County

1 INTRODUCTION AND PURPOSE

GHD Inc. and Northern Hydrology & Engineering (NHE) are currently developing a City of Arcata Sea Level Rise Vulnerability and Adaptation Planning Services Project (Project) for the City of Arcata. This technical memorandum summarizes a coastal flood analysis conducted by NHE to support the Project.

The purpose of this analysis determines representative still water levels, wind setup, wave setup and runup values from locally generated wind-waves, and total water levels for the City of Arcata's shoreline in Arcata Bay (North Bay). Results are provided for a combination of wind speeds and water levels that span tidal datums to extreme annual exceedance probability events. Total water level estimates are provided for both natural and armored shoreline segments, with the difference between estimates being the inclusion of wave setup and runup for the armored shoreline.

This analysis was conducted in SI units (e.g. wave height in meters, wind speed as meters per second) but tabulated results will be presented in both SI and English units. Water levels or water surface elevations are referenced to the North American Vertical Datum of 1988 (NAVD88).

2 PROJECT SETTING AND LOCATION

2.1 Physical Setting

Humboldt Bay is a multi-basin, bar-built coastal lagoon located approximately 260 miles (418 km) north of San Francisco, California, is the second largest natural bay in California, and the only major harbor between San Francisco and Portland, Oregon (Costa and Glatzel 2002). Humboldt Bay consists of three basins, Arcata Bay (or North Bay), Entrance Bay and South Bay (Figure 1). North Bay is connected to Entrance Bay by a long narrow channel (North Bay Channel) that splits into multiple channels at the northern end of the channel, and South Bay and Entrance Bay are separated by a constriction between King Salmon and the South Bay spit. Humboldt Bay has a water surface area of approximately 25 mi^2 (65 km^2) at high tide, 8 mi^2 (21 km^2) at low tide, and about 70% of the bay is exposed tidal mudflat at low tide, with most of the mudflat contained in shallower North and South Bays (Costa and Glatzel 2002).

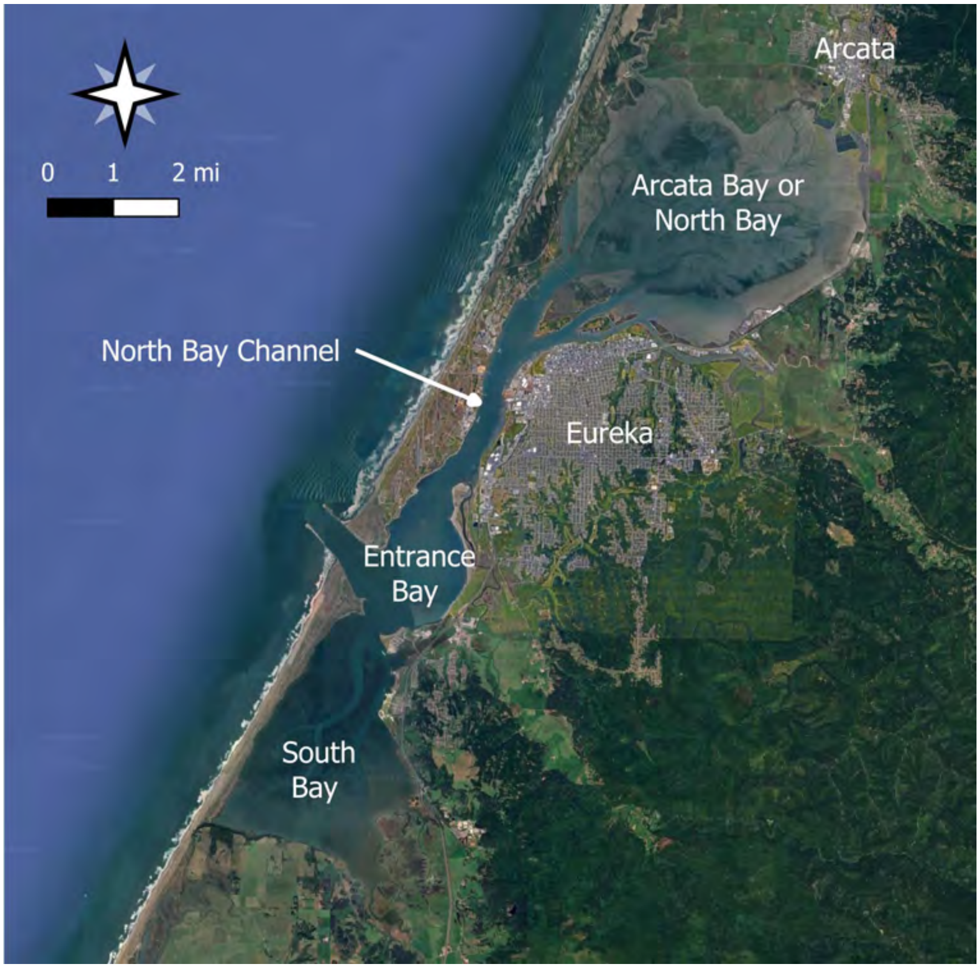

Figure 1. Humboldt Bay vicinity and location map.

Humboldt Bay lies within the 42 mile (67 km) long Eureka littoral cell (ELC) which is bounded by Trinidad Head to the north and False Cape to the south (see Figure 5). The region is known for its high erosion rates and fluvial sediment supply, which is generally attributed to a combination of unique land use, climate, geology and tectonics (Kelsey 1980; Mackey et al. 2011; Warrick et al. 2013). The ELC has an approximate 4,520 mi^2 (11,700 km^2) contributing watershed, and the two largest rivers (Eel River and Mad River) discharge directly into the ELC. In comparison, the Humboldt Bay watershed is relatively small at 223 mi^2 (578 km^2). The four largest Humboldt Bay streams are Jacoby Creek and Freshwater Creek that discharge into North Bay, Elk River that discharges into the northern end of Entrance Bay, and Salmon Creek that discharges into South Bay. Although the region's climate is relatively moderate (cool temps with moderate precipitation of 30-40 inches/year), the wave climate is quite extreme with large frequent swells emanating from both the North and South Pacific (Wheatcroft and Borgeld 2000; Costa and Glatzel 2002; George and Hill 2008).

The dominant forcing in Humboldt Bay are tides, followed by incident ocean waves that pass through the jetty into Entrance Bay, with wind and locally generated wind-waves having a secondary forcing in the shallow North and South Bays (Costa and Glatzel 2002). Due to the small watershed size and low freshwater flows, the circulation in Humboldt Bay is tidally dominated and the bay consists of well-mixed marine water. Seasonal estuarine conditions are generally associated with the sub-estuary regions of the bay tributaries (Costa and Glatzel 2002).

2.2 Project Location

This analysis assesses coastal flooding along a portion of the northern shoreline in Arcata Bay (North Bay). For this assessment the Project shoreline is defined as the portion shoreline that includes the City of Arcata Wastewater Treatment Facility (WWTF) oxidation ponds, treatment wetlands, enhancement wetlands and Klopp Lake levees, and the tidal wetlands/levees that make up the southern shoreline of the McDaniel Slough/Janes Creek restoration project (Figure 2). The Project shoreline consists of both natural and armored shoreline segments. The natural shoreline consists of tidal wetland segments, and rock revetments make up the armored shoreline. Most of the rock revetment in the Project shoreline armor the levees that surround the WWTF.

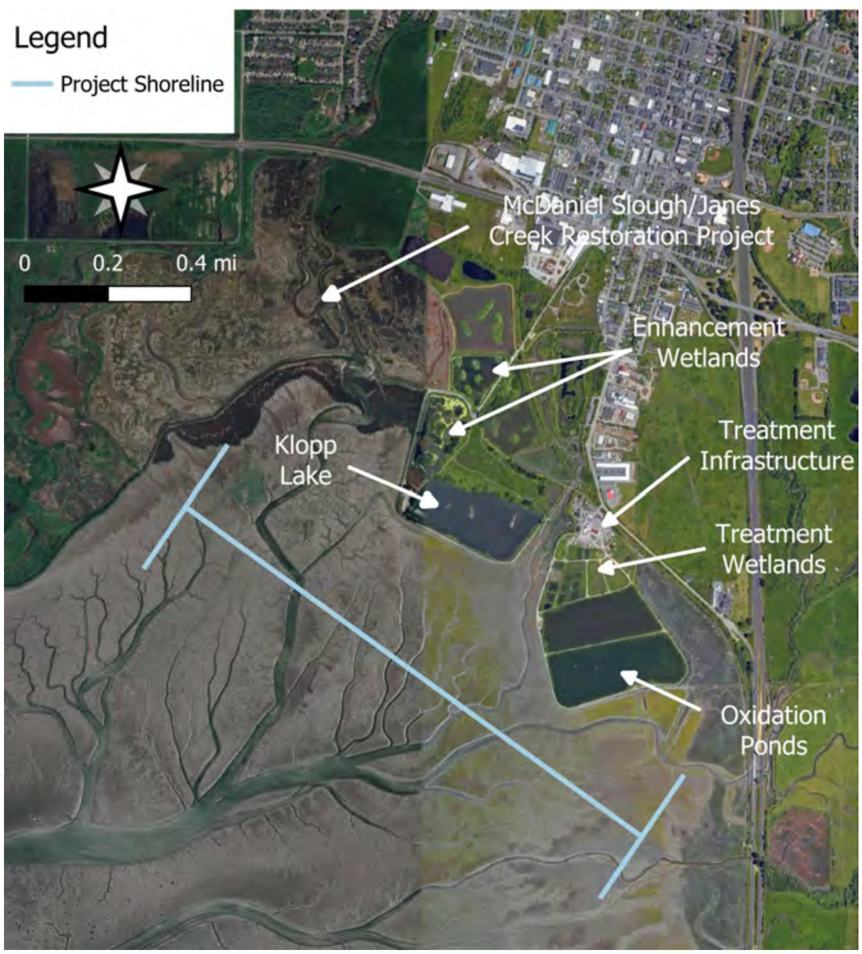

Figure 2. The City of Arcata Project shoreline in northern portion of Arcata Bay (North Bay).

2.3 Topography and Bathymetry

Project area topography and bathymetry was defined by the 2020 USGS Coastal National Elevation Database (CoNED) 1-meter topobathymetric digital elevation model (TBDEM) for the Northern California Coast (2020 USGS CoNED DEM). The 2020 USGS CoNED DEM (or Project DEM) consists of multiple topographic and bathymetric data sets ranging in dates from approximately 1986 to 2019 that have been aligned vertically and horizontally to a common reference system (OCM Partners 2024). Figure 3 shows the topography and bathymetry of the City of Arcata Project shoreline in North Bay.

According to the online metadata information (OCM Partners 2024), it appears the topographic data surrounding Humboldt Bay relied on the City of Eureka 2019 Humbold Bay LiDAR (24 September 2019 acquisition date). For this assessment, it was assumed the City of Eureka 2019 LiDAR represents ground elevations in 2019 at the time of the acquisition and has not been adjusted for vertical land motion either before or after the acquisition date. This distinction is important when comparing ground elevations to observed or modeled water surface elevations, and when considering future sea-level change.

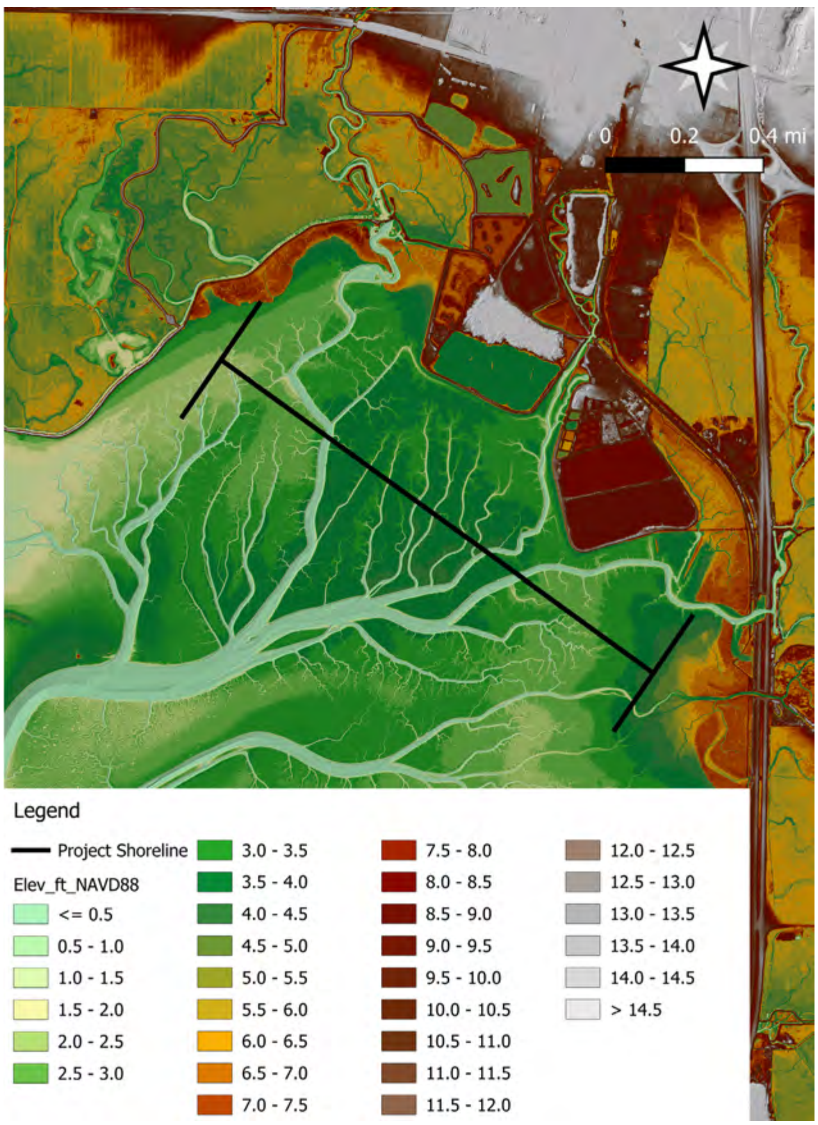

Figure 3. Project area topography and bathymetry in vicinity of the City of Arcata Project shoreline in North Bay. Topography and bathymetry based on 2020 USGS CoNED DEM.

2.4 FEMA Flood Hazard Maps

The Project shoreline is in a Federal Emergency Management Agency (FEMA) Special Flood Hazard Area for which 1% base flood elevations (BFE) have been determined from a detailed coastal flood hazard analysis for the open coast and Humboldt Bay (FEMA 2014 and 2018). FEMA determined a constant still water elevation of 10.2 ft NAVD88 for Humboldt Bay. The coastal analysis BFE represents the 1% total water level (TWL), which includes the still water elevation and increased elevation from wave setup and wave runup at the shoreline. To determine locally generated wind-waves in Humboldt Bay, FEMA assumed an extreme wind speed of 45 mph (20.1 mps).

Figure 4 shows the Project shoreline on Flood Insurance Rate Map (FIRM) map panels 06023C0835G, 06023C0845G, 06023C0852G and 06023C0855G. Within the Project shoreline, areas behind levees, revetments or far enough inland from the shoreline that wave runup does not apply are within an AE zone with a BFE of 10 ft (NAVD88). Areas in front of shoreline levees and revetments are mapped as VE zones with a BFE of 13 to 14-ft, due to wave setup and runup. It should be noted that areas within the McDaniel Slough/Janes Creek restoration area have BFE ranging from 11 to 12-ft due to wave growth landward of the levee.

The 1% flood elevations determined in this assessment can be considered refinements to the FEMA 1% BFEs for the Project shoreline. The 1% flood elevations are a composite water level estimate specific to the Project shoreline consisting of coastal extreme high-water levels (e.g. storm surge), wind effects (wind setup), wave effects (e.g. wave runup), and sea-level change adjustments.

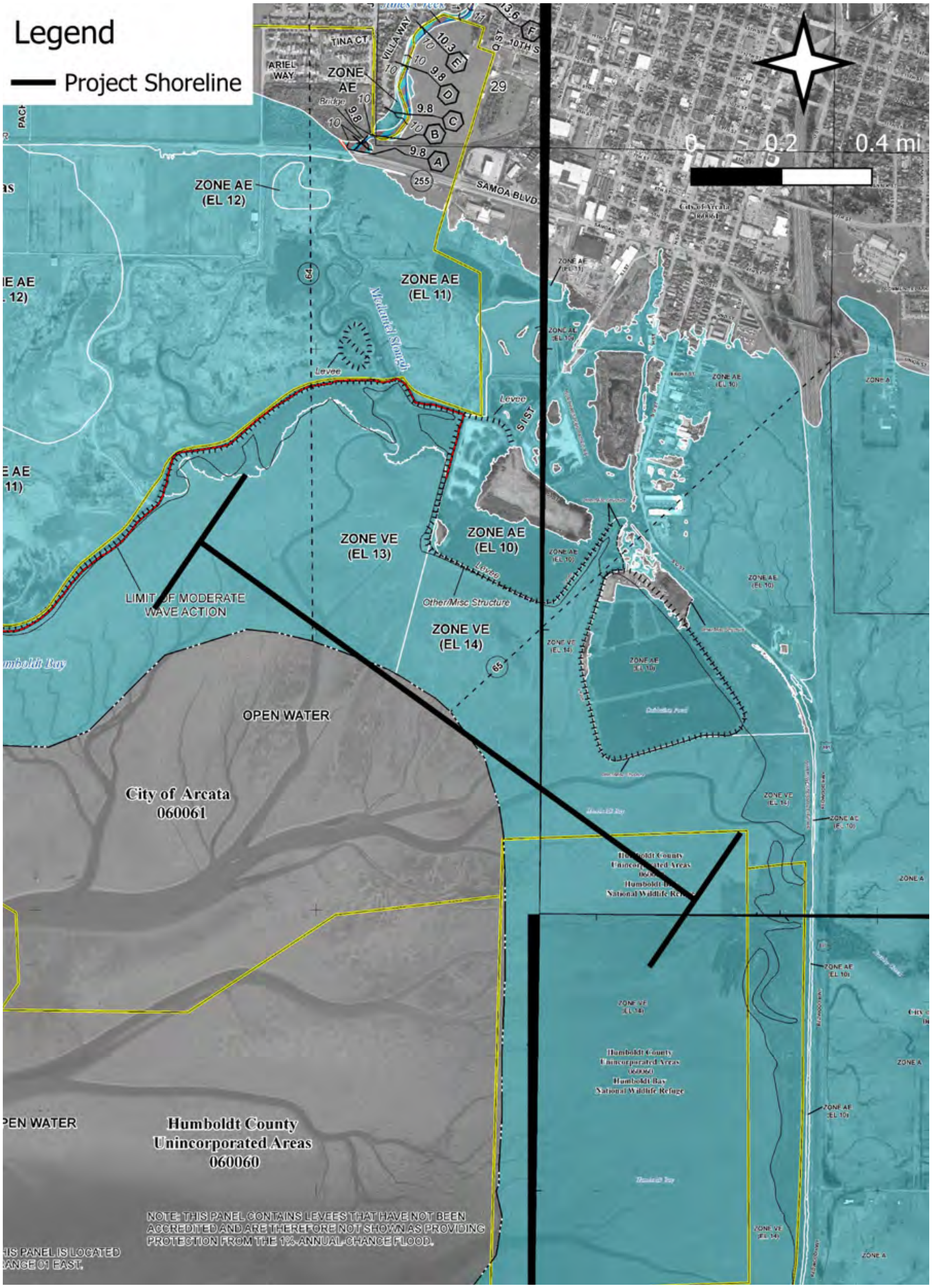

Figure 4. FEMA Base flood elevations (BFE) in ft (NAVD88) for the North Bay Project shoreline (FIRM map panels 06023C0835G, 06023C0845G, 06023C0852G and 06023C0855G).

3 HUMBOLDT BAY COASTAL HYDROLOGY AND FLOOD HAZARDS

This section describes the coastal hydrology in Humboldt Bay related to the general Project site location. Figure 5 shows Humboldt Bay within the context of the Eureka Littoral Cell, and the locations of Humboldt Bay tidal stations nearby weather stations.

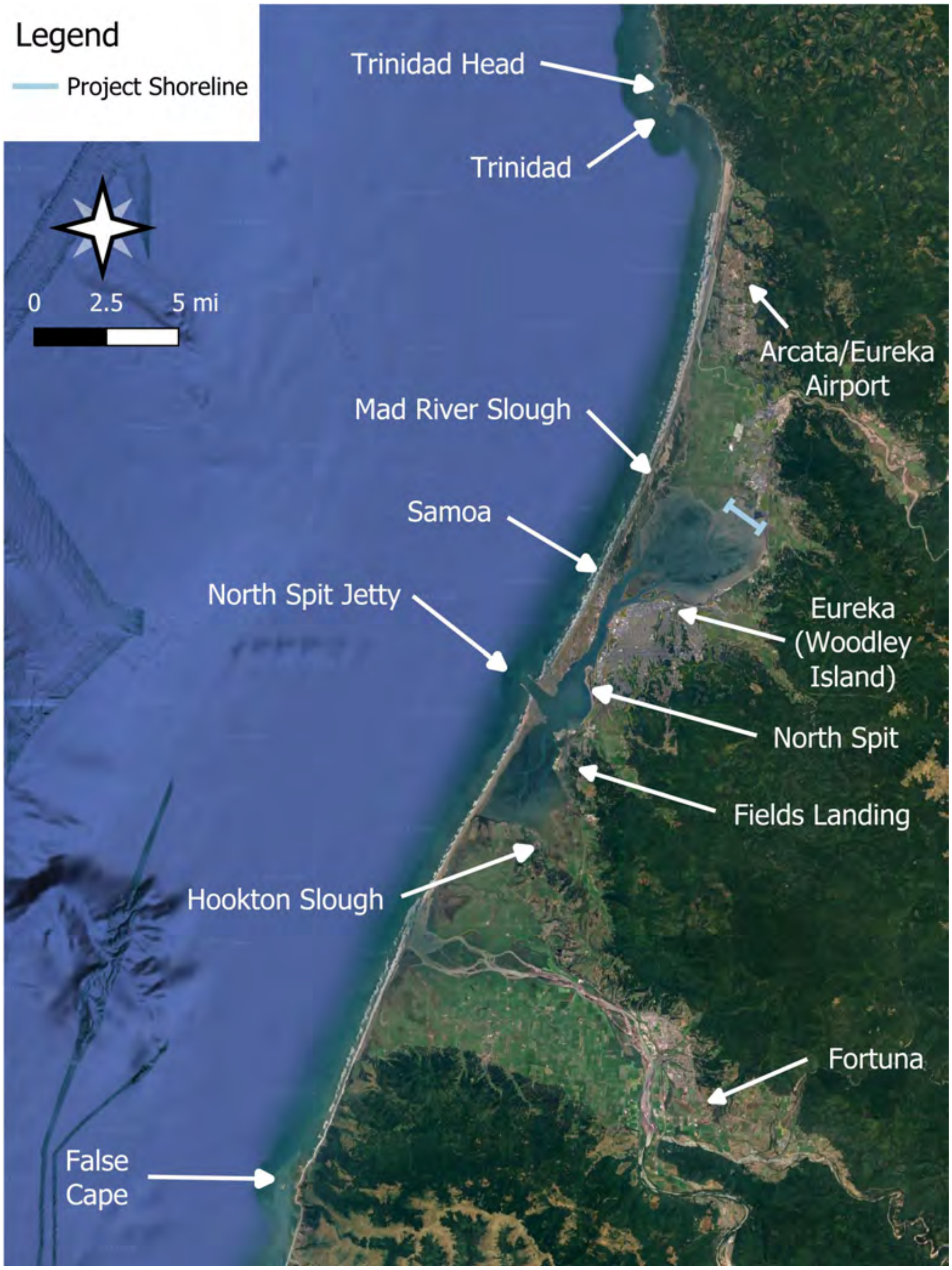

Figure 5. Location of NOAA tide stations in Humboldt Bay and Trinidad, weather stations in the Project area, and the extents of the Eureka Littoral Cell from Trinidad Head to the north and False Cape to the south. Crescent City tide station is located approximately 68 miles (109 km) north of the North Spit station.

3.1 Tide Levels and Tidal Datums

Humboldt Bay tides have a mixed semidiurnal pattern with two unequal high and low tides during each tidal (or lunar) day of duration 24 hours and 50 minutes. Continuous water level observations are available for the National Oceanic and Atmospheric Administration (NOAA) primary North Spit, CA tide station (Station ID: 9418767) with data spanning August 1977 to present. Tidal datums for the North Spit station and a secondary NOAA tide station in North Bay, Mad River Slough (Station ID: 9418865) are provided in Table 1 for the 1983-2001 tidal epoch. The location of the tidal stations relative to the Project shoreline are shown in Figure 5.

Table 1. Tidal datums and water levels reported by NOAA for North Spit and Mad River Slough tidal stations for the 1983-2001 tidal epoch; datums and elevations referenced to NAVD88.

		North Spit (NS) ID: 9418767		Mad River Slough (MRS) ID: 9418865	
Description	**Abbrev.**	**Value (m)**	**Value (ft)**	**Value (m)**	**Value (ft)**
Highest Observed Tide	HOT	2.910	9.54	NA	NA
Highest Astronomical Tide	HAT	2.592	8.50	NA	NA
Mean Higher High Water	MHHW	1.987	6.51	2.021	6.63
Mean High Water	MHW	1.770	5.80	1.800	5.90
Mean Tide Level	MTL	1.025	3.36	0.953	3.13
Mean Sea Level	MSL	1.025	3.36	0.990	3.25
Mean Low Water	MLW	0.280	0.91	0.105	0.34
North American Vertical Datum 1988	NAVD88	0.000	0.00	0.000	0.00
Mean Lower Low Water	MLLW	-0.103	-0.34	-0.305	-1.00
Lowest Astronomical Tide	LAT	-0.835	-2.74	NA	NA
Highest Observed Tide	LOT	-0.986	-3.24	NA	NA
Diurnal Tidal Range (MHHW – MLLW)	2.090	6.86	6.86	2.326	7.63

3.2 Sea-Level Change and Vertical Land Motion

Humboldt Bay has the highest rates of sea-level rise in California. (NHE 2018). Recently, Patton et al. (2023) updated relative sea-level (RSL) and vertical land motion (VLM) rates and standard errors (SE) for the Crescent City and Trinidad tide stations, and five stations in Humboldt Bay (Figure 5 and Table 2). RSL rates were refined by combining the individual station rates and the difference in rates between stations in a weighted least squares adjustment. The VLM rates were resolved by subtracting the regional (or absolute) sea-level (ReSL) rate of 1.99 mm/yr for the Pacific Northwest region (Montillet et al. 2018) from the adjusted RSL rates. Within Humboldt Bay there is a significant north to south longitudinal gradient in RSL and VLM rates, consisting of lower rates to the north and higher rates to the south. The North Spit (NS) and Mad River Slough (MRS) stations are the same in Table 1 and Table 2.

Table 2. Tide station relative sea level (RSL) and vertical land motion (VLM) rates and standard errors (SE) from Patton et al. (2023); VLM determined by differencing RSL and the regional (or absolute) sea level (ReSL) rate of 1.99 ± 0.16 mm/yr (Montillet et al., 2018).

Station and Abbreviation	NOAA Station ID	Relative Sea-Level (RSL) (mm/yr)		Vertical Land Motion (VLM) (mm/yr)	
		Rate	SE	Rate	SE
Crescent City (CC)	9419750	-0.84	0.14	2.83	0.21
Trinidad (TR)	9419059	2.86	1.10	-0.87	1.11
Mad River Slough (MRS)	9418865	2.53	0.41	-0.54	0.44
Samoa (SO)	9418817	3.92	0.35	-1.93	0.38
North Spit (NS)	9418767	5.20	0.17	-3.21	0.23
Fields Landing (FL)	9418723	4.65	0.33	-2.66	0.37
Hookton Slough (HS)	9418686	6.64	0.65	-4.65	0.67

3.3 Estimated Extreme Water Levels and Tidal Datum Still Water Levels

The coastal still water levels for this analysis came from the 2D hydrodynamic model developed as part of the Humboldt Bay sea-level rise modeling and inundation vulnerability mapping project (NHE 2015). Estimates of Year 2023 extreme high-water levels were determined at a representative grid cell location (adjacent to Klopp Lake) along the Project shoreline reach (Figure 2). The maximum daily water elevation (NAVD88) for each day of the 100-yr simulation was extracted from the results database resulting in 36,525 daily values for each selected grid cell.

Estimates of the mean higher high water (MHHW) tidal datum, and the mean monthly maximum water (MMMW) and mean annual maximum water (MAMW) levels were determined from the 36,525 daily maximum values. An estimate of mean high water (MHW) was provided by subtracting 21.7 cm (9.54 in) from MHHW (NHE 2015).

An extreme value analysis (EVA) was conducted on the daily maximum water levels at each grid cell using the peaks-over-threshold (POT) approach and Generalized Pareto Distribution (GPD). A theoretical definition, more detailed information, and an explanation of the parameter estimation process for the POT and GPD can be found in Coles (2001). The EVA and parameter estimation were conducted with the R package extRemes (Gilleland and Katz 2016). All model distribution parameters were determined with the maximum likelihood estimation approach (Coles 2001). For this analysis, the threshold value was set to 97% of the maximum daily data. To satisfy the independence requirement of the EVA analysis, a de-clustering time of 3 days was used. Using these threshold and de-clustering values results in an approximate mean number of exceedances per year of 3.9, which is consistent with recommendations for regional and global extreme sea level analysis (Arns et al. 2017).

Results of the tidal datum and still water level EVA for the Project shoreline are provided in Table 3. Water levels were adjusted for sea-level rise to represent Year 2023 estimates using a ReSL value of 1.99 mm/yr. For comparison results for the North Spit tide station grid cell location are also provided.

Costa and Glatzel (2002) noted that tidal amplification and phase lag occur within the bay based on distance from the entrance. Both the reported NOAA tidal datum values (Table 1) and the modeled tidal datum and EVA water levels (Table 3) show tidal amplification into North Bay, along with an increase in the diurnal tidal range (difference between MHHW and MLLW.

Table 3. Summary of tidal datum and extreme value analysis (EVA) still water levels for the Project shoreline and North Spit tide station for Year 2023. Water levels adjusted to Year 2023 using a ReSL value of 1.99 mm/yr.

Tidal Datum and Annual Exceedance Probability (%)	Annual Expected Number of Occurrences (#/yr)	Annual Average Recurrence Interval (yr)	Year 2023 Estimated Still Water Levels (NAVD88)			
			Project Shoreline		North Spit	
			Value (m)	Value (ft)	Value (m)	Value (ft)
MHW[1]			1.994	6.54	1.838	6.03
MHHW			2.176	7.14	2.055	6.74
MMMW			2.584	8.48	2.441	8.01
MAMW			2.896	9.50	2.753	9.03
99.0	0.99	1.01	2.836	9.30	2.694	8.84
95.0	0.95	1.053	2.841	9.32	2.699	8.86
90.9	0.91	1.1	2.847	9.34	2.705	8.87
80.0	0.80	1.25	2.862	9.39	2.721	8.93
66.7	0.67	1.5	2.885	9.46	2.742	9.00
50.0	0.50	2	2.918	9.57	2.776	9.11
20.0	0.20	5	3.017	9.90	2.872	9.42
10.0	0.10	10	3.082	10.11	2.937	9.64
5.0	0.05	20	3.142	10.31	2.996	9.83
4.0	0.04	25	3.160	10.37	3.014	9.89
2.0	0.02	50	3.211	10.54	3.065	10.05
1.0	0.01	100	3.258	10.69	3.111	10.21
0.5	0.005	200	3.300	10.83	3.152	10.34
0.2	0.002	500	3.349	10.99	3.201	10.50

[1] MHW was estimated by subtracting 21.7 cm (8.54 in) from MHHW (NHE 2015).

3.4 Winds

Humboldt Bay has distinct seasonal wind patterns, with winds from the north to northwest from March through October, and southeast to southwest winds from November to February (Costa and Glatzel 2002). Several weather stations exist in the Project vicinity with wind speed and direction data (Figure 5 and Table 4).

Table 4. Weather stations in Project vicinity with wind speed and direction data. Arcata/Eureka Airport data downloaded from NOAA Integrated Surface Data (ISD) database; data for other stations from Iowa Environmental Mesonet of Iowa State University.

Station Name	Station ID	Coordinates	Elevation	Period of Record	Notes
Arcata/Eureka Airport	ACV	40.97811°N, 124.10861°W	66 m (217 ft)	1949 to present	Wind analysis
Fortuna	FOT	40.55390°N, 124.13270°W	112 m (369 ft)	2011 to present	Wind rose
Eureka (Woodley Island)	EKA	40.80970°N, 124.16030°W	18 m (599 ft)	1948 to 2022	Wind rose
North Spit (9418767)	HBYC1	40.76700°N, 124.21700°W	7.6 m (25.9 ft)	2016 to present	Wind rose
Samoa - North Jetty Landing	NJLC1	40.76890°N, 124.23890°W	6 m (20 ft)	2020 to present	Wind rose

Hourly wind data for the stations listed in Table 4 were used to generate wind roses (Figure 6). The two land-based automated surface observation stations (ASOS) (Eureka/Arcata Airport and Fortuna) show an opposing northwest to southeast wind direction pattern, while the three stations located in Humboldt Bay (Eureka and North Spit) and nearshore (North Jetty Landing) show a stronger north to south pattern. This indicates that the topography of the easterly Northern Coast Range adjacent to Humboldt Bay may have a topographic steering effect on wind directions of the land-based stations.

An extreme 2-min wind speed and direction analysis was conducted by NHE for the Natural Shoreline Infrastructure project using the Arcata/Eureka Airport wind data (Appendix D, GHD et al. 2022). Reference to Appendix D can be made for a detailed discussion of the analysis methods and results.

Peak 2-min wind speeds (assuming a Gumbel distribution) differ by wind direction in Humboldt Bay (Figure 7). The fastest wind speeds are from the east-southeast (112.5°) to north (360°) directions, with peak winds from easterly directions being much lower. Consistent with the Arcata/Eureka Airport wind rose (Figure 6) maximum peak winds appear to come from two dominant and opposing directions, southeast (135°) and northwest (315°). The extreme wind speed analysis was based on a GPD-POT approach and used the maximum daily 2-min wind speed neglecting wind direction. Consequently, the resulting extreme wind speeds are applicable for any wind direction from approximately 112.5° to 360°. Table 5 lists the estimated 2-min extreme wind speeds affecting the Project shoreline.

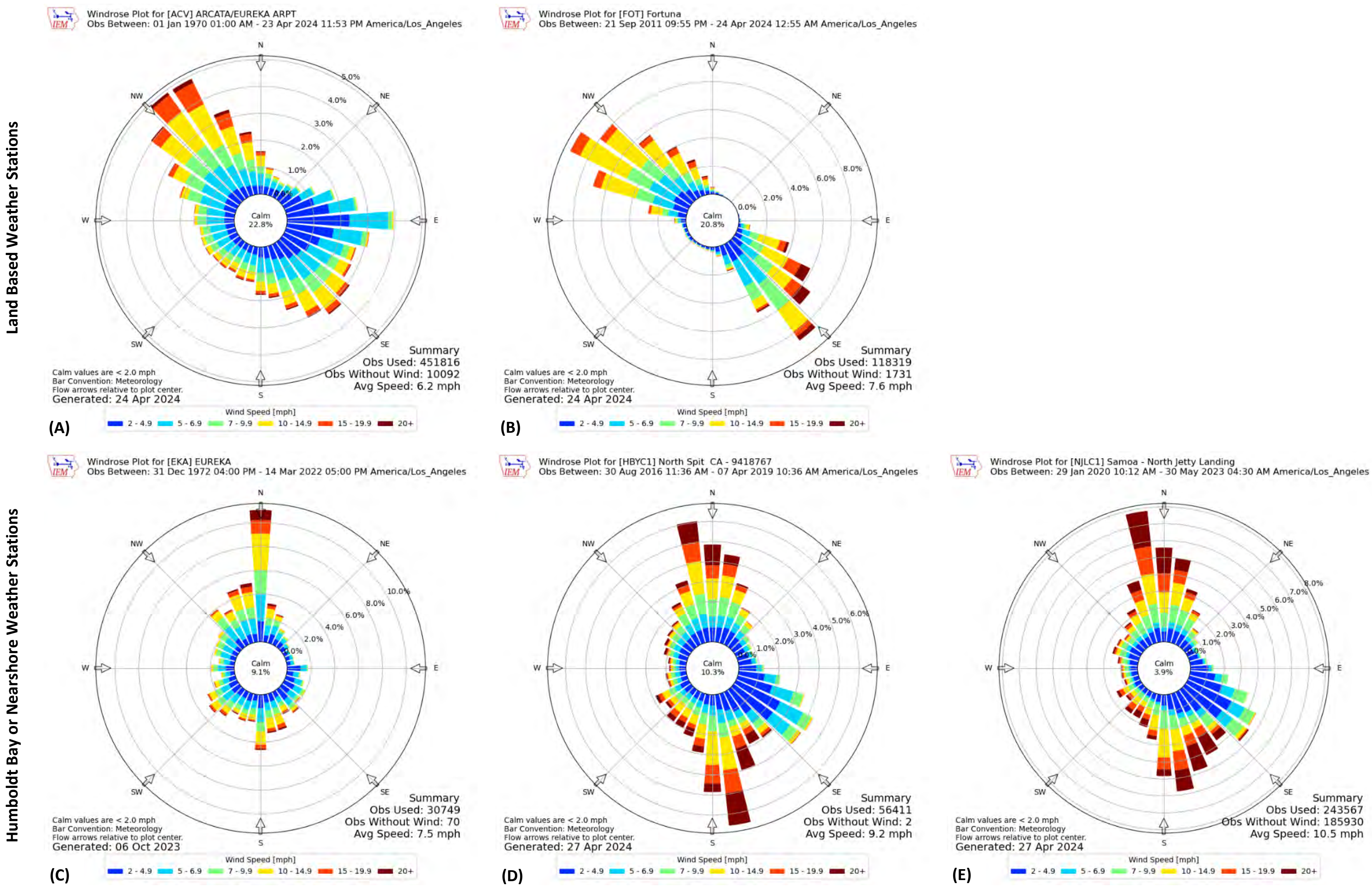

Figure 6. Wind rose for Arcata/Eureka Airport (A), Fortuna (B), Eureka (C), North Spit (D) and North Jetty Landing (E). Plots generated from Iowa Environmental Mesonet of Iowa State University.

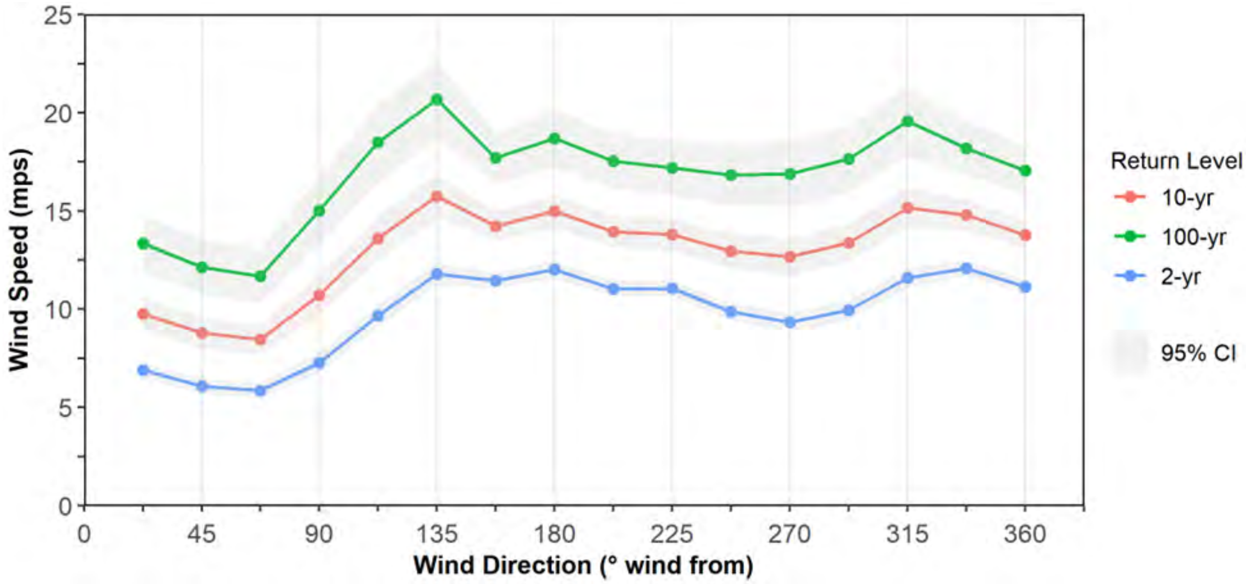

Figure 7. Peak 2-min wind speed estimates and 95% confidence intervals by wind direction from a Gumbel distribution for the 2-yr, 10-yr and 100-yr return levels (figure from Appendix D, GHD et al., 2022).

Table 5. Extreme 2-min wind speed estimates from the POT/GPD analysis of the Arcata/Eureka Airport data (Appendix D, GHD et al. 2022). Wind speeds have been adjusted to 2-min average duration and 10 m height.

Annual Exceedance Probability (%)	Annual Expected Number of Occurrences (#/yr)	Annual Average Recurrence Interval (yr)	Extreme 2-min Wind Speed (mps)		Extreme 2-min Wind Speed (mph)	
			Estimate	95% CI	Estimate	95% CI
~100	~1	~1	16.85	[15.90, 17.79]	37.7	[35.6, 39.8]
95.0	0.95	1.053	16.94	[15.98, 17.90]	37.9	[35.7, 40.0]
80.0	0.80	1.25	17.22	[16.22, 18.23]	38.5	[36.3, 40.8]
66.7	0.67	1.5	17.51	[16.46, 18.57]	39.2	[36.8, 41.5]
50.0	0.50	2	17.94	[16.82, 19.07]	40.1	[37.6, 42.7]
20.0	0.20	5	19.11	[17.69, 20.53]	42.7	[39.6, 45.9]
10.0	0.10	10	19.82	[18.11, 21.53]	44.3	[40.5, 48.2]
4.0	0.04	25	20.58	[18.38, 22.78]	46.0	[41.1, 51.0]
2.0	0.02	50	21.04	[18.39, 23.70]	47.1	[41.1, 53.0]
1.0	0.01	100	21.43	[18.25, 24.60]	47.9	[40.8, 55.0]
0.5	0.005	200	21.75	[17.97, 25.52]	48.6	[40.2, 57.1]
0.2	0.002	500	22.09	[17.38, 26.79]	49.4	[38.9, 59.9]

3.5 Wind Fetch Direction and Length

The Project shoreline is most vulnerable to wind setup and locally generated wind-waves in North Bay from southeast to southwest winds. Since waves in North Bay are fetch limited, the longest fetch length for a given constant wind speed will produce the largest wave heights. For this analysis, wave conditions were estimated at a single location with the longest fetch length and the resulting wind-waves can be considered maximums for the Project shoreline. For this assessment, wind setup and wind-wave heights and periods were estimated for winds from a west-southwest (240.3°) direction, which is the longest fetch with a length of 8.4 km (5.2 miles). Figure 8 shows fetch directions and lengths at 22.5° intervals and the longest fetch relative to the Project shoreline. It should be noted that the Project shoreline for the wind-wave analysis is the armored shoreline adjacent to Klopp Lake, and the longest fetch wave direction is 32.8° relative to the shore normal transect at this location.

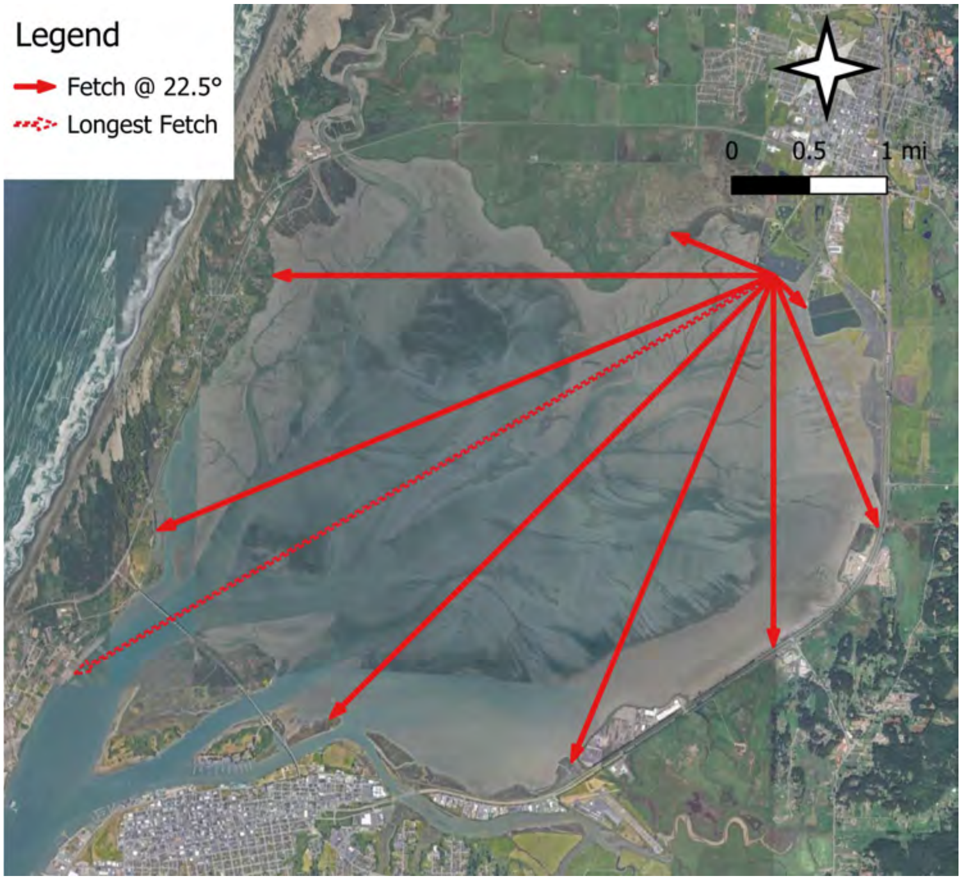

Figure 8. Fetch directions relative to the Project shoreline adjacent to Klopp Lake in North Bay.

3.6 Estimated Wind Setup

The Humboldt Bay hydrodynamic model (Figure 9) developed as part of the Natural Shoreline Infrastructure project (GHD et al. 2022) was used to estimate wind setup at the Project site for various wind speeds and directions. Reference to the GHD et al. (2022) report can be made for a description of the hydrodynamic model setup and parameters.

The tidal open boundary condition (Figure 10) for the analysis consisted of a 10-day period from the 100-yr hourly sea level height series (NHE 2015) derived for the Crescent City tide station (NOAA Station ID: 9419750). The 10-day period spanned 22 to 31 January 1983. During this 10-day period a large El Niño driven storm coincided with higher-than-normal astronomical tides producing the highest water levels of record at the Crescent City tide gauge. This 10-day series contains a large tidal height range spanning MHHW to above the 1% annual chance extreme high-water level event. The wind speeds and directions were held constant for each 10-day simulation.

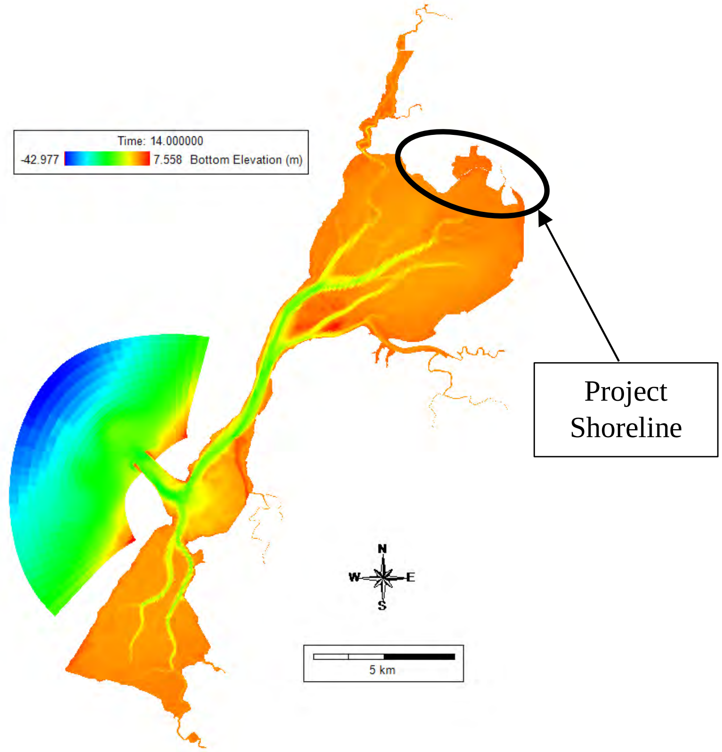

Figure 9. Humboldt Bay 3D circulation model domain. Bathymetry/topography based on grid cell elevations.

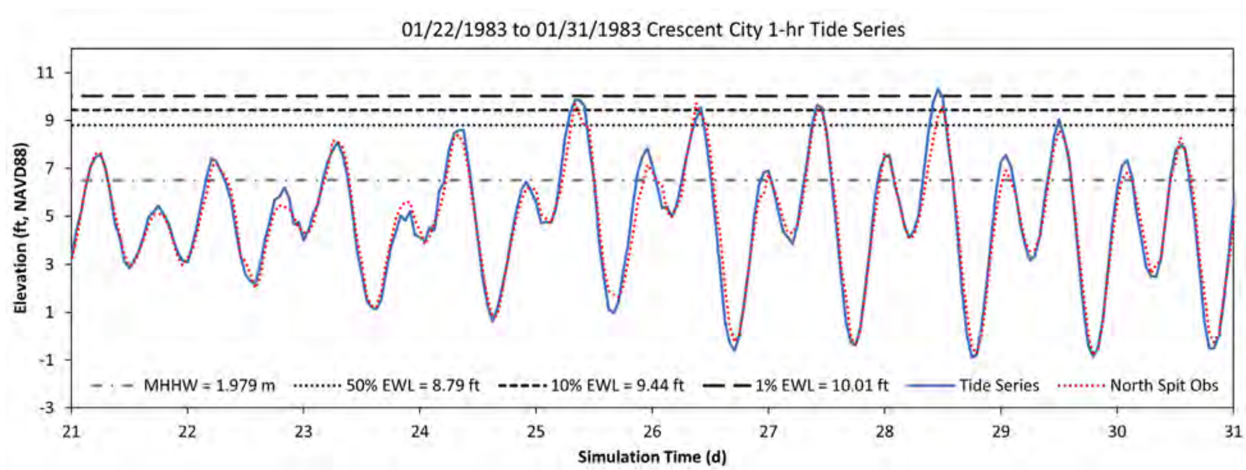

Figure 10. Tidal open boundary condition (blue line) used for model simulations. Tidal series based on Crescent City tide station (ID: 9419750). Observed North Spit tide station (ID: 9418767) observations (red dotted line) corrected for ~2 mm sea-level change from 1982 to 2012. MHHW is mean higher high water; #% EWL (e.g. 1% EWL) represents the #% annual chance extreme high-water level (e.g. 1% chance extreme high-water level).

Wind setup results at the Project shoreline were extracted at the peak water level near day 25.36 of the simulation which represents the approximate 1% extreme high-water level. Results of the wind setup analysis for a constant wind speed of 20 mps (44.7 mph) and different wind directions are listed in Table 6 and shown on Figure 11. The variation in wind setup by wind speed for the wind directions (180° to 270°) that produce the highest wind setup values are shown on Figure 12.

Table 6. Summary of wind setup for 20 mps (44.7 mph) wind speed and various directions at the Project shoreline. Wind setup estimate for the longest fetch is also provided (grey cell). Water levels were extracted at the approximate 1% extreme high-water level.

Wind Direction (from)	Wind Direction From (°)	Wind Speed (not adjusted) (mps)	Wind Speed (not adjusted) (mph)	~1% Water Level (m, NAVD88)	Wind Setup (m)	Wind Setup (ft)
No wind	No wind	20	44.7	3.165	0.000	0.00
East-Southeast	112.5	20	44.7	2.991	-0.174	-0.57
Southeast	135.0	20	44.7	3.105	-0.060	-0.20
South-Southeast	157.5	20	44.7	3.217	0.052	0.17
South	180.0	20	44.7	3.323	0.158	0.52
South-Southwest	202.5	20	44.7	3.394	0.228	0.75
Southwest	225.0	20	44.7	3.445	0.280	0.92
Longest Fetch[1]	240.3	20	44.7	NA	0.274	0.90
West-Southwest	247.5	20	44.7	3.427	0.262	0.86
West	270.0	20	44.7	3.397	0.232	0.76
West-Northwest	292.5	20	44.7	3.305	0.139	0.46
Northwest	315.0	20	44.7	3.194	0.029	0.09
North-Northwest	337.5	20	44.7	3.059	-0.107	-0.35
North	360	20	44.7	2.929	-0.237	-0.78

[1] Wind setup estimates for the longest fetch (240.3°) were determined by interpolating setup values between the southwest (225°) and west-southwest (247.5°) wind directions.

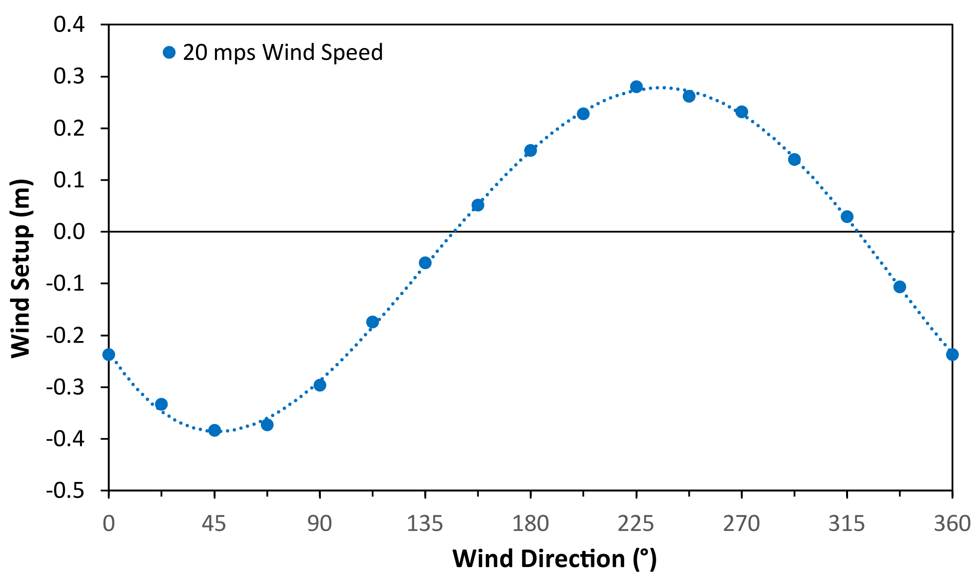

Figure 11. Wind setup by wind direction for a 20 mps (44.7 mph) wind speed at the Project shoreline.

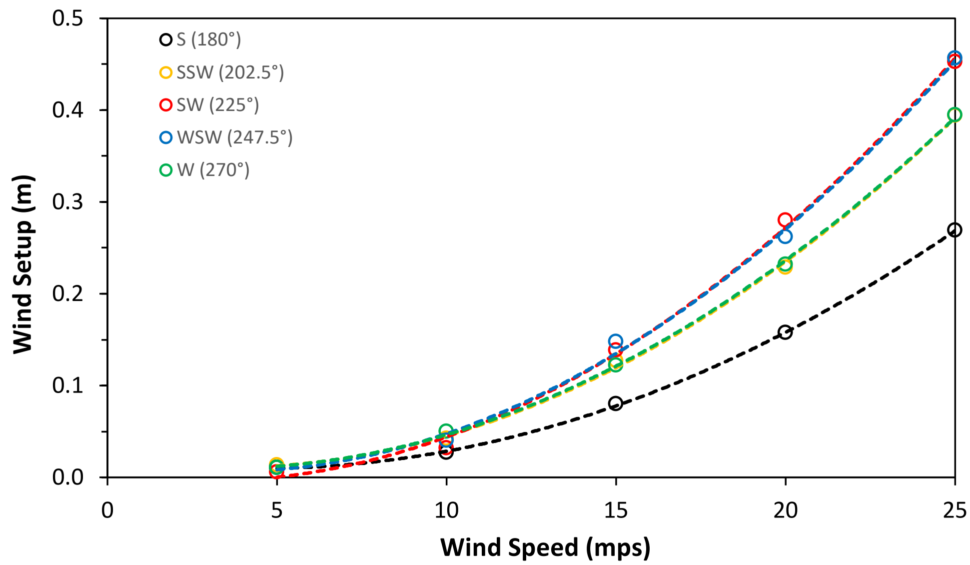

Figure 12. Wind setup by wind speed for wind directions from the south to west (180° to 270°).

Results for the 20 mps (44.7 mph) wind speed, which is close to the 10% adjusted wind speed (Table 5) of 19.8 mps (44.3 mph), indicate that winds from the south-southwest to northwest directions (157.5° to 315°) push water out of South Bay into North Bay and/or from the west to east shorelines of North Bay creating positive wind setup values up to a maximum of 0.28 m (0.9 ft). Winds from the other directions tend to push water out of North Bay into South Bay and/or away from the Project shoreline resulting in negative wind setup values down to a minimum of -0.24 m (-0.8 ft).

Wind setup values along the longest fetch direction (240.3°) are summarized in Table 7 for eight extreme wind speeds (95, 66.7, 50, 20, 10, 4, 2 and 1% exceedance probability). The longest fetch direction is between the two highest wind setup directions (225° to 247.5°). Consequently, conditions that produce the largest wind-waves and wave runup values along the Project shoreline also generate large wind setup values.

Table 7. Summary of wind setup values for the longest fetch (240.3°) relative to the Project shoreline for different extreme wind speeds. Wind setup estimates were determined by interpolating setup values between the southwest (225°) and west-southwest (247.5°) wind directions.

Annual Exceedance Probability (%)	Extreme 2-min wind speed (mps)	Adjusted Wind Speed (mps)	Adjusted Wind Speed (mph)	Wind Direction From (°)	Wind Setup (m)	Wind Setup (ft)
95	16.94	16.83	37.6	240.3	0.179	0.59
66.7	17.51	17.41	38.9	240.3	0.195	0.64
50	17.94	17.85	39.9	240.3	0.207	0.68
20	19.11	19.04	42.6	240.3	0.241	0.79
10	19.82	19.76	44.2	240.3	0.263	0.86
4	20.58	20.54	45.9	240.3	0.288	0.95
2	21.04	21.01	47.0	240.3	0.304	1.00
1	21.43	21.41	47.9	240.3	0.318	1.04

3.7 Wind-Waves for the Project Shoreline

3.7.1 Estimated Wind-Wave Height and Period

Wave heights and periods were determined along the longest fetch direction for eight extreme wind speeds (95, 66.7, 50, 20, 10, 2 and 1% exceedance probability) outlined in Table 5. Fetch-limited peak wave heights and periods were estimated using the simplified procedures for wind adjustments and wave prediction outlined in CEM (2015). This procedure adjusts wind speeds to fetch-limited conditions by (1) adjusting wind speed for duration and fetch length, and (2) applying a 1.2 factor for overwater wind speeds for fetch lengths less than 16 km (~10 mi). The fetch lengths, adjusted wind speeds, and predicted peak wave heights and periods for the five wind speeds are summarized in Table 8.

Table 8. Wind-wave analysis summary of adjusted wind speeds and predicted peak wind-wave heights and periods for eight extreme wind speeds for the Project shoreline. Wave conditions are along the longest fetch (west-southwest direction (240.3°), 8.359 km length) relative to the shoreline.

Annual Exceedance Probability (%)	Extreme 2-min wind speed (mps)	Adjusted Wind Speed (mps)	Adjusted Wind Speed (mph)	Peak Wave Height (m)	Peak Wave Height (ft)	Wave Period (s)
95	16.94	16.83	37.6	0.72	2.35	2.66
66.7	17.51	17.41	38.9	0.75	2.45	2.70
50	17.94	17.85	39.9	0.77	2.53	2.73
20	19.11	19.04	42.6	0.83	2.74	2.80
10	19.82	19.76	44.2	0.87	2.87	2.85
4	20.58	20.54	45.9	0.92	3.01	2.90
2	21.04	21.01	47.0	0.94	3.09	2.92
1	21.43	21.41	47.9	0.96	3.17	2.95

3.7.2 Estimated $R_{2\%}$ Wave Runup

The $R_{2\%}$ wave runup values were estimated for the Project shoreline following the Technical Advisory Committee for Water Retaining Structures (TAW) method (van der Meer 2002) as modified in FEMA (2005) and used in the Natural Shoreline Infrastructure project (Appendix E, GHD et al. 2022). The approach in Appendix E is consistent with the approach used by FEMA (2014) to determine wave runup in Humboldt Bay where the shoreline is composed of a natural shoreline (without fringing tidal wetland) or shoreline structures. Reference to Appendix E (GHD et al. 2022), FEMA (2005) or FEMA (2014) can be made for more information regarding the wave runup methodology.

As noted in FEMA (2005 and 2014), the TAW equation is based on wave tank measurements which accounts for wave setup landward of the shoreline or structure toe, and FEMA (2005) recommends reducing the dynamic setup to account for this. If the incident waves have not broken prior to reaching the structure toe, then wave setup is not included in the total runup, which is consistent with the approach used by FEMA (2014) for determining wave runup estimates in Humboldt Bay. For runup estimates where the toe water depths were less than 0.78 times the wave height, wave runup estimates were based on the broken wave height determined as 0.78 times the toe water depth; and the static wave setup was determined using the Direct Integration Method (DIM) as described in FEMA (2005 and 2014), but the dynamic setup was assumed zero. For the water elevations listed in Table 3 greater than MHHW, the water depth at the toe of the shoreline or structure is greater than 0.78 times the wave height, indicating that waves have not broken prior to reaching the toe and wave setup was assumed zero.

The Project shoreline consists of both armored (rock revetment) and natural shoreline segments, and the armored shorelines will produce the highest $R_{2\%}$ wave runup estimates. For this assessment, wave runup estimates were only determined for the armored shoreline, using the following representative rock revetment geometry:

- Crest elevation: 3.5 m (11.5 ft)
- Toe elevation: 1.2 m (3.9 ft)
- Structure slope: 1V:2H
- Crest width: assumed negligible

Since runup estimates are along the longest fetch affecting the Project shoreline, the $R_{2\%}$ wave runup values listed in Table 9 can be considered maximum values for each wind speed analyzed. For this assessment it was assumed that portions of Project shoreline consisting of natural shoreline segments will attenuate wave height and runup to values below the crest elevation.

Table 9. Summary of $R_{2\%}$ wave runup estimates for extreme wind speeds at the armored Project shoreline with rock revetment. Runup estimates are maximum values for the reported still water levels (tidal datums or exceedance probabilities (EP)). Wave conditions are along the longest fetch (west-southwest direction (240.3°), 8.359 km length) relative to the shoreline, and a 1V:2H revetment slope.

Annual Exceedance Probability (%)	Annual Average Recurrence Interval (yr)	Applicable Still Water Level	Adjusted Wind Speed (mps)	Adjusted Wind Speed (mph)	Wave Runup - $R_{2\%}$ (m)	Wave Runup - $R_{2\%}$ (ft)
95	1.053	>= MHHW	16.83	37.6	1.262	4.14
66.7	1.5	>= MHHW	17.41	38.9	1.306	4.29
50	2	>= MHHW	17.85	39.9	1.340	4.40
20	5	>= MHHW	19.04	42.6	1.433	4.70
10	10	>= MHHW	19.76	44.2	1.490	4.89
4	25	>= MHHW	20.54	45.9	1.551	5.09
2	50	>= MHHW	21.01	47.0	1.589	5.21
1	100	>= MHHW	21.41	47.9	1.621	5.32

3.8 Total Water Levels at Project Shoreline

Total water levels (TWL) at the Project shoreline are a combination of still water levels (tide levels plus storm surge), wind setup, and wave setup and runup from locally generated wind-waves. For this analysis, wave runup values include wave setup. Tabulated results of TWL estimates for the Project shoreline are provided in Table 10 for a combination of still water levels (MHHW, MMMW, and 95%, 50%, 10%, 4% and 1% exceedance probabilities) and wind speeds (95%, 50%, 10%, 4% and 1% exceedance probabilities). Two TWL estimates are provided. One can be used as a TWL estimate for natural shorelines and combines still water level and wind setup, but assumes the natural shoreline attenuates waves and wave runup to negligible values. The other TWL estimate applies to armored shoreline segments and includes still water level, wind setup and the $R_{2\%}$ wave runup values.

Table 10. Summary of total water levels (TWL) at the Project shoreline. An estimate of TWLs for a natural shoreline is provided by combining still water level and wind setup values (green cells). The TWL for an armored shoreline includes still water level, wind setup and $R_{2\%}$ wave runup (blue cells).

Annual Exceedance Probability (%) (Recurrence Interval (yr))		Still Water Level (m, NAVD88)	Wind Setup (m)	TWL (NAVD88) Estimate for Natural Shoreline		$R_{2\%}$ Wave Runup (m)	TWL (NAVD88) for Armored Shoreline	
Water Level	Wind Speed			Value (m)	Value (ft)		Value (m)	Value (ft)
MHHW	No wind	2.176	0.000	2.176	7.14	0.000	2.176	7.14
	95 (1.05-yr)		0.179	2.355	7.73	0.179	3.617	11.87
	50 (2-yr)		0.207	2.382	7.82	0.207	3.723	12.21
	10 (10-yr)		0.263	2.439	8.00	0.263	3.929	12.89
	4 (25-yr)		0.288	2.464	8.08	0.288	4.016	13.17
	1 (100-yr)		0.318	2.494	8.18	0.318	4.114	13.50
MMMW	No wind	2.584	0.000	2.584	8.48	0.000	2.584	8.48
	95 (1.05-yr)		0.179	2.763	9.06	0.179	4.025	13.20
	50 (2-yr)		0.207	2.790	9.15	0.207	4.130	13.55
	10 (10-yr)		0.263	2.847	9.34	0.263	4.337	14.23
	4 (25-yr)		0.288	2.872	9.42	0.288	4.423	14.51
	1 (100-yr)		0.318	2.901	9.52	0.318	4.522	14.84
95 (1.05-yr)	No wind	2.841	0.000	2.841	9.32	0.000	2.841	9.32
	95 (1.05-yr)		0.179	3.020	9.91	0.179	4.282	14.05
	50 (2-yr)		0.207	3.048	10.00	0.207	4.388	14.40
	10 (10-yr)		0.263	3.104	10.19	0.263	4.595	15.07
	4 (25-yr)		0.288	3.129	10.27	0.288	4.681	15.36
	1 (100-yr)		0.318	3.159	10.36	0.318	4.779	15.68
50 (2-yr)	No wind	2.918	0.000	2.918	9.57	0.000	2.918	9.57
	95 (1.05-yr)		0.179	3.098	10.16	0.179	4.359	14.30
	50 (2-yr)		0.207	3.125	10.25	0.207	4.465	14.65
	10 (10-yr)		0.263	3.182	10.44	0.263	4.672	15.33
	4 (25-yr)		0.288	3.207	10.52	0.288	4.758	15.61
	1 (100-yr)		0.318	3.236	10.62	0.318	4.857	15.93
10 (10-yr)	No wind	3.082	0.000	3.082	10.11	0.000	3.082	10.11
	95 (1.05-yr)		0.179	3.262	10.70	0.179	4.524	14.84
	50 (2-yr)		0.207	3.289	10.79	0.207	4.629	15.19
	10 (10-yr)		0.263	3.346	10.98	0.263	4.836	15.87
	4 (25-yr)		0.288	3.371	11.06	0.288	4.922	16.15
	1 (100-yr)		0.318	3.400	11.16	0.318	5.021	16.47
4 (25-yr)	No wind	3.160	0.000	3.160	10.37	0.000	3.160	10.37
	95 (1.05-yr)		0.179	3.339	10.95	0.179	4.601	15.09
	50 (2-yr)		0.207	3.366	11.04	0.207	4.706	15.44
	10 (10-yr)		0.263	3.423	11.23	0.263	4.913	16.12
	4 (25-yr)		0.288	3.448	11.31	0.288	4.999	16.40
	1 (100-yr)		0.318	3.477	11.41	0.318	5.098	16.73
1 (100-yr)	No wind	3.258	0.000	3.258	10.69	0.000	3.258	10.69
	95 (1.05-yr)		0.179	3.437	11.28	0.179	4.699	15.42
	50 (2-yr)		0.207	3.464	11.37	0.207	4.805	15.76
	10 (10-yr)		0.263	3.521	11.55	0.263	5.011	16.44
	4 (25-yr)		0.288	3.546	11.63	0.288	5.098	16.72
	1 (100-yr)		0.318	3.576	11.73	0.318	5.196	17.05

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Appendix B

Hydraulic Model Technical Memorandum

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).

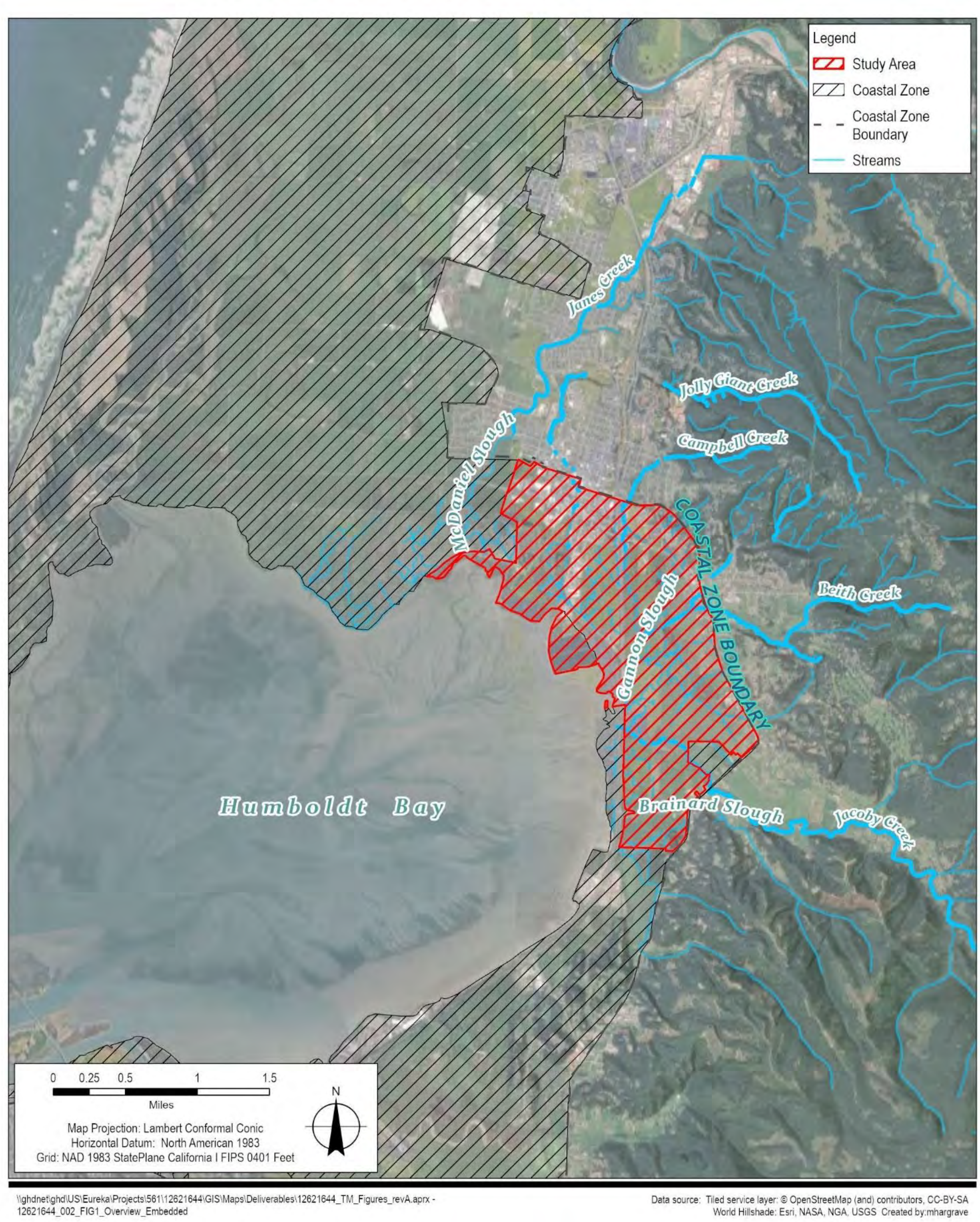


Figure 1 Study Area

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.

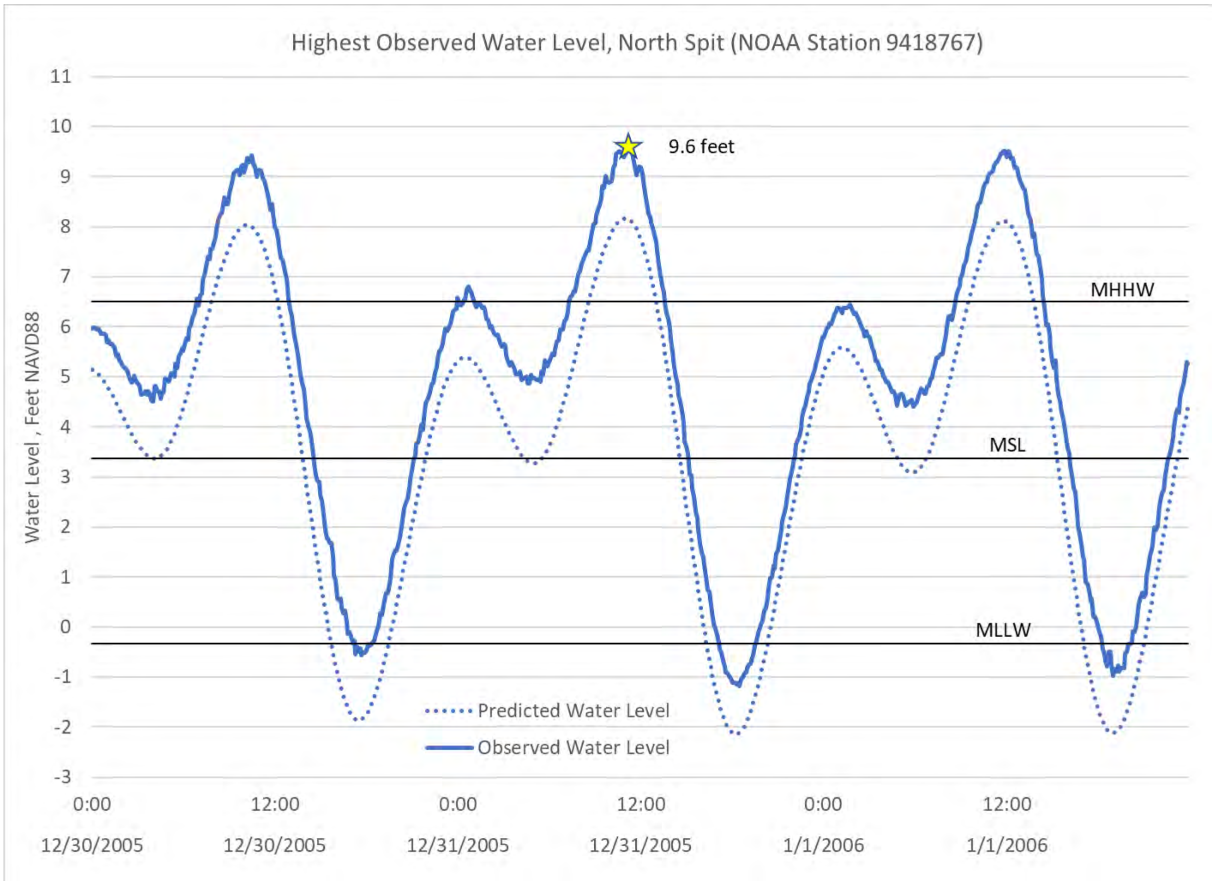


Figure 2 Highest Observed Water Level at North Spit (NOAA Sta 9418767)

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.

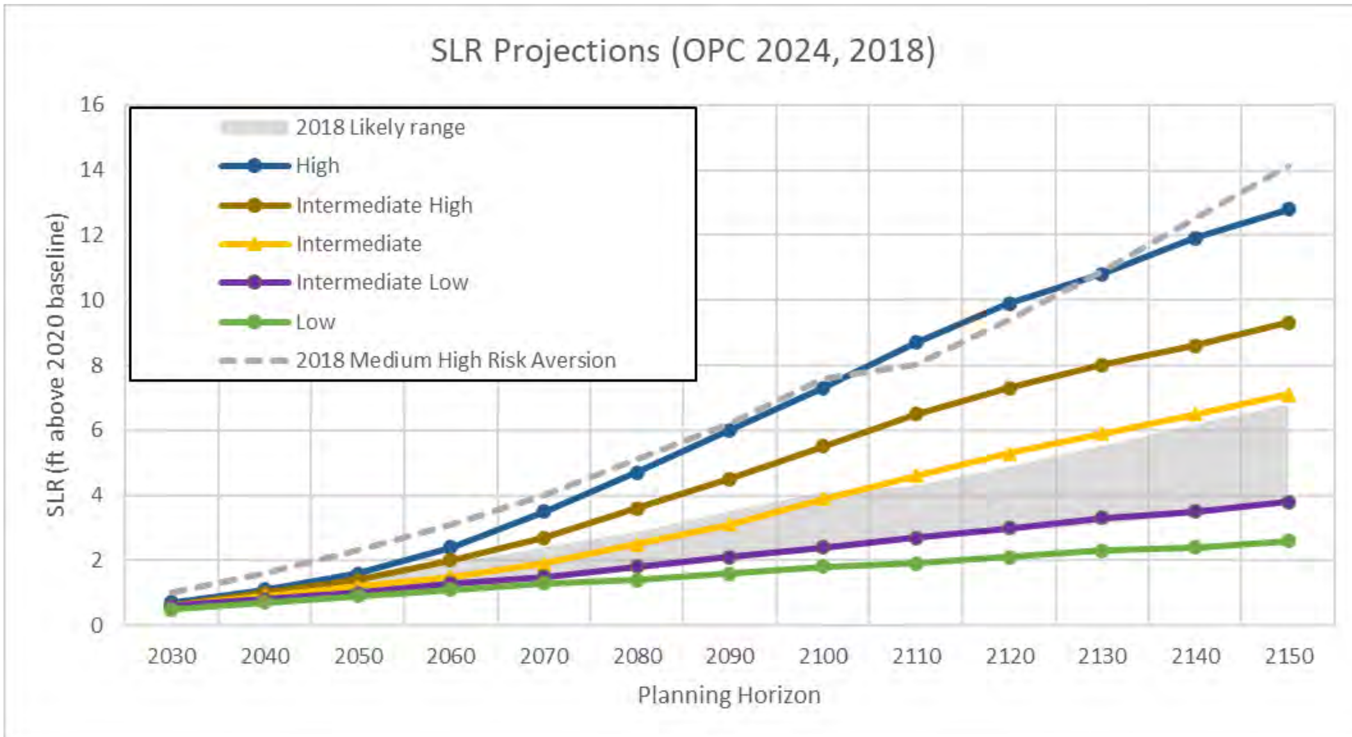


Figure 3 SLR projections from OPC 2024 and OPC 2018.

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%.

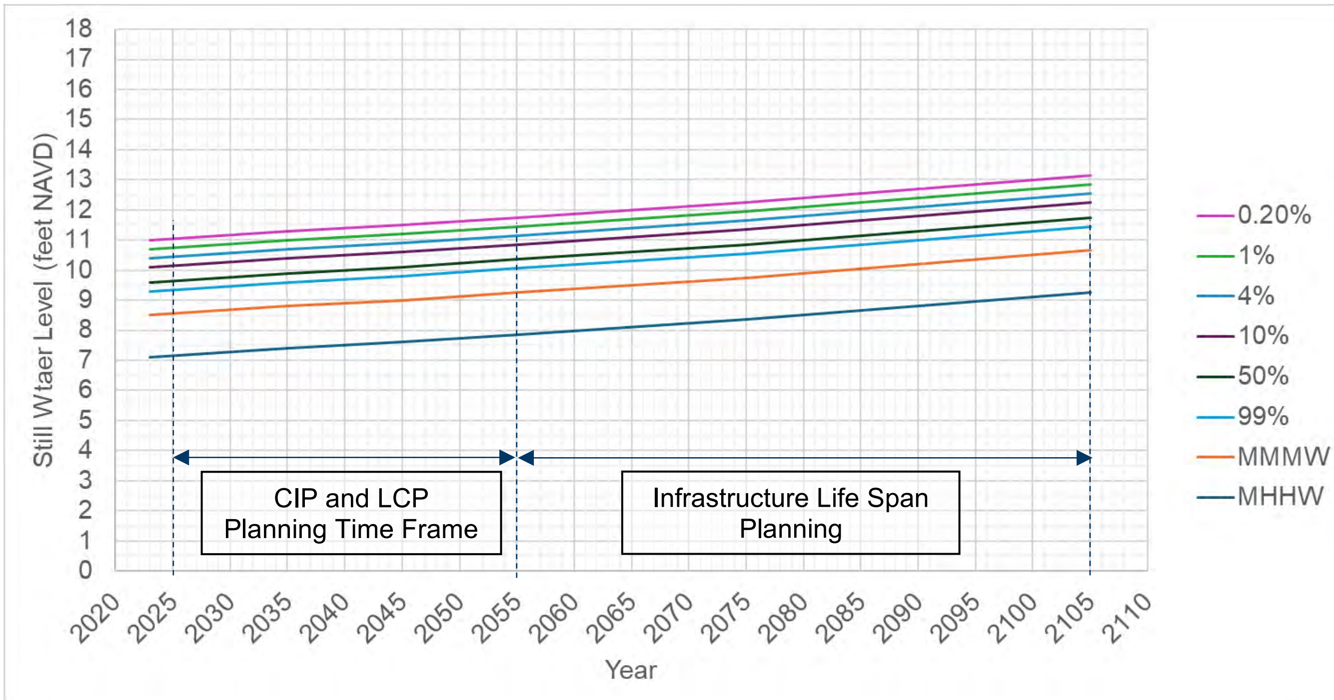


Figure 4 Still Water Datums and OPC Intermediate-Low Sea Level Rise Projection (Lower Bound of Most Likely Range of Sea Level Rise by 2100).

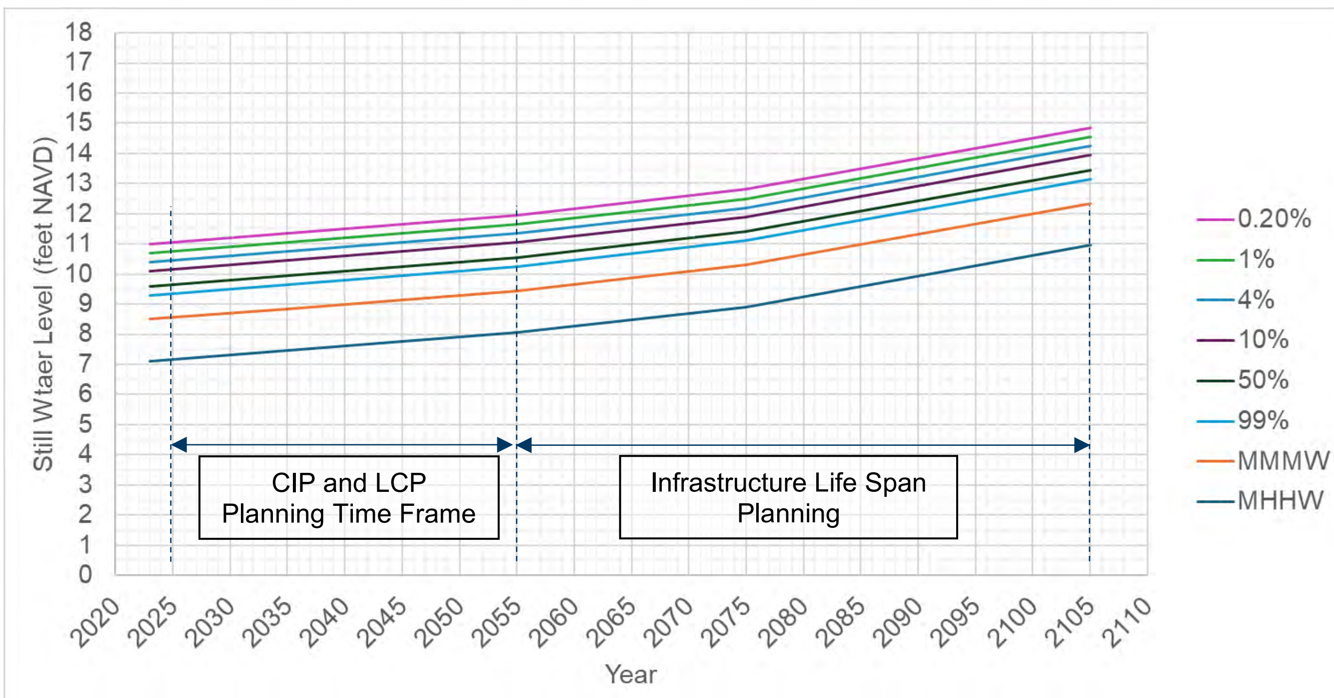


Figure 5 Still Water Datums and OPC Intermediate Sea Level Rise Projection (Upper Bound of Most Likely Range of Sea Level Rise by 2100).

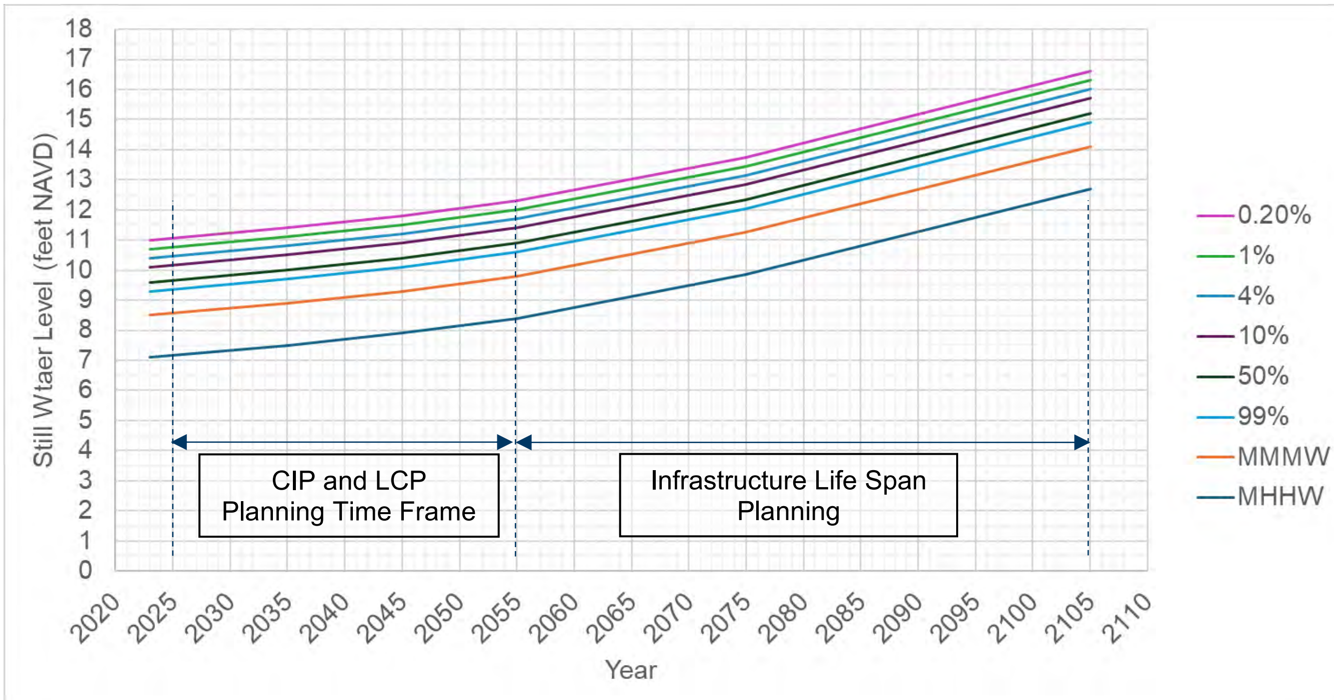


Figure 6 ***Still Water Datums and OPC Intermediate-High Sea Level Rise Projection (Plausible High-End Projection by 2100).***

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.

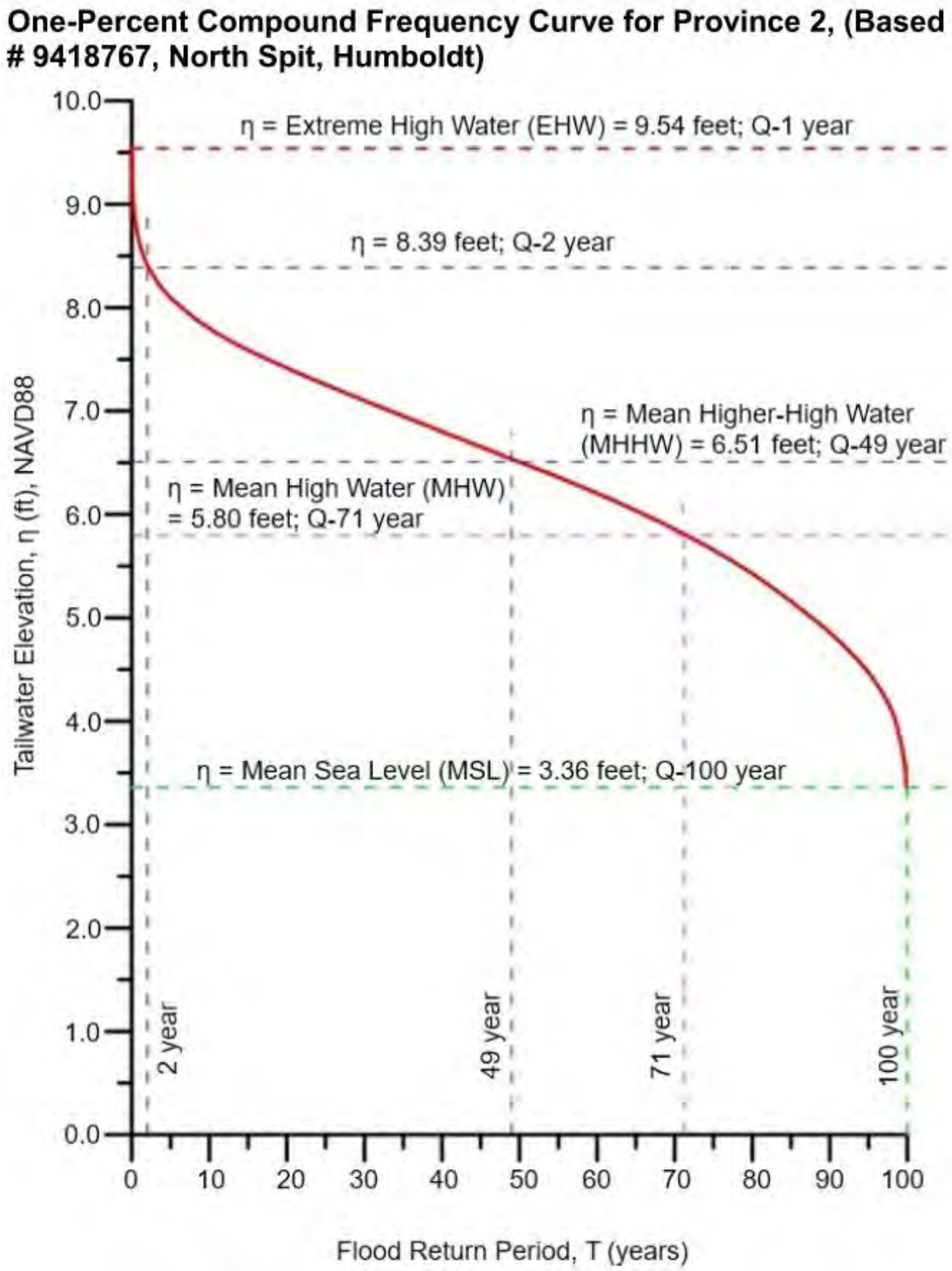


Figure 7 One-percent compound frequency curve for Humboldt Bay North Spit (Caltrans, 2020).

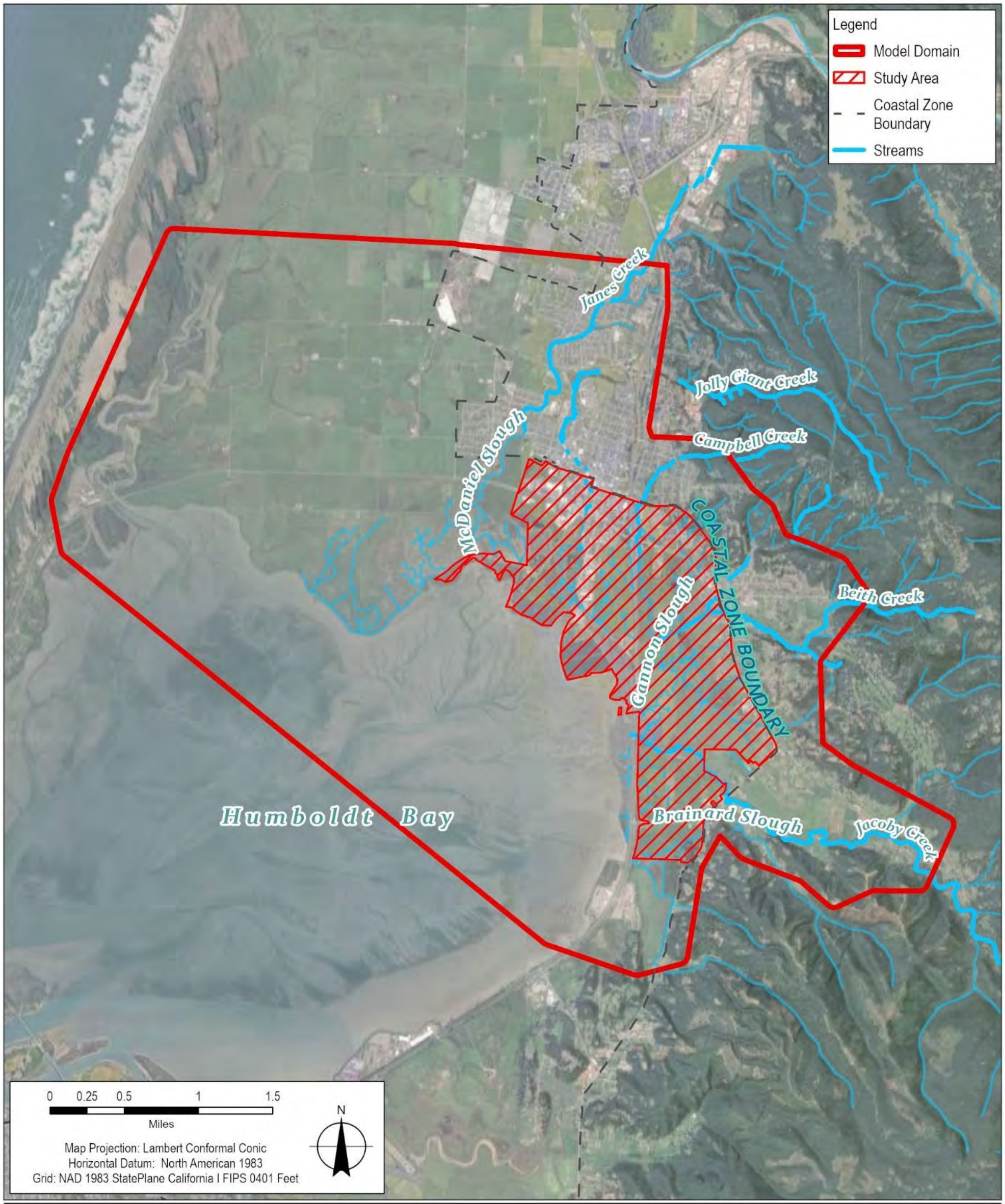
4. Hydraulic Model Development

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.



\\ghdnet\ghd\US\Eureka\Projects\561\12621644\GIS\Maps\Deliverables\12621644_TM_Figures_revA.aprx - 12621644_003_FIG2_ModelDomain

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

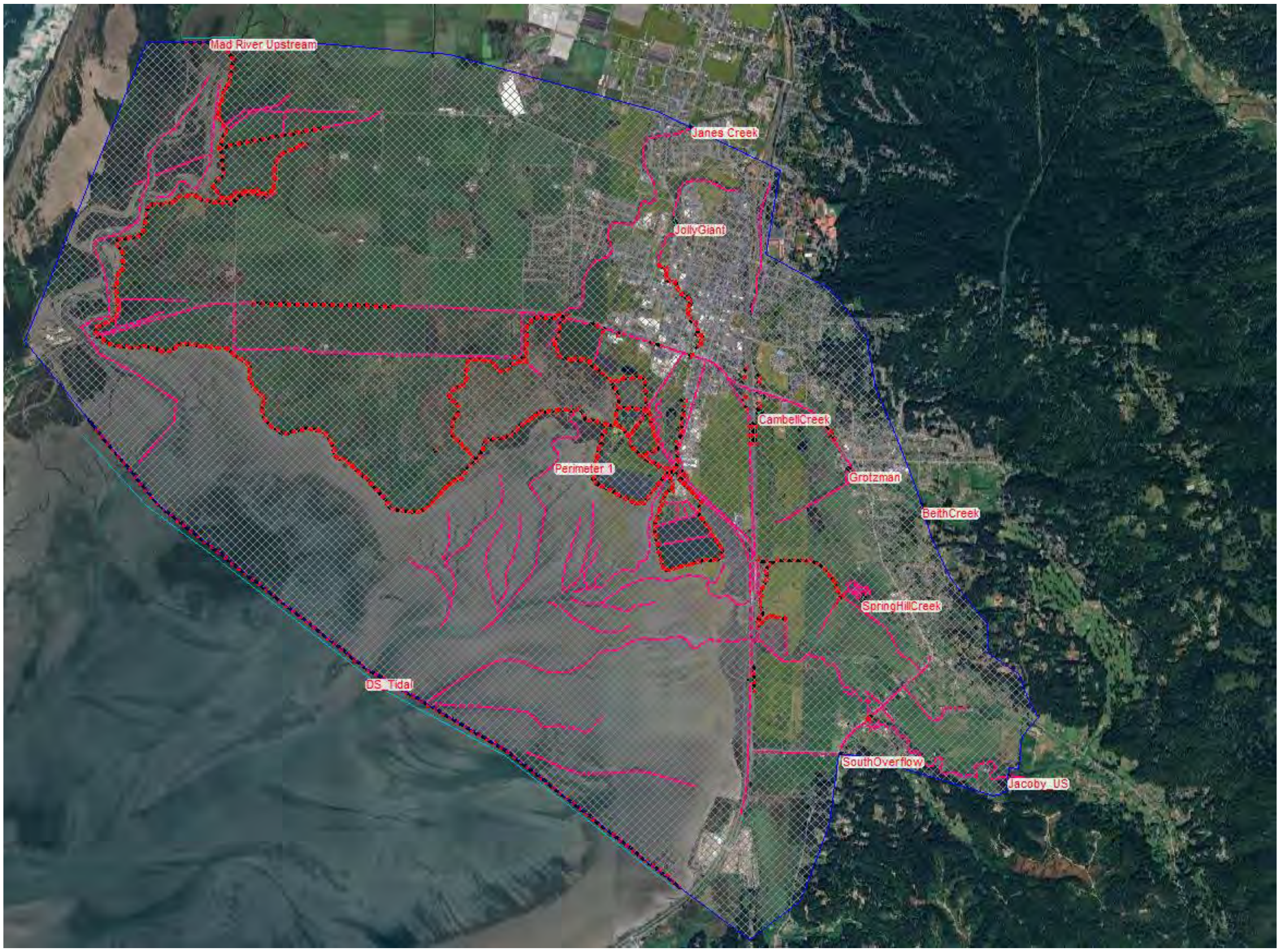


Figure 9. HEC-RAS Model 2-D Domain.

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.

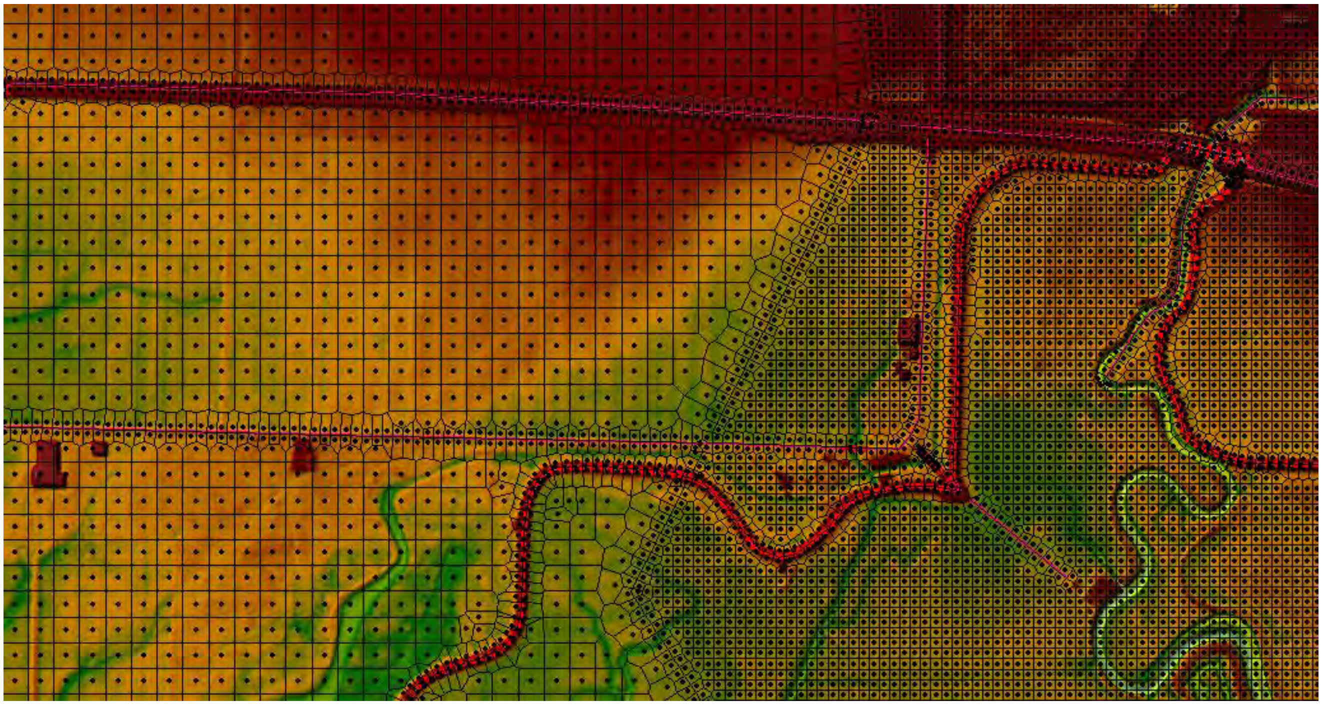


Figure 10 Example of breaklines and 2D/SA connections used to define critical topographic features such as top of l;eves and channel thalwegs

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

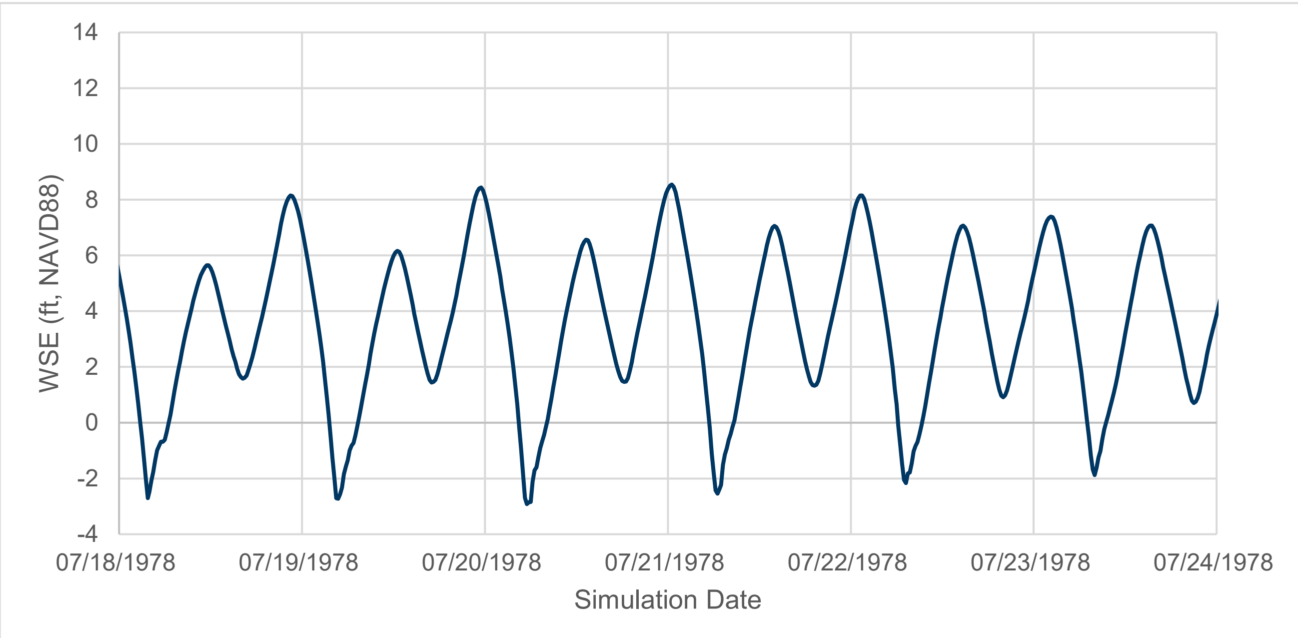


Figure 12. Mean Monthly Maximum Water Level (MMMW) tidal boundary condition

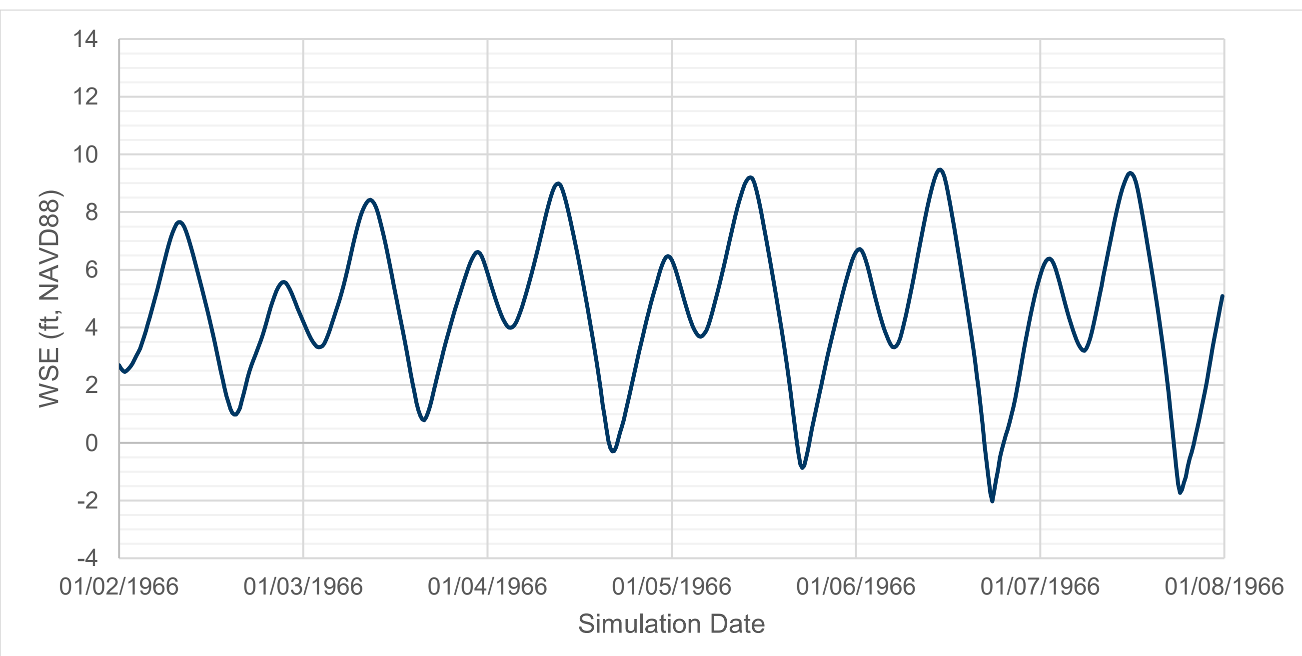


Figure 13. Tidal boundary condition with peak of 9.5 feet

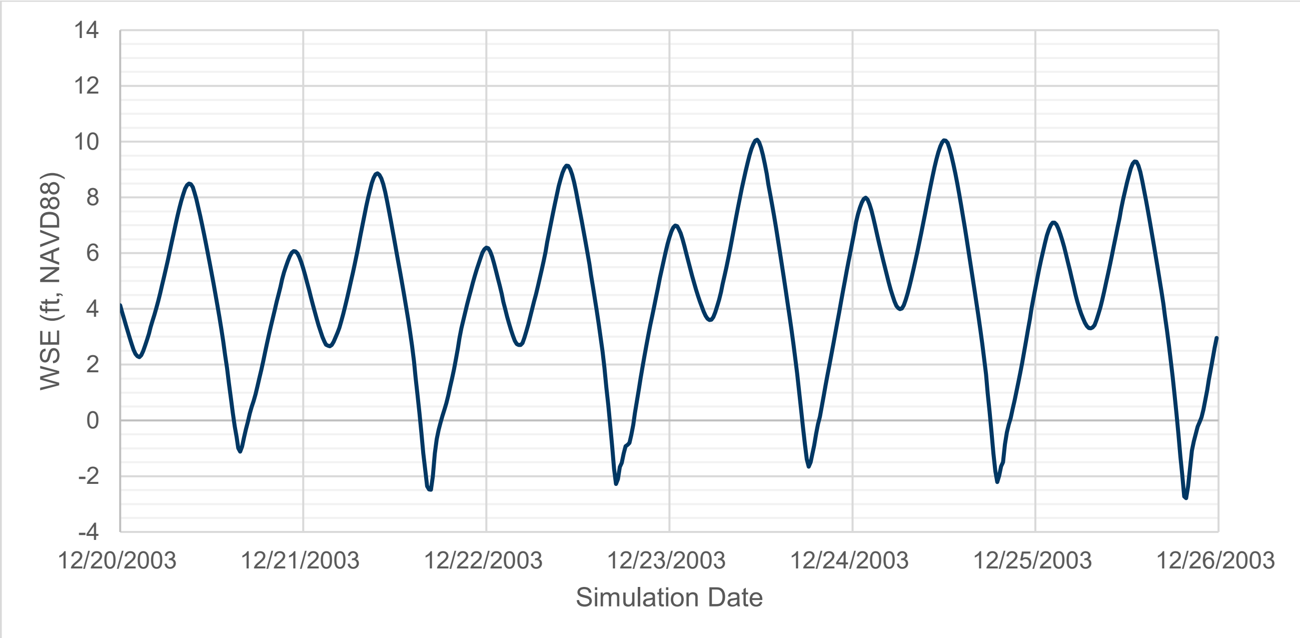


Figure 14. Tidal boundary condition with peak of 10.1 feet

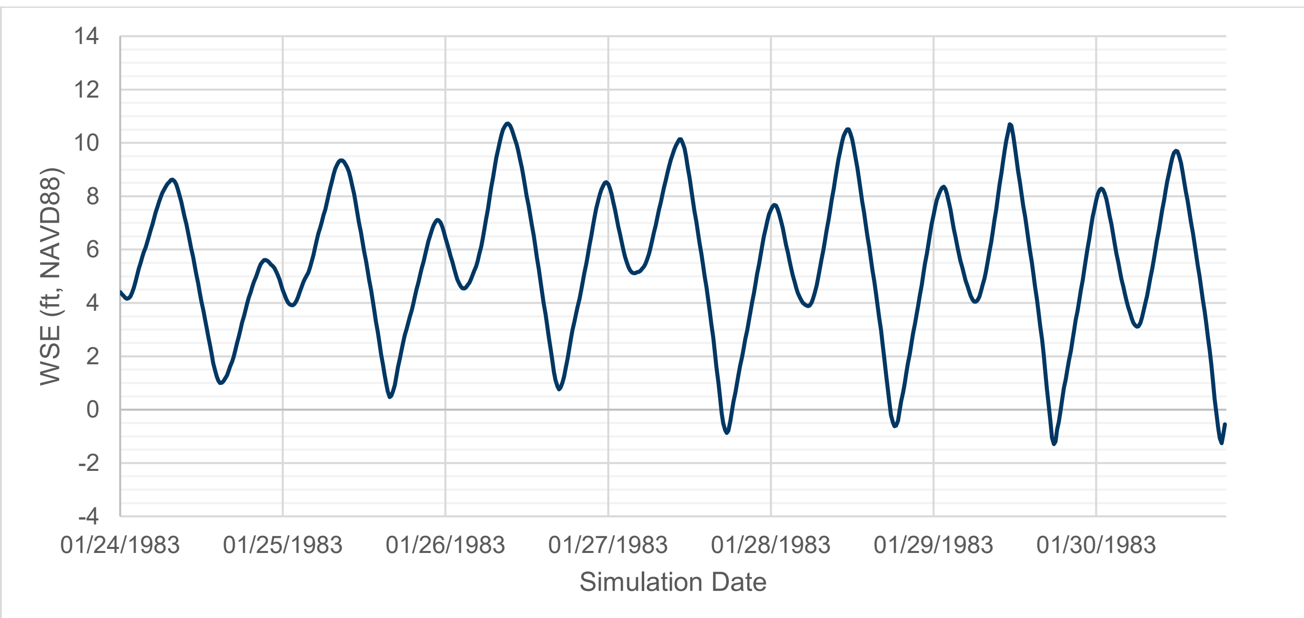


Figure 15. Tidal boundary condition with peak of 10.7 feet

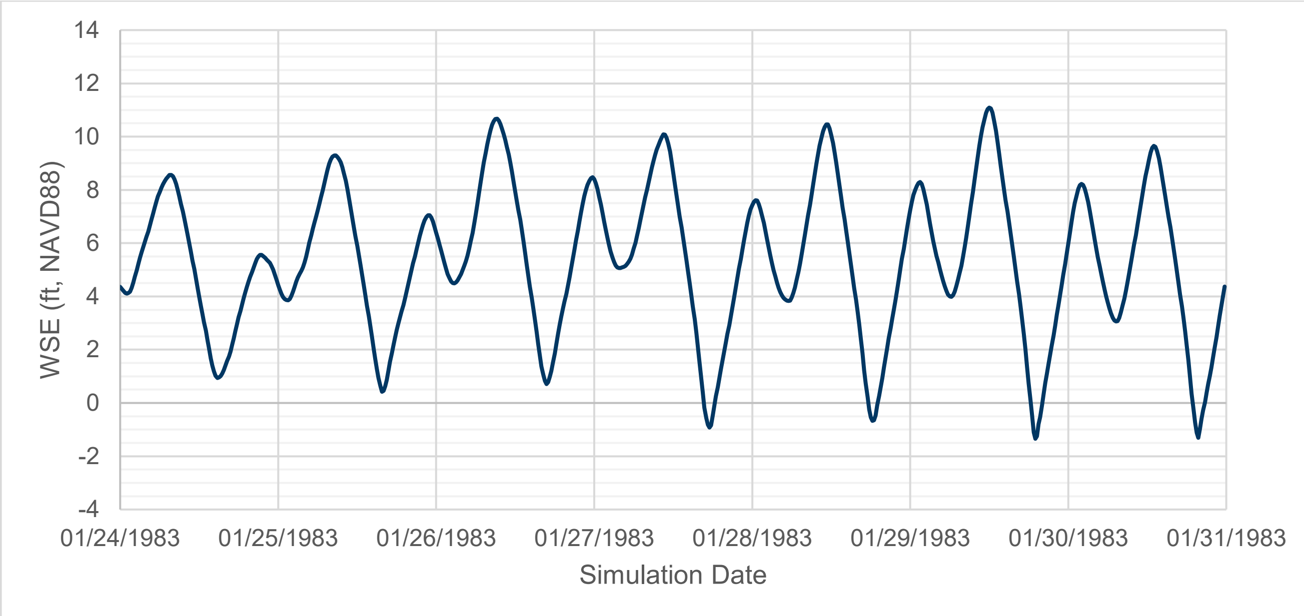


Figure 16. 1 Tidal boundary condition with peak of 11.1 feet

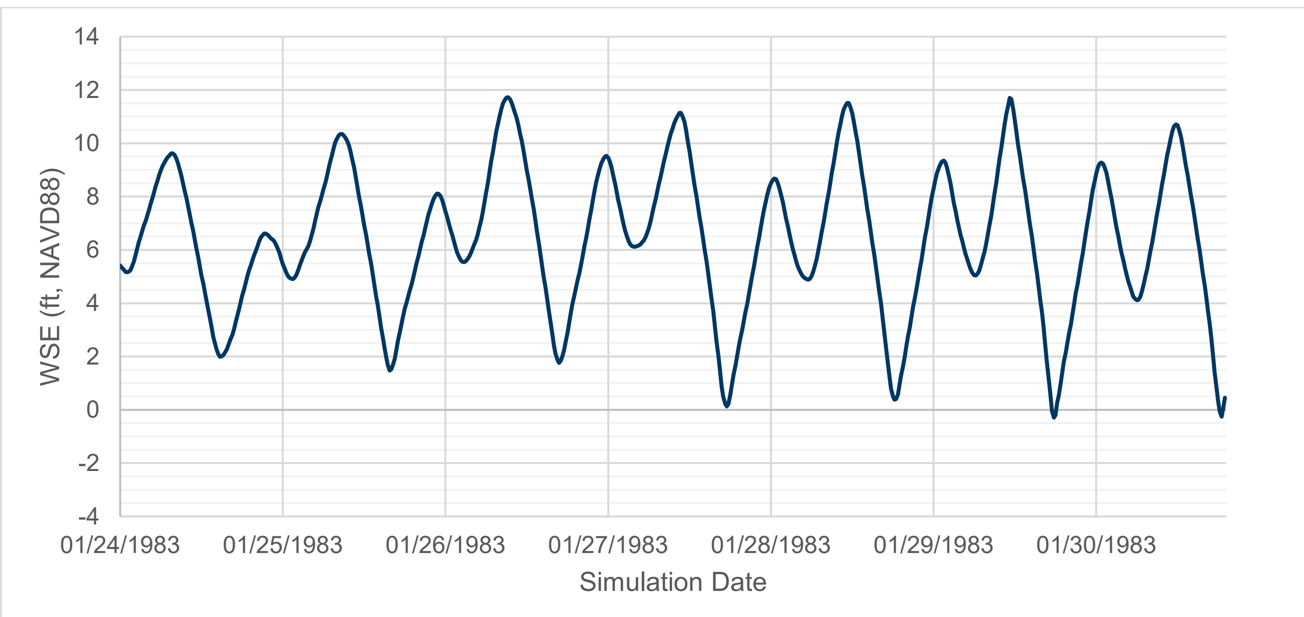


Figure 17. Tidal boundary condition with peak of 12.7 feet

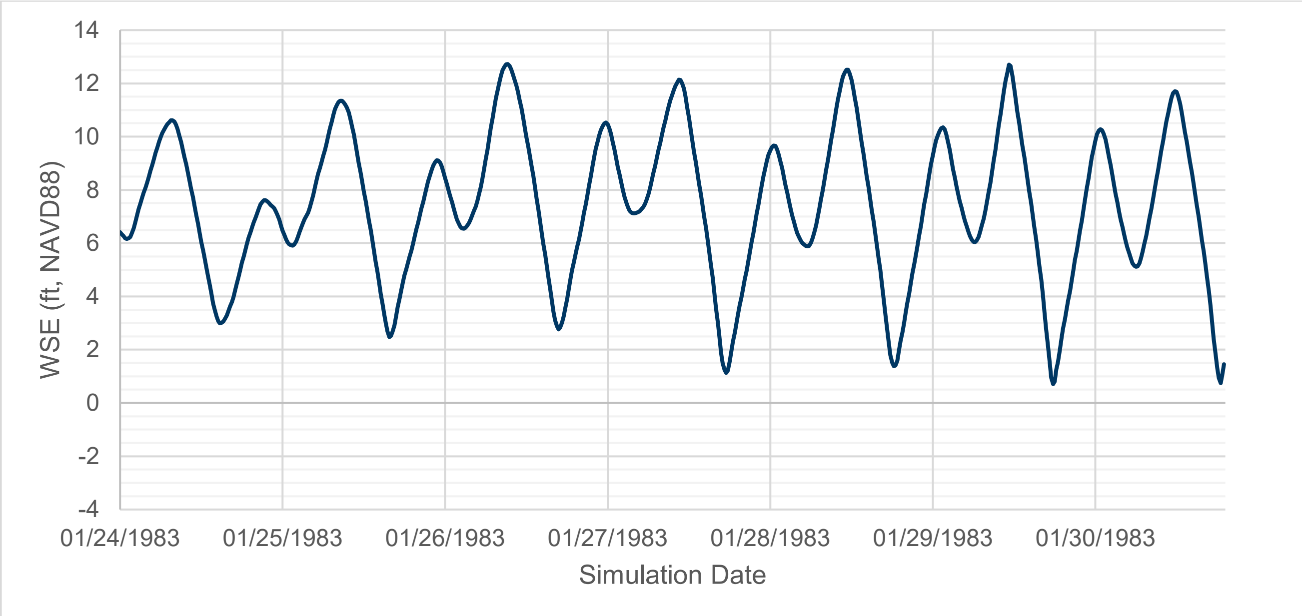


Figure 18. Tidal boundary condition with peak of 12.7 feet

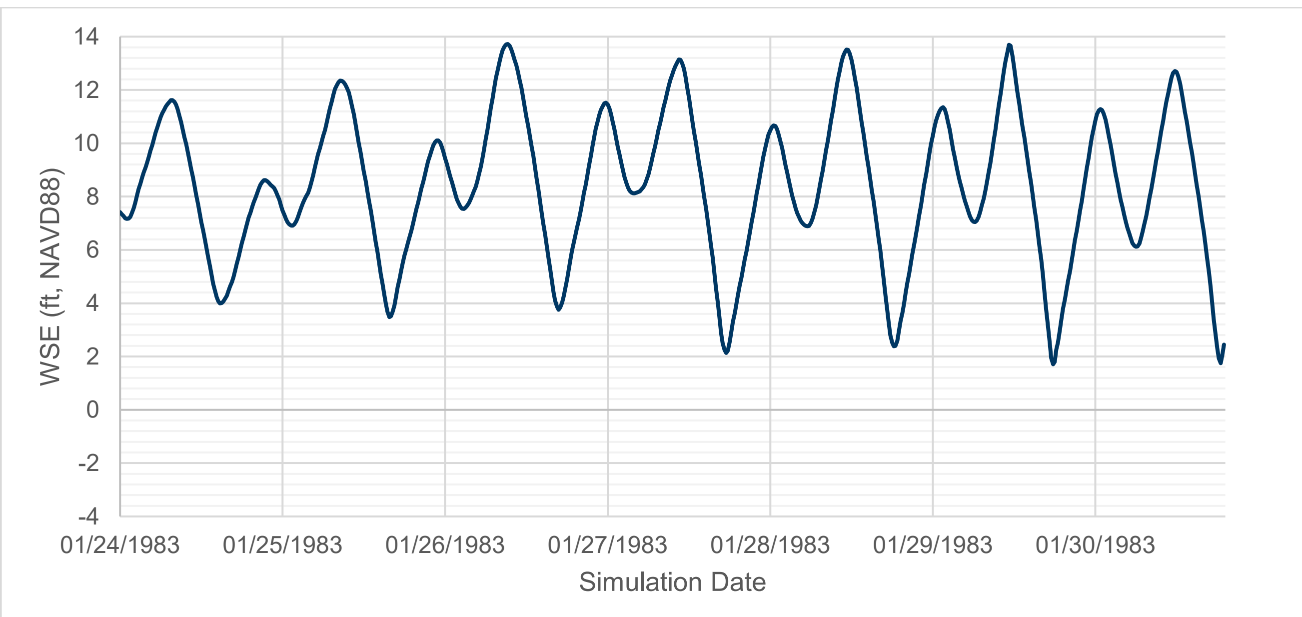


Figure 19. Tidal boundary condition with peak of 13.7 feet

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.

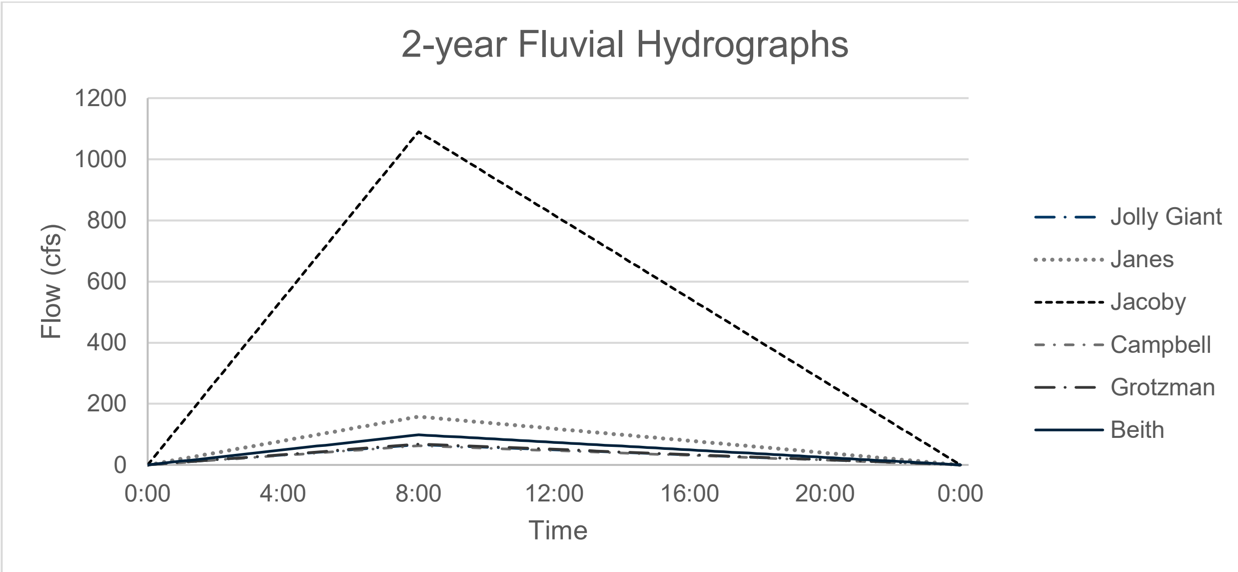


Figure 20. 2-year recurrence stream flows

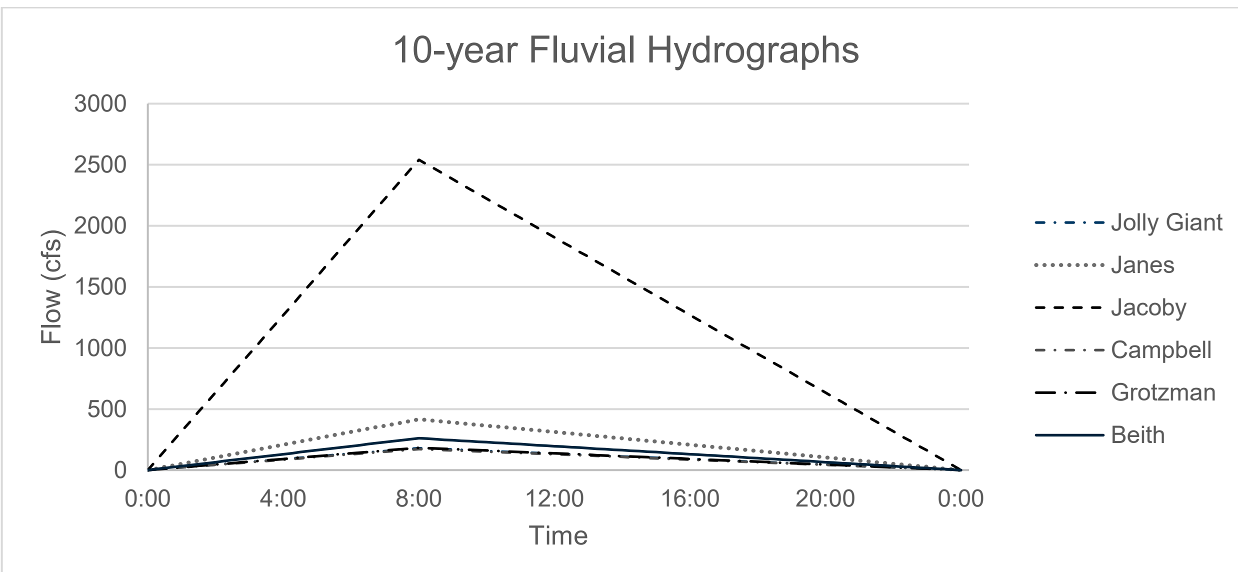


Figure 21. 10-year recurrence stream flows

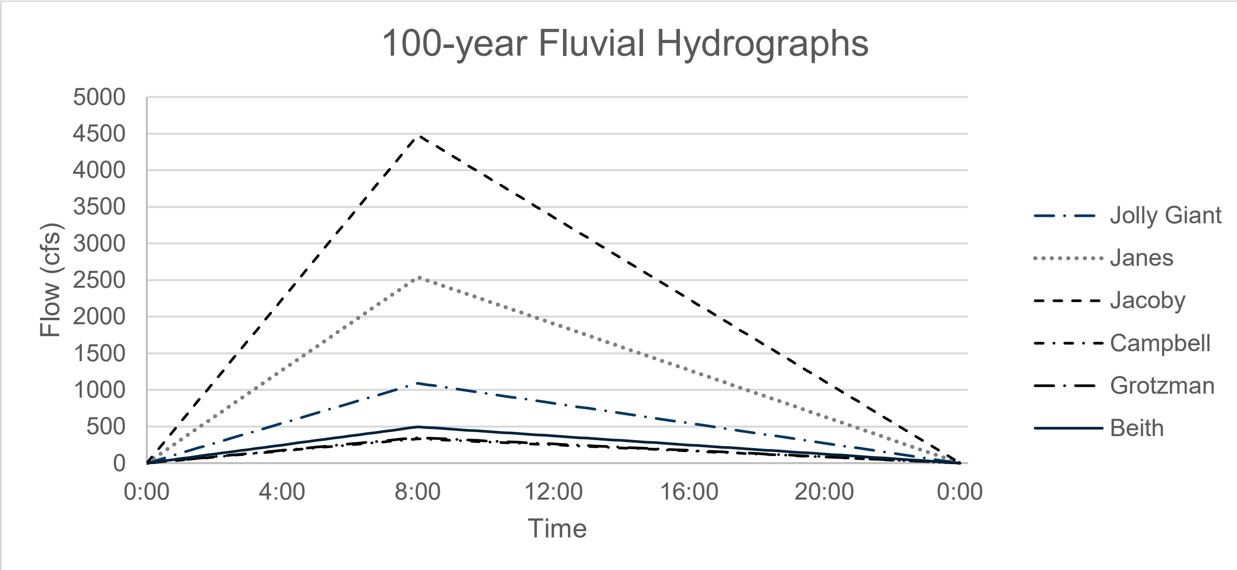


Figure 22. 100-year recurrence stream flows

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.

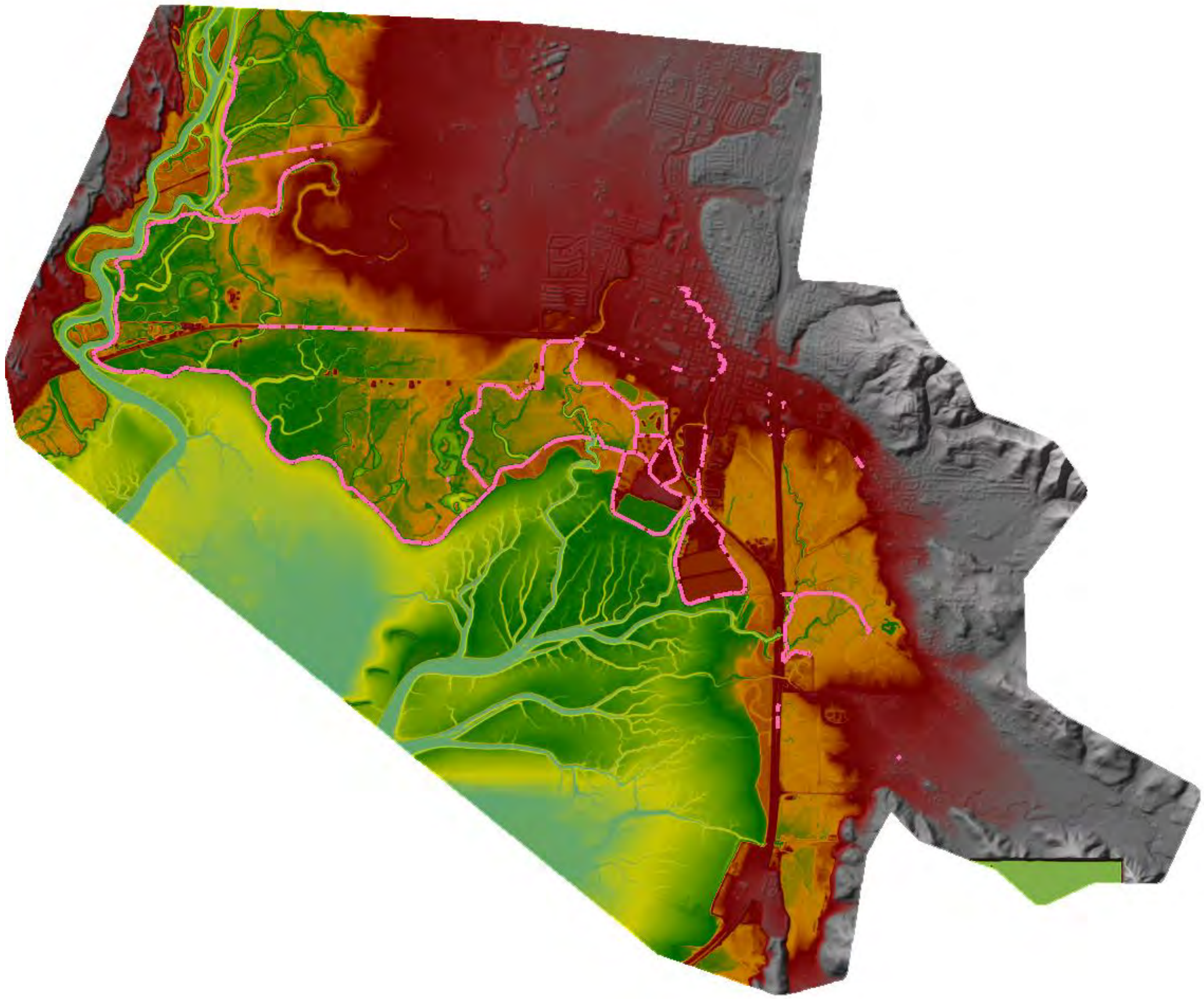


Figure 23 Locations of structures included in the model

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.

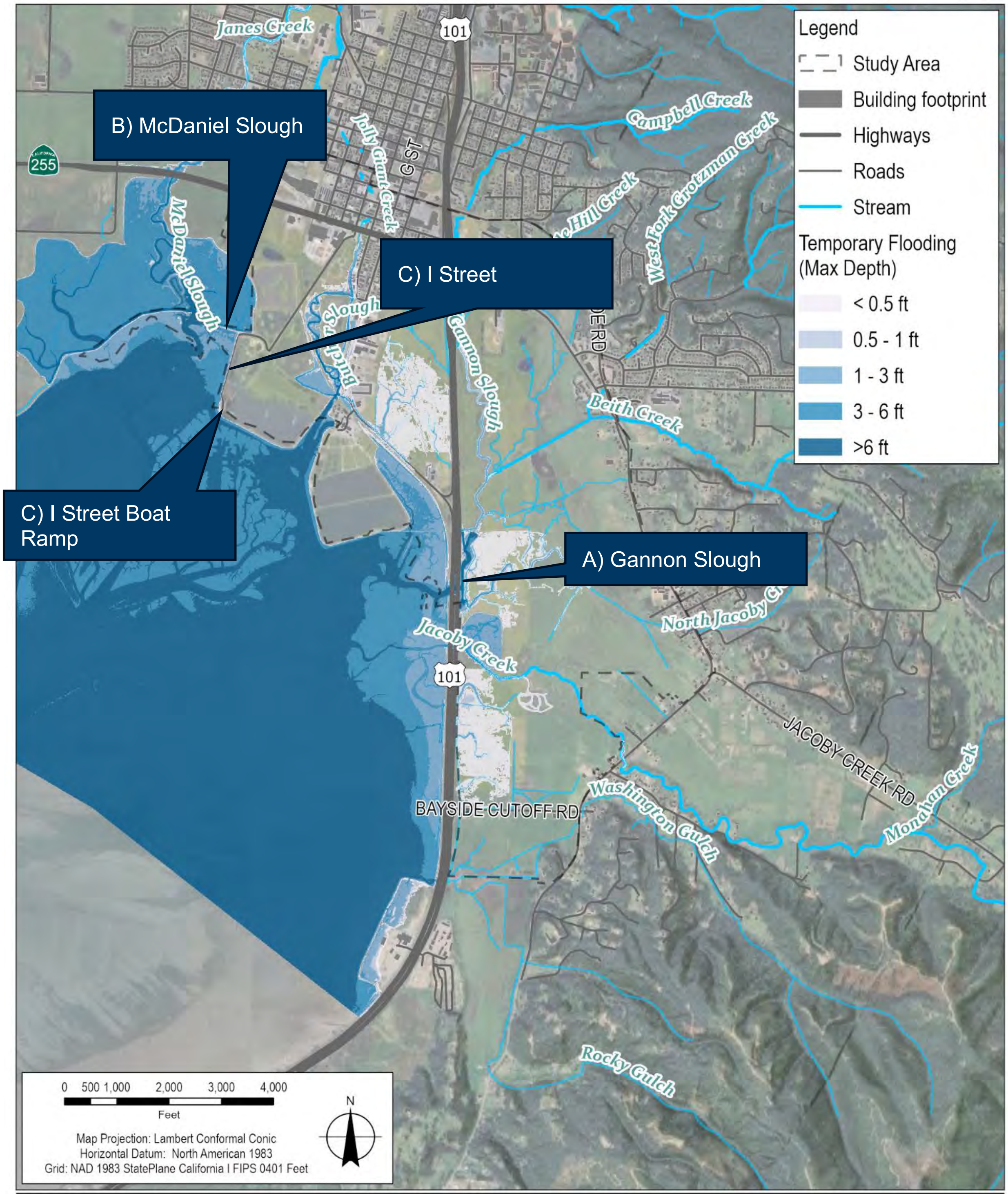
A) 

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)***



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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 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).

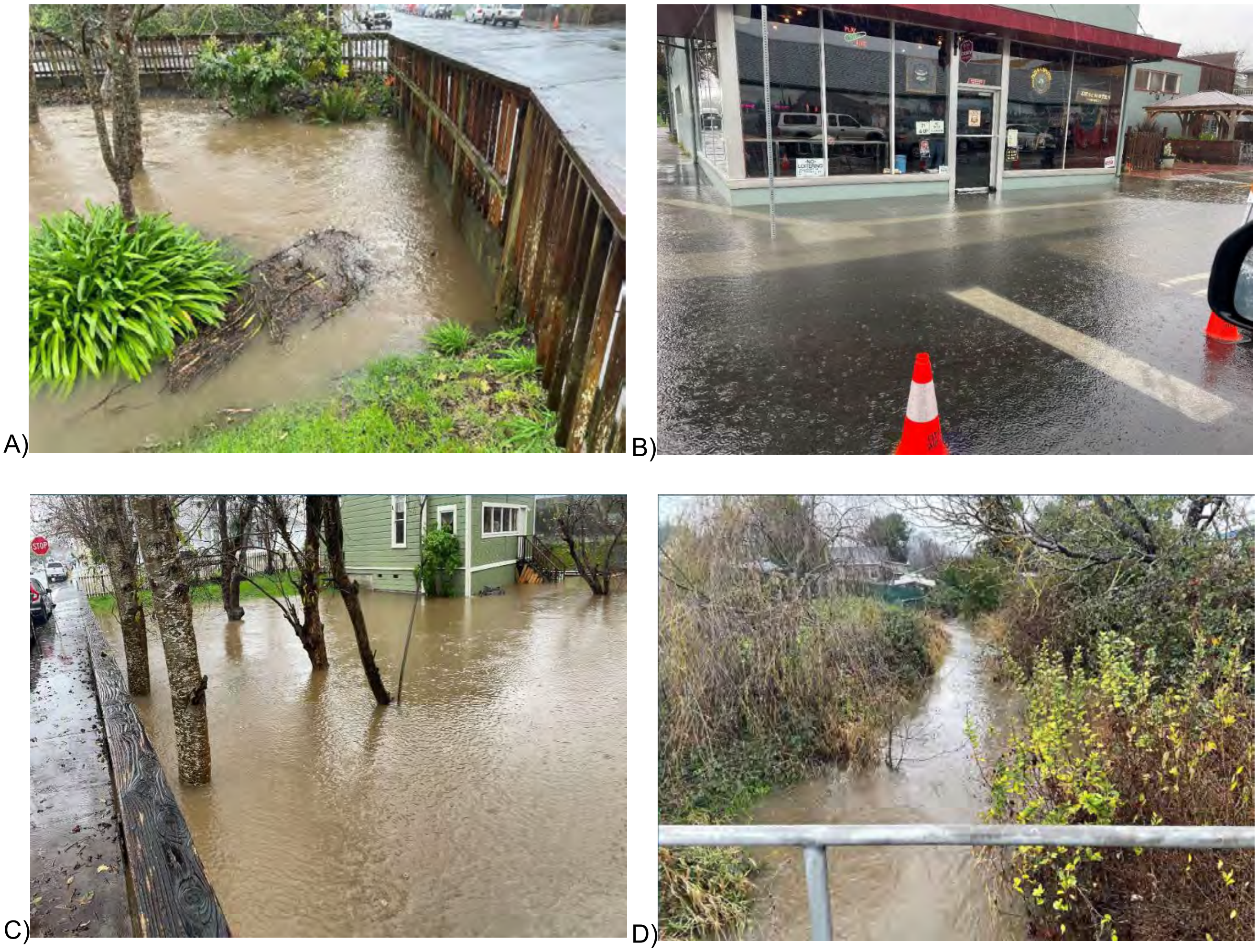


Figure 26 ***Flooding along Jolly Giant Creek on January 13. 2024 A) Corner of 9th and J Streets B) Corner of 8th and J Streets C) Corner of 7th and I Streets D) Samoa Blvd.***

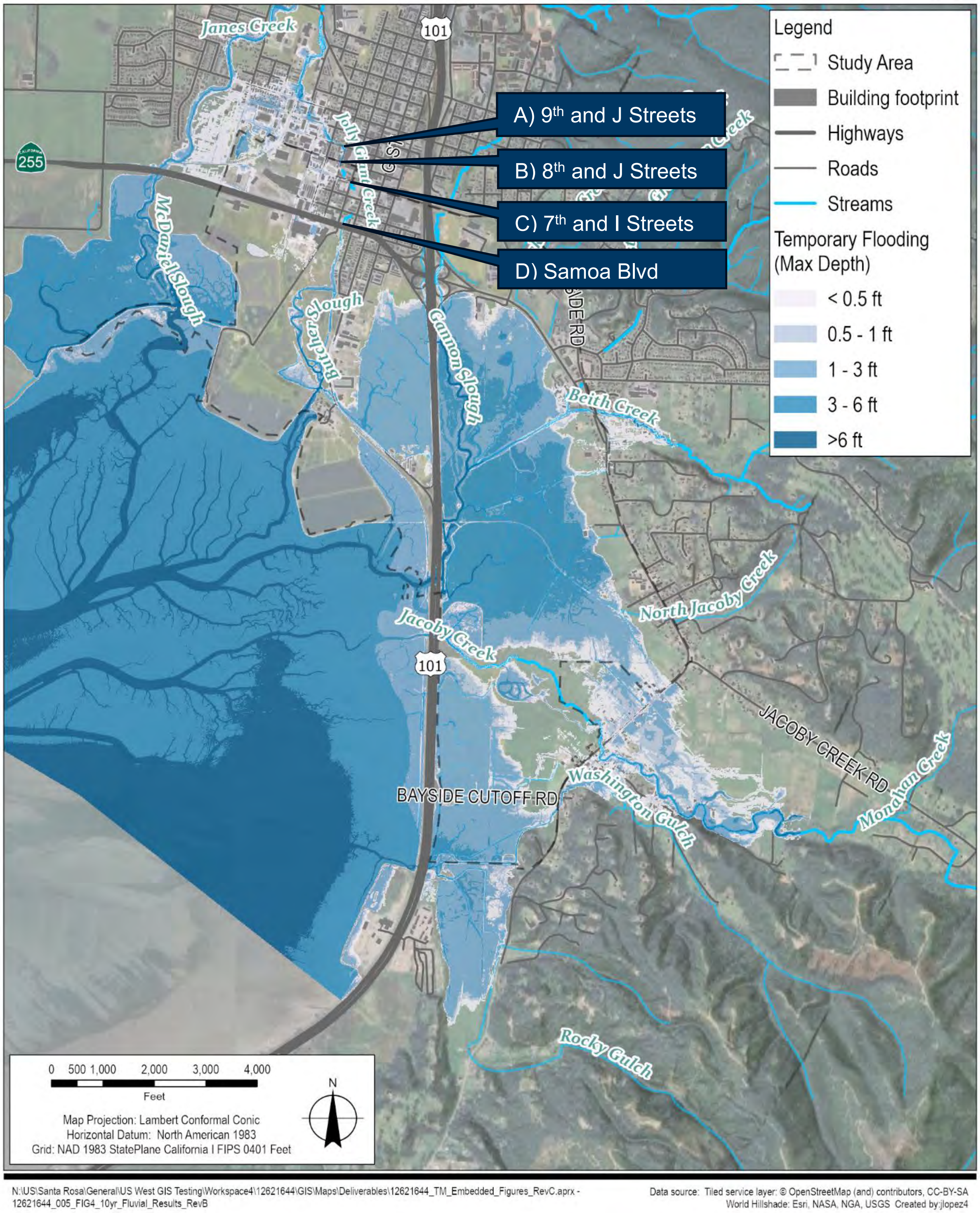


Figure 27 *Model results of the 10-year fluvial event and photo points evaluated for model validation.*

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)

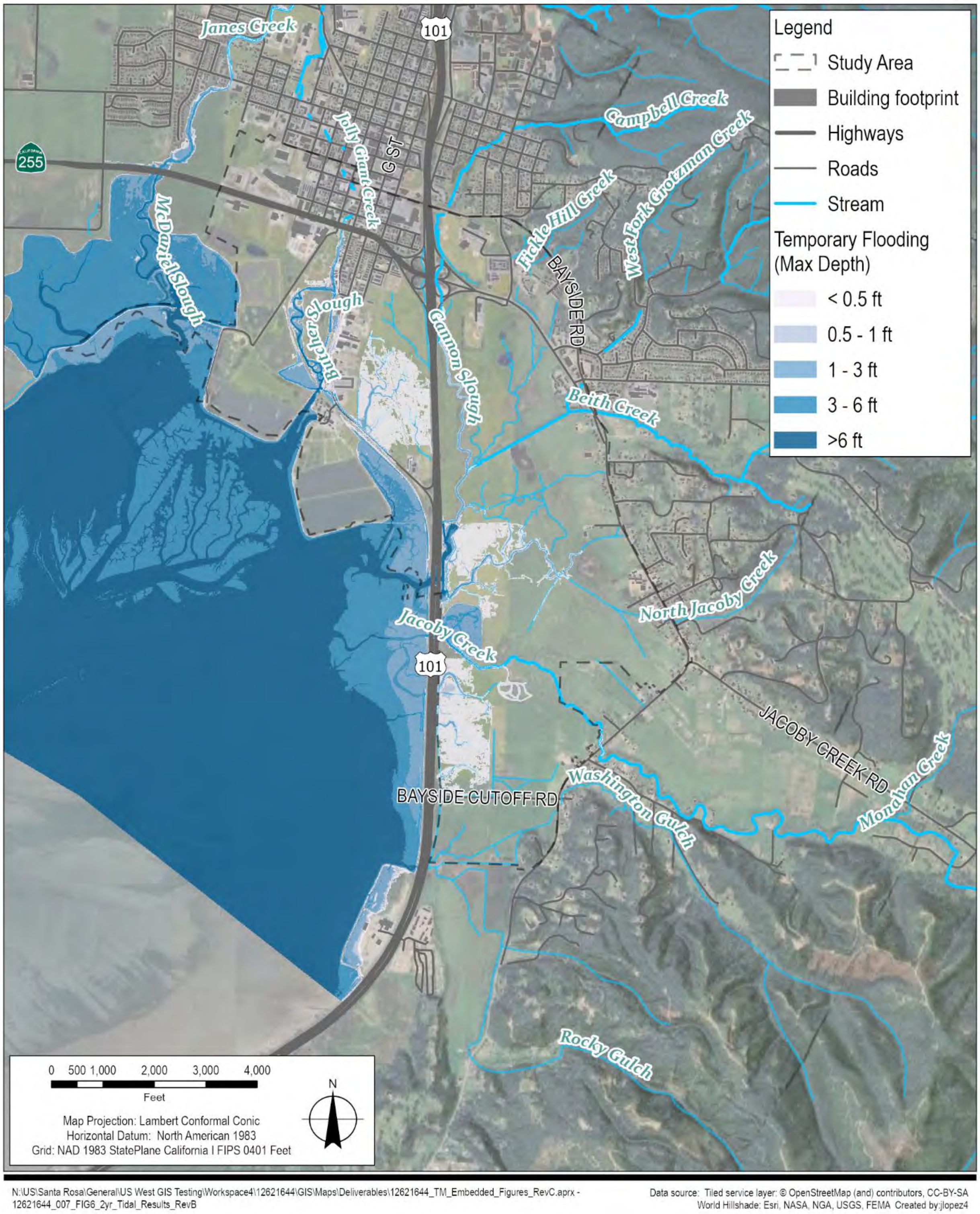


Figure 28 ***Model results for the peak 9.5 feet (existing 2-year) tidal boundary conditions.***

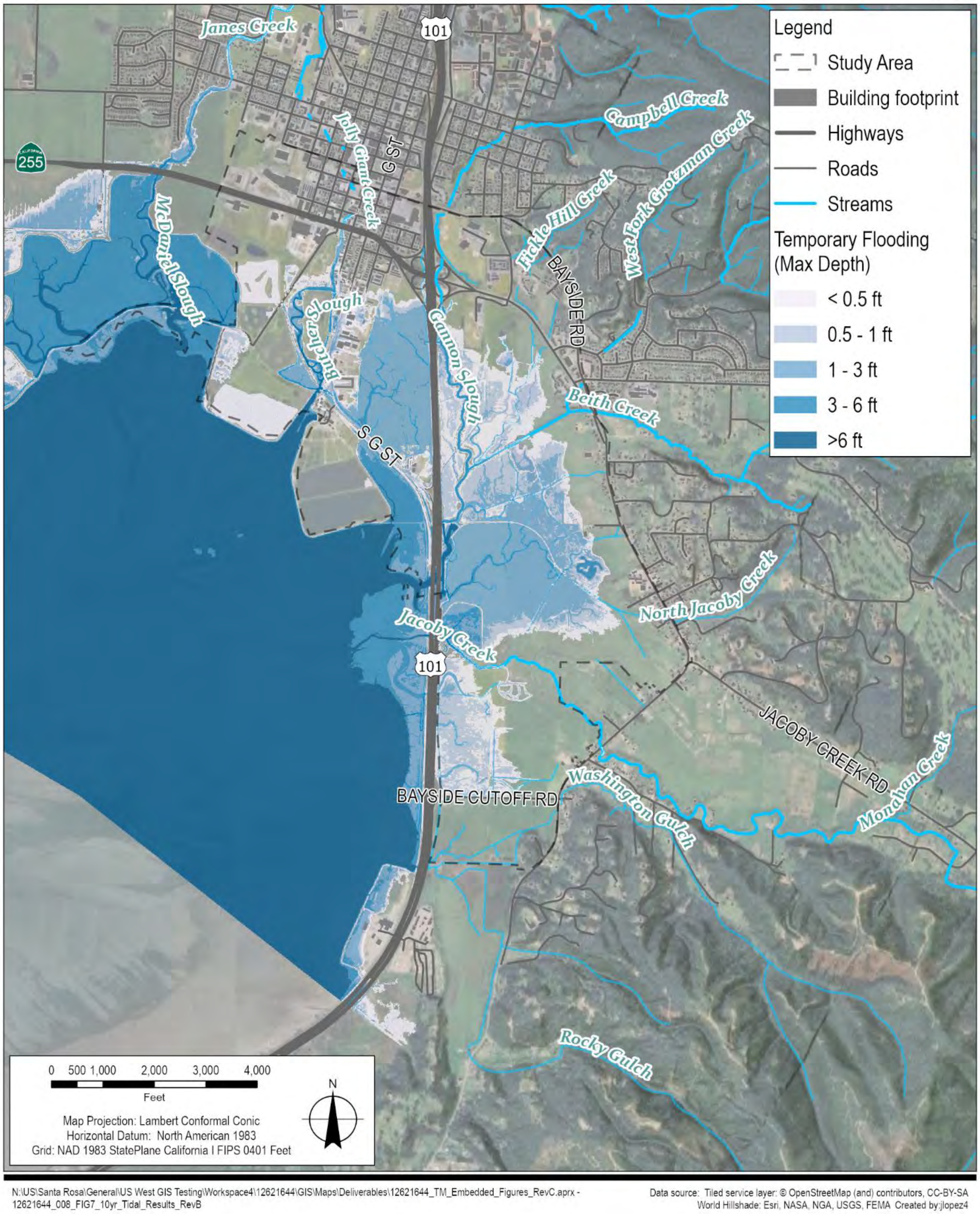
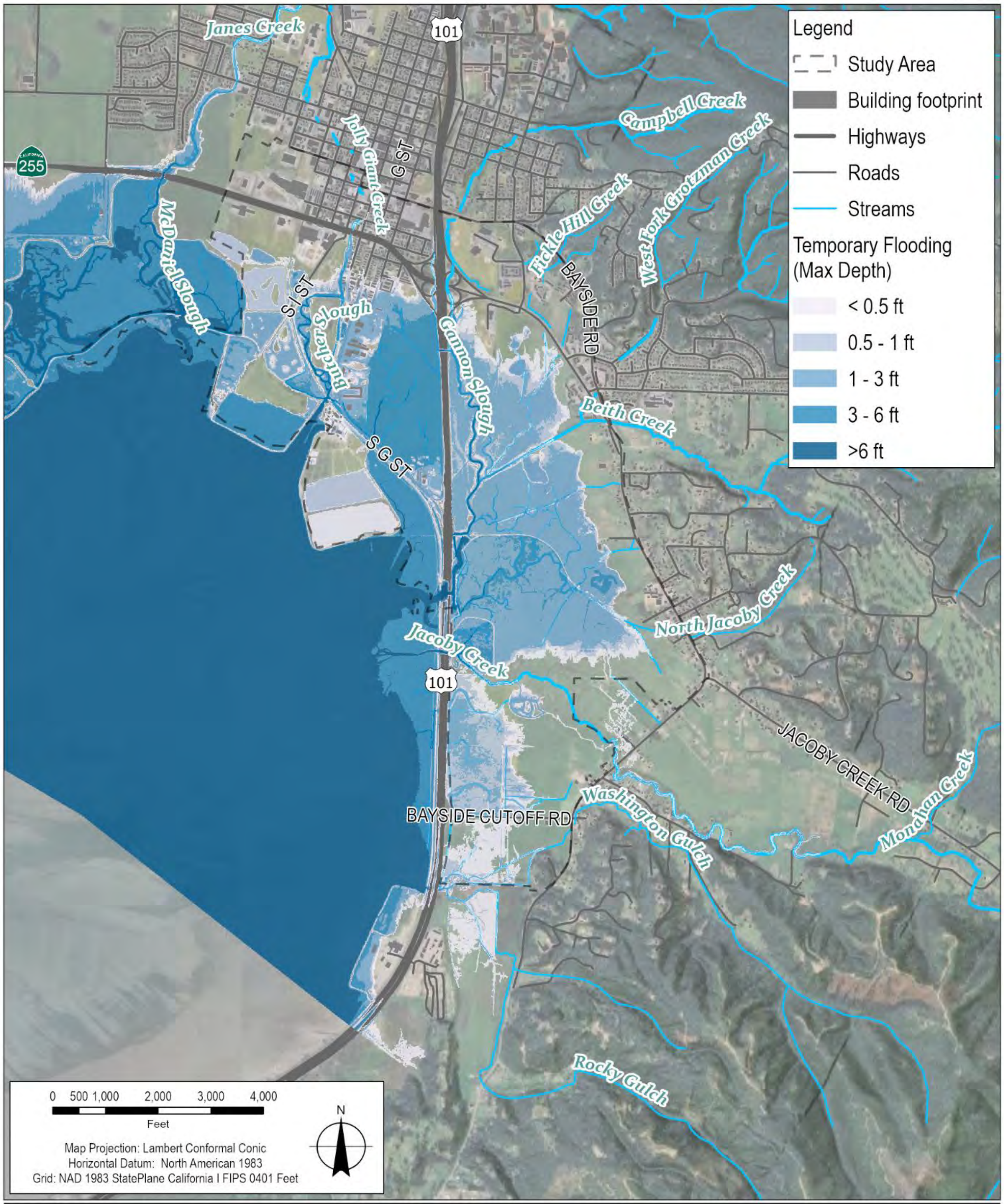


Figure 29 ***Model results for the peak 10.1 feet (existing 10-year) tidal boundary conditions.***



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

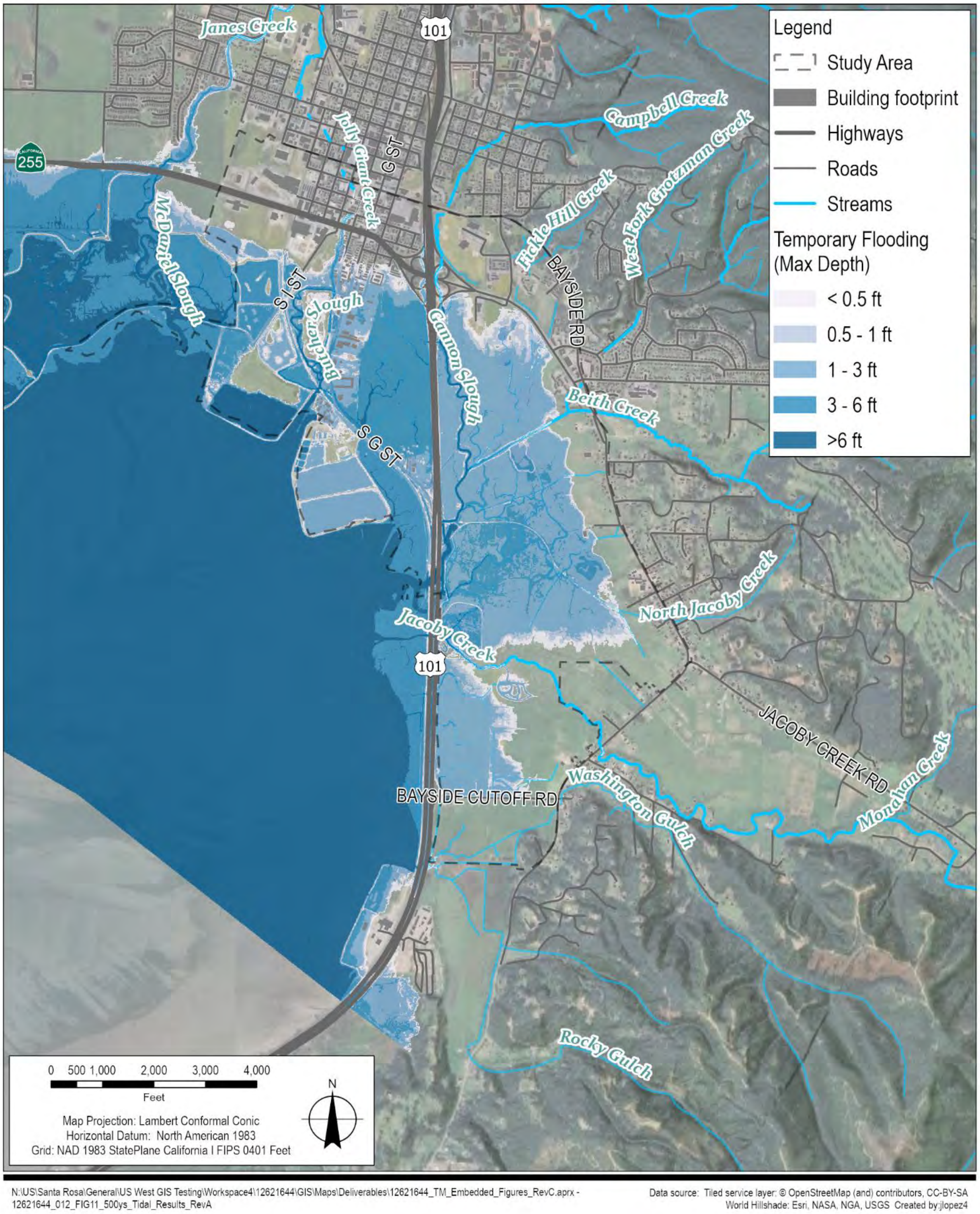


Figure 31 ***Model results for the peak 11.1 feet (existing 500-year) tidal boundary conditions.***

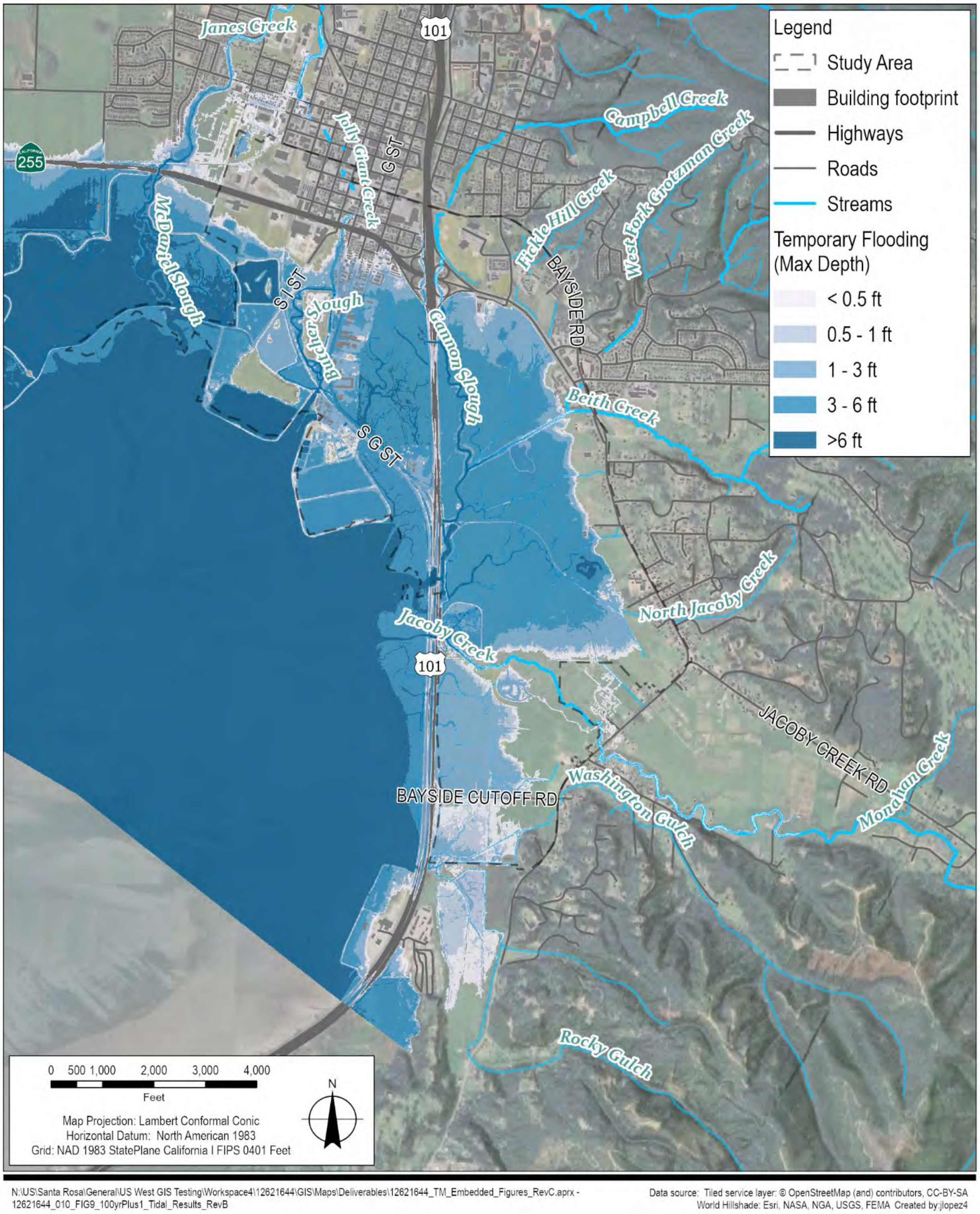
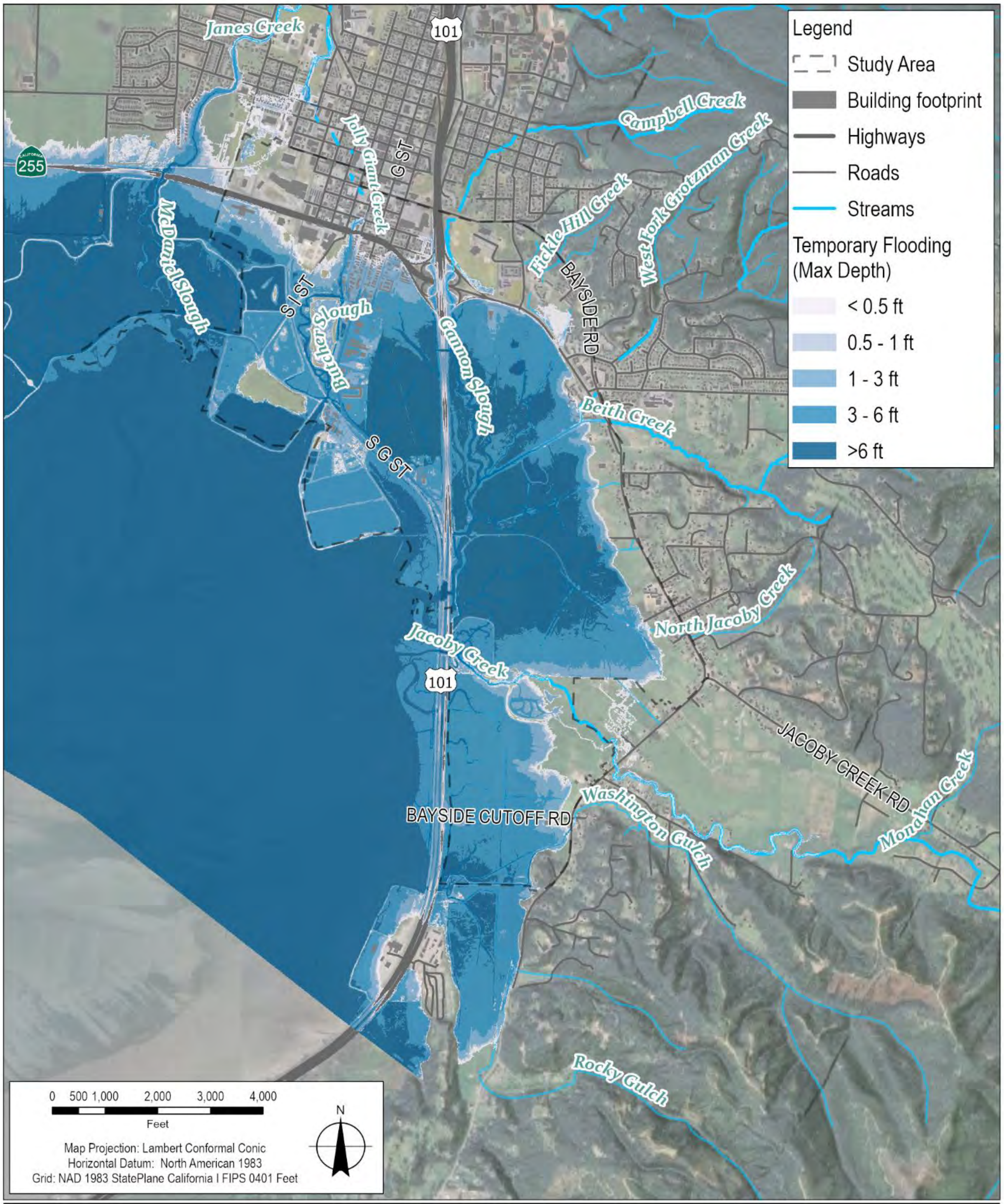


Figure 32 ***Model results for the peak 11.7 feet (existing 100-year + 1 foot SLR) tidal boundary conditions.***



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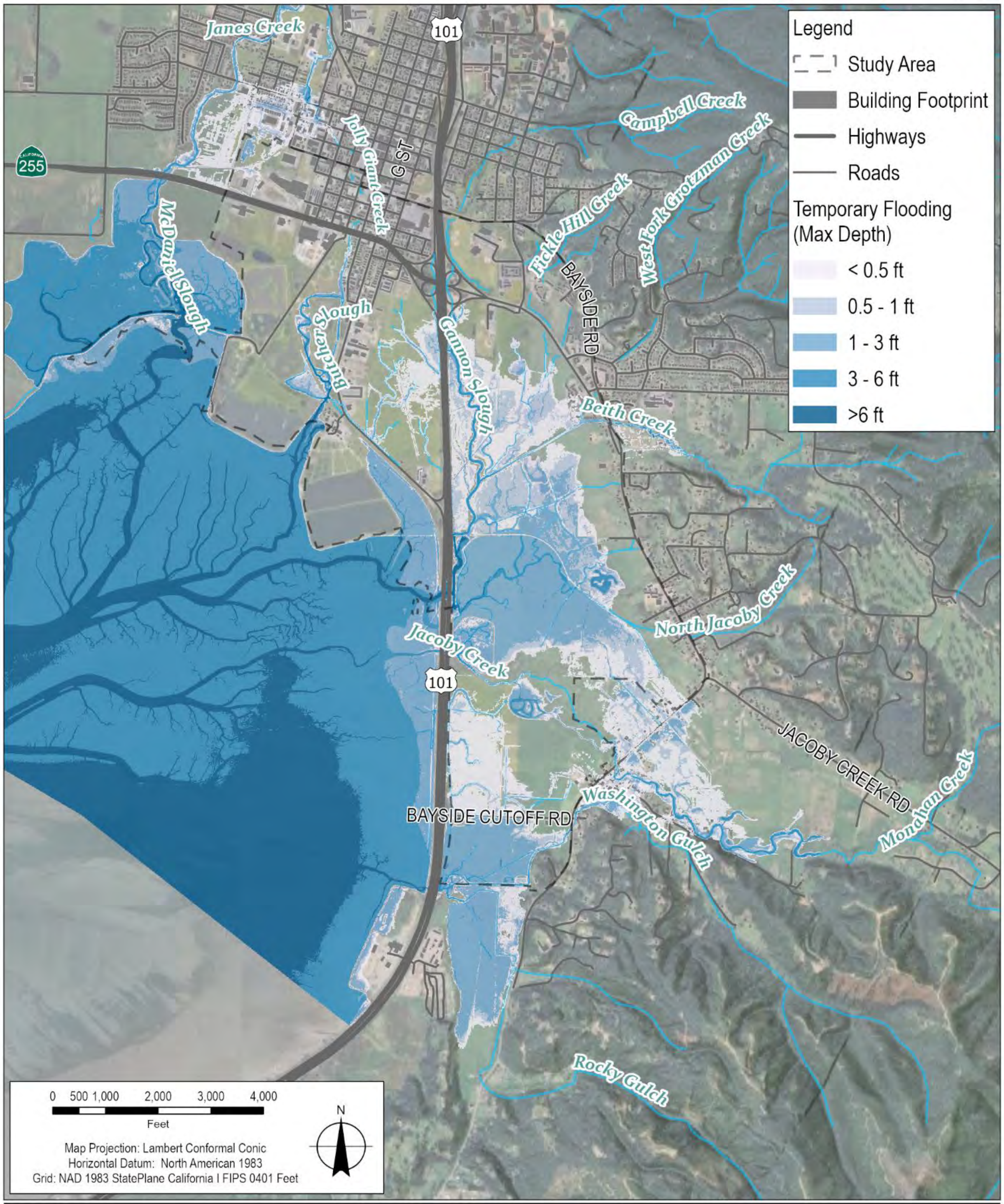
Data source: Tiled service layer: © OpenStreetMap (and) contributors, CC-BY-SA World Hillshade: Esri, NASA, NGA, USGS, FEMA Created by:jlopez4

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.***

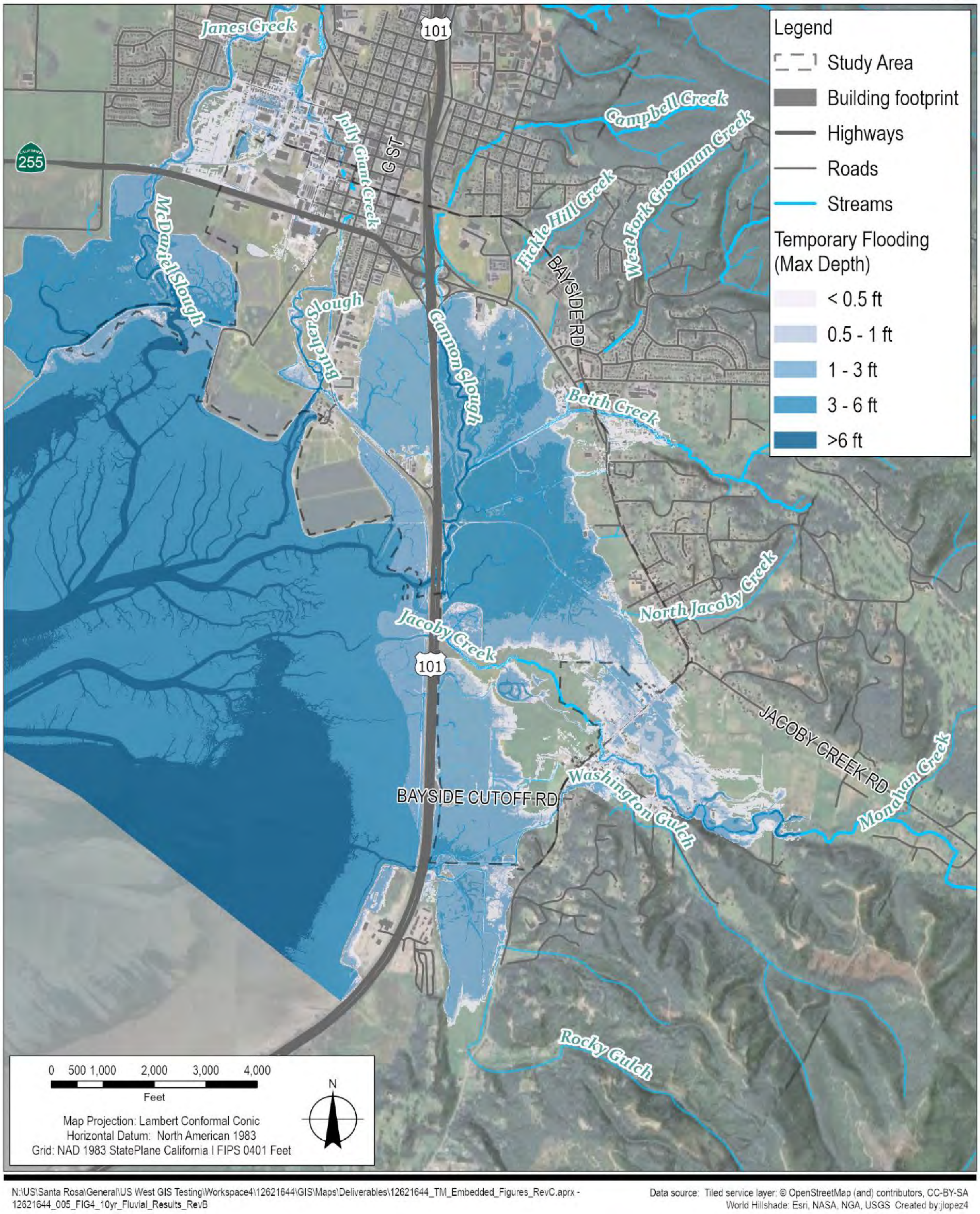


Figure 36 ***Model results for the 10-year fluvial and MMMW tidal boundary conditions.***

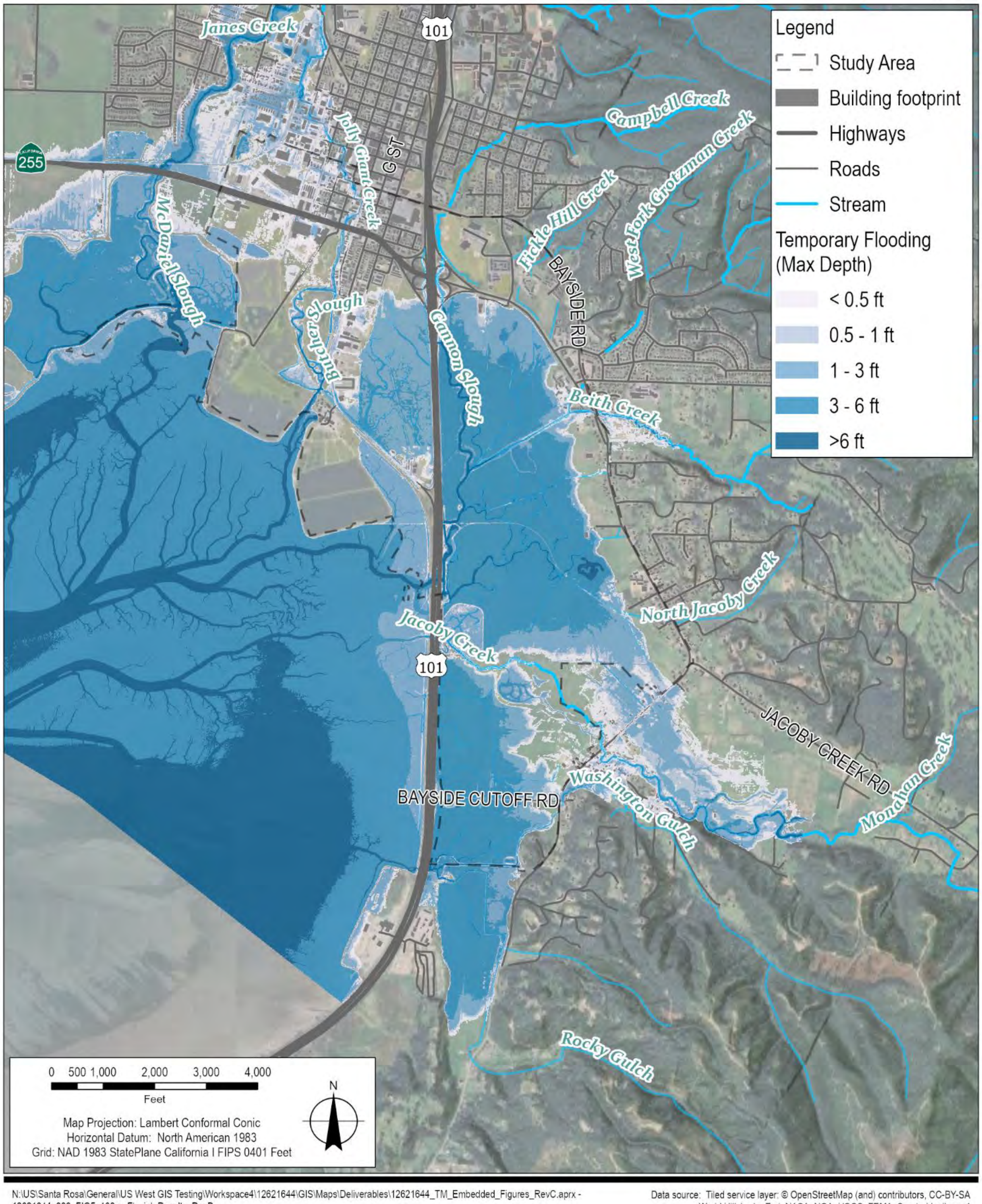
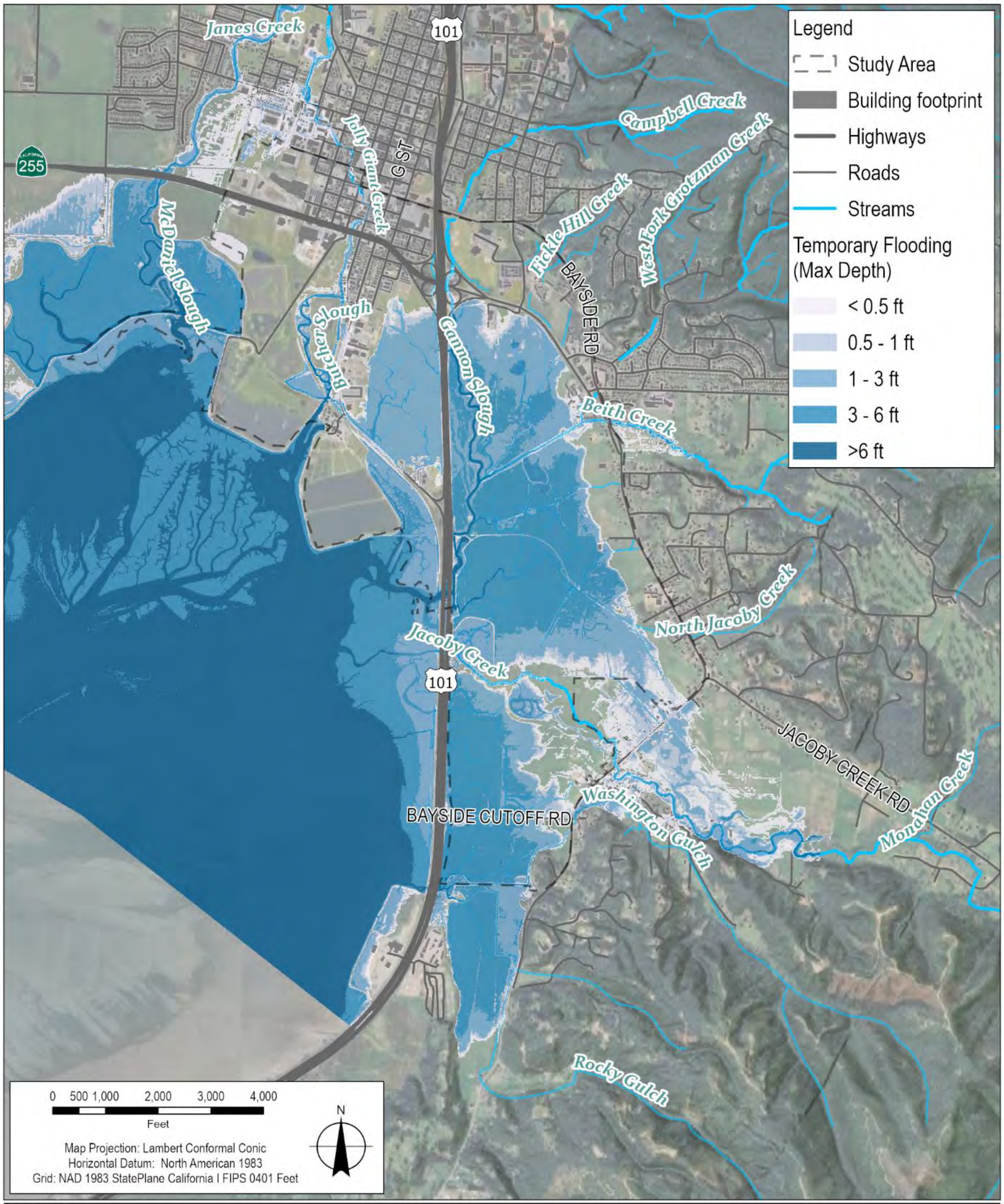


Figure 37 ***Model results for the 100-year fluvial and MMMW tidal boundary conditions.***



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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.***

6. References

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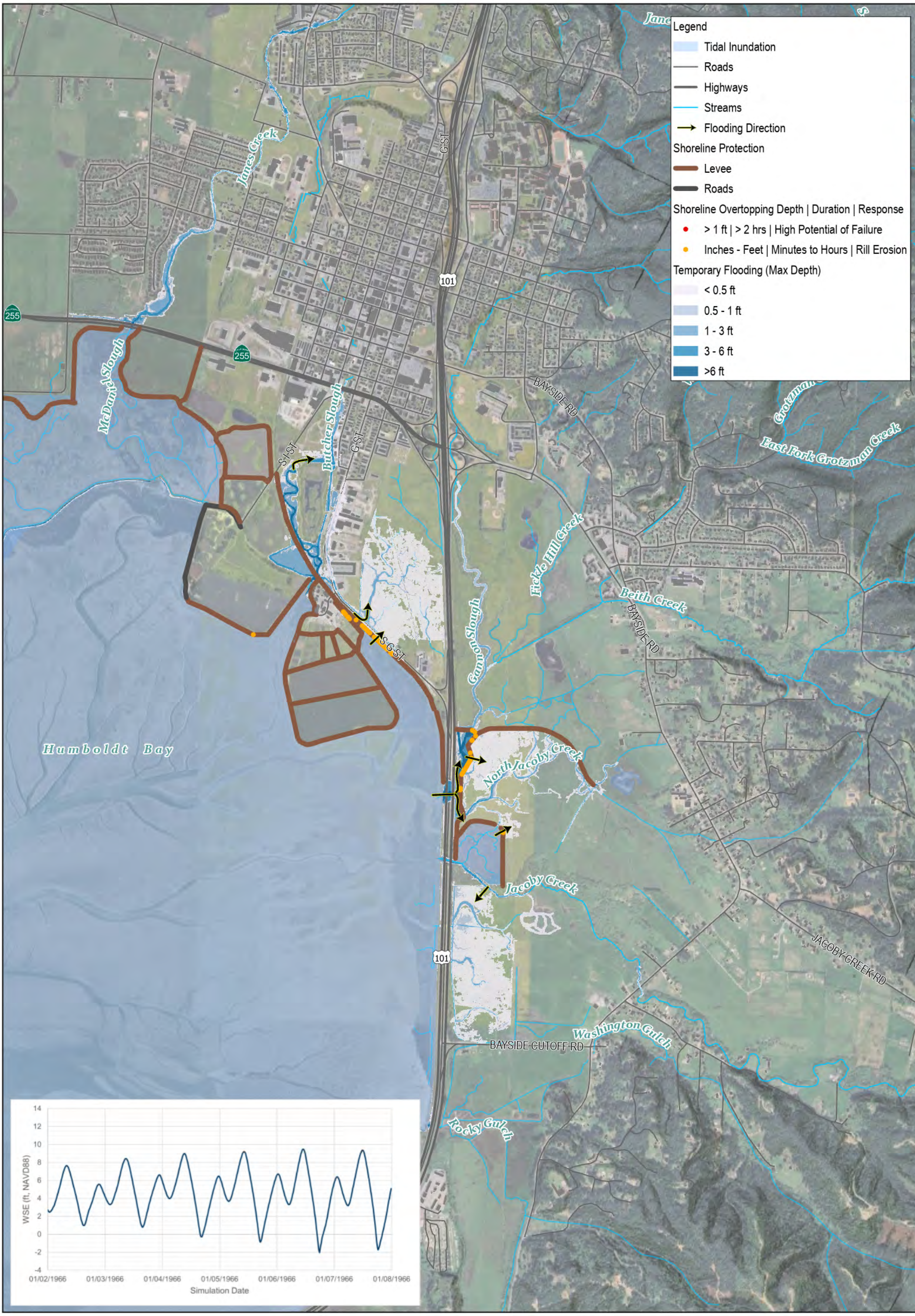
Appendix C

Exhibits: Flood Pathways, Transportation Exposure, and Utilities Exposure

– **Exhibits 1.1 through 1.11 Flooding Pathways:** show the locations of shoreline overtopping and associated depth and duration that may result in erosion or potential failure of the shoreline structure, maximum depth and extent of flooding, and flood pathways for coastal flood scenario.
– **Exhibits 2.1 through 2.11 Transportation Exposure:** show the extent and depth of flooding with road and trail locations exposed to coastal flood scenarios.
– **Exhibits 3.1 through 3.11 Utilities Exposure:** show water and wastewater lines, lift stations, and wastewater manholes exposed to coastal flood scenarios.



Paper Size ANSI B

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 9.5ft (NAVD88)
Tidal Flooding Pathways

Project No. **12621644**
Revision No. **-**
Date **May 2024**

EXHIBT 1.1

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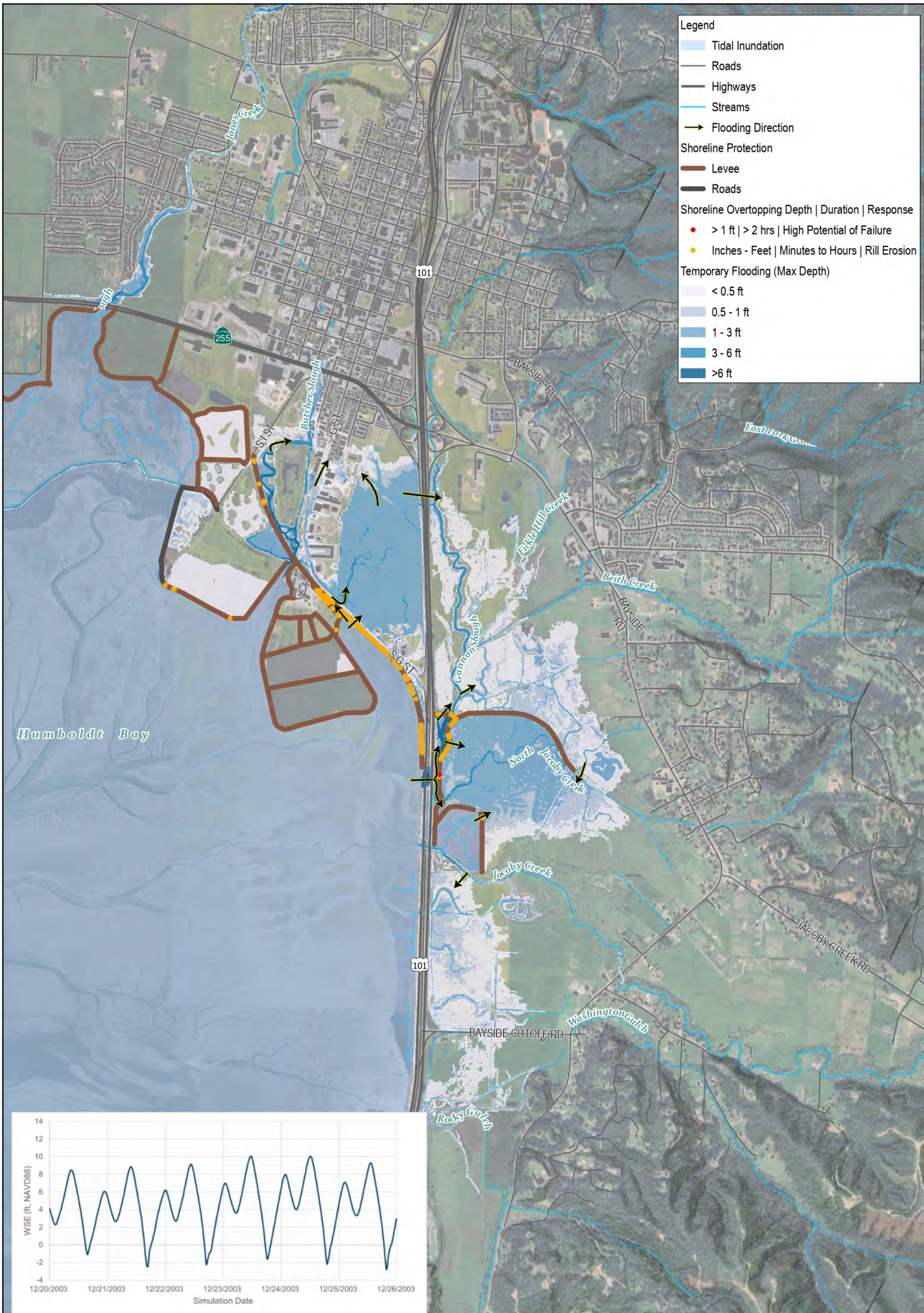

Paper Size ANSI B

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Feet

N

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 10.1ft (NAVD88)
Tidal Flooding Pathways

Project No. **12621644**
Revision No. **-**
Date **May 2024**

EXHIBIT 1.2

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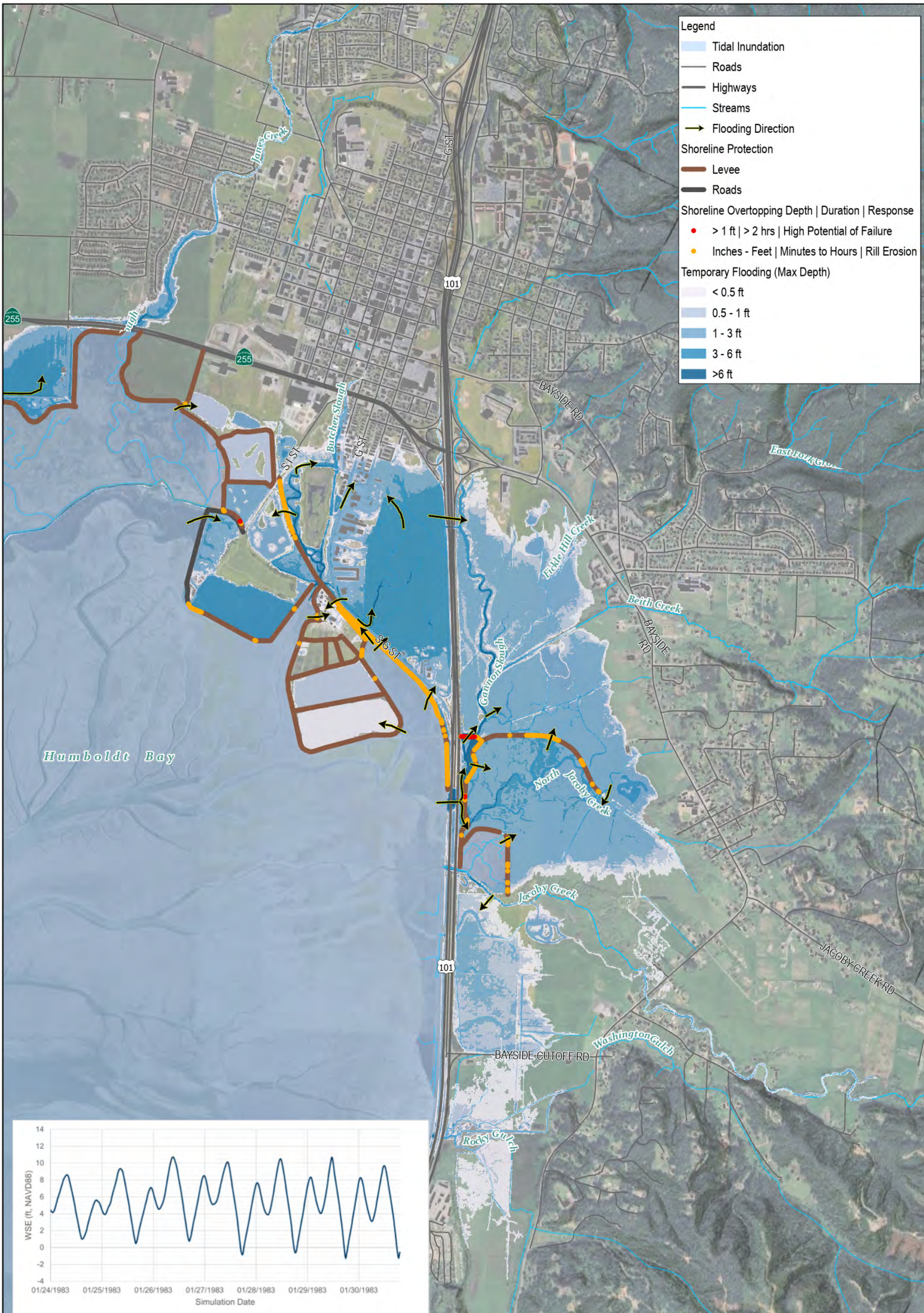

Paper Size ANSI B

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Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 10.7ft (NAVD88)
Tidal Flooding Pathways

Project No. **12621644**
Revision No. **-**
Date **May 2024**

EXHIBIT 1.3

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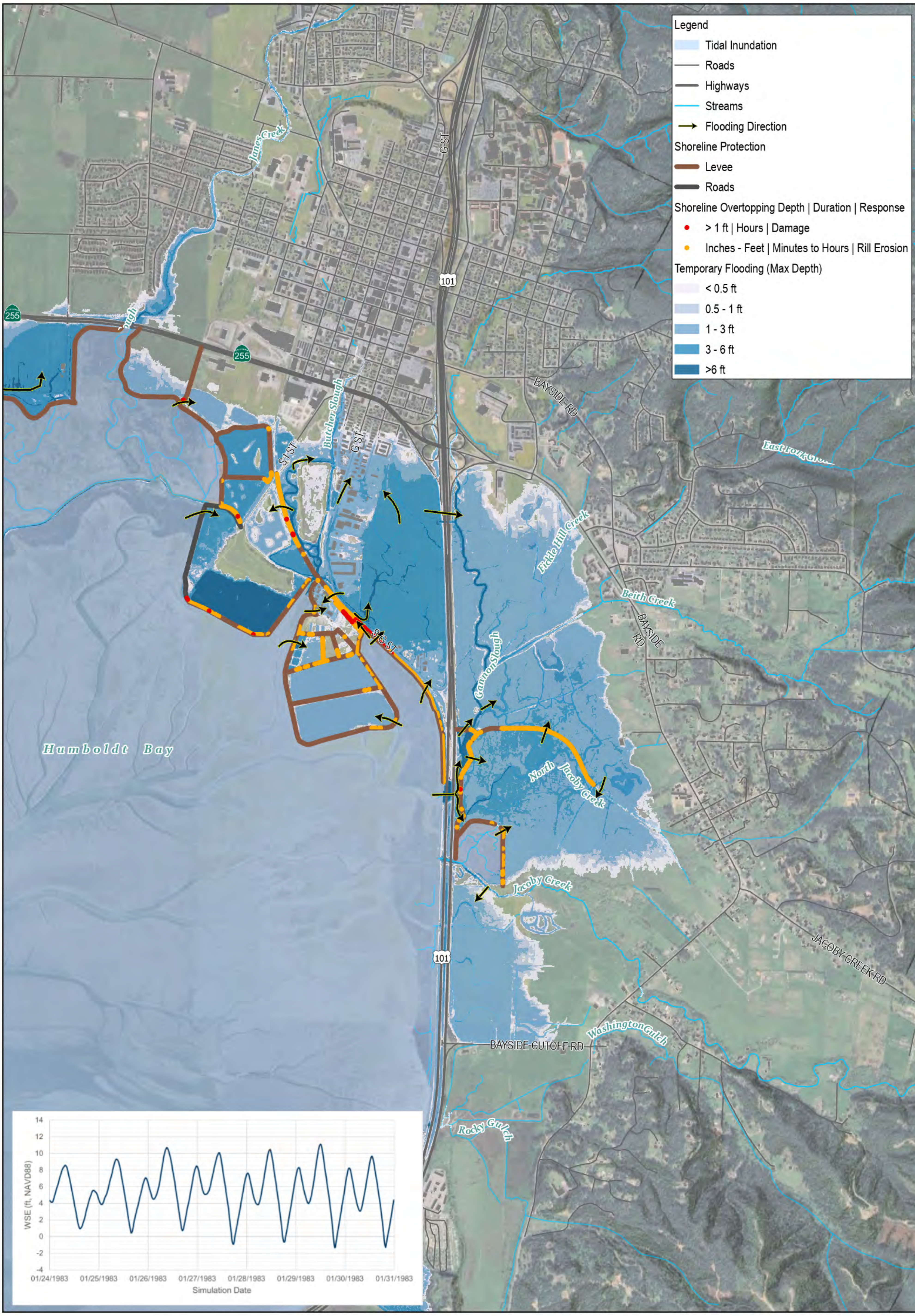

Paper Size ANSI B

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 11.1ft (NAVD88)
Tidal Flooding Pathways

Project No. **12621644**
Revision No. **-**
Date **May 2024**

EXHIBIT 1.4

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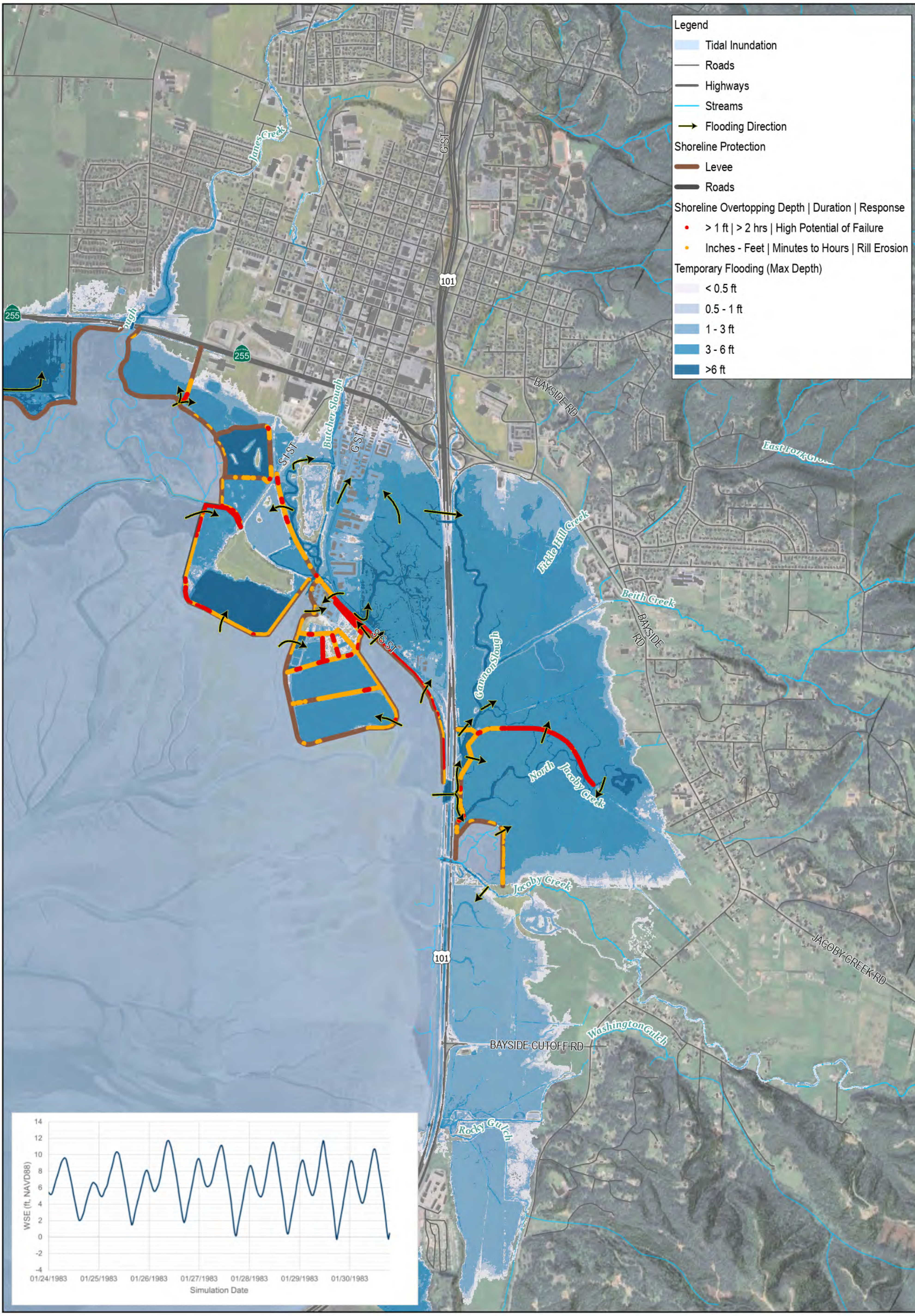

Paper Size ANSI B

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 11.7ft (NAVD88)
Tidal Flooding Pathways

Project No. **12621644**
Revision No. **-**
Date **May 2024**

EXHIBIT 1.5

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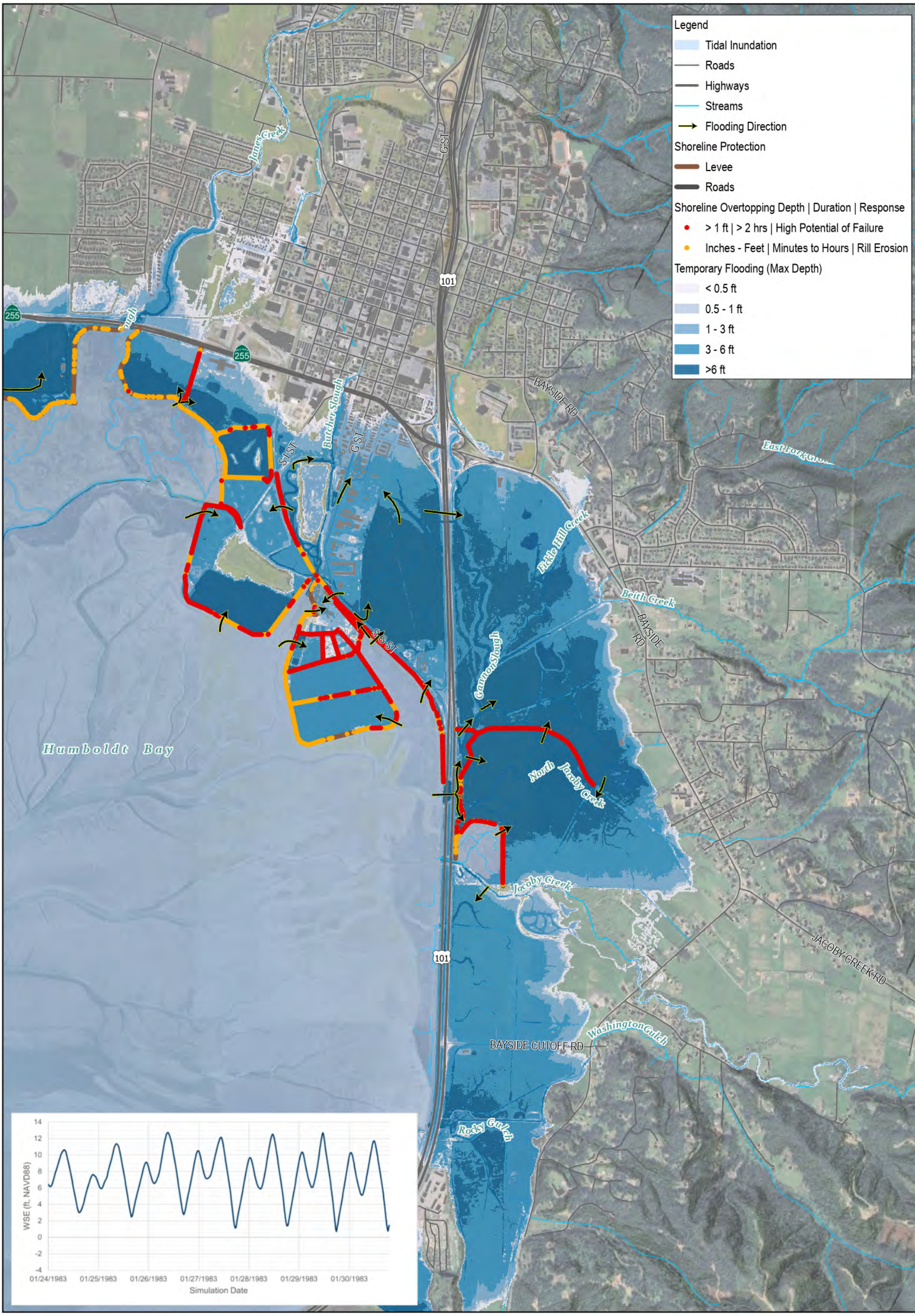

Paper Size ANSI B

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 12.7ft (NAVD88)
Tidal Flooding Pathways

Project No. **12621644**
Revision No. **-**
Date **May 2024**

EXHIBIT 1.6

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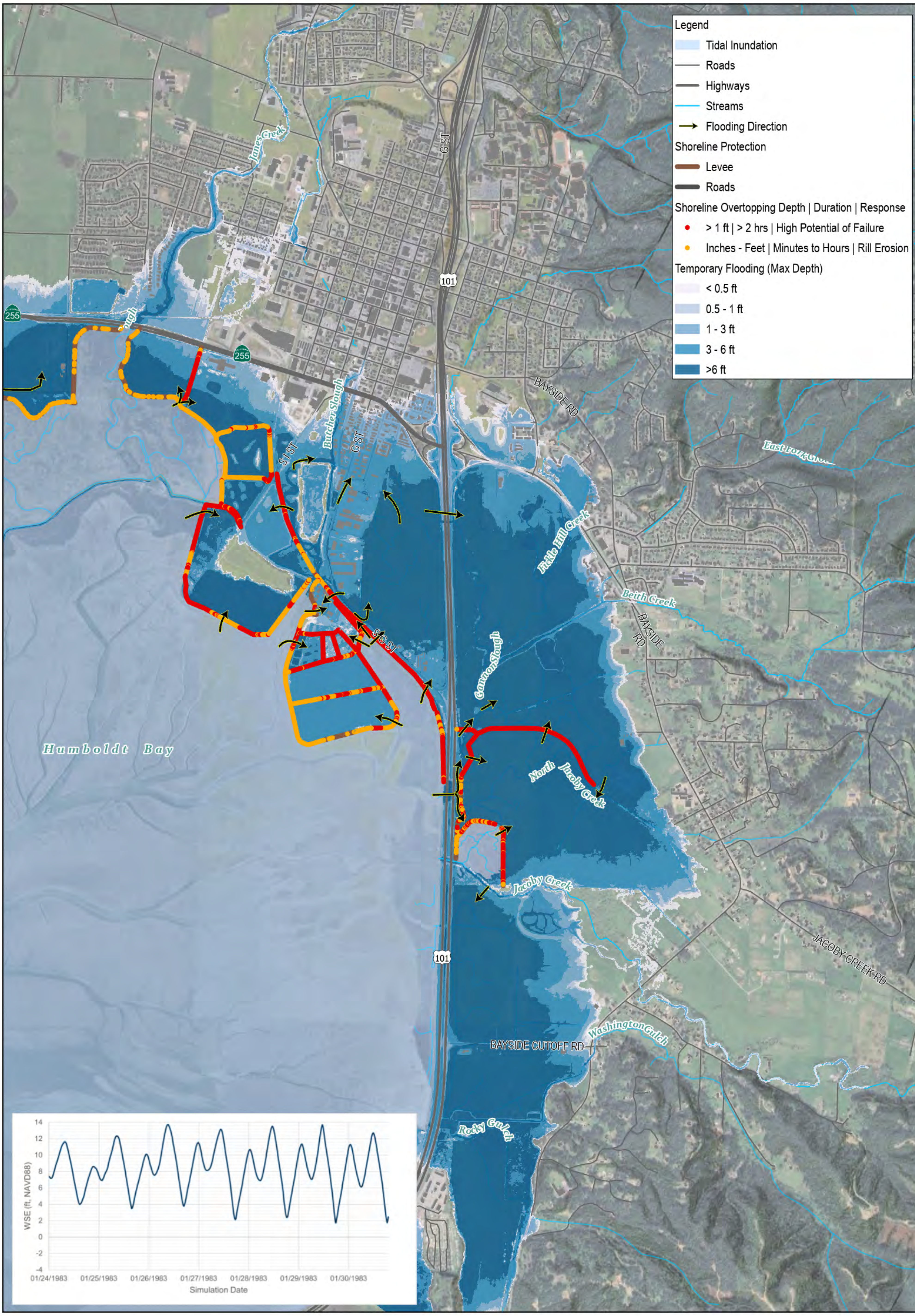

Paper Size ANSI B

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 13.7ft (NAVD88)
Tidal Flooding Pathways

Project No. **12621644**
Revision No. **-**
Date **May 2024**

EXHIBIT 1.7

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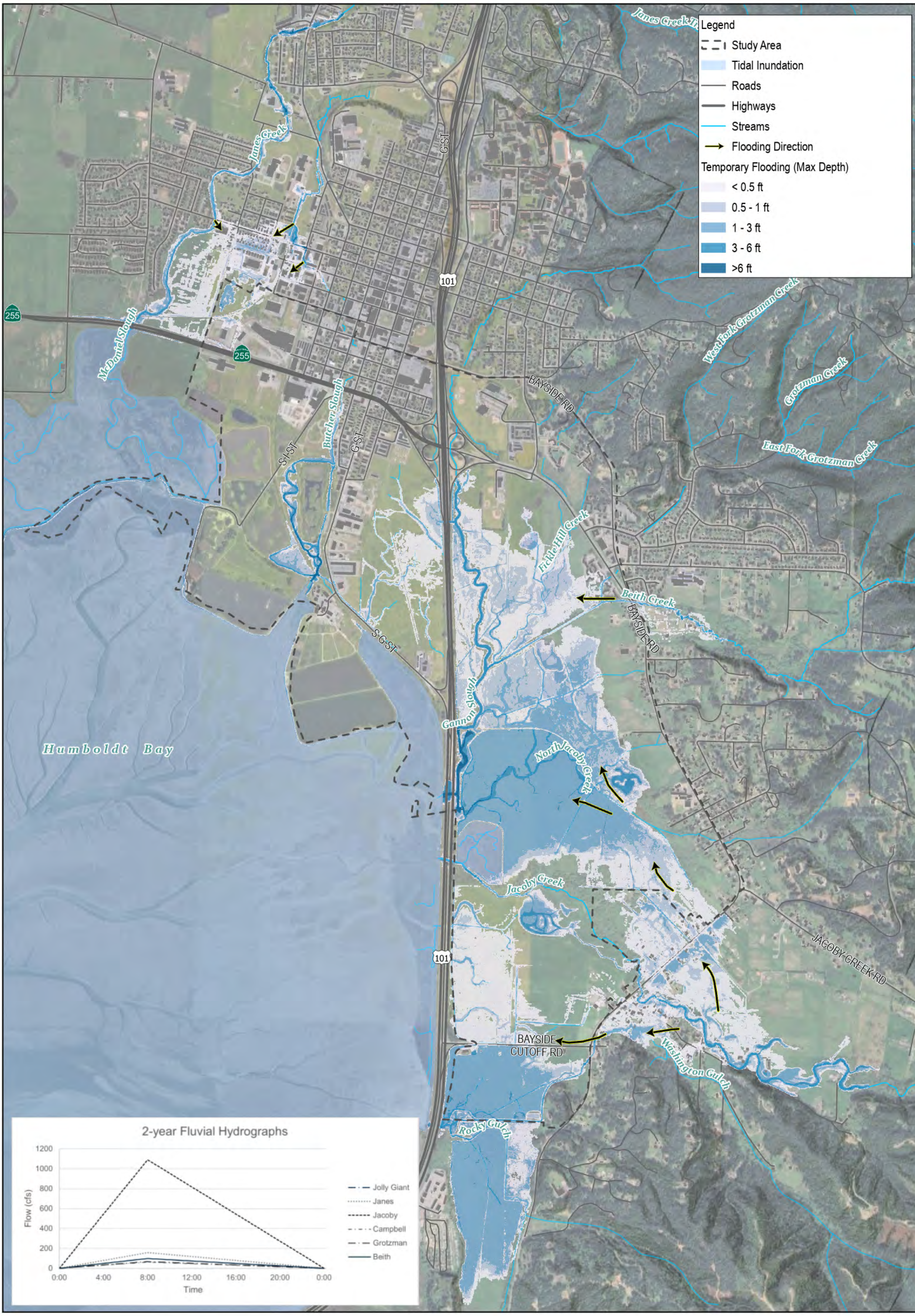

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Feet

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Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

2-year
Fluvial Flooding Pathways

Project No. **12621644**
Revision No. **-**
Date **May 2024**

EXHIBIT 1.8

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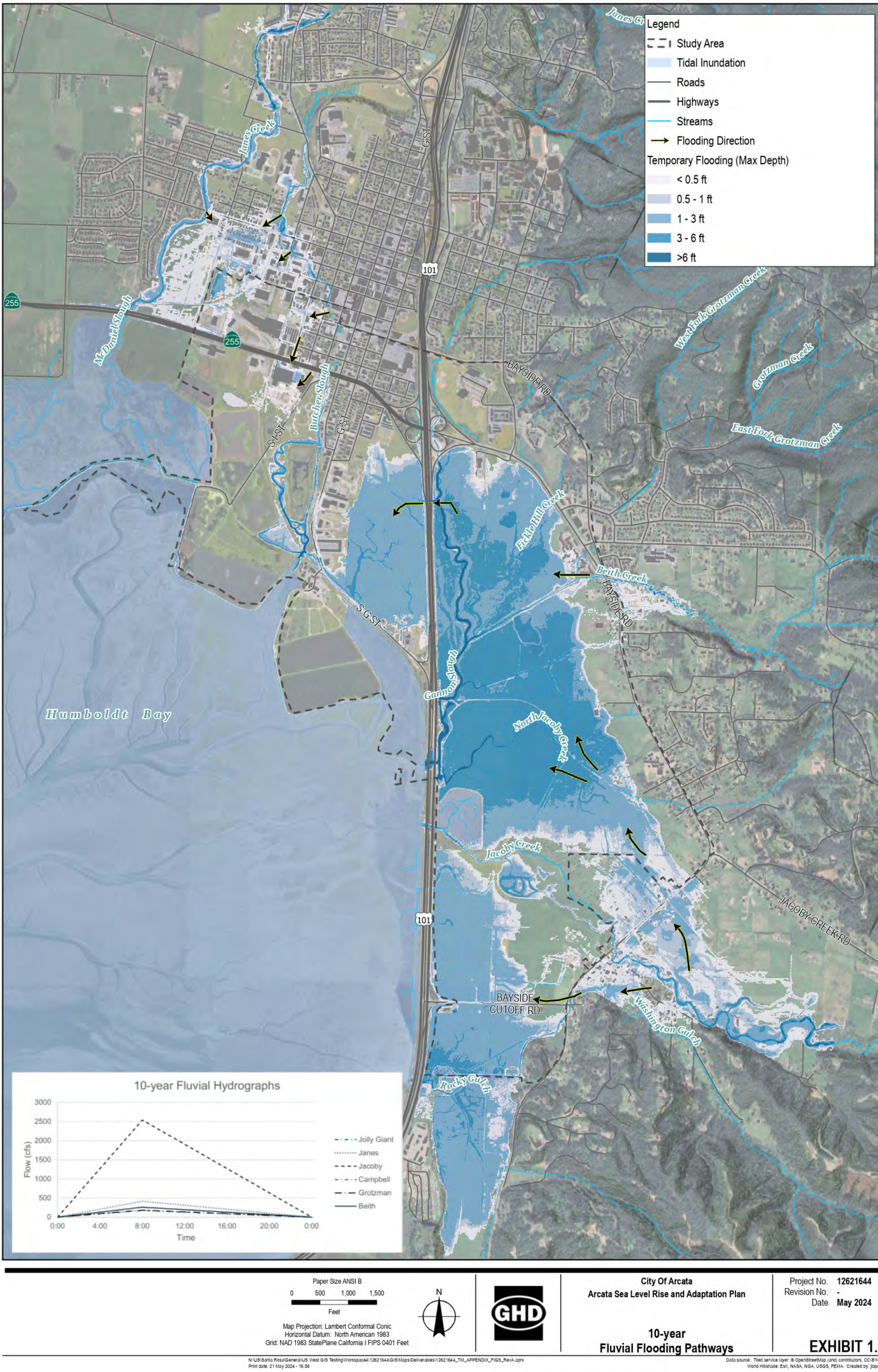

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Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

10-year
Fluvial Flooding Pathways

Project No. **12621644**
Revision No. **-**
Date **May 2024**

EXHIBIT 1.9

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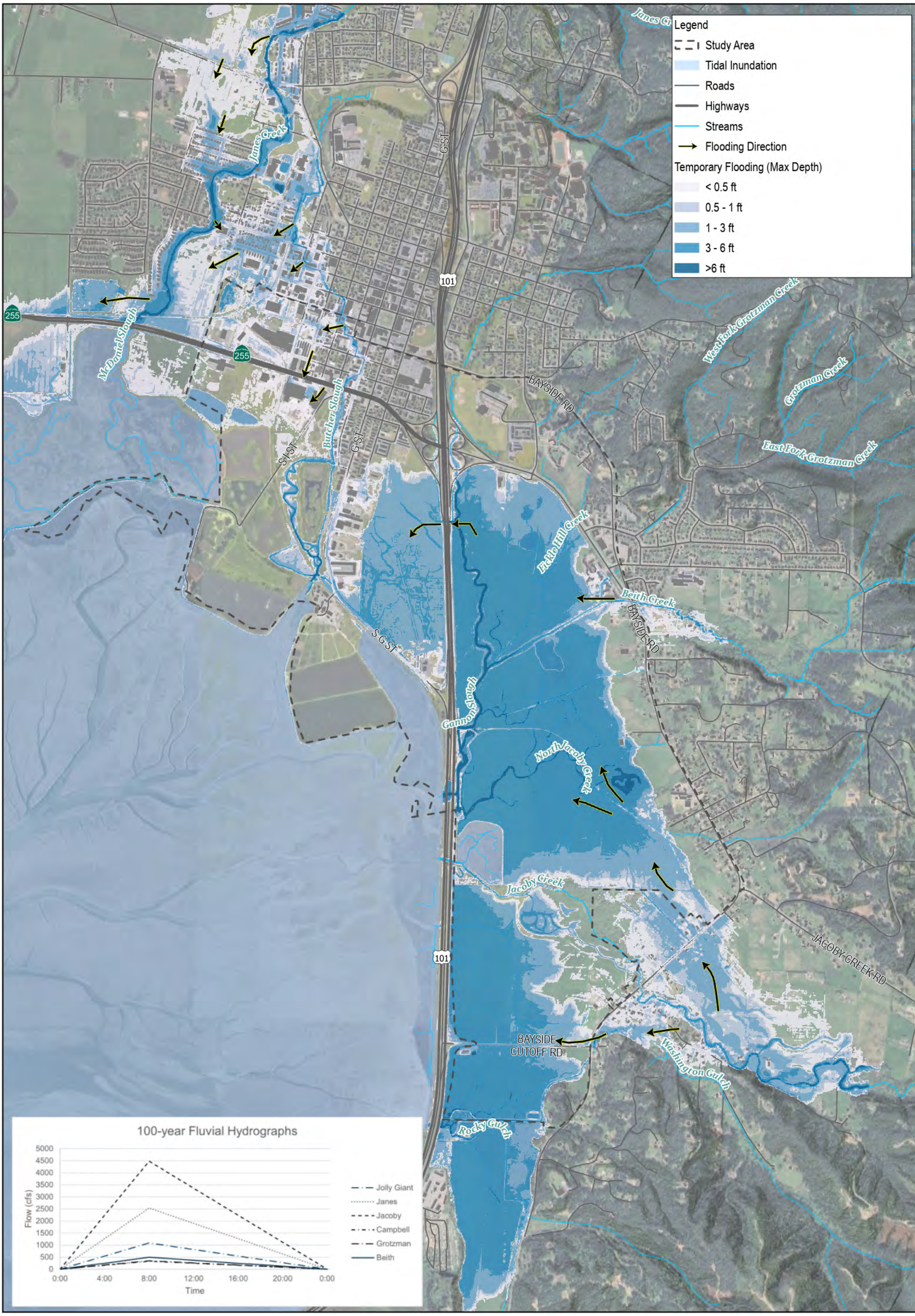

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N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

100-year
Fluvial Flooding Pathways

Project No. **12621644**
Revision No. **-**
Date **May 2024**

EXHIBIT 1.10

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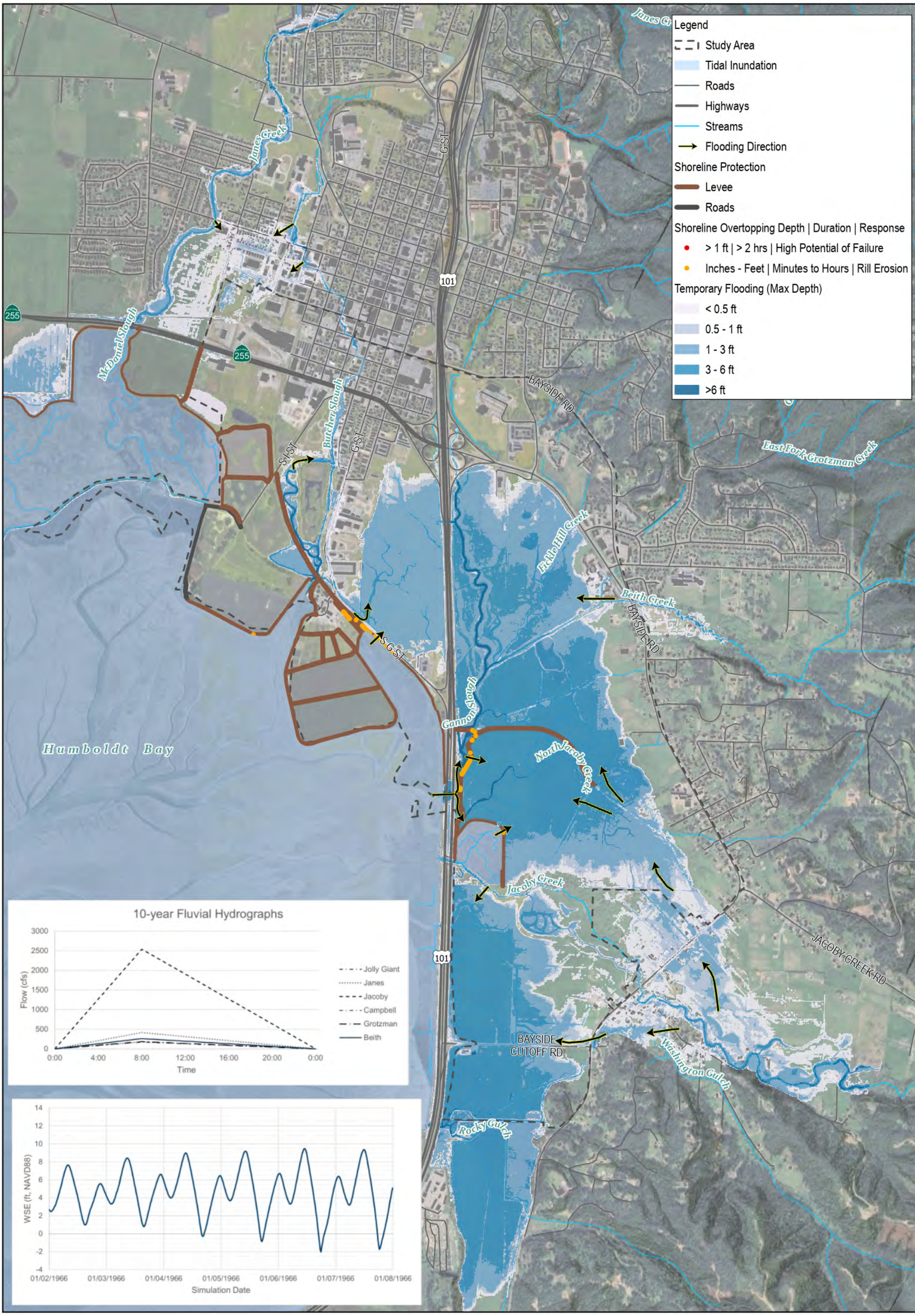

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Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

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GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 9.5 feet and 10-year Fluvial Event Flooding Pathways

Project No. **12621644**
Revision No. **-**
Date **May 2024**

EXHIBIT 1.11

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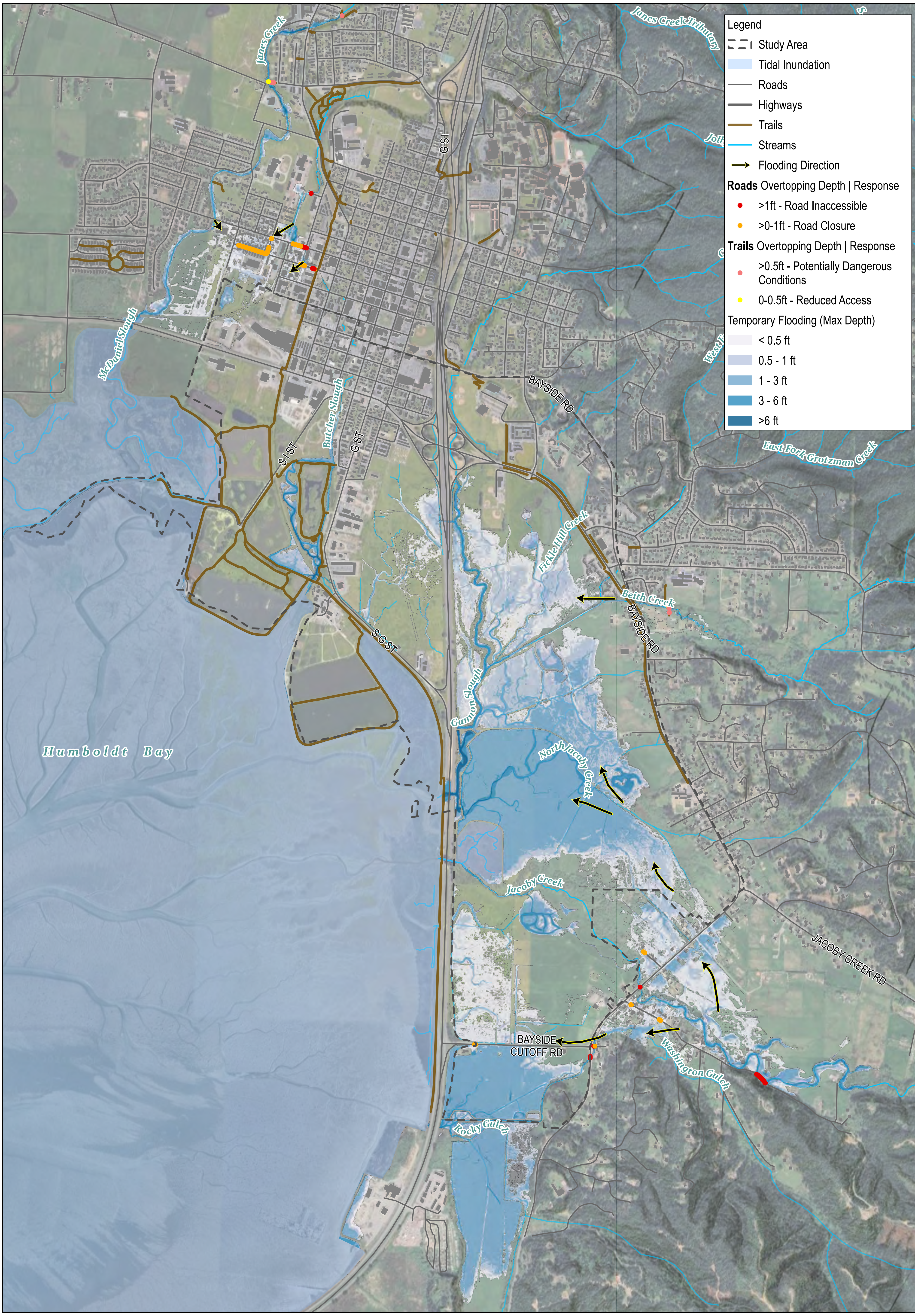

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

2-year Fluvial Flooding
Affected Transportation

Project No. **12621644**
Revision No. **-**
Date **Oct 2024**

EXHIBIT 2.8

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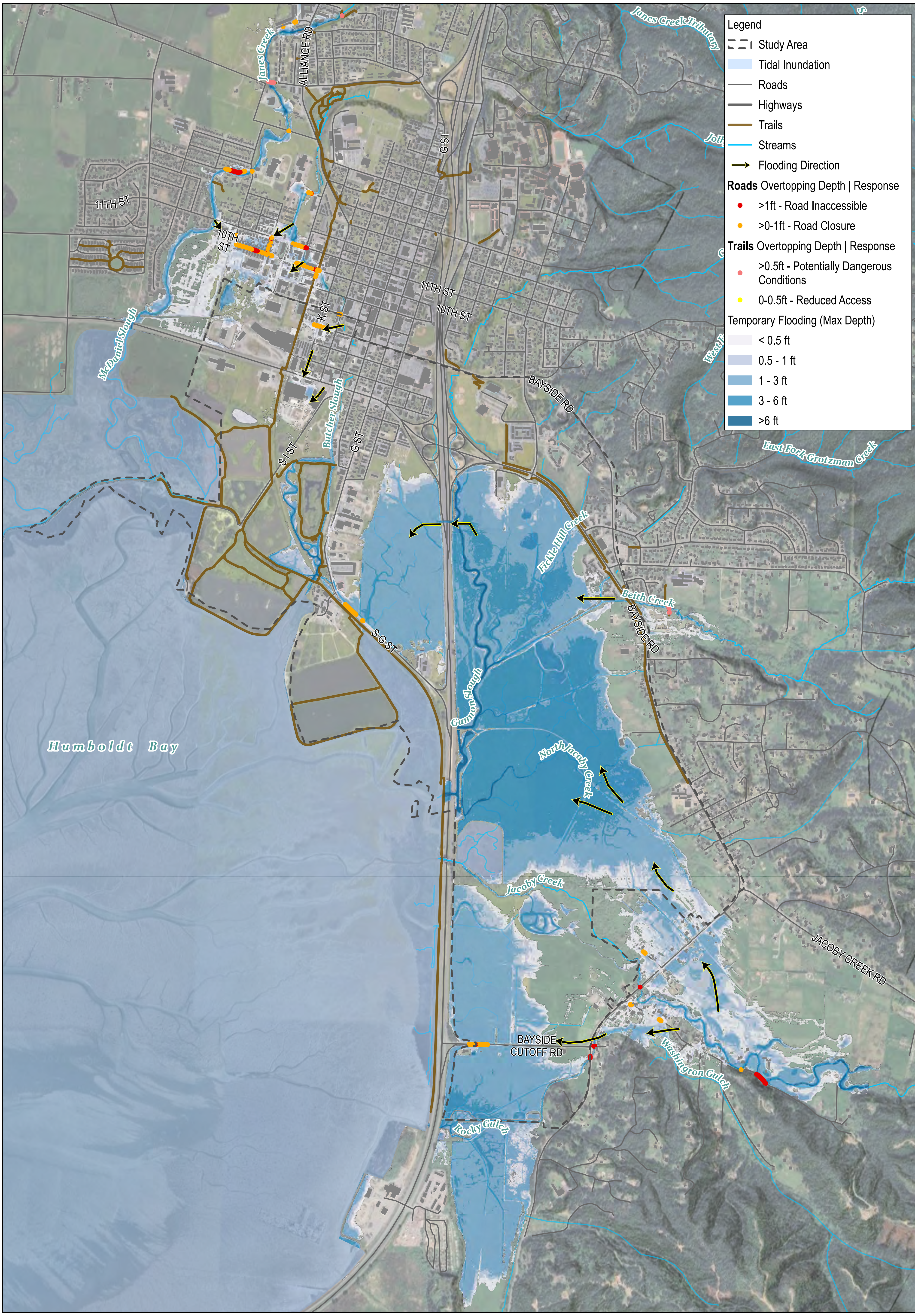

Paper Size ANSI B

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

10-year Fluvial Flooding
Affected Transportation

Project No. **12621644**
Revision No. **-**
Date **Oct 2024**

EXHIBIT 2.9

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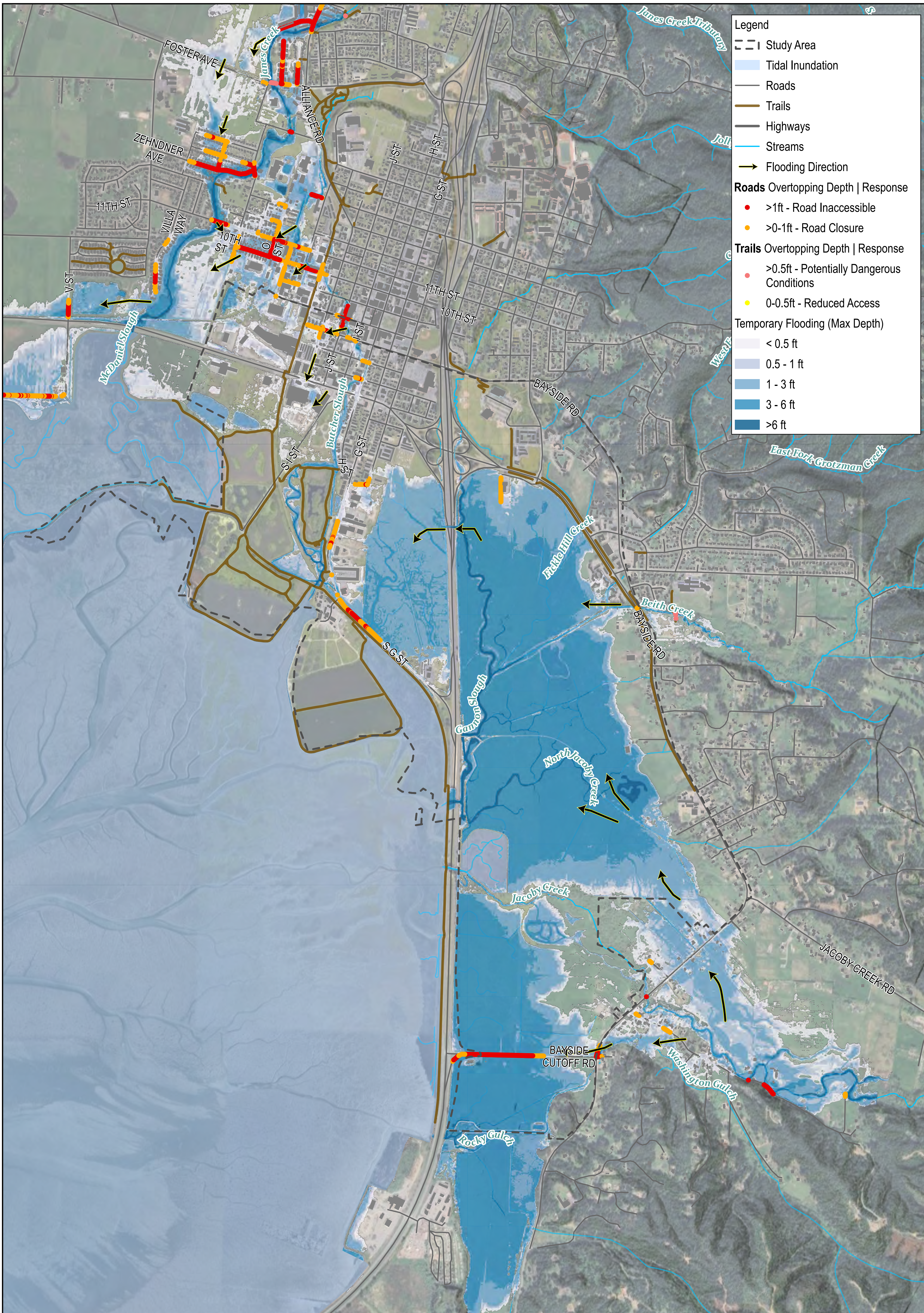

Paper Size ANSI B

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

100-year Fluvial Flooding
Affected Transportation

Project No. **12621644**
Revision No. **-**
Date **Oct 2024**

EXHIBIT 2.10

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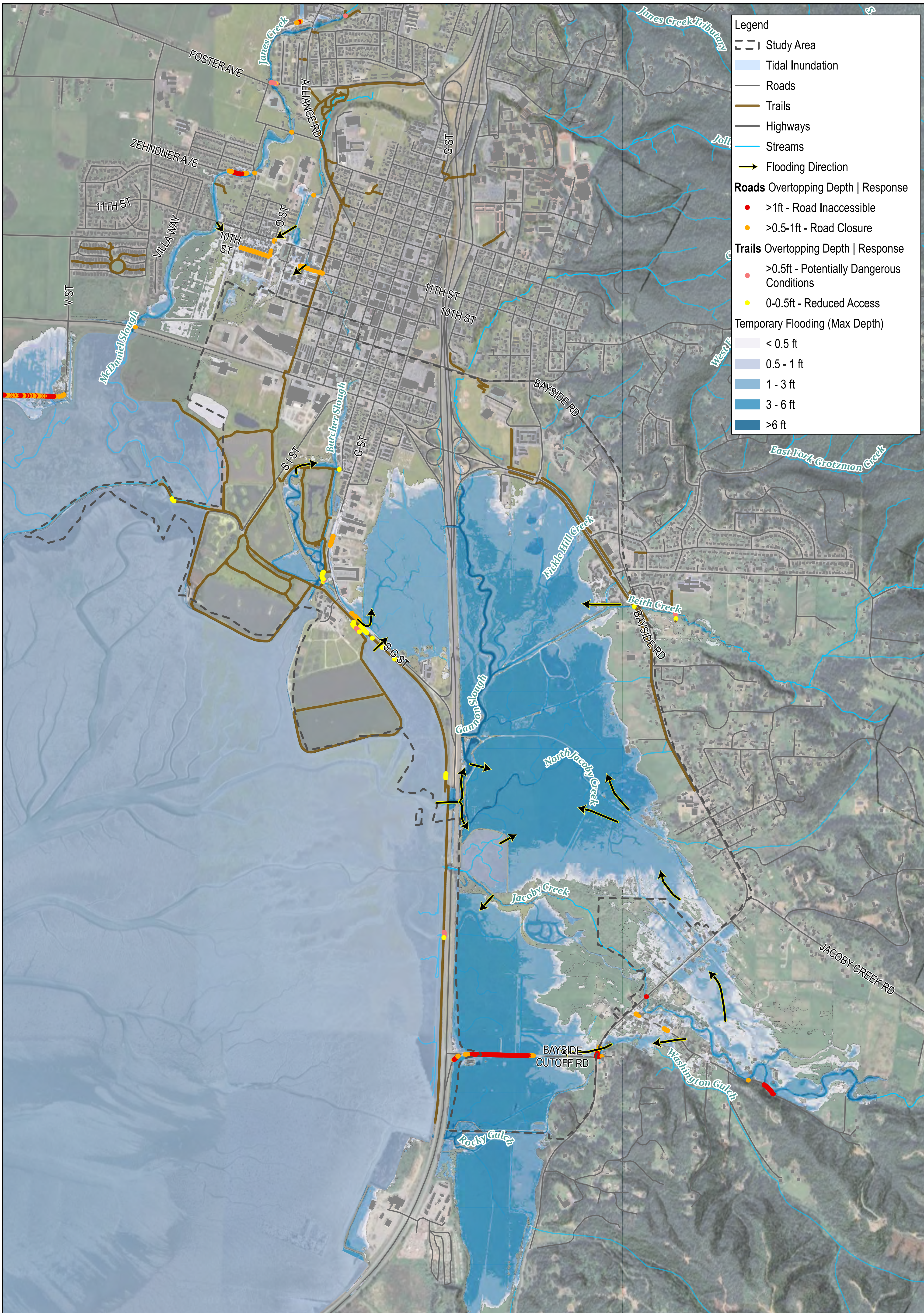

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Feet

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Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata

Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 9.5 feet and 10-year Fluvial Affected Transportation

Project No. **12621644**
Revision No. **-**
Date **Oct 2024**

EXHIBIT 2.11

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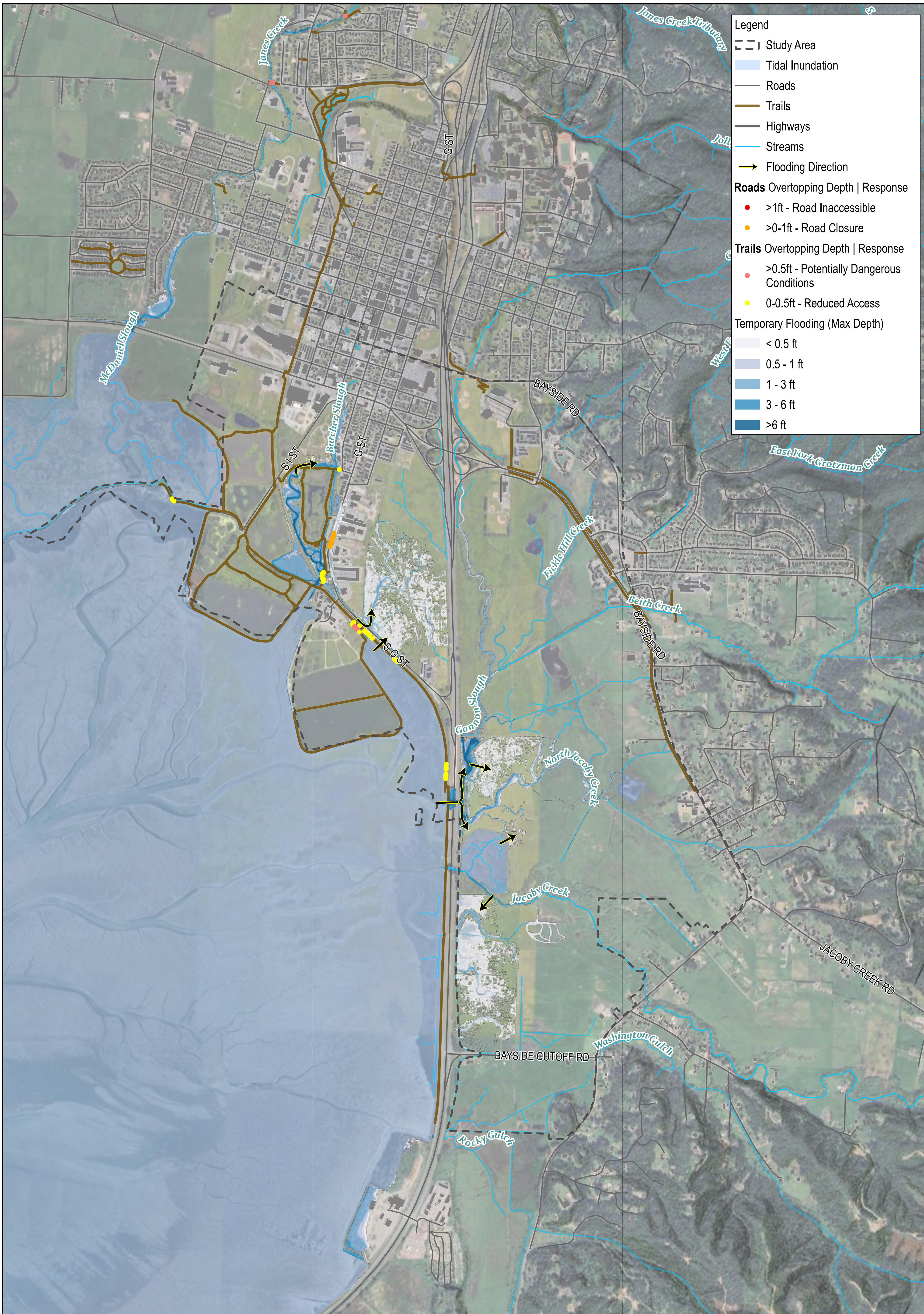

Paper Size ANSI B

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 9.5ft (NAVD88)
Affected Transportation

Project No. **12621644**
Revision No. **-**
Date **Oct 2024**

EXHIBIT 2.1

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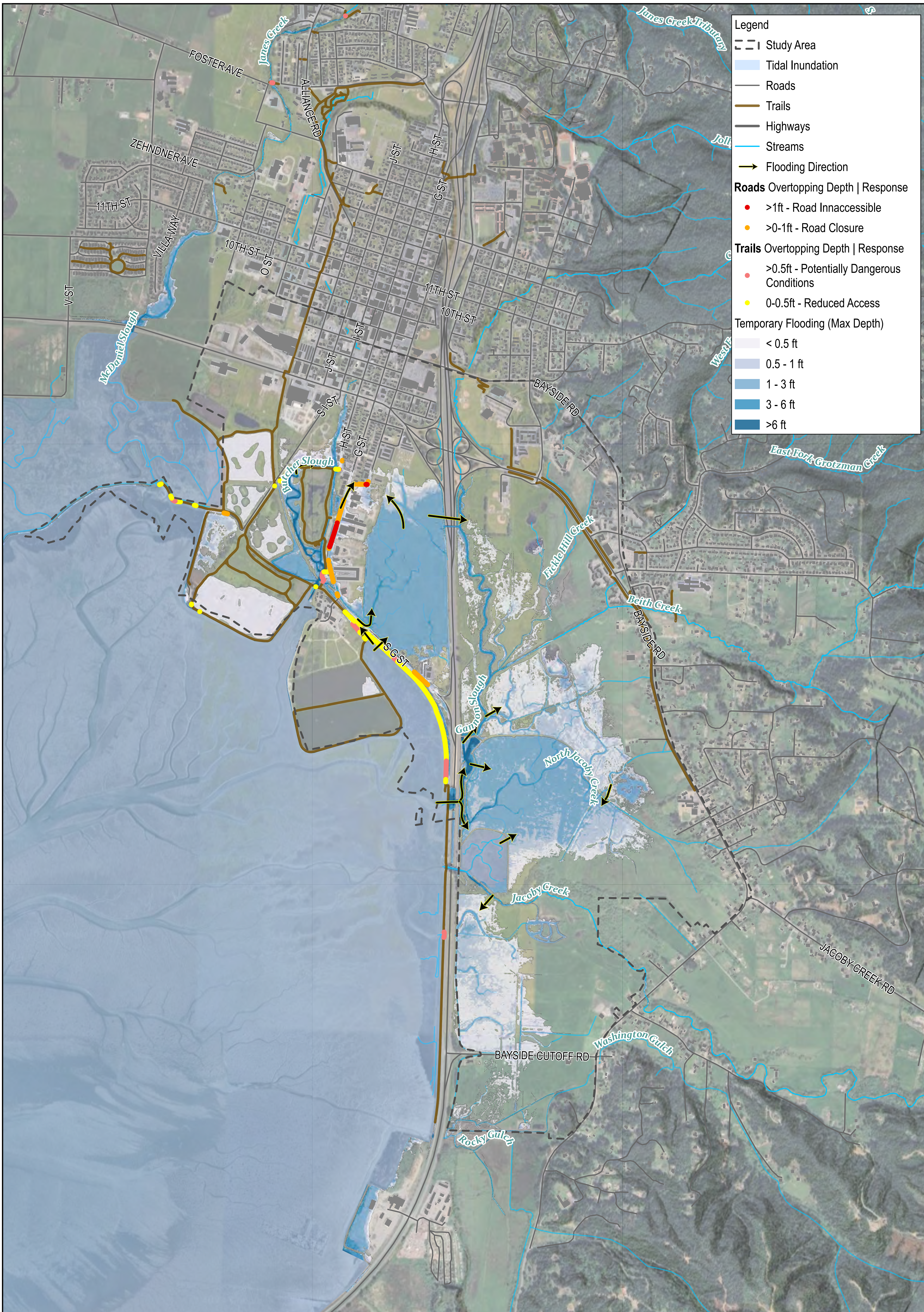

Paper Size ANSI B

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Feet

N

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 10.1ft (NAVD88)
Affected Transportation

Project No. **12621644**
Revision No. **-**
Date **Oct 2024**

EXHIBIT 2.2

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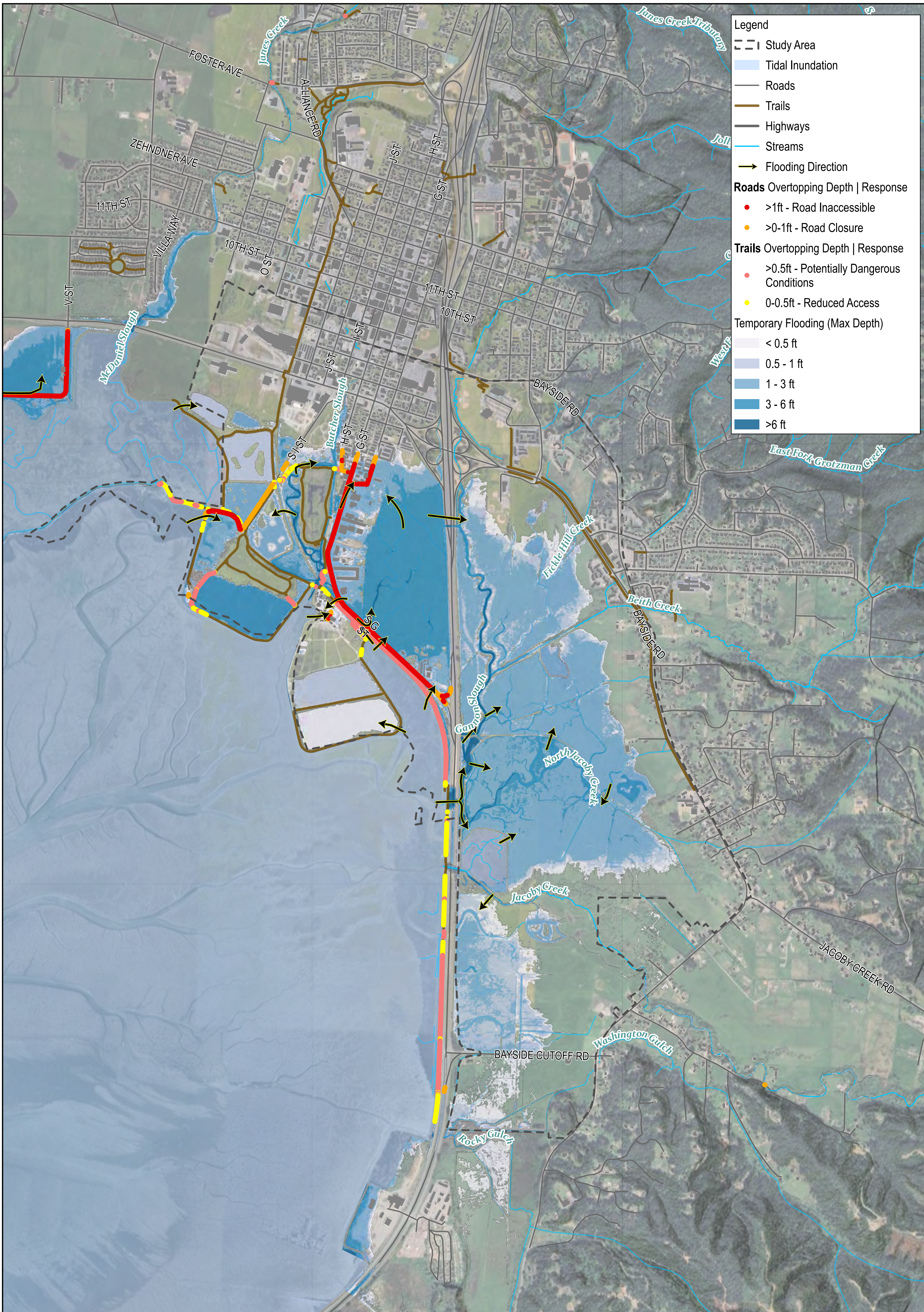

Paper Size ANSI B

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Feet

N

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 10.7ft (NAVD88)
Affected Transportation

Project No. **12621644**
Revision No. **-**
Date **Oct 2024**

EXHIBIT 2.3

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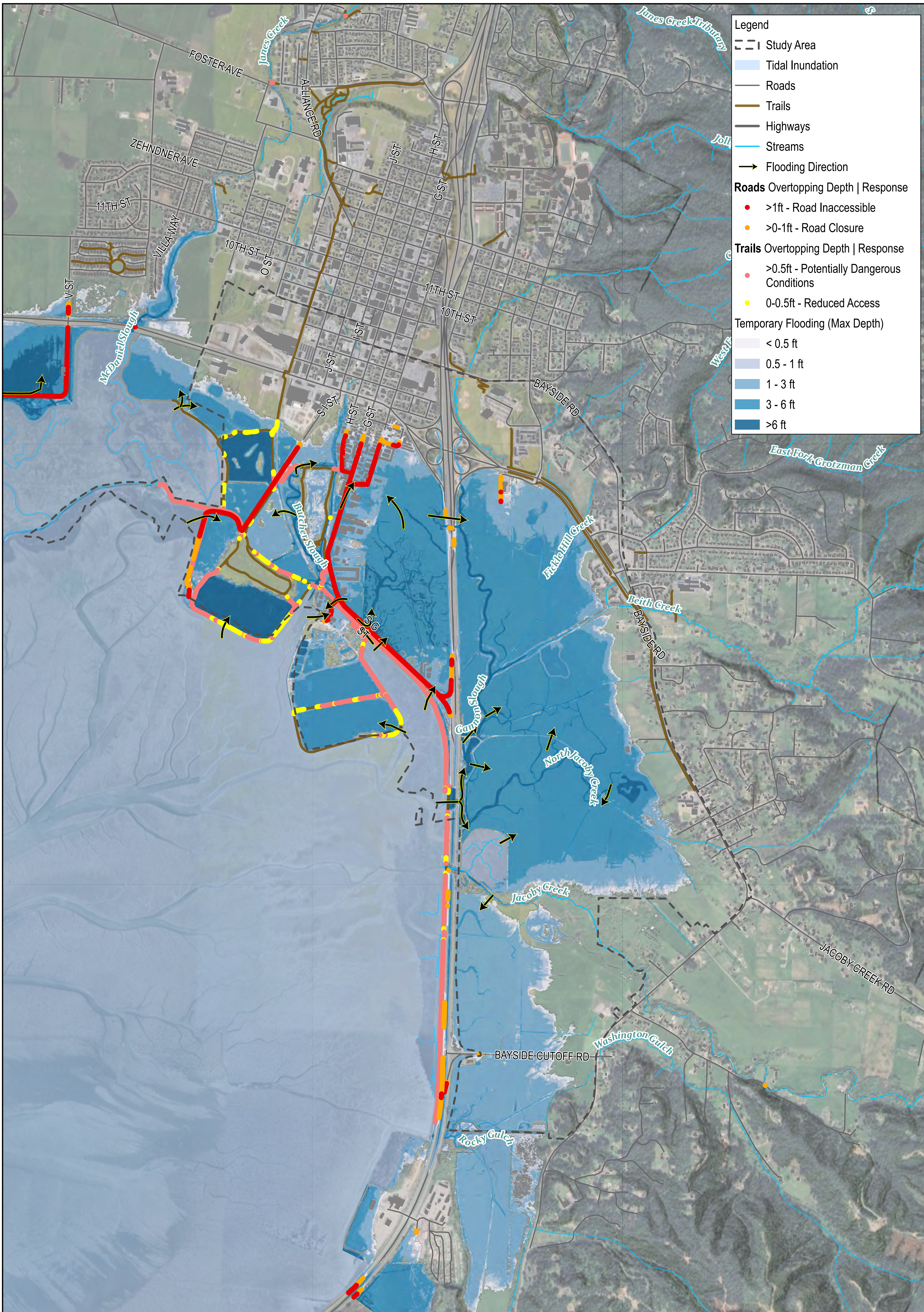

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 11.7ft (NAVD88)
Affected Transportation

Project No. **12621644**
Revision No. **-**
Date **Oct 2024**

EXHIBIT 2.5

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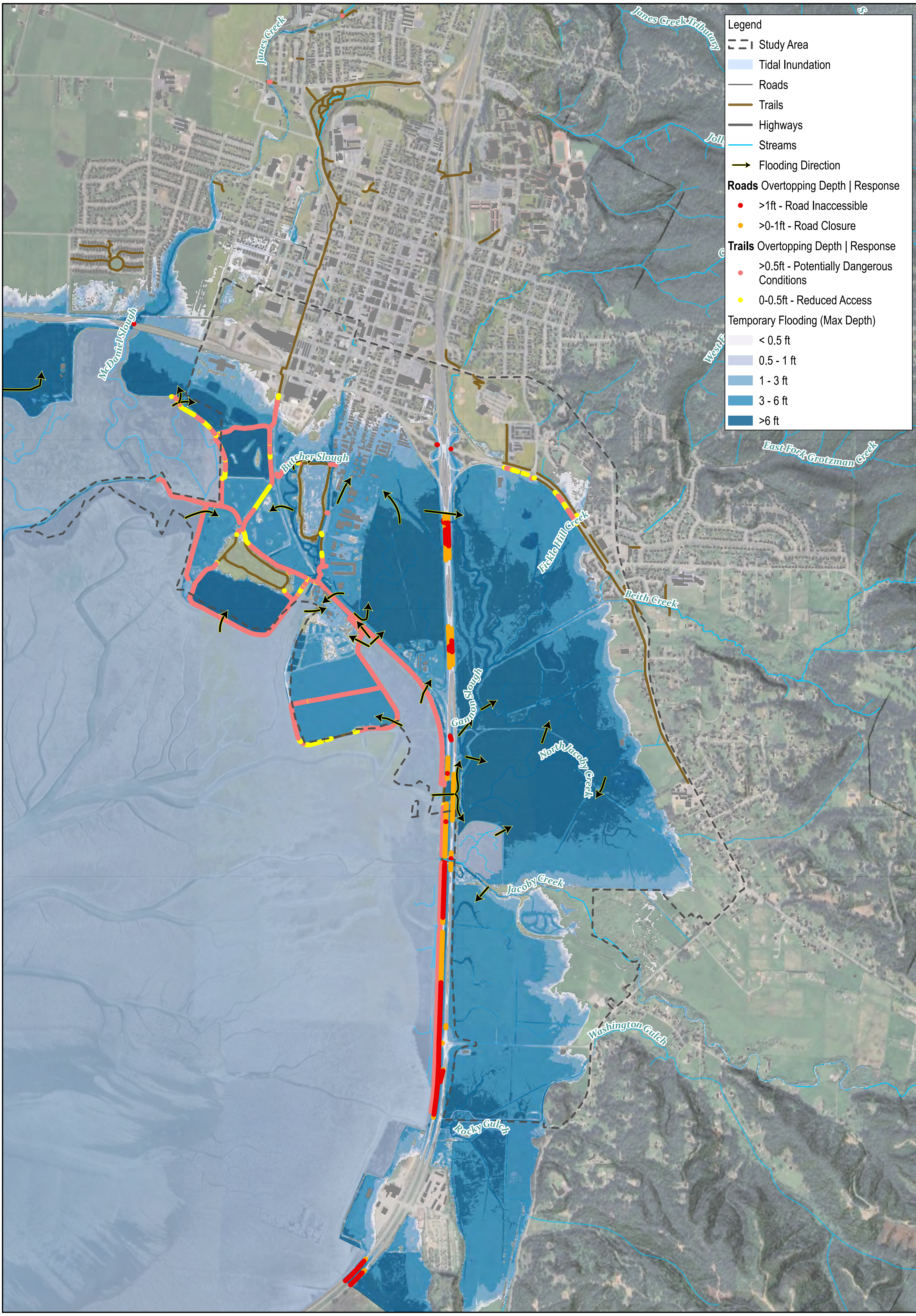

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

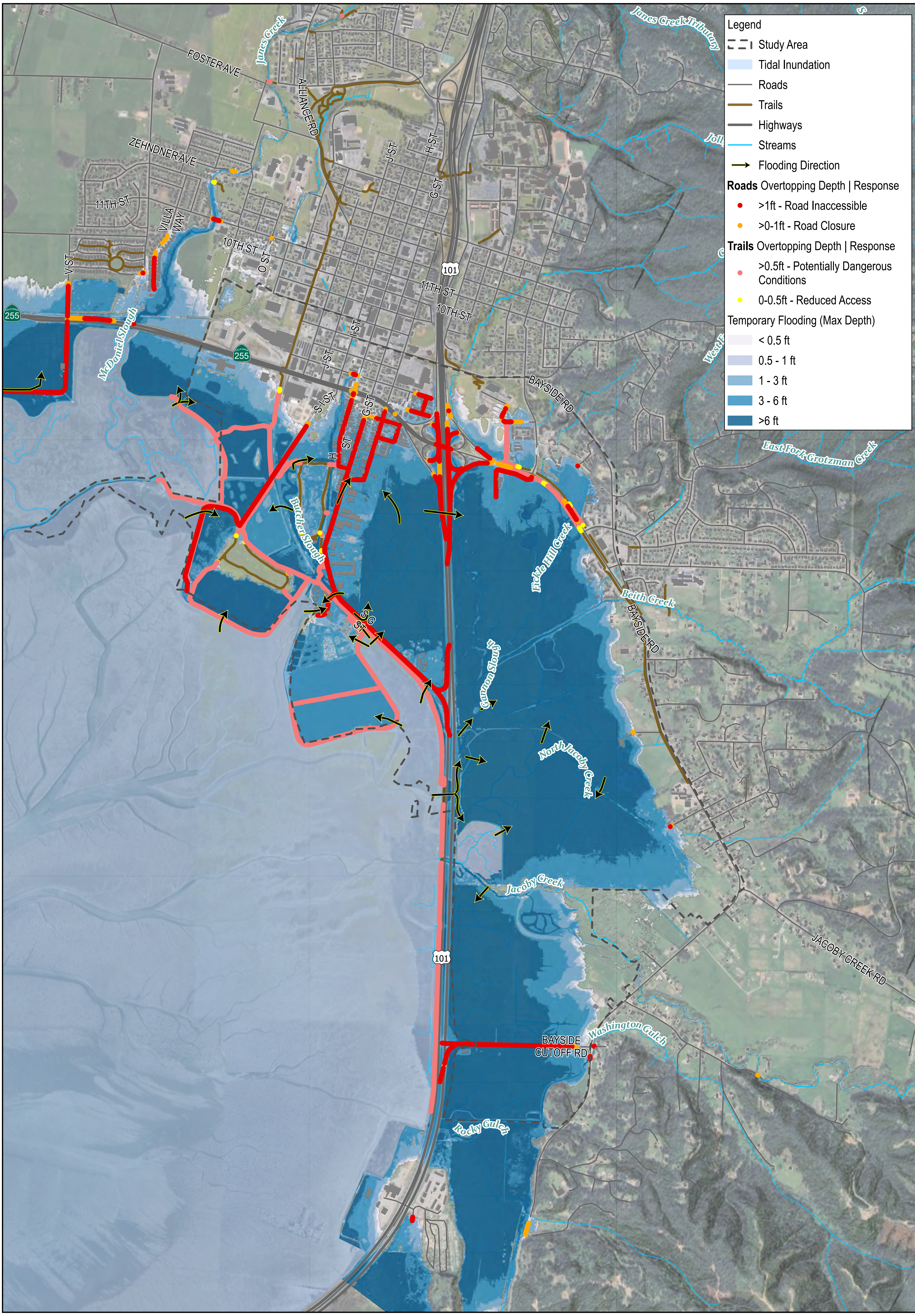
Maximum Tidal Elevation 12.7ft (NAVD88)
Affected Transportation

Project No. **12621644**
Revision No. **-**
Date **Oct 2024**

EXHIBIT 2.6

N:\US\Azure\EastUS\12616645\GIS\Maps\Working\12616645_TidalFloodTransportationFigs\12616645_TidalFloodTransportationFigs.aprx
Print date: 09 Oct 2024 - 16:00

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



Paper Size ANSI B

0 500 1,000 1,500
Feet

N

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

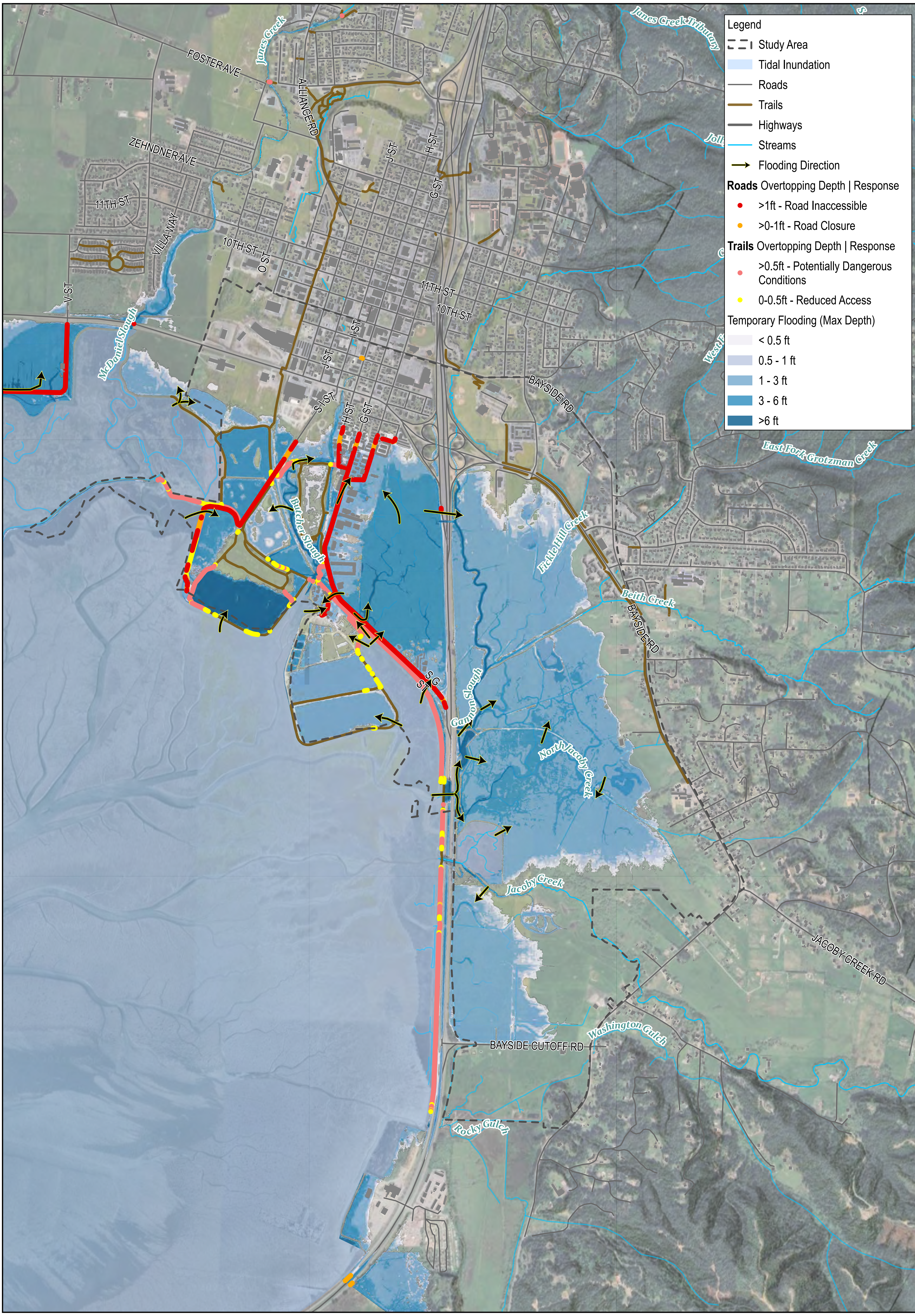
Maximum Tidal Elevation 13.7ft (NAVD88)
Affected Transportation

Project No. **12621644**
Revision No. **-**
Date **Oct 2024**

EXHIBIT 2.7

N:\US\Azure\EastUS\12616645\GIS\Maps\Working\12616645_TidalFloodTransportationFigs\12616645_TidalFloodTransportationFigs.aprx
Print date: 09 Oct 2024 - 13:47

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



Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 11.1ft (NAVD88)
Affected Transportation

Project No.	**12621644**
Revision No.	**-**
Date	**Oct 2024**

EXHIBIT 2.4

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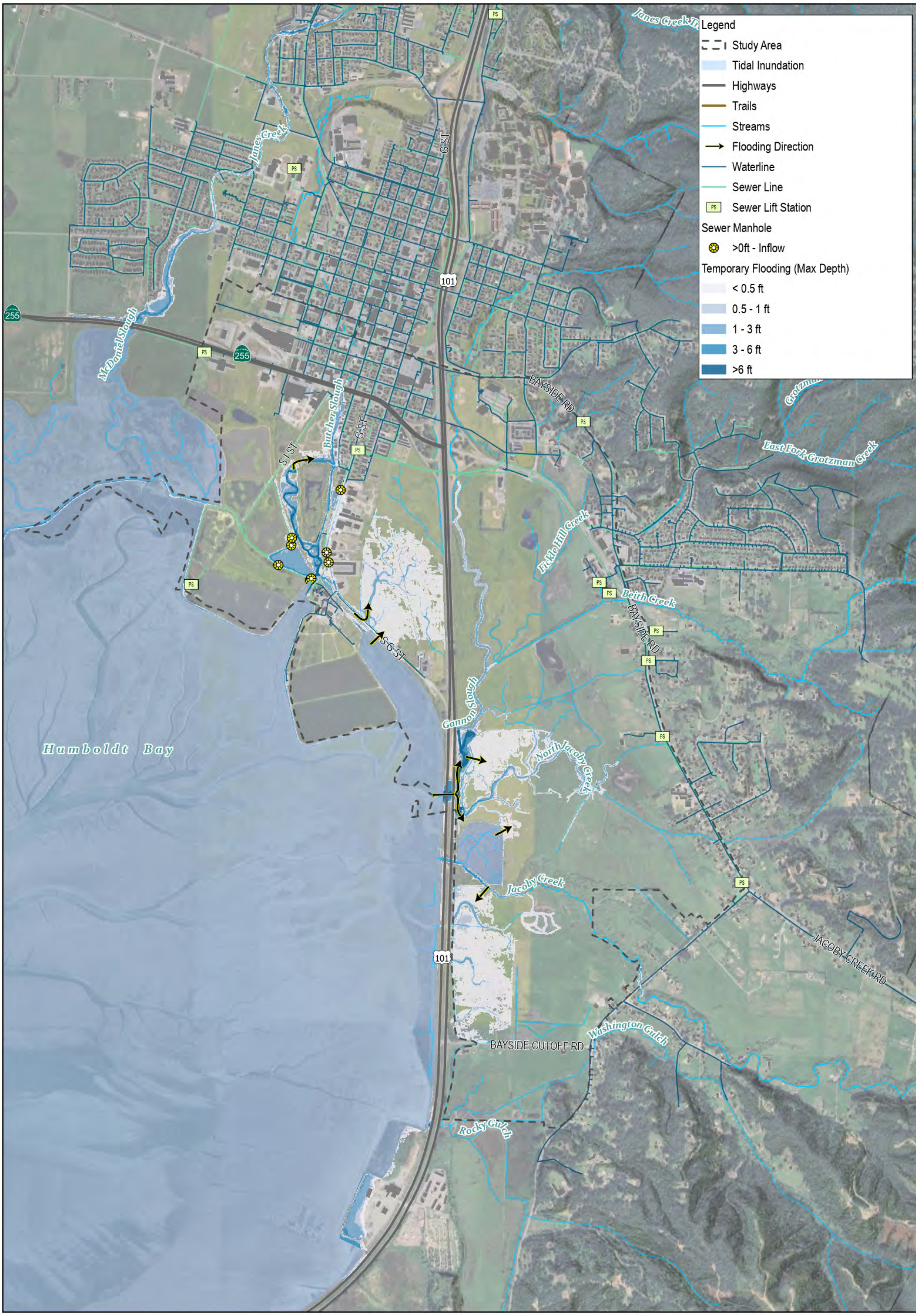
Print date: 09 Oct 2024 - 13:49

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



Paper Size ANSI B

0 500 1,000 1,500

Feet

N

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 9.5ft (NAVD88)
Affected Utilities

Project No. **12621644**
Revision No. **-**
Date **Jun 2024**

EXHIBIT 3.1

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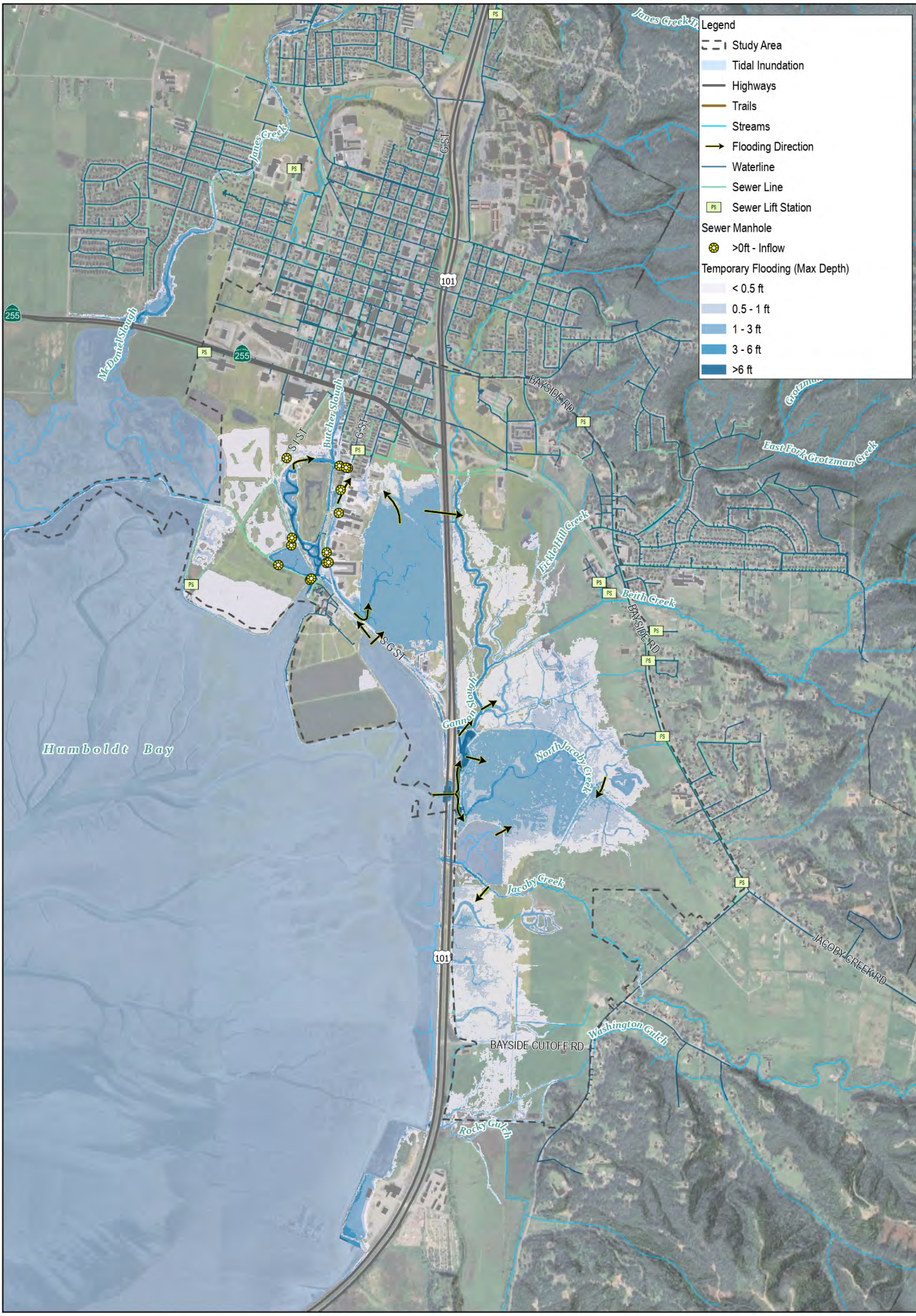


Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

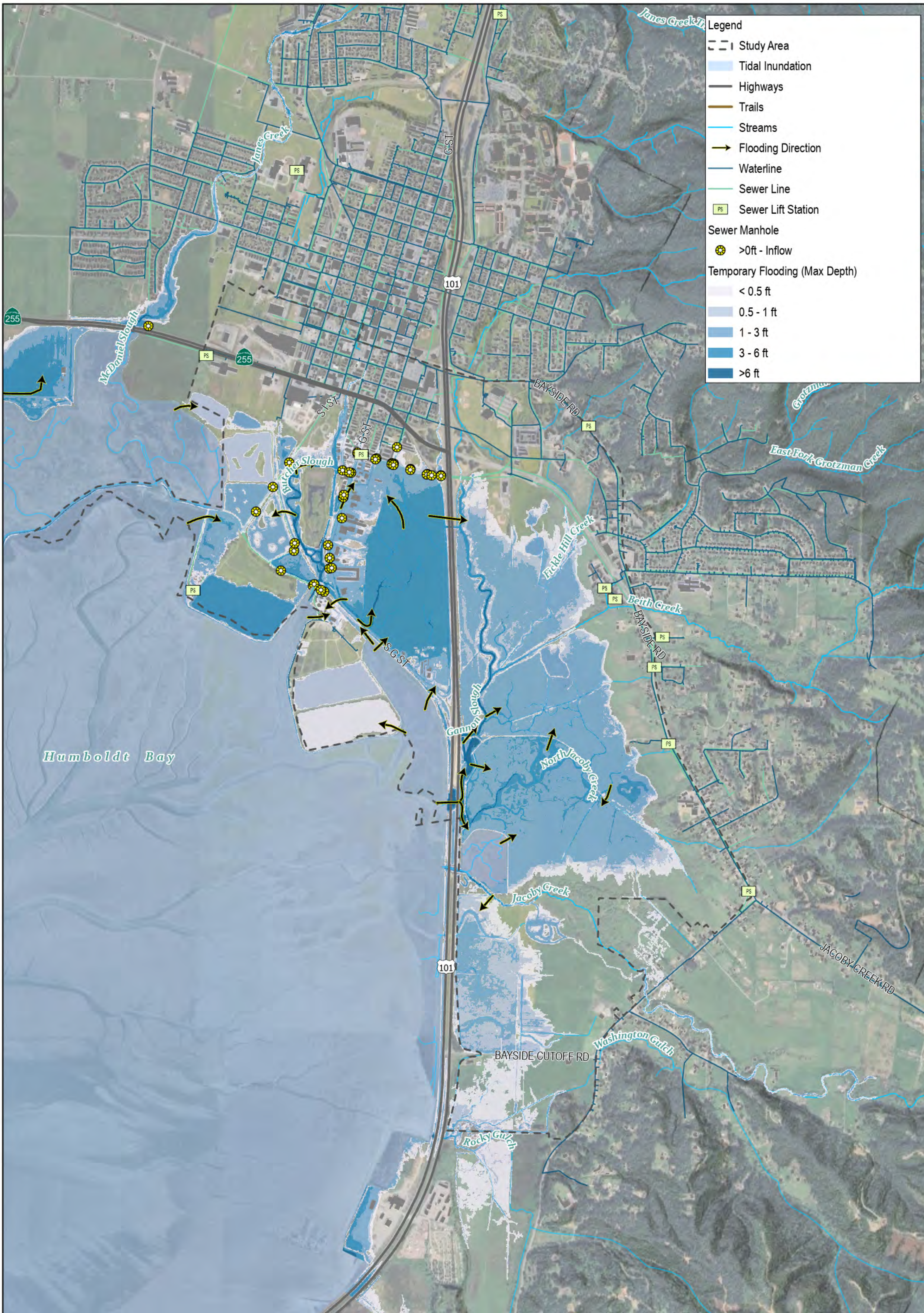
Maximum Tidal Elevation 10.1ft (NAVD88)
Affected Utilities

Project No. **12621644**
Revision No. **-**
Date **Jun 2024**

EXHIBIT 3.2

N:\US\Santa Rosa\General\US West GIS Testing\Workspace4\12621644\GIS\Maps\Deliverables\12621644_TM_APPENDIX_FIGS_RevA.aprx
Print date: 12 Jun 2024 - 14:29

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



Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 10.7ft (NAVD88)
Affected Utilities

Project No. **12621644**
Revision No. **-**
Date **Jun 2024**

EXHIBIT 3.3

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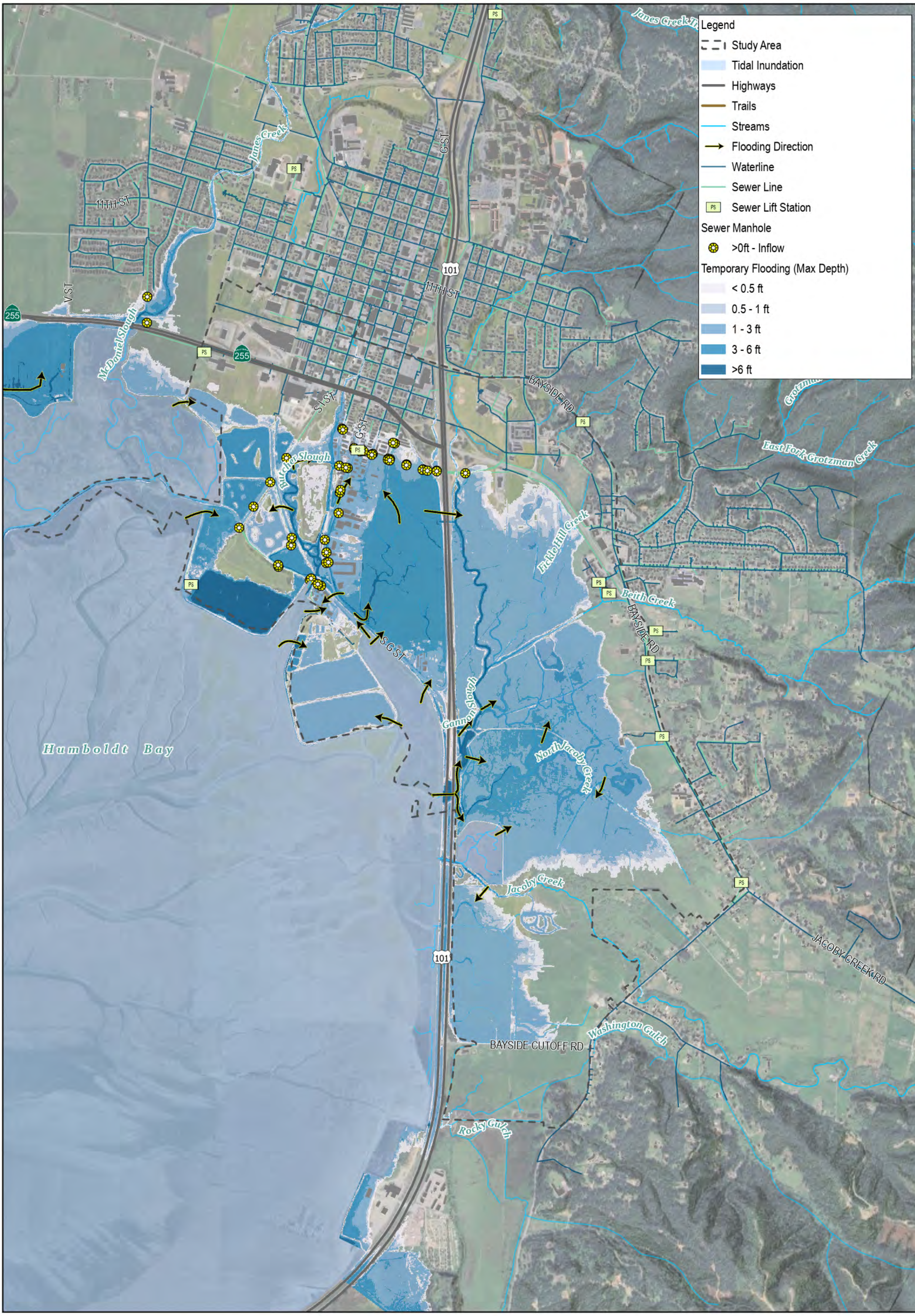


Paper Size ANSI B

0 500 1,000 1,500

Feet

N

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

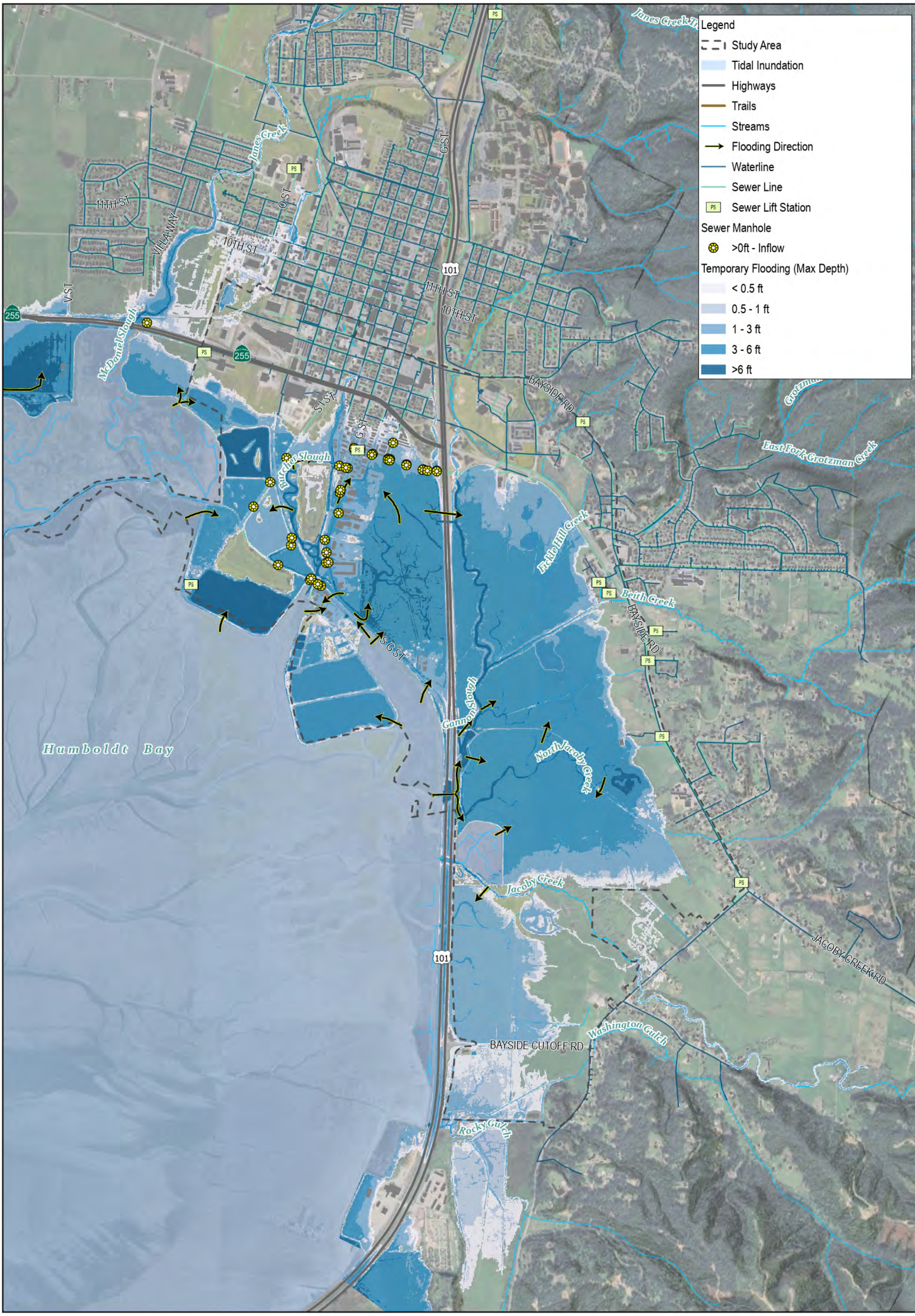
Maximum Tidal Elevation 11.1ft (NAVD88)
Affected Utilities

Project No. **12621644**
Revision No. **-**
Date **Jun 2024**

EXHIBIT 3.4

N:\US\Santa Rosa\General\US West GIS Testing\Workspace4\12621644\GIS\Maps\Deliverables\12621644_TM_APPENDIX_FIGS_RevA.aprx
Print date: 12 Jun 2024 - 14:32

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



Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation 11.7ft (NAVD88)
Affected Utilities

Project No. **12621644**
Revision No. **-**
Date **Jun 2024**

EXHIBIT 3.5

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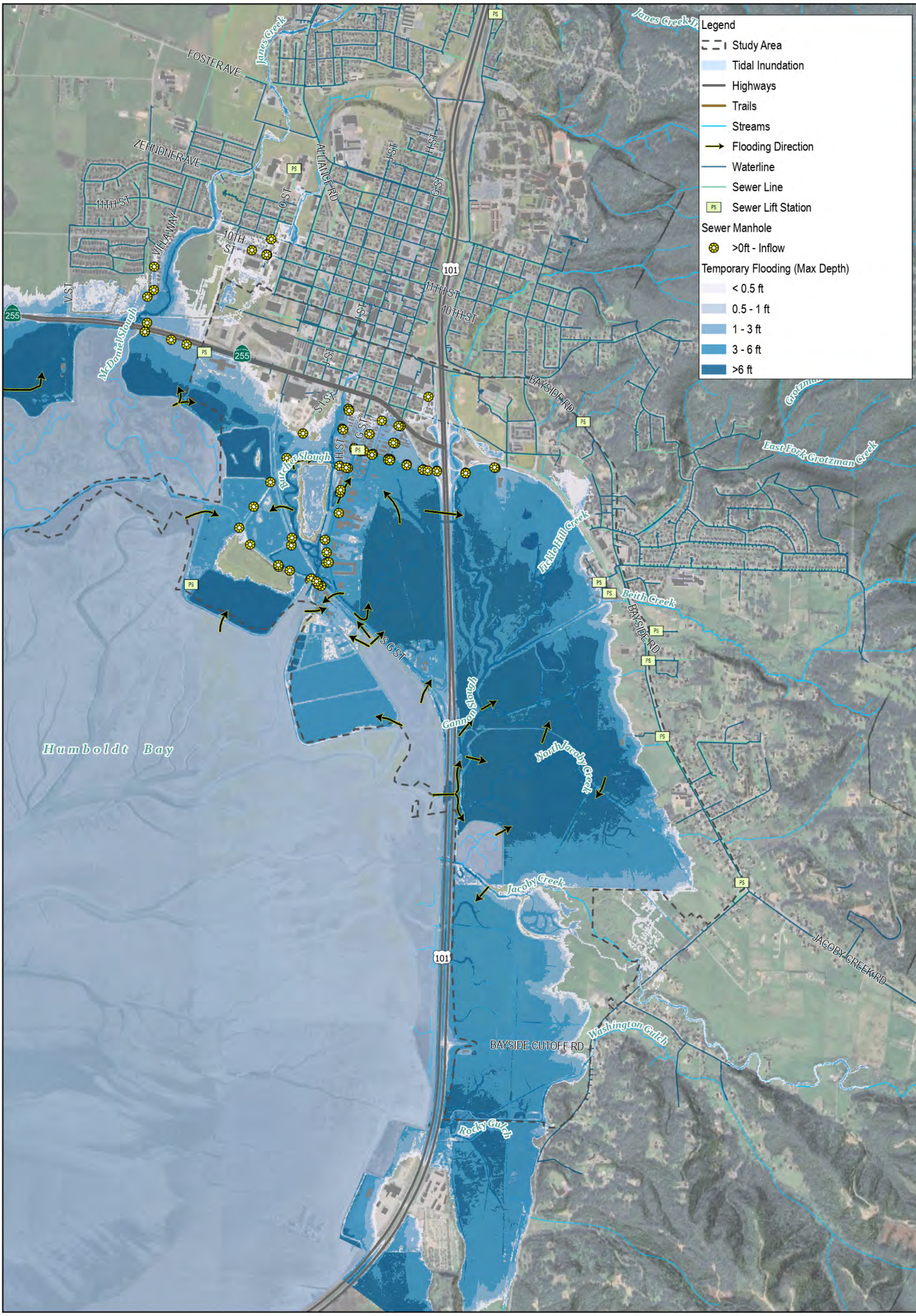
Print date: 12 Jun 2024 - 14:42

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



Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

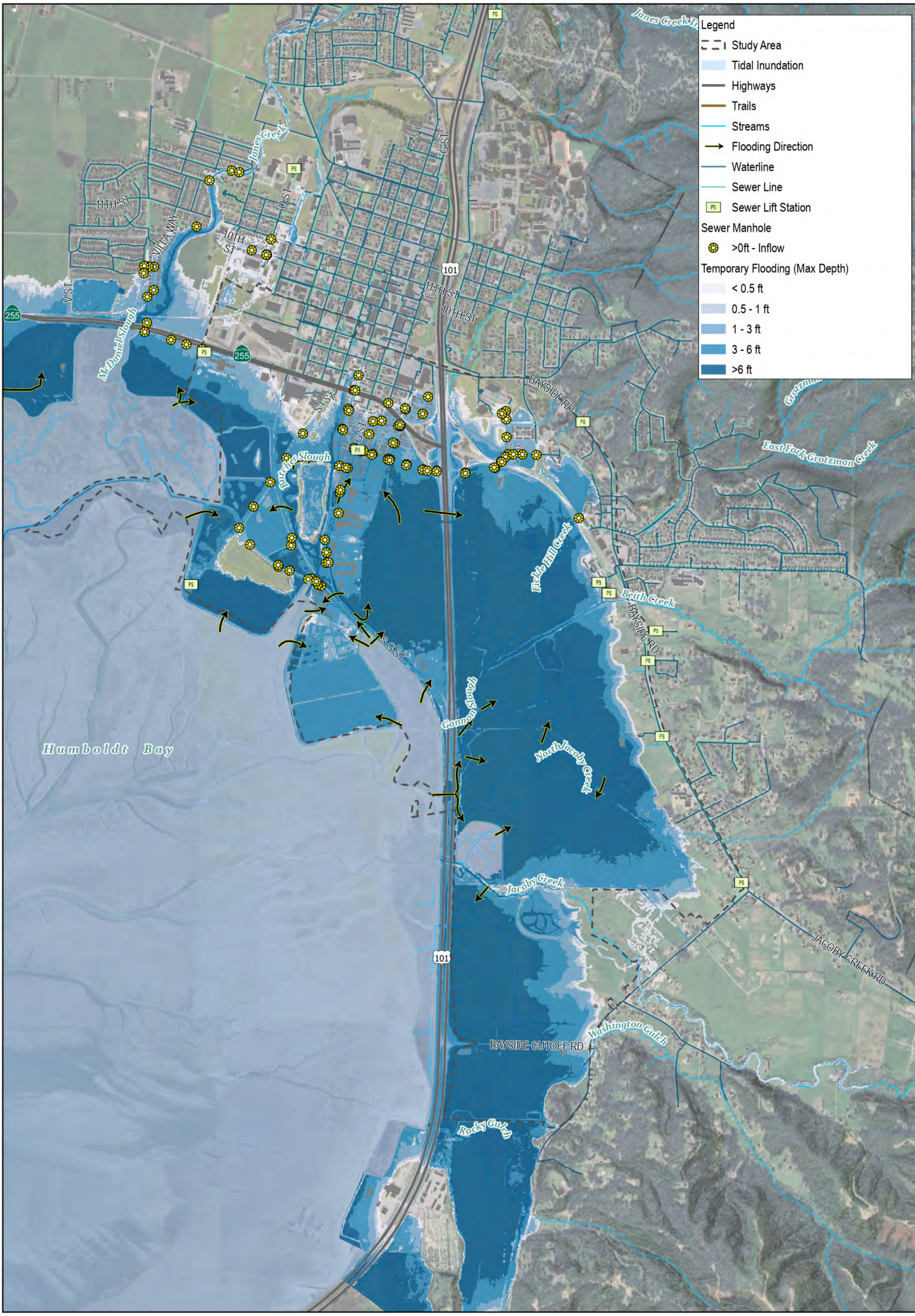
Maximum Tidal Elevation 12.7ft (NAVD88)
Affected Utilities

Project No. **12621644**
Revision No. **-**
Date **Jun 2024**

EXHIBIT 3.6

N:\US\Santa Rosa\General\US West GIS Testing\Workspace4\12621644\GIS\Maps\Deliverables\12621644_TM_APPENDIX_FIGS_RevA.aprx
Print date: 18 Jun 2024 - 09:41

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



Paper Size ANSI B

0 500 1,000 1,500

Feet

N

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

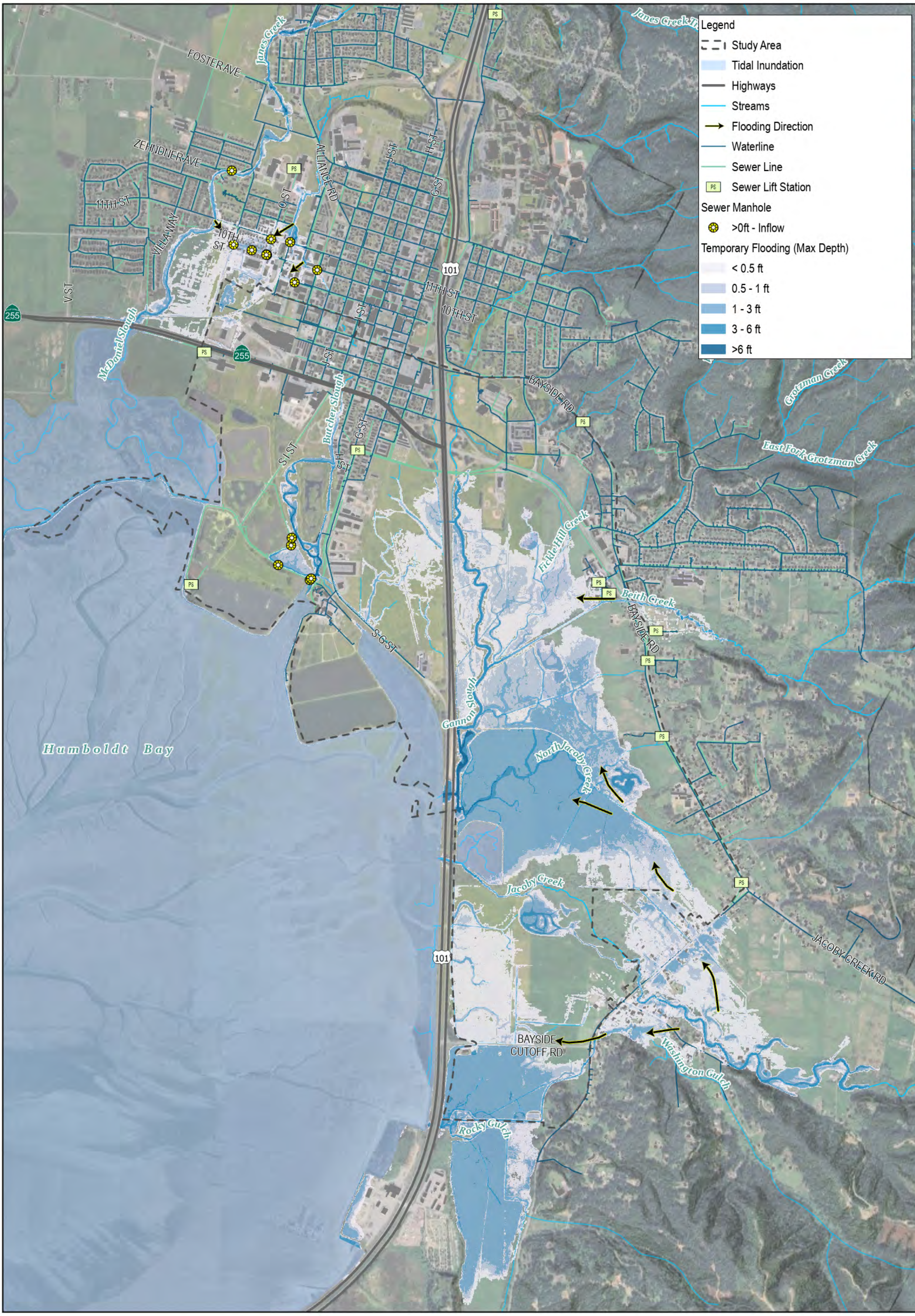
Maximum Tidal Elevation 13.7ft (NAVD88)
Affected Utilities

Project No. **12621644**
Revision No. **-**
Date **Jun 2024**

EXHIBIT 3.7

N:\US\Santa Rosa\General\US West GIS Testing\Workspace4\12621644\GIS\Maps\Deliverables\12621644_TM_APPENDIX_FIGS_RevA.aprx
Print date: 18 Jun 2024 - 09:43

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



Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

2-year Fluvial Flooding
Affected Utilities

Project No. **12621644**
Revision No. **-**
Date **Jun 2024**

EXHIBIT 3.8

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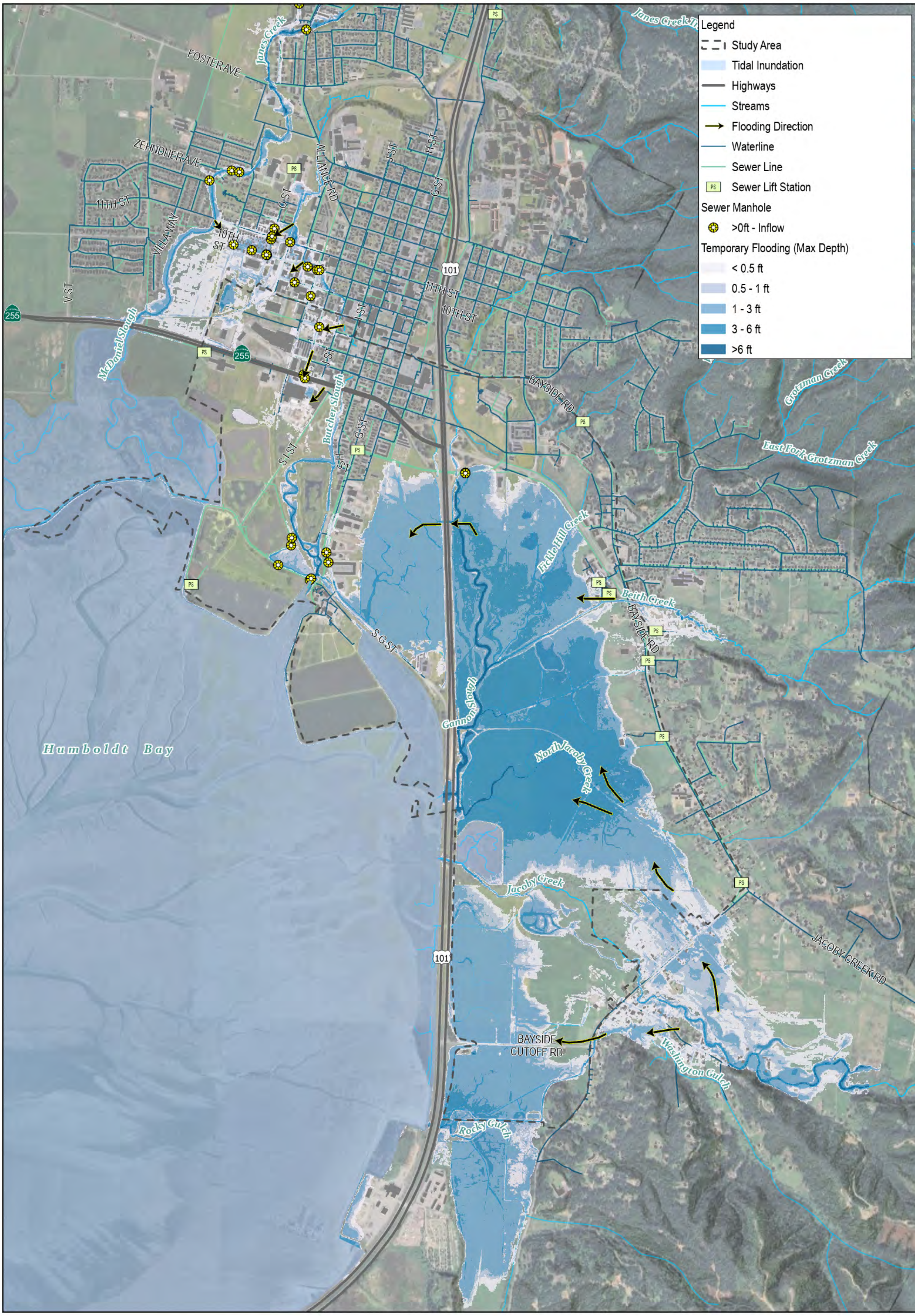


Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

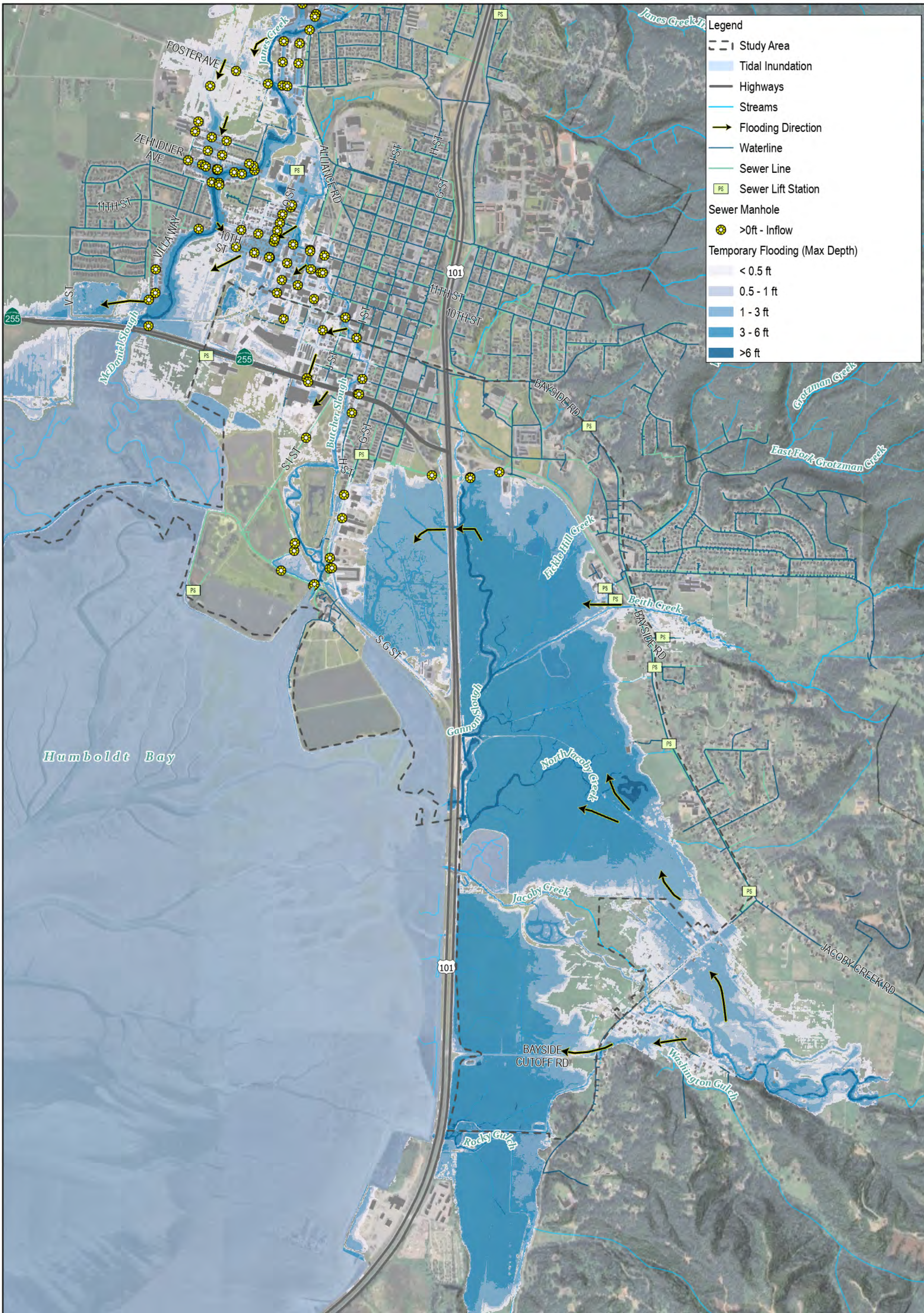
10-year Fluvial Flooding
Affected Utilities

Project No. **12621644**
Revision No. **-**
Date **Jun 2024**

EXHIBIT 3.9

N:\US\Santa Rosa\General\US West GIS Testing\Workspace4\12621644\GIS\Maps\Deliverables\12621644_TM_APPENDIX_FIGS_RevA.aprx
Print date: 13 Jun 2024 - 08:59

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



Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

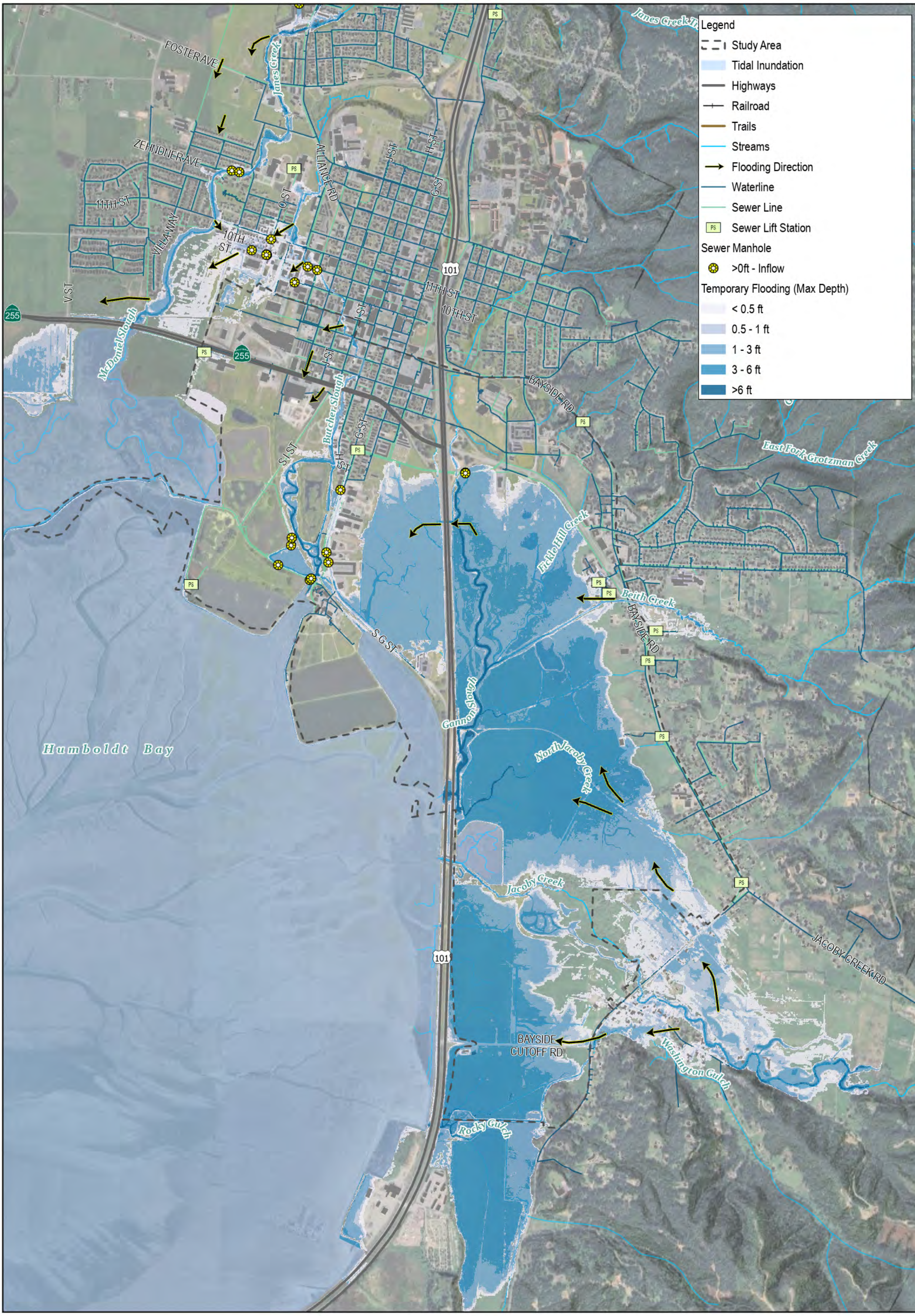
100-year Fluvial Flooding
Affected Utilities

Project No. **12621644**
Revision No. **-**
Date **Jun 2024**

EXHIBIT 3.10

N:\US\Santa Rosa\General\US West GIS Testing\Workspace4\12621644\GIS\Maps\Deliverables\12621644_TM_APPENDIX_FIGS_RevA.aprx
Print date: 13 Jun 2024 - 09:04

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



Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

Maximum Tidal Elevation
9.5 feet and 10-year Fluvial
Affected Utilities

Project No. **12621644**
Revision No. **-**
Date **Jun 2024**

EXHIBIT 3.11

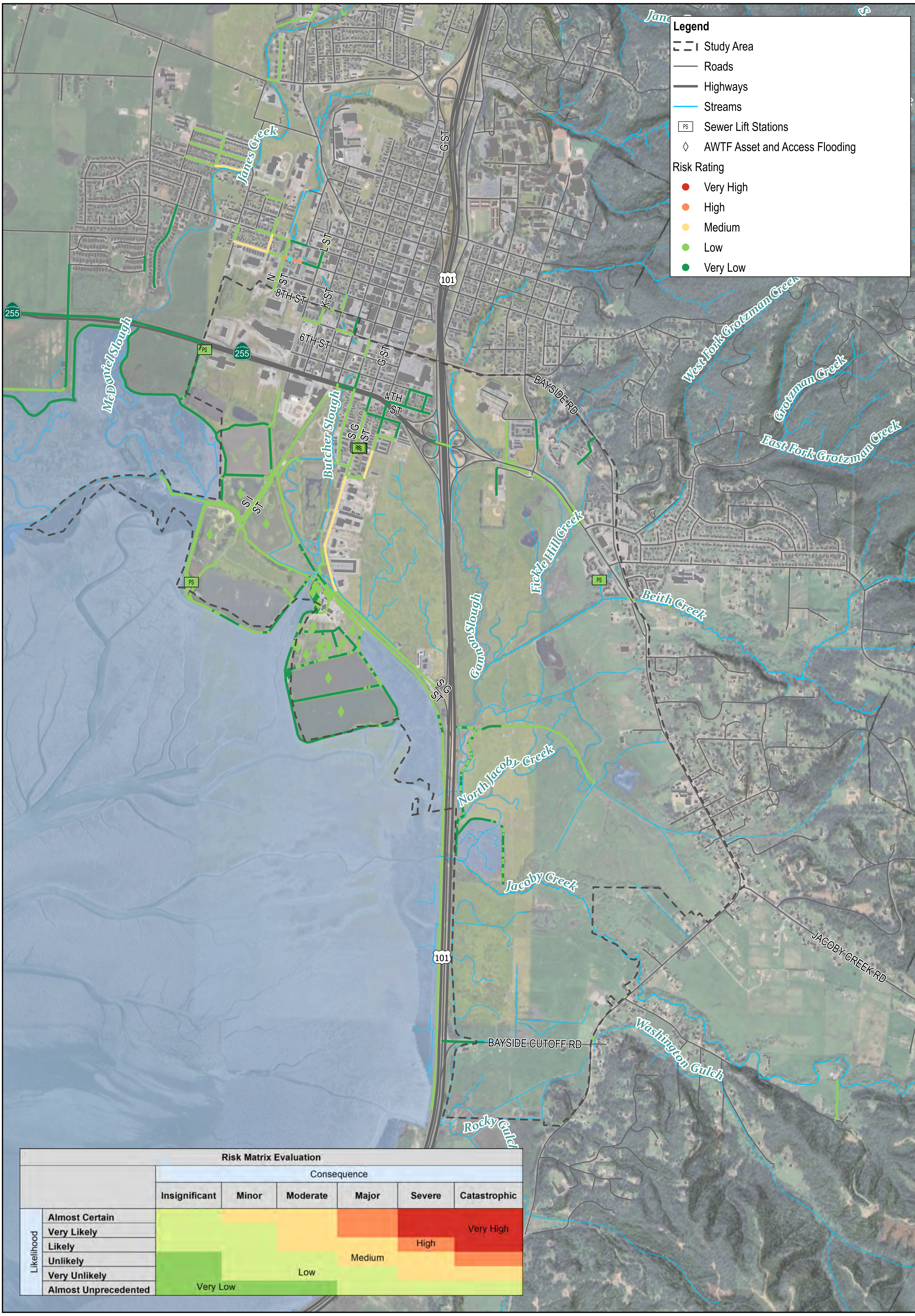
N:\US\Santa Rosa\General\US West GIS Testing\Workspace4\12621644\GIS\Maps\Deliverables\12621644_TM_APPENDIX_FIGS_RevA.aprx
Print date: 13 Jun 2024 - 09:11

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

Appendix D

Exhibits: Qualitative Risk Assessment

- Exhibit 4.1: 2024 Risk Assessment
- Exhibit 4.2: 2055 Risk Assessment
- Exhibit 4.3: 2075 Risk Assessment
- Exhibit 4.4: 2105 Risk Assessment



Risk Matrix Evaluation

Likelihood	Insignificant	Minor	Moderate	Major	Severe	Catastrophic
Almost Certain						
Very Likely						Very High
Likely					High	
Unlikely				Medium		
Very Unlikely			Low			
Almost Unprecedented	Very Low					

(Consequence across; Likelihood down)

Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

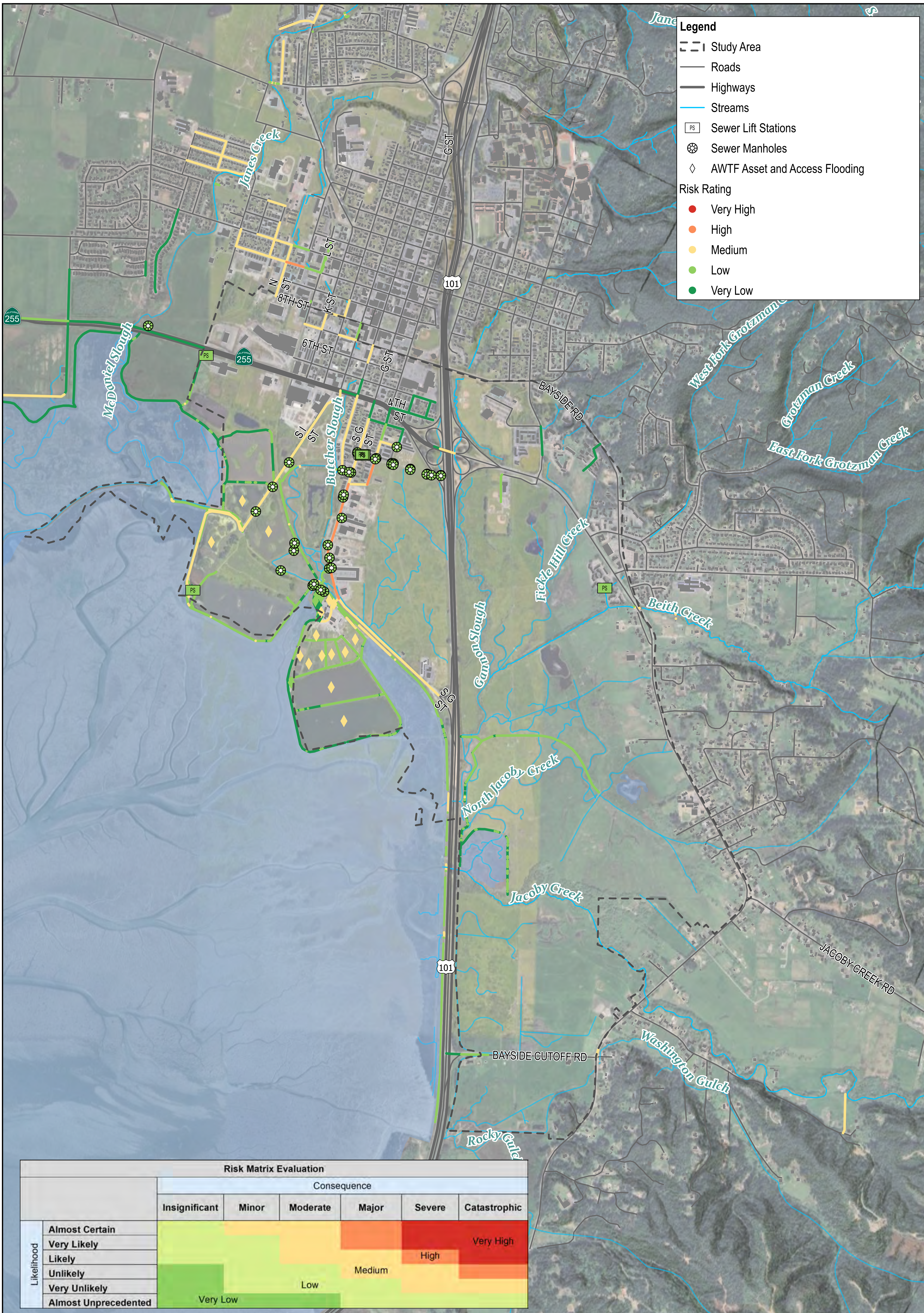
2024
Risk Assessment

Project No. **12616645**
Revision No. **-**
Date **Nov 2024**

EXHIBT 1.1

N:\US\Azure\EastUS\12616645\GIS\Maps\Deliverables\12616645_RiskAssesment.aprx- 12616645_013_2024_RiskAssesment_RevB
Print date: 22 Nov 2024 - 15:25

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



Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

2055
Risk Assessment

Project No. **12616645**
Revision No. **-**
Date **Nov 2024**

EXHIBT 1.2

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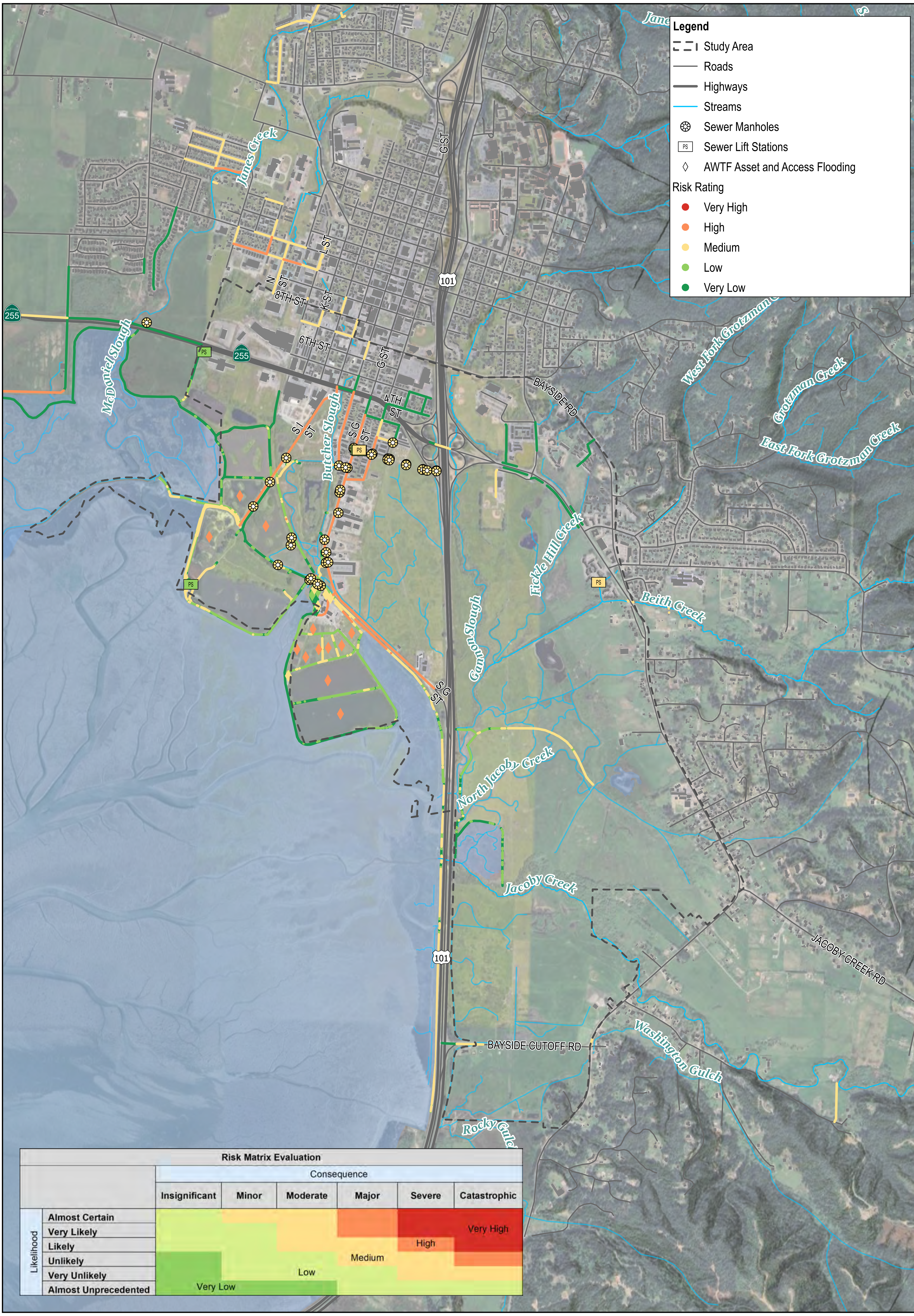

Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

2075
Risk Assessment

Project No. **12616645**
Revision No. **-**
Date **Nov 2024**

EXHIBT 1.3

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Print date: 22 Nov 2024 - 15:32

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

Risk Matrix Evaluation

		Consequence					
		Insignificant	Minor	Moderate	Major	Severe	Catastrophic
Likelihood	Almost Certain						
	Very Likely						Very High
	Likely					High	
	Unlikely				Medium		
	Very Unlikely			Low			
	Almost Unprecedented		Very Low				

Paper Size ANSI B

0 500 1,000 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California I FIPS 0401 Feet

N

GHD

City Of Arcata
Arcata Sea Level Rise and Adaptation Plan

2105
Risk Assessment

Project No. 12616645
Revision No. -
Date Nov 2024

EXHIBT 1.4

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Print date: 22 Nov 2024 - 15:33

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

ghd.com

→ The Power of Commitment