**White Paper**

# Sea Level Rise + Climate Change

**October 2021**

CITY OF PETALUMA
GENERAL PLAN UPDATE

*Response to Comments Received by May 23,2022*

*-From the Petaluma Valley Historical Hydrology and Ecology Study, "Prior to Spanish and American settlement of the region, the Petaluma River watershed supported a dynamic and interconnected network of streams, riparian forests, freshwater wetlands, and tidal marshes." Much of these ecosystems are actively managed by native American peoples. Tidal wetlands have been reduced by 58% and non-tidal wetlands by 84% since 1850, with significant and deleterious impacts not just on wildlife habitat but also flood impacts due to loss of natural hydrological function.*

*-The areas of remaining marshland along the southern reaches of the Petaluma River provide significant wildlife habit value, and help protect the City from Storm Surge flooding. Only the areas within City limits are shown in the included maps. For an assessment of the 2015 extents of wetland and aquatic habitat types in the watershed, please see Figure 6.2 of the Petaluma Valley Historical Hydrology and Ecology Study, 2018.Future flood impacts to these marshes will be significant and deleterious due to SLR, particularly where they are prevented from migration by natural or human embankments, or if sea levels rise faster than marshes can naturally evolve. The 2022 updated flood study will cover the entirety of the city, and further creek reaches upstream. It will be an integrated flood model of the 100 year rainfall event which also considers Sea Level Rise, increased precipitation due to Climate Change, and increased impermeable surface coverage. These maps will pair with and supersede figures 5-16 of this document.*

*-As an Existing Conditions Report this document cannot fully explore adaptation strategies such as adaptive retreat or floodable redevelopment. These strategies will be considered during alternatives phases of the General Plan Update. Consideration should be given during that phase to the regions of the City which are appropriate to certain adaptation methods, such as in/off stream detention, channel widening, flood plain restoration, groundwater banking and more. The Upper Petaluma River Flood Control Project SCWA Flood Control Zone 2a Update presentation of January 10,2019, slides 19-22. These slides indicate certain areas of the city, primarily along the main stem of the river north of the Payran weir, and potions of Lynch and Willow brook creeks as being particularly valuable to the City for future flood control projects.*

*-Impacts from the 100 year flood are spread across portions of the City, and do affect disadvantages communities. The Local Hazard Mitigation Plan assessed impacts from the 100 year flood as shown in current FEMA maps including financial impacts to structures and infrastructure, and also concluded that 147 people are at risk of residential property flooding in the 100 year events, and a further 1,396 in a 500 year event. The report also assessed the impacts from Sea Level Rise flooding during extreme storm surge events, which are discussed in this paper. With the newly developed 10 year floodplain maps which incorporate forward projections of SLR, rainfall depth and impervious cover, these impact assessment can be revaluated to assess current assets at risk, and provide an understanding of the demographic impacts of flooding.*

*-For visual clarity, not all creeks are marked on the flood impact maps. The updated flood modeling is developing higher detail maps which will provide more clear impacts. For further exploration of the watershed, visit watershedclassroom.org*

*-The 1996 Petaluma River Access and Enhancement Plan describes a master plan for the development of access and habitat restoration along the river within city limits. Informed by community engagement and the General Plan it rein visioned the river as the centerpiece of the city. It provided a trail alignment that connected the city north-south and east-west, site plans for various segments along the river, guidelines for a greenway and preservation of natural habitats, natural channel enhancements and more. The document represents significant community input and interest, and is valuable as planning guidance.*

*6/15/22*

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# List of Acronyms

| | |
|---|---|
| ART | Adapting to Rising Tides |
| BCDC | Bay Conservation and Development Commission |
| CAP | Climate Action Plan |
| CCC | California Coastal Commission |
| CoSMoS | Coastal Storm Modeling System |
| FEMA | Federal Emergency Management Agency |
| FIRM | Flood Insurance Rate Maps |
| GHG | Greenhouse Gases |
| H++ | “Extreme Scenario” |
| LHMP | Local Hazard Mitigation Plan |
| MHHW | Mean Higher High Water |
| NOAA | National Oceanic and Atmospheric Administration |
| NBCAI | North Bay Climate Adaptation Initiative |
| NRC | National Research Council |
| NFIP | National Flood Insurance Program |
| OCOF | Our Coast Our Future |
| OPC | Ocean Protection Council |
| RCD | Resource Conservation District |
| RCP | Representative Concentration Pathway |
| SCWA | Sonoma County Water Agency |
| SLR | Sea Level Rise |
| USGS | United States Geological Survey |

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# Definition of Key Terms

The following terms, as they may appear in this white paper, are defined as such:

- 100-year flood: A flood that has a 1% chance of occurrence in any given year.
- 100-year floodplain: Lands that are susceptible to inundation by a 100-year flood.
- 100-year storm: A storm that has a 1% chance of occurrence in any given year.
- Adaptation: A project, action, strategy, or other effort initiated to help mitigate or prepare for the current or potential effects of a hazard.
- Climate change: A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.[1]
- Flood: An event in which a body of water rises and overflows beyond its assigned boundary, especially into areas that are, or are designed to be, normally dry.
    - FEMA definition: A general and temporary condition of partial or complete inundation of 2 or more acres of normally dry land area or of 2 or more properties.[2]
- Floodway: An area within the wider 100-year floodplain designated as the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 100-year flood can be carried without substantial increases in flood heights.
- Greenhouse gases: The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds.[3]
- Hydrology: The study of the properties, distribution, circulation, and management of water.
- King tides: The highest tides that occur at least once a year, which are significantly greater than the MHHW level and potentially flood-inducing.
- Mean high higher water (MHHW): The surface water elevation representing the average daily highest tide elevations that occur in an area over the National Tidal Datum Epoch.
- Representative Concentration Pathway (RCP): A trajectory mapping the potential future greenhouse gas concentration on Earth, associated with the use and emission of greenhouse gases for energy.
- Sea level rise (SLR): An increase in the surface water elevation of the world's oceans and associated waters, including bays and rivers.
- Special Flood Hazard Areas (SFHAs): A FEMA designation referring to the lands that will be inundated by a 100-year flood and compose what is often referred to as the 100-year floodplain.
- Storm surge: The increase in surface water elevation during a storm beyond the level expected from routine tidal variation.
- Tidal slough: A system of marshes and wetlands fed by saltwater and/or freshwater which experience saltwater inundation due to tidal forces.

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[1] *"Annex II: Glossary." AR5 Climate Change 2014: Synthesis Report. IPCC, 2014, page 120, https://www.ipcc.ch/site/assets/uploads/2018/02/AR5_SYR_FINAL_Annexes.pdf.*

[2] *"Glossary." FEMA, Section F page 2, https://www.fema.gov/about/glossary. Accessed July 2021.*

[3] *"Annex II: Glossary." AR4 Climate Change 2007: Synthesis Report. IPCC, 2007, page 76, https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_appendix.pdf.*

# Introduction

The City of Petaluma is located in the Petaluma Valley, an alluvial plain with elevation ranging from sea level along the Petaluma River, to over 400 feet in the nearby hills. This valley is characterized by a Mediterranean climate with long and dry summers, followed by cool and wet winters. The mean annual precipitation over the valley is approximately 26 inches.[4] The main waterways in the City include the Petaluma River, Adobe Creek, Lynch Creek, Lichau Creek, Willow Creek , Ellis Creek and smaller branches or tributaries such as, Thompson Creek,, Washington Creek, Kelly Creek, Capri Creek, and Corona Creek. The City of Petaluma is primarily located within the San Pablo Bay sub-watershed and the Petaluma River-Frontal San Pablo Bay Estuaries sub-watershed, both of which are part of the greater San Pablo Bay Watershed.

The Petaluma River is historically important due to its key role in enabling exploration activities, settlement and the development of the Petaluma and San Pablo Bay watersheds, accomplished in part due to a historical presence of dredging the River. During storm events, water levels increase above their historic tidal elevations threatening the areas along the Petaluma River and other main waterways and tributaries with flooding. Floods can and have caused substantial damage to structures, landscapes, and infrastructure as well as life safety issues in the city.

These flood hazards from both Rainfall flowing down the river, and Storm Surge pushing bay water up the river will be exacerbated by future sea level rise (SLR), a consequence of climate change caused by global increases in greenhouse gas (GHG) emissions. According to scientific research, GHG emissions have increased and will continue to increase Earth's temperatures, even with significant reductions of GHG emissions. Increased temperatures cause thermal expansion of the oceans and melting of ice sheets consequently resulting in SLR. Sea Level Rise of about 8 inches has already occurred in the last century, and several feet or more of SLR is projected by the end of this century.[5] In the San Pablo Bay, increased water levels due to SLR are expected to exacerbate the frequency and severity of flooding along the banks of Petaluma River and adjoining creeks.

This white paper was developed with the following objectives:

- To set the stage for a comprehensive approach that addresses flooding and SLR. As such, this white paper is to lay the foundation for the development of multi-functional solutions to flooding and other climate change risks related SLR that focus on ecological interventions, quality of life, and economic opportunity. It consolidates relevant literature and latest-available modelling outputs into a document that provides the city with a tool for understanding the potential impact of flooding and SLR impacts and applying best available practices to the planning process.
- Provide a summary of local and regional resources and data prepared and available to date.
- Identify key agencies with some level of oversight in Petaluma, and associated planning regulations and drivers.

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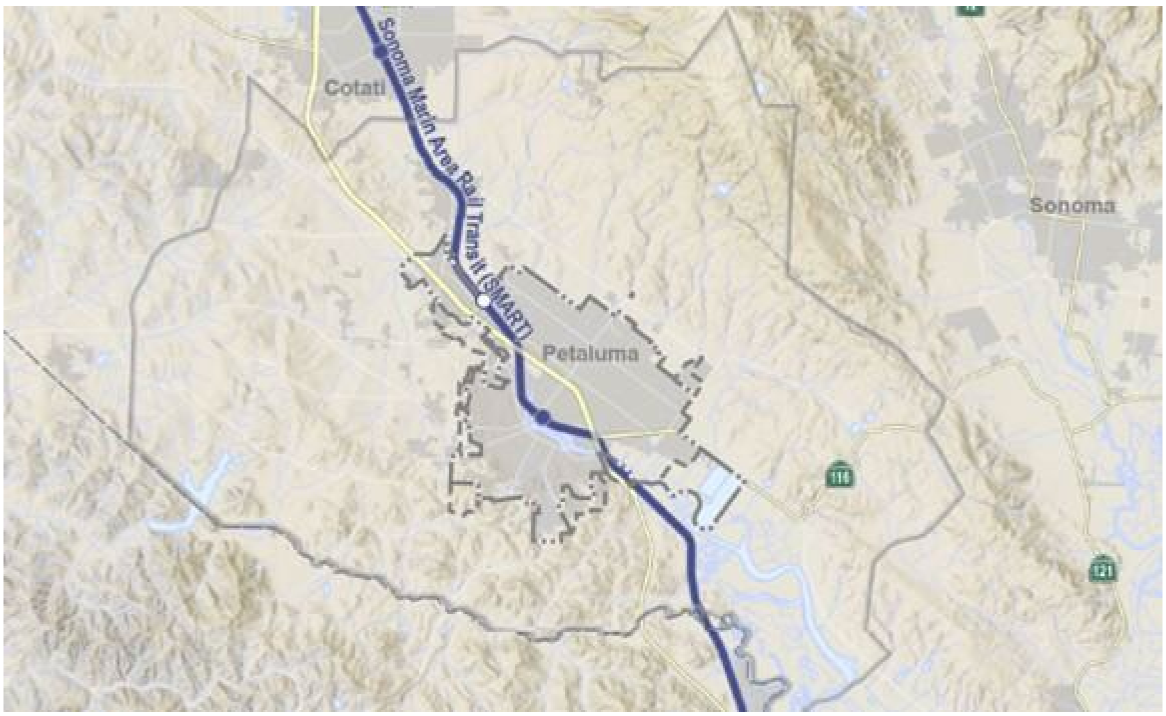
[4] *"City of Petaluma Floodplain Management Plan." City of Petaluma, 15 Oct. 2015, page 4, https://cityofpetaluma.org/documents/floodplain-management-plan/.*

[5] *National Research Council. "Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future." The National Academies Press, 2012, https://www.nap.edu/catalog/13389/sea-level-rise-for-the-coasts-of-california-oregon-and-washington.*

- Report on what has been or is being studied and pursued in the Bay Area related to SLR to date.
- Synthesize the recent planning updates and efforts guiding Petaluma's mitigation and adaptation strategies.
- Identify unique local conditions and historical considerations, as well as critical vulnerabilities within Petaluma (preliminary assessment).
- Propose key implications of existing and future challenges.
- Identify next steps for Petaluma and provide potential high level adaptation considerations and strategies for incorporation as part of the General Plan process.

**Figure 1. Location Overview Map**




# Assessment of Existing Conditions and Assets at Risk

This section explores the current rainfall flood hazards from the three main flood risks to the City. Rainfall Flooding as described by FEMA in the 100- and 500-year flood events, the future potential flood scenarios from sea level rise (SLR), and the impacts from Storm Surge forcing bay water up-river. The mapping efforts show these different types of flooding combined where the existing hydrological modelling allows, such as Sea Level Rise with additional Storm Surge. Existing modelling does not exist which integrates Rainfall Flooding maps with SLR scenarios or Storm Surge conditions. This data-gap is described more thoroughly below.

# Rainfall Flood Hazards

Rainfall floods, primarily associated with seasonal storms and thunderstorms, can occur in the City of Petaluma primarily during the rainy season between November and March. This type of flood results from prolonged heavy rainfall over the main watershed and tributary areas and is characterized by high peak flows of moderate duration. Flooding is more severe when a previous rain event has resulted in saturated ground conditions. The City of Petaluma is susceptible to various types of flood events due to prolonged rainfall including riverine flooding, localized flooding, and levee failure flooding. This section summarizes the sources of flood hazards that can threaten Petaluma with inundation from rainfall events. It presents the existing flood hazards from coastal and riverine sources and describes the potential ways in which climate change may affect the existing flood hazards.

# Historic Flood Hazards

The City experienced historic flooding conditions in its central and northern areas on December 31, 2005. Consequently, it incurred $56 million in structural damages affecting 53 structures. Flooding also damaged streets and river channel banks, particularly within the Petaluma Factory Outlets, and at several commercial structures and mobile homes. This flood event led to a State and Federal Disaster Declaration.[6] Additional flooding of roads and structures has occurred in 2014, 2017, and 2019.

The historic flood on January 3–5, 1982, which flooded over a 50 block area on both sides of the river, was the largest flood of record in the City leading to approximately $28 million in damages. In many cases, water damage reached two to three feet inside structures. The most severely hit areas were along Jess Avenue where most homes had four to five feet of water above ground, and Payran Street with flooding reaching over three feet inside structures. Most of the 500 homes and 100 commercial-industrial establishments in the area incurred some type of flood damage.[7]

# Storm Surge Flood Hazards

During storm events, the San Francisco Bay experiences higher elevations of flooding due to storm surge, stronger waves, and increased inflows from rivers, increasing the San Francisco Bay elevation by upwards of 42 inches in a 100-year storm event. The San Pablo Bay, a tidal estuary forming the northern extension of the San Francisco Bay, connects to the Petaluma River, and similarly experiences these impacts from storm events. The Our Coast Our Future (OCOF) model used to map storm surge impacts considers the local conditions of San Pablo Bay. Because the city of Petaluma sits on a tidal slough, this increased Bay water elevation can cause flooding in low lying areas not near creeks, and cause backwater conditions which induce further flooding in the city.

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[6] *Wood Environment & Infrastructure Solutions, Inc. "City of Petaluma Local Hazard Mitigation Plan." City of Petaluma, Nov. 2020, page 4-104, https://cityofpetaluma.org/documents/lhmp/.*

[7] *Wood Environment & Infrastructure Solutions, Inc. "City of Petaluma Local Hazard Mitigation Plan." City of Petaluma, Nov. 2020, page 4-104, https://cityofpetaluma.org/documents/lhmp/.*

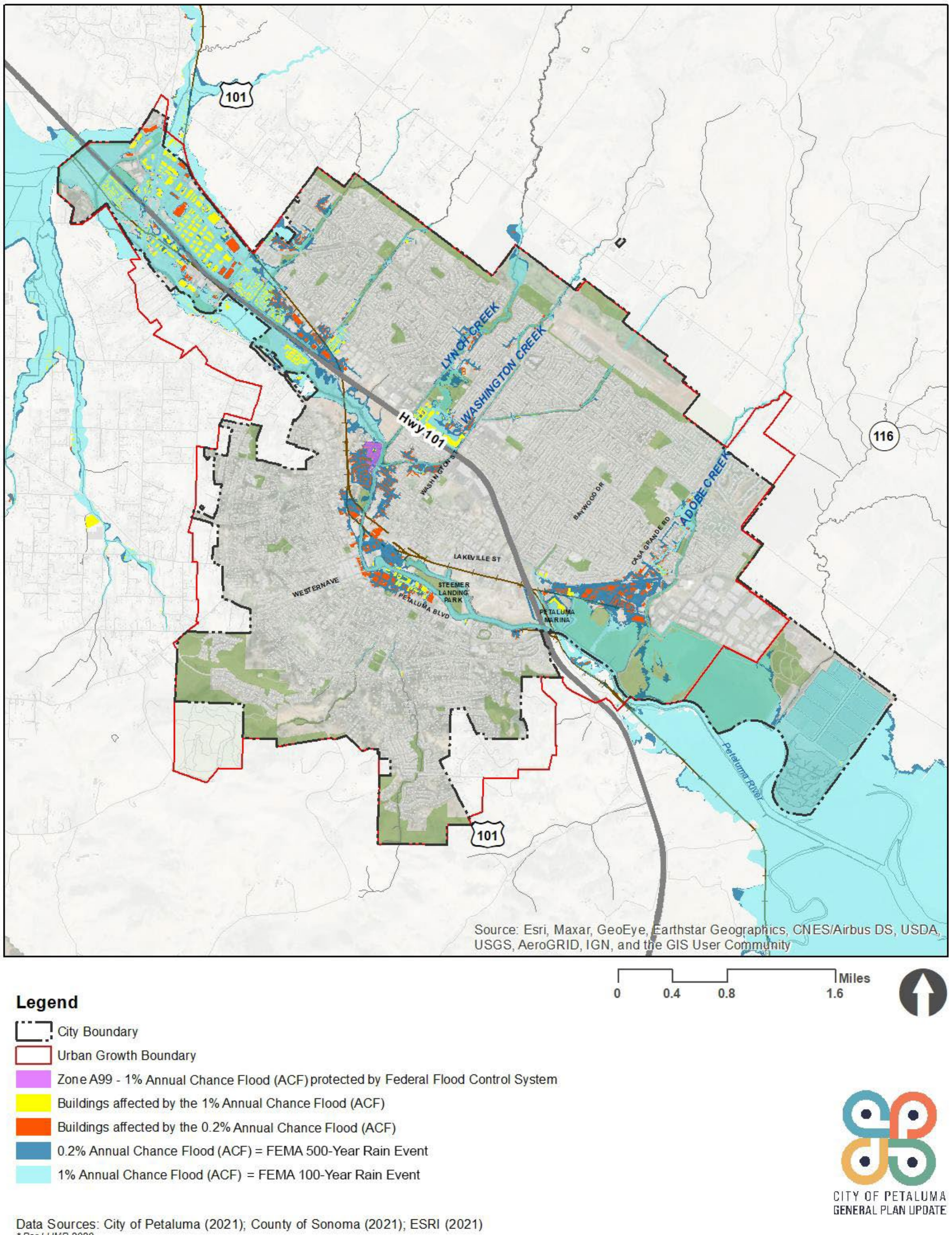
## FEMA Flood Insurance Rate Mapping

The Federal Emergency Management Agency (FEMA) conducts nationwide flood hazard mapping as part of the National Flood Insurance Program (NFIP). The resulting Flood Insurance Rate Maps (FIRMs) are used to identify flood-prone areas, support the NFIP, and reduce flood damages. FEMA focuses on identifying the flooded extent and water levels that have a 1% annual chance of being equaled or exceeded in any year, often termed the "100-year flood." The surface water elevation associated with the 1% annual chance event is referred to as the base flood elevation (BFE). Areas predicted to be inundated in a 1% chance event are delineated on a FIRM as Special Flood Hazard Areas (SFHAs) and form what is commonly referred to as the "100-year floodplain." The 100-year floodplain for the City of Petaluma is shown in Figure 2. A 500-year flood is a flood that has a 0.2% chance of being equaled or exceeded in any given year. A 500-year flood event would be slightly deeper and cover a greater area than a 100-year flood event. Buildings and other structures in an SFHA must meet certain requirements to receive a floodplain development permit and qualify for NFIP insurance and federally backed mortgages. FEMA maps are developed using historical rainfall data and current development conditions. FEMA does not consider projected impacts of SLR or other future conditions related to climate change such as increased rainfall intensity when mapping SFHAs. FEMA's definition of a "floodway" refers to the channel of a river or watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height. Communities are required to regulate development in the floodway to ensure there are no increases in upstream flood elevations. The floodplain refers to any land area susceptible to being inundated by floodwaters from any source.[8] So, while the floodway speaks to the area transmitting flow, the floodplain's area subject to inundation can contribute to the river's capacity to flow.

[8] *National Flood Insurance Program Terminology Index. https://www.fema.gov/flood-insurance/terminology-index*

## Figure 2. Buildings Affected by the 100- and 500-Year FEMA Flood Zones

**Buildings Affected by the 1% and 0.2% Annual Likelihood Rainfall Floods**




*Source: City of Petaluma*

## FEMA Map Limitations

Using FEMA flood maps to reliably predict potential flood impacts presents several resiliency challenges to planners and developers. The 100-year flood event describes a flood that statistically has a 1% chance of occurring in any given year. However, the average recurrence interval of 100 years is not necessarily an accurate depiction of flood risk intervals, especially factoring in considerations for climate change. While updated FEMA models and flood insurance rate mapping may improve the accuracy of riverine flooding, they only utilize and consider existing data. Critical considerations including increased precipitation estimates from climate change models, changes in local land use and increases in impervious surfaces, and considerations for SLR and storm surge, are not accounted for in FEMA's modeling. Additionally, the 500-year storm event is often ignored in development planning, although it merits additional consideration as flood events and storm intensities increase. In preparing for an uncertain future, the city may consider utilizing more risk averse map scenarios for certain permanent development projects to ensure adequate considerations are accounted for.

The City currently uses a XPStorm model, developed as the basis for the FEMA 2012 submittal, for planning review. The model is known to have inaccuracies from limited complexity of the upstream watershed designations, and from not modeling upstream reaches as floodplains. The City is currently upgrading the flood model through Spring 2022 to a new HEC-RAS 2D model utilizing 2014 LiDAR terrain data, which will allow it to leverage modeling of the upper watershed already completed by Sonoma Water. This will be included as part of the General Plan Update as an errata to this document. Subsequent to city modelling efforts, a FEMA re-mapping application will be processed and accounted for in the General Plan Update. It will analyze the 100-year flood event and results will begin a process of FEMA floodplain revision. There is no plan for the new model to consider SLR scenarios or increased rainfall intensity. The City has requested but is not in contract on model revisions which would include Climate Change impacts to the rainfall flooding hydrologic models.

Of particular concern is to explore the impact that climate change might have on future rainfall flood events which consequently and directly affect hydrology. Most models for California indicate a shift towards more intense rainfall events. This increased rainfall intensity, combined with potentially hotter conditions would lead to an exacerbated severity of flooding. FEMA only accepts mapping that meets their standards based on modelling of historic rainfall and current development, however the city recognizes that additional modeling and mapping efforts incorporating SLR considerations are crucial to resilient planning efforts.

While FEMA maps play an important role in flood mitigation, planning and coordination, including providing eligibility for funding mechanism, these maps do not and will not sufficiently address considerations of climate change including future precipitation patterns, development patterns and SLR. Therefore, these considerations must be addressed and integrated as part of independent city modelling initiatives.

## Unique Floodplain Conditions

The Petaluma Watershed, particularly the former floodplains and main channel, have been significantly altered in the last century and a half. According to the San Francisco Bay Estuary Institute Petaluma Valley Historical Hydrology and Ecology Study, before colonial settlement, few of the eastern creeks had defined channels that connected them to the main stem of the river. Instead, their flows mostly spread and meandered to the tidal marshes which used to flank the main stem of the Petaluma River. These large areas of non-tidal wetlands have been reduced since 1850 by 84%. Historically known as the Petaluma Slough or Creek, the main channel was only classified as a River in 1958 in order to be eligible for federal maintenance funds. Dredging and straightening has significantly shortened the river and its contributing creeks,  resulting in a narrower and shallower river mouth. Before modern dredging was used to connect channels to the river, there were significant areas in the east and north of the city that had seasonal ponded storm water, vernal pools and freshwater meadows. Many of those drained areas are now still subject to flooding in the 100 Year storm according to FEMA maps. Figure 3 illustrates the current Petaluma landscape overlayed by the historical habitats and land types of areas in Petaluma.

These historical conditions suggest that much of the flooding the city currently experiences can be thought of not as areas with inadequate drainage infrastructure, or bad soils, but rather the remnants of historical hydrology. These areas not only provided areas for flood water expansion but also provided habitat enhancements and groundwater recharge. Because these areas previously featured marshes and wet meadows, soils are frequently slow draining and “perch” flood water. Figure 3 shows the historical presence of wet meadows in a large area of the City, effectively the entire east side of Petaluma. Given its original conditions and land use, that area would be prone to flooding and have unique geotechnical concerns including expansive clay soils. Observations of these natural patterns can inform appropriate strategies for stormwater management in order to mitigate flooding, or strategies to protect from SLR impacts.

**Figure 3. Historical Wet Meadow Distribution and Floodplain Function Map**

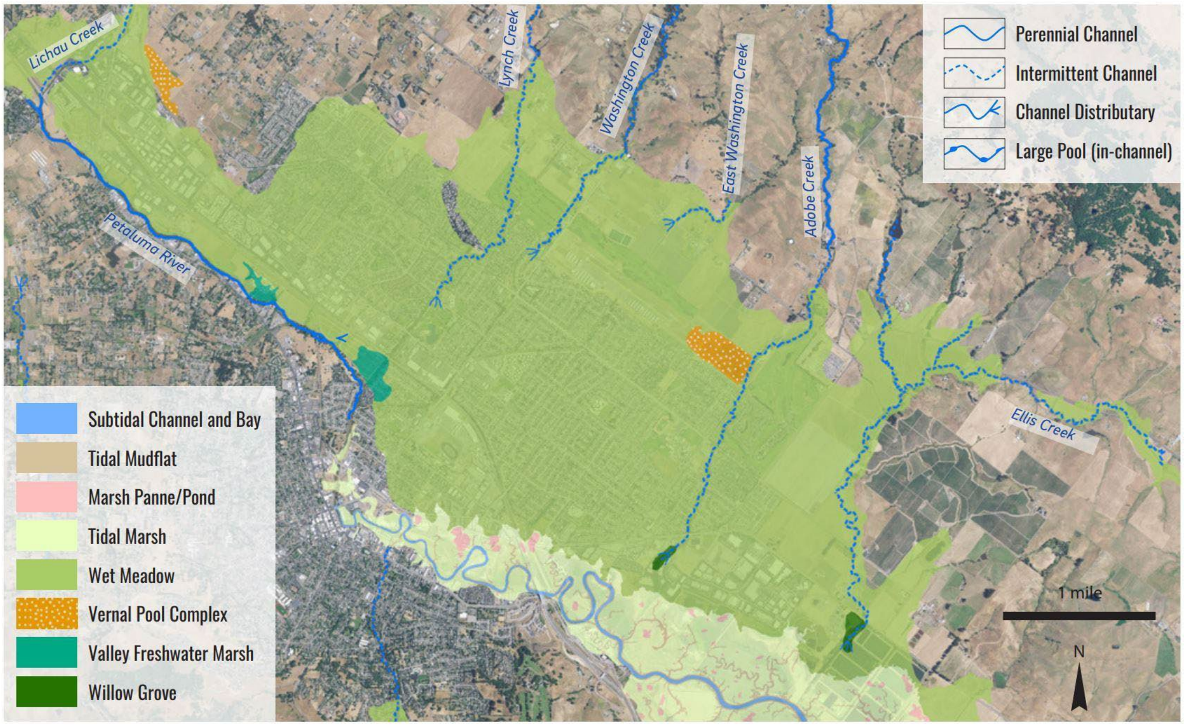



**Figure 5.1. During the mid-19th century, thousands of acres of seasonally flooded wet meadow, with smaller patches of vernal pool complex and willow groves, occupied the valley floor east of the river.** Tributaries draining off of the Sonoma Mountains dissipated as they flowed across the broad alluvial plain. *(NAIP 2016)*

***Source: Petaluma Valley Historical Hydrology and Ecology Study, 2018.***

# San Francisco & San Pablo Bay Tides

Water levels in the San Francisco Bay, and correspondingly the San Pablo Bay, are controlled by water level fluctuations in the Pacific Ocean that travel through the Golden Gate. Changes in ocean water levels occur daily due to the astronomic tide, water level fluctuations caused by forces between the astronomic bodies of the earth, the sun, and the moon. The San Francisco Bay experiences a semidiurnal tide, meaning each day comprises two high and two low tides of unequal heights. The astronomic tide range varies by a few feet on about a two-week cycle, with larger tidal ranges called "spring" tides and lower tidal ranges called "neap" tides. The largest spring tides of the year usually occur in in winter months between December and February and are commonly known as "king" tides. King tides can increase the San Francisco Bay high tide elevation as much as 12 to 24 inches.[9] [10] [11] The National Oceanic and Atmospheric Administration (NOAA) maintains a network of tide gages that report observed tides and

[9] *AECOM. "San Francisco Bay Tidal Datums and Extreme Tides Study." Adapting to Rising Tides. BCDC, Feb. 2016, page 2-9, https://www.adaptingtorisingtides.org/howto/art-supplies/20160429-sfbay_tidal-datums_and_extreme_tides_study-final/.*

[10] *"Bay Shoreline Flood Explorer" Adapting to Rising Tides. BCDC, https://explorer.adaptingtorisingtides.org/learn.*

[11] *"ART Bay Area: Regional Sea Level Rise Vulnerability and Adaptation Study." Adapting to Rising Tides. BCDC, Mar. 2020, page 1-27, http://www.adaptingtorisingtides.org/wp-content/uploads/2020/03/ARTBayArea_Main_Report_Final_March2020_ADA.pdf.*

tidal datums within the Bay. Common tidal datums, which are statistics used to characterize local water levels, include:

- Mean higher high water (MHHW)—average of each day's highest tide.
- Mean sea level (MSL)—average of all stages of the tide.
- Mean lower low water (MLLW)—average of each day's lowest tide.

# Assets At Risk from Flooding

According to the 2020 Local Hazard Mitigation Plan (LHMP), Petaluma has roughly 200 parcels in the 100-year FEMA floodplain, with a total value of roughly $424 million. The LHMP finds that six critical structures are vulnerable to a 100-year flood event, including a daycare facility, a government-administration facility, an electrical substation, the D Street drawbridge, and two water facilities.[12] These vulnerable structures present risk to people, lifeline utility systems, and transportation. Recent projects in the Denman reach portion of the river, culminating in a stormwater control weir, have provided for a portion of the Payran neighborhood originally classified as 100-year floodplain (areas shown in purple in Figure 2) to be re-listed as structures in the 100-year floodplain that are protected by a Federal Flood Control System, following construction of the structure.

Flooding also impacts the city in other ways beyond damage to structures. As buildings are flooded or evacuated, businesses must close, and city emergency services are strained. Road closures prevent movement through the city for those not at immediate risk from flooding. Other infrastructure such as roads, parks, landscaping, vehicles, and minor utilities are also subject to damage by standing or flowing water. Furthermore, flood water can also be a vector for disease.

Future development within the City and in the contributing watershed poses greater potential for flood risk if flood impacts are not fully mitigated. If land surfaces are made less permeable due to paving, new buildings, soil compaction or vegetation removal, the new rainfall runoff contributes to downstream flooding risk, even if to an unmeasurable extent. Similarly, the construction of drainage infrastructure such as culverts and channels can increase downstream flooding by eliminating the temporary detention of stormwater in those newly drained areas. Land development that channelizes stormwater alters and confines natural drainage channels can create localized flooding problems inside and outside of natural floodplains. When coupled with greater intensity and unpredictable storms brought on by climate change, future development can further stress dams, levees, and other flood mitigation infrastructure.[13] The water management system includes water supply in addition to stormwater control, and both can be stressed by growing development, especially when flood drainage and control structures are overwhelmed. Many jurisdictions establish stormwater management regulations to mitigate the impact of development on the stormwater system by requiring that stormwater is retained on site, released gradually, or at a similar rate as before the site was developed.

[12] *Wood Environment & Infrastructure Solutions, Inc. "City of Petaluma Local Hazard Mitigation Plan." City of Petaluma, Nov. 2020, page 4-111, https://cityofpetaluma.org/documents/lhmp/.*

[13] *Wood Environment & Infrastructure Solutions, Inc. "City of Petaluma Local Hazard Mitigation Plan." City of Petaluma, Nov. 2020, page 4-113, https://cityofpetaluma.org/documents/lhmp/.*

# Sea Level Rise

Sea level rise (SLR) is a rise in the average elevation of global oceans. SLR also increases the average water surface elevation (WSE) of rivers and associated bodies of water, like the Petaluma River, in areas near where these waters drain into the ocean or a bay. Global sea level rise refers to the long-term gradual increase of sea levels driven by the expansion of ocean waters as they warm, the addition of freshwater to the ocean from melting land-based ice sheets and glaciers, and extractions from groundwater. Regional and local factors such as tectonics and ocean and atmospheric circulation patterns result in relative sea level rise rates that can be higher or lower than the global average.

SLR will contribute to increased coastal flooding and more frequent and severe tidal inundation which can exacerbate existing flood hazards from severe storms, as well as alter the function of salt marshes and tidal flats near the confluence of Petaluma River and San Pablo Bay. Because the southern reaches of the Petaluma River and its surrounding marshlands are tidally influenced, as sea level rises so do the mean, high, low, and other tides currently present in the city. The extent of tidal influence along the Petaluma River is generally understood to impact above the Washington Creek confluence, and many consider the Lynch Creek / Payran Weir confluence to be the limit of tidal influence.[14] The current OCOF SLR viewer does not attempt to model sea level or storm impacts above the Washington Creek confluence, resulting in unknown conditions upstream, including in the Payran neighborhood. Tidal inundation and sea level rise combined with coastal storm events will also occur and result in greater impacts. Over time, existing low-lying tidal flat areas near the southern portion of Petaluma are expected to be semi-permanently inundated as a result of SLR.

Over the last century, the tide gauge in San Francisco has recorded sea-level rise of 8 inches.[15] In addition to this observed past sea-level rise, the best available science, as reviewed specifically for California by a panel of national experts predicts that sea-level rise will continue and accelerate throughout this century and into the next century.[16]

## SLR Scenarios

While sea-level rise models and predictions are science-based, SLR values vary depending on the scenario(s) and location and value-ranges are usually assigned rather than exact numbers. Figure 4 shows the historical data and future projections for SLR in the San Francisco Bay, with shaded areas bounded by dashed lines representing the 5th and 95th percentiles of the projections. The Representative Concentration Pathways (RCPs) represent different trajectories of future global GHG concentrations. RCP 8.5 corresponds to a “high emission” scenario, and RCP 2.6 corresponds to a “low emission” scenario, and both have an associated SLR projection. The H++ SLR projection is not associated with an

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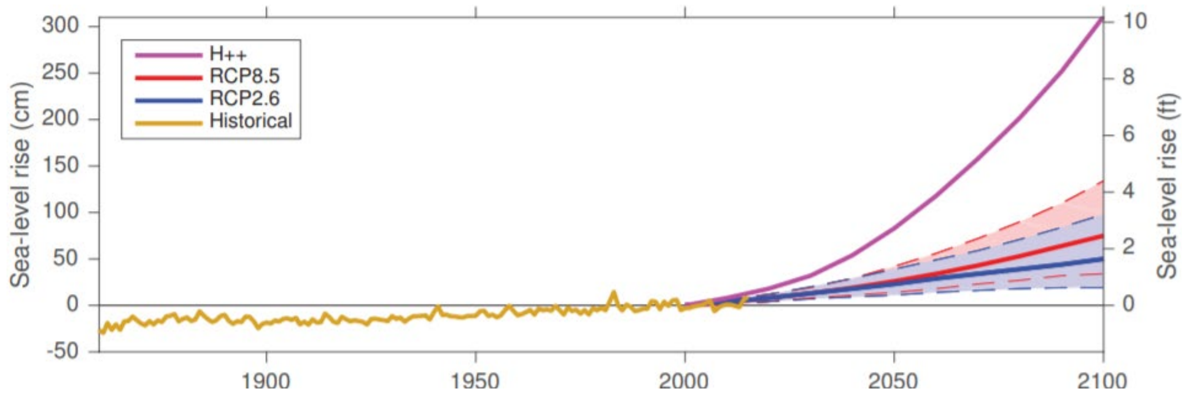
[14] *Sonoma Resource Conservation District. “Draft Petaluma Watershed Enhancement Plan” 2015, https://sonomarcd.org/wp-content/uploads/2017/06/Petaluma-Watershed-Enhancement-Plan-2015.pdf*

[15] *“Sea Level Trends.” NOAA, https://tidesandcurrents.noaa.gov/sltrends/. Accessed 2021.*

[16] *Griggs, et. al. “Rising Seas in California: An Update on Sea-Level Rise Science.” California Ocean Protection Council, Apr. 2017, http://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf.*

RCP and is instead based on a single scenario that models the potential instability of the Antarctic and Greenland ice sheets.

**Figure 4. Graph of Relative Sea Level in the San Francisco Bay**




***Source: Rising Seas in CA: An Update on Sea-Level Rise Science, 2007, page 25)***

To help governing bodies plan for and assess risks related to SLR, the California Ocean Protection Council (OPC) adopted the *State of California Sea-Level Rise Guidance: 2018 Update* and, in 2020, released the *Making California's Coast Resilient to Sea Level Rise: Principles for Aligned State Action* document.

The *State of California Sea-Level Rise Guidance: 2018 Update*, herein referred to as the 2018 State Guidance, provides a standardized process for evaluating potential SLR impacts and elevations using a risk-probability approach calibrated to local tide stations throughout California. It presents projected SLR elevations for the San Francisco Bay Area for low- and high-emission scenarios, following the RCP 2.6 and RCP 8.5 trajectories, respectively, and remarks that world GHG concentrations are following the RCP 8.5 trajectory.[17] The 2018 State Guidance is recognized as the best available science by the CCC,[18][19] and is recommended by the BCDC in its current draft of the *San Francisco Bay Plan Climate Change Policy Guidance*.[20] In the draft document, the BCDC also notes that the low-emissions scenario is becoming increasingly unlikely, and the current trajectory of world GHG concentrations may fall somewhere between the low- and high-emission SLR projections presented in the 2018 State Guidance. An update to state guidance is anticipated in 2023. The maps presented in this white paper base their SLR scenarios on the high-emission projections as presented in the 2018 State Guidance.

17 *"State of California Sea-Level Rise Guidance: 2018 Update." California Ocean Protection Council, 2018, page 17, https://opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf.*

18 *"California Coastal Commission Sea Level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits." California Coastal Commission, 2018, page 17, https://documents.coastal.ca.gov/assets/slr/guidance/2018/0_Full_2018AdoptedSLRGuidanceUpdate.pdf.*

19 *Ainsworth, John, et al. "Briefing and consideration of adopting 'Making California's Coast Resilient to Sea Level Rise: Principles for Aligned State Action'." California Coastal Commission, 2021, page 6, https://documents.coastal.ca.gov/reports/2020/5/W6g/w6g-5-2020-report.pdf.*

20 *Staff Report on Draft San Francisco Bay Plan Climate Change Policy Guidance. Page 74. BCDC March 2021.*

The City of Petaluma has previously utilized the SLR scenarios presented in the 2018 State Guidance for developing its Local Hazard Mitigation Plan (LHMP) in 2020. The scenarios are suited to support the goals of the General Plan by providing alternative outcomes based on the probability of various SLR scenarios. This allows city planners to apply different risk aversion standards to meet various project considerations. Critical infrastructure planning might consider a different risk aversion standard than the design of a public green space.

The 2018 State Guidance provides ranges of possible SLR for each decade from 2030 to 2150. This white paper uses 2030 (short-term), 2050 (General Plan time horizon), and 2100 (end-of-century) as relevant timeframes. For each timeframe, this white paper considers the following three sets of SLR projections for the San Francisco Bay under the RCP 8.5 emission scenario. The projections do not account for wave run-up or episodic increases in sea level, such as those due to storm surges or king tides (these will be considered elsewhere in this paper).

1. The “likely” scenario describes the upper bound of a set of SLR projections that have a 66% chance of occurring. Using this scenario corresponds to a low level of risk aversion for a given project. A low level of risk aversion is recommended for adaptive, lower consequence projects or projects with a relatively short functional lifespan. It does not adequately address the effects of high impact, low probability events.[21]
2. The “medium-high risk aversion” scenario describes a set of SLR projections that have a 0.5% chance of occurring by the indicated date. This level of risk aversion is recommended for less adaptive, more vulnerable projects or populations that will experience medium to high consequences as a result of underestimating sea level rise.[22] This includes projects that would be affected by flooding resulting in damage, such as residential or commercial development, or where the required components for project permit approval could be jeopardized by SLR and there is little space for future adaptation.
3. The “H++” scenario is an extreme risk aversion scenario with no assigned probability of occurrence. Due to the complexities and uncertainties of modelling the potential ice loss from the Greenland and Antarctic ice sheets, especially in the second half of this century, it is difficult to predict whether current SLR trends will follow the H++ trajectory for timeframes beyond 2050. Consideration of the H++ scenario is recommended for projects that have minimal or no adaptive capacity, a long functional lifespan, or would be significantly costly to repair after being damaged by flooding. Projects with a low tolerance for risk also include those that would have considerable public health, public safety, or environmental impacts should the H++ scenario occur.[23]

The nearest tide station in the to the City of Petaluma in the 2018 State Guidance is the San Francisco station. The SLR estimates for each probability scenario are listed below in Table 1.

[21] *“State of California Sea-Level Rise Guidance: 2018 Update.” California Ocean Protection Council, 2018, page 25,* *https://opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf.*

[22] *“State of California Sea-Level Rise Guidance: 2018 Update.” California Ocean Protection Council, 2018, page 25,* *https://opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf.*

[23] *“State of California Sea-Level Rise Guidance: 2018 Update.” California Ocean Protection Council, 2018, page 25,* *https://opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf.*

**Table 1. Projected SLR Scenarios (in Feet)**

| Year | Likely Flood Height (66% probability) | Medium -High Risk Aversion Flood Height (0.5% probability) | H++ Flood Height (no probability assigned) |
|---|---|---|---|
| 2030 | 0.5’ | 0.8’ | 1.0’ |
| 2050 | 1.1’ | 1.9’ | 2.7’ |
| 2080 | 2.4’ | 4.5’ | 6.6’ |
| 2100 | 3.4’ | 6.9’ | 10.2’ |

***Source: State of California Sea-Level Rise Guidance: 2018 Update***

In addition to the base SLR projections, this white paper also considers the effects of Mean Higher High Water “High” tides, the 20 – and 100-year storm event, and king tides, as noted below.

- Mean high higher water (MHHW) represents the average daily highest tide elevation and is used as the base SLR elevation for all maps. All elevations below MHHW are routinely submerged during any given day.
- A 20-year storm is a storm that has a 5% probability of occurring during any given year and causes increased sea level elevations, known as storm surge. For maps that include the effects of a storm surge caused by a 20-year storm, MHHW is still used as the base sea level elevation.
- A 100-year storm is a storm that has a 1% probability of occurring during any given year and causes increased sea level elevations, known as storm surge. For maps that include the effects of a storm surge caused by a 100-year storm, MHHW is still used as the base sea level elevation.
- A “king tide” refers to an exceptionally high tide that is guaranteed to occur at least once a year. King tides are unlikely to overlap with a 100-year storm surge, and MHHW is the standard base sea level condition for hydrology models, so the effects of king tides are not compounded with storm surge scenarios. The King tides are shown in maps as a comparison to MHHW, since the King tides will occur at least once annually.

The considerations listed above also match the assessment conditions set forth in the Petaluma LHMP report scenarios. The guidance presented in the 2020 *Making California’s Coast Resilient to Sea Level Rise* document, herein referred to as the 2020 State Guidance, provides principles to help align SLR action efforts across the state using a single SLR scenario of 3.5 feet by 2050.[24] This SLR value is derived from the 2018 State Guidance and occurs at the higher end of the “likely” scenario for 2100. The recommended planning target for 2050 accordingly provides a 50-year margin of safety, which the OPC

[24] *“Making California’s Coast Resilient to Sea Level Rise: Principles for Aligned State Action.” California Ocean Protection Council, 2020, page 2, https://www.opc.ca.gov/webmaster/_media_library/2021/01/State-SLR-Principles-Doc_Oct2020.pdf.*

administered due to its observation that new models regularly predict greater amounts of SLR and the lack of inclusion of king tides and storm events in the 2018 State Guidance projections.[25] This white paper uses the 2018 State Guidance projections, rather than the 2020 State Guidance target for 2050, to better align itself with the assessments carried out for the 2020 Petaluma LHMP and provide a probability-based matrix of potential SLR scenarios.

## Non-Progressive Storm Surge Flooding

The OCOF viewer allows users to independently add the effects of an annual, 20-year, or 100-year storm surge onto any SLR scenario.[26] For most areas within Petaluma, a 20-year storm surge produces greater flooding than a 100-year storm surge. Figure 5 below provides an example with a base SLR of 6.6 feet, showing less severe flooding extents with a 100-year storm surge (right), in comparison to the more severe flooding extents caused by a 20-year storm (left).

This phenomenon is known as non-progressive flooding and is the result of multiple factors within the CoSMoS framework utilized by the OCOF viewer. The OCOF website states that non-progressive flooding can be caused by differences in the direction of waves for model 20- and 100-year storms, the complexities involved in simulated beach profile erosion, and site-specific vulnerabilities to wave and current directions within pond structures and levee networks. It does not define non-progressive flooding as an incorrect projection or a calculation error. The website also notes that the flood extents of the 100-year storm surge may be underpredicted in the vicinity of the Petaluma River and Novato. The exact reasons behind the model's indication of non-progressive flooding within the City of Petaluma are not precisely known. 100 Year Flood Events were utilized in the scenarios and impact assessment for the white paper as they match previous City reports such as the LHMP, but it should be made clear that the 20 year storm induces increased flooding and is 5 times more likely to occur in any year than the 100 year storm.

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[25] *"Making California's Coast Resilient to Sea Level Rise: Principles for Aligned State Action – Frequently Asked Questions." California Ocean Protection Council, 2020, page 2, http://www.opc.ca.gov/webmaster/_media_library/2020/05/SLR-Principles-FAQ-Final-051320.pdf.*

[26] *Our Coast Our Future (OCOF). https://ourcoastourfuture.org/*

**Figure 5. Example of Non-Progressive Flooding in Petaluma**

Flooding due to 100-year storm surge added onto 6.6 feet of SLR, near Kenilworth Park and Fairground.

Flooding due to 20-year storm surge added onto 6.6 feet of SLR, near Kenilworth Park and Fairground.

## SLR Maps

Several online resources provide visual guides that display various levels of SLR along shorelines in California. The Point Blue website hosts the Our Coast Our Future (OCOF) SLR viewer, which uses the modelling framework of the USGS Coastal Storm Modeling System (CoSMoS). The OCOF viewer allows users to display multiple SLR elevations, the effects storm surge events and king tides, and other geographic information related to SLR and flooding. The viewable SLR elevation values provided by the OCOF viewer do not exactly match the elevation values of the 2018 State Guidance projections. This white paper uses the SLR scenarios provided by the OCOF viewer, thus the maps included herein are approximate representations of the 2018 State Guidance projections, as indicated below in Table 2. SLR predictions for the Likely SLR Scenarios are presented for 2050 and 2100 (2030 is skipped as the predictions are insignificant). These Likely scenarios are presented in different combinations with MHHW Tide, King Tide, and different storm surge conditions, as indicated on the maps. SLR predictions for The Medium-High Risk Aversion Scenarios are presented for 2030, 2050, 2100, again with different tide and storm conditions. Table 3 below shows a comparison between the OCOF elevations used by the Petaluma LHMP and the OCOF elevations used by maps in this white paper. The included maps, which illustrate the flood extents of SLR at MHHW and King Tide and MHHW with the addition of a 20- and 100-year storm surge, are listed below in Figure 6, Figure 8, Figure 9, Figure 10, and Figure 9.

**Table 2. Comparison of 2018 State Guidance Projections and Mapped OCOF Scenarios**

| Year | Map 1 | Map 2 |
|---|---|---|

| | Likely Scenario Flood Height | | Medium -High Risk Aversion Scenario Flood Height | |
|---|---|---|---|---|
| | 2018 State Guidance Projection (not shown on map) | OCOF Elevation Shown on Map | 2018 State Guidance Projection (not shown on map) | OCOF Elevation Shown on Map |
| 2030 | 0.5’ | - | 0.8’ | 0.8’ |
| 2050 | 1.1’ | 0.8 | 1.9’ | 1.6’ |
| 2100 | 3.4’ | 3.3’ | 6.9’ | 6.6’ |

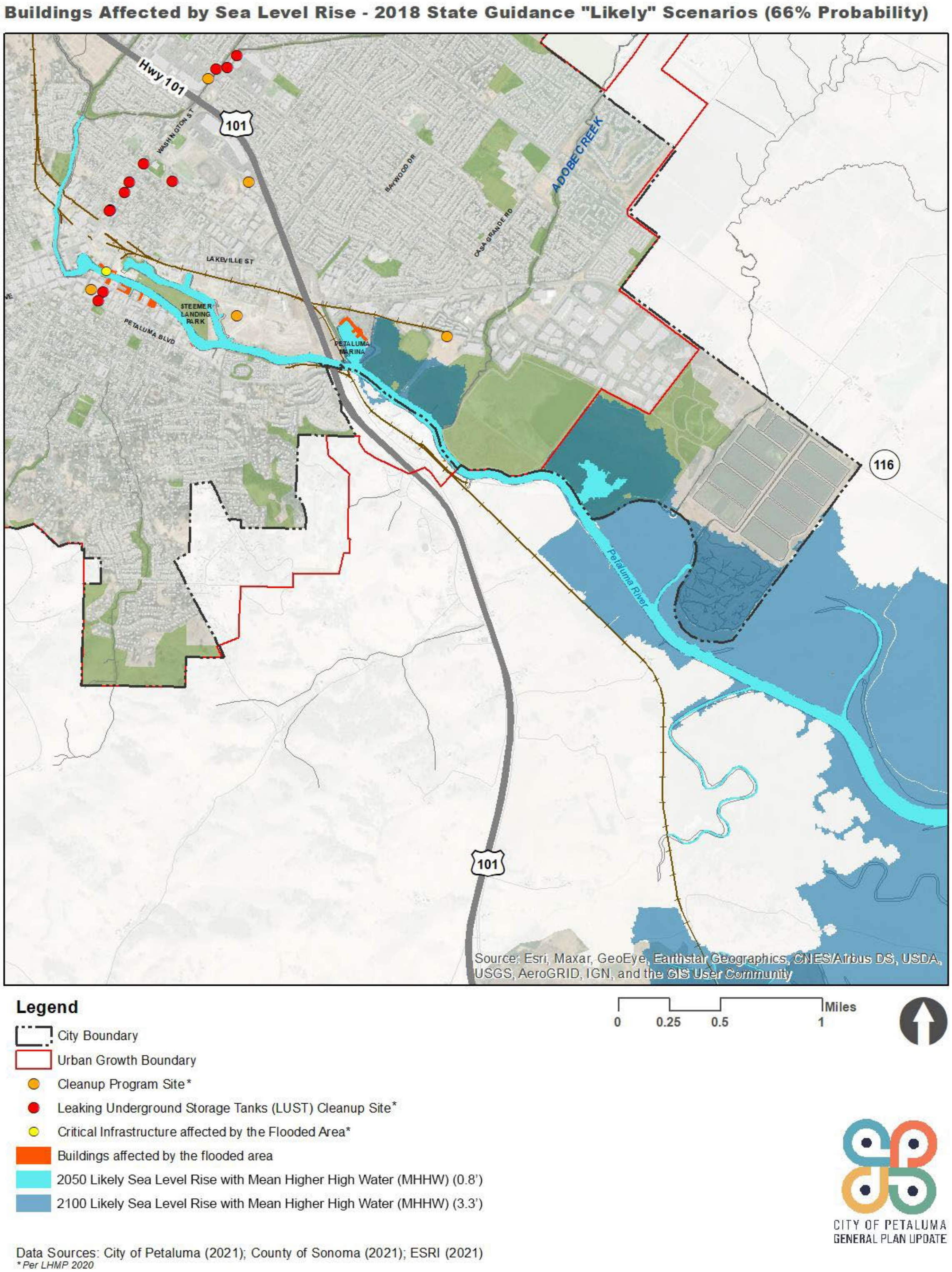
***Sources: State of California Sea-Level Rise Guidance: 2018 Update, Flood Map. OCOF. CoSMoS v2.1.***

**Table 3. Comparison of SLR Scenarios in the LHMP and this White Paper**

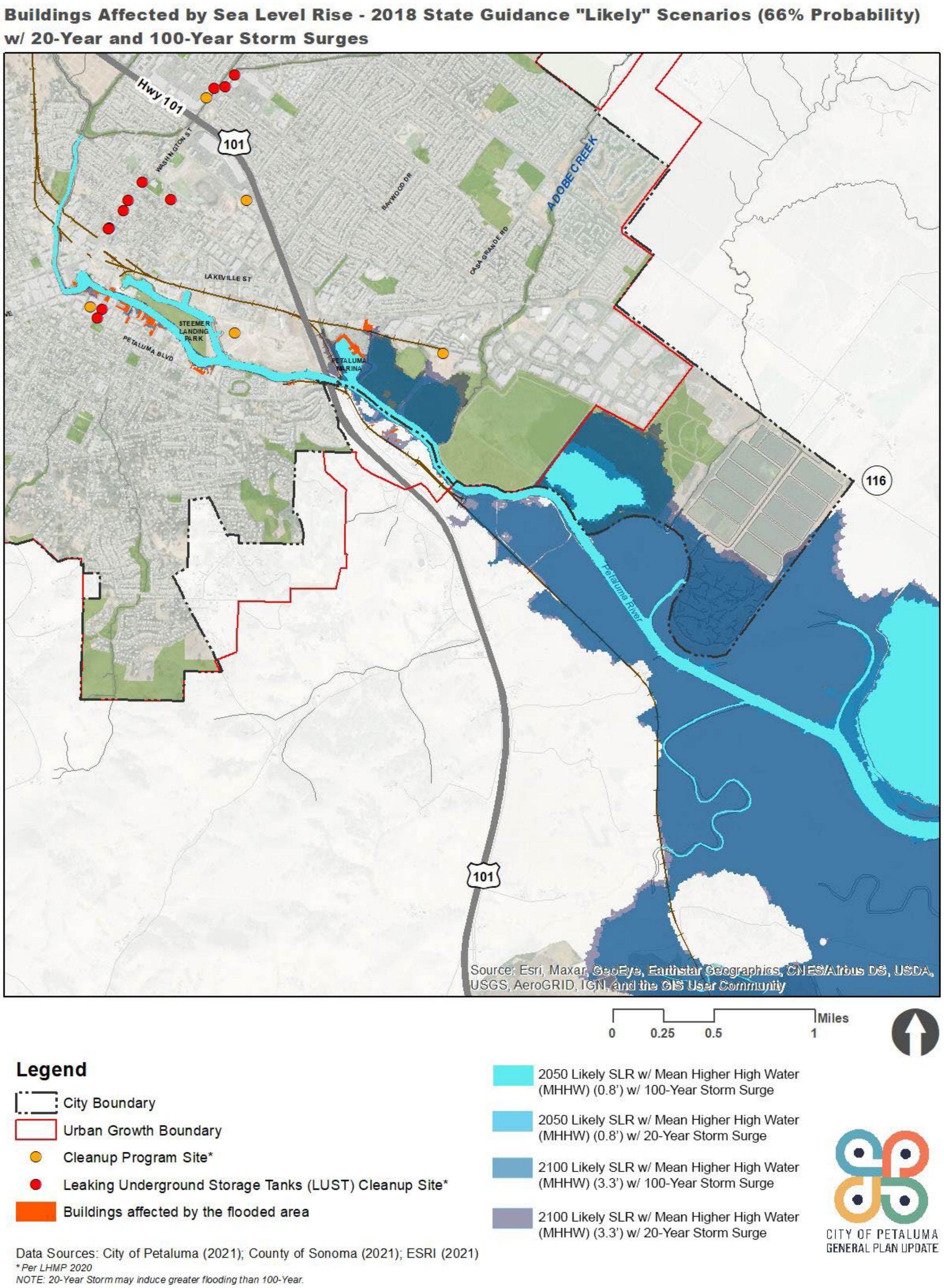
| SLR Elevations Available on OCOF Viewer | Presence on Maps | | |
|---|---|---|---|
| | Petaluma LHMP Maps | White Paper “Likely” Maps | White Paper “Medium-High Risk Aversion” Maps |
| 0.8’ | ✓ | ✓ | ✓ |
| 1.6’ | - | - | ✓ |
| 2.5’ | ✓ | - | - |
| 3.3’ | - | ✓ | - |
| 4.1’ | - | - | - |
| 4.9’ | - | - | - |
| 5.7’ | - | - | - |
| 6.6’ | ✓ | - | ✓ |
| 16.4’ | - | - | - |

***Sources: Petaluma LHMP. 2020, Flood Map. OCOF. CoSMoS v2.1.***

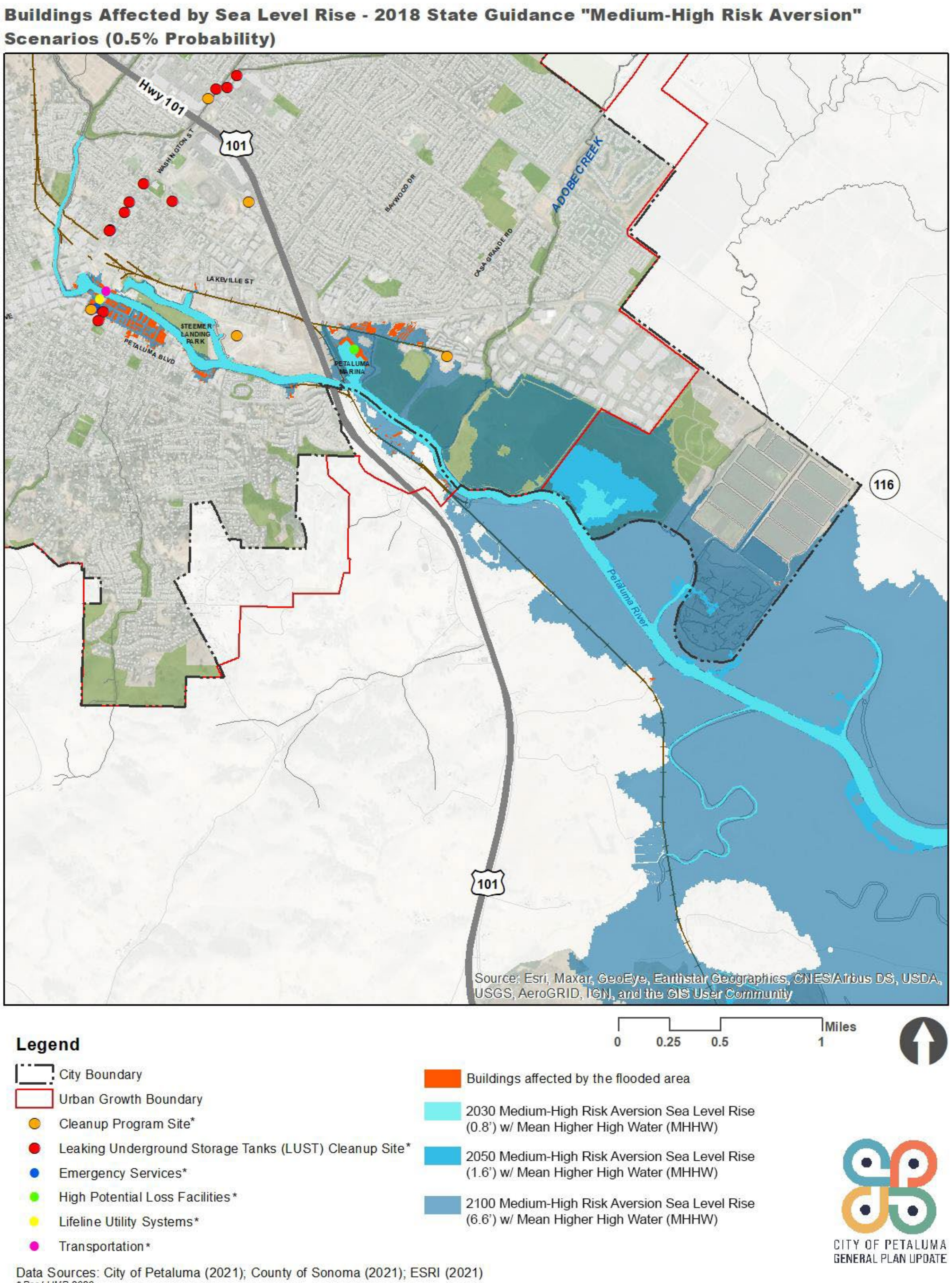
## Figure 6. Likely SLR Scenarios w/ MHHW



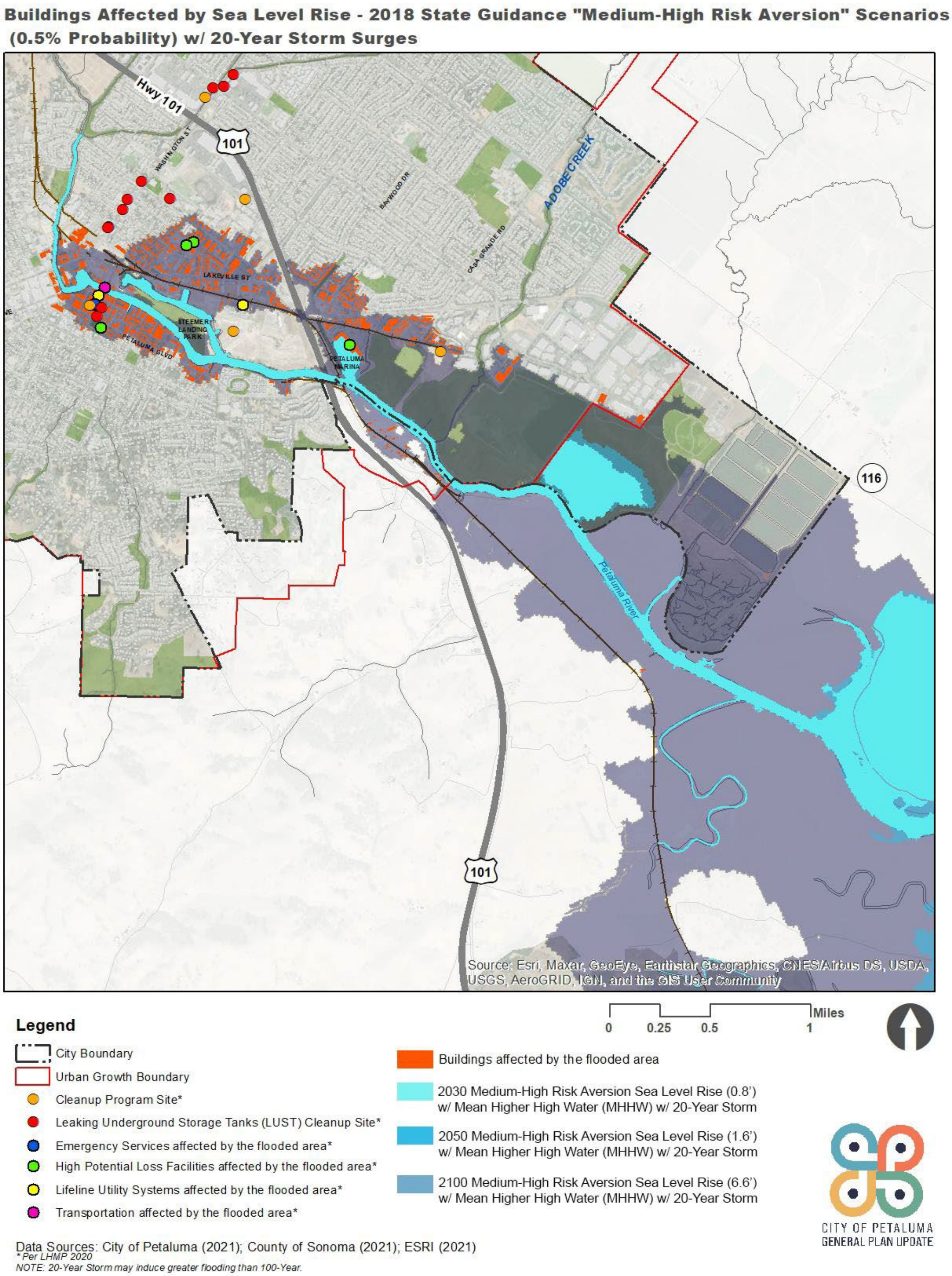
## Figure 7. Likely SLR Scenarios w/ 20- and 100-Year Storm Surge



## Figure 8. Medium-High Risk Aversion SLR Scenarios w/ MHHW

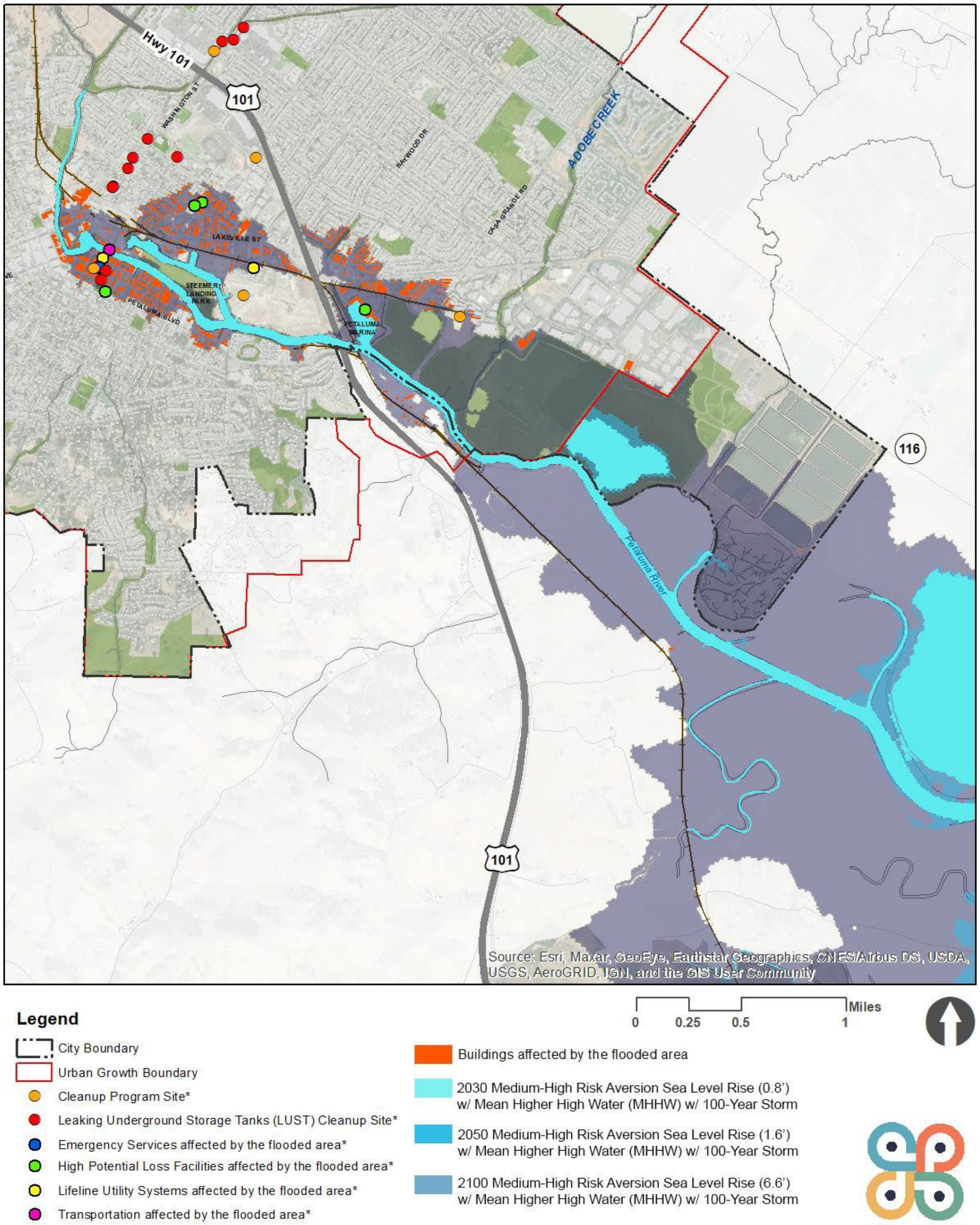


## Figure 9. Medium-High Risk Aversion SLR Scenarios w/ 20-Year Storm Surge



## Figure 10. Medium-High Risk Aversion SLR Scenarios w/ 100-Year Storm Surge

**Buildings Affected by Sea Level Rise - 2018 State Guidance "Medium-High Risk Aversion" Scenarios (0.5% Probability) w/ 100-Year Storm Surges**




Data Sources: City of Petaluma (2021); County of Sonoma (2021); ESRI (2021)
*Per LHMP 2020
NOTE: 20-Year Storm may induce greater flooding than 100-Year.

## Model Limitations

The OCOF elevation model is based on a 2-meter DEM and has an elevation accuracy of 7.1 inches. Mapping may not properly render the flooding in marsh lands due to the elevation model being distorted by standing vegetation. The model attempts to accurately represent the impact of levees and dams but cannot anticipate how those will be operated during storm events or in the future. The OCOF model also does not consider that storm severity is expected to increase with climate change. The maps also do not consider what changes to the shoreline may occur in the next decades from natural or human processes. The map is not intended to provide parcel level analysis of SLR impacts or exact predictions of where sea levels will be in certain years, but rather provide general guidelines related to potential impacts of SLR at various intervals.

While the OCOF model considers inflows from the Petaluma River on bay elevation, it does not factor that water flow into the height of the Petaluma River. The available SLR model therefore doesn't consider that the flooding at the upper reaches of the river may be more significant than shown here, because the upper watershed is attempting to drain its stormwater into a river that is elevated. It is not possible to simply overlay these SLR and Storm Surge maps with the FEMA Rainfall Flood maps in hopes of assessing the combined impacts. The FEMA maps are backwards facing maps of current rainfall flooding, and do not consider a river that is elevated due to SLR and Storm Surge. The SLR maps on the other hand are forward facing, and though they consider SLR and the Surge of bay water that a storm pushes up towards the city, they don't consider the rain falling on the city and watershed trying to flow downriver at the same time. Comprehensive inclusion of these considerations will constitute an important update to the modelling effort, which should be amended to consider increased precipitation intensity from climate change, a higher San Pablo Bay elevation from SLR, and increased flooding from storm surge. The Hydrological Model would need to consider the increased runoff in future storms from climate change and increased impermeability, SLR Predictions raising the tidal level of the Petaluma River as well as the likelihood of a rainfall event coinciding with a Storm Surge driving bay water up the river. This model does not currently exist and is not under development.

Additional model limitations are included and discussed in further detail in Appendix B.

## Assets at Risk from SLR

For effective adaptation planning to occur, assets in a community are first assessed and have their vulnerability defined through vulnerability assessments. There is no single method to assess vulnerabilities in an area, but it is important that any assessment method meets the goals and needs of the local community. Typically, a vulnerability assessment may assess entities by hazard category, such as sea level rise, flooding, extreme heat, seismic activity, or drought. When considering sea level rise hazards, different scenarios are often selected by sea level elevation, year, and whether the effects of king tide or storm surges are included. Flooding hazards are often categorized by zones vulnerable to 100-year and 500-year floods. These considerations allow a greater sense of when and how often different entities are predicted to become more vulnerable to sea level rise and flooding. Vulnerabilities may be classified by likelihood of occurrence, magnitude, geographic extent, affected communities, affected utilities and critical infrastructure, and other characteristics. For example, the Petaluma LHMP measures hazard significance using criteria such as frequency and resulting damage, including deaths, injuries, and property and economic damage.

The 2020 LHMP reviewed the impacts to critical infrastructure from multiple sea level rise scenarios. The results of the vulnerability assessment are summarized below. Images in the following sections provide zoomed-in views of the maps presented in the previous section for clearer visualization of relevant at-risk areas. Many of the risks posed by flooding due to sea level rise are similar to the previously discussed rainfall flooding risks. Future development and climate change may create new risks or exacerbate current ones, due to channelized natural systems with no access to its floodplain, more intense and unpredictable storms that result in higher flow discharges, and a strained water management system including stressed dams, levees, and water supply infrastructure.

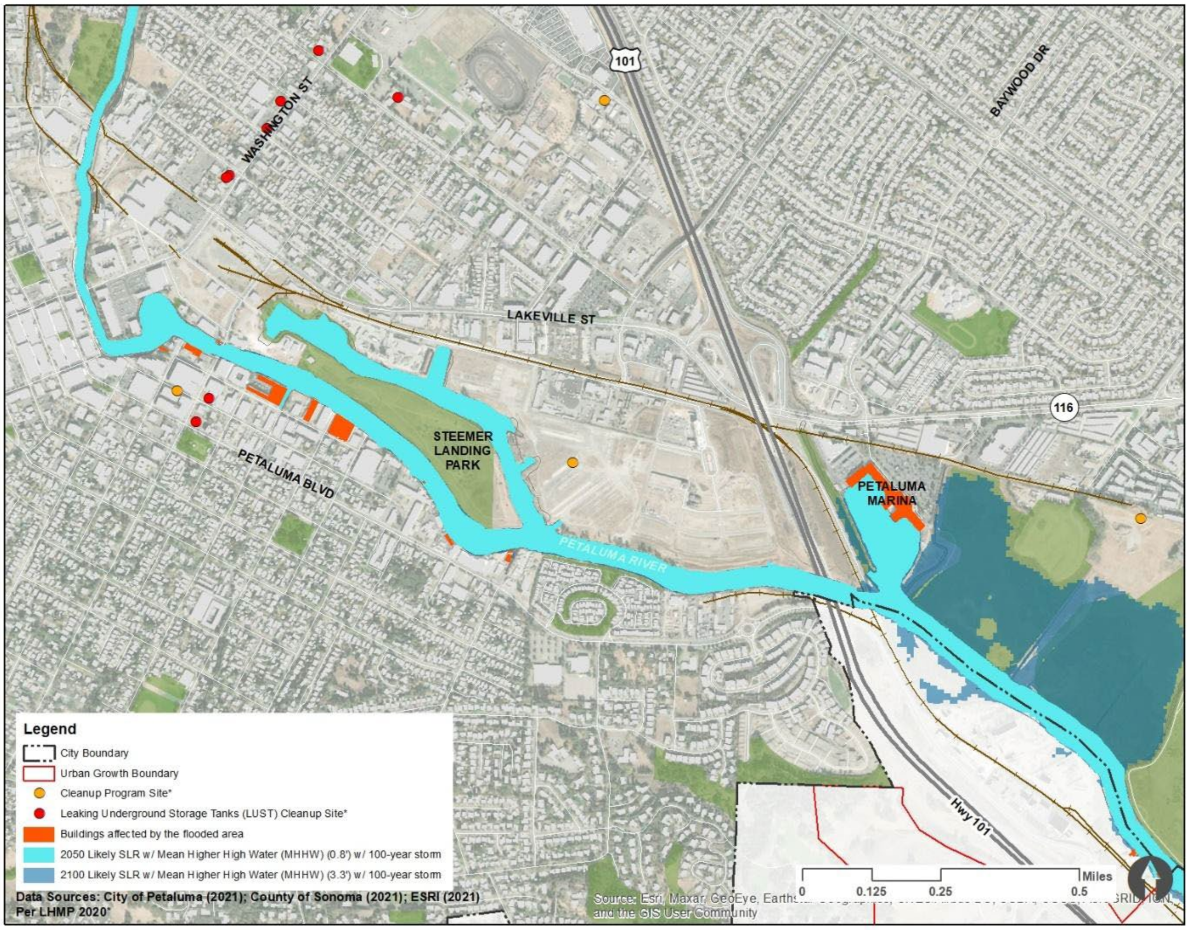
The parameters and methods in the LHMP match that of the SLR maps shown above, as both used flood extent scenarios available by the OCOF viewer. This white paper thus reiterates impact predictions from the LHMP as noted. The results obtained from the scenarios and shown in the maps within this white paper and the LHMP are predictions based on the modelling output of OCOF viewer and do not predict the future with certainty.

### Likely Scenario

The likely SLR scenarios predict minimal impacts to structures within this century. The flooding extents shown in Figure 11 below as darker blue areas represent 3.3’ of SLR with 100-year storm surge. Orange denotes affected buildings, but does not detail the significance of the impact, as buildings may have raised floor elevations. The base SLR elevation of 3.3’ approximates 2018 State Guidance likely projection of 3.5’ of SLR in 2100 and the 2020 State Guidance preparation target of 3.5’ of SLR by 2050. With 3.3’ of SLR and 100-year storm surge, few buildings are impacted though tidal marshes east of the Petaluma Marina become flooded.

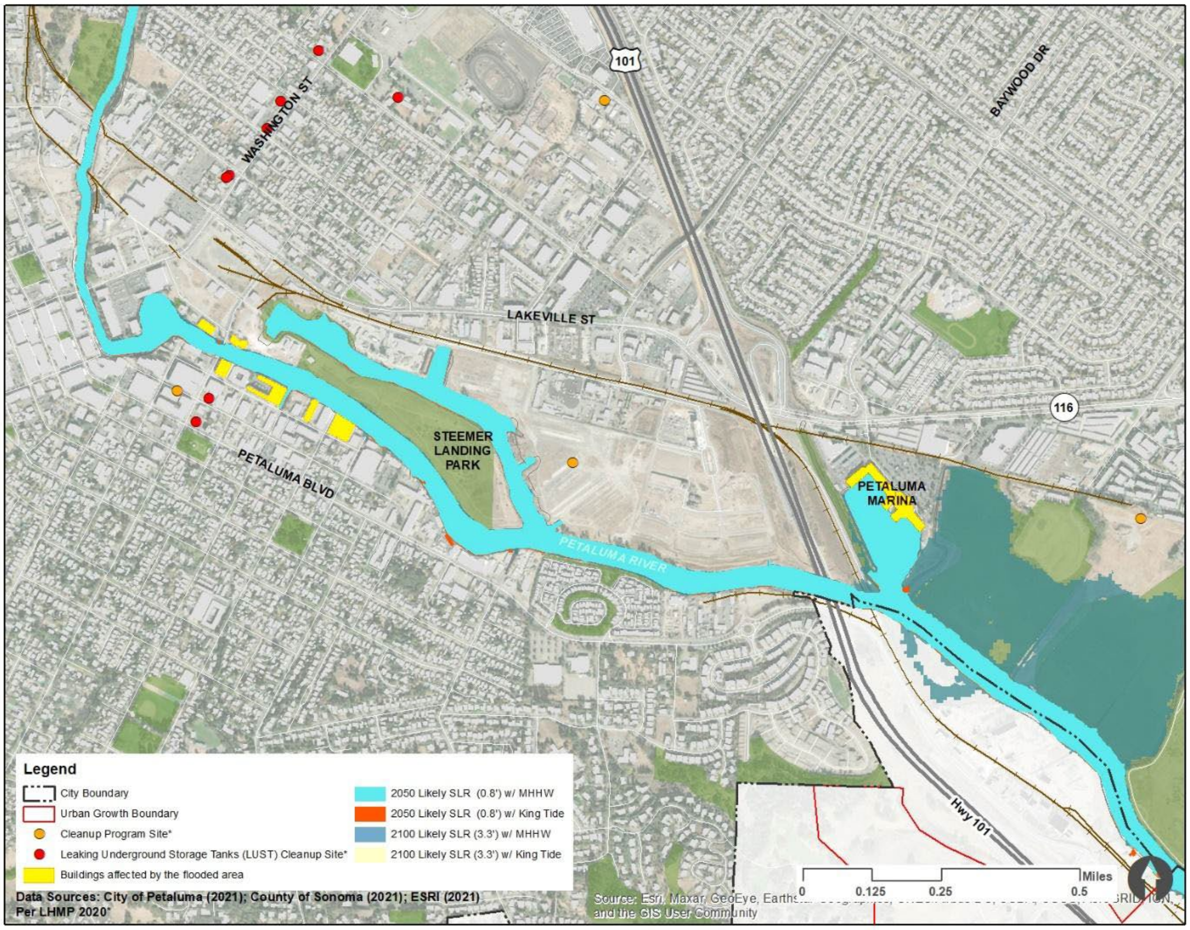
The Petaluma LHMP presents an SLR scenario of 2.5’ and finds that zero members of the population are at risk and no buildings are affected. After adding a 100-year storm surge onto the base SLR of 2.5’, the LHMP finds that no additional parcels or members of the population are affected. Tidal marshes east of the Petaluma Marina remain unflooded in both scenarios. These results of the LHMP assessment may report fewer affected entities than an assessment carried out with 3.3’ of SLR (as is shown in Figure 11). The scenario of 2.5’ of SLR with a 20-year storm surge is not shown in the LHMP or this white paper.

**Figure 11. Zoomed View of Likely SLR Scenarios w/ 100-Year Storm Surge**




The King Tide Scenario can be expected at least annually. As shown below in Figure 12, in the case of the Likely Scenarios, if this King Tide occurs at a time with no storm surge, the impact will be minimal until the 2100 prediction of 3.3'. Because the river is significantly channelized, there is little impact to structures from King Tides during the Likely SLR scenarios this century.

**Figure 12. Zoomed View of Likely SLR Scenarios w/ King Tide**




## Medium-High Risk Aversion Scenario

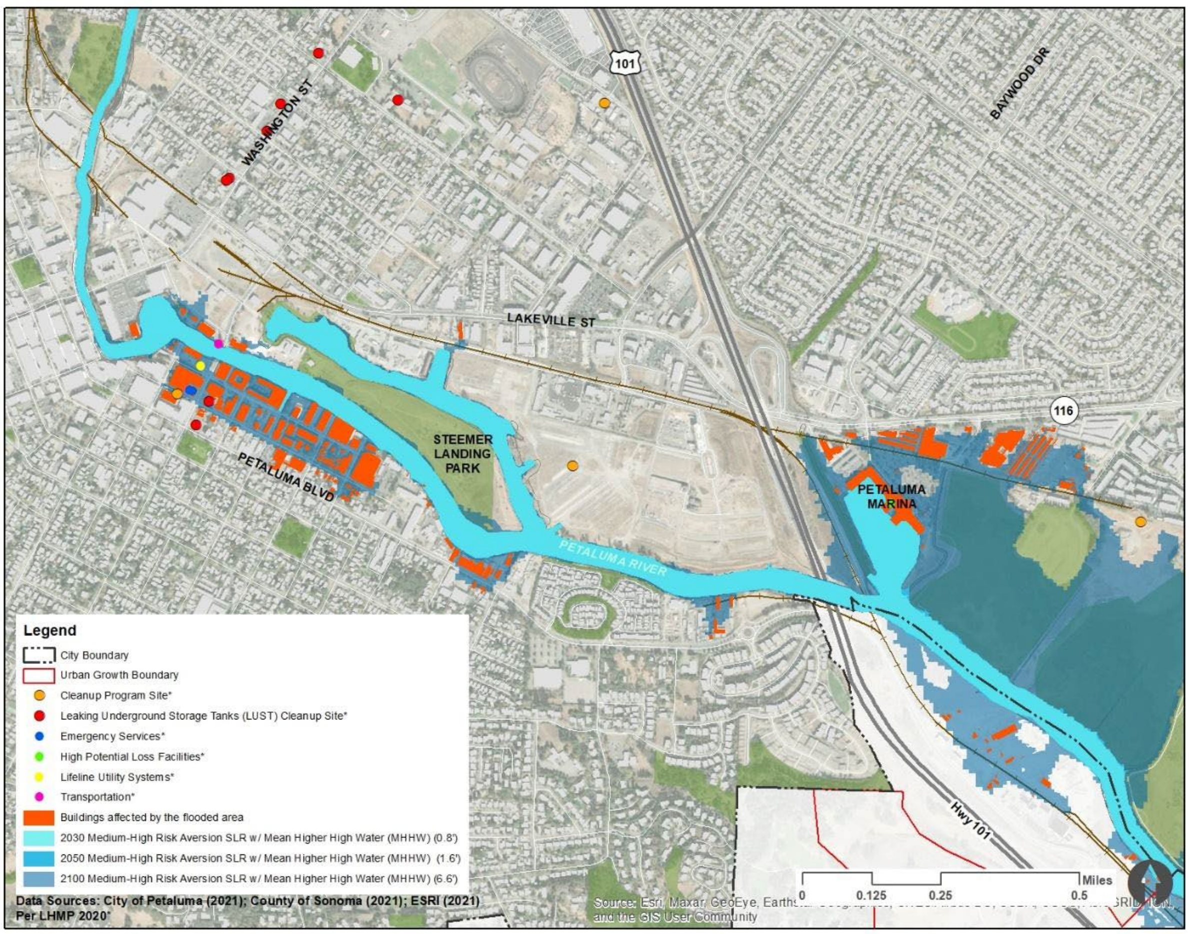
The SLR elevations used in this white paper to approximate the medium-high risk aversion projections match the SLR elevations assessed by the LHMP. In the following maps, the three colors of blue indicate the maximum reach of flood waters each year's prediction. These are areas that will experience standing water for at least a few minutes or longer. There is a 0.5% probability that by 2100 the areas under the lightest blue will experience flooding at MHHW, or the average daily highest tide. A king tide event, which occurs 1-2 times per year on average, would increase this flood elevation up to 12 to 24 inches. Orange denotes affected buildings, but does not detail the significance of the impact, as buildings may have raised floor elevations.

Figure 13 below shows affected buildings in the medium-high risk aversion scenario for 2100 at MHHW. This corresponds to 6.6’ of SLR, which approximates the 2018 State Guidance medium-high risk aversion projection of 6.9’ of SLR by 2100. According to the LHMP, emergency services, high potential loss facilities, lifeline utility systems, and a transportation system would be at flood risk. These include the following five critical facilities:

- Petaluma Fire Department Station 1 (headquarters)
- Petaluma Fire Emergency Medical Services Station
- D Street Bridge House
- Petaluma Station C (Electrical)
- Petaluma Marina

The LHMP also predicts that 32 commercial buildings, 17 multifamily structures, and 228 residential buildings would be affected. Estimated impacts were valued at $195 million with 155 members of the population at risk. These predictions are based on 2020 development density and property values. Three Hazardous Material sites are also indicated to be affected by flooding.

**Figure 13. Zoomed View of Medium-High Risk Aversion SLR Scenarios w/ MHHW**




The following map shown by Figure 14 shows impacts from the medium-high risk aversion SLR scenarios, with an additional 100-year storm surge. Significantly more structures are affected. By 2100, the LHMP estimated that 138 commercial, 17 multifamily, and 228 residential structures would be affected. It estimated the value of the impacts at $588 million, with 657 members of the population put at risk. These predictions are based on 2020 development density and property values. Sections of Highway 116 toward the unincorporated community of Lakeville are also indicated by the flood map to be affected. Values from the LHMP do not consider that the same storm surge may also be inducing creek and river flooding upstream of the areas shown in the image.

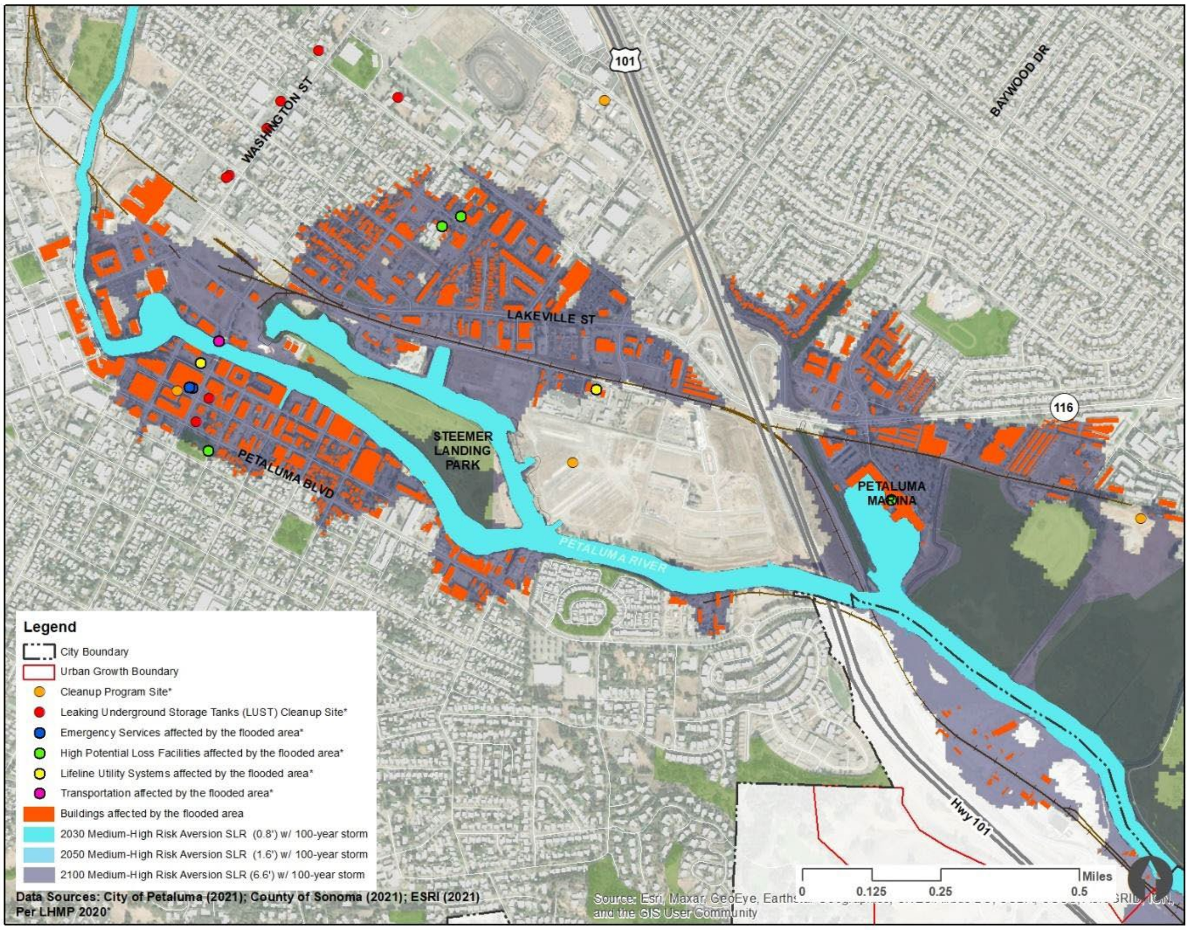
In addition to the facilities previously listed as flooded due to 6.6' of SLR at MHHW, additional critical facilities are expected to become flooded when a 100-year storm surge is added onto the base 6.6' of SLR. The critical facilities which encompass high potential loss facilities and lifeline utility systems, include:

- San Antonio High School
- Valley Oaks Elementary School and High School
- Parks and Recreation Maintenance Building
- Hopper Street Primary Influent Pump Station (PIPS) and PW&U Corporation Yard
    - The PIPS is critical for pumping wastewater to the Ellis Creek Facility, and additionally this site houses the Mary Isaak Homeless Shelter Clinic (COTS)
- Ellis Creek Water Recycling Facility
    - The outfall and hydraulic profile of the plant are susceptible to flooding, and require facility improvements to become resilient to SLR

These impact summaries do not consider the human impact of flood impacts. With many roads, bus lines, and the SMART rail station affected, transportation will be hindered. Damages and disruptions are disproportionately focused on communities which sit along waterways or in low lying areas. A review of current and planned land uses, and projects should be undertaken to ensure that disadvantaged communities are not at particularly risk from future flooding. This includes building standards in flood prone areas that protect property and livelihood, and zoning modifications to ensure that low income and affordable developments are not focused in the floodplain.

These predictions do not factor in stormwater runoff flooding downriver from the 100-year storm, future development which might place more critical infrastructure in the flooded areas, or adaptation measures which may protect structure from flood waters. The impact of an additional king tide, which is guaranteed to occur at least once a year and can add up to 12 to 24 inches of surface water elevation, is also not considered in these impacts.

**Figure 14. Zoomed View of Medium-High Risk Aversion SLR Scenarios w/ 100-Year Storm Surge**




Despite the risk flooding presents due to rainfall and SLR, ecological areas that are historically in the floodplain often benefit from periodic flooding as a naturally occurring event. The LHMP remarks that these areas can reduce flood impacts by allowing absorption and infiltration of floodwaters.[27] SLR flooding represents a permanent increase in water elevation, unlike rainfall flooding. Hence, implementation of adaptation strategies is a must.

Due to Non-Progressive Storm Surge Flooding, the 20 year storm surge actually induces greater flooding in the city, as shown below in figure 15. THE LHMP did not quantify the impacts from this increased flood area. Most importantly with the 20 year storm surge is the fact that it is 5 times more likely to occur in any given year than the 100 year storm, and therefore has a higher likelihood of occurring at the same time as a King Tide, which would further increase flood impacts in this "Worst Case" scenario which cannot be reliably mapped with the existing modelling.

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27 *Wood Environment & Infrastructure Solutions, Inc. "City of Petaluma Local Hazard Mitigation Plan." City of Petaluma, Nov. 2020, page 4-113, https://cityofpetaluma.org/documents/lhmp/.*

**Figure 15. Zoomed View of Medium-High Risk Aversion SLR Scenarios w/ 20-Year Storm Surge**

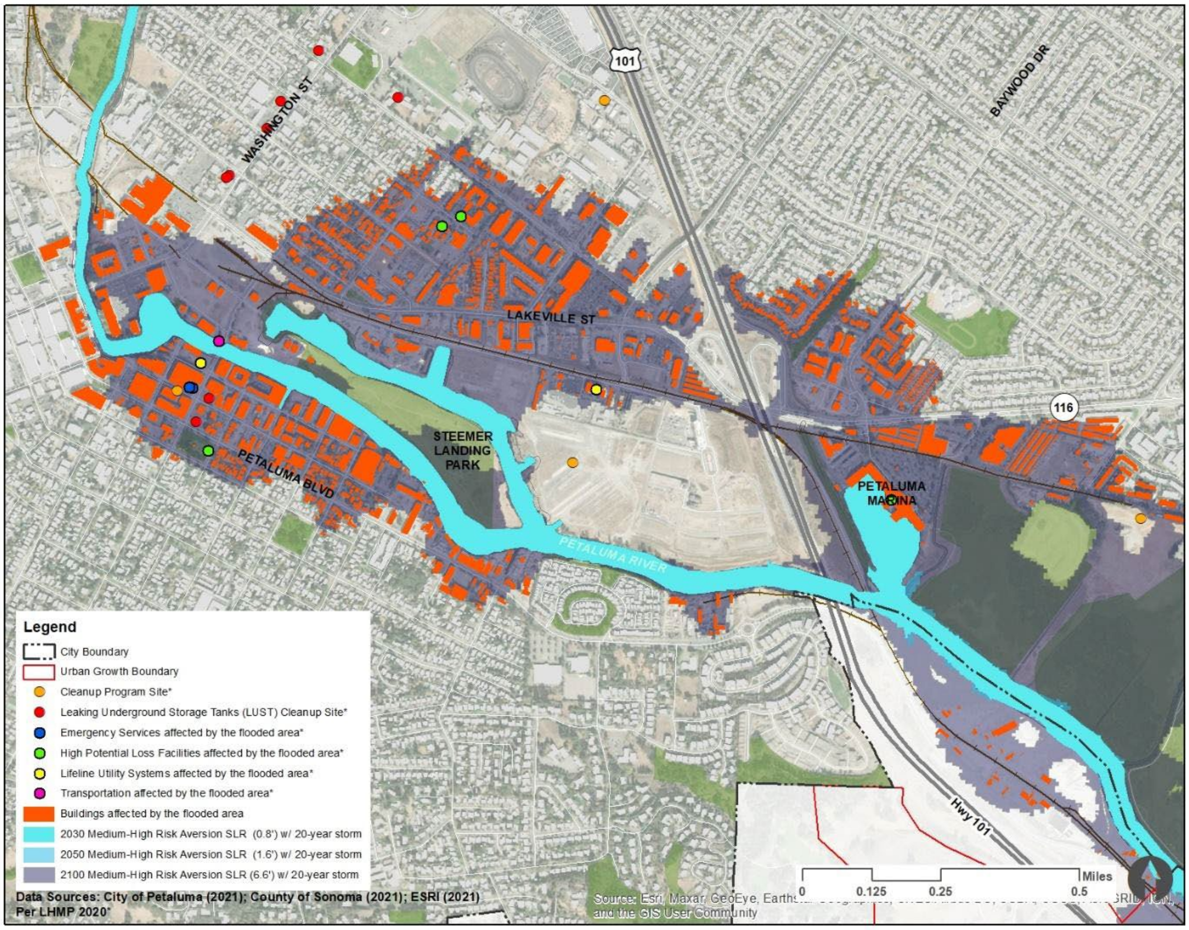
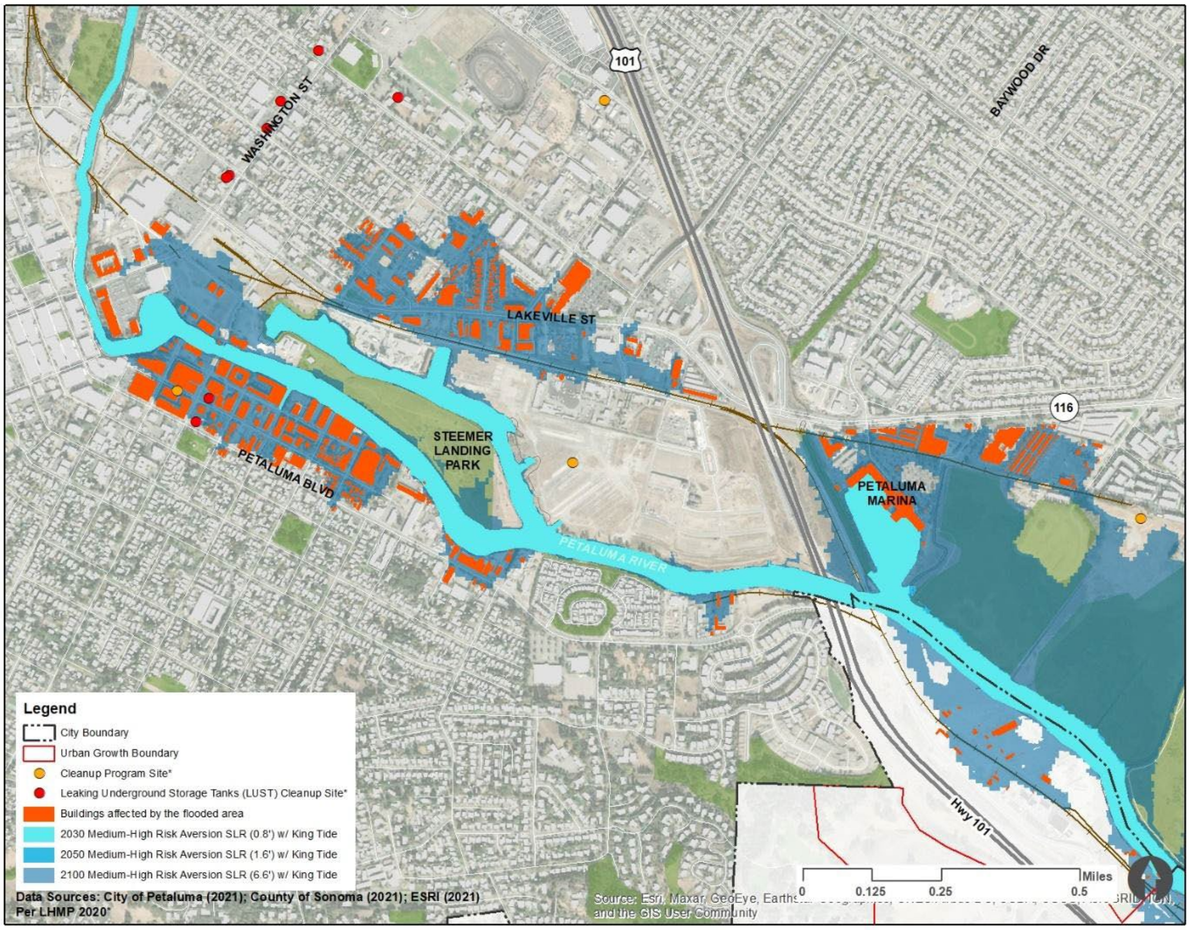



Figure 16 below shows the impact of a King tide during the Medium-High Risk Aversion scenarios. While these SLR scenarios only have a 0.5% likelihood to occur by the indicated date, it is worth showing how severe the impacts are simply from a King Tide (no additional Storm Surge as shown above in Figure 15), which will happen at least once every year.

**Figure 16. Zoomed View of Medium-High Risk Aversion King Tide**




# Considerations for Interventions

This report has identified a critical data gap around the lack of coordinated and comprehensive information informing flood mapping based on a variety of conditions. A holistic model for flood risk that incorporates climate change considerations is therefore the most critical and urgent planning tool necessary for resiliency. The Cities current endeavor to update the River Flooding models will improve Rainfall Flood Maps but is not yet scoped to integrate climate change predictions of Increased Rainfall, Storm Surge and Sea Level Rise. In parallel and following the development of a comprehensive model, various interventions and actions will pave the way for a resilient and adaptable Petaluma.

Adaptation strategies, adaptation measures, and other similar terms all refer to ways to address the risks posed by current and future hazards. Sea level rise and flooding present risks today that are predicted to increase in severity in the future. Adaptation allows communities to prepare for and mitigate these risks. To produce effective adaptation planning against sea level rise and flooding, a community identifies relevant legal regulations, community and stakeholder goals, funding sources, and other factors that must be considered. This section summarizes both ongoing and recently completed projects and additional adaptation measures for Petaluma.

Table 4 summarizes potential adaptation strategies the City of Petaluma may adopt to pursue adaptation to the hazards posed by sea level rise and flooding. Adaption actions are categorized by whether they are primarily achievable or provide benefits in a short- and long-term timeframe, whether they are based on grey infrastructure (conventional infrastructure that works to manage and control nature with minimal concern for ecosystem provisioning, such as dams and seawalls) or nature-based infrastructure (design solutions utilizing and mimicking ecological processes that evolve over time, such as bioswales and enhanced riparian corridors), and whether they pertain to other aspects of action, such as funding measures, policy updates, and community involvement.

**Table 4. Potential Adaptation Strategies against SLR and Flooding**

| Adaptation Strategy | Applicable Classification | | | | |
|---|---|---|---|---|---|
| | Short-Term Target | Long-Term Target | Grey Infrastructure | Nature-based Infrastructure | Other |
| Baylands restoration | | ✓ | | ✓ | |
| Carbon reduction & sequestration | | ✓ | | ✓ | |
| Climate advocacy | ✓ | | | | ✓ |
| Coordinating strategies & tactics across policy documents | ✓ | | | | ✓ |
| Elevated & Retrofitted Development | | ✓ | ✓ | | |
| Floodplain development setbacks & restrictions | ✓ | | | | ✓ |
| Hard walls & armoring | ✓ | | ✓ | | |
| Horizontal ecotone levee systems | | ✓ | | ✓ | |

| | | | | | |
|---|---|---|---|---|---|
| Improved Hydrology modelling | ✓ | | | | ✓ |
| Migration space preparation for tidal marshes | ✓ | ✓ | | ✓ | |
| Polder management | | ✓ | | ✓ | |
| Protection of at-risk utilities | | ✓ | ✓ | | |
| Reduction of impervious surfaces | ✓ | ✓ | ✓ | | |
| Upland retention & infiltration | ✓ | ✓ | | ✓ | |
| Vulnerability assessment | ✓ | | | | ✓ |
| Zoning & land -use updates | | ✓ | | | ✓ |

# Ongoing & Completed Projects: Ecological Quality Enhancement

A series of ecological quality enhancement strategies and programs have been either implemented or are in the process of being implemented in Petaluma. Components of ecological quality involve actions relating to habitat and biodiversity, including consideration of estuary, marshland, river, and creek habitats, water quality, ecological and hydrological connectivity, and historical functioning.

## Baylands Projects

Spearheaded locally by the Sonoma Land Trust and Sonoma Resource Conservation District (RCD), marsh restoration projects continue to progress in the Petaluma Baylands, for the most part outside of the city limits. These projects include marsh nourishment using dredging sediment, moving levees back from the river channel to convert existing farmland into storm surge mitigating tidal marshes as well as levee maintenance to protect existing uses. Marsh restoration can provide protection from storm surges and tidal effects while restoring destroyed habitats and sequestering carbon. Activities within the current and former marshlands within the city limits could use similar strategies. This is particularly important as the rate of sea levels rise, and existing levees and barriers may prevent existing marshes from naturally migrating upland with rising water levels. Additionally, the Sonoma RCD helps landowners navigate the regulatory hurdles by administering joint permits for levee maintenance.

## Petaluma Marsh Expansion Project

The Petaluma Marsh Expansion Project[28] was a project to restore 108 acres of diked farmland. This project occurred outside of the City of Petaluma, directly on the Marin bank of San Antonio Creek which marks the Marin-Sonoma County line. In addition to ecosystem restoration work, the project involved the lowering of the creekside levee to MHHW and raising a levee inland to protect the neighboring SMART rail track. This is an example of a sea level rise mitigation project using marsh restoration to intercept wave and storm energy. By moving the existing levee away from the creek, the channel is allowed to reconnect to its floodplain providing more space for energy dissipation and more natural and less damaging flow conveyance. Additionally, the levee does not need to reach the same height above sea level to provide equal flood protection.

## River Dredging

Historically the Petaluma River was dredged on a regular maintenance cycle of every 4-7 years prior to 2003 by the U.S. Army Corps of Engineers. There have been significant gaps in recent history of maintenance dredging of the navigable channel and Turning Basin, severely limiting the conveyance of flow. The last such dredging occurred in the fall of 2020, the first dredging since 2003, from the City of Petaluma Turning Basin to San Pablo Bay and restored the main channel of the Petaluma River to 8 foot depth. [29] Dredging allows for a larger conveyance flow section and subsequently lets the river accommodate larger boats and provides more space for larger flood flows. In City of Petaluma, spoils are deposited on Shollenberger Park and from there can be removed to other beneficial reuse sites south of Petaluma to the San Pablo Bay. USACE provided a 9.7 million dollar funding for this project, and mechanical dredging of the Marina is planned for 2022.

# Ongoing & Completed Projects: Flood and Storm Mitigation

## Sonoma RCD

The Sonoma Resource Conservation District (RCD) is involved in many projects implementing flood control, channel maintenance, and revegetation projects on Adobe, Lichau, Capri, and Lynch creeks and the Denman and Corona reaches along the Petaluma River. As a part of the Petaluma River Watershed Collaborative, they are organizing the development of a revised version of the Draft Petaluma Watershed Enhancement Plan and an Action Plan. The City of Petaluma staff representatives to the Watershed Collaborative are submitting projects within the city limits for consideration.

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[28] *Siegal Environmental LLC. "Year 10 (2016) Monitoring Report: Petaluma Marsh Expansion Project." Marin Audubon Society, 20 Nov. 2017, https://www.marinaudubon.org/pdf/Year-10-MonReport_final_PMEP_2017-1120.pdf.*

[29] *"River Dredging Schedule & Info." City of Petaluma, 2020, https://cityofpetaluma.org/riverdredging/.*

## Flood Control Zone 2A Advisory Committee Recommendations

On March 25, 2021, the Flood Control Zone 2A Advisory Committee recommended the design and implementation of a project which would provide flood control benefits to Petaluma. The project includes installing a stormwater retention basin planned to control flows which exceed the capacity of Copeland creek, which would reduce the peak flow of water through Penngrove (upstream of Petaluma) by 9% in the 100-year storm. A Second project is still being developed, which would add detention basins along Lichau creek near downtown Penngrove to reduce urban flooding.

## Petaluma Flood Control Manual

The Petaluma Floodplain Management Plan calls for the utilization of flood terraces adjacent to the riparian corridors. These terraces provide the opportunity for sediment and pollutants, including trash, to settle out of the flowing water and facilitate easy pick-up and disposal following the storm events. The Floodplain Management Plan also calls for bank repairs, channel re-contours, and installation of a sediment capture feature to increase the stability of project reach channels and reduce sedimentation to the Petaluma River and tributaries. These flood terraces reconnect the flow channel to the historic floodplain reducing depth of out-of-bank flows, and, where possible, allow:

- Daylighting of channelized closed-piped storm flows to a natural channel.
- Augmentation of the river corridor floodplain to capture and transport additional surface flows.
- Decrease and delay of peak discharges of storm flows, allowing ponding and recharge through pervious soils within the flood terraces, provides recharge benefits for shallow aquifers.
- Groundwater benefits from infiltration of water from ponding and terracing improvements that reduce the volume and velocity of downstream runoff (RCD Watershed Enhancement Plan).

## Payran Reach USACE Flood Control Project

After repetitive flooding along the Payran Reach of the Petaluma River, the FEMA Hazard Mitigation Grant Program provided $2.9 million in addition to $32 million of City funds and $5 million of USACE funding to complete a multi-part mitigation project to protect against flooding during the 100-year flood event. Completed in 2004, this included modifications to several bridges, a weir, storm drain modifications, a new pump station, 3,300 feet of floodwall, as well as over 10 acres of riverbank planting. The 2008 FEMA Loss Avoidance Study estimates that $44 million in flooding impacts were saved.

## Denman Reach Flood Adaptations

The Denman Reach flood adaptations near the northwest section of the Petaluma River include 4 phases, initiated in 2005 and completed in 2020.[30] With DWR funds, the initial 3 phases included vacant parcel acquisition, trail easements, extending a flood terrace, bank widening and riparian plantings.[31] [32]

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[30] *"Project: Petaluma River Flood Management and Enhancement Project." California Natural Resources Agency, 2020,* http://bondaccountability.resources.ca.gov/Project.aspx?ProjectPK=10700&PropositionPK=5.

[31] *"Denman Reach Phase 4." City of Petaluma, 3 Jan 2020,* https://cityofpetaluma.org/denman-reach-phase-4/.

[32] *Wood Environment & Infrastructure Solutions, Inc. "City of Petaluma Local Hazard Mitigation Plan." City of Petaluma, Nov. 2020, page 5-27,* https://cityofpetaluma.org/documents/lhmp/.

The recently completed Phase 4 project includes: (1) Acquiring the last undeveloped parcel on Industrial Avenue on the river side, 5.47 acres purchased in 2018); (2) Developing a multi-use trail; (3) Creating two flood detention basins; (4) Developing mitigation wetlands and riparian habitat; and (5) Removing sediment buildup in the Petaluma River stream channel at the Corona Road Bridge while reducing further erosion.

# Multi-Functional Adaptation Strategies

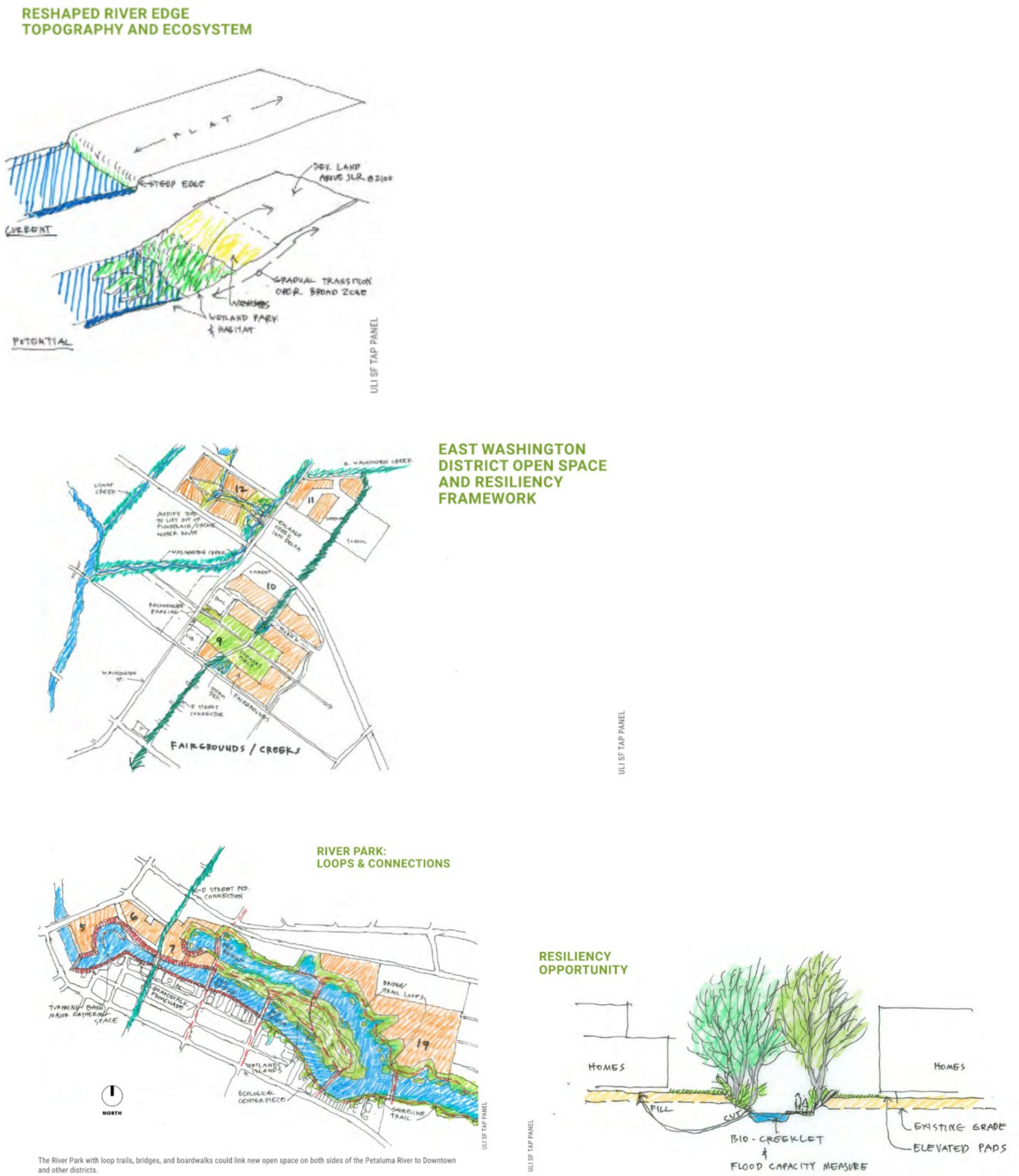
Climate change considerations of sea level rise and flooding permeate many aspects of policies and implementation strategies. These include relevant impacts spanning various disciplines including transportation infrastructure, housing, economic development, and environmental considerations. The use of both human engineered "grey" infrastructure and nature-based "green" and "blue-green" infrastructure solutions plays a key role in developing mitigation and adaptation strategies. Identifying potential structural implementations and options for managed retreat alongside policy decision making, community integration, and connectivity to existing and ongoing planning and capital improvement endeavors set the stage for developing meaningful, site-specific strategies that will serve Petaluma now and in the future. Various adaptation measures exist, and no one measure is a stand-alone solution for every scenario, driving the need for holistic and comprehensive strategies and recommendations.

**Figure 17. Resilient Adaptation Measures for Consideration**


***Source: Sherwood Design Engineers, 2021***

Implementations considered to address elements of climate change due to sea level rise and flooding throughout the General Plan process should prioritize and target strategies that provide multi-benefit solutions and respond to ecological, social, and economic prosperity. For example, flood mitigation enhancements in the downtown area around the Turning Basin, Steamer Landing Park, and McNear Channel are a unique opportunity for improving public access to the river while creating ecosystem habitat and benefits, in a location that will experience significant impacts from sea level rise. Recommendations from the ULI TAP Report highlight site specific strategies that promote increased stormwater functioning while also enhancing public amenities. Potential opportunities include restoration of river-edge topography and new open space through recovery of the original tidal estuary; creation of a blue-green mobility network to daylight river sections, cultivate new riparian vegetation and create above ground stormwater storage via enhanced wetlands; a river park with looped trails, bridges and boardwalks to connect east and west; and strategic stormwater capacity and conveyance strategies, such as bio-creeklets, utilizing existing and proposed open space.

## Figure 18. TAP Recommendations for Blue-Green Infrastructure




*Source: ULI San Francisco, City of Petaluma Technical Assistance Panel Report, 2020*

# Realigning Assets to Mimic Historical Hydrology Patterns

The historical ecology and hydrology of Petaluma managed natural tidal influences and flooding through wetlands, riparian habitats, and tidal marshes. The potential restoration, reestablishment, and reintegration of these key ecological and hydrological assets across Petaluma and its broader regional watershed presents opportunities for habitat provisioning as well as ecosystem functioning for stormwater management, carbon sequestration, and connectivity. Specific nature-based adaptations within the City of Petaluma as presented in the SF Bay Shoreline Adaptation Atlas include tidal marshes migration space preparation. Horizontal ecotone levee systems and polder management are also listed as potential adaptations suitable for nearby areas outside the city limits. Land uses that allow for development to be flooded such as parks and open space should also be considered alongside natural assets.[33]

The LHMP explores opportunities for natural protection with wetland enhancement, marshland protection, and restoration project implementation in the Petaluma River and San Pablo Bay transition zone, in addition to open space preservation in areas prone to sea level rise along the Petaluma River. Considerations for these endeavors include land use decision making and prioritization of restoration areas based on available opportunities and recognized vulnerabilities.

The *Upper Petaluma River Watershed Flood Control Project Scoping Study 2012* contains multiple maps that locate the feasibility of different watershed restoration strategies which provide flood risk mitigation to the city. This study represents a watershed-wide approach to restoration and protection. In recognizing the important link between regional and local opportunities, the city coordinates with Zone 2A and Sonoma Water on watershed restoration initiatives. Many opportunity sites for watershed restoration that would protect the city exist inside city limits, as shown below in Figure 12. Many of these strategies, such as restoring historical freshwater and riparian wetlands by managed drainage would not only represent cost effective and low carbon flood control infrastructure but may also have a myriad of side benefits from groundwater recharge, endangered species habitat restoration and carbon sequestration. Many of these green infrastructure techniques can also integrate well into open space, parks, and regenerative agricultural practices.

[33] *Beagle, J, et al. "San Francisco Bay Shoreline Adaptation Atlas: Working with Nature to Plan for Sea Level Rise Using Operational Landscape Units." SFEI & SPUR, 2019, page 128, https://www.sfei.org/sites/default/files/biblio_files/SFEI%20SF%20Bay%20Shoreline%20Adaptation%20Atlas%20April%202019_lowres_0.pdf.*

## Figure 19. Potential Opportunities to Restore a Range of Wetland and Riparian Habitat Types

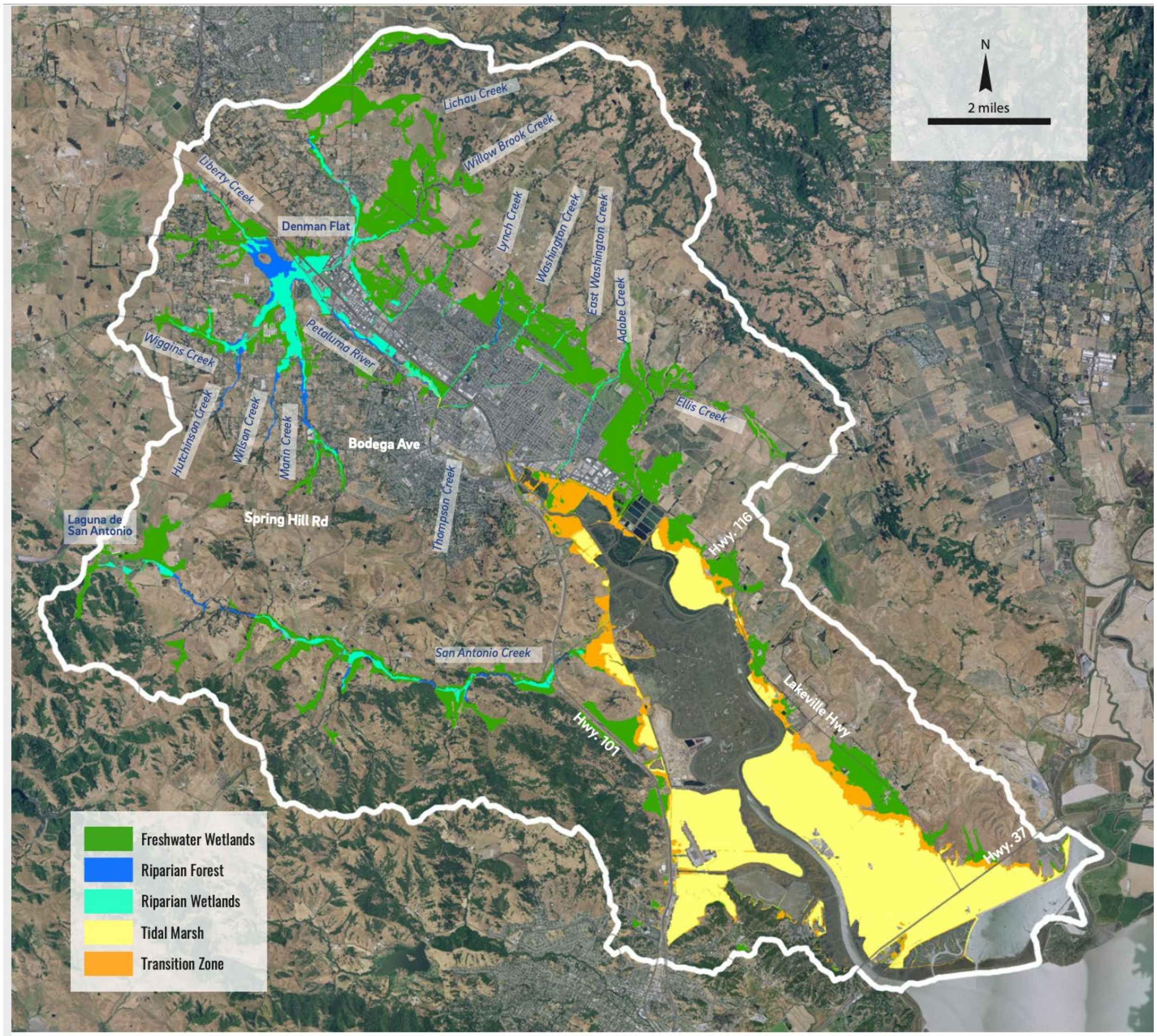



**Figure 7.2. Potential opportunities to restore a range of wetland and riparian habitat types,** including tidal marsh (yellow), tidal-terrestrial transition zones (orange), freshwater wetlands (green), riparian forests (blue), and riparian wetlands (teal), exist on relatively undeveloped lands throughout the watershed (including lands currently in agricultural use). These potential restoration opportunity areas meet basic physical criteria necessary to support various types of wetland habitats, such as poorly drained soils, periodic flooding, and/or elevations within or near the tidal range. Further analysis, taking into account landowner interest and a range of other physical characteristics, will be needed to determine the feasibility and priority of restoration for particular sites. *(NAIP 2016)*

*Source: Petaluma Valley Historical Hydrology and Ecology Study, 2018*

## Adaptation of Elevation and Slopes

Potential solutions utilizing topography to manage flood elevations include the reconstruction of land to create barriers to structural assets, the reconstruction of roadways and other critical infrastructure to higher elevations than projected inundation areas, and the adoption of elevated development. Soft armoring in this context may include marsh restoration, and protection in place may include the elevation of buildings, roads, and grades.

Similarly, dredging is among these options. The Petaluma River Dredging Program for enhanced flood resilience is a strategy that has been recommended for scheduled continuation. Prior to 2003, the river was dredged every four years with funding and management direction from the USACE but was not dredged afterward for 17 years. Since the completion of the 2020 dredging, the City of Petaluma is pursuing Measure AA funding and 10-year maintenance dredging permits to support future dredging efforts. The city is also investigating the beneficial reuse of dredging spoils for adaptation projects in the Bay Area that require sediment, such as Petaluma Marsh resiliency enhancement projects and other projects that help protect vulnerable locations along the Petaluma River. Restoration of the historical floodplain by modifying built-up banks would provide more flood capacity while restoring tidal wetland habitat.[34]

## Additional Green Infrastructure Adaptation Solutions

Horizontal ecotone levee systems involve a levee, wetland, and upland slope that offer multi-benefits to address wave attenuation and impacts from storm surge inundation. This minimizes scouring and erosion and provides gently sloped areas of habitat and marshland migration zones between the wetland and upland transition areas. These living systems adapt to changes in sea level rise by growing to meet new elevations and expanding natural assets. In coordination with natural lands provisioning for new or expanded wetlands, living shorelines, and enhanced naturalized shoreline protection create opportunities to protect today while adapting to future resilience considerations through a lens of layered protection strategies.

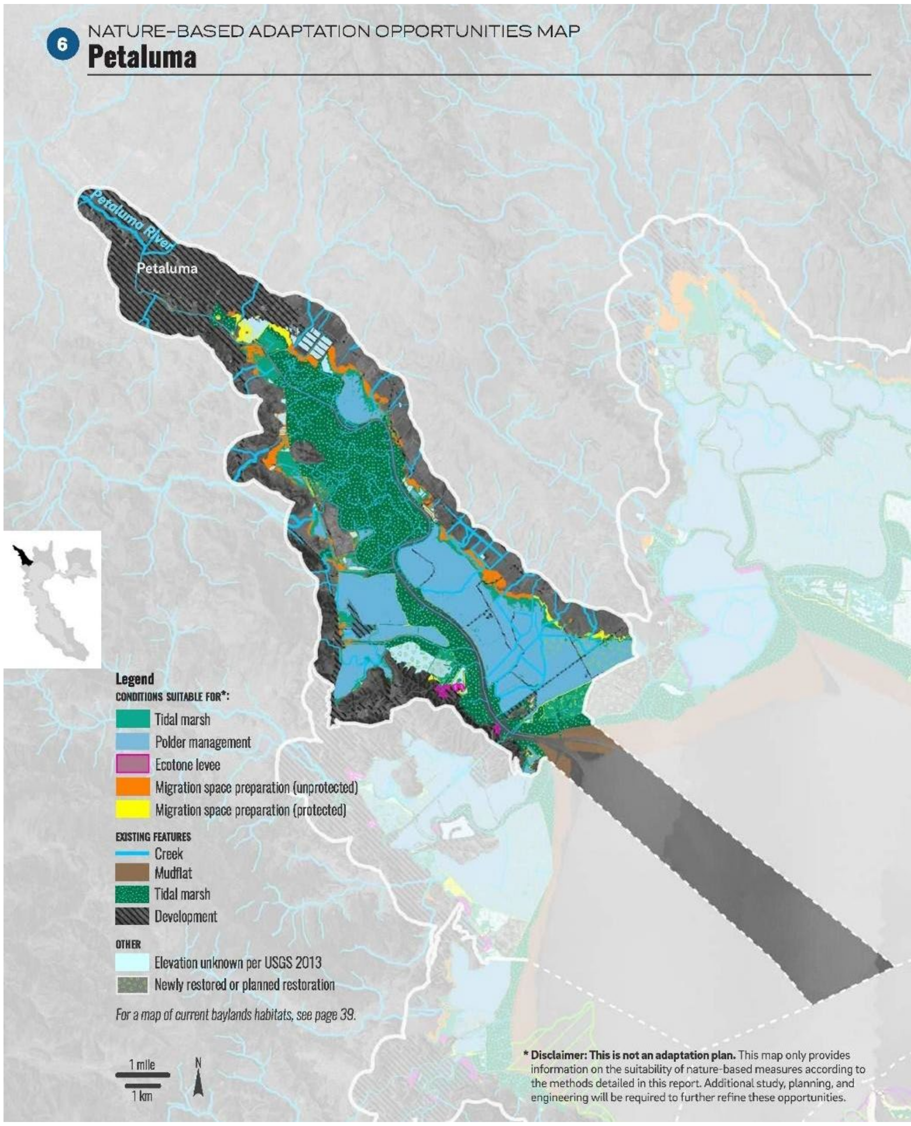
The SF Bay Adaptation Atlas, which analyzes areas across the entire Bay Area, does not recognize any areas within the City of Petaluma as suitable for the development of horizontal levees. Further investigation by the city would allow a more detailed assessment of horizontal levee viability in open space areas adjacent to the Petaluma River and adjoining creeks.

## Migration Space Preparation

Migration space preparation reserves open space around marshlands to allow the natural uphill migration of marshes as rising sea levels transform low-lying marshes into mudflats and other related tidal habitats. This also creates open space habitats valuable for their ecological benefit. The SF Bay Adaptation Atlas identifies open space areas near the marshes east of the Petaluma Marina as viable for migration space preparation. Most of these identified areas are already classified as protected for open space purposes according to the Adaptation Atlas, which sources data from the California Protected Areas Database (CPAD).

[34] *"River Dredging Schedule & Info." City of Petaluma, 2020, https://cityofpetaluma.org/riverdredging/.*

**Figure 20. Petaluma Nature Based Adaptation Opportunities**




***Source: SFEI and SPUR San Francisco Bay Shoreline Adaptation Atlas, April 2019. Page 128.***

## Grey Infrastructure Adaptation Solutions and In-Place Protection

In certain instances, traditional "grey" infrastructure may be necessary to deter inundation and mitigate impacts from flooding and sea level rise, especially in areas that do not provide the opportunity for more natural adaptation strategies. Possible considerations include barrier and tidal barrage, tidal gates, pump stations, seawalls and raised bulkheads. Development strategies may also include managed retreat and adaptation of land uses as well as floating structures. The edge of the Petaluma River bordering the Downtown Petaluma area does not have large areas of open space. Nevertheless, the city should investigate possibilities to use nature-based infrastructure to the maximum extent, or a combination of green-grey infrastructure wherever viable.

## Non-Structural Strategies

In tandem with physical implementation strategies, non-structural adaptation measures that include policy and regulatory acts, assessment and planning initiatives, and financial mechanisms are key to a successful adaption and resilience plan. Appropriate community engagement, education, and collaboration between government, local citizenry and supporting partners all play an important role in these efforts. The successful management and implementation of adaptation strategies is rooted in the potential for considered and chosen strategies to reflect diverse considerations and ensure equitable protection and opportunities for prosperity across communities. Comprehensive consideration of all parties involved will ensure that residents and business owners, as well as government leaders, are apprised of the latest science, best practices, and available opportunities for the development and funding of holistic solutions to address sea level rise and flooding.

Petaluma has already made significant efforts toward documenting the risks from flooding and SLR, particularly in the 2020 LHMP. This report lists recommended hazard mitigation actions to help Petaluma reduce hazard-related losses including:

- Explore natural protection with wetland enhancement, marshland protection, and restoration project implementation in the Petaluma River and San Pablo Bay transition zone.
- Continue Petaluma River Dredging Program to enhance flood resilience.
- Open space preservation in areas prone to sea level rise along the Petaluma River.
- Map and assess vulnerability to sea level rise and integrate the information with the City GIS mapping capabilities to educate the community and help them gain awareness of the potential impacts and actions the city is taking to plan and adapt.
- Assess sea level rise modelling and how current and best available projections can be routinely re-evaluated in subsequent climate adaptation planning efforts.
- Updates to City Implementing Zoning Ordinance (IZO) to manage development in high-risk areas.

# Considerations for Strategic Incorporation into General Plan Policies and Programs

## Alignment of Strategies to Planning Efforts

### Coordination and Collaboration

The integration of actions and strategies across multiple planning initiatives is imperative to ensure that solutions are recognized from various lenses of the General Plan and that pathways exist to foster alignment between various planning efforts. The compilation of previous plans, reports and strategies summarized in this document highlight the many occurrences of climate change considerations within City and County regulatory and informing documentation. As with all coordinated efforts, plans, policies, programs, and strategic actions should be developed in coordination across various entities, scales and timelines. Overarching considerations for planning level policies and regulations should support a wide range of potential solutions while maintaining the vision and goals of how Petaluma must interact with and adapt to climate change. The implementation of similar strategies, both proposed and implemented, can therefore build off one another, creating opportunities for connected interventions, scaled funding opportunities, and the integration of lessons learned. In development of the General Plan, multiple elements must ensure collaboration to address key considerations. Most notably the Safety Element, Sustainability Element, Housing Element, and strategies and regulations for SLR and flooding will greatly impact land use alternatives and decision making. Additionally, the General Plan Update strategies should provide streamlining for the CEQA process, including monitoring of adopted targets to allow for a clearer picture on what strategies to improve, advance, or discontinue to successfully move forward towards a resilient and highly adaptable City of Petaluma.

## General Plan Update

The sections of the General Plan which pertain to flood and watershed management should be reviewed and updated to reflect recent city and community efforts in Local Hazard analysis, updated FEMA flood maps and other hydrologic models combined with up to date SLR scenarios, and resilience in the face of the newest climate change predictions. Provisions of the General Plan may require updating to be in alignment with the evolving goals of the City and its communities. Concerted analysis should be given to analyzing previous developments since the last General Plan Update to confirm that existing planning and permitting adequately promotes the goals set forth in the General Plan. We recommend developing a regional flood control and resilience collaboration with the RCPA, ARCA, or other county or region wide entity, to integrate diverse input into assuring that the General Plan moves the City forward towards its flood and watershed management goals. This may be set up as a short-term action item under the GP and CAAP and extend further beyond the GP process. Existing TACs include the Climate Action Commission (CAC) and the General Plan Advisory Commission (GPAC). It is recommended to work with the guidance of technical county stakeholders, including Zone 2A as an existing watershed technical stakeholder and advisor, on an ad-hoc basis, as well as have the CAC in its advisory capacity inform plan development, and utilize the GPAC to support advisory on overall alignment with the GPU. This group should include input from county as well as local stakeholders, since much of the available land for flood prevention projects are located outside city limits. Special focus should be placed on identification and preservation of properties along waterways which provide the now limited opportunities to mitigate and adapt to flood risks from SLR, Rain Events and Storm Surge.

Specifically, the 2015 Flood Management Plan was guided by a Technical Advisory Committee which advanced recommendations for floodplain management. These recommendations should be confirmed to be active components of the General Plan and Zoning Ordinances, and include:

- Keeping floodplains open, acquiring more open space
- 2’ flood freeboard, beyond the 1’ described in GP 8-p-37f
- Net zero fill on all development in the floodplain
- Enhance resources in urban growth boundary GP 4-p-1 to 4-p-4
- Complete “Petaluma River floodway acquisition” Phase III and other CIP

## Public Outreach and Engagement

Current and potential climate change impacts due to SLR and flooding must be appropriately conveyed to community members so that holistic decision making encompasses a variety of voices and values. Effective community engagement, education and advocacy are key drivers encouraging active participation in the development of policies and planning for adaptation and resilience measures. The development of and access to knowledge platforms and participation opportunities is paramount to the success of the General Plan and can be supported by a series of workshops and educational forums. In addition, alignment with equity and inclusivity targets identified in the Climate Emergency Framework and initial General Plan update outreach throughout resilience planning and mitigation efforts are a clear opportunity to achieve climate justice and environmental justice goals.

## Equity and Environmental Justice

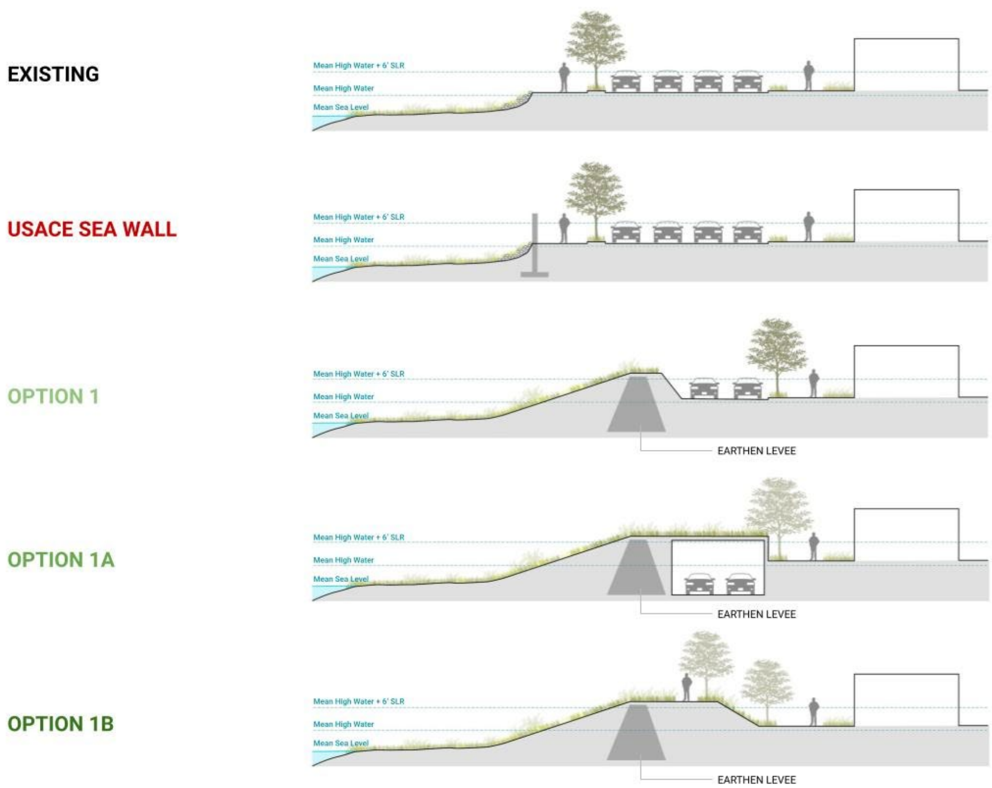
Sea level rise and flooding should play a major consideration in the design and city development. The LHMP performed a significant analysis of the impacts from FEMA Floods and up to date SLR scenarios on buildings and critical infrastructure but appears to have missed critical elements of the city, such as the Transit center/SMART rail station, and a homeless shelter, both apparently located in the SLR flood risk area. Future vulnerability assessments and LHMPs, as well as planning activities undertaken in conjunction with and subsequent to the General Plan Update should be expanded to include these features, as well as an analysis of what communities will receive the brunt of future flooding. This could include an overlay of flood scenarios on median household income, demographics, and SB 335 Disadvantaged Communities Mapping. Existing zoning should be evaluated to confirm that permitted uses in flood risk properties are not skewed development towards peoples and uses which will exacerbate social justice issues in the city.

# Embedding Opportunities for Adaptation and Resilience

Future plans and policies should continue to follow the best available science, data, and modelling, calling on the City and its partners to stay current on data and monitor current studies and efforts across the region. The SLR and flooding scenarios reviewed in this document should inform relevant planning initiatives, ensuring that the appropriate scenarios and modelling tools are reflected to the appropriate degree for various utilizations. These planning considerations involve the development and adaptation of critical infrastructure, integration into ecological regeneration initiatives, and alignment to housing and economic development especially as related to environmental justice. The considerations for future modelling, planning and management efforts to work towards inclusion of comprehensive scenario planning will further allow the best scientific rigor to be integrated into these efforts. However, while these complex initiatives may be slow to thoroughly integrate, present day solutions must proactively address measures and adaptations necessary to meet future challenges.

The development of layered and integrated solutions that can be implemented over time, and the alignment of phased implementations to capital improvements and development initiatives are paramount to this success. In some cases, capital improvements can align to stages of a long-term project, co-allocating infrastructure and construction costs. Where future solutions may exist but are not within immediate reach due to lack of funding, alternative systems being in place, or limited stakeholder support, presenting infrastructure adaptation strategies as phased options creates opportunities to build resilient solutions over time. Investments in fixed infrastructure often carry a long-term locked-in-place result, an especially important consideration for the transition of infrastructure and preservation of natural spaces. Figure 21, Layered and Multi-Phased Solutions, presents an example of potential alternative strategies to a hard infrastructure option addressing impacts from SLR and storm surge by removing traffic lanes over time to create a buffered coastal natural protective edge and enhanced pedestrian amenity.

**Figure 21. Layered and Multi-Phased Solutions**




***Source: Sherwood Design Engineers, 2021***

Both the level of risk aversion and the length of functional life for repairs, retrofits, and newly developed projects must be carefully considered. Designs safe in 2050 may become impacted by SLR and flooding by 2100 or other future timeframes. For example, the “H++” projection of 2.7’ of SLR by 2050 may appear conservative, but it is expected to be met and surpassed by 2100, according to the far less conservative “likely” projections.

The appropriate identification of next steps will enable the city to utilize the existing data and present thinking to inform future strategies. Petaluma should prioritize the development of a vulnerability and risk assessment that considers key critical infrastructure and proposes nature oriented site-specific solutions to mitigate and adapt to future challenges. Additionally, the impacts of SLR and flooding should be assessed for all new development to ensure additions are aligned to sustainability, safety and development priorities as defined in the General Plan. Guidance should also continue to incorporate SLR and flooding into Petaluma’s capital improvement planning process, formally and informally, and streamline this process to best support adaptations and Citywide considerations.

# Key Metrics and Indicators

Regular monitoring of key metrics and indicators is critical to ensure that individual and combined strategies and programs are functioning at the level required to adapt to rainfall flood and sea level rise flood risks. Metrics typically require the establishment of a baseline measurement. This allows changes in the metric to be monitored, indicating the success of or need for adaptation measures. Different metrics may be assigned different weights of significance should they be compared, combined, or summarized in a numerical or spatial analysis for the City of Petaluma.

Table 5 below lists potential metrics related to measuring the efficacy of or need for adaptation measures, as they relate to flood hazards posed by climate change. The table is adapted from the June 2020 draft *Resilience Metrics White Paper* released by the Technical Advisory Committee Resiliency Metrics Workgroup for the Governor's Office of Planning and Research.[35] The metrics were developed for the State of California and have been adapted to the City of Petaluma as needed, and not all metrics originally listed in the *Resilience Metrics White Paper* have been listed below. Additional metrics not included in the original *Resilience Metrics White Paper* have been included as well. During the planning process, metrics such as these will be used across topic areas to inform the 'Objective Targets and Factors Affecting Growth' and 'Land Use Alternatives Analysis' phases of the GPU, and later be addressed as part of the implementation process to craft the 'Metrics and Evaluation Plan'. The below metrics are a suggested, preliminary list for potential incorporation in further stages of the implementation plan component of the General Plan to formally track progress over time.

**Table 5. Metrics Related to Flood Hazards and Adaptations**

| Metric | Context and Rationale |
|---|---|
| Number or percentage of individuals, residencies, businesses, exposed utilities, and other entities located in areas at-risk to rainfall flooding and flooding due to SLR. | This metric tracks how much of the City of Petaluma is at risk and indicates whether future adaptations have alleviated an amount of risk. A vulnerability assessment will likely be necessary to define at risk areas. |
| Total economic value of entities located in areas at risk to rainfall flooding and flooding due to SLR | This metric tracks the amount of economic prosperity that is at risk to flood events in the City of Petaluma and helps assess the costs and benefits of implementing adaptation measures. |
| Reductions in post-flood recovery costs and time | This metric indicates the economic value of implemented adaptation measures after a flood event and whether further adaptation measures should be considered. |
| Reduction in the number of repetitive loss | This metric measures the success of adaptation |

[35] *TAC Resilience Metrics Workgroup. "Draft Resilience Metrics White Paper." California Ocean Protection Council, 10 Jun. 2020,* https://opr.ca.gov/meetings/tac/2020-06-10/docs/20200610-2_White_Paper-Resilience_Metrics_Workgroup.pdf.

| | |
|---|---|
| properties | efforts, especially as new flood events occur. |
| Number of residents who are members of vulnerable and disadvantaged populations in flood hazard areas | This metric may be able to capture whether expanding hazard areas due to climate change are disproportionately impacting vulnerable and disadvantaged populations and inform City responses. Climate change will exacerbate existing environmental hazards for the most vulnerable in society, so spatially tracking the expansion of risk and vulnerability will be important. Changes in these measurements, as indicated by current and future vulnerability assessments, show the success of development projects or the need for further adaptations. |
| Acres of wetlands habitat restored or protected | This metric tracks the acreage of wetlands, marshes, and critical habitat restored within the city. Plans such as the 2015 update to the Baylands Ecosystem Habitat Goals, which offer recommendations for promoting healthy baylands in light of climate-induced erosion and inundation, can guide these efforts. |
| Average observed sea level rise in inches over past century and changes in sea level rise projections | Sea levels measured at stations in San Francisco and La Jolla have risen at a rate of 8 and 6 inches over the century, respectively. Sea level rise in could lead to loss of marshlands east of the Petaluma Marina, saltwater contamination of drinking water, impacts on roads and bridges, and harmful ecological effects. Recording this metric will signal whether identified vulnerabilities or the efficacy of any considered adaptation measures should be re-evaluated. |
| Disaster funds disbursed to fix transportation assets after rainfall flood events | This metric shows the cost of protecting road and transportation-related infrastructure. The costs of flood recovery will grow as climate change accelerates, further stressing transportation assets and the system at large. Early adaptation measures could save the state a significant amount of money. |
| Miles of transportation network impacted by rainfall flood events | This metric, when analyzed over time, will track changes in flood impacts to transportation infrastructure, indicating the need for or success of adaptation measures. |
| Reduction in rate of land consumed for | . Healthy, well-maintained natural systems can provide significant climate mitigation benefits and |

| | |
|---|---|
| development | can also provide resilience in the face of change. Natural infrastructure is the preservation and/or restoration of ecological systems, or utilization of engineered systems that use ecological processes, to increase resiliency to climate change and/or manage other environmental problems (AB 1482 and SB 379). |
| Change in impervious surface coverage and tree canopy, especially in at-risk flood areas | Impervious surfaces do not allow water to infiltrate into the soil. Allowing water to infiltrate into soil reduces flooding, recharges ground water supplies, and filters water. Increasing the amount of tree coverage has a number of benefits for climate change and communities, including reduction of storm water runoff, which decreases flood risk and soil erosion while improving water quality. |
| Households in “at-risk” toxic site exposure areas | Climate change increases the risk of disruption and damage to critical infrastructure, including toxic sites in locations projected to be impacted by sea level rise. Further, communities living in proximity to these sites face an increased threat of exposure to toxic substances. |
| Species range, abundance, diversity, and area of presence | Flood and SLR impacts to individual fish, wildlife, and plant species, especially in the marshlands within the city, can collectively alter broader natural community structure and composition. Tracking species diversity (number of species and their relative abundance in a given ecosystem) can serve as a measure of changing community dynamics. Presence or relative abundance of plant and animal species in both aquatic and terrestrial environments can be monitored as part of this effort (e.g. key species population levels). |
| Total funding available that directly considers and builds resilience to climate impacts | Since climate change is already exacerbating existing in inequities and vulnerabilities, efforts to build healthy and equitable communities must be considered. |
| New units approved in hazard areas | This metric would help the city track whether existing land use and hazard avoidance guidance is effectively safeguarding members of the population. |
| Community service hours that directly build adaptive capacity in communities | This metric would help measure the resources being allocated toward adaptive capacity. |

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| Climate change, housing, transportation, or land use investment plans or programs that incorporate measures to prevent residential and economic displacement. | Transit investments and other amenities such as improved housing options are often provided to improve livability and reduce the need to drive, thus reducing greenhouse gases. These strategies may inadvertently drive up median area income, property taxes, and rents. A possible result of such changes is that existing residents and small business owners may no longer be able to afford living or doing business in their neighborhoods and will be forced to move farther away. Displacement has harmful effects on physical and mental health of children and adults, and most harms people with low incomes. |
| Number of staff and other individuals enrolled in climate related education courses and other trainings | This metric can be used to evaluate progress towards increasing awareness of climate impacts to biodiversity and adaptation options by state agency staff working on natural resource issues. |
| Projects and programs that focus on sea-level rise and climate adaptation | Tracking the number of such projects helps indicate whether the city has allocated enough resources toward adaptation response. |
| People who receive training or information annually on coastal and ocean climate risks and adaptation planning | This metric tracks participation in outreach events, webinars, and other trainings on coastal and ocean climate risks and adaptation planning. |

# Appendix A: Regulations, Plans, Studies and Resources in the Bay Area and Beyond

Regulatory measures and a wide variety of resources at the federal, state, regional, county, and local levels have been produced to guide communities through the adaptation planning process. Resources typically use the best available science at the time (for example, the recommended set of sea level rise projections has been updated several times in the past decade) and should be referenced with the understanding that new data may currently be available or will be available in the future.

## Regulatory Guidance for SLR- and Flood-related Adaptation Planning

### National Flood Insurance Act of 1968, Flood Disaster Protection Act of 1973, Executive Order 11988

As a part of federal efforts to manage emergencies and disasters, the United States Congress created the National Flood Insurance Program (NFIP) through the National Flood Insurance Act of 1968. Subsequent legislation, including the Flood Disaster Protection Act of 1973 and Executive Order 11988, further defined and regulated the economic, conservational, safety requirements within areas at risk to flooding. The NFIP provides flood insurance and reduces flood-related damages by regulating development within floodplains. Floodplains and other zones of varying flood risk are legally defined by the Federal Emergency Management Agency (FEMA) and are visible on Flood Insurance Rate Maps (FIRMs). The zones currently administered by FEMA are as follows:[36]

- Zones A, AE, AH, AO, AR, A99, V and VE denote Special Flood Hazard Areas. These zones denote areas with a 1% chance of flooding in any given year and are referred to as being within the 100-year floodplain. These zones require any residing entity to purchase flood insurance, while all other zones do not.
- Zone X (shaded) denotes moderate flood hazard areas, defined as areas with a 0.2% chance of flooding in any given year (or, 1% chance of flooding at least once during a 500-year period).
- Zone X (unshaded) denotes minimal flood hazard areas.
- Zone D denotes undetermined-risk areas. These are areas in which flood risk exists, but no flood hazard analysis has been conducted.

In accordance with the National Flood Insurance Reform Act of 1994,[37] FEMA is required to assess the need to revise and update all floodplain areas and flood-risk zones every five years. The current FIRMs for the City of Petaluma were most recently updated in 2008, 2014, and 2015, with preliminary FIRMs for

[36] *"Flood Zones." FEMA, 8 Jul 2020, https://www.fema.gov/glossary/flood-zones. Accessed May 2021.*

[37] *"Title V—National Flood Insurance Reform." FEMA, 1994, page 24, https://www.fema.gov/sites/default/files/2020-07/national-flood-insurance-reform-1994.pdf.*

2020 awaiting approval. More information regarding individual maps is provided on the FEMA Flood Map Service Center.

While FIRMs are required to be considered for city planning and insurance purposes, FIRMs do not consider future flooding conditions. Because the effects of sea level rise and flood hazards are projected to increase in the future, cities should also consider these projections for future development.

## CA Assembly Bill 32 and Senate Bill 375; Senate Bill 379; Senate Bill 1000

The Global Warming Solutions Act of 2006 (California Assembly Bill 32) established a state-wide program to reduce greenhouse gas emissions, leading to the Sustainable Communities and Climate Protection Act of 2008 (California Senate Bill 375), which primarily targets reductions in greenhouse gas emissions from passenger vehicles. Senate Bill 375 requires the 18 regional metropolitan planning organizations in California to each create a Sustainable Communities Strategy (SCS) to align with the greenhouse gas emission reduction targets set by the California Air Resources Board (CARB). In the Bay Area, the SCS has been implemented in the form of Plan Bay Area, a regional resource that releases guidelines and tools to local Bay Area communities to address the effects of climate change, including sea level rise and increased risk of flooding.

Senate Bill 379, approved in 2015, requires counties and cities within California to incorporate the adoption of a safety element in their general plan update, to protect communities from the risks of various hazards, including flooding, geologic hazards, wildland fires, and urban fires. Senate 379 further requires that the safety element adoption process must consist of the following components:

- A vulnerability assessment that identifies risks related to climate change,
- A set of adaptation and resilience goals, policies, and objectives based on the information gained from the vulnerability assessment,
- A set of feasible implementation measures designed to carry out the set of adaptation and resilience goals, policies, and objectives.

This adoption must occur on or after January 1, 2017, upon the next revision of their local hazard mitigation plan. If the local jurisdiction has not adopted a local hazard mitigation plan (LHMP), the requirement for this is set to January 1, 2022. A city may summarize and reference the information contained within its LHMP or climate action plan (CAP) when incorporating the safety element into the updated general plan, so long as its LHMP or CAP contains climate adaptation information compliant with Senate Bill 379. The City of Petaluma released an updated LHMP in 2020 in which some vulnerabilities to sea level rise and flooding were assessed.

Senate Bill 1000, approved in 2016, requires the incorporation of environmental justice into a city’s general plan update, either integrated throughout the update or as a stand-alone element. This includes the consideration of disadvantaged communities when selecting areas for implementing sea level rise and flooding adaptations.

## San Francisco Bay Plan

The San Francisco Bay Plan, managed by the BCDC and most recently revised in 2019, outlines policies pertaining to development projects and the protection of the entire San Francisco Bay and areas subject to tidal action, including the Petaluma River up to its confluence with Adobe Creek. The Plan recommends that state agencies should generally not develop any new significant structure in areas that are at significant risk to sea level rise, storm surges, or coastal erosion.

Strategies to protect existing structures are encouraged to implement innovative design solutions that are resilient to potential flood and erosion events or are easily relocated or removed to allow for progressive adaptation to sea level rise, flood, and erosion. New shoreline developments should be subject to a risk assessment, based on the best projected 100-year flood elevation, while also considering future mid-century and end-of-century sea level rise.

## Plan Bay Area 2050

Plan Bay Area 2050 is a long-range plan that outlines economic, environmental, housing, and transportation guidelines for the Bay Area region, continuing the vision set forth by Plan Bay Area 2040. The Plan is the Bay Area's implementation of a Sustainable Communities Strategy, as mandated by Senate Bill 375, and represents a joint effort between 4 agencies: the Association of Bay Area governments (ABAG), the BCDC, the Metropolitan Transportation Commission (MTC), and the Bay Area Air Quality Management District (BAAQMD). Plan Bay Area 2050 is slated for adoption in fall 2021. In its assessment of sea level rise impacts and current adaptation investments, the Plan assumes two feet of sea level rise by 2050, based on "high-risk" projections given in the *State of California Sea-Level Rise Guidance 2018 Update*.

Plan Bay Area 2050 emphasizes the use of nature-based "green" infrastructure, rather than traditional "grey" infrastructure in its list of adaptation strategies for sea level rise. Not all strategies discussed in the Plan are appropriate for use within the City of Petaluma. To assist the integration of adaptation strategies against environmental hazards in the Bay Area, the Plan also aims to provide means-based financial support for retrofitting existing residential buildings.

# Federal and State Resources for Adaptation Planning

## California Adaptation Planning Guide 2020

The *California Adaptation Planning Guide* (2020), prepared by the Governor's Office of Emergency Services (Cal OES), provides guidelines to local governments on adaptation and resiliency planning to address potential consequences to climate change, including sea level rise. The guide gives information on four primary steps in the adaptation planning process: (1) explore, define, and initiate the planning process; (2) assess community vulnerability to climate hazards and other climate effects; (3) define adaptation framework and strategies to improve community resilience; (4) implement, monitor, evaluate, and adjust the adaptation strategies.

## Adaptation Clearinghouse

The Adaptation Clearinghouse is a website that provides a searchable database of curated climate adaptation resources. Documents listed on the websites include reports, tools, and guides that address vulnerability assessments, adaptation strategies, and other information related to sea level rise and flooding.

## Safeguarding California Plan: 2018 Update

The *Safeguarding California Plan: 2018 Update*, prepared by the California Natural Resources Agency, outlines how California's state government is responding to climate change and provides the state's next steps to achieve and implement goals related to climate change concerns. It does not provide guidance to local governments.

## Planning and Investing for a Resilient CA: A Guidebook for State Agencies

*Planning and Investing for a Resilient CA: A Guidebook for State Agencies* (2017), prepared by the Governor's Office of Planning and Research in partnership with the Technical Advisory Group formed under the direction of Executive Order B-30-15, outlines guidance for state agencies to implement climate change concerns into future planning decisions and investments. The document is not geared toward local governments but may provide an example for how the City of Petaluma can integrate climate change into local planning projects.

## Regional Resilience Toolkit - 5 Steps to Build Large Scale Resilience to Natural Disasters

The Regional Resilience Toolkit, created through a partnership between FEMA, US EPA, MTC, and ABAG, provides step-by-step guidance to jurisdictions for meeting the many different state and federal planning requirements, as well as advisory tools for communicating with stakeholders, conducting vulnerability assessments, and successfully implementing new plans. The steps outlined in the Toolkit are intended for regions or communities of any size and are designed to fulfill requirements for LHMP approval and update. The steps also follow the FEMA Local Mitigation Planning Handbook.

## Coastal Plan Alignment Compass

The Coastal Plan Alignment Compass, produced by the California Governor's Office of Planning and Research (Cal OPR) in 2019, provides guidance for coastal communities in California as they address issues related to sea level rise and flooding in their local plans. The tool presents legal requirements, best practices, tips, and other organized information that should be considered when updating or implementing local hazard mitigation plans, adaptation plans, general plans, and local coastal programs.

# Regional Resources for Adaptation Planning

## San Francisco Bay Shoreline Adaptation Atlas (2019)

The *San Francisco Bay Shoreline Adaptation Atlas: Working with Nature to Plan for Sea level Rise Using Operational Landscape Units* (2019), prepared by the San Francisco Estuary Institute (SFEI) and the San Francisco Bay Area Planning and Urban Research Association (SPUR), identifies over two dozen adaptation measures that address risks related to erosion, sea level rise, fluvial flooding, and combined (fluvial and tidal) flooding in the Bay Area. The Adaptation Atlas establishes a framework of dividing the Bay Area into 30 Operational Landscape Units (OLUs), separated by non-artificial boundaries created through natural processes such as tides, waves, and sediment movement. As a practical way to explore different adaptation measures for specific areas within the Bay Area, the OLU framework has also been used by other organizations to explore potential adaptations throughout the Bay Area.

Adaptation measures suggested for the Petaluma OLU include tidal marshes, polder management, and preparing migration spaces that marshes can transition into as the sea levels continue to rise. The report also discusses other structural adaptations, including both nature-based and conventional “grey” measures. Non-structural adaptations discussed include policy and regulatory measures, such as laws, permits, zoning, and general plans, as well as financial measures, such as methods of creating incentives and disincentives to enable implementation of other structural and policy measures.

# Regional Adapting to Rising Tides (ART) Projects

The Adapting to Rising Tides (ART) Program, led by BCDC, leads and supports the integration of climate adaptation into local and regional planning across the Bay Area. The ART website supplies a set of findings, projects, “how-to” guides, and other information developed by the ART Program for use in climate adaptation. Examples of the information provided include guidance for shoreline protection, flood control, and stormwater management; step-by-step documentation for setting resilience goals, conducting vulnerability assessments, and developing adaptation responses; and case studies of previous climate adaptation efforts throughout the Bay Area.

Regional resources developed by the ART Program include:

- *ART Bay Area* (2020) is a project that assessed and compiled the vulnerabilities of four Bay Area systems (transportation infrastructure, vulnerable housing communities, future growth areas, and natural lands) with regard to sea level rise and flooding at ten different water levels. The project also provides potential adaptation responses for the identified vulnerabilities. Since the systems function on a regional level, the responses provided by the ART Bay Area project do not necessarily provide specific recommendations to individual communities, and no assets within the City of Petaluma were assessed. Among the types of responses provided are nature-based adaptations, grey infrastructure, and retrofits, along with promoting management programs and identifying adaptation funding mechanisms.

- *Stronger Housing, Safer Communities* (2015) assesses communities throughout the Bay Area for vulnerability to flooding and seismic hazards. Vulnerability reduction strategies that function at state, regional, and local levels are provided in the report, as are the associated funding mechanisms that may be pursued to help fund each strategy. Local measures related to reducing vulnerability to sea level rise and flooding include reducing development in high hazard areas, retrofitting and repairing structures, policy tools that support financing mechanisms, preparing for post-disaster recovery, and coordinating with non-profit organizations and community organizations.
- The *Tidal Creeks and Flood Control Channels: Guidance for Assessing the Impacts of Sea Level Rise on This Flooding* project (2015) developed guidance related to assessing the vulnerability of tidal creeks and flood control channels to sea level rise. Sea level rise will exacerbate the existing risks associated with flooding in waterways that drain to the bay, and because no current modeling software holistically combines riverine flooding and sea level rise, this guidance may be useful for Petaluma planning purposes. It is recommended that planners work with flood managers to evaluate combined coastal-riverine flooding. The guidance is currently being used to evaluate flood control projects in the Contra Costa County ART Project.

## Sea Level Rise Adaptation Framework

The *Sea Level Rise Adaptation Framework* (2019), developed by Point Blue Conservation Science and the San Francisco Estuary Institute (SFEI) in partnership with the County of Marin, is a guide that aids the development of nature-based sea level rise adaptation strategies. The framework, which operates using the OLUs established by the San Francisco Bay Shoreline Adaptation Atlas, is intended to help planners both identify a range of landscape-scale adaptation strategies for coastal vulnerabilities and prioritize adaptations based on how they address community and stakeholder objectives.

The framework acknowledges the difficulty and importance of assessing a vulnerability's root cause (such as coast flooding, riverine flooding, combined flooding, or erosion from waves) in order to help select the most effective adaptation measures. Once a set of adaptation strategies have been developed, they can be compared, using characteristics such as length-of-life, cost, services provided to the ecosystem, carbon storage, recreation, and impacts to transportation.

## San Francisco Bay Regional Coastal Hazard Resiliency Group (CHARG)

The San Francisco Bay Regional Coastal Hazard Resiliency Group (CHARG), an organization of flood managers and scientists, provides a sea level rise resiliency map which highlights the locations of both city-wide and county-wide projects throughout the Bay Area. Projects include levees, seawalls, pump stations, restoration projects, sediment removal, resilience studies, vulnerability assessments, and other projects with known shoreline extents. The CHARG website also provides a resources page that provides quick access to various guidance, policy, scientific, and planning documents related to local and regional sea level rise vulnerability and adaptation planning.

## Climate Change Hits Home: Adaptation Strategies for the San Francisco Bay Area (SPUR, 2011)

*Climate Change Hits Home: Adaptation Strategies for the San Francisco Bay Area* (2011), developed by SPUR, identifies and compares the pros and cons of specific adaptation strategies that address climate-change-related hazards in the Bay Area. The seven sea level rise adaptation measures assessed include barrier or tidal barrage, coast armoring, elevated development, floating development, floodable development, living shorelines or wetlands, and managed retreat. Recommendations for sea level rise planning are also provided, some of which the City of Petaluma is already undertaking.

## Raising the Bar on Regional Resilience produced by Bay Area Regional Collaborative (BARC)

Written to give background on the Bay Area's progress in resiliency planning after the adoption of Plan Bay Area, the 2018 Raising the Bar on Regional Resilience report provides multi-benefit, regional resiliency planning to address issues related to climate, sea level rise, and hazard response. The report also identifies example adaptation strategies and vulnerability assessments occurring throughout the Bay Area as case studies in multi-hazard resilience planning. Contributors to the report include ABAG, the Bay Area Regional Collaborative (BARC), and BCDC.

## 2013 PRBO NBWA report "Adapting to Sea Level Rise Along the North Bay Shoreline"

This 2013 report focuses on the ecological bird response to rising sea levels in marsh habitats, while also providing projections for marsh habitat resiliency, including marshes around upper and lower portions of the Petaluma River. Two particular areas of the Upper Petaluma River within the Petaluma city limits that were assessed in the report include the Petaluma Dog Park and Gray's Ranch. The report also suggests the use of the Future San Francisco Bay Tidal Marshes tool (https://data.pointblue.org/apps/sfbslr/), which provides projections of changes in marsh, mudflat, upland, and subtidal areas as sea levels rise throughout San Francisco Bay. In its modeling process, the tool accounts for changes in the shoreline due to rates of marsh accretion due to the deposition of suspended sediment and organic material.

The report was developed by Point Reyes Bird Observatory Conservation Science (PRBO, now known as Point Blue Conservation Science) in partnership with the North Bay Watershed Association (NBWA).

## 2013 "Analysis of the costs and benefits of using tidal marsh restoration as a sea level rise adaptation strategy in San Francisco Bay" by ESA-PWA environmental firm

This 2013 report, prepared for the Bay Institute by ESA-PWA (Environmental Science Associates - Philip Williams & Associates, now known simply as ESA, Environmental Science Associates) assesses different levee strategies in managing the increasing rates of levee overtopping as sea levels rise in the San Francisco Bay, assigning a financial value to tidal marshes as a part of its restoration cost-benefit analysis. The report recommends the use of "horizontal" levees, rather than traditional levee approaches, as well as levee relocation (retreating levees inland). As elucidated in the report, horizontal levee systems involve a levee, wetland, and "upland ecotone slope" that maintains pace with sea level rise by automatically increasing in elevation as root systems grow.

# Countywide Resources for Adaptation Planning

## USGS Petaluma Valley Groundwater Study

The USGS partnered with Sonoma Water and the City of Petaluma to complete the "Evaluation of the groundwater resources of the Petaluma Valley" (https://www.usgs.gov/centers/ca-water/science/evaluation-groundwater-resources-petaluma-valley?qt-science_center_objects=0#qt-science_center_objects). The report, in conjunction with a 3D geologic hydromodel, will describe and quantify the groundwater conditions in the basin. Though drafts have been released for review, it has not been finally published. Though data suggests that groundwater elevations are relatively stable, long-term declines in the northwest portion of the basin, nitrate contamination in the western portion, and saltwater intrusion in the southern portion are noted.

# Petaluma Valley GSA

The city of Petaluma is a board member of the Petaluma Valley groundwater Sustainability Agency (GSA) which is tasked under the 2014 Sustainable Groundwater Management Act (SGMA) to develop a Groundwater Sustainability Plan (GSP) which will provide for the management of the local groundwater basin, as defined by DWR. Though the city utilizes surface water imported from the Russian River watershed for nearly all functions, the city does overlay the basin, and has emergency backup wells in the aquifer. Plan development is in process and will be completed by 2022. SLR predictions are a critical part of the GSP process. The GSP must address the minimum state standards of:

1. Lowering Groundwater Levels
2. Seawater Intrusion
3. Reduction of Storage
4. Land Subsidence
5. Degraded Groundwater Quality
6. Surface Water Depletion

# Upper Petaluma River Watershed Flood Control Project Scoping Study 2012

A technical memo prepared in 2012 for Sonoma County Water Agency titled “Upper Petaluma River Watershed Flood Control Project Scoping Study” discusses project implementation strategies to address flooding in the Upper watershed while providing additional benefits such as ecosystem restoration and groundwater recharge. Though most of the watershed is outside of the city limits, portions of the study scope were identified as Flood/Recharge Concept areas (primarily along the river and Corona, Capri and Lynch creeks. It describes a feasibility/design/install procedure for projects, provides permit/funding guidance as well as key outcomes for multiple benefits. It provided general guidance for Low Impact development and policy review and development, as well as summarized multiple strategies that can be used and highlighted which portions of the watershed they are applicable to, including:

- Managed Floodplain
- Off-stream detention
- In-Stream detention
- Floodplain Modification
- Levee/Floodwall
- Channel Modification
- Bypass Channel
- Bridge Improvement and Debris Removal
- Direct Groundwater injection

## Sonoma Water "Southern Sonoma County Storm Water Resources Plan"

Per Senate Bill 985 (2014) to maintain eligibility for voter approved bond measures for stormwater projects, Sonoma Water developed a Storm Water Resources Plan (SWRP) to identify and prioritize objectives. This is used by the County and City of Petaluma. The plan attempted to develop a watershed-based approach by engaging multiple stakeholders and prioritize interventions which provided multiple benefits such as environmental enhancement, flood protection, groundwater recharge, water quality improvement and recreational opportunities. The report provides a summary of conditions in the Watershed, including water quality compliance, an inventory of existing programs and regulatory processes. Further information at https://www.sonomawater.org/media/PDF/Water%20Resources/Stormwater/Stormwater%20Resource%20Plan/Southern_Sonoma%20County_SWRP_Final%20Update_2019-05.pdf.

## Climate Ready Sonoma County: Climate Hazards and Vulnerabilities by NBCAI

This 2014 North Bay Climate Adaptation Initiative (NBCAI) report identifies expected climate hazards that will affect Sonoma County, including bigger and more frequent floods, and higher sea level and storm surge. The report summarizes the vulnerabilities related to each hazard in Sonoma County by classifying whether the vulnerabilities affect people and social systems, built systems, or natural and working lands.

Some of the vulnerabilities to increased flooding include loss of critical infrastructure, water quality problems, economic losses, increased erosion, loss of habitat complexity, and loss of recreational areas. Vulnerabilities to sea level rise include difficulty providing emergency services to low-lying communities, loss of habitats that buffer against storm surge, risk of levee breaches, saltwater intrusion, and disruption to communications, transportation, water, and energy systems.

## Petaluma Watershed Enhancement Plan

The Petaluma Watershed Enhancement Plan is currently being updated by the Sonoma Resource Conservation District to replace the 1998 plan. The most recent draft available, dated as being a 2013 draft, provides new information for urban and rural areas within the Petaluma watershed and proposed recommendations for improved water quality, habitat, and agricultural and rural sustainability. The plan identifies potential climate change impacts, in which increased risks associated with sea level rise and flooding are included and lists recommended actions to address the impacts. The recommendations focus on improving the natural environment, participation in restoration projects, and green and hybrid infrastructure approaches, rather than introducing new grey infrastructure. Further information at https://sonomarcd.org/wp-content/uploads/2017/06/Petaluma-Watershed-Enhancement-Plan-2015.pdf.

## Climate Ready North Bay

Climate Ready North Bay is a project led by the Terrestrial Biodiversity Climate Change Consortium (TBC3) in partnership with the Sonoma County Regional Climate Protection Authority (RCPA) and the NBCAI that assessed vulnerabilities in the North Bay watersheds to assist local government and agencies to develop climate adaptation strategies. Individual maps, graphs, and summary technical reports tailored to site-specific resource management challenges within the North Bay are provided. The vulnerability assessment lists key findings related to rising temperatures, more variable rainfall, future arid conditions, increasingly flashy runoff, the importance of protecting recharge areas, increased water demand, increased fire frequencies, and the response vegetation has to changing climates. Sea level rise and flooding are not directly addressed as major considerations in this vulnerability analysis.

The project also provides a "lessons learned" webpage to inform other climate adaptation planning efforts using high-resolution climate data at a regional scale for specific management applications. These lessons focus on effective tactics for organizing and using scientific data, framing questions, and ensuring relevant climate scenarios are selected for analysis. Further information at http://climate.calcommons.org/crnb/home.

## Climate Action 2020 and Beyond - Sonoma County Regional Climate Action Plan, by the Sonoma County RCPA,

Climate Action 2020 and Beyond (July 2016) is a county-wide initiative in Sonoma that focuses on reducing greenhouse gas emissions through individual climate action plans (CAPs) for all communities in Sonoma. The Sonoma County Regional Climate Action Plan (2016) developed as a part of the project provides a framework for implementing measures to reduce emissions. The plan reiterates the vulnerabilities that people and social systems, built systems, and natural and working lands have to the potential impacts of climate change as assessed in the NBCAI report Climate Ready Sonoma County: Climate Hazards and Vulnerabilities. Additionally, the action plan identifies climate change adaptation goals, as well as opportunities to help achieve the goals and the climate hazards addressed in the process.

The action plan states that climate readiness strategies should be explicitly integrated into existing plans and programs that are already used to promote public health, safety, and prosperity in Sonoma County. Examples of such plans and programs include hazard mitigation plans, general plans, water supply and stormwater plans and ordinances, environmental impact reports, transportation and other capital improvement plans, emergency preparedness plans, groundwater management plans, and administrative policies, procedures and initiatives. Further information at https://rcpa.ca.gov/projects/climate-action-2020/.

## A Roadmap for Climate Resilience in Sonoma County by NBCAI

A Roadmap for Climate Resilience in Sonoma County (April 2016), developed by the NBCAI, outlines a climate adaptation approach that classifies different types of strategies based on long-term and short-term effectiveness and how much priority should be given to each. The document focuses on the tangible benefits of climate resilience actions and the broad steps involved in developing them:

- Define desired state based on vision - What would a resilient Sonoma County look like?
- Define the system in terms of causes and effects. What factors influence the goals?

- Assess vulnerabilities - Climate impacts adaptive capacity, timing, uncertainties
- Prioritize adaptive needs based on goals, systems analysis, and plausible future scenarios
- Identify strategies - Estimate their efficacy, co-benefits, feasibility, timing.
- Prioritize strategies - Show why these strategies are best.
- Implement in phases. Create accountability.
- Monitor implementation & resilience indicators. Evaluate new information. Adapt strategies and continue.

The Roadmap document remarks that the major resources on vulnerabilities it references are the Climate Ready Sonoma County report and the results from Climate Ready North Bay.

# City of Petaluma Plans and Policies

## City of Petaluma's General Plan

The City of Petaluma is in the process of updating the 2025 General Plan, which was adopted in 2008. The existing General Plan discusses the Petaluma River Corridor as a green ribbon of ecological connectivity and public access that utilizes flood terraces to retain and increase stormwater capacity to reduce the extent of localized flooding, and reviews existing conditions and strategies for surface water management. Flooding is a normal occurrence in the Petaluma River Basin after heavy storms, leading the city to develop a host of efforts to address this. These strategies include the City's involvement in the National Flood Insurance Program (NFIP) Community Rating System (CRS), and the NWS Automated Local Evaluation in Real Time (ALERT) emergency flood warning system. The 2005 General Plan utilized the 1989 Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs) to delineate the floodway and floodplain. Goals around watershed scale management and policies pertaining to surface water management through the Petaluma River Corridor are discussed, including appropriate setbacks and development requirements, coordination with other plans and agencies, ensuring the protection of property and design conveyance capacity, and promoting enhanced water quality and historic preservation of flood management areas. As the Petaluma General Plan update develops, refined tools, models, resources and strategies are collected and synthesized to ensure planning efforts reflect the most current precedent thinking and scientific strategies as they relate to flooding and sea level rise.

## Petaluma Climate Emergency Action Framework

Adopted by the City Council in January 2021, the Climate Emergency Action Framework is the product of the Petaluma Climate Action Commission, members of the Petaluma community, staff, and the City Council. It provides a framework for community engagement that focuses on developing equitable and just responses for the city to mitigate and adapt to Climate Change. Preparing for inundation and flooding from Sea Level Rise and increased storm severity in the 100-year time horizon is a component of the Framework, which also includes significant Appendices exploring further goals and strategic approaches. The Framework sets overarching goals which include substantially reducing direct GHG emissions, reducing emissions from goods and services consumed within Petaluma, eliminating emissions from the building and transportation sector, and sequestering/offsetting emissions through regenerative land management and other practices such as Urban Reforestation to reverse climate change. The framework is one of the tools the city plans to use to achieve carbon neutrality, city wide, by 2030. The framework is intended to provide guiding principles for the city's operations, planning and budgeting processes, and to be a guiding document for the General Plan Update and future planning efforts, such as a Climate Action Plan.

# Petaluma Hazard Mitigation Plan Flooding and SLR sections

The 2019 City of Petaluma Local Hazard Mitigation Plan (LHMP) adopted in 2020, by City of Petaluma Public Works, prepped by Wood Environment and Infrastructure Solutions, superseded the 2010 Bay Area wide LHMP developed by the Association of Bay Area Governments. It assesses the risk and vulnerabilities from multiple sectors, such as fire, earthquake, as well as flooding and sea level rise. The flooding section was organized to provide data for the FEMA CRS process. The process involved community input and was tailored to the needs of the city, and details proposed mitigation strategies. The LHMP allows the City to apply for certain federal emergency planning and disaster mitigation.

Section 4.3.5 of the LHMP explores the impacts from flooding in the City. The City's history with flooding, previous planning and mitigation strategies are summarized. The 2014 FEMA 100-year flood maps were interpreted, with consideration that climate change impacts will have a high impact on the severity of flooding events.

Section 4.3.6 of the LHMP considers potential impacts from varying Sea Level prediction. The LHMP utilizes the risk-based method described in the California Ocean Protection Council (OPC) 2018 report. This both provides ranges of sea level rise for different target dates, but also organizes them by the likelihood they will occur. The California Coastal Commission (CCC) Sea Level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits (CCC 2018) then describes how these different risk-levels should be applied to planning processes. Three SLR predictions were then selected and mapped, the 0.8', 1.6' and 6.6' levels at MHHW, as well the same SLR scenarios with an additional 100-year storm event increasing the bay elevation. Though far from open water, Petaluma is still greatly affected by tidal forces and storm surge. The impacts to properties and critical infrastructure from these SLR predictions is described below.

# 2015 Petaluma Floodplain Management Plan

The 2015 Update to the Flood Management Plan was undertaken to allow a public process in developing a report to meet FEMA National Flood Insurance Program audits for qualifying for National Flood Insurance Program (NFIP) discounts. The document describes the history of flooding in the city, activities that are in process or proposed to prevent future flooding, and plans for further actions in the floodplain to prevent flood losses. This updated the Community Rating Service (CRS) rating for the affected properties in the city. The plan is currently in an update process to be completed in October 2021.

The document describes historic floods, particularly the 2005 "New Years" flood whose impacts were well documented. It highlights some known areas of flooding concern, such as certain public works buildings and portions of the city wastewater treatment/recycling facility. The document describes sections of the current General Plan and other policies which have promoted improved floodplain management. Some strategies were not recommended by the Technical Advisory Committee, such as a ban on placing new critical infrastructure in the 500 year floodplain.

## Sonoma County Flood Control Zone 2A Advisory Committee

Flood Control Zone 2A Advisory Committee members meet to discuss stormwater management and flood control issues and provide recommendations on annual budgets involving expenditures related to flood protection, stream maintenance, and stormwater management. Zone 2A encompasses the City of Petaluma and contributing watersheds. Its appointed seven-member board represents varying interests in the region.

## Petaluma Zoning Code Chapter 6 Floodway and Floodplain Districts

Chapter 6 is intended to establish regulations for properties within city limits that lie within the FEMA designated floodway and floodplain in order to minimize impacts from flooding. It is limited to those properties, not properties which may be later within the FEMA flood zone due to changes in climate, development, or sea level. The chapter describes the permitted and conditional approved uses of the floodway. Projects inside the floodplain are regulated by detailed requirements such as minimum freeboard above base flood elevation, anchoring, erosion control, drainage, impacts to flow capacity, net-zero fill.

The primary methods the ordinance utilizes to mitigate impacts to and from the floodway/floodplain are:

1. Restricting or prohibiting uses which are dangerous to health, safety, and property due to water or erosion hazards, or which result in damaging increases in erosion or flood heights or velocities;
2. Requiring that uses vulnerable to floods, including facilities which serve such uses, be protected against flood damage at the time of initial construction;
3. Controlling the alteration of natural floodplains, stream channels, and natural protective barriers, which help accommodate or channel flood waters;
4. Controlling filling, grading, dredging, and other development which may increase flood damage; and
5. Preventing or regulating the construction of flood barriers which will unnaturally divert flood waters or which may increase flood hazards in other areas.

## City of Petaluma Stormwater Management Plan 2003

As a part of the application for its NPDES Phase 2 permit, the city submitted its Stormwater Management Plan. This primarily is intended to summarize the existing and proposed programs and practices to prevent pollutant loads in stormwater runoff from city jurisdiction.

## City of Petaluma Ellis Creek Water Recycling Facility – Sea Level Rise Analysis

In early 2021 the possible Sea Level Rise impacts to the Ellis Creek Wastewater Recycling Facility were analyzed in a technical Memo. The report concluded that there was little risk from permanent inundation from SLR except for in the H++ extreme SLR predictions for 2070-2100 (3-5' f SLR). Lower SLR predictions which include tidal effects or storm surge may require retrofits to the treatment outfalls. The memo was developed using the OPC 18 guidelines and a 50-year lifespan (2070 predictions). The scenarios range from 1-5.2' of SLR increase at MHHW.

## Petaluma Watershed Enhancement Plan

The Petaluma Watershed Enhancement Plan, finalized in 1998, and updated in 2015, provides recommendations for water management strategies. The plan includes technical information from the urban and rural areas of the watershed, as well as social and resource related recommendations for improved water quality, habitat, and agricultural sustainability. Several prior plans supported its establishment, including the 1992 Petaluma River Marsh Enhancement Plan which completed a plan for 300 acres adjacent to the Petaluma River south of the Marina and north of Adobe Creek, including disturbed wetland habitat, industrial, commercial, and open spaces areas. Marsh restoration of a 45 acre area occurred on a subsided diked bayland of the Petaluma River. Additional previous Petaluma plans include the River Access and Enhancement Plan, the Petaluma Demonstration Marsh and Effluent Management Plan, and the Ellis Creek Watershed Enhancement and Wetland Mitigation Plan.

## ULI TAP Recommendations

The Urban Land Institute convened a Technical Assistance Panel to set policies and best-practice development strategies in order to meet City goals for Infill housing development while meeting aggressive climate goals. One recommendation was to create a "blue-green mobility network" by placing new parks and multi-use trails on new green infrastructure that provides enhanced stormwater management. Restoration of the historical floodplain by modifying built-up banks would provide more flood capacity while restoring tidal wetland habitat. The downtown area around the Turning Basin, Steamer Landing Park and McNear Channel are a unique opportunity for improving public access to the river, in a location that will experience significant impacts from sea level rise.

# Examples of SLR and Flooding Adaptation Plans

Adaptation strategies and vulnerability assessments concerning sea level rise and flooding have been employed throughout the Bay Area at the regional, county, and city levels. While these do not involve in-depth analysis of potential adaptations and vulnerabilities within the City of Petaluma, they provide reference for potential similar projects that may be implemented in Petaluma in the future

The following resources can be used to access comprehensive but non-exhaustive lists of materials related to local-level adaptation and vulnerability assessment efforts throughout the Bay Area:

- The ART website lists vulnerability assessments and adaptation response projects that have been conducted for Alameda County, Contra Costa County, the Hayward shoreline, Oakland, and Corte Madera.
- The Bay Adapt website (https://www.bayadapt.org/resources/) provides links to several resources regarding sea level rise in the Bay Area. Among these, links to ongoing projects in the counties of San Mateo, San Francisco, Alameda, Marin, Napa, and Contra Contra are listed. The initiatives

vary in breadth of content and may include topics such as recent vulnerability assessments, climate action plans, adaptation strategies, and other projects being employed by each county.
- The Bay Area Climate Adaptation Network (BayCAN) website (https://www.baycanadapt.org/recources-by-members), run by a network of local government staff and partnering organizations within the Bay Area, also provides links to studies and projects related to sea level rise in the Bay Area.

Each of these communities has released guides, reports, and other information related to adaptation planning and vulnerability assessments. Vulnerability assessments have been conducted as both stand-alone reports and as elements integrated into cities' LHMPs. These local-level documents can be referenced in addition to similar documents provided at the regional and county levels.

Many local-level documents also list tools for implementing adaptation measures, sometimes separating them into categories and weighing the pros and cons for each measure. The documents often identify the usefulness of green and hybrid infrastructure. Several documents now provide guidance for identifying possible adaptations appropriate for an individual community as listed in this paper's sections for adaptation planning resources.

# Adaptation Plan Example: Marin County

An example specific to Marin County is the Adaptation Land Use Planning: Guidance for Marin County Local Governments document (https://www.marincounty.org/-/media/files/departments/cd/slr/alup0228.pdf?la=en), which presents adaptation planning guidance for Marin communities. It classifies adaptation implementation tools under the following categories:

- planning tools
- regulatory tools
- market-based tools
- engineering tools.

The guide also explains the following adaptation measures in depth, with notes about potential costs, factors to consider, visual appeal, impacts on public access, and other details provided. Each measure is preceded by the type of category or categories it falls under.

- Living shoreline: near shore biological habitat
- Barrier and living shoreline: horizontal levee
- New development strategies: floating structure and floodable property
- Protect in place: elevate buildings, roads, and grades
- Soft armoring: dune restoration and beach nourishment
- Protect in place: pump stations
- Protect in place: tidal gates
- Hard armoring: seawalls and raised bulkheads
- New development strategies: manage retreat

# Adaptation Plan Example: San Francisco

Another example is San Francisco's Sea Level Rise Action Plan (2016), which presents the following six-step adaptation process framework:

- Review science: Select the most reliable climate information by relying on local, regional, and national scientific expertise. Projections and adaptation strategies currently selected for San Francisco will be revisited and revised over time with changes in the best available science.
- Assess vulnerability: Identify the types of potential damage an asset may incur upon exposure to a hazard (such as flooding).
- Assess risk: Identify the potential consequences and likelihood of damage for the identified vulnerabilities.
- Develop adaptation plan: After prioritizing assets for adaptation, an evaluation concerning the best strategies to reduce vulnerability and risk must be conducted. Good planning will engage those who may be affected by or responsible for the impacts of sea level rise. This step will encourage innovative, interdisciplinary design thinking and adaptation strategies.
- Implement adaptation: Current adaptation implementation will continue to address future risks as necessary information, funding, and partnerships become available. Larger scale strategies developed in the Adaptation Plan will be phased in over longer time frames.
- Monitor implementation: Continually monitoring the effectiveness of the actions taken in the previous steps is critical. Unintended consequences and new data may change recommended strategies or inspire new ones. Effective adaptation planning includes monitoring types and timeframes, thresholds, reporting requirements, and identification of responsible parties.

The Action Plan also estimates the cost of inaction, including the expected losses in public and private property value, in order to inform decisions about balancing the costs of post-disaster relief with the costs of adaptation measures.

## Ongoing Efforts Example: Climate Adaptation Planning in the City of San Rafael

The City of San Rafael has worked to address the risks of future climate hazards, including sea level rise. Some of the steps the city has taken include, but are not limited to, the following. (https://www.cityofsanrafael.org/what-is-the-city-doing-around-adapting-to-climate-impacts/)

- In 2014, San Rafael released *Climate Adaptation - Sea level Rise*, a preliminary whitepaper that identified agencies and resources that provide information related to sea level rise throughout the Bay Area. Next steps were proposed along with the possible challenges that may affect the climate adaptation planning process. Adaptation strategies potentially suitable for San Rafael were identified as well.
- In June 2017, San Rafael prepared a Local Hazard Mitigation Plan (LHMP) to help guide hazard mitigation planning. The LHMP identifies and assesses many types of hazards that may affect San Rafael in the future, including 100- and 500-year floods, localized flooding, and levee failure. Vulnerability assessments were conducted to analyze the effects of the identified hazards. The LHMP also provides mitigation strategies to address the vulnerabilities and information regarding the successful implementation of the strategies.
- In June 2017, as a part of the County of Marin's BayWAVE initiative, the Marin Shoreline Sea Level Rise Vulnerability Assessment was released. This assessment identified vulnerabilities related to sea level rise and flooding in areas along the bay shoreline and near waterways that drain to the bay. This report has been used to further climate adaptation efforts by communities throughout Marin County, including San Rafael.
- In May 2018, the Resilient by Design Challenge: Elevate San Rafael project brought together local residents, public officials, and local, national, and international experts to help develop

innovative strategies to address risks related to sea level rise, severe storms, flooding, and earthquakes. Elevate San Rafael envisioned a scenario in which the San Rafael waterfront has been physically elevated to both mitigate the near- and long-term risks of flooding, as well as raise the quality of life for local residents of the community.
- In March 2019, San Rafael adopted its Wildfire Prevention and Protection Action Plan (WPPAP), which outlines goals to aggressively address the wildfire risks.
- In May 2019, San Rafael adopted the San Rafael Climate Action Plan 2030 (CCAP 2030), which focuses on reducing greenhouse gas emissions and pollution that contributes to climate change. The plan includes programs to adapt rising sea levels and expected impacts of climate change.
- In July 2020, San Rafael released its Flood Risk & Sea Level Rise Adaptation Report. This report builds off the foundation laid by the 2017 Marin Shoreline Vulnerability Assessment conducted under the BayWAVE initiative. This report outlines initial guidance for developing an adaptation plan and includes policy and regulatory measures, financing and insurance information, and other information related to implementing adaptations.
- Ongoing: San Rafael General Plan 2040 is currently in development. The city released a draft in October 2020 and has published changes made to the draft as of May 2021. The 2020 Flood Risk & Sea level Rise Adaptation Report will be incorporated in the General Plan 2040.

# Appendix B: SLR Modelling

## Model Limitations

### Lack of Coordinated Flooding (FEMA) / SLR Data and Modeling

One distinct issue in predicting the impact of SLR on the City is its location at the upper reaches of a tidal slough. The city experiences significant flooding in the FEMA 100-year flood event (for example the Denman Reach), in an area just upstream from the limit of SLR induced flooding we have shown in the maps above (for example Downtown). Increased sea levels will induce higher water levels in the river during peak storm events. A higher bay/river level can create a backwater condition where creeks or stormwater infrastructure are not as able to drain. Though FEMA flood maps are frequently revised, and consider the actual Sea Level, they do not model for conditions under future SLR scenarios. This means there is no flood model currently available which shows the combined effect of a 100-year storm on creek flooding as under future SLR scenarios. In 2017, the Marin vulnerability assessment produced for the BayWAVE project remarked that "One limitation of the model and every sea level rise model available at this time is the failure to combine sea level rise, stormwater drainage, and creeks."[38] Other SLR and flooding assessment efforts in the Bay Area continue to share the same weakness. This is a critical data gap that the City of Petaluma has been attempting to fill. This means that the planning process can currently rely either on SLR flood predictions or FEMA 100-year flood maps, but not any resource which integrates both. It is a goal of this general plan update to incorporate overlay maps to study the cumulative/integrated effects of both storm and SLR flood scenarios.

### Only Showing Current Development/Census

While SLR predictions look forward decades and centuries, they cannot predict changes to the developments around the city, or up and down the county. As the upper watersheds are further developed, peak storm runoff is likely to increase, resulting in more impacts from the 100-year flood event. Additional development near the river, floodplains or creeks, and are therefore "expanding the bullseye", creating more structures and people to be impacted by future flood events. Estimated financial impacts are based on current values. The model assumes no changes to existing landform, flood control structures such as levees, which may be improved, removed, or naturally fail.

### Dense Vegetation at the Petaluma River causes CoSMoS to Underpredict Flooding Elevation

Another known issue is that the OCOF SLR viewer is based on a 2-meter Digital Elevation Model (DEM) collected using LiDAR scans in 2010/2011. Mapping may not properly render the flooding in marsh lands due to the elevation model being distorted by standing vegetation. Though very detailed, these scans can

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[38] *BVB Consulting LLC. "Marin Shoreline Sea Level Rise Vulnerability Assessment." Marin Watershed Program. Marin County Department of Public Works, Jun 2017, page xv,* https://www.marinwatersheds.org/sites/default/files/2019-04/BAYWAVE%20final.pdf.

misconstrue dense vegetation as land. In marsh areas this can cause the flood model to underestimate the flooding in an area, or overestimate that area's effectiveness as a high spot which might be blocking flooding from reaching further inland. This is more of a concern for the baylands south of Petaluma but may still be relevant to the south portion of the city.

# Future Refinement of Modeling to Inform Updated Analysis

## Hydrologic Models with integrated SLR scenarios

A Hydrologic Model is required which considers the impact of different sea level rise predictions, including various storm surges, on the 100- and 500-year Storm flooding in the upper watershed.

## Unpredictability of Climate Change

This paper, and the cities LHMP SLR impacts section used SLR predictions based on the 2018 California Sea Level Guidance (OPC 2018). That report superseded the previous 2013 guidance which used 2012 SLR predictions from the National Research Council (NRC) which did not provide probability ratings to the different predictions. Even in the short time between 2012 and 2018 the science of climate modelling had significantly improved and was showing that the rate of ice loss was increasing. In 2020, the Ocean Protection Council released the "Making California's Coast Resilient to Sea Level Rise: Principles for Aligned State Action" (OPC 2020). This recommended simplifying the OPC 2018 risk-based scenarios for one unified prediction, 3.5' of SLR by 2050. This value supersedes the previous guidance, including the H++ extreme case, but provides for more adaptation time. One critical focus was to "Develop and utilize more protective baseline 2050 and 2100 targets for road, rail, port, power plants, water and waste systems, and other critical infrastructure." (OPC 2020) This white paper uses the more detailed, probability-based guidance of the 2018 OPC.

## Extreme Events Scenarios (H++), Increased Rainfall

Utilizing the 2018 OPC guidelines this paper shows two risk-levels of SLR predictions, the "Likely" scenario with a 66% chance of exceedance, and the "High Risk" with a 0.5% chance. The OPC report does however state that "The probabilistic projections may underestimate the likelihood of extreme sea-level rise (resulting from loss of the West Antarctic ice sheet), particularly under high emissions scenarios." It provides these extreme case predictions as its "H++" predictions. Due to the data showing increased vulnerability of the West Antarctic ice sheet being so new, this scenario has not been provided a probability, but it should be clarified, that does not mean it is any more or less likely than the "High Risk" scenario, but merely that the probability has not yet been published. The H++ scenario for 2100 predicts a sea level rise of 10.2', significantly more impactful than the "High Risk" 2100 scenario of 6.6'. These extreme scenarios become more likely if emissions cuts are not drastically undertaken and could lead to sea level rise above 2 inches per year 30-40 times the rate experienced over the last century.

What is also not considered in this report but should be considered in the City's long-range planning is the prevailing science which indicates that California will experience rainfall events of a higher intensity, which causes higher flood events. The 100-year storm is described as the storm with a 1% chance of occurring each year, but climate change will likely bring those storms more frequently.

## Evolution of SLR Modeling on Long Range Planning Efforts

As SLR Models improve with improved mapping, updated SLR projections, new urban developments, new weather forecasts, and improved FEMA flood maps, Cities and planning authorities will need to update their forecasted impacts. These maps should be based on the most up to date and reliable science of their time, but with an eye for risk aversion from the extreme scenarios as well.