

Draft

CENTRAL COAST HIGHWAY ONE CLIMATE RESILIENCY STUDY

Study Report

Prepared for
Association of Monterey Bay Area
Governments (AMBAG)

May 2020



The Nature
Conservancy



Middlebury Institute of
International Studies at Monterey
Center for the Blue Economy



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ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Definition
AADT	Annual Average Daily Traffic
AMBAG	Association of Monterey Bay Area Governments
BIRIS	Bridge Inspection Records Information System
CalSTA	California State Transportation Agency
Caltrans	California Department of Transportation
CBE	Center for the Blue Economy
CCC	California Coastal Commission
CCWG	Central Coast Wetlands Group
CDFW	California Department
ESA	Environmental Science Associates
ESF	Elkhorn Slough Foundation
ESNERR	Elkhorn Slough National Estuarine Research Reserve
GHG	Greenhouse Gas Emissions
Hwy	Highway
MLW	Mean Low Water
MLLW	Mean Lower Low Water
MLWA	Moss Landing Wildlife Area
MSL	Mean Sea Level
MHW	Mean High Water
MHHW	Mean Higher High Water
MLML	Moss Landing Marine Labs
MP	Milepost
MTP/SCS	Metropolitan Transportation Plan/Sustainable Communities Strategy
OPC	Ocean Protection Council
SCC	California State Coastal Conservancy
SLAMM	Sea Level Affecting Marshes Model
sea-level rise	Sea Level Rise
SR	State Route
TAMC	Transportation Agency for Monterey County
TCR	Transportation Concept Report
TNC	The Nature Conservancy
VHT	Vehicle Hours Traveled
VMT	Vehicle Miles Traveled

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1. EXECUTIVE SUMMARY

Elkhorn Slough is a major estuary located in Monterey Bay, California that provides valuable habitat area for hundreds of aquatic bird, fish, marine mammal and invertebrate species. With nearly 2,700 acres of a suite of intact habitat types, the Slough is critical to regional biodiversity. Estuarine habitats within the Slough and the ecosystem services they provide are at risk to substantial losses with sea-level rise. With Central California already having lost over 90% of its historical estuarine marsh habitat area (Brophy et al. 2019), every effort is needed to maintain what remains in the face of sea-level rise. Presently, Elkhorn Slough holds the third largest extent of estuarine marsh in California, however, approximately 85% of this area may be lost with sea-level rise.

Transportation assets in this region are also vulnerable to sea-level rise impacts. The eight-mile stretch of Highway One through Elkhorn Slough is a critical transportation asset for the region and beyond, providing local access to Moss Landing, essential to freight movement and the economy, and a major commuting route. With 2 feet (ft) sea-level rise, major disruptions to its transportation function are anticipated. The railway, which traverse the Slough for five miles, is also critical to freight movement and envisioned to serve expanded passenger service to meet the needs of a growing population. Extreme tides, known as “King Tides” already cause periodic flooding and disruptions to the railway, which will increase in frequency and severity as sea levels rise.

Maintaining or enhancing both transportation function and the extent of estuarine marsh in Elkhorn Slough are important priorities for the Central Coast and beyond. The Central Coast Highway One Climate Resiliency Study (Study) is a unique partnership between the Association of Monterey Bay Area Governments (AMBAG), California Department of Transportation (Caltrans), The Nature Conservancy (TNC), the Center for the Blue Economy (CBE) at the Middlebury Institute of International Studies (CBE), and Environmental Science Associates (ESA) to develop and evaluate adaptation strategies for Highway One, the railway and surrounding ecology through Elkhorn Slough. Integrating regional development and adoption of natural infrastructure and transportation planning can provide better outcomes for both sectors (Marcucci & Jordan, 2013) and Federal Highway Administration guidance and California policy are encouraging this integrated approach (Safeguarding California Plan: 2018 Update, 2018). The project was funded by the Caltrans via an SB-1 adaptation planning grant, with additional funding provided by AMBAG, TNC and the CBE.

The Project Team coordinated with a wide range of local and regional stakeholders to gather existing conditions, develop transportation and ecological adaptation concepts,

develop adaptation scenarios, and refine and modify the concepts and scenarios with Steering Committee and community input. Throughout the study, an adaptation pathways approach was used in order to explore a variety of strategies that could cultivate transportation and ecological resilience over a range of time horizons (Hasnoot, 2013). A suite of near-term actions (e.g. next ten years) are identified to mitigate flooding impacts to transportation and ecology, in addition to developing long-range adaptation scenarios to be implemented later in the century. The adaptation pathways approach yields deeper insight into what additional steps (e.g. planning, timing, funding) may be necessary to bridge near-term actions to a long-term vision. After assessing a preliminary suite of adaptation scenarios, three revised roadway and railway adaptation scenarios, which were compared against a no action scenario, were evaluated and are described below:

- **Scenario C0 (No-Action):** No Action
- **Scenario C1 (2-Lane Elevated Highway):** Two Lane Highway One Elevated, Single Track Railway on Trestle adjacent to existing alignment and Marsh Restoration East of Railway
 - **Scenario C1A:** Reaches 1-4 elevated on piles with levee ecotone
 - **Scenario C1B:** Reaches 1, 3 and 4 elevated on piles, Reach 2 by Moss Landing Wildlife Area elevated on fill with levee ecotone
- **Scenario C2 (Managed Retreat/Widening G-12 4 Lanes):** Managed Retreat to relocate Highway One traffic capacity inland to existing G-12 roadway, G-12 Widening to 4 Lanes, Single Track Railway on Trestle adjacent to existing alignment and Marsh Restoration East of Railway
- **Scenario C3 (4-Lane Elevated Highway):** Four Lane Highway One Elevated along existing alignment, Single Track Railway on Trestle adjacent to existing alignment and Marsh Restoration East of Railway
 - **Scenario C3A:** Reaches 1-4 elevated on piles with levee ecotone
 - **Scenario C3B:** Reaches 1, 3 and 4 elevated on piles, Reach 2 by Moss Landing Wildlife Area elevated on fill with levee ecotone

The roadway and railway adaptation scenarios were evaluated using best available modeling tools to investigate systemic changes to transportation, hydrology and ecology triggered by certain adaptation actions. Building upon the results of the hydrodynamic, transportation and habitat modeling, a probabilistic benefit-cost analysis was applied to the scenarios to account for the valuation of ecosystem services and transportation function and provide perspective on which adaptation scenario provides more in gains than is given up in costs. The major takeaways from each portion of the evaluation are briefly described here.

Transportation Modeling

AMBAG utilized the Regional Transportation Demand Model (RTDM) to evaluate the proposed transportation improvements in the adaptation scenarios in order to identify the most viable and effective solution for the study area. The results of the modeling for each scenario were compared against one other and to a no action scenario to analyze the impacts of each under a variety of performance metrics. These performance metrics are indicators of how the adaptation scenarios would perform and how effectively they would serve the needs of this critical transportation corridor with future growth and demand.

The results of the transportation modeling indicate that Scenario C3 (4-Lane Elevated Highway) would best suit the needs of the corridor, allowing for increased capacity on a road that is already overburdened by demand. Widening Highway One to four lanes would provide the greatest relief to congestion and delay, leading to less time spent on the roadway and greater ease of travel. Allowing the roadway to flood (No Action Scenario) would not only increase congestion and delay in the study area, it would limit access to transit for disadvantaged communities within the Moss Landing and Elkhorn Slough area. Scenario C2 (Managed Retreat/Widening G-12 4 Lanes) presents the same problems as a no action scenario, and does not outperform Scenario C3 (4-Lane Elevated Highway) under any transportation metric. An elevated two-lane Highway One (Scenario C1) does not provide relief to the demand on Highway One that already exists in the study area, but does present viable operational improvements that can be implemented to benefit travel time and safety through the corridor.

Flood Hazards Modeling

ESA applied the Coastal Resilience Monterey Bay (CRMB) hazard mapping resource to assess the extents of Highway One at risk to flooding, resulting in identification of four sections of Highway One, called Reaches 1, 2, 3 and 4 (Figure 3). Reach 1 is between Struve Pond and Bennett Slough; Reach 2 is between the North Harbor and Bennett Slough; Reach 3 crosses Moro Cojo Slough, and Reach 4 crosses an historical slough, now a swale / drainage through agricultural lands. ESA then updated the CRMB maps to better account for micro-topography, overland flow and existing hydraulic control structures, resulting in revised flood water-surface elevations for each Reach for monthly and 100-year recurrence floods from coastal and river sources under existing and future climate-effected sea-levels and runoff from the Reclamation Ditch - Gabilan Creek drainage. The refined flood hazard mapping indicates Highway One will be impacted by a 100-year flood by 2030 (less than one foot of sea-level rise), and by monthly high water by 2050 (about 2 ft of sea-level rise).

The high CRMB sea-level rise scenarios were used, amounting to 2.4 ft by 2060 and 5.2 ft by 2100, and rounded to 2 ft by 2050 and 5 ft by 2100 in subsequent hydrodynamic and habitat modeling. This sea-level rise scenario is similar to but lower than the most recent (2018) California guidance for a medium-high risk aversion scenario.

Hydrodynamic Modeling

ESA utilized the Delft3D hydrodynamic model to evaluate impacts to overall Slough hydrodynamics as a consequence of sea-level rise for the proposed roadway and railway adaptation scenarios. Flood extents, water depths and velocities were analyzed at locations within the study domain to assess changes in local hydrologic conditions.

Hydrodynamic modeling results indicate that a new flood pathway east of the managed ponds in Moss Landing Wildlife Area will develop under 2 to 3 ft of sea-level rise (time horizon of 2050 to 2070), with or without roadway modifications. Consequently, Struve Pond and Upper Bennett Slough will be tidally connected to the main channel of Elkhorn Slough. This indicates that improvements made to the roadway (e.g. elevating a segment on piles or fill) will have decreasing control over flooding in this part of the Slough, as sea-level rises. Additionally, the model shows overtopping of Potrero Road and Moss Landing Road, resulting in bypassing of tide gates and overland flooding of the low-lying agricultural parcels by Highway One and Moro Cojo Slough, assuming 3 ft of sea-level rise. Likely, around mid-century, maintaining farming operations in the low-lying agricultural lands near Reaches 3 and 4 will be untenable. These results support ongoing integrated, collaborative efforts around Moro Cojo Slough to plan for future land use under SLR.

The hydrodynamic modeling also shows that tidal velocities in the main Slough channel will increase under future sea-level rise in all scenarios, which will exacerbate net sediment export and marsh loss within the system. Under proposed marsh restoration of the complexes east of the railway (about 700 acres of intertidal areas), the overall increase in tidal prism associated with sea-level rise is reduced.

Habitat Modeling

ESA utilized the Sea Level Affecting Marshes Model (SLAMM) to predict wetland habitat evolution within the Slough for the roadway and railway adaptation scenarios and to assess how much additional wetland habitat could be provided from proposed marsh restoration east of the railway, compared to a no action scenario.

The habitat modeling results strongly support action to create and sustain estuarine marsh habitat acreages within the Slough. Raising the marsh plain grade to future MHHW at mid-century for Parsons Slough, North/Estrada Marsh and Azevedo Ponds is predicted to have longevity over several decades. This action would enhance 700 acres at 2050. Around 290 acres of additional restored estuarine habitat remain at year 2100 (5 ft of sea-level rise) as a consequence of proposed marsh restoration. As estuarine habitats throughout the Slough are drowned under sea-level rise, the importance of these complexes and the ecosystem services they provide to the Slough will grow. The cost and difficulty of restoring marshes to higher tidal elevations after mid-century will increase substantively, given that many habitat acres may have already converted to estuarine open water.

Additionally, proposed grading by Reach 2 for levee ecotone creation for Scenarios C1A (2-Lane Elevated Highway with Reach 2 on Piles), C1B (2-Lane Elevated Highway with Reach 2 on Fill), C3A (4-Lane Elevated Highway with Reach 2 on Piles) and C3B (4-Lane Elevated Highway with Reach 2 on Fill) will produce between 72 to 83 acres of estuarine marsh habitat, assuming construction by mid-century. Since this study is planning-level, if there is interest in pursuing this adaptation measure, the total number of estuarine marsh habitat acreages will likely be refined and could potentially be greater. Scenarios C1B (2-Lane Elevated Highway with Reach 2 on Fill) and C3B (4-Lane Elevated Highway with Reach 2 on Fill) result in the greatest number of estuarine marsh habitat from the associated restoration adaptation actions across the different scenarios (607 acres remaining at 2100, compared to 260 acres from the no action scenario).

The model results also confirm that in addition to restoration of existing wetland habitat, present and future land use planning for low-lying agricultural lands by Reaches 3 and 4 will have a significant impact on how much wetland habitat will exist in the future. The parcels south and southwest of Moro Cojo Slough, if allowed to convert, represent a strong opportunity to mitigate wetland habitat loss (up to 50%) experienced by Elkhorn Slough under future sea-level rise.

Benefit-Cost Analysis

Data from the analysis of changes in the transportation system and in Elkhorn Slough brought about by sea-level rise and the choices made about adaptation responses were used to conduct a benefit-cost analysis of the options under consideration. The benefit-cost analysis allows comparison of different consequences on a common monetary basis and permits identification of those scenarios that most likely to return more in gains than is given up in costs.

The results of the analysis show that the costs of doing nothing about sea-level rise's possible effects on Highway One are likely to far exceed the benefits of saving money by taking no action. Of the three response scenarios, only the combined elevation and widening to four lanes of Highway One return more in benefits than their costs. This includes the costs of both the highway and the wetlands enhancements/restoration. Scenario C1 (2-Lane Elevated Highway) returns less than its costs because traffic delays and safety costs remain high with a continued two-lane configuration. Scenario C2 (Managed Retreat/Widening G-12 4 Lanes) also costs more than its benefits because of high delay and safety costs.

The benefit-cost analysis also considered how to address the uncertainties about the pace and extent of sea-level rise. Following guidance from the California Ocean Protection Council, the assumptions of sea-level rise are conservative (that is high sea-level rise but with low probability). Using these probabilities, the analysis examines the point at which sea-level rise hazards are great enough to initiate planning for a major project on Highway One. The result indicates that a point in the early 2040s when sea-level rise-enhanced storm flooding on Highway One indicates a high probability that

future damages from sea-level rise will be sufficient to economically justify some adaptation.

Major Takeaways

The results of the evaluation emphasize the importance of planning for Highway One and railway adaptation in the early to mid-2030s and implementing a course of action well before sea levels are predicted to follow the exponential part of the curve in mid- to late- 21st century. Following Scenario C0 (No Action) inadvertently, by delaying action on climate change adaptation, will result in widespread loss of habitat and biodiversity through the Slough (up to 85% of estuarine marsh habitat) and worsen an existing transportation function problem, to the detriment of the community, region, and the many visitors to Monterey Bay. A no action pathway is not a viable option for Moss Landing and Elkhorn Slough. The benefits of implementing adaptation actions, such as large-scale marsh restoration, are greater the earlier they happen in the century (2030s).

Based off of the analysis in this study, Scenario C3 (4-Lane Elevated Highway) would be economically justified, since the value of reduction in traffic delays would be greater than the costs associated with transportation and ecological improvements. However, the analysis also indicates that if it were possible to significantly reduce delays for Scenario C1 (2-Lane Elevated Highway), potentially through shifts in alternate modes of travel or technological changes in motor vehicle transportation, Scenario C1 (2-Lane Elevated Highway) would also be viable. Construction of a new highway facility would have numerous adverse impacts on adjacent wetland habitat. Further study and analysis in the next decade will be necessary in order to investigate the impacts of both scenarios at a more detailed level. Pathways to partnerships and processes supporting integrated approaches around climate change adaptation, including triggers for collective action, must be in place now in order for communities and ecosystems to successfully adapt to future sea levels. The process and findings presented in this study will hopefully serve as a critical link to the future of the transportation and ecology by Moss Landing and Elkhorn Slough.

2. STUDY NEED, OBJECTIVES AND FRAMEWORK

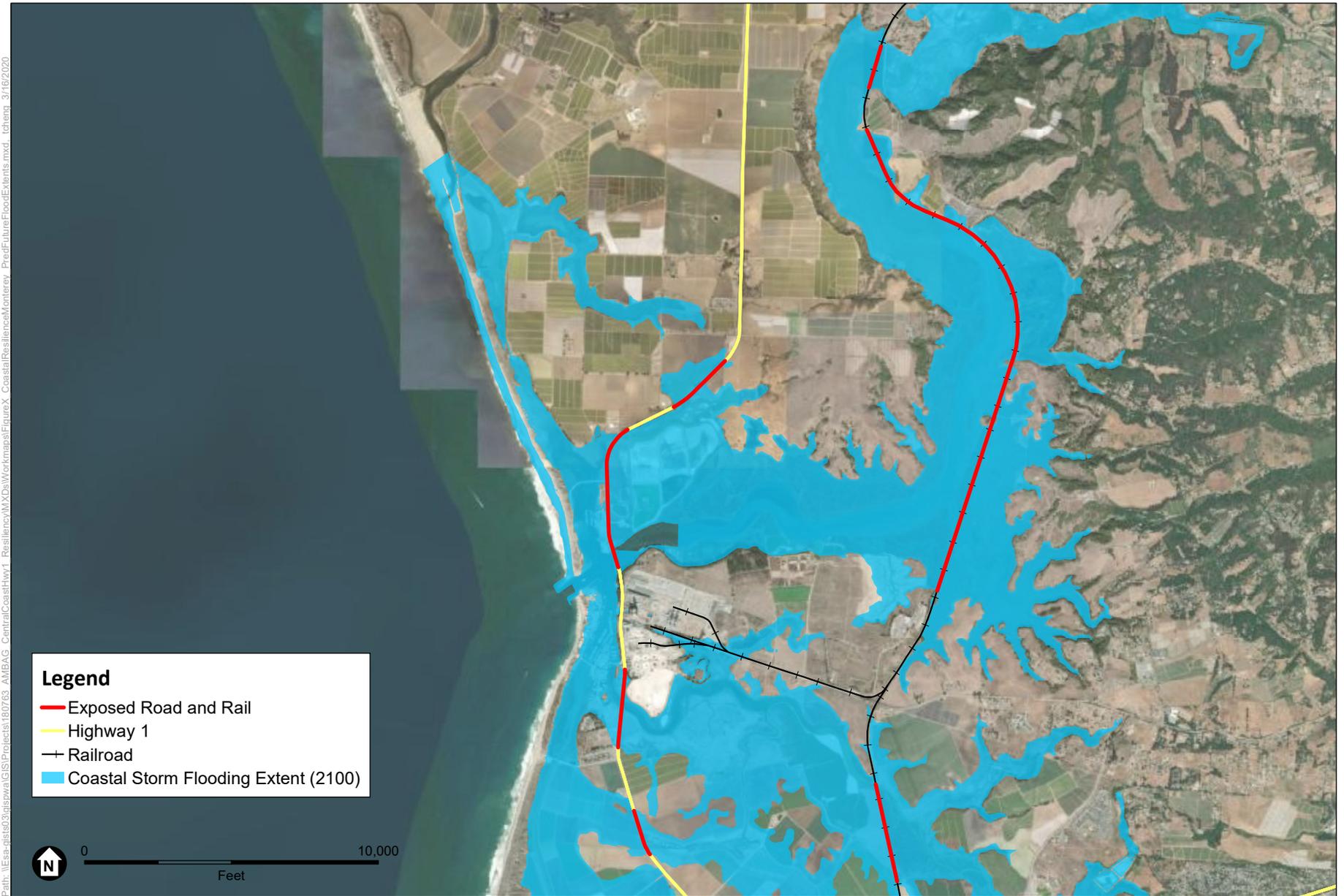
2.1 Study History

The Central Coast Highway One Climate Resiliency Study (Study) is a unique partnership between the Association of Monterey Bay Area Governments (AMBAG), Caltrans, The Nature Conservancy (TNC), the Center for the Blue Economy at the Middlebury Institute of International Studies (CBE), and Environmental Science Associates (ESA) on climate change adaptation planning for Highway One and the railway through Elkhorn Slough and surrounding ecology. Integrating regional development and adoption of natural infrastructure and transportation planning can provide better outcomes for both sectors through more responsive regional transportation, shared funding, preservation or enhancement of local ecosystem services, and streamlining of the project environmental review process (Marcucci & Jordan, 2013). Guidance documents from the Federal Highway Administration and California policy are encouraging this integrated approach, although relatively few demonstrations have been implemented (Webb et al., 2019) (Safeguarding California Plan: 2018 Update, 2018).

Previous flood hazard mapping work for the Coastal Resilience Monterey project show these major transportation assets and large swaths of Slough habitat, which provide invaluable ecosystem services to the region at large, are at risk under future sea-level rise (sea-level rise), with some areas impacted as soon as 2030 (**Figure 1**). The study began in October 2018 and will conclude in June 2020, with a final report deliverable summarizing the data collection, development and evaluation of long-term adaptation scenarios and recommendations for future near-term actions. The study is funded through the Caltrans Adaptation Planning Grant Program, part of Senate Bill 1 (SB 1), which intends to advance adaptation planning by local and regional agencies on state transportation infrastructure. The study does not conform to standard Caltrans transportation procedures, and does not necessarily inform Caltrans planning. The California State Transportation Agency (CalSTA) providing additional funding in Spring 2019 to include adaptation planning for the railway in this study.

2.2 Study Need

The study is a first step in developing transportation improvements and nature-based strategies that work in tandem to enhance ecological and transportation resilience through the Moss Landing and Elkhorn Slough area under future conditions, including sea-level rise. Primarily, the transportation assets the study focuses on are Highway One



SOURCE: Coastal Resilience Monterey (2019)

Central Coast Highway 1 Climate Resiliency Study . D180763.00

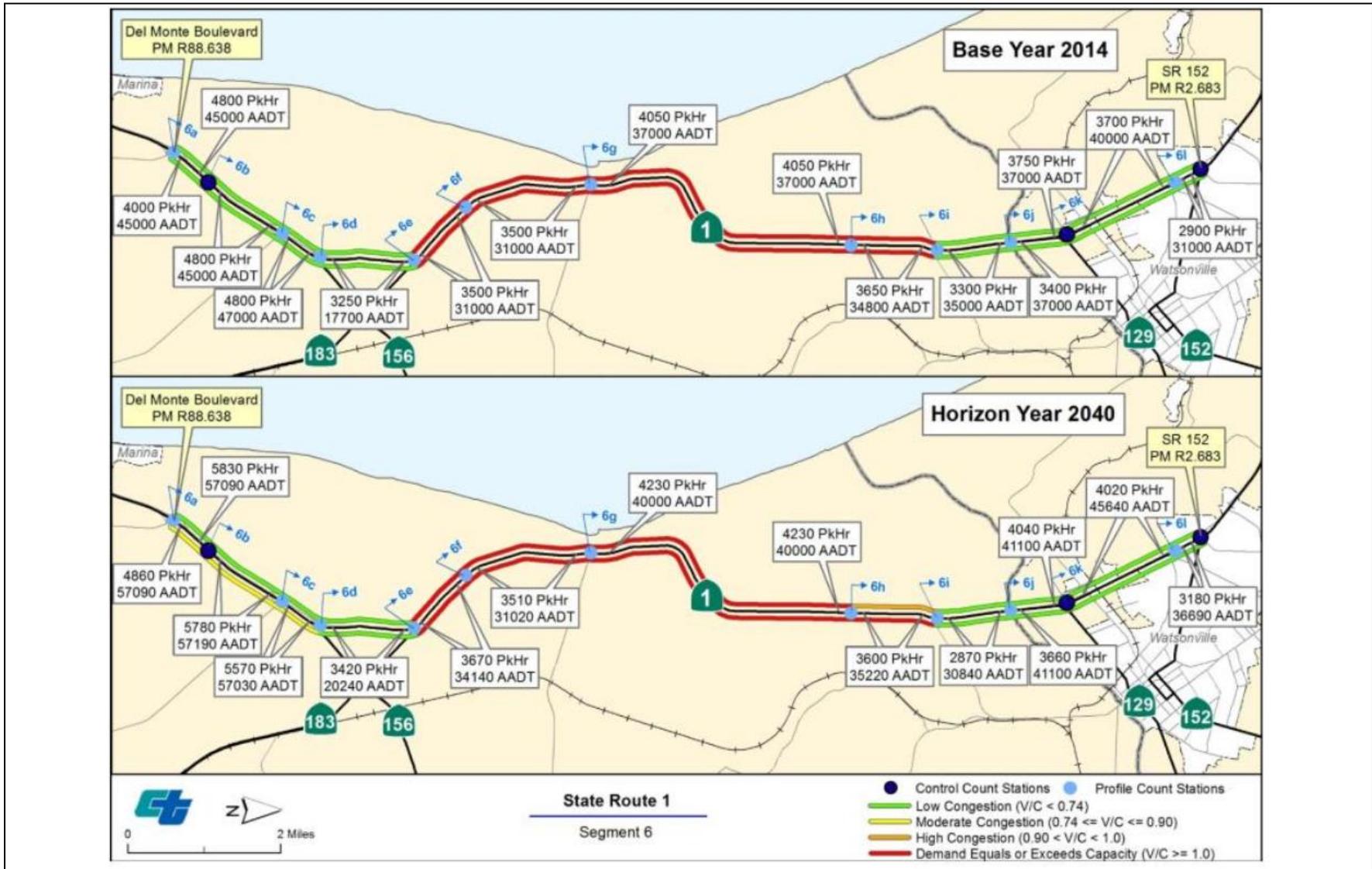
Figure 1
Coastal Resilience Monterey
Predicted Future Flooding Extents (2100)

and the railway. The adaptation scenarios from this study are planning-level and informed by, at the time of the study process, the most recent and available data from Monterey County and relevant stakeholders. The outcomes of this study are intended to inform future transportation and nature-based adaptation strategy planning and design for the roadway, railway and adjacent areas.

Inadequate Transportation Function. Existing transportation demand on Highway One near Elkhorn Slough is severely constrained and passengers regularly experience long traffic delays in this corridor. The corridor experiences frequent disruptions to traffic flow, which impact overall safety. The California Highway Patrol Statewide Integrated Traffic Records System (SWITRS)¹ show about 700 reported collisions along the Highway One study area between January 1, 2013 and December 31, 2018, a number of which are focused in the northern section of the study area and in the area south of Dolan Road. The highway is a major coastal route for commuters from the Santa Barbara, San Luis Obispo, Monterey and Santa Cruz Counties within Caltrans District 5. **Figure 2** shows existing and future traffic volumes for Highway One, which indicate the need to improve transportation function in this corridor. Both Highway One and the Elkhorn Slough railway will be increasingly impacted by flooding as sea levels rise, with some segments of transportation infrastructure already flooding during present-day king tides².

Loss of Wetland Habitat. Elkhorn Slough is the 7th largest estuary in California at over 3,400 acres, with the third largest extent of salt marsh in the state. The Slough provides critical habitat for more than 135 aquatic bird species, 550 marine invertebrate species, and 102 fish species, including six species that are threatened and endangered. It is also home to southern sea otters, sea lions, harbor seals, and more than 200 different bird species that use the Slough as a resting spot during their annual migration. Over the last 70 years, Elkhorn Slough has lost half of the valuable tidal marsh habitat, approximately 1000 acres, due to human impacts and development (Elkhorn Slough Tidal Wetland Project Team, 2007). The wetland habitats work to improve water quality by filtering polluted waters, provide high carbon sequestration rates, and serve as key nursery habitat for commercially valuable fisheries. Sea-level rise is projected to accelerate habitat conversion within the Slough from salt marsh to mudflat and permanently drowned estuarine waters, sharply decreasing habitat for marsh-dependent wildlife species.

-
- 1 The California Highway Patrol Statewide Integrated Traffic Records System (SWITRS) can be accessed at this address: <http://iswitr.chp.ca.gov/>
 - 2 King tide refers to an ocean and Elkhorn Slough water level that happens about once per year during high astronomical tides, and often elevated by winter weather, as well as climate conditions such as El Niño and abnormally warm ocean waters.



SOURCE: Caltrans Transportation Concept Report (TCR) State Route 1 (SR-1) (2017)

Central Coast Highway 1 Climate Resiliency Study
Figure 2
 Existing and Projected Future Travel Demand in Study Area

2.3 Goals & Objectives

The Project Team developed study objectives, which were refined with input from the Steering Committee. The study objectives are to:

- *Evaluate and identify the transportation and ecological needs of the study area*
- *Develop a suite of nature-based adaptation strategies and transportation improvements to enhance the transportation and ecological resilience of the study area under projected future sea-level rise conditions*

The study utilizes an adaptation pathways framework to develop adaptation scenarios that will be resilient to future sea-level rise and adaptable to future anticipated changes. Given the complex nature of impacts posed to the transportation, ecological and community resources by climate change, the study does not suggest a single preferred adaptation scenario for further evaluation. A subset of adaptation scenarios, with Steering Committee and community input, were refined and are presented as potential options for the future. For planning purposes, the study assumes a sea-level rise projection of 2 feet by 2050 and 5 feet by 2100. These values are consistent with the upper range of projected sea-level rise indicated in the National Research Council's 2012 report (NRC, 2012) and previous flood hazard mapping from the Coastal Resilience hazard mapping³. The sea-level rise amounts are similar to but slight lower than the medium-high risk aversion scenario defined by recently updated California policy (CalNRA and OPC 2018; CCC 2018).

2.4 Framework

The Project Team initiated a public planning process to encourage communication and collaboration with a range of local stakeholders, community members, regulatory agencies and others. The study planning process included a Project Team, a Steering Committee, community outreach and early coordination with regulatory agencies and major stakeholders in the area through the duration of the study.

i. Project Team

The Project Team is comprised of the Association of Monterey Bay Area Governments (AMBAG), The Nature Conservancy (TNC), Center for the Blue Economy (CBE) and Environmental Science Associates (ESA) and WMH Corporation, Inc. WMH provided highway engineering expertise for the adaptation scenarios development. Members from Caltrans Headquarters, Caltrans District 5 and the Transportation Agency of

³ Coastal Resilience Hazard Mapping resources for Monterey Bay are described in ESA PWA 2014 (https://maps.coastalresilience.org/california/methods/sea-level-rise_Monterey.pdf) . Hazard maps for Monterey Bay and other locations are available on line at (last visited May 2020): <https://maps.coastalresilience.org/>

Monterey County (TAMC) regularly attended monthly team meetings to provide input on study direction and progress. Valle Translations, Inc. provided interpretation and translation services for the public workshops.

ii. Steering Committee

A Steering Committee was assembled at the beginning of the study, November 2018, to provide feedback on the project and adaptation scenario development and evaluation. The Committee includes representatives from local and regional transportation agencies, state and federal government agencies, the Moss Landing community, and conservation non-profits and research groups affiliated with Elkhorn Slough. Over the course of the study, the Committee has met four times: February 2019, July 2019, December 2019 and April 2020.

The Steering Committee consists of representatives from:

- California Department of Fish and Wildlife (CDFW)
- County of Monterey
- California Coastal Commission (CCC)
- State Coastal Conservancy (SCC)
- Central Coast Wetlands Group (CCWG)
- Caltrans Headquarters and District 5
- Elkhorn Slough Foundation (ESF)
- Elkhorn Slough National Estuarine Research Reserve (ESNERR)
- Moss Landing Harbor District
- Ocean Protection Council (OPC)
- Transportation Agency of Monterey County (TAMC)

The Steering Committee has provided valuable feedback to the Project Team, including information on concurrent local and regional planning studies, existing conditions and constraints and input on adaptation concepts and scenarios.

iii. Community Meetings

As part of the study input process, the Project Team convened community meetings in Moss Landing and Marina for interested members of the public to learn more about the

study and provide feedback and comments on the study and adaptation scenarios. To date, the Project Team has held two public meetings:

- *August 2019* – to present and discuss study background, goals and objectives, and initial adaptation concepts
- *February 2020* – to present and discuss the evaluation of adaptation scenarios and gather input for strategies moving forward

iv. Web-based Outreach

AMBAG hosts a study website to provide project information, including project funding sources and collaborators, to the public. Materials and notes from the public meetings are posted here: <https://ambag.org/programs-services/planning/central-coast-highway-1-climate-resiliency-study>

v. Early Agency Coordination

The Project Team conducted additional outreach with and gathered input from members of regulatory and policy state agencies who are expected to have an interest in the adaptation scenarios developed in the Project Team meetings and community meetings, including:

- California Coastal Commission (CCC)
- State Coastal Conservancy (SCC)
- California Ocean Protection Council (OPC)

vi. Virtual Reality Visualization Tool

The Project Team, with Virtual Planet Technologies, is developing a virtual reality experience to visualize sea-level rise impacts, adaptation scenarios and communicate results from the study analyses to the stakeholders and the community. The tool is currently in development and is expected to be complete by September 2020.

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3. EXISTING CONDITIONS

3.1 Site Location

The study area encompasses Highway One by Moss Landing, Elkhorn Slough habitats and the railway, and adjacent lands. Moss Landing is located mid-way in Monterey Bay, approximately 16 miles north of the City of Monterey and 25 miles south of the City of Santa Cruz. The study focuses on the eight miles of Highway One, from MP 94 to MP 102 and five miles of railway located within Elkhorn Slough. **Figure 3** shows the study area and segments of exposed transportation infrastructure at risk from sea-level rise.

3.1.1. Surrounding Land Uses and Property Ownership

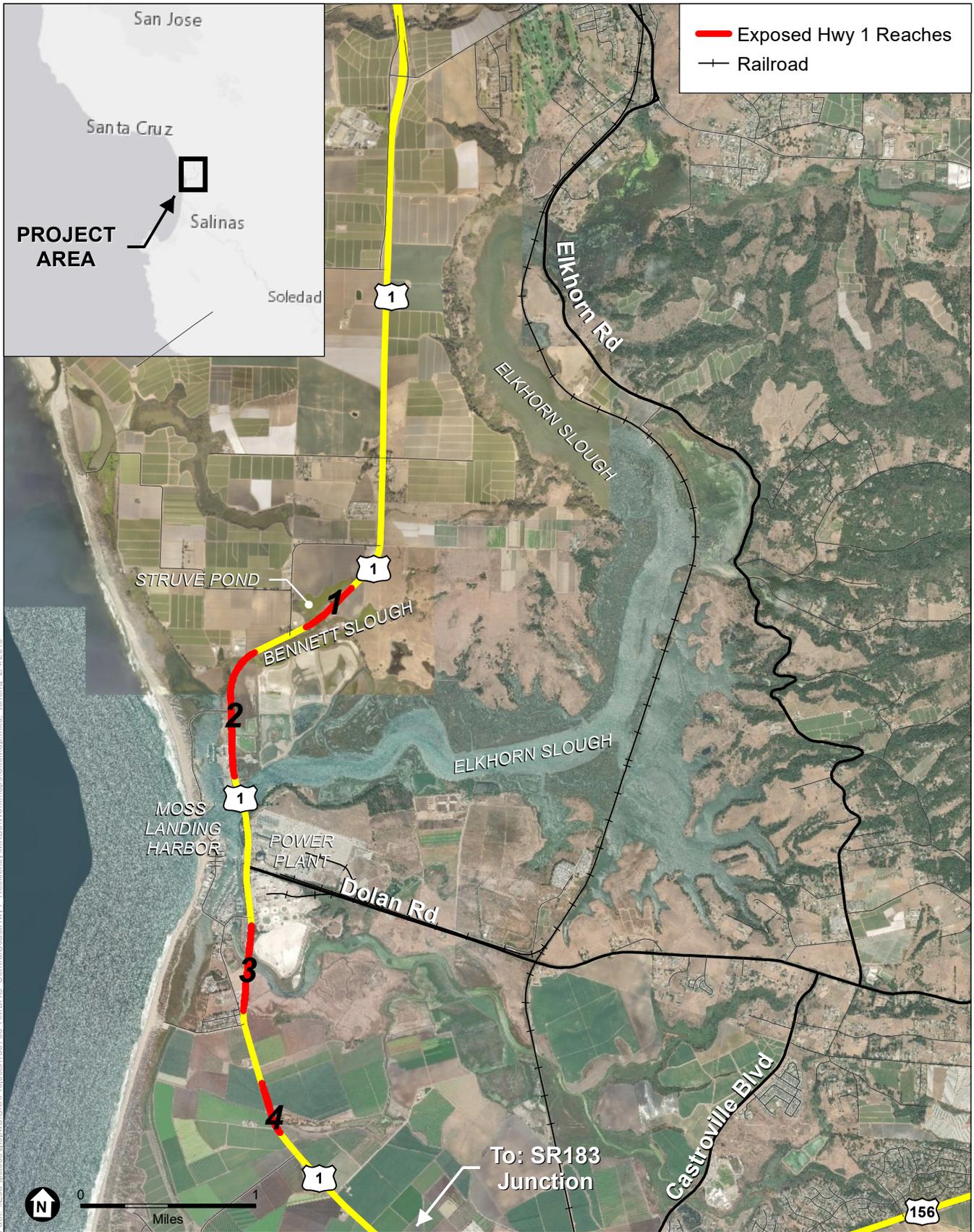
Figure 4 shows existing land use within Moss Landing and Elkhorn Slough (Caltrans, 2018). The study area consists of a mix of publicly owned and privately owned parcels. Areas north of Struve Pond and Bennett Slough, as well as areas south of Moro Cojo Slough, are used for agriculture. Most commercial land use is located around the Moss Landing Harbor. Known landmarks (e.g. utilities, infrastructure, commercial) within the community and the study area include:

- Moss Landing Harbor District, North and South Harbors, including the Monterey Bay Aquarium Research Institute (MBARI)
- Moss Landing Power Plant
- Moss Landing Marine Labs
- Moss Landing Wildlife Area
- Elkhorn Slough National Estuarine Research Reserve

A number of habitat conservation groups and state and local agencies own land in and adjacent to Elkhorn Slough. **Figure 5** shows protected wetlands and ownership boundaries around the Slough (Elkhorn Slough Tidal Wetland Project Team, 2007).

3.2 Site History

Present-day Moss Landing and Elkhorn Slough were historically part of an interconnected network of estuaries, including Moro Cojo Slough, Tembladero Slough and the Salinas river (**Figure 6**). The area was dominated by wetland habitats, specifically tidally influenced salt marshes and mudflats along the main channels and brackish and/or freshwater marshes along the Slough edges. The historic mouth of

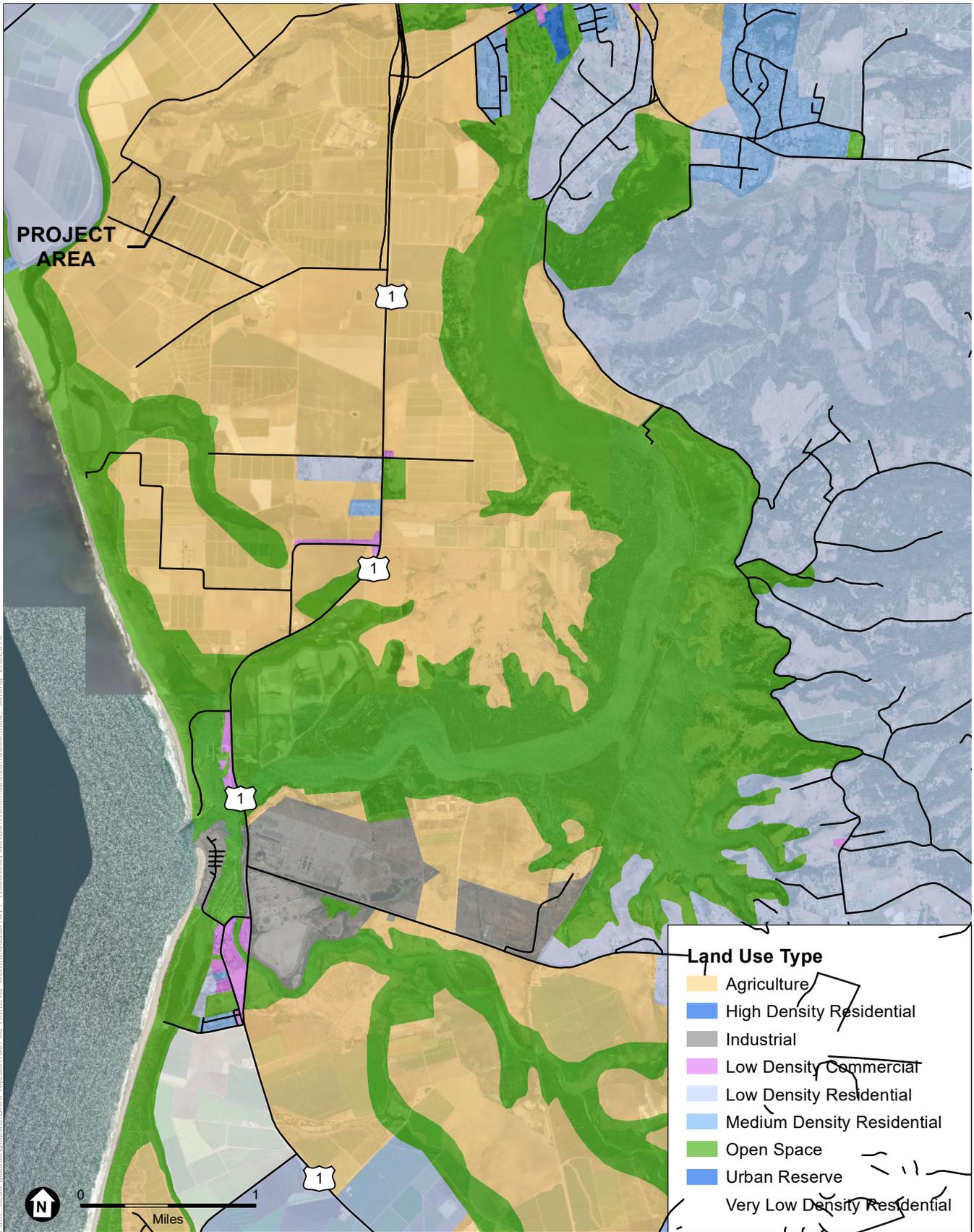


SOURCE: ESRI Imagery, 2019

AMBAG Central Coast Highway 1 Resiliency Study . D180763

Figure 3
Site Map

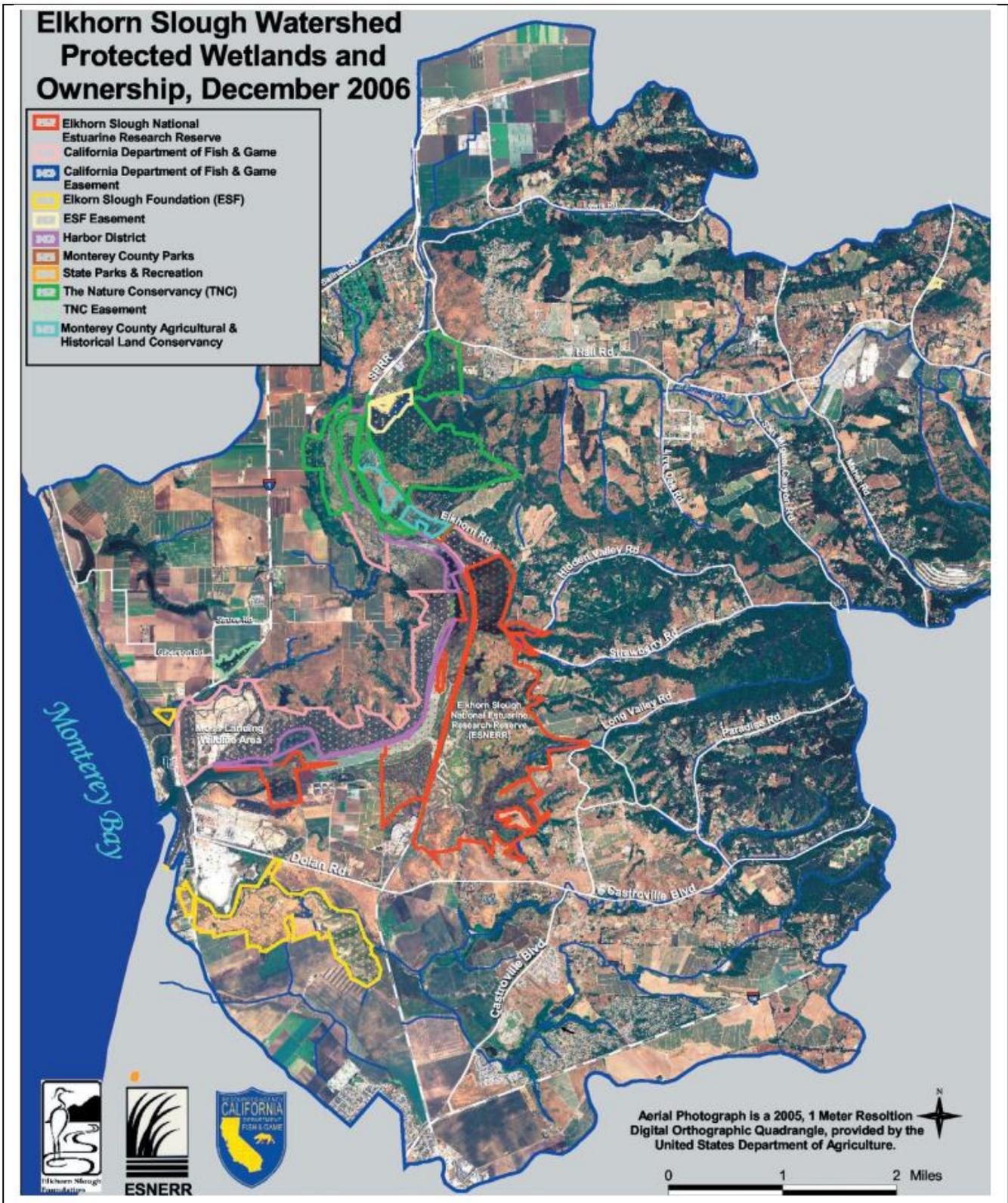




SOURCE: ESRI Imagery, 2019, CALTRANS

AMBAG Central Coast Highway 1 Resiliency Study . D180763

Figure 4
Land Use Type

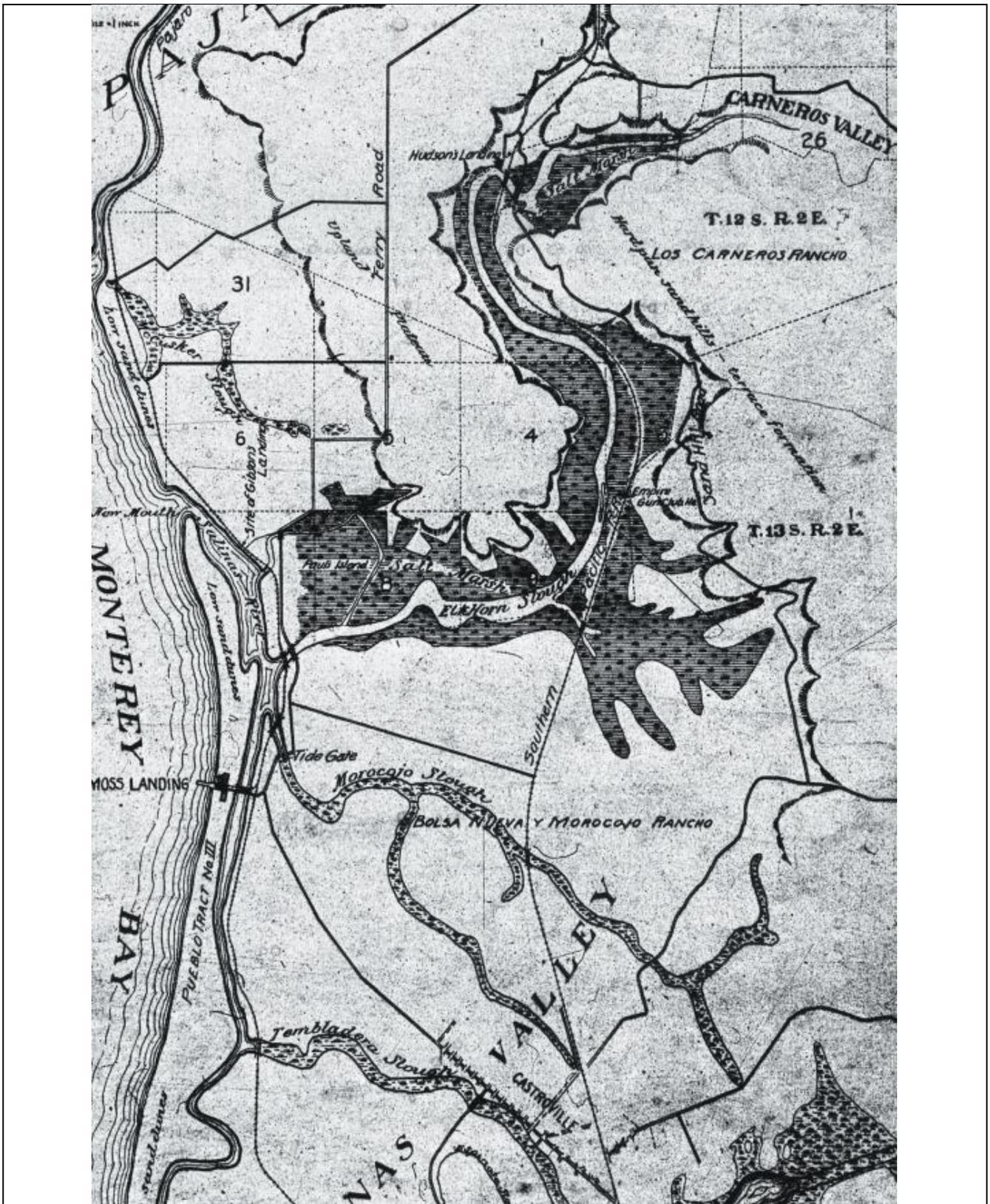


Source: Elkhorn Slough Tidal Wetland Strategic Plan (2007)

Central Coast Highway 1 Climate Resiliency Study

Figure 5

Elkhorn Slough Protected Wetland Boundaries and Ownership



Source: Elkhorn Slough Tidal Wetland Strategic Plan (2007)

Central Coast Highway 1 Climate Resiliency Study
Figure 6
 Historic Elkhorn Slough

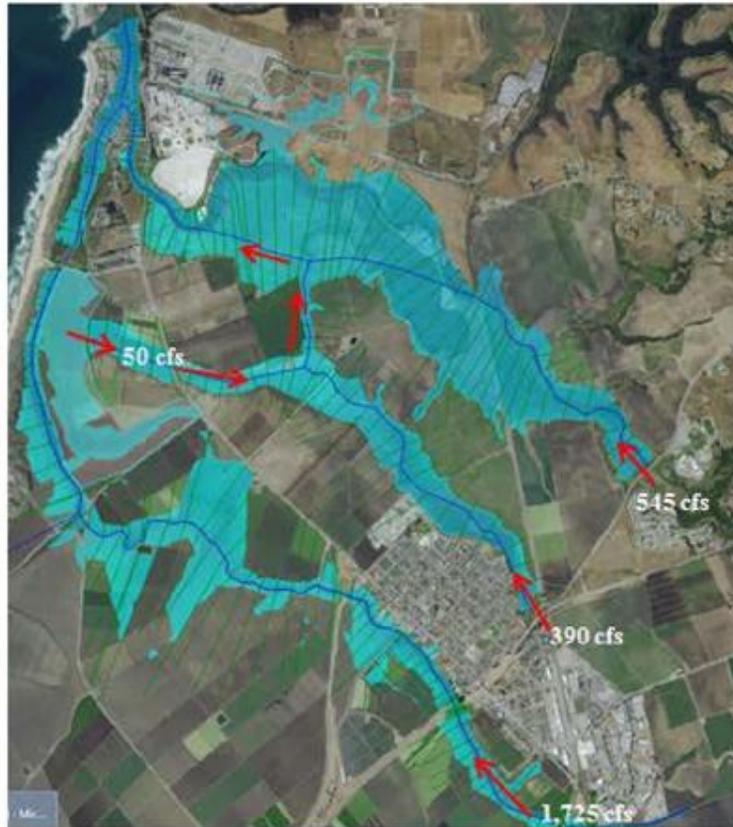
Elkhorn Slough was connected to Bennett Slough and located north of the existing jetties and Moss Landing Harbor.

Estuarine habitats in Elkhorn Slough have been largely impacted by human modifications and development over the last 150 years (Elkhorn Slough Tidal Wetland Project Team, 2007). Roadway and railway construction, including levees and bridges, built in marshlands during the 1860s and 1870s led to decreased tidal connections throughout Elkhorn Slough. Specifically, these blocked Upper Bennett Slough and adjacent areas from tidal influence. At the same time, industrialization spurred mass land clearing and increased sediment inputs. Additionally, the diversion of the Salinas River in 1909 drastically reduced freshwater and sediment inputs into Elkhorn Slough. As more land was used for agriculture, farmers installed hydraulic control structures (e.g. dams, culverts, tide gates) to support agricultural operations. This led to significant estuarine habitat loss and subsidence across the Slough. The construction of Moss Landing Harbor in 1947 established a permanently open tidal connection between Monterey Bay and Elkhorn Slough, in contrast to the historic seasonal opening configuration, increasing tidal action and erosion.

These modifications to establish community use and transportation infrastructure, contributed to changes in the dominant tidal hydrodynamic and geomorphology patterns in Elkhorn Slough. The severe reduction in sediment sources to the Slough, and permanent, deeper, wider opening, have resulted in a net sediment export. These phenomena drive marsh dieback and loss of estuarine habitats. Since the 1980s, major conservation efforts spearheaded by the by The Nature Conservancy (TNC), Elkhorn Slough Foundation (ESF), the Elkhorn Slough National Estuarine Research Reserve (ESNERR), California Department of Fish and Wildlife (CDFW), and other groups have led to ongoing wetland management and marsh restoration projects around the Slough, such as the Hester Marsh Restoration.

Modifications to drainages include multiple tide gates and leveed channels, which have modified but not alleviated flood risks, including flood risks to Highway One. Riverine flooding occurs in the southern section of the study area, affecting Highway Reaches 3 and 4, via the Reclamation Ditch (Gabilan Creek). The 100-year river flood modeling is consistent with flood limits experienced in December 12 2015 when flood waters flowed across reach 4 to Moro Cojo Slough and past Reach 3, through Moss Landing Harbor and to Elkhorn Slough as shown in **Figure 7** (CCWG 2017; ESA 2016).

100-year inundation



December 2014



Comparison of Modeled 100-year flowpaths and observed flowpaths during December 2014 flood

SOURCE: ESA (2016)

Central Coast Highway 1 Climate Resiliency Study
Figure 7
Reclamation Ditch (Gabilan Creek) Flood Flow Routing

3.3 Topography and Bathymetry

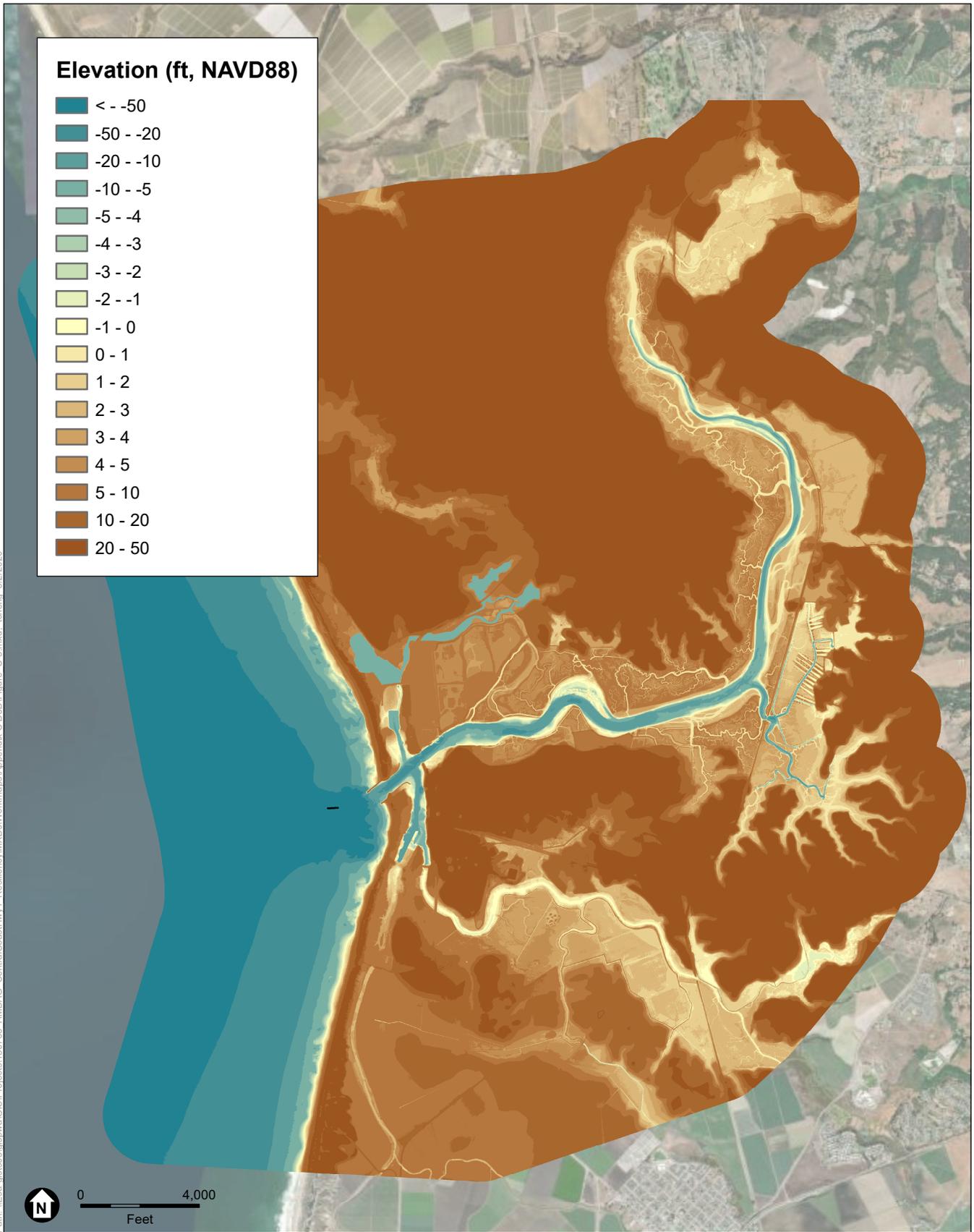
As part of existing conditions review, ESA gathered latest available topography and bathymetric information for the study area and merged them in ArcGIS 10.6 for a single elevation dataset. The sources ranged from elevation information collected via Light Detection and Ranging (LiDAR) to backscatter to capture shallow estuarine bathymetry within Elkhorn Slough. **Figure 8** shows elevations from the combined dataset. This dataset informed model inputs for the Delft3D hydrodynamic modeling, as part of the evaluation of the adaptation scenarios (Section 6.3).

Table 1 lists elevations of key transportation infrastructure and habitats within the study area. Wetland habitats are described in terms of tidal datums, which is a reference elevation of sea level established over the National Tidal Datum Epoch. Tidal datums vary geographically and related to geodetic datums by a conversion factor established by a geodetic survey at the tide gauge location. Mean lower low water (MLLW) is defined as the lowest of the two low tides per day. Mean high water (MHW) represents the average of all daily tidal high water heights. Mean Higher High Water (MHHW) refers to the average height of the daily highest tide. Tidal elevations at the site are defined in Section 3.5.1.

Table 1. Key Elevations of Features within Study Area

Location	Min. Elevation (ft, NAVD88 ⁴)
<i>Highway One</i>	
Reach 1	7.6
Reach 2	8.9
Reach 3	8.8
Reach 4	9.0
<i>Railway</i>	5.5
<i>Elkhorn Slough</i>	<i>Tidal Elevations</i>
Mudflat	MLLW to MHW
Tidal Marsh	MHW to MHHW

⁴ NAVD stands for North American Vertical Datum (1988), which is a commonly used geodetic vertical datum. Water level (tidal) datums vary geographically and are typically related to land datums using geodetic surveys at tide gauges.



SOURCE: USGS (2017), CSUMB (2011), CCWG (2019)

Central Coast Highway 1 Climate Resiliency Study

Figure 8
Elevations (Topo-Bathymetry) within Study Domain

3.4 Transportation

This section describes existing conditions for major transportation infrastructure through Moss Landing and Elkhorn Slough and data sources collected by the Project Team.

3.4.1 Roadway

Present-day Highway One through Moss Landing is a 2-lane roadway facility needing major upgrades to improve safety, travel time and overall transportation function. Characterizing existing conditions for the highway is key to identifying relevant opportunities and constraints for developing adaptation strategies. AMBAG and Caltrans District 5 staff provided numerous reports related to existing transportation conditions and the associated opportunities and constraints.

A large portion of residents in the area commute to jobs outside the region via Highway One. Major sectors in the region that require highway use and reliable connectivity include tourism, agriculture, education, military and the government. The 2040 Metropolitan Transportation Plan/Sustainable Communities Strategy (MTP/SCS) predicts population growth up to 883,300 in the Monterey Bay area, a 16% increase from existing conditions (AMBAG, 2018). Additionally, a significant rise in freight movement in the Central Coast is anticipated (AMBAG, 2012). Congestion and travel accidents are predicted to increase as the number of roadway users increase in the future. The Caltrans Transportation Concept Report (TCR) (2017) states that the route concept for Segment 6, which is the study area, is to maintain 2 to 5 lanes and minimize and consolidate highway access points.

The Caltrans TCR also recommends increasing shoulder widths as necessary for cyclists. TAMC and the Santa Cruz County Regional Transportation Commission (SCCRTC) are developing a Monterey Bay Sanctuary Scenic Trail, which will pass through Moss Landing. A Class 1 Bikeway, which provides bicycle and pedestrian travel on a right-of-way separate from a street or highway, is planned for the segment of Highway One by the bridge crossing. The bike trail is planned to be 12 feet wide and would start at the intersection of Moss Landing Road and Highway One, running parallel and west of Highway One heading north, and crossing the existing highway bridge (TAMC, 2008).

Caltrans supplied data for Highway One between mile posts 90 and 102 in Monterey County. Types of information included -built drawings, Bridge Inspection Records Information System (BIRIS) files for Elkhorn Slough Bridge, documentation of road or drainage modifications in the last decade, accident data, geotechnical reports, detour route information, road closure/impact data from flood events, boring logs, and descriptions of any planned roadway modifications and schedule. According to Caltrans, there is no record of road closures from flooding nor formal detour routes specified during extreme precipitation events.

3.4.2 Railway

The existing railroad infrastructure (tracks, fill embankment, bridges) was first built in the early 1870s, as an extension of the Southern Pacific Railroad, dividing the main stem of Elkhorn Slough from marshlands to the east (e.g. Azevedo Ponds, North and Estrada Marsh complexes), which reduced tidal exchange. Agricultural land use, including cattle grazing, in the area have led to numerous installations of hydraulic structures underneath the railroad in an effort to control water levels landward of the railway embankment. Details of these hydraulic structures have been collected as part of the existing data collection (Section 3.5.2).

The existing railway is owned and operated by Union Pacific Railroad. Other existing and future operators include Amtrak and Caltrain. Presently, Amtrak operates the Coast Starlight, which provides rail service from Los Angeles, CA to Seattle, WA, with a stop at Salinas, CA. The Monterey County Rail Extension project developed by TAMC will extend commuter rail service from Santa Clara County to Salinas through the railway corridor through Elkhorn Slough.

Union Pacific was not involved in the development of this study. Several attempts to establish communication with Union Pacific were made through the duration of the study in order to obtain design drawings and other relevant information; no reply was received. The Project Team was able to gather railway dimensions (e.g. widths), elevations and conditions from Google Earth, best available LiDAR and site photos.

3.5 Hydraulics & Hydrology

3.5.1 Tides

Water levels within Moss Landing Harbor and Elkhorn Slough are driven by ocean water surface fluctuations. Typically, water surface fluctuations are influenced by astronomical tides, which result from gravitational forces between the earth, moon and sun. The National Oceanographic and Atmospheric Administration (NOAA) maintains the Monterey tide gage (NOAA Station #9413450). The station began operations in November 1973. **Table 2** shows the tidal datums at the Monterey tide gauge.

Table 2. Tidal datums at the NOAA Monterey Tide Gage (Station #9413450)

Datum	Elevation (ft, NAVD88)
Mean Higher High Water (MHHW)	5.20
Mean High Water (MHW)	4.50
Mean Sea Level (MSL)	2.69
Mean Low Water (MLW)	0.95
Mean Lower Low Water (MLLW)	-0.14

Tides from Monterey Bay are modified as they propagate through the Slough, due to bottom bathymetry, friction and interaction with irregular shorelines. Specifically, tidal amplitude and phasing are muted as they travel further up the main channel of the Slough.

ESNERR maintains a system of gauges throughout the Slough, the data from which are accessible via the NERR Centralized Data Management Office. Data collected include hourly measurements of salinity, temperature, water level, pH, turbidity and other parameters. The closest station to Highway One is the Vierra Mouth station, approximately 1500 ft east of the bridge, with observations dating back to 2001. The Monterey Bay Aquarium Research Institute (MBARI) also operates the Land/Ocean Biogeochemical Observatory (LOBO) network, which provides additional information about water levels and water quality around the Slough.

Several King Tide events, which refer to the highest predicted high tide event, have occurred since the beginning of the Study, resulting in flooding along the railway (**Figure 9**).

3.5.2 Hydraulic Structures

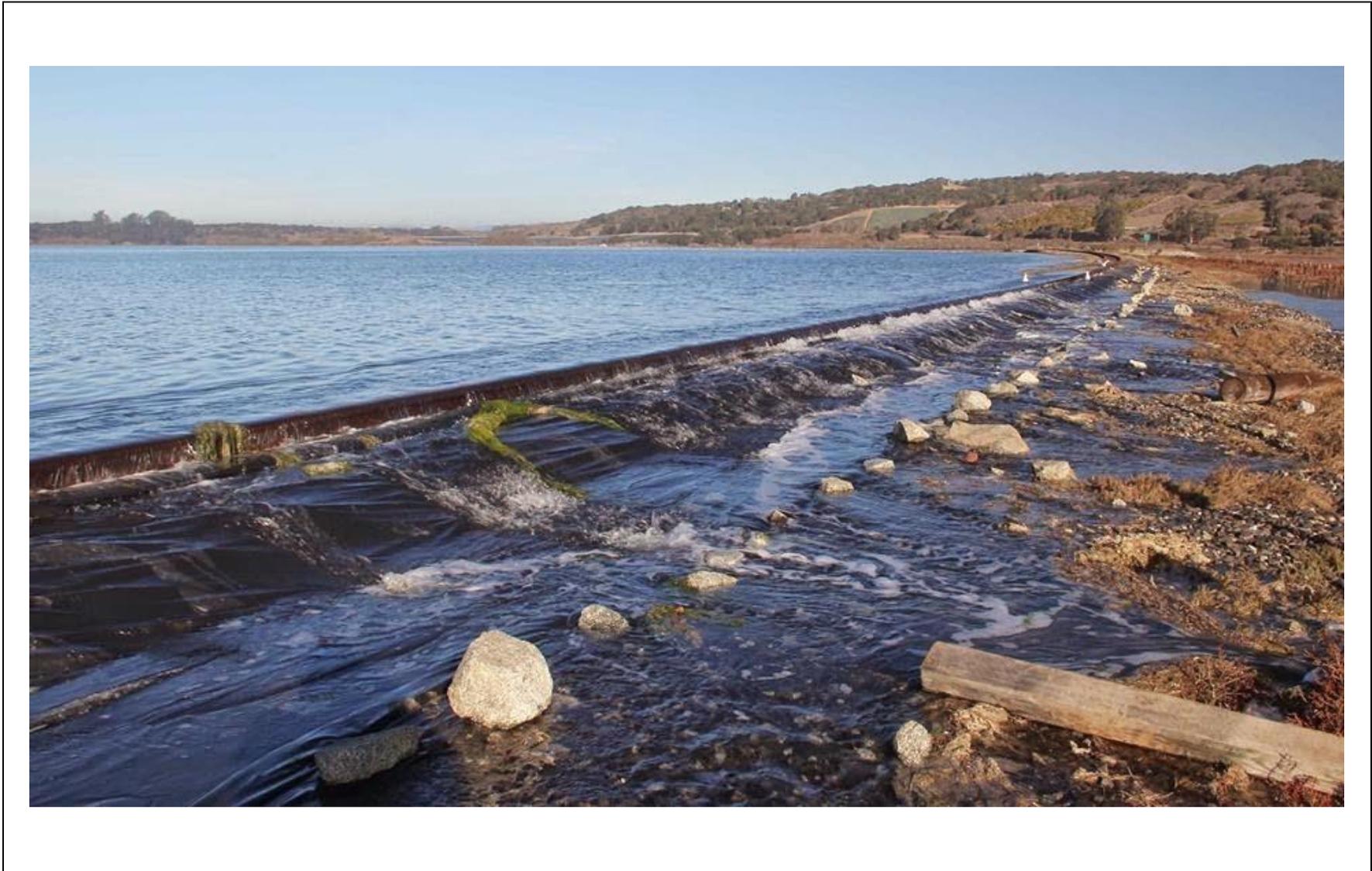
ESA conducted a culvert survey in November 2018 to verify the location and condition of culverts located under Highway One in the study area and collect structure specifications (e.g. diameter, invert elevation, material). Additionally, ESNERR and the Central Coast Wetlands Group (CCWG) provided data for known hydraulic structures throughout the Slough and by the railway embankment. These data were one of the model inputs into the Delft3D hydrodynamic modeling that is part of the evaluation of adaptation scenarios. Further information on hydraulic structure data collected can be found in Appendix A.

3.6 Sea-Level Rise

The study requires calculations of damages and outputs for a range of future physical conditions driven primarily by sea-level rise. This text proposes an approach to both build upon prior work, conform to California's most recent (2018) guidance, and support Center for Blue Economy's (CBE) probabilistic economics analysis.

Discrete Sea-level Rise Scenarios

The Coastal Resilience Monterey Bay future hazards mapping was developed using the guidance produced by the National Research Council for the Pacific States (ESA, 2014; OPC, 2013; NRC, 2012). Hence the Coastal Resilience Monterey Bay is consistent with California's 2013 guidance. The time horizons and sea-level rise amounts are summarized in **Table 3** (ESA, 2014).



SOURCE: ESF (2019)

Central Coast Highway 1 Climate Resiliency Study

Figure 9

January 2019 King Tide

Railway Flooding

Table 3. Sea-level rise scenarios used for Coastal Resilience Monterey Bay (ESA, 2014; TNC, 2015)

Year	Low SLR	Medium SLR	High SLR
2030	3 cm (1.1inches)	10 cm (4 inches)	22 cm (8.8 inches)
2060	16 cm (6.3 inches)	33 cm (12.8 inches)	72 cm (28.3 inches)
2100	41 cm (16.1 inches)	88 cm (34.5 inches)	159 cm (62.6 inches)

California updated its guidance in 2018 (CalNRA & OPC, 2018; CCC 2018) based on an updated assessment of climate change science (Griggs et al, 2017). This guidance provides probabilities for particular sea-level rise amounts and defines sea-level rise amounts for selected levels of risk tolerance. This substantial update can be cross-walked with the prior California guidance (OPC, 2013): Sea-level rise curves derived from the existing guidance (2018) and prior guidance (2013) are plotted in **Figure 10**.

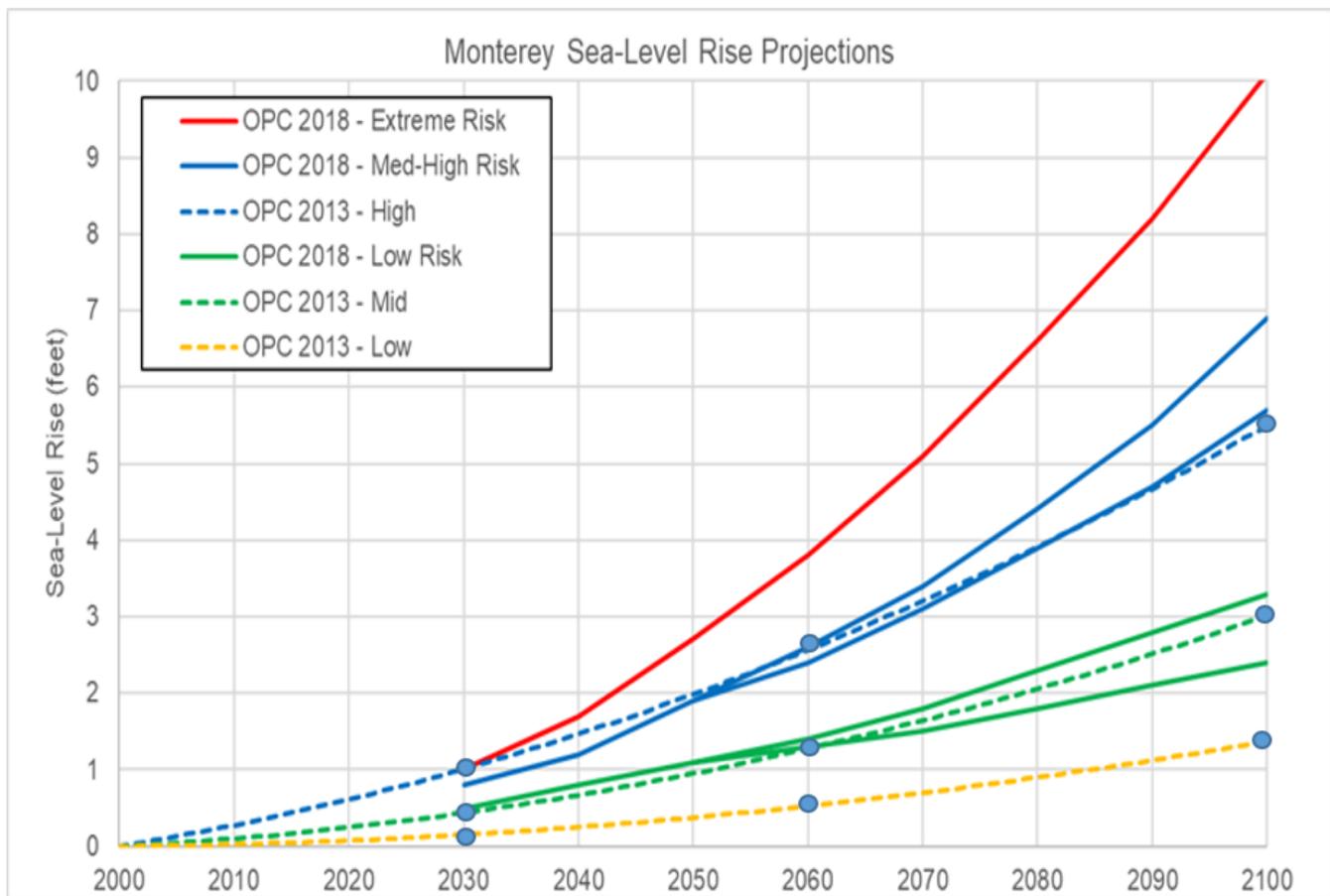
The updated (2018) Medium-High Risk Aversion sea-level rise amounts are similar to the High Sea-level Rise amounts from the prior guidance (2013). Similarly, the 2018 Low Risk Aversion is similar to the Medium Sea-level Rise amounts (2013). Consequently, the Project Team proposes to use the available hazards from the Coastal Resilience Monterey Bay, high and medium (projection) sea-level rise curves, to develop the adaptation scenarios. Results from these discrete scenarios may then be used by CBE to quantify the probabilistic analysis.

3.7 Ecology

Elkhorn Slough is the 3rd largest tract of tidal wetlands in California. Located in Monterey Bay in Central California that provides valuable habitat area for hundreds of aquatic bird, fish, marine mammal and invertebrate species. With nearly 2,700 acres of a suite of intact habitat types, including a wide range of estuarine habitats (e.g. salt marsh, tidal brackish marsh, mudflat), the Slough is critical to regional biodiversity.

Figure 11 shows general habitat types throughout the Slough. Estuarine habitats occur on regularly and irregularly flooded areas along the shoreline; different types of wetland habitat can be found across the tidal elevation range (**Figure 12**).

Estuarine habitats within the Slough and the ecosystem services they provide are at risk to substantial losses with sea-level rise. With Central California already having lost over 90% of its historical estuarine marsh habitat area (Brophy et al. 2019), every effort is needed to maintain the remaining 10% in the face of sea-level rise. Presently, Elkhorn Slough holds the third largest extent of estuarine marsh in California, however, approximately 85% of this area may be lost with sea-level rise. Thus, maintaining or enhancing the extent of estuarine marsh in this well conserved estuary is an important priority.

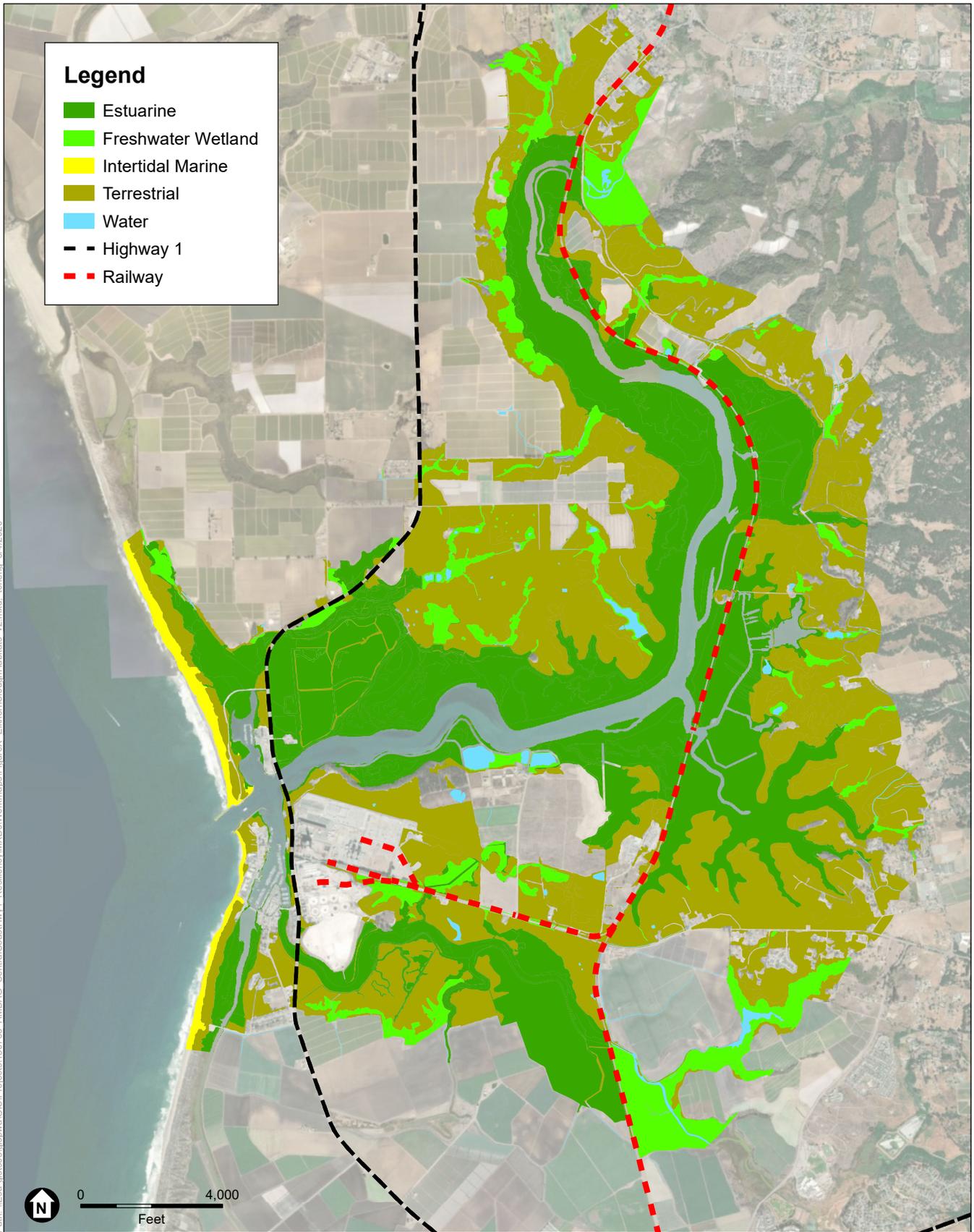


● Blue circles represent scenarios mapped by Coastal Resiliency Monterey Bay.

Comparison of sea-level rise scenarios used for Coastal Resiliency Monterey Bay (ESA, 2014; TNC, 2015) based on prior State guidance (NRC, 2012; OPC, 2013) and current State Guidance (Griggs et al, 2017; OPC, 2018). For current state guidance (solid lines), the higher line is the high emission scenario (RCP 8.5) and the lower line is the low emission scenario (RCP 2.6).

SOURCE: Ocean Protection Council (2013), Ocean Protection Council (2018)

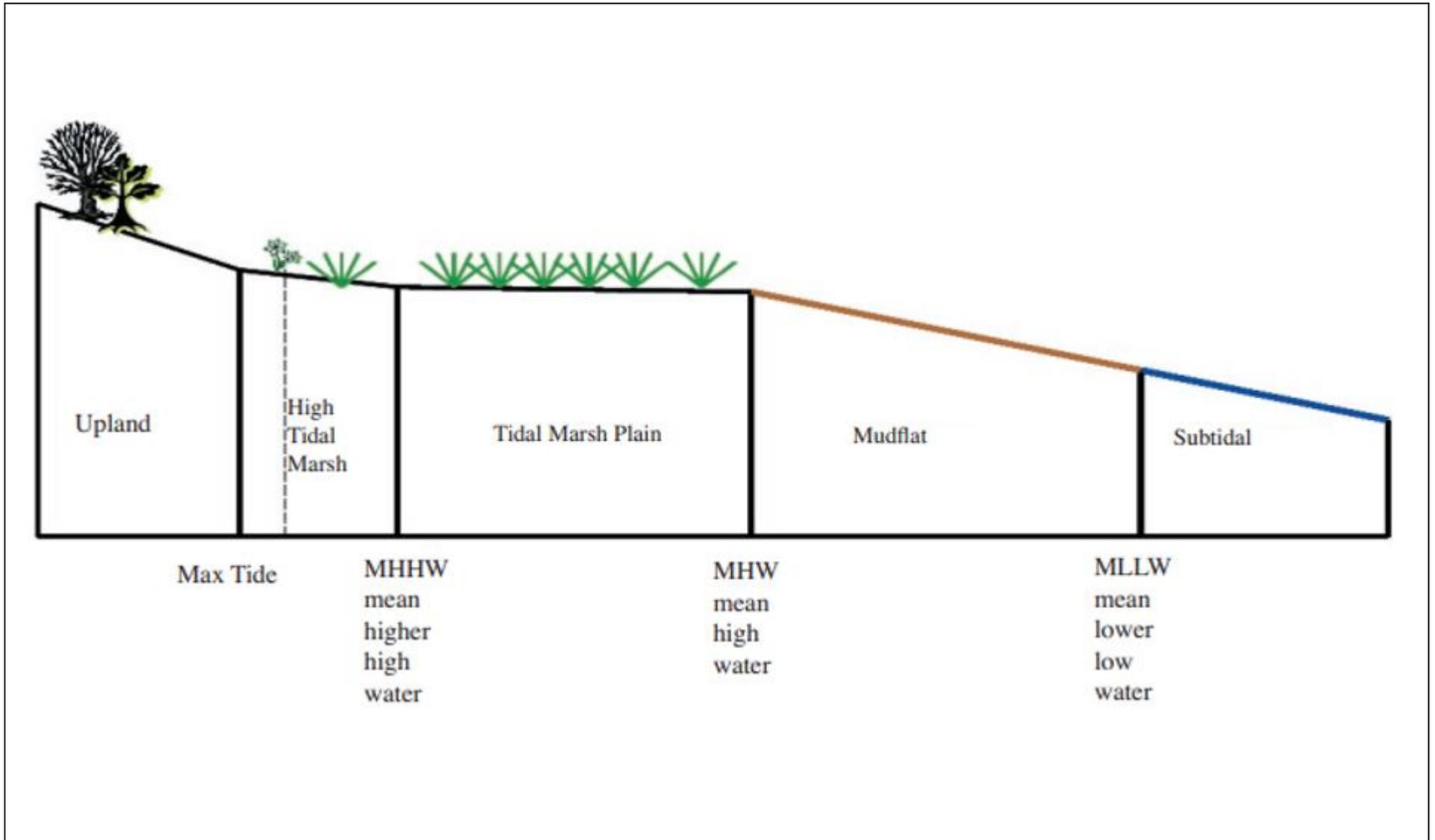
Central Coast Highway 1 Climate Resiliency Study
Figure 10
 Monterey Sea-Level Rise Projections
 OPC 2013/2018 Guidance Cross-walk



Source: The Nature Conservancy, CA State Coastal Conservancy (2017)

Central Coast Highway 1 Climate Resiliency Study

Figure 11
Study Area Habitat Classification



SOURCE: Design Guidelines for Tidal Wetland Restoration in San Francisco Bay (PWA and Faber, 2004), Elkhorn Slough Tidal Wetland Project Team (2007)

Central Coast Highway 1 Climate Resiliency Study

Figure 12

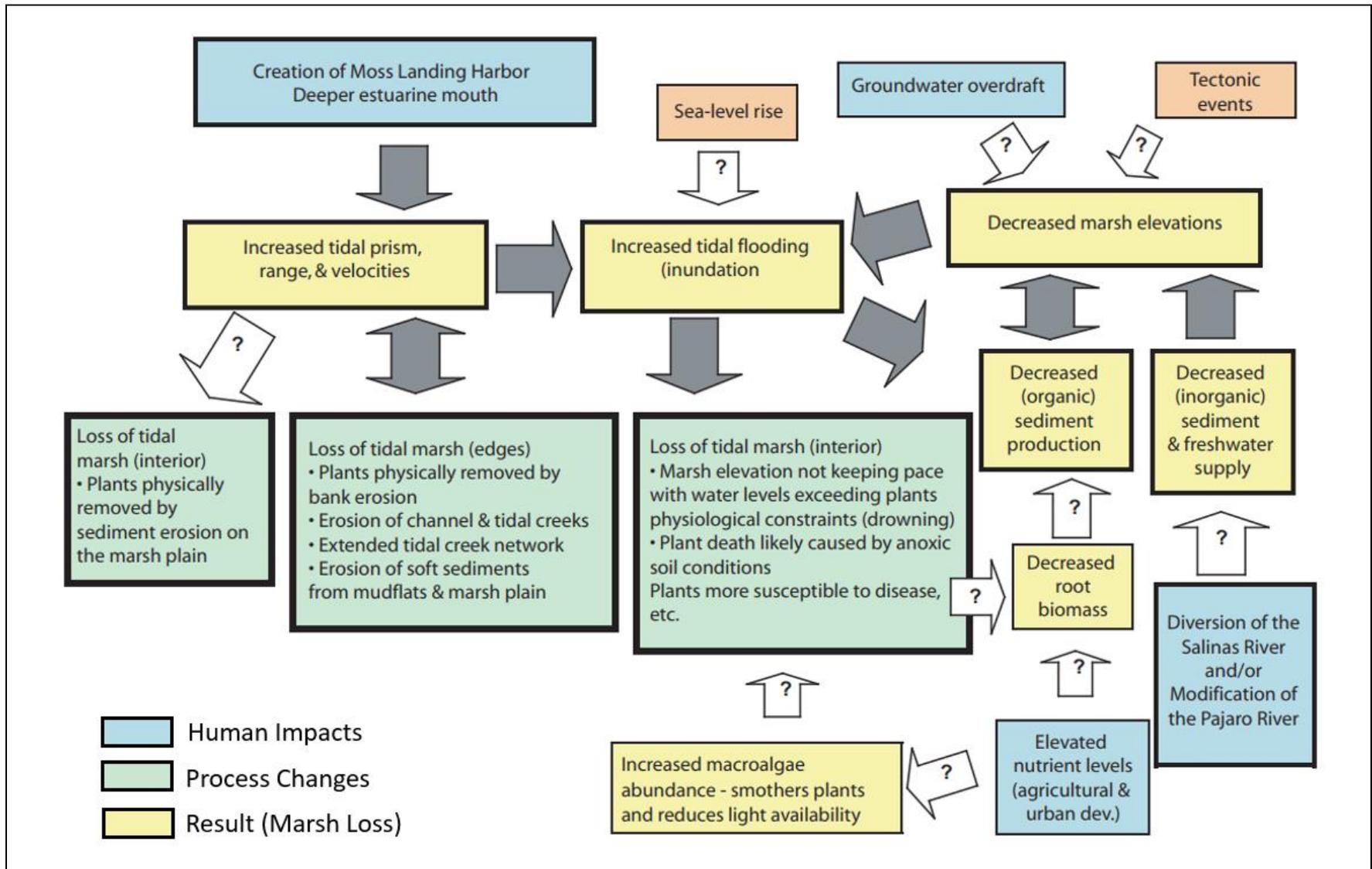
Vertical Profile of Tidal Marsh

Large-scale human modifications from the construction of transportation infrastructure, development and agricultural operations around the Slough since the late 1800s resulted in a number of adverse habitat impacts, including persistent marsh loss, habitat erosion and degradation, water pollution and eutrophication. Moreover, these changes to the built environment have altered the hydrology and geomorphology of the system, which in turn impact estuarine habitats (**Figure 13**). The re-location of the Slough mouth and construction of the Moss Landing Harbor jetties have increased tidal velocities in the main channel of the Slough. In conjunction with decreased sediment supply to the Slough over the last century, this has resulted in the Slough experiencing net sediment export and bank erosion along wetland complexes. Modifications to Slough hydrology that increase tidal prism (i.e. the volume of water that is drained during a tidal cycle), including sea-level rise, are predicted to exacerbate this trend (Elkhorn Slough Tidal Wetland Project Team, 2007).

Extensive efforts have been undertaken by conservation groups, local and state agencies, and community stakeholders to restore marsh habitat in the Slough over the past several decades. This planning-level study seeks to identify opportunities to strengthen ecological resilience as part of improvements to transportation facilities.

Several major wetland complexes are located adjacent to the roadway and railway, with varying histories of human modification and existing management. These are referenced throughout the study report and are described briefly below.

- *Struve Pond/Bennett Slough Wetland Complex*: Struve Pond and Bennett Slough are located adjacent to Highway One Reaches 1 and 2, northeast of the Slough mouth. Habitats found here range from salt marsh, tidal flats, tidal brackish marsh and freshwater ponds. Highway construction in the early 1930s led to the existing configuration where culverts were installed underneath the road embankment between Struve Pond and Upper Bennett Slough, and between Lower and Upper Bennett Slough. Subsequent construction of the Moss Landing Harbor mouth in 1947 and Jetty Road significantly reduced tidal exchange to this area.
- *Moss Landing Wildlife Area (Salt Ponds)*: The managed salt ponds portion of the Moss Landing Wildlife Area is approximately 153 acres of former salt marsh that were diked/leveed for salt production. The ponds are currently managed by California Department of Fish and Wildlife (CDFW) and act as valuable nesting and breeding habitat for the Western Snowy Plover, wintering waterfowl and shorebirds.
- *Azevedo Ponds*: The Azevedo Ponds wetland complex (20 acres total) are a series of three wetland areas (North, Middle and Southern) located on the eastern side of Elkhorn Slough. These wetlands are separated from the main channel by the railway fill embankment and experience limited tidal exchange due to the installation of hydraulic control structures.



SOURCE: Elkhorn Slough Tidal Wetland Project Team (2007)

Central Coast Highway 1 Climate Resiliency Study

Figure 13

Conceptual Model of Major Mechanisms of Marsh Loss

Elkhorn Slough

- *North/Estrada Marsh Complexes:* The North/Estrada Marsh complexes are historic salt marsh and tidal creek habitat located on the eastern side of Elkhorn Slough. They are presently separated from the main channel of the Slough by the existing railway embankment, which reduces tidal exchange to the site. Conversion of the wetlands to pasture land has resulted in subsidence through the complex. The installation of tide gates in 1986 introduced tidal connectivity back to the wetlands. Currently, the area is characterized by mudflat and estuarine open water habitat, with salt marsh along the fringes.
- *Parsons Slough:* The Parsons Slough wetland complex (429 acres) is located in the southeastern area of Elkhorn Slough. Prior to human modification, this area was characterized by estuarine marsh and tidal creeks. The wetland has experienced subsidence due to diking and draining from historic conversion of the habitat for grazing. Since the average elevation of the complex cannot support marsh vegetation, large portions of the complex are comprised of unvegetated mudflat, with tidal marsh and subtidal creek habitats distributed along the fringes.

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4. ADAPTATION PATHWAYS AND STRATEGIES FOR RESILIENCE

4.1 Adaptation Pathways

The adaptation scenarios developed within this study are presented in a pathways approach to account for uncertainty around climate change decision-making. An adaptation pathways approach enables consideration of multiple possible futures and allows for analysis of the robustness and flexibility of a range of adaptation scenarios (Haasnoot, 2013). Determining a sequence of short-, medium- and long-term actions can assist stakeholders in identifying opportunities and/or constraints that may arise in the future. Additionally, by considering a wide swath of potential futures, planners can identify when an option or pathway will shut down future options and adjust as needed. An adaptation pathways framework was used throughout the study process to develop and communicate the adaptation scenarios internally and externally.

4.2 Community Climate Change Adaptation Planning

Local and regional planning are currently ongoing to address sea-level rise and climate change at Moss Landing and Elkhorn Slough. The below provides a brief summary of ongoing (or recently completed) planning at the time of study:

- *Moss Landing Community Plan* - the Moss Landing Community Plan and Coastal Implementation Plan, which are components of the Monterey County Local Coastal Program, are currently being updated. Representatives from Monterey County have been part of the Steering Committee through the entire duration of the study, to ensure consistency with any developments.
- *Elkhorn Slough Tidal Wetland Program (TWP)* – The Elkhorn Slough TWP is led by ESNERR and convenes a number of stakeholders and scientists to develop and implement strategies to conserve and restore estuarine habitats within the Slough. The TWP has recommended various approaches for restoration efforts, including restoring subsided marsh by sediment placement and increasing tidal connectivity to wetlands behind water control structures. Recent projects undertaken by TWP have included the Hester Marsh restoration and Parsons Slough Project.
- *Moss Landing Harbor Sea Level Rise Vulnerability and Adaptation Strategy Assessment* - CCWG conducted a vulnerability assessment for the Moss Landing

Harbor District and identified critical coastal infrastructure at risk by 2030, 2060 and 2100 and a range of adaptation strategies for the Moss Landing community. The report predicts that monthly tidal flooding by 2060 will be significant, with major impacts to the infrastructure and commercial areas in the North and South Harbors. Additionally, large areas of intertidal marsh and beach habitat are projected to convert to subtidal habitats by mid-century. Beach and dune nourishment are identified as a potential mitigation/adaptation measure to address vulnerabilities to the existing infrastructure at Moss Landing Harbor.

4.3 Near-Term Actions

Since the adaptation scenarios developed in this study are meant to be implemented in the long-term (several decades from present-day), a range of near-term (i.e. the next few years to decades) maintenance/operational actions and ecological enhancements are identified to increase transportation and habitat resilience in the interim. These are informed by a review of the existing condition of transportation infrastructure, strategies identified by community climate change adaptation planning, and ongoing conservation efforts around Moss Landing and Elkhorn Slough. These proposed actions include:

- Raising the roadway facility in low-lying areas by regrading, reconstruction
- Outer coast dune enhancements to protect Moss Landing Harbor from wave overtopping
- Increasing hydraulic conveyance (e.g. culvert replacement and modifications) to decrease flooding impacts
- Operational restrictions on railway when water levels are elevated
- Strategic planning for marsh restoration projects around Elkhorn Slough

Some of these actions, such as planning for marsh restoration around the Slough, have been in progress for decades prior to this study. They are included to further underline the importance of continuing these efforts to preserve valuable wetland habitat as sea levels rise. Other actions, such as restricting the use of the railway during king tides and storm events which is presently accomplished by Union Pacific⁵, will need to be implemented more often as water levels rise and the frequency of disruption to transportation service increases.

5 Personal communication, ESNERR

5 ADAPTATION SCENARIOS DEVELOPMENT

The following adaptation elements were developed as potential actions to reduce flood exposure and maintain natural habitats, in particular tidal marsh, under future sea-level rise conditions. These scenarios were developed based on the understanding of existing flood hazards to roadway and railway infrastructure and surrounding ecology, as well as recent planning around floodplain management for distinct areas by Highway One. These formed the first stage of adaptation scenario development and evaluation over Fall and Winter 2019. With Steering Committee and community input, a subset of these adaptation scenarios was further refined and evaluated through Spring 2020. This section provides a summary of this process.

5.1 Transportation Adaptation Action Elements

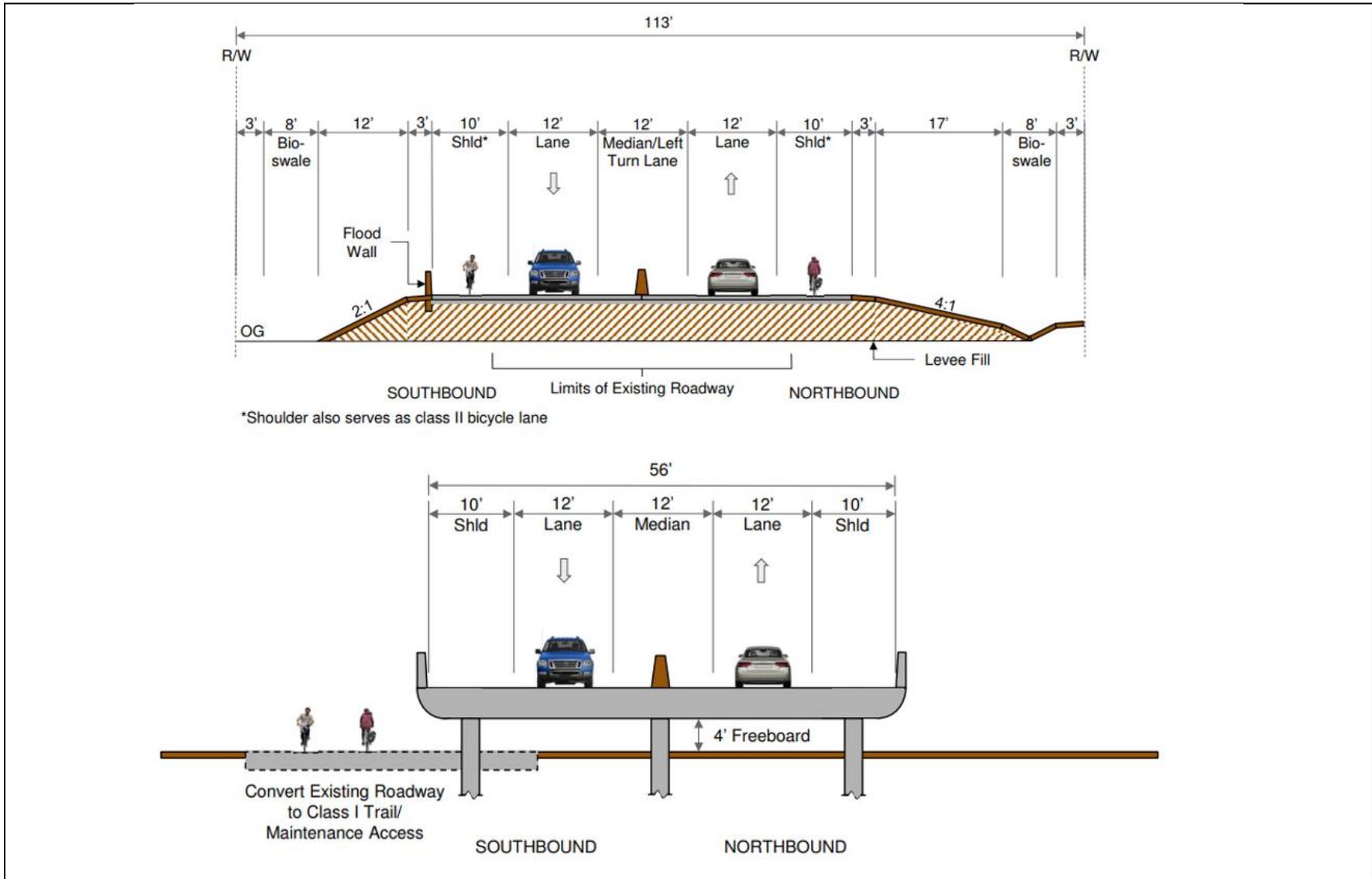
The existing transportation function of the roadway and railway are impacted by disruptions posed by flooding and constraints in capacity. The below describes changes to the infrastructure that would strengthen transportation resilience.

- **Elevate Infrastructure on Fill and/or Piles**

To adapt the transportation infrastructure to rising sea levels, the existing roadway and railway could be elevated via two methods: 1) raised fill embankment and 2) piles. An embankment entails placing and compacting a volume of earthen material (fill) in order to raise the grade of a roadway above adjacent ground surface. Embankments typically have steeper side slope ranging from 2H:1V to 4H:1V⁶ extending out on either side. Where space allows, traditional engineered side slopes can be graded to a much gentler slope (up to 20H:1V) to allow for additional habitat area creation. Piles (pylons) refer to structures that support bridge or highway overpasses, typically elevating them over water. **Figure 14** shows a conceptual cross-section for a 2-lane roadway elevated on fill and/or piles.

Current planning by Moss Landing includes a Class I bike trail, as part of the Monterey Bay Sanctuary Scenic Trail Plan. The bike path trail would start at the intersection of Moss Landing Road/Highway One and run parallel and to the west of Highway One heading

⁶ This notation refers to the slope of an embankment, in terms of horizontal and vertical distance (ex. 2H:1V indicates that for every 2 units of horizontal distance traveled, the elevation of a slope changes 1 unit.)



Central Coast Highway 1 Climate Resiliency Study

Figure 14

2-Lane Roadway Elevated on Fill (Top) or Piles (Bottom)

Conceptual Schematic

north and cross Elkhorn Slough west of the existing highway bridge. The proposed roadway sections, whether elevated on fill or pile, include space (approx. 12 ft) for bike and pedestrian use. Since its construction in the late 1800s, the railway through Elkhorn Slough has operated on tracks elevated on fill embankment. The present railway floods under king tide conditions, with disruptions to service until water levels return to normal⁷. To avoid more frequent disruptions to this transportation function as sea levels rise, the grade of the fill embankment could be raised higher to keep pace with water levels. Alternatively, the railway could be raised on trestle, which is an open cross-braced framework used to support an elevated structure (e.g. bridge). Figure 15 shows a conceptual cross-section for a railway elevated on fill and/or trestle.

A key constraint for fill embankments is the weakness of the existing soils. The soil weakness will result in settlement of the fill, requiring additional fill volume to compensate for the loss of elevation. Also, fill placement will need to be carefully implemented to avoid failure and deformation of the underlying soils and embankment, and uneven settlement (called *differential settlement*) or mass movements during earthquakes. This weak soils constraint on the embankment option can likely be addressed across existing uplands but is considered not likely to be feasible for the existing railway because it is largely in the Elkhorn Slough.

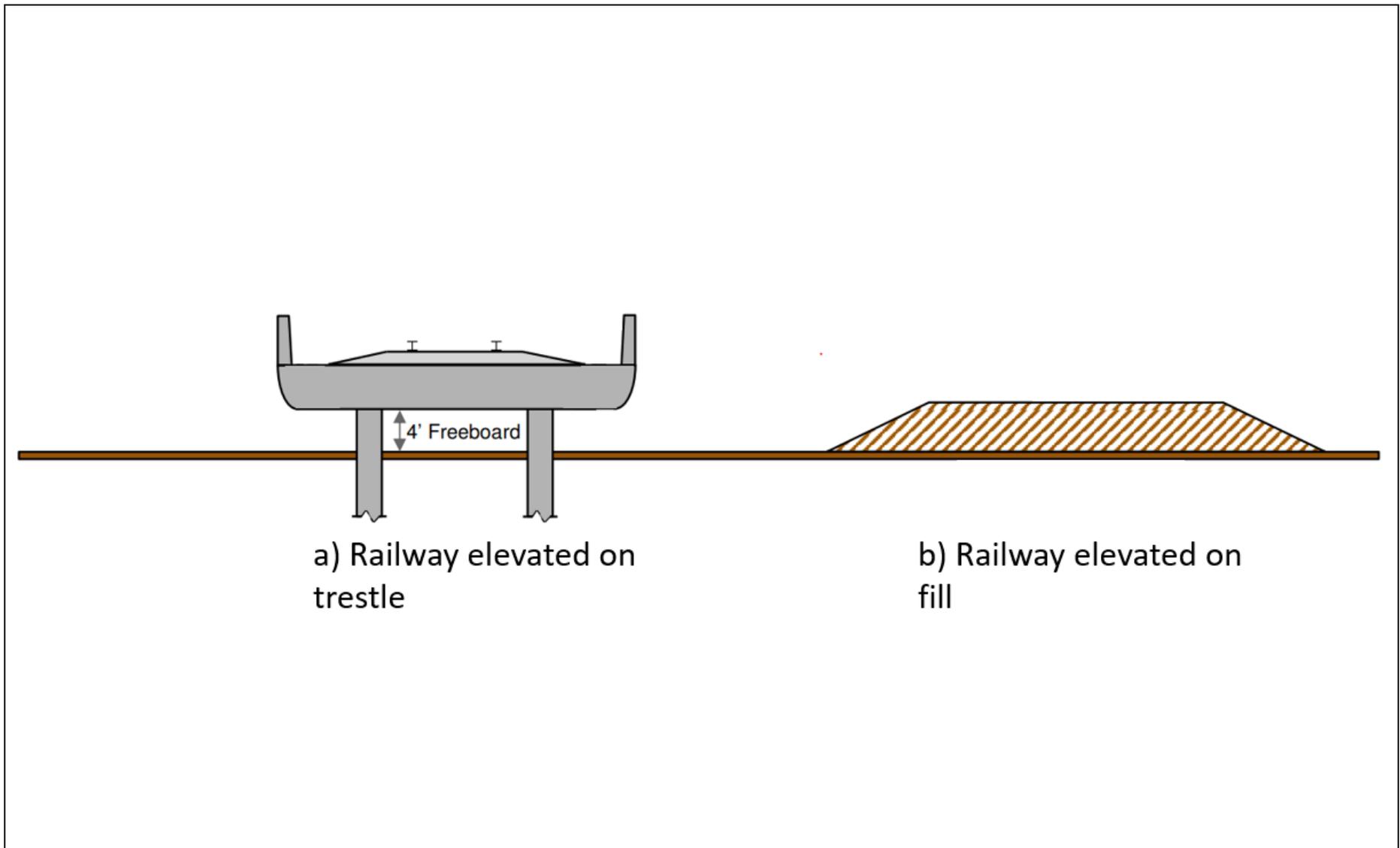
- **Widening the Roadway**

The existing transportation function of the roadway does not meet the transportation demand, resulting in frequent slowdowns, delay and traffic accidents. Widening the highway facility to 4-lanes to improve congestion and other transportation function parameters through the study area is included as an adaptation element. The Caltrans TCR (2017) states that the future vision for Highway One would be widened to 4 lanes through the Moss Landing area. Widening to a 4-lane highway would require building out a significant part of the existing alignment in multiple phases, which would have large impacts on the adjacent habitat. **Figure 16** shows the conceptual cross-section for a 4-lane highway elevated on fill and/or piles. These sections also include future planning for a bike/pedestrian path.

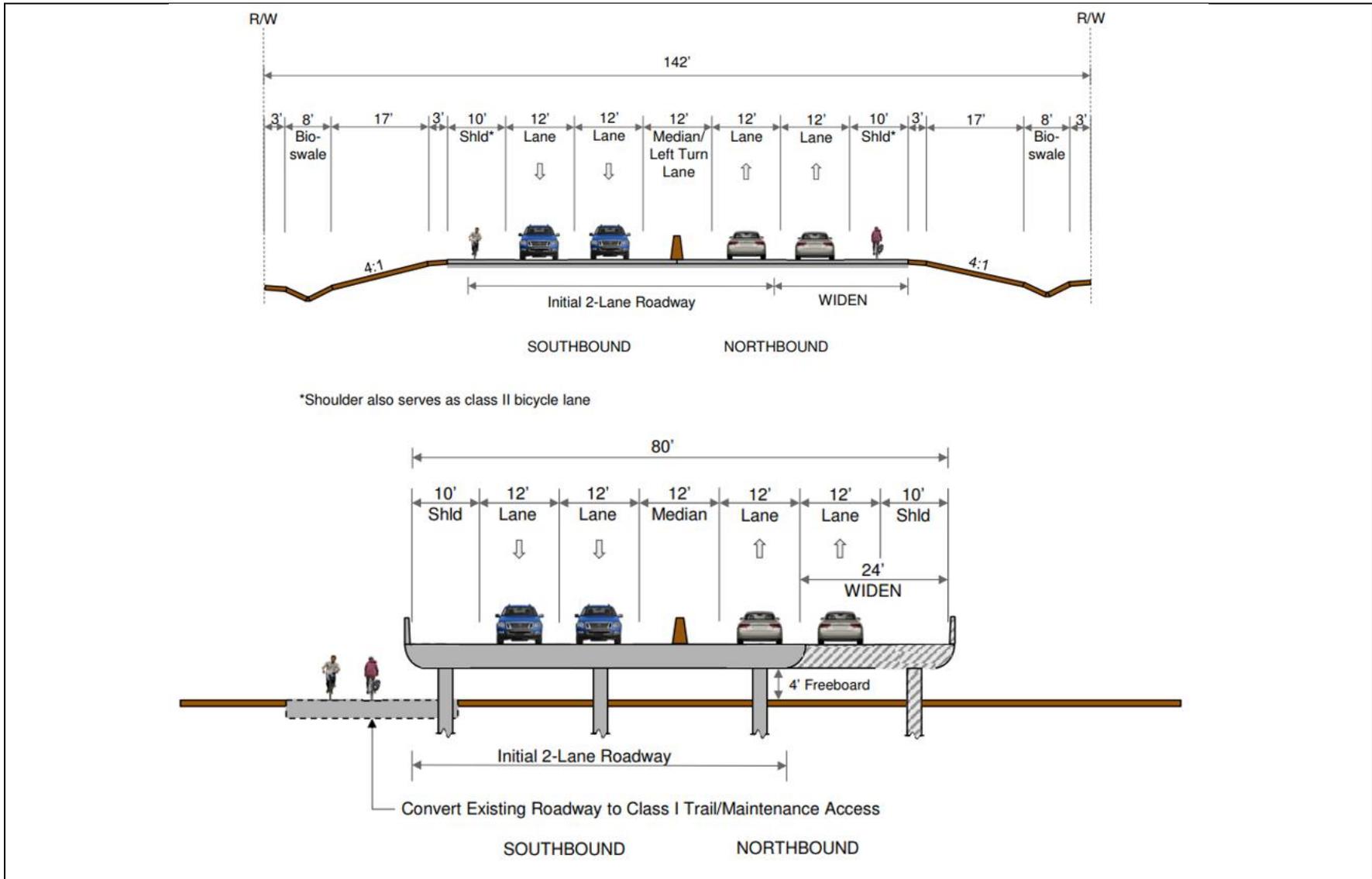
- **Co-located Roadway and Railway Facilities**

Constructing a new alignment inland of the existing roadway was included as adaptation concept to examine potential opportunities for long-term transportation and ecological resilience. This facility proposed co-locating road and rail infrastructure in a single facility and would be located approximately 1.3 mi east from the Slough mouth. The current railway crosses through the Slough, adjacent to 4.7 mi of wetland habitat. Selecting a different alignment at the narrowest point of the Slough channel for a co-

⁷ Personal communication, ESNERR



Central Coast Highway 1 Climate Resiliency Study
Figure 15
Railway Elevated on Trestle (Left) or Fill (Right)
Conceptual Schematic



Central Coast Highway 1 Climate Resiliency Study

Figure 16

4-Lane Roadway Elevated on Fill (Top) or Piles (Bottom)

Conceptual Schematic

located facility could alleviate transportation impacts to marsh complexes east of the existing railway alignment, but may also result in other impacts to ecology. This roadway concept included 4-lanes, consistent with the Caltrans TCR (2017).

Figure 17 shows the conceptual cross-section for a co-located 4-lane roadway and dual-track railway.

5.2 Ecology Adaptation Action Elements

The following ecology adaptation action elements were developed in close coordination with the Steering Committee and stakeholder groups around Elkhorn Slough through Summer 2019.

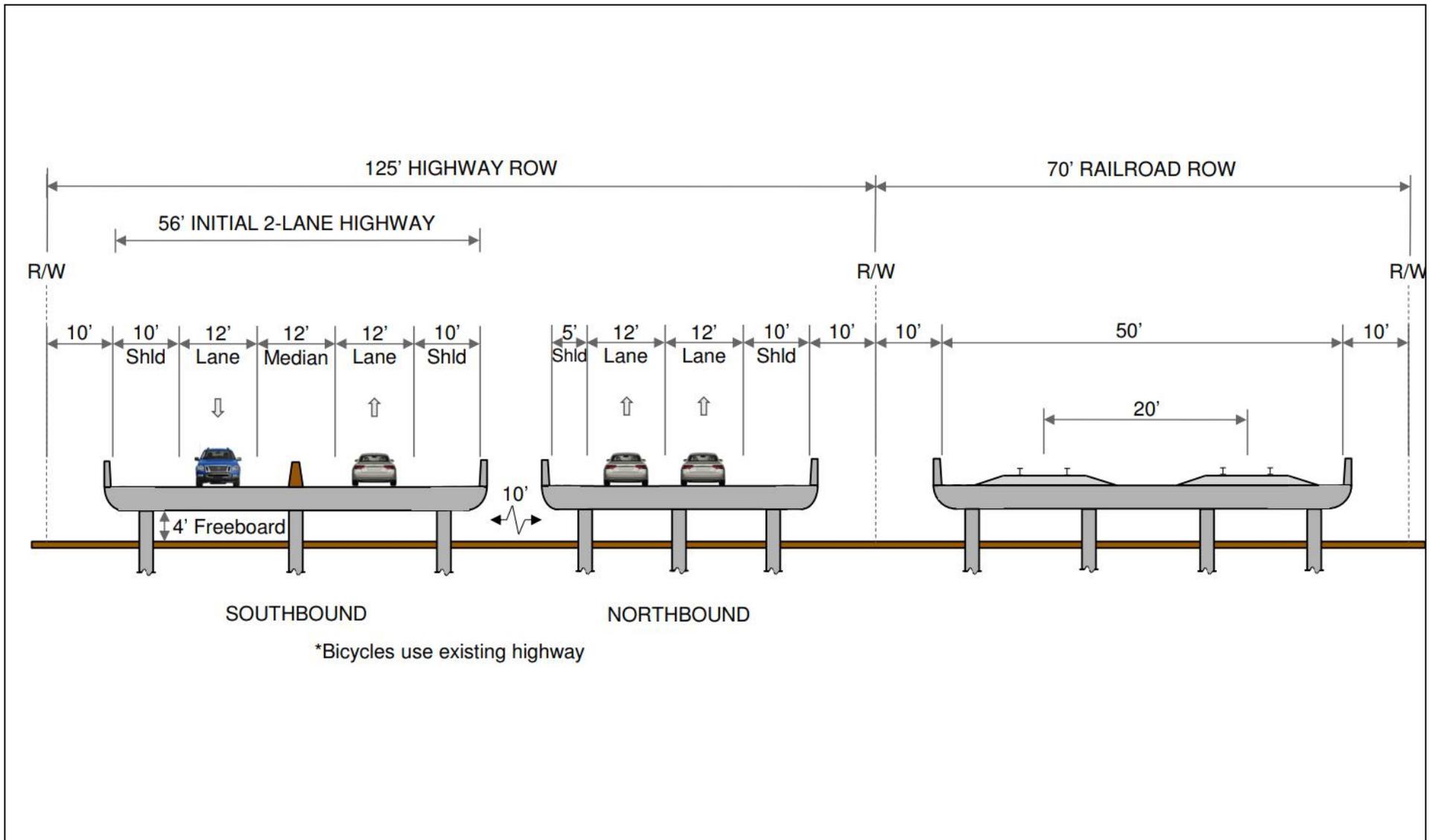
- **Levee Ecotone Creation**

Levee ecotone⁸ creation entails grading a gentle slope (20H:1V) down from a levee (in this case, the roadway crest) into tidal elevations, where space allows (**Figure 18**). Ecotones can be vegetated and create wet area on the landward transitional edge for a range of marsh habitats. Tidal marsh can slow wave action and reduce overtopping during flood conditions, while upper marsh area gain elevation from sediment accretion. These provide sea-level rise resilience for assets landward of the ecotone.

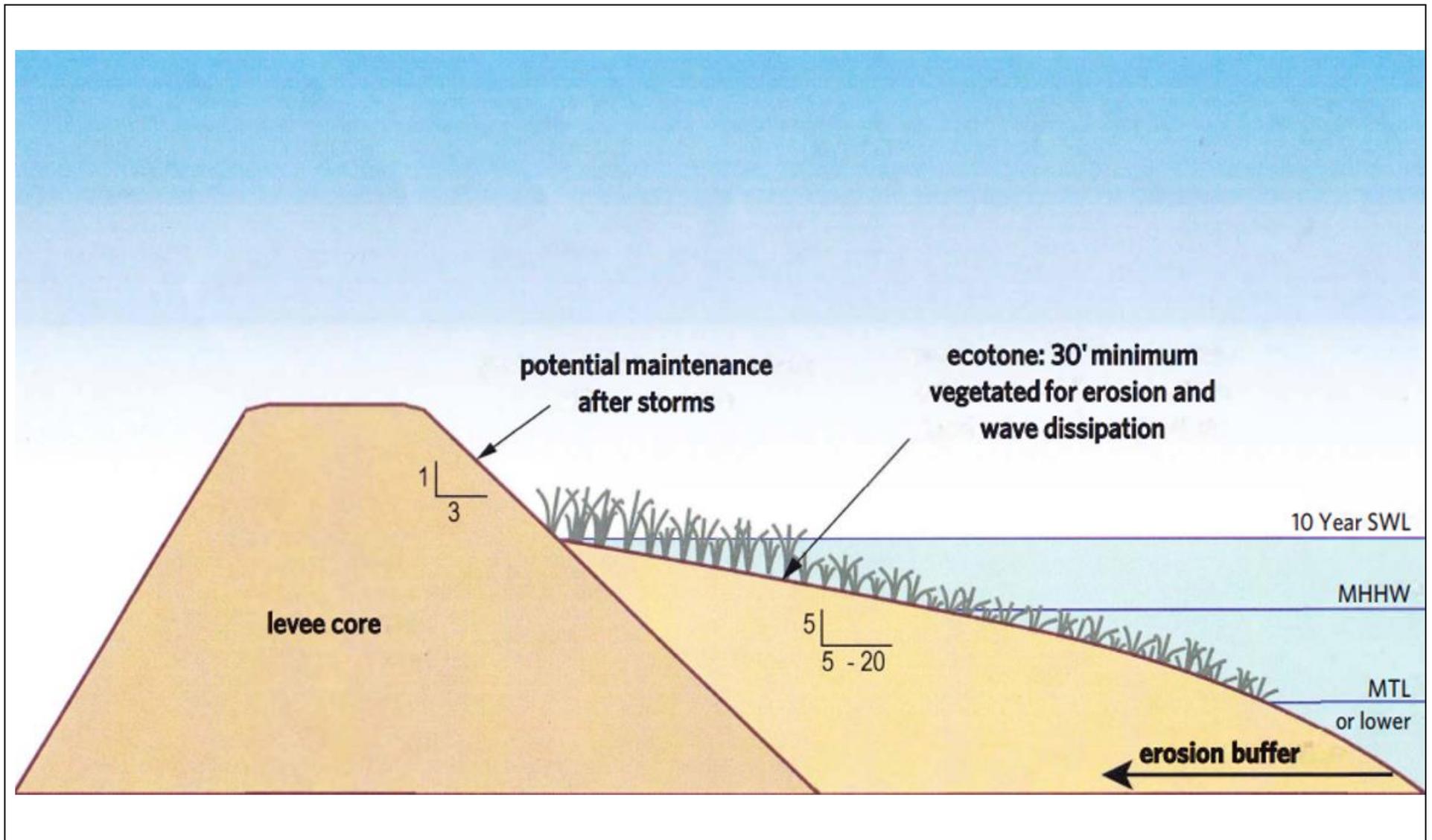
- **Marsh Restoration**

Several marsh complexes, including Parsons Slough, North/Estrada Marsh Complexes and Azevedo Ponds, are located east of the existing railway embankment. Due to the historic installation of tide control structures underneath the rail, North/Estrada Marshes and Azevedo Ponds experience muted tides and water quality issues. The railway overtops in present-day king tide conditions. With increasing water levels, the habitats in these areas are at risk to be permanently drowned. Restoration of these complexes, which entails sediment deposition to raise the marsh grade plain and creation of new tidal channels, would boost maintenance of valuable wetland habitat acreages and ecosystem services these habitats provide under future sea-level rise.

⁸ “ecotone” refers to a transition between two or more ecology communities, and in this case from wetlands to uplands along a slope, and where wetlands can migrate upward with sea-level rise.



Central Coast Highway 1 Climate Resiliency Study
Figure 17
 Co-located 4-Lane Roadway and Dual-Track Railway Facility
 Conceptual Schematic



Central Coast Highway 1 Climate Resiliency Study

Figure 18

Levee Ecotone Schematic

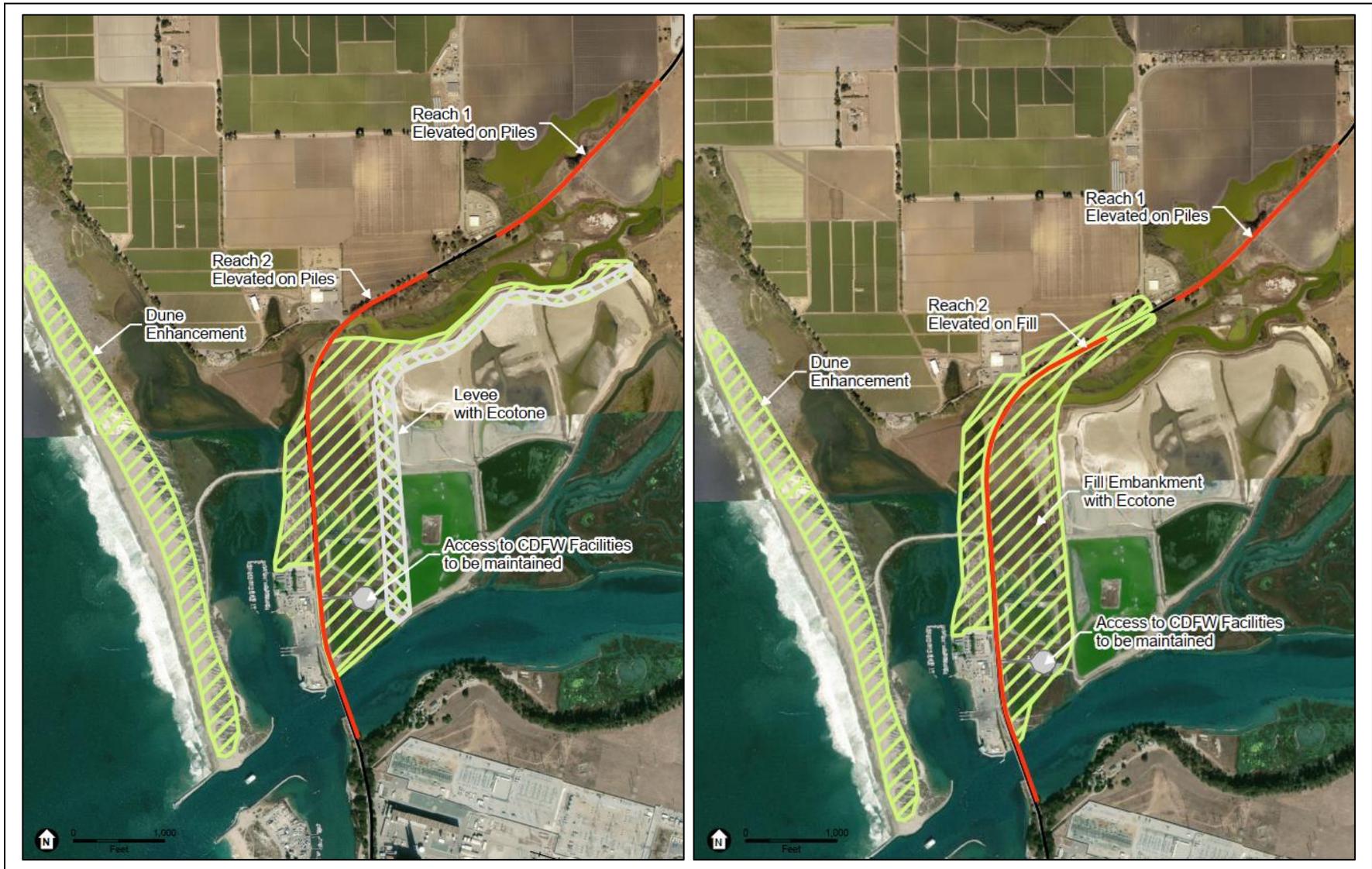
5.3 Preliminary Roadway and Railway Adaptation Scenarios

Preliminary roadway and railway adaptation scenarios were developed based off the suite of transportation and ecological adaptation elements described above. Since the study area spans a large extent of Moss Landing and Elkhorn Slough, development of the adaptation scenarios was informed by existing floodplain management, community planning and system-wide and local ecological conditions. In particular, additional focus was placed on which segments of the roadway would be elevated on fill embankment or piles, since these influence local flow patterns (e.g. tidal connectivity) that indirectly influence habitat quality.

5.3.1 Reaches 1 and 2

The construction of the transportation corridor and other human activities around Elkhorn Slough have largely shaped existing hydrology and hydraulics in the area. Struve Pond and Upper Bennett Slough are currently blocked off from tidal connection due to re-location of the Harbor mouth and construction of the existing Highway One facility. Reconnaissance of the existing highway show that there are a number of hydraulic structures, in varying condition, underneath the embankment which control tidal connectivity and flood patterns in the area. ESA verified that the culvert underneath Highway One Reach 2 connecting Lower and Upper Bennett Slough was crushed and seemed to convey little to no flow. Both Struve Pond and Upper Bennett Slough have been identified as areas with poor water quality, due to the lack of flushing and runoff from adjacent agricultural lands and the roadway.

Highway One Reaches 1 and 2 are located adjacent to the western portion of the Moss Landing Wildlife Area (MLWA), an 872-acre property with large amounts of salt marsh habitat. The portion of the wildlife area next to the roadway is managed to provide habitat to Western Snowy Plover in spring and summer and flooded in the fall and winter to provide wintering waterfowl habitat. CDFW provided locations and heights of perimeter and internal berms in the pond system. Additionally, CDFW confirmed that the artificial salt ponds at this location would continue to be managed in this way over the next several decades and the opportunity to create additional habitat area between the western edge of the wildlife area and Highway One Reach 2 would be beneficial. Therefore, in design development for Highway One Reach 2, the Project Team assumed that the ponds would remain in-place and that the space between Highway One and MLWA would be available for levee ecotone creation. **Figure 19** shows the locations and extents of the levee ecotone creation corresponding to Reach 2 elevated on fill or piles.



Central Coast Highway 1 Climate Resiliency Study

Figure 19

Levee Ecotone Creation (Conceptual)
 Reach 2 Elevated on Piles (Left) or Fill (Right)

5.3.2 Reaches 3 and 4

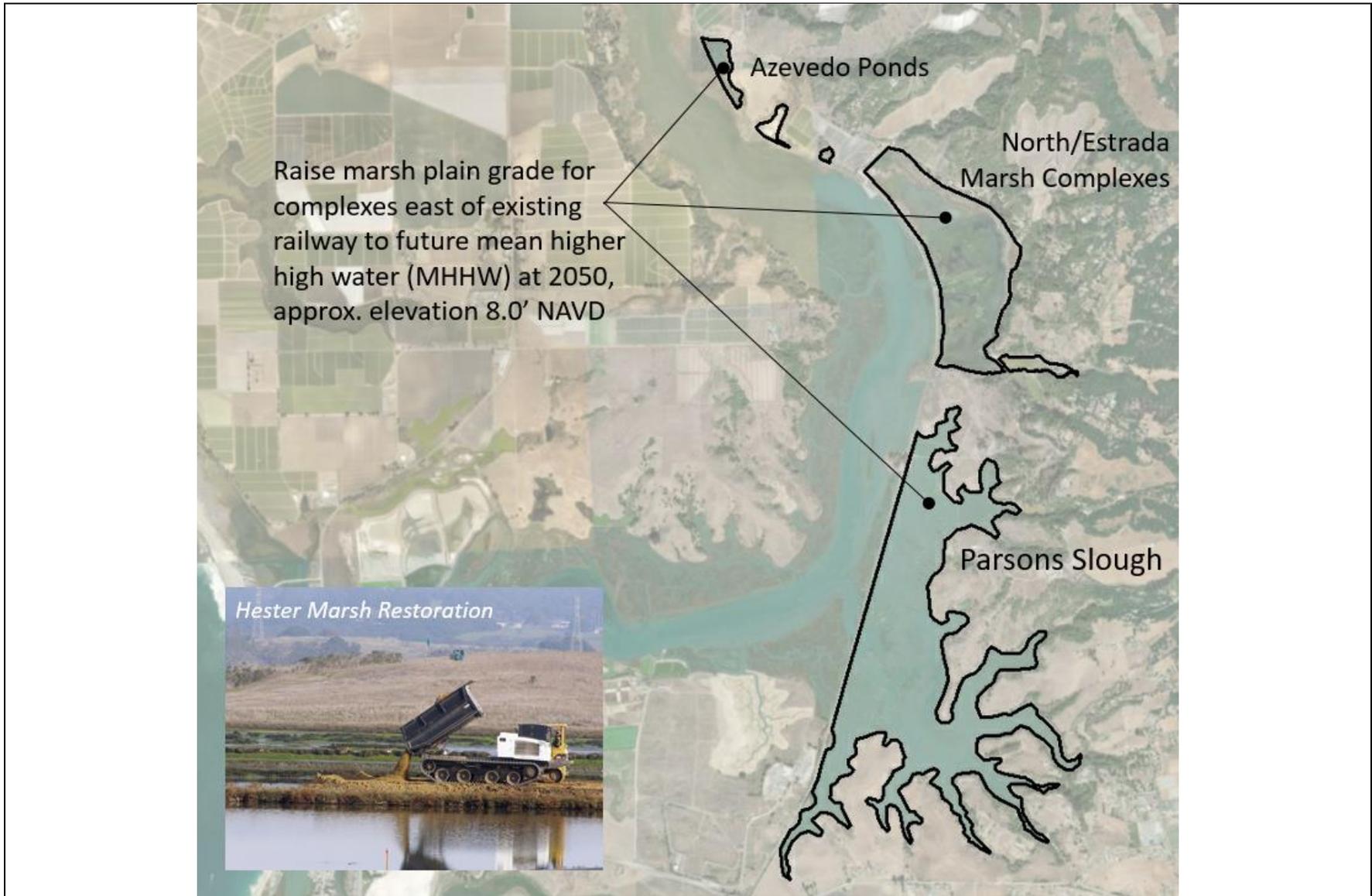
Highway One Reaches 3 and 4 are located south of the Elkhorn Slough bridge crossing, upstream of tide gates, and near low-lying agricultural lands. The Moro Cojo Management Enhancement Plan (2013) lists conservation strategies for Moro Cojo Slough, including acquisition of key lands, including viable farmlands, to protect and restore marsh habitat. Implementation of the Plan include acquisition of parcels adjacent to the Slough, creation of pond and freshwater habitat, and extensive coordination with local landowners. Discussions with Central Coast Wetland Group (CCWG) and other Moro Cojo Slough stakeholders indicate that these efforts will continue as part of the overall management plan for Moro Cojo Slough system. For consistency with this current planning, the study assumes that Reaches 3 and 4 would be elevated on piles in the future, in order to allow for tidal connectivity as the adjacent lands flood under future sea-level rise. The existing roadway embankment is assumed to be left in-place to provide more flexibility in floodplain management into the future (e.g. hydraulic control mechanism for inland areas)

5.3.3 Elkhorn Rail

Due to concerns around subsidence within the Slough, elevating the railway on a raised fill embankment was removed from consideration. Improvements to the railway would assume that the facility would be elevated on trestle. The existing railway embankment serves as a hydraulic control mechanism for the inboard marshes and may potentially aid in sediment retention. The study assumes that the existing facility would be left in-place and a new facility offset from the existing railway alignment would be constructed. For all adaptation scenarios, restoration of the marsh complexes east of the railway (e.g. Azevedo Ponds, North/Estrada Marsh, Parsons Marsh) by raising marsh elevations is assumed (**Figure 20**). These would be similar to recent efforts in other locations within the Slough, such as Hester Marsh Restoration, where 65 acres of salt marsh was restored by raising the existing marsh plain grades.

5.3.4 Alternate Routes to the Existing Roadway Alignment

Alternatives to modifying the existing roadway alignment, such as re-routing to an inland alignment, were developed as potential adaptation scenarios. Input from the Steering Committee informed the development of a managed retreat scenario where traffic is diverted from Highway One to the existing G-12 corridor that runs along San Miguel Canyon Road. TAMC completed a G-12 corridor study identifying mid-term and long-term improvements with other planned regional improvements. Managed retreat is generally associated with allowing coastal erosion and flooding to displace built assets, but is more accurately defined as a coastal land use strategy to proactively adapt to landward shore migration and increasing hazards associated with sea-level rise. Based on the Moss Landing Harbor SLR Vulnerability Assessment (CCWG, 2019), much of the developed area by Moss Landing Harbors North and South will be inundated frequently by mid-century and the community may consider migrating landward as part of its long-term climate change adaptation plan.



Source: Elkhorn Slough Foundation (2018)

Central Coast Highway 1 Climate Resiliency Study

Figure 20

Proposed Salt Marsh Restoration Areas

5.3.5 Time Horizons and Sea Level Rise Considerations

Typically, major transportation infrastructure projects are designed to last for a specific project lifetime, or be able to withstand future conditions. Roadway and railway facilities constructed by mid-century (e.g. 2050) would be designed for a sea-level rise amount corresponding to a time horizon in late-century (e.g. 2070, 2100), or later. For the purposes of planning-level design and evaluation, it is assumed that the roadway and railway elevations would be in place by 2050 and designed for a 2070 time horizon (equivalent to 3 ft of sea-level rise for the panning scenario). All reaches of Highway One and the railway were assumed to be elevated to accommodate 3 ft of sea-level rise with an additional foot of freeboard⁹. For roadway segments elevated on piles, an additional height of 4 ft was added to account for the roadway deck width. Similarly, the proposed marsh restoration east of the railway would be designed for future elevations. The marsh plain grade is assumed to be raised to future MHHW at mid-century, which is approximately 8.0' NAVD.

Table 4 describes the preliminary roadway and railway adaptation scenarios in detail, including locations and specifications of adaptation actions. A number of associated access improvements (e.g. intersection improvements, frontage roads) must be made in tandem with elevating and widening the roadway. Figure 21 through 26 show locations of planned access improvements for each of the preliminary adaptation scenarios.

⁹ Freeboard is defined as the distance between the water line and top of a structure or mass above the water (e.g. roadway deck).

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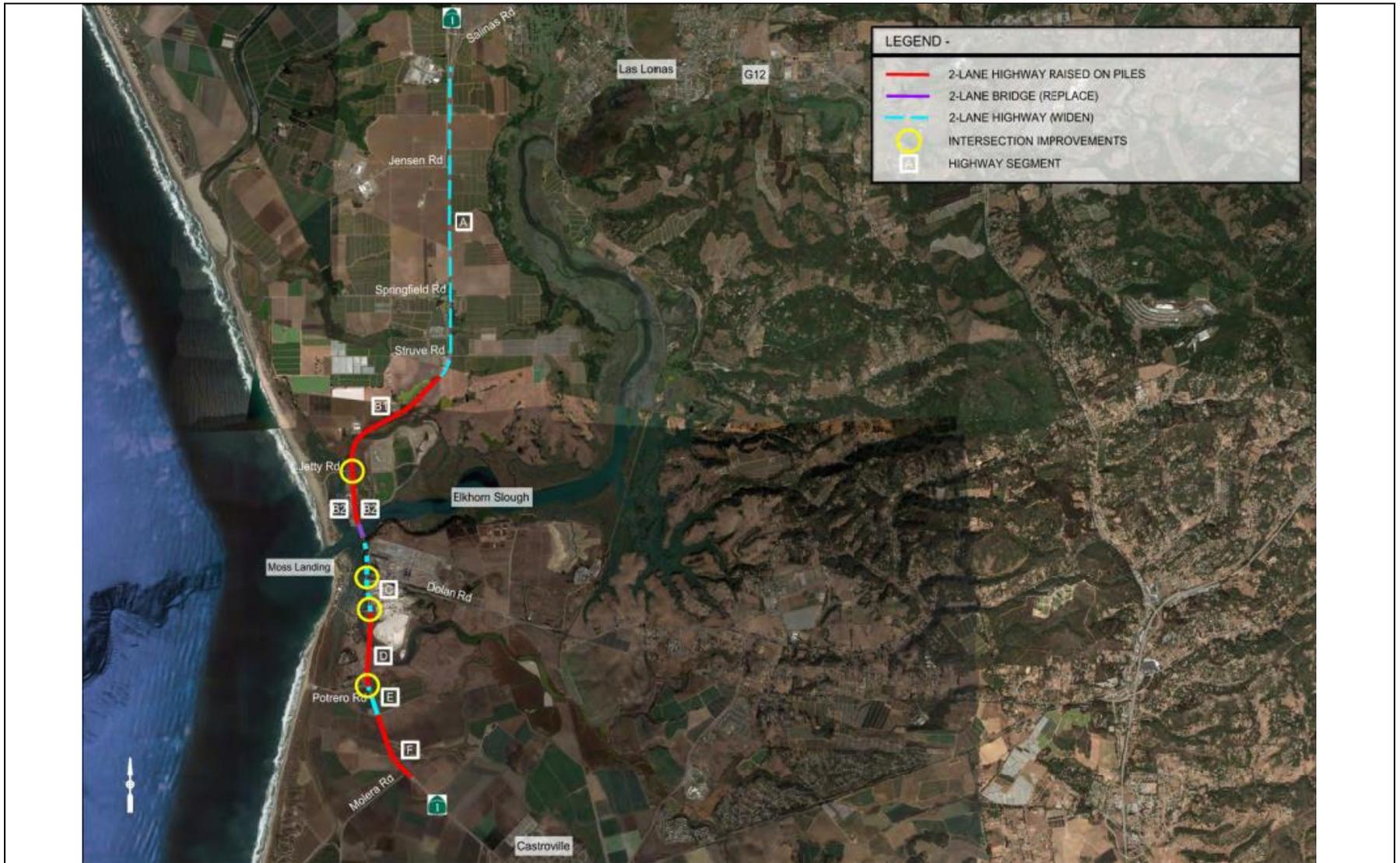
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Table 4. Preliminary Roadway and Railway Adaptation Scenarios

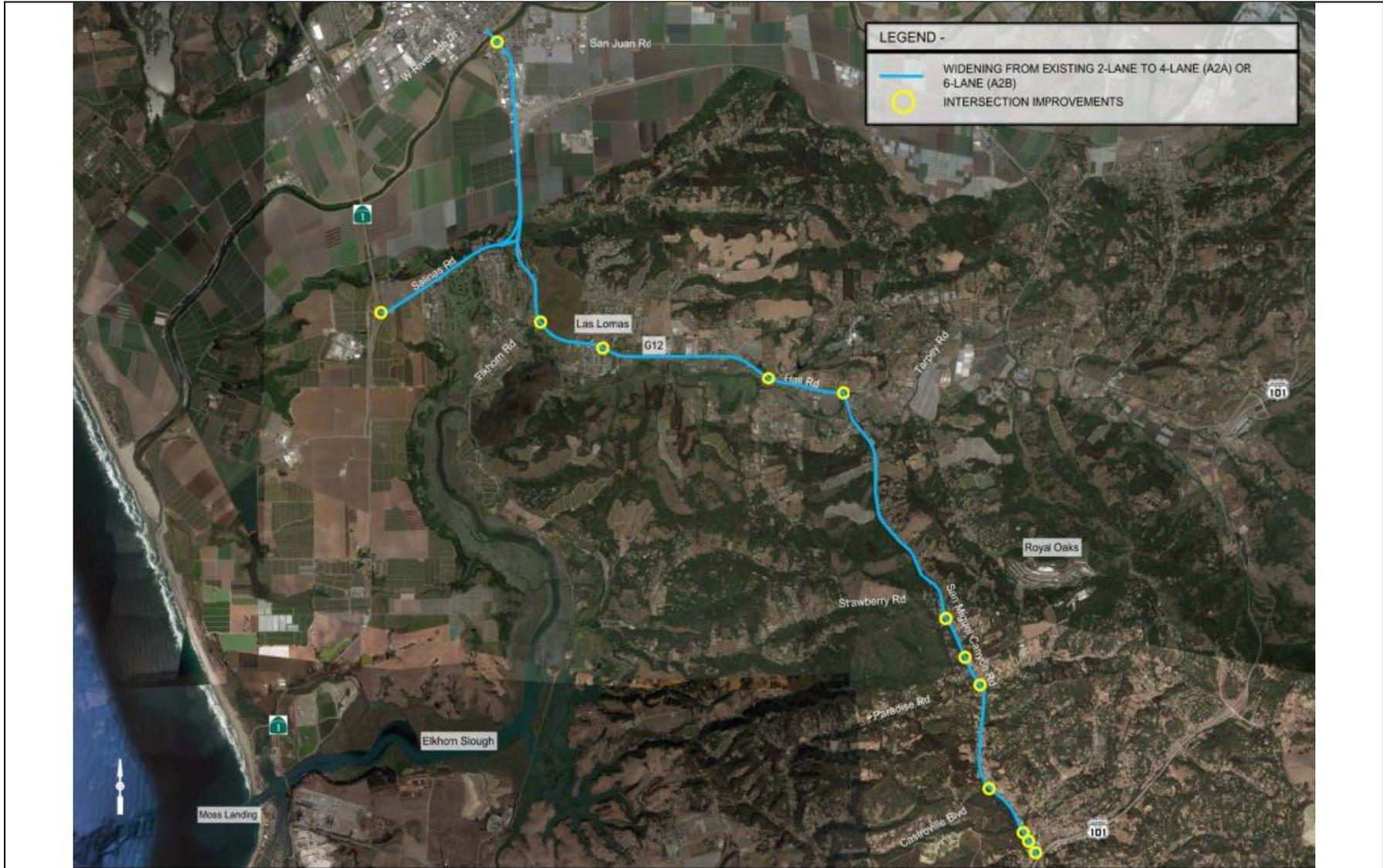
Scenario	Short Name	Roadway		Railway	
		Transportation	Ecology	Transportation	Ecology
A0/B0	No Action	No-action	No-action	No-action	No-action
A1A	2-Lane Elevated Highway with Reach 2 on Piles	2-lane roadway with operational improvements, including access improvements and bike/pedestrian trail. Reaches 1-4 would be elevated completely on piles, with +3 ft allowance for sea-level rise and 1' of additional freeboard.	A levee ecotone would be constructed on the inboard side of Reach 2, with a crest along the inner perimeter of MLWA and sloping downwards (underneath the elevated highway) to Moss Landing Harbor (North). This would provide additional future wetland habitat under sea-level rise.	A new dual-track railway facility would be constructed adjacent to the existing railway fill embankment and elevated on trestle. The existing railway fill embankment would be left in place, to potentially aid in sediment retention for the inboard marsh complexes.	Marsh complexes east of the existing railway fill embankment, including Azevedo Ponds, North/Estrada Marsh and Parsons Marsh, would be restored to keep pace with sea-level rise. Existing marsh grade plain for these areas would be raised to future MHHW at mid-century, which is approximately 8.0' elev. NAVD. To increase tidal connectivity to these areas, new tidal channel openings North/Estrada Marsh complexes and the larger Azevedo Pond would be created.
A1B	2-Lane Elevated Highway with Reach 2 on Fill	2-lane roadway with operational improvements, including access improvements and bike/pedestrian trail. Reaches 1, 3 and 4 would be elevated completely on piles and Reach 2 would be elevated on fill embankment, with +3 ft allowance for sea-level rise and 1' of additional freeboard.	Levee ecotones would be constructed on both sides of Reach 2, gently sloping to match grade at Moss Landing Harbor and Moss Landing Wildlife Area. This would provide additional future wetland habitat under sea-level rise.		
A2A	Managed Retreat/Widening G-12 (4-Lanes)	Traffic from existing Highway One would be diverted to the G-12 corridor. Salinas Road and San Miguel Canyon Road would be widened to 4-lanes with a number of intersection improvements.	No action		
A2B	Managed Retreat/Widening G-12 (6-Lanes)	Traffic from existing Highway One would be diverted to the G-12 corridor. Salinas Road and San Miguel Canyon Road would be widened to 6-lanes with a number of intersection improvements.	No action		
A3A	4-Lane Elevated Highway with Reach 2 on Piles	4-lane roadway, including access improvements and bike/pedestrian trail. Reaches 1-4 would be elevated completely on piles, with +3 ft allowance for sea-level rise and 1' of additional freeboard.	Same as A1A		
A3B	4-Lane Elevated Highway with Reach 2 on Fill	4lane roadway, including access improvements and bike/pedestrian trail. Reaches 1, 3 and 4 would be elevated completely on piles and Reach 2 would be elevated on fill embankment, with +3 ft allowance for sea-level rise and 1' of additional freeboard.	Same as A1B		
A4/B1	Co-Located 4-Lane Elevated Highway and Dual-Track Railway	A co-located 4-lane roadway facility and dual-track railway facility would be constructed inland (east) of the existing roadway alignment. The roadway would be elevated on piles and railway on trestle. The new alignment would cross approximately the Slough below Struve Rd/Highway One. The roadway and railway facilities would diverge after the Slough crossing. The new roadway would continue south and rejoin the existing highway by Castroville. The new railway would reconnect the existing railway by Dolan Road and Moro Cojo Slough.			
B2	Dual Track Railway	No planned transportation improvements to roadway facility.	No planned ecology adaptation actions by roadway facility.	A new dual-track railway facility would be constructed adjacent to the existing railway fill embankment and elevated on trestle. The existing railway fill embankment would be left in place, to potentially aid in sediment retention for the inboard marsh complexes.	

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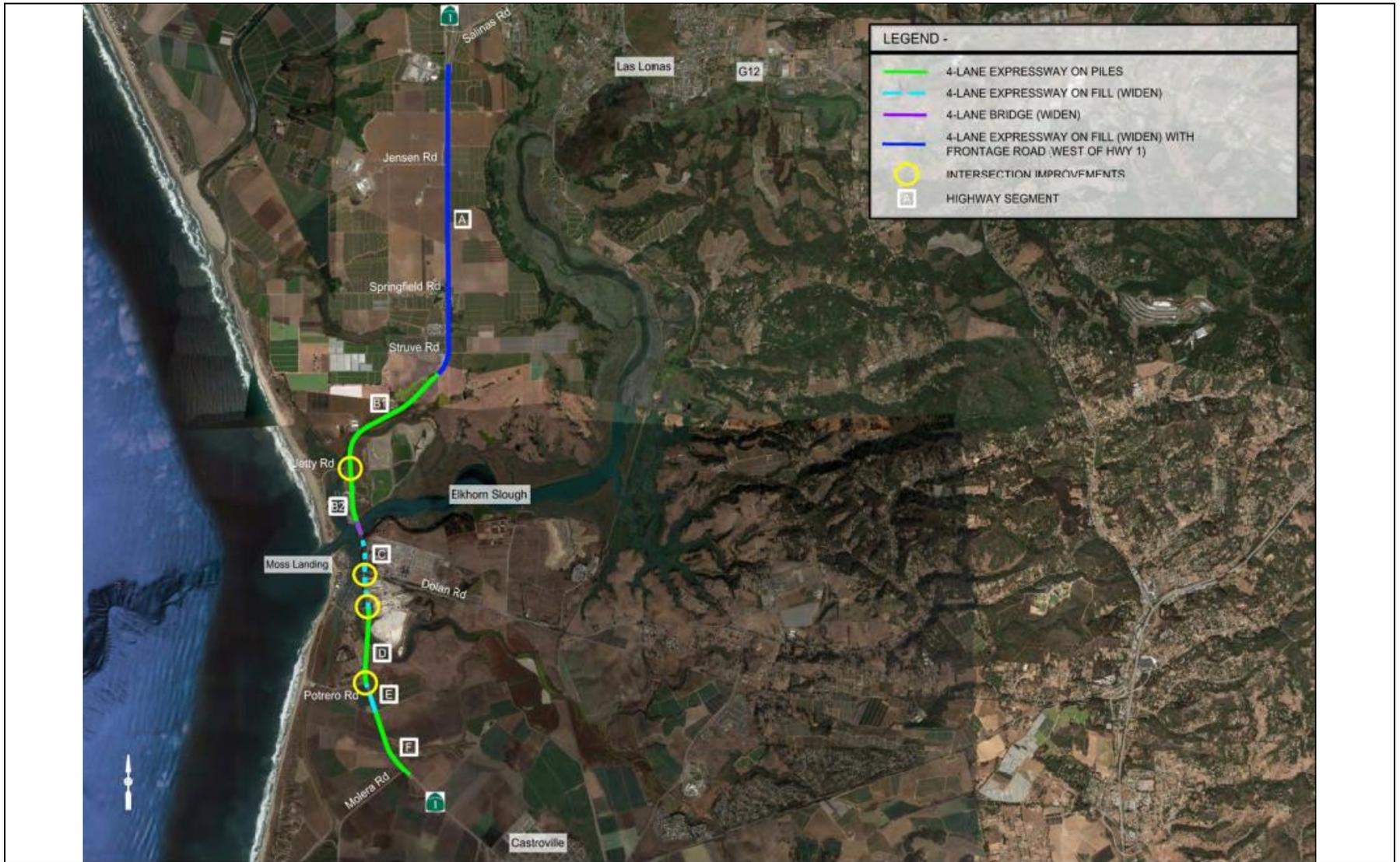
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Central Coast Highway 1 Climate Resiliency Study
Figure 21
 Scenario A1 (Conceptual)
 2-Lane Highway with Operational Improvements



Central Coast Highway 1 Climate Resiliency Study
Figure 22
 Scenario A2 (Conceptual)
 G-12 Widening to 4- or 6- Lanes



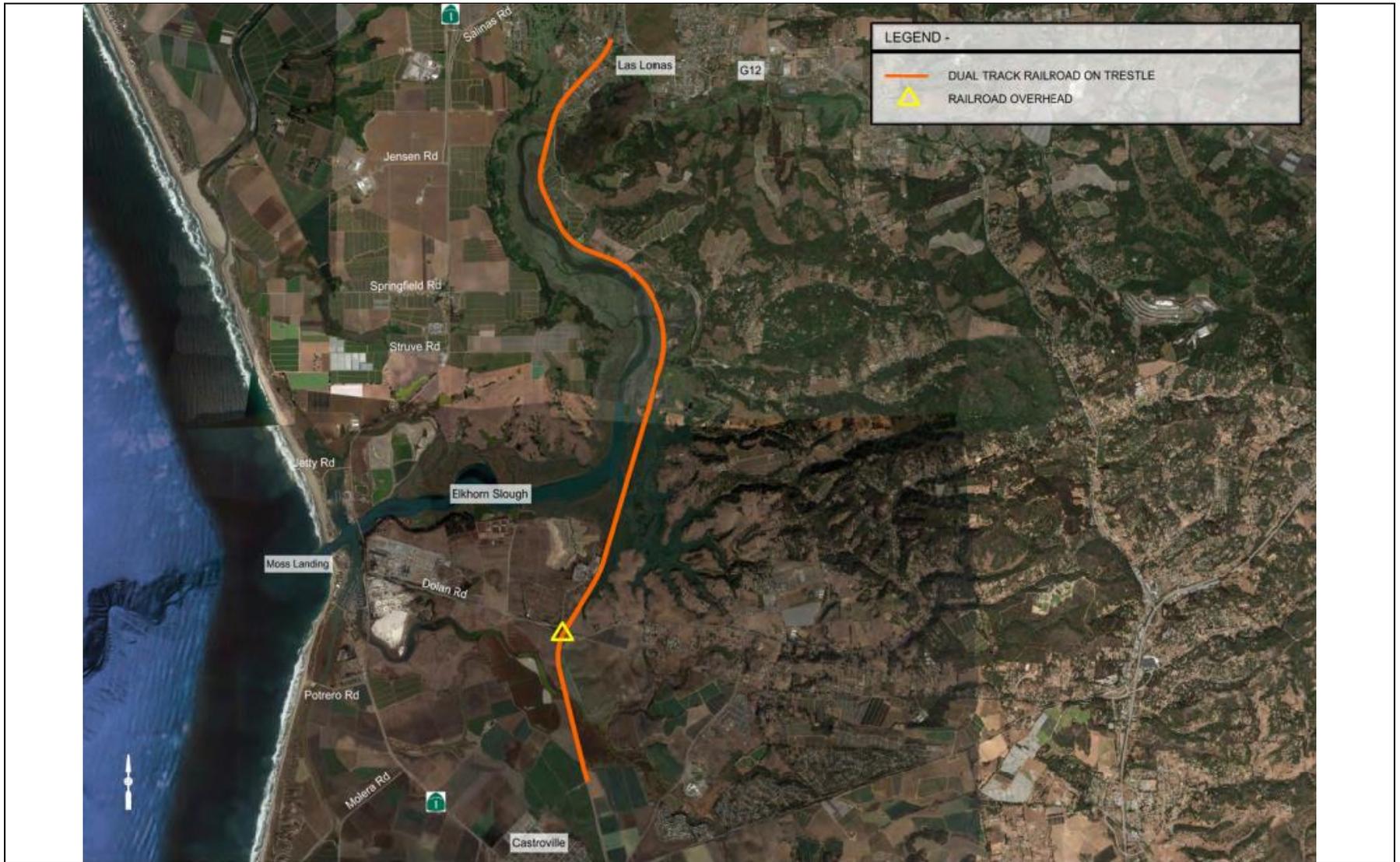
Central Coast Highway 1 Climate Resiliency Study
Figure 23
 Scenario A3 (Conceptual)
 4-Lane Highway (Existing Alignment)



Central Coast Highway 1 Climate Resiliency Study
Figure 24
 Scenario A4/B1 – Phase 1 (Conceptual)
 Co-located Roadway and Railway Facility (New Alignment)



Central Coast Highway 1 Climate Resiliency Study
Figure 25
 Scenario A4/B1 – Final Phase (Conceptual)
 Co-located Roadway and Railway Facility (New Alignment)

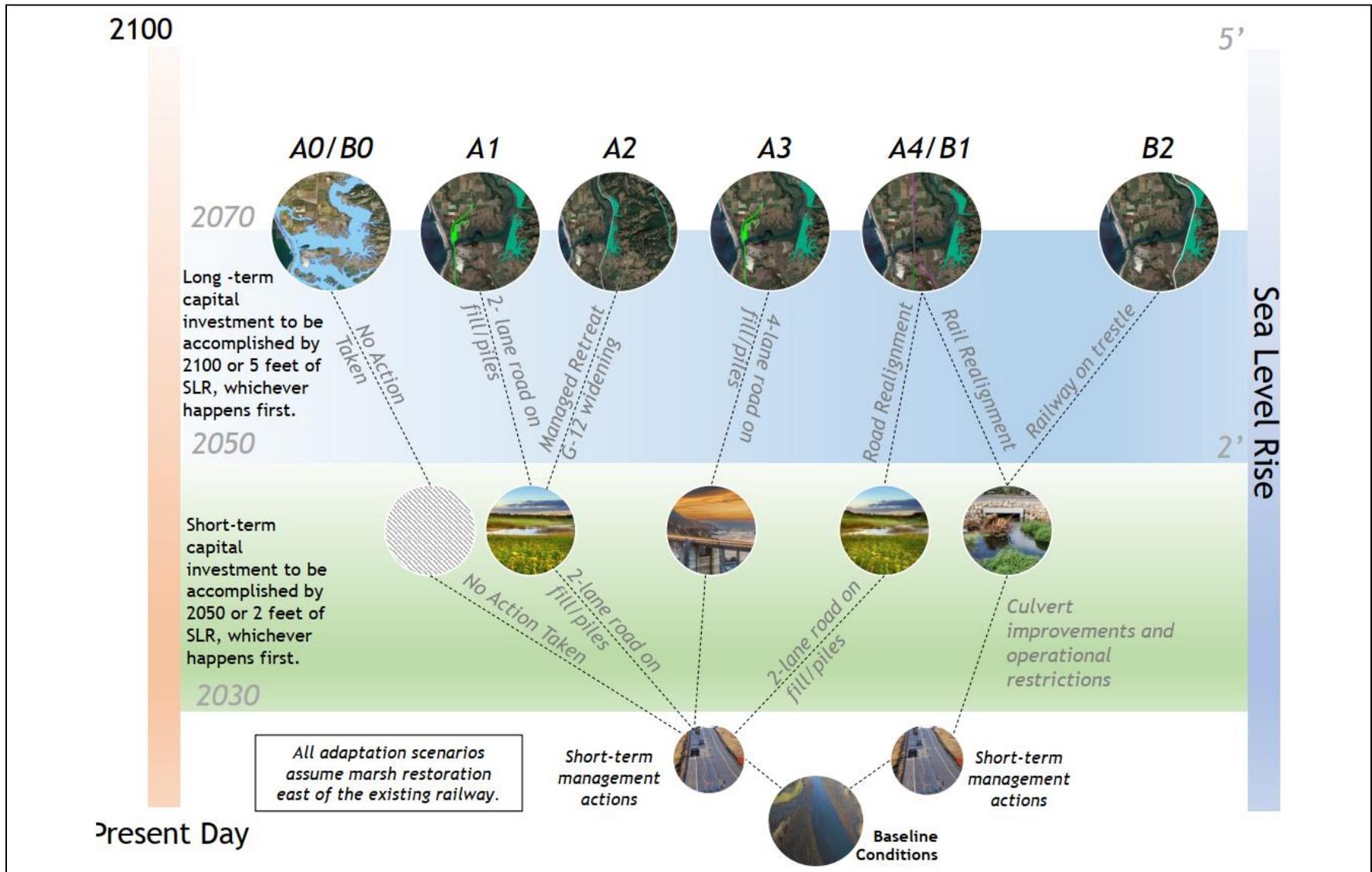


Central Coast Highway 1 Climate Resiliency Study
Figure 26
Scenario B2 (Conceptual)
Dual-Track Railroad on Trestle

5.3.6 Adaptation Pathways Approach

The various transportation and ecological components of the adaptation scenarios will require significant capital investment and time for planning, design, regulatory review processes and construction. As discussed in Section 4, the study utilizes an adaptation pathways approach to outline timing of recommended near-term actions, short-term capital and long-term capital investments and place the adaptation scenarios into context with existing climate change adaptation planning efforts and predicted sea-level rise amounts for the Monterey Bay Area region. **Figure 27** shows the adaptation pathways diagram for the range of preliminary roadway and railway adaptation scenarios. The preliminary adaptation scenarios, represented by circular nodes, are located at the 2070 time horizon to indicate that the transportation and ecology components are designed for future sea-level rise conditions.

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Central Coast Highway 1 Climate Resiliency Study

Figure 27

Preliminary Roadway and Railway Adaptation Scenarios
Adaptation Pathways Diagram

6. SCENARIOS EVALUATION

This section describes the methods used for evaluating the adaptation scenarios and major conclusions stemming from analyzing the preliminary set of roadway and railway adaptation scenarios. These, in conjunction with input from the Steering Committee and community workshop, informed refinement of a subset of the adaptation scenarios for full evaluation with the economic benefit-cost analysis.

6.1 Evaluation Methods

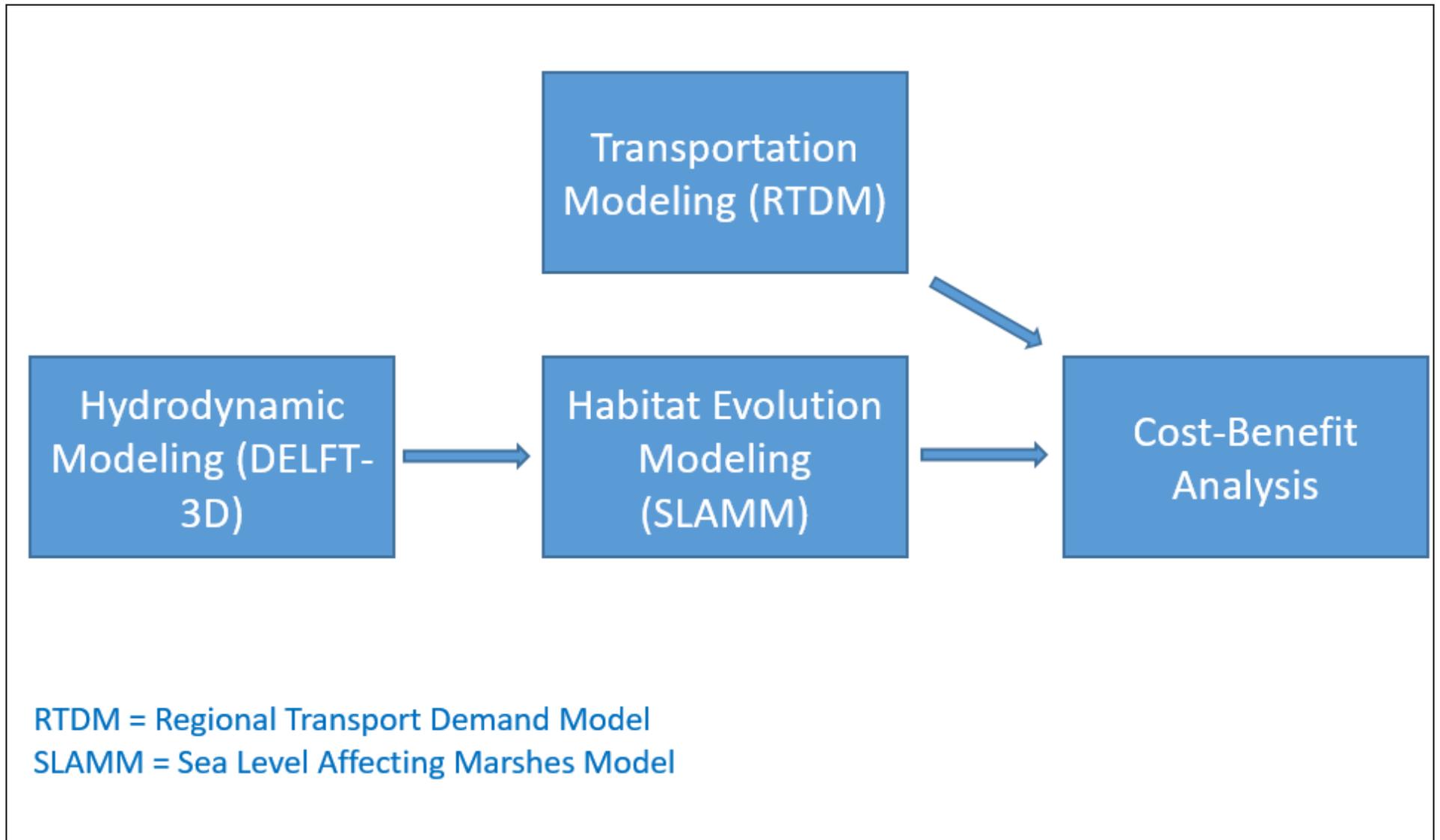
The dual nature of the study necessitates the use of several models to establish the performance of the adaptation scenarios with respect to transportation and ecology parameters. Flood hazards for existing and future sea levels was conducted using Coastal Resilience methods, with refinements for existing and future conditions. Hydrodynamic modeling and habitat evolution modeling were conducted for the adaptation scenarios in order to establish impacts to wetland habitats. Transportation modeling was conducted to assess improvements in future transportation function. Outputs from these modeling processes informed the economic benefit-cost analysis portion of the scenarios evaluation. **Figure 28** shows the overall study process and workflow.

6.2 Flood Hazards

Flood hazard maps for Monterey Bay were developed as part of the Coastal Resilience Program¹⁰. Flood and erosion hazard maps developed with funding from the State of California are available for viewing on-line, and geographical information system files are available for download, together with technical report documentation¹¹. ESA, the original developer of the maps and supporting methodology, modified the hazard maps for this project. Modifications consisted of refinements to flood elevations at the Highway Reaches by more precise computation of overland flood routing and potential groundwater levels with sea-level rise, and consideration of the effects of Highway Adaptation scenarios. Also, a representative elevation for each Highway Reach was

¹⁰ Coastal Resilience Program, an approach and on-line decision support tool (last visited May 2020): <https://coastalresilience.org/about/>

¹¹ Coastal Resilience Mapping Portal (last visited May 2020): <https://maps.coastalresilience.org/>



Central Coast Highway 1 Climate Resiliency Study
Figure 28
Study Process for Evaluation of Adaptation Scenarios

selected as the “flood threshold”, and compared to the computed water levels in order to identify the amount of sea-level rise that would initiate flooding and hence degradation of the road and its transportation function under no project, future conditions. The results are summarized in **Table 5** below. Coastal and Fluvial Storm have 100-year recurrence intervals. Monthly refers to the maximum monthly water level, also called Extreme Monthly High Water.

Table 5. Flood Thresholds, sea-level rise and time horizons developed in this study for the four Reaches of existing Highway One

Reach	Minimum Elevation (ft, NAVD)	Coastal Storm Threshold	Fluvial Storm Threshold	Monthly Inundation Threshold
1	7.6	By 2040 [2030 southbound lane impacted, WSE* 7.3 ft and sea-level rise** = 0.7']	N/A	By 2050 [Bennett Slough WSE 7.6' with 2 ft sea-level rise]
2	8.9	2030 [0.7' sea-level rise]	N/A	2060 [2.4' sea-level rise]
3	8.8	2040 [1.3 ft sea-level rise]	2040 [1.3 ft sea-level rise]	2065 [2.6' sea-level rise]
4	9.0	2045 [1.4' sea-level rise]	2040 [1.3 ft sea-level rise]	2070 [2.8' sea-level rise]

* WSE = water surface elevation in feet, NAVD

** sea-level rise = sea-level rise in feet relative to existing conditions

6.3 Evaluation of Preliminary Roadway and Railway Scenarios

6.3.1 Hydrodynamic Modeling (Delft3D)

ESA utilized Delft3D, a hydrodynamic model, to evaluate potential hydraulic impacts (e.g. changes to flow patterns and flood extents) of the adaptation scenarios. Delft3D models hydrodynamics, sediment transport and morphology, and water quality for fluvial, estuarine and coastal environments. This application provides hydrodynamics using a two-dimensional, depth-averaged configuration.

ESA updated an existing application of Delft3D, which was developed to evaluate management actions for Elkhorn Slough, to encompass the full study area, including: Struve Pond, Bennett Slough and adjacent roadway area, Moro Cojo Slough, North/Estrada Marsh Complexes and Azevedo Pond. Grid cell resolution was refined to

30 ft around the transportation infrastructure to adequately resolve hydraulic impacts around the roadway and railway. ESA incorporated the latest elevation (topography/bathymetry) data provided by National Oceanic and Atmospheric Administration (NOAA), California State University, Monterey Bay (CSUMB) and Central Coast Wetlands Group (CCWG). Hydraulic structures located through the roadway and railway infrastructure were modeled, based on data provided by ESNERR and MLML. More technical detail on model development and results can be found in Appendix C.

Modeling results for Scenario A0/B0 (No Action) confirm that with no adaptation actions, the roadway and railway infrastructure will be flooded under future sea-level rise. Previous flood hazard modeling work conducted, Coastal Resilience Monterey, show Reaches 1 and 2 by Struve Pond and Bennett Slough flooding by 2060; the hydrodynamic model results for Scenario A0/B0 are consistent with this conclusion and show flooding in those areas and through most of the existing railway, assuming 3 ft of sea-level rise at 2070. Although Scenario A2 (Managed Retreat/Widening G-12) was not explicitly modeled, the results from the revised flood hazard mapping for Scenario A0/B0 (No Action) indicate that the local access to the Moss Landing community would only be available until 2050 (2 ft of sea-level rise), assuming conversion of the existing Highway One to a local road and managed retreat.

Modeling results for Scenario A1A (2-Lane Elevated Highway, Reach 2 Elevated on Piles), show lower Bennett Slough and Struve Pond with increased tidal action, which may improve historic water quality issues in those areas (e.g. pollution from agricultural and road runoff). Scenarios A1A (2-Lane Elevated Highway, Reach 2 Elevated on Piles) and A1B (2-Lane Elevated Highway, Reach 2 Elevated on Fill) also show flooding of Struve Pond and Bennett Slough via an alternate pathway behind Moss Landing Wildlife Area. This indicates that modifications made to the roadway may have decreasing control over flooding in this part of the Slough, as sea levels rise and new flood pathways develop. These modeling results are predicted to be similar for Scenario A3 (4-Lane Elevated Highway) in both variations (Reach 2 on fill and piles), from a hydraulic standpoint.

Scenario A4/B1 (Co-Located 4-Lane Elevated Highway and Dual Track Railway) was not explicitly modeled for a number of reasons. Firstly, since the new alignment would likely only span a short section of the Slough channel and was assumed to not have major impacts on the overall hydrodynamic patterns of the Slough, in comparison to modifications made to the existing roadway and railway. Further, as the existing Highway One would need to remain under this scenario to provide local access for residents and businesses, the new alignment would not alleviate any environmental stress from Elkhorn Slough's ecosystems but would instead be completely additive in impact. Input from the Steering Committee made it apparent that the new alignment would cut through several different types and locations of intact, sensitive habitats supporting species protected under State and Federal Endangered Species Acts. Finally, similar to Scenario A2 (Managed Retreat/Widening G-12 4-6 Lanes), the results of Scenario A0 (No Action) represents local transportation assuming conversion of the

existing Highway One to a local road and managed retreat of the Moss Landing community. Results indicate that the local access to the Moss Landing community would only be available until 2050 (2 ft of sea-level rise) into the future, and thus the new alignment would also fail to support the local community.

Preliminary results for all adaptation scenarios assuming marsh restoration show that flow velocities by the areas of marsh restoration and inner Slough are lower compared to Scenario A0/B0 (No Action) under future sea-level rise, which may be beneficial for retaining sediment within the Slough. Given that the Slough has been experiencing a net export of sediment (i.e. losing sediment), pursuing marsh restoration and using the existing railway embankment as a dike could help support the resilience of these habitats under future conditions.

6.3.2 Preliminary Transportation Modeling

AMBAG evaluated the transportation improvements in the adaptation scenarios using the AMBAG Regional Travel Demand Model (RTDM) and GIS. The current RTDM's horizon year is 2040. There are no transportation models for the AMBAG region that go beyond 2040. The 2015 existing network in the travel demand model represents existing conditions.

AMBAG evaluated eight scenarios containing a variety of roadway, transit, rail and active transportation improvements. All 2040 scenarios include future population, housing and employment growth in the region. The initial eight scenarios plus the existing conditions are described below.

- Scenario A0/B0 (No Action) was separated into two sub-scenarios, A0A/B0A and A0B/B0B, and modeled for comparative purposes to see what would happen when Highway One was unavailable. Scenario A0A/B0A (No Action Without Highway) presents a future 2040 scenario without Highway One. This reflects what would happen if Highway One were to flood and be completely unavailable, and traffic was rerouted to the G12 corridor or other roadways. Transit stops would no longer exist along the Highway One corridor. No changes to the rail corridor.
- Scenario A0B/B0B (No Action with Highway) is the same as the existing 2015 network with no improvements to Highway One or the rail in the study area. In this scenario it is assumed that Highway One would often be unavailable due to flooding.
- Scenario A1 (2-Lane Elevated Highway) has a two-lane Highway One elevated, either on fill or piles, with access point modifications. Access to Highway One would be improved with grade separation at the Dolan Road and Potrero Road intersections. Highway access at the north end of Moss Landing Road would no longer exist. The bus and rail components would remain the same as existing conditions.

- Scenario A2A (Managed Retreat/Widening G-12 4-Lanes) removes Highway One from the study area and widens the G12 corridor to four lanes from U.S. 101 to Salinas Road. Monterey-Salinas Transit bus routes would be terminated in Castroville. No changes would be made to the rail corridor. Scenario A2B (Managed Retreat/Widening G-12 6 Lanes) is identical to scenario A2A, but the G12 corridor is widened to six lanes instead of four. This was separated into two sub-scenarios to compare the 4-lane and 6-lane options.
- Scenario A3 (4-Lane Elevated Highway) is similar to scenario A1, but Highway One is widened to 4 lanes. Additionally, access at Struve Road would be improved by grade separation, and there would be southbound access to the north end of Moss Landing Road. Bus and rail would remain the same as existing.
- Scenario A4/B1 (Co-Located 4-Lane Elevated Highway and Dual Track Railway) presents a realignment of both Highway One and rail. Highway One is widened to four lanes, and relocated east of the current alignment, and the double-tracked railway is moved west of its current alignment through the middle of the slough. Additionally, new interchanges would be created at Highway One83, Dolan Road, Struve Road, and Salinas Road. Bus would no longer run on Highway One, but rail service would increase its frequency to every 30 minutes.
- Scenario B2 (Dual Track Railway) is similar to scenario A0B/B0B, but rail service is increased to every 30 minutes. Highway One and bus service remain the same.

For each scenario, the RTDM was utilized with specific network and transit components, and the output was analyzed quantitatively. The evaluation criteria listed below were applied to each scenario, and the results were compared relative to each scenario. The goal of this process was to identify scenarios that best met the purpose and need of the Central Coast Highway One Resiliency Study.

Figure 29 is a matrix of how each scenario performed relative to each scenario for each of the performance measures.

The following performance measures were developed as the best set of metrics using data available to inform the technical analysis of the adaptation scenarios:

Roadway

Vehicle miles traveled (VMT) is the total distance traveled by all vehicles in a given area over a given period of time. It is calculated by the number of vehicles multiplied by the miles traveled in a given area or on a given highway during the time period. In general, daily VMT remains consistent for each of the scenarios, apart from Scenarios A2B (Managed Retreat/Widening G-12 6 Lanes), A3 (4-Lane Elevated Highway), and A4/B1 (Co-Located 4-Lane Elevated Highway and Dual Track Railway), where it increases. A4/B1 (Co-Located 4-Lane Elevated Highway and Dual Track Railway) has the highest daily VMT, while Scenario A0A/B0A (No Action Without Highway) has the lowest.

Performance Measures for Central Coast Highway 1 Climate Resiliency Study

PM ID	DESCRIPTION	2015 Existing	2040 A0A/B0A	2040 A0B/B0B	2040 A1	2040 A2A	2040 A2B	2040 A3	2040 A4/B1	2040 B2
1	VMT Total ¹	N/A	=	=	=	=	-	-	-	=
2	Congested VMT ²	N/A	-	-	-	=	=	+	+	-
3	Average Travel Time ¹	N/A	+	=	=	+	+	-	-	=
4	VHT Total ¹	N/A	=	=	=	=	=	=	=	=
5	Vehicle Delay ²	N/A	-	-	-	-	=	+	+	-
6	Freight Delay (VHT) ¹	N/A	=	-	-	=	=	=	=	-
7	GHG (CO2) Emissions from all land use and VMT per capita (lbs) ²	N/A	=	=	=	=	=	=	=	=
8	Collisions/Accidents (Annual projected number of injury and fatal collisions per thousand VMT) ²	N/A	=	=	=	=	=	=	=	=
9	Multimodal Trips/Mode Share (Transit, Bike, Ped) ¹	N/A	+	=	=	+	+	-	-	=
10	Disadvantaged Communities Accessibility ²	N/A	-	+	+	-	-	+	+	+
11	Impact to Natural Resources ²	N/A	+	+	+	-	-	-	-	-

+ Scenario would result in positive benefits

= Scenario would result in neutral benefits

- Scenario would result in negative impacts

¹Regionwide

²Project Area

Central Coast Highway 1 Climate Resiliency Study
Figure 29
 Transportation Performance Matrix
 Preliminary Roadway and Railway Adaptation Scenarios

Congested VMT (CVMT) is the total vehicle miles traveled at level of service, E and F (volume/capacity ≥ 0.86 for functional class 2 and where volume/ capacity ≥ 0.90 for functional classes 3-7) divided by total vehicle miles traveled in the peak periods. CVMT is highest for scenarios A0A/B0A (No Action Without Highway), A0B/B0B (No Action With Highway), A1 (2-Lane Elevated Highway), and B2 (Dual Track Railway). Scenarios A2A (Managed Retreat/Widening G-12 4 Lanes) and A2B (Managed Retreat/Widening G-12 6 Lanes) have roughly equal CVMT, while Scenarios A3 (4-Lane Elevated Highway) and A4/B1 (Co-Located 4-Lane Elevated Highway and Dual Track Railway) have the lowest CVMT of the scenarios.

Vehicle hours traveled (VHT) is an aggregate of vehicle miles traveled divided by vehicle speed for all trips in the region. VHT remains consistent for each of the scenarios, showing no significant increase or decrease.

Vehicle Delay: This performance measure shows hours of delay for passenger vehicles in the study area. Vehicle delay is closely correlated with CVMT, with scenarios A0A/B0A (No Action Without Highway), A0B/B0B (No Action With Highway), A1 (2-Lane Elevated Highway), B2 (Dual Track Railway), and A2A (Managed Retreat/Widening G-12 4 Lanes) having the highest numbers for vehicle delay. Scenarios A3 (4-Lane Elevated Highway) and A4/B1 (Co-Located 4-Lane Elevated Highway and Dual Track Railway) have the lowest vehicle delay, while scenario A2B falls in the middle.

Freight Delay: This measure estimates the daily truck hours of delay. Over the next several decades, the Central Coast region can expect to see significant increases in freight movement due to population increases and a continued expansion of the region's agricultural production. A focus on enhancing the efficiency and safety of the region's goods movement system is critical to supporting the economic health of the region and the quality of life for its residents. Hours of truck delay are increased in scenarios A0B/B0B (No Action With Highway), A1 (2-Lane Elevated Highway), and B2 (Dual Track Railway), while the remaining scenarios have consistent levels of freight delay with each other.

Collisions/Accidents: This performance measure evaluates the safety of the transportation system by using data on injuries and fatalities to calculate a per capita rate of injury or fatality. It is an annual projected number of injury and fatal collisions per thousand VMT. This is a particularly difficult measure to project because it assumes that fatalities and injuries are held constant for every vehicle mile traveled. The percentage of collisions and accidents per thousand VMT remains consistent across each scenario.

Historical collision data for the study roadways and intersections were derived from the California Highway Patrol Statewide Integrated Traffic Records System (SWITRS). Data was collected on the Highway One study area for a six-year period between January 1, 2013 and December 31, 2018. Based on the collision data, there were roughly 700 reported collisions along the Highway One study area. A number of collisions are

focused in the northern section of the study area and in the area south of Dolan Road. This suggests that improvements in these areas should be implemented in the near term to address these issues.

General/Multimodal

Average Travel Time: This performance measure shows average commute travel time in minutes. Average travel time is consistent for Scenarios A0B/B0B (No Action With Highway), A1 (2-Lane Elevated Highway), and B2 (Dual Track Railway). Scenarios A0A/B0A (No Action Without Highway), A2A (Managed Retreat/Widening G-12 4 Lanes), and A2B (Managed Retreat/Widening G-12 6 Lanes), show improved average travel times, while Scenarios A3 (4-Lane Elevated Highway) and A4/B1 (Co-Located 4-Lane Elevated Highway and Dual Track Railway) have longer average commute travel times.

Multimodal trips: This is defined as the percentage of total trips that are shared ride, walk, bike, transit, school bus, or other. Scenarios A0B/B0B (No Action With Highway), A1 (2-Lane Elevated Highway), and B2 (Dual Track Railway) have similar percentages of multimodal trips, while Scenarios A0A/B0A (No Action Without Highway), A2A (Managed Retreat/Widening G-12 4 Lanes) and A2B (Managed Retreat/Widening G-12 6 Lanes) have greater percentages of multimodal trips. Scenarios A3 (4-Lane Elevated Highway) and A4/B1 (Co-Located 4-Lane Elevated Highway and Dual Track Railway) show a decrease in the percentage of multimodal trips.

Social Equity

Disadvantaged Communities: This performance measure evaluates the percent of low income populations and racial and ethnic minority groups that are located within one-half mile of a transit stop. Census data was used to identify Census tracts that contained greater than 65% of households with an income of less than \$75,000 per year, as well as tracts where 65% or more of the population is non-white. Much of population within the study area is both low income and home to communities of color. This performance measure was calculated using GIS.

Scenarios A0B/B0B (No Action With Highway), A1 (2-Lane Elevated Highway), A3 (4-Lane Elevated Highway), A4/B1(Co-Located 4-Lane Elevated Highway and Dual Track Railway), and B2 provide the greatest accessibility to transit for disadvantaged communities. Scenarios A0A/B0A (No Action Without Highway), A2A (Managed Retreat/Widening G-12 4 Lanes), and A2B (Managed Retreat/Widening G-12 6 Lanes), in which transit along the existing Highway One corridor is removed, inhibit accessibility for disadvantaged communities.

Environment

Impacts to Natural Resources: This performance measure shows the total acres of natural resource areas, wetlands, critical habitats, open space areas, and farmlands consumed by each scenario. This was calculated using GIS using data from the U.S. Fish

& Wildlife Service, California Department of Fish & Wildlife, Farmland Mapping and Monitoring Program and the California Protected Areas Database. Further ecological impacts are presented in the habitat modeling section (Section 6.5.1) for the adaptation scenarios. Scenario A4/B1 (Co-Located 4-Lane Elevated Highway and Dual Track Railway) has the largest impact on natural resources, consuming substantially more acreage than the other scenarios. Further ecological impacts are also discussed in the ecological modeling section. Scenarios A2B (Managed Retreat/Widening G-12 6 Lanes), A3 (4-Lane Elevated Highway), and B2 (Dual Track Railway) are roughly equal in their negative impact to natural resources, while scenario A2A would be slightly less. Scenarios A0A/B0A (No Action Without Highway), A0B/B0B (No Action With Highway) and A1 (2-Lane Elevated Highway) would result in little impact on natural resources compared to existing conditions.

Cost

Costs vary by scenario. A summary of the cost estimates, which include right-of-way acquisition and mitigation costs, are shown below in **Table 6**:

Table 6. Conceptual Transportation Cost Estimates for Preliminary Adaptation Scenarios

<u>Scenario</u>	<u>Draft Cost Estimate (2019 dollars)</u>
A1 (2-Lane Elevated Highway)	\$240 million
A2A (Managed Retreat/Widening G-12 4 Lanes)	\$190 million
A2B (Managed Retreat/Widening G-12 6 Lanes)	\$280 million
A3 (4-Lane Elevated Highway)	\$445 million
A4/B1(Co-Located 4-Lane Elevated Highway and Dual Track Railway)	\$1.8 billion
Scenario B2 (Dual Track Railway)	\$470 million

6.4 Refined Roadway and Railway Scenarios

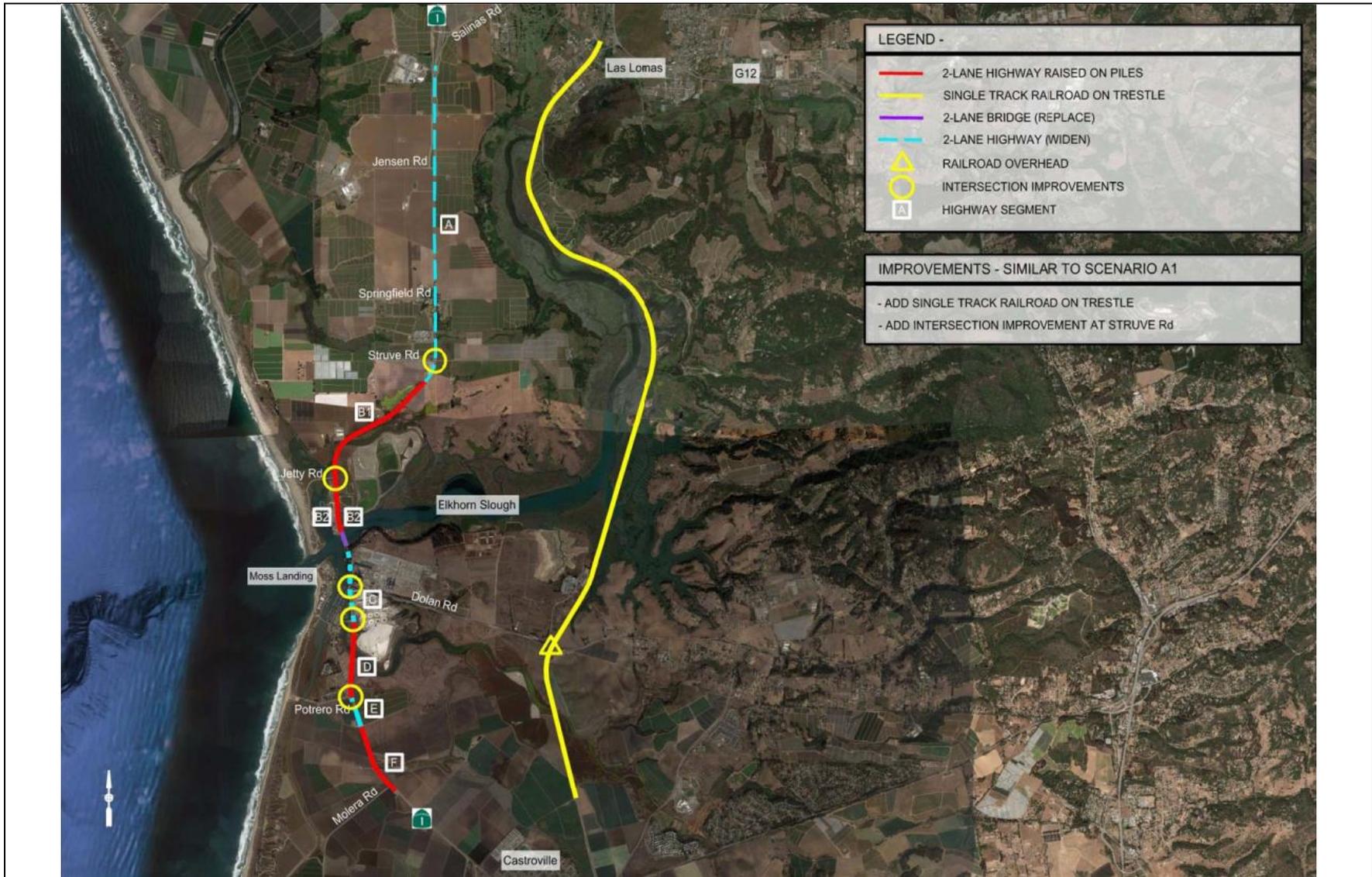
Results from the hydrodynamic and transportation modeling for the preliminary adaptation scenarios were presented at the December 2019 Steering Committee meeting. Based on input from the Steering Committee, the set of preliminary adaptation scenarios were narrowed to three refined scenarios for the habitat modeling and full benefit-cost analysis. Additional discussions regarding double tracking the railway resulted in the assumption that the railway did not need to double tracked through the Elkhorn Slough area. The railway is assumed to be double tracked outside of the study area but remain as a single track in each of the revised adaptation scenarios. **Table 7** describes the revised adaptation scenarios. Adjustments to access improvements and revised adaptation pathways diagram are shown in **Figure 30** through **Figure 32**.

Table 7. Revised Roadway and Railway Adaptation Scenarios

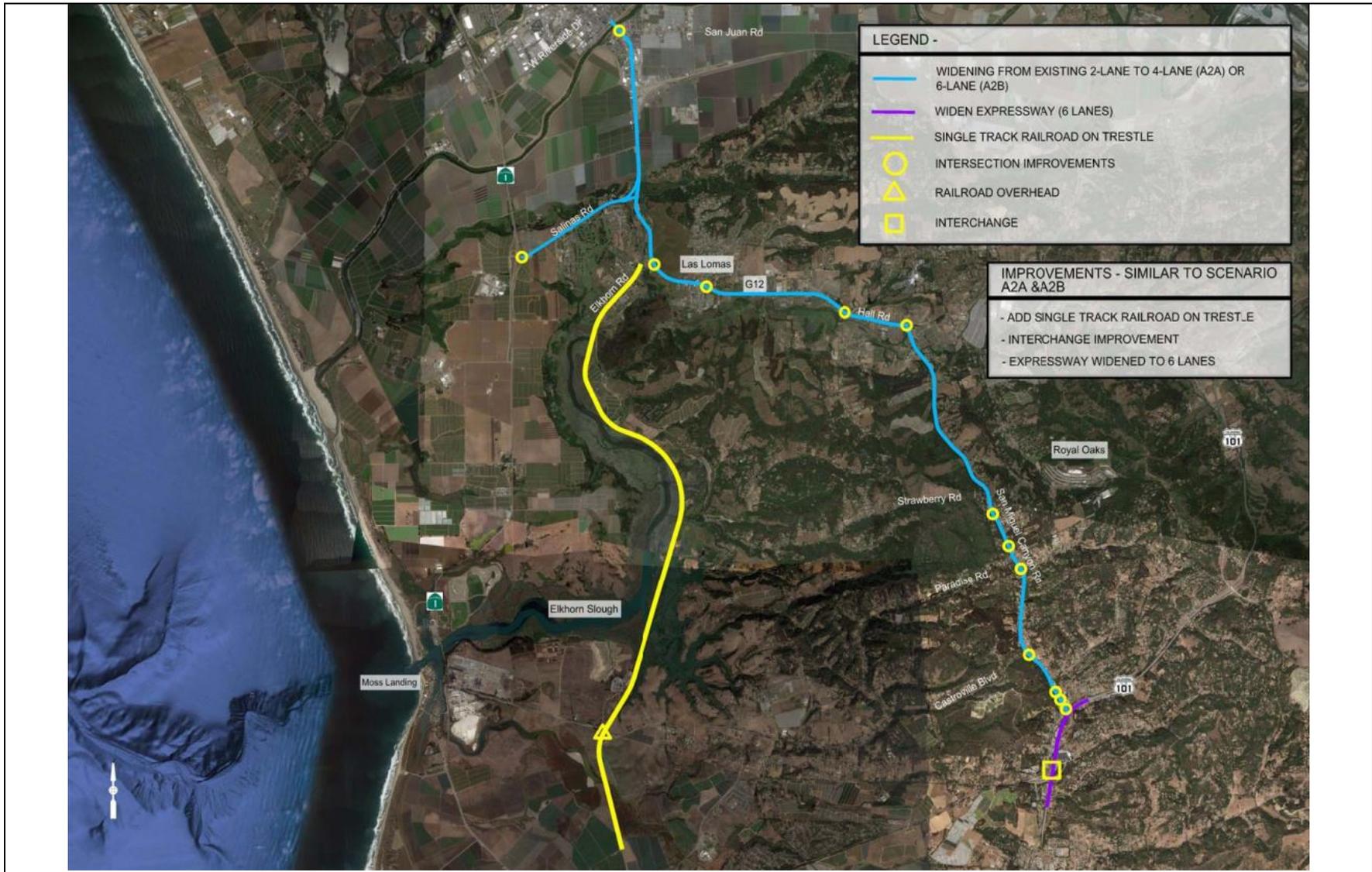
Scenario	Short Name	Roadway		Railway	
		Transportation	Ecology	Transportation	Ecology
C0	No Action	No action	No action	No action	No action
C1A	2-Lane Elevated Highway, Reach 2 on Piles	2-lane roadway with operational improvements, including access improvements and bike/pedestrian trail. Reaches 1-4 would be elevated completely on piles, with +3 ft allowance for sea-level rise and 1' of additional freeboard.	A levee ecotone would be constructed on the inboard side of Reach 2, with a crest along the inner perimeter of MLWA and sloping downwards (underneath the elevated highway) to Moss Landing Harbor (North). This would provide additional future wetland habitat under sea-level rise.	A new single-track railway facility would be constructed adjacent to the existing railway fill embankment and elevated on trestle. The existing railway fill embankment would be left in place, to potentially aid in sediment retention for the inboard marsh complexes.	Marsh complexes east of the existing railway fill embankment, including Azevedo Ponds, North/Estrada Marsh and Parsons Marsh, would be restored to keep pace with sea-level rise. Existing marsh grade plain for these areas would be raised to future MHHW at mid-century, which is approximately 8.0' elev. NAVD. To increase tidal connectivity to these areas, new tidal channel openings North/Estrada Marsh complexes and the larger Azevedo Pond would be created.
C1B	2-Lane Elevated Highway, Reach 2 on Fill	2-lane roadway with operational improvements, including access improvements and bike/pedestrian trail. Reaches 1, 3 and 4 would be elevated completely on piles and Reach 2 would be elevated on fill embankment, with +3 ft allowance for sea-level rise and 1' of additional freeboard.	Levee ecotones would be constructed on both sides of Reach 2, gently sloping to match grade at Moss Landing Harbor and Moss Landing Wildlife Area. This would provide additional future wetland habitat under sea-level rise.		
C2	Managed Retreat/Widening G-12	Traffic from existing Highway One would be diverted to the G-12 corridor. Salinas Road and San Miguel Canyon Road would be widened to 4-lanes with a number of intersection improvements.	No-action		
C3A	4-Lane Elevated Highway, Reach 2 on Piles	4-lane roadway, including access improvements and bike/pedestrian trail. Reaches 1-4 would be elevated completely on piles, with +3 ft allowance for sea-level rise and 1' of additional freeboard.	A levee ecotone would be constructed on the inboard side of Reach 2, with a crest along the inner perimeter of MLWA and sloping downwards (underneath the elevated highway) to Moss Landing Harbor (North). This would provide additional future wetland habitat under sea-level rise.		
C3B	4-Lane Elevated Highway, Reach 2 on Fill	4-lane roadway, including access improvements and bike/pedestrian trail. Reaches 1, 3 and 4 would be elevated completely on piles and Reach 2 would be elevated on fill embankment, with +3 ft allowance for sea-level rise and 1' of additional freeboard.	Levee ecotones would be constructed on both sides of Reach 2, gently sloping to match grade at Moss Landing Harbor and Moss Landing Wildlife Area. This would provide additional future wetland habitat under sea-level rise.		

DRAFT

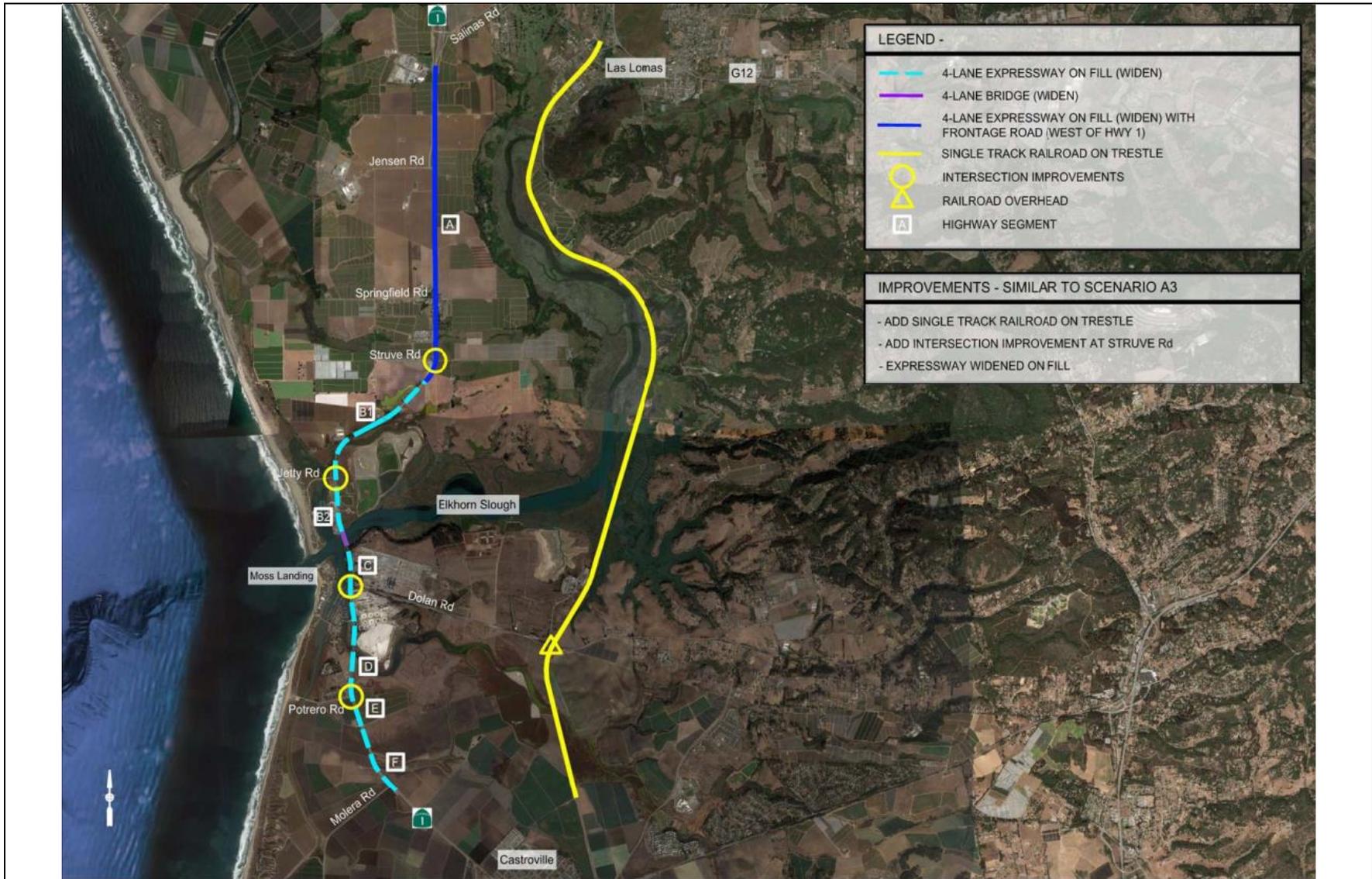
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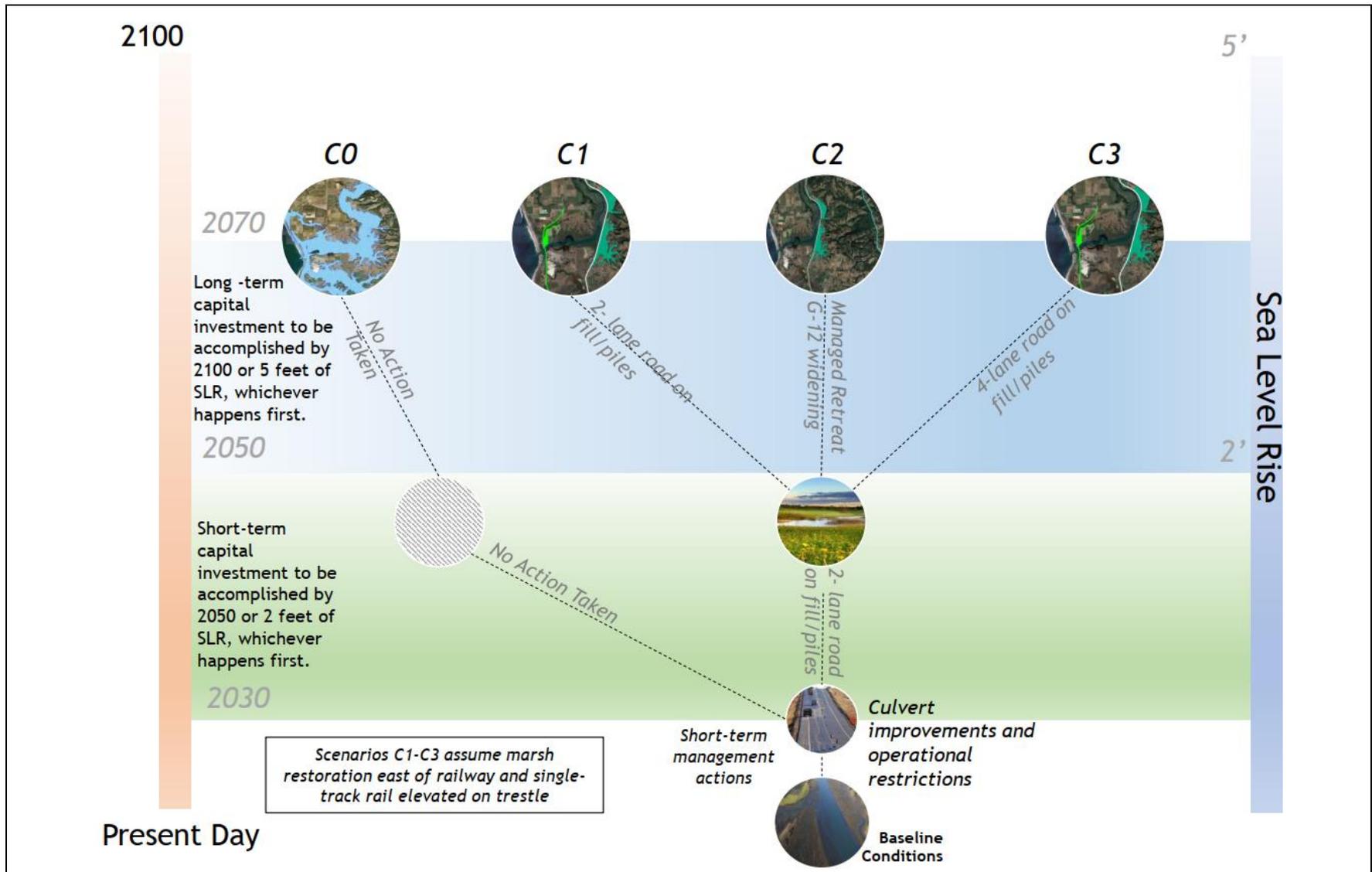
Central Coast Highway 1 Climate Resiliency Study
Figure 30
 Scenario C1 (Conceptual)
 2-Lane Elevated Highway and Single-Track Railway



Central Coast Highway 1 Climate Resiliency Study
Figure 31
 Scenario C2 (Conceptual)
 Managed Retreat/Widening G-12 (4-Lanes) and Single Track
 Railway



Central Coast Highway 1 Climate Resiliency Study
Figure 32
 Scenario C3 (Conceptual)
 4-Lane Elevated Highway, Single Track Railway



Central Coast Highway 1 Climate Resiliency Study

Figure 33

Preliminary Roadway and Railway Adaptation Scenarios
Adaptation Pathways Diagram

6.5 Evaluation of Refined Roadway and Railway Scenarios

6.5.1 Habitat Modeling (SLAMM)

ESA used the Sea Level Affecting Marshes Model (SLAMM)¹² developed by Warren Pinnacle Consulting to project habitat changes in response to sea-level rise for each of the selected Adaptation Scenarios (Warren Pinnacle Consulting, 2016). A no-action scenario (Scenario C0) was run from present-day (2020) until 2100 to use as a baseline for evaluating the performance of the different Adaptation Scenarios. Scenarios C1A (2-Lane Elevated Highway, Reach 2 on Piles), C1B (2-Lane Elevated Highway, Reach 2 on Fill), C2 (Managed Retreat/Widening G-12 4 Lanes), C3A (4-Lane Elevated Highway, Reach 2 on Piles) and C3B (4-Lane Elevated Highway, Reach 2 on Fill) were evaluated using SLAMM from 2050 (time of adaptation) to 2100. Habitat acreages and maps were output for every decade for each Adaptation Scenario and no-action. The following results and acreages refer to model outcomes assuming that agriculture and developed areas will be defended and wetland habitats are allowed only to migrate into existing habitat areas including terrestrial upland habitats. Technical detail on model input development and process is provided in Appendix D.

Levee Ecotone

The levee ecotone by Reach 2, in Scenarios C1A (2-Lane Elevated Highway, Reach 2 on Piles), C1B (2-Lane Elevated Highway, Reach 2 on Fill), C3A (4-Lane Elevated Highway, Reach 2 on Piles) and C3B (4-Lane Elevated Highway, Reach 2 on Fill), result in the creation of transitional marsh habitat under future sea-level rise conditions. Scenarios C1A (2-Lane Elevated Highway, Reach 2 on Piles) and C3A (4-Lane Elevated Highway, Reach 2 on Piles) result in approximately 72 acres of estuarine marsh habitat creation by Reach 2 and Moss Landing Wildlife Area at 2050, assuming Reach 2 is elevated on piles. 52 acres of estuarine marsh remain at 2100 assuming this configuration. Scenarios C1B (2-Lane Elevated Highway, Reach 2 on Fill) and C3B (4-Lane Elevated Highway, Reach 2 on Fill) result in approximately 83 acres of estuarine marsh habitat creation by Reach 2 at 2050, assuming Reach 2 is elevated on fill, with 70 acres remaining at 2100. For Scenarios C1B (2-Lane Elevated Highway, Reach 2 on Fill) and C3B (4-Lane Elevated Highway, Reach 2 on Fill), the difference in roadway “footprint” for a 2-lane and 4-lane highway in Reach 2 is approximately 0.5 acres. Therefore, the habitat acreage numbers reported for these two scenarios in that particular location are similar. It should be noted that the model does not capture impacts to habitats as a consequence of construction of a new 4-lane highway facility. Construction of a 4-lane highway will have significant impacts on habitat adjacent to the existing roadway alignment. Any

¹² More information on SLAMM can be accessed at this address:
<http://warrenpinnacle.com/prof/SLAMM/>

construction impacts would be evaluated in the future if a project were to move forward as part of the project development process.

Marsh Restoration

Marsh restoration east of the railway was included in all three adaptation scenarios evaluated. The adaptation scenarios assume that the existing railway embankment, which acts as a hydraulic control for the inboard water levels, will remain in place as a new railway is elevated on trestle. Marsh restoration, which includes creating new tidal openings to the marsh complexes east of the railway, would assist with equalizing the water levels on either side of the embankment, which would improve stability and support sediment retention in the newly restored marshes. With marsh restoration, the total acreage of estuarine marsh habitat at 2050 is approximately 1500 acres, compared to 971 acres for Scenario C0 (No Action) at the same time horizon. The total acreage of mudflat habitat at 2050 for the adaptation scenarios is approximately 1250 acres, compared to 1634 acres for Scenario C0 (No Action) at the same time horizon. The mudflat acreage is lower at mid-century for the adaptation scenarios because the proposed restoration would elevate areas that had converted to mudflat. The remaining estuarine marsh predicted at 2100 (approx. 550 acres) is about 40% of the total restored acreage at 2050, respectively. At 2100, the remaining mudflat habitat (approx. 800 acres) for the adaptation scenarios assuming marsh restoration, compared to 639 acres for Scenario C0 (No-Action). show the habitat trends across adaptation scenarios for estuarine marsh and tidal flats.

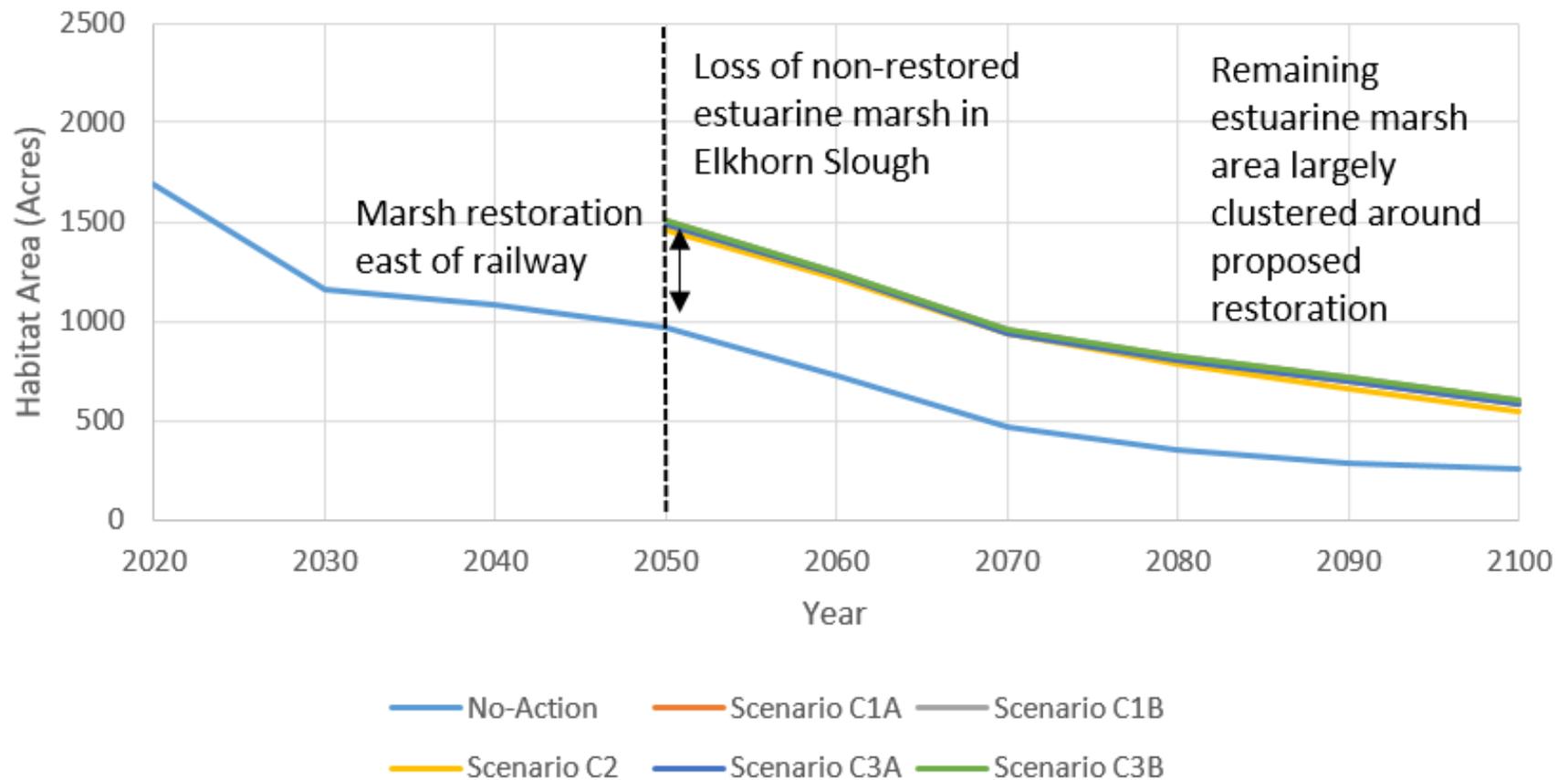
The results of the habitat modeling confirm that without marsh restoration, up to 85% of existing estuarine marsh habitat in Elkhorn Slough will be drowned by sea-level rise and convert to mudflat and estuarine open water habitat types by 2100 (5 ft of sea-level rise). Up to 50% of existing mudflat habitat will be lost by 2100. Marsh complexes restored to an elevation of 8' NAVD (future MHHW at 2050) were predicted to persist through the end of the century and help mitigate these losses.

Model results show that estuarine marsh acreages amongst the adaptation scenarios trend similarly, with loss of marsh areas west of the railway and by the main channel stem. At 2100, the estuarine marsh remaining is primarily those that were assumed restored at mid-century.

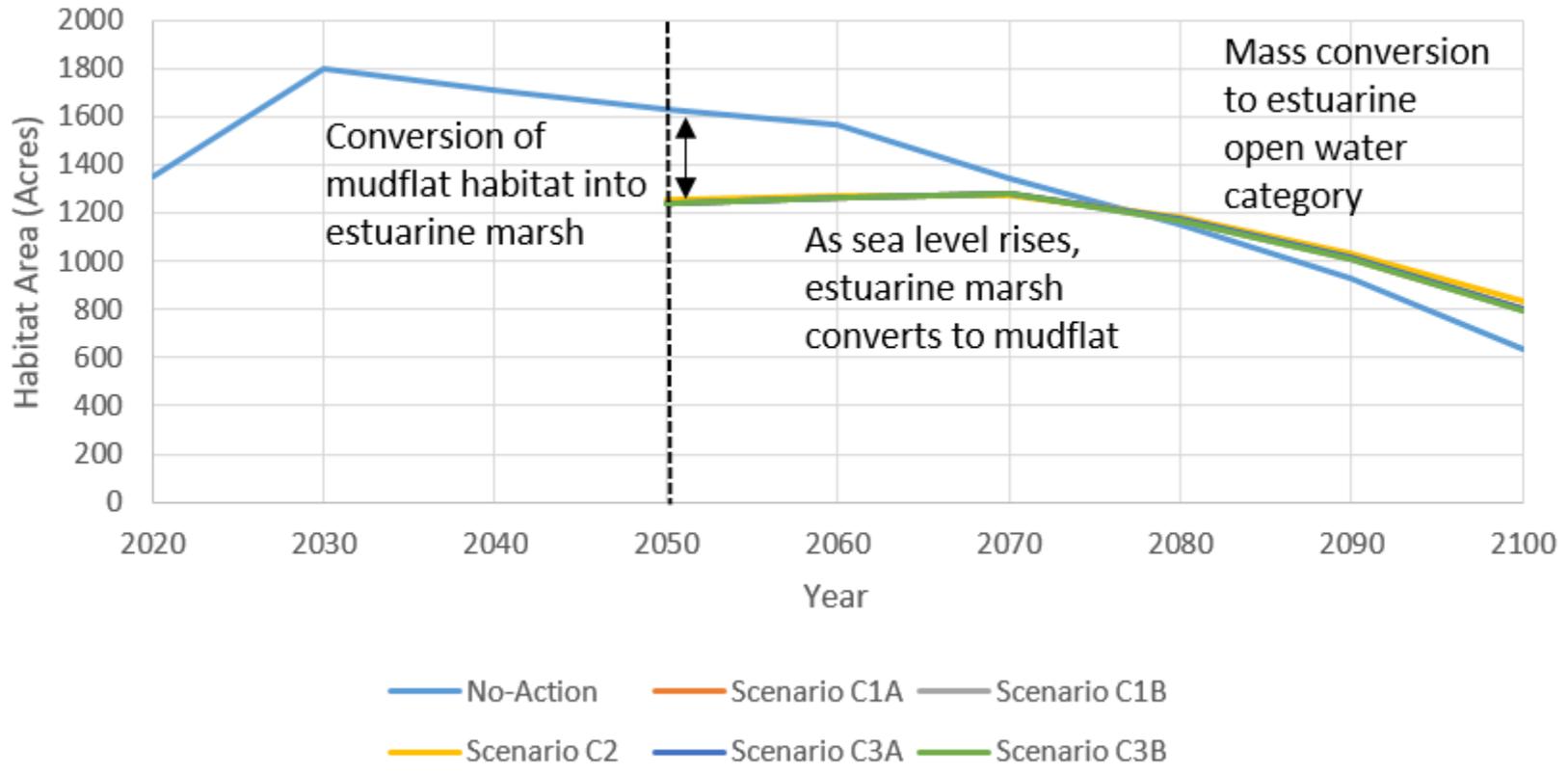
Impacts to Agricultural Lands

When habitat migration is allowed into agricultural lands, the model predicts that the low-lying agricultural lands by Highway One Reaches 3 and 4 and Moro Cojo Slough will convert to wetland habitat (approx. 1100 acres). This indicates the vulnerability of these land uses to sea-level rise. As the productivity and value of these land uses as agriculture decreases, the opportunity of these lands to revert into wetland habitats increases with the potential to mitigate estuarine habitat loss.

Estuarine Marsh - Protect Developed Dry and Agriculture



Tidal Flat - Protect Developed Dry and Agriculture



6.5.2 Transportation Modeling for Revised Scenarios

AMBAG evaluated the transportation improvements included in Scenarios C1 (2-Lane Elevated Highway), C2 (Managed Retreat/Widening G-12 4 Lanes), and C3 (4-Lane Elevated Highway) using the RTDM and GIS. All 2040 scenarios include future population, housing and employment growth in the region. The three scenarios are described below.

- Scenario C1 (2-Lane Elevated Highway) is based on Scenario A1 from the previous round of scenario evaluations, with additional access point modifications and increased bus and rail services. Access to Highway One would be improved at the Struve Road, Jetty Road, Dolan Road, Moss Landing Road and Potrero Road intersections. Monterey-Salinas Transit Routes 27, 28, 78, and 79 would operate with a bus rapid transit type service at 30-minute frequencies between Santa Cruz and Monterey/Salinas and passenger rail service would operate at an hourly frequency.
- Scenario C2 (Managed Retreat/Widening G-12 4 Lanes) is a managed retreat from Highway One, widening the G12 corridor to four lanes. The Highway One01/156 interchange would be improved, and Highway One01 would be widened to six lanes from San Miguel Canyon Road to the SR 156 interchange. Highway One would operate as a local access road between Springfield Road and Moss Landing Road. MST routes 27 and 28 would end in Castroville, but passenger rail would operate on an hourly service from Salinas north to San Jose.
- Scenario C3 (4-Lane Elevated Highway) is similar to scenario C1, but Highway One is widened to 4 lanes. Additionally, a frontage road would extend from Struve Road to Salinas Road on the west side of Highway One, with no access to the highway at Jensen Road. MST Routes 27, 28, 78, and 79 would operate with a bus rapid transit type service at 30-minute frequencies and passenger rail service would operate at an hourly frequency.

For each conceptual scenario, the RTDM was utilized with specific network and transit components, and the output was analyzed quantitatively. The evaluation criteria listed below were applied to each of the three scenarios, and the results were compared relative to each scenario.

Figure 36 is a matrix of how each scenario performed relative to each scenario for each of the performance measures.

Performance Measures for Central Coast Highway 1 Climate Resiliency Study

PM ID	DESCRIPTION	2040 No Action	2040 C1	2040 C2	2040 C3
1	Vehicle Miles Traveled Total ¹	=	-	-	-
2	Congested Vehicle Miles Traveled ²	-	-	=	+
3	Average Travel Time ¹	+	=	=	-
4	Vehicle Hours Traveled Total ¹	=	=	=	+
5	Vehicle Delay ²	-	=	-	+
6	Freight Delay (Vehicle Hours Traveled) ¹	=	=	=	+
7	Greenhouse Gas Emissions (CO2) Emissions from all land use and Vehicle Miles Traveled per capita (lbs) ¹	=	=	=	=
8	Collisions/Accidents (Annual projected number of injury and fatal collisions per thousand Vehicle Miles Traveled) ²	=	=	=	=
9	Multimodal Trips/Mode Share (Transit, Bike, Ped) ¹	+	-	=	=
10	Disadvantaged Communities Accessibility ²	-	=	-	=
11	Impact to Natural Resources ²	+	+	-	-

- + Scenario would result in positive benefits
- = Scenario would result in neutral benefits
- Scenario would result in negative impacts

¹ Regionwide

² Study Area

Central Coast Highway 1 Climate Resiliency Study
Figure 36
 Transportation Performance Matrix
 Revised Roadway and Railway Adaptation Scenarios

Roadway

VMT: In general, daily VMT remains consistent for each of the scenarios, increasing from a 2040 No Action scenario.

CVMT: CVMT is highest for Scenario C1 (2-Lane Elevated Highway), lowest for Scenario C3 (4-Lane Elevated Highway), and Scenario C2 (Managed Retreat/Widening G-12 4 Lanes) falls between C1 (2-Lane Elevated Highway) and C3 (4-Lane Elevated Highway).

VHT: VHT is roughly equal for Scenarios C1 and C2 (Managed Retreat/Widening G-12 4 Lanes), while C3 has the lowest VHT.

Vehicle Delay: Scenario C2 (Managed Retreat/Widening G-12 4 Lanes) has the highest amount of delay, Scenario C3 (4-Lane Elevated Highway) has the lowest, and Scenario C1 (2-Lane Elevated Highway) falls between the C2 (Managed Retreat/Widening G-12 4 Lanes) and C3 (4-Lane Elevated Highway).

Freight Delay: Hours of truck delay are relatively equal for Scenarios C1 (2-Lane Elevated Highway) and C2 (Managed Retreat/Widening G-12 4 Lanes), and Scenario C3 (4-Lane Elevated Highway) has the lowest amount of freight delay.

Collisions/Accidents: The percentage of collisions and accidents per thousand VMT remains roughly consistent across each scenario.

General/Multimodal

Average Travel Time: Average travel time is consistent for Scenarios C1 (2-Lane Elevated Highway) and C2 (Managed Retreat/Widening G-12 4 Lanes), while Scenario C3 (4-Lane Elevated Highway) has the longest average commute time.

Multimodal trips: Scenarios C2 (Managed Retreat/Widening G-12 4 Lanes) and C3 (4-Lane Elevated Highway) have similar percentages of multimodal trips, while Scenario C1 (2-Lane Elevated Highway) has the lowest percentage.

Environment

Impacts to Natural Resources: Scenario C1 (2-Lane Elevated Highway) provides the lowest impact on natural resources, while Scenarios C2 (Managed Retreat/Widening G-12 4 Lanes) and C3 (4-Lane Elevated Highway) have a larger impact. Construction impacts were not included in this evaluation but would be evaluated in the future when a project would move forward into project development.

Social Equity

Disadvantaged Communities: Scenarios C1 (2-Lane Elevated Highway) and C3 (4-Lane Elevated Highway) provide the greatest accessibility to transit for disadvantaged communities. Scenario C2 (Managed Retreat/Widening G-12 4 Lanes), in which transit along the Highway One corridor is removed, inhibits accessibility for disadvantaged communities.

Cost

Planning level cost estimates were prepared for each scenario. A summary of the cost estimates, which include right-of-way acquisition and mitigation costs are shown below in **Table 8:**

Table 8. Conceptual Transportation Cost Estimates for Revised Roadway and Railway Adaptation Scenarios

Scenario	Draft Cost Estimate (2019 dollars)
C1 (2-Lane Elevated Highway)	\$570 million
C2(Managed Retreat/Widening G-12 4 Lanes)	\$680 million
C3 (4-Lane Elevated Highway)	\$750 million

Based on the transportation evaluation of these three adaptation scenarios, Scenario C3 (4-Lane Elevated Highway) is the best performing scenario in terms of the transportation, mobility and accessibility needs in the corridor. Many of the components of the Scenario C3 (4-Lane Elevated Highway) are longer term and require a large amount of funding to be secured in order to be implemented. Some of the operational improvements components from Scenario C1 (2-Lane Elevated Highway) could be considered as shorter term improvements in the corridor. Additional information from the Benefit-Cost analysis would provide additional information from an economic perspective on the transportation investments.

6.5.3 Benefit-Cost Analysis

A benefit-cost analysis was undertaken to examine the economic consequences of selecting one of the four scenarios defined above. Benefit-cost analysis helps answer three essential questions about making complex investment decisions:

- Will we get back more than we give up from a particular option?
- Of those options that have a positive return, which should be selected?
- In the case of decisions being driven by highly uncertain processes like climate change, how can we assure the greatest chance of a positive return?

Benefit-cost analysis addresses these questions because it uses economic theory and methods to convert disparate types of changes arising from a decision to a common monetary metric. It is thus possible to compare the economic consequences of changes in the transportation system with changes in ecosystems.

Benefit-cost analysis compares positive and negative changes in economically valuable goods and services. A gain in something of value is a benefit; a reduction in value is a cost. With projects such as those dealing with climate change, the comparison is made between the consequences of taking no action to address climate change and the consequences of one or more identified adaptation scenarios. Taking no action to address climate change generally results in a set of expected damages and consequent losses, which are the costs of a no action alternative. Taking action avoids these losses to some extent. These avoided costs thus become the benefits of an adaptation scenario. At the same time, the expenditures on adaptation which are costs in evaluating an adaptation scenario are benefits in the no action alternative since those expenditures are available for other uses.

The benefits and costs in this analysis can be briefly summarized as follows. Details concerning sources and calculations are provided in Appendix E.

Expenditures on the planning, development, and construction of the highway projects. Estimates of these expenditures were provided by WMH, the highway engineering partner in the construction team. These expenditures are spaced out over 10 years from initiation of the planning through completion of construction.

- *Expenditures for the ecotones and marsh restoration projects.* These estimates were provided by ESA and were spread over three years, coinciding with the three-year construction period for highway projects estimated by WMH.
- *Changes in the value of travel time.* These were estimated as changes in hours of delay as estimated by the AMBAG transportation model for the Area of Interest (AOI). The value of the time of delay is set as a proportion of the average hourly wage, which was estimated as the average wage for Santa Cruz and Monterey counties. The proportion, which varies from 50% to 100%, depends on the purpose of the trip, which is derived from trip data in the AMBAG model.
- *Changes in value of traffic safety.* Using data from the California Highway Patrol, the number of accidents by type (from property damage to fatality) per vehicle mile traveled in the study area of interest was estimated for the period 2013-2019. The accident rates were then multiplied by the estimated vehicle miles traveled (VMT) for each scenario to get the total number of accidents by type. These were then multiplied by estimates of the value of accidents by type prepared for the National Highway Transportation Safety Administration.

-
- *Changes in vehicle operating costs.* Changes in routes may increase or decrease expenditures on fuel and other per mile costs. The changes in VMT estimated for each scenario were multiplied by 16 cents per mile which was based on an adjusted Department of Transportation estimate of vehicle operating costs for the average fleet. The DOT estimate was adjusted upward for inflation in motor fuels and down for increases in vehicle efficiency to arrive at the 16 cents number.
 - *Changes in the Value of Ecosystem Services.* Estuaries like Elkhorn Slough are some of the most productive ecosystems providing habitat services to a diversity of species as well as abundant ecosystem services to people (Barbier et al. 2011). However, putting dollar amounts to habitat and ecosystem services is challenging. One ecosystem service that is more easily valued is recreation. Around 30,000 people visit the Slough every year for kayaking, motorboat tours, bird watching, and hiking. The value to these visitors of their recreational experience may be altered depending on the adaptation option selected. The value of these recreational experiences was estimated through a survey of visitors conducted in 2019 by the Center for the Blue Economy.

In addition to recreation, Elkhorn Slough provides a variety of other ecosystem services including habitat for juvenile commercial fish species, birds, and flood protection. The estimation of the value of each of these services individually is a complex task that was beyond the scope of the current project. To estimate these values, information on the purchase price of the lands that make up the current ownerships around Elkhorn Slough was provided by the Elkhorn Slough NERR. This information was then matched to the habitat types on each parcel based on the information from the SLAMM model (Section 6.5.2) for 2020 and the sales price (adjusted for inflation) to estimate a per acre price for each habitat. Average per acre prices for each habitat type were calculated and these prices were used to estimate changes in wetlands values based on the SLAMM estimates of habitat changes for each scenario described above.

An important feature of a benefit-cost analysis is that it compares benefits which will be received over many years in the future with costs that are incurred up front in a project. Making comparison requires that costs undertaken and benefits received in the future be discounted; that is adjusted for the fact that expenditures committed to one purpose might earn a higher return if invested at some interest rate. That interest rate is called *the discount rate*. For this analysis a discount rate of 3% was used along with a project period of 40 years beyond the completion of construction. The result of discounting is called *the present value*.

Adding the cost and benefits produces two important measures. The benefit-cost ratio is calculated as the present value of benefits *divided by* the present value of costs. If the

result is greater than 1 the project returns more in benefits over its life than the costs. The other measure is the net present value - the present value of benefits *minus* the present value of costs. As a general rule, projects that have a benefit-cost ratio greater than 1 should be considered economically viable; of these options, the one with the greatest net present value of benefits is the economically “best” alternative. The results of this analysis are shown in **Table 9**.

Table 9. Sum of Benefits and Costs by Option with Net Present Value and Benefit-Cost Ratio

		No Action	C1		C2	C3	
			On Piles	On Fill		On Piles	On Fill
Highway	Costs		-\$443.67	-\$443.67	-\$677.24	-\$583.10	-\$583.10
	Benefits	\$443.67					
Ecotone + Restoration	Costs		-\$330.24	(\$321.43)	-\$221.78	-\$330.24	-\$321.43
	Benefits	\$321.43					
Travel Delay Passenger	Costs	-\$102.99					
	Benefits		-\$115.13	-\$115.13	-\$159.00	\$511.10	\$511.10
Travel Delay Freight	Costs	-\$100.97					
	Benefits		-\$103.85	-\$103.85	-\$80.78	\$43.27	\$43.27
Travel Safety	Costs	-\$776.02					
	Benefits		\$534.56	\$534.56	\$644.91	\$644.91	\$644.91
Vehicle Operating Costs	Costs						
	Benefits	\$93.76	-\$217.15	-\$217.15	-\$335.30	-\$335.30	-\$335.30
Recreation	Costs	-\$64.33					
	Benefits		\$69.08	\$69.08	\$7.12	\$84.72	\$84.72
Wetlands	Costs	-\$428.63					
	Benefits		\$156.61	\$157.45	\$152.80	\$137.27	\$137.83
TOTAL	Costs	-\$1,472.95	-\$773.91	-\$765.10	-\$899.02	-\$913.34	-\$904.54
	Benefits	\$858.86	\$324.12	\$324.95	\$229.76	\$1,085.97	\$1,086.52
Net Present Value		(\$614.09)	(\$449.79)	(\$440.15)	(\$669.26)	\$172.63	\$181.98
Cost Benefit Ratio		0.58	0.42	0.42	0.26	1.19	1.20

In **Table 9**, a negative number is shown in red. Post construction effects may be positive or negative and negative effects could be designated as either costs or benefits. Costs and benefits of the no-action scenario and the adaptation scenarios are reversed; that is the costs in no action are the post-construction effects and the benefits are not spending funds on the highway.

The results of the benefit-cost analysis indicate the following:

- Scenario C0 (No Action) has highest net costs even without spending the large amounts on the highway projects. Taking no action results in large losses to travelers in delay and safety and there are large losses in the value of wetlands. The least expensive (Scenario C2) construction alternative is used for comparison, but even if the most expensive option (Scenario C3) were selected, losses would still outweigh gains if no action is taken
- Of the action options, only Scenario C3 (4-Lane Elevated Highway) has a benefit-cost ratio greater than 1 and thus also has the highest net present value. Only this alternative reduces the costs of traffic delays sufficiently to offset the total costs of the highway construction and marsh restoration.
- Scenario C1 (2-Lane Elevated Highway) does have the greatest present value of wetlands benefits but these are not sufficient to offset the costs of delay. All else equal, the value of wetlands would have to be more than \$220 million higher for C1 to result in a benefit-cost ratio greater than 1.
- Scenario C2 (Managed Retreat/Widening G-12) has even greater delay costs even with the lane expansion of San Miguel Canyon Road (G12) and Route 101. The choice between highway construction on fill or on piles would favor construction on fill based on net present value, but the difference between the two is relatively small, only about \$9 million in present value terms. More detailed evaluation of these alternatives may clarify which is preferable.

The estimates of benefits and costs provided here depends in large part on the timing of the investment in adaptation which in turn is dependent on the extent and pace of sea-level rise. Committing the large amount of funds involved in one of the actions too soon, that is before sea-level rise occurs at the rates underlying the models and analyses used in this study risks diverting funds from other needs. Committing the funds too late risks enduring potentially large losses from damages to the highway and to Elkhorn Slough before adaptation could be implemented. Understanding the nature of the sea-level rise guidance provided by the Ocean Protection Council and considering alternative interpretations can provide guidance on the best timing for initiating the process of selecting an adaptation option.

The Ocean Protection Council guidance for sea-level rise related planning (Ocean Protection Council 2017) was based on sea-level rise projections developed at Rutgers University (Sweet et al. 2017; Kopp et al. 2014). These projections were based on models that combined the effects of changes in ocean temperatures, ice melt in Greenland and Antarctica, glacial melt, and runoff from the land, as well as local changes in land elevation. The projections recognize the fundamental uncertainties in

the pace and extent of climate change and sea-level rise by calculating not a single forecast, but a range of forecasts ordered by the likelihood of each forecast occurring.

The OPC guidance used for this study is based on what the OPC describes as the “medium to high risk aversion” scenario with an assumption of high emissions levels. For Monterey Bay (based on the Monterey tide gauge), that scenario recommends assuming sea-level rise listed in **Table 10**:

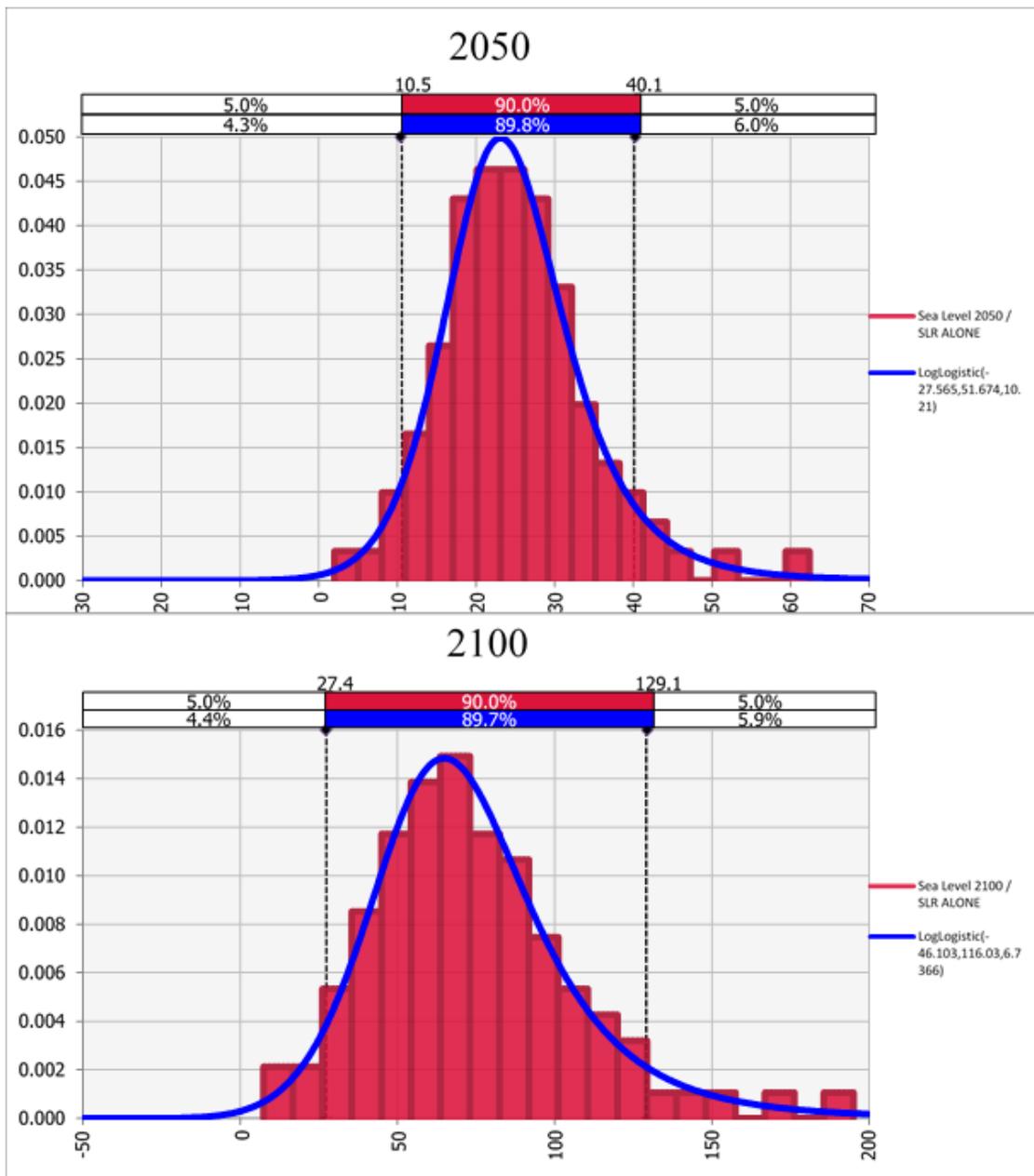
Table 10. Ocean Protection Council Guidelines Sea Level Rise at Monterey for Medium-High Risk Aversion High Emissions Scenario

	OPC Guidance	
Year	Feet	Centimeters
2050	1.9	58
2060	2.6	79
2070	3.4	104
2080	4.4	134
2090	5.5	168
2100	6.9	210

It is not a “worst case” scenario but assumes little progress is made globally in restraining greenhouse gas emissions over the next thirty years and thus climate change and sea-level rise will be very significant.

The curves shown in **Figure 10** (Section 3.6) depict a relatively smooth upward progression out to 2100. But these are not an accurate depiction of the actual data from which the OPC guidance is derived. Each of the decadal points is actually estimated as the probability of that value occurring based on 10,000 iterations of a probability model. A more accurate representation of the sea-level rise projection is given in **Figure 37**, which shows two histograms of possible sea-level rise in 2050 and 2100 for Monterey.

In these graphs the extent of sea-level rise (in centimeters, where 1 foot = approximately 35 centimeters) is shown on the horizontal axis and the probability of that level occurring in that year is shown on the vertical axis. It can be seen from these figures that the values for sea-level rise specified by the Ocean Protection Council guidance (58 centimeters in 2050, and 210 centimeters in 2100) are at the far-right end of the probability distribution. In fact, the OPC guidance specifies that the Medium-High Risk/High Emissions estimates have only a 0.5% chance of happening in the specified years.



Central Coast Highway 1 Climate Resiliency Study
Figure 37
 Histograms of Projected Sea Level Rise for Monterey
 2050 (top) and 2100 (bottom)

This is an extremely risk averse position to take. If that probability were applied to the estimates of benefits and costs from **Table 10** to calculate the expected net present value (or the risk-adjusted net present value) the result would be very small values (**Table 11**)¹³.

Table 11. Comparison of Net Present Value and Expected Net Present Value at OPC Guidance Probabilities

		Expected Net Present Value	Net Present Value
	No Action	(\$2.57)	(\$513.12)
C1	On Piles	(\$1.73)	(\$345.93)
	On Fill	(\$1.69)	(\$337.13)
C2		(\$1.34)	(\$268.71)
C3	On Piles	\$2.33	\$465.21
	On Fill	\$2.37	\$474.02

This is an extremely risk averse position to take. If that probability were applied to the estimates of benefits and costs from **Table 10** to calculate the expected net present value (or the risk-adjusted net present value) the result would be very small values (**Table 11**).

Table 11 shows, in effect, that, from today’s perspective, Scenario C0 (No Action) would probably result in very small losses and Scenario C3 (4-Lane Elevated Highway) would probably have very small gains. The question is, therefore, how will this look at various time periods in the future? Put another way, based on the OPC guidance, when does the probability of taking action result in a reasonable probability that an adaptation option

¹³ To understand the expected present value, consider what you would do if someone offered to flip a coin; if it comes up heads you would be paid \$1.00. If it comes up tails, you would be paid nothing. What amount would you take in place of making the bet? The answer should be 50 cents, or 0.5 (the probability of heads or tails) times \$1.00. In the current context, if the state invested ~\$100 million in alternative C3, they could expect to get back ~\$470 million over and above the \$100 million. But that is the “sure bet” amount. In reality, the probability of sea-level rise high enough to produce the projected costs and benefits would return only ~\$2.35 million above the ~\$100 million expenditure. This would be a return of about 2.3%, which is less than the 3% discount rate; from a strictly economic perspective Caltrans would better off buying a bond.

should be seriously considered. Or what is the probability of sea-level rise occurring that should trigger the initiation of the ten-year planning and development process?

This is obviously a matter of judgment for Caltrans and associated stakeholders, but it is possible to use the data underlying the OPC guidance to suggest points at which the decision to proceed should be actively investigated. For this purpose, we identified two alternative trigger points:

- *Trigger A* The ESA modeling of sea-level rise effects on Elkhorn Slough and Highway One indicates that tides will be high enough on the extreme monthly high water basis to regularly flood the highway in the stretch just north of the Highway One bridge over Elkhorn Slough at about two feet (70 centimeters) of sea-level rise.
- *Trigger B* Disruptions to the traffic on Highway One are likely to be caused by a combination of sea-level rise and storms before regular tidal inundation becomes a problem. The ESA modeling that the combination of threats from sea-level rise and storms will begin to affect the highway at 0.72 feet or 22 centimeters.

Table 12 shows the probabilities of reaching the 22-centimeter and 70-centimeter levels using the probability distributions in the OPC Medium High Risk Averse/High Emissions scenario.

Table 12. Probability of Reaching Possible Trigger Sea Levels

	Probability of sea-level rise of:	
	Trigger B 22 centimeters	Trigger A 70 centimeters
2020	0%	0%
2030	0%	0%
2040	19%	0%
2050	60%	0%
2060	82%	1%
2070	92%	5%
2080	95%	16%
2090	97%	32%
2100	97%	49%

Table 12 confirms that waiting until regular tidal flooding of Highway One is likely to delay initiation of adaptation actions too late. Even by 2100, the probabilities never exceed 50%. The probabilities suggest that it would be into the 22nd century before the

project had a high probability of returning sufficient benefits. During the interim, the probabilities also indicate that periodic and likely significant disruptions from sea-level rise-enhanced storms will be accumulating damages to travelers and to Elkhorn Slough.

Table 12 also indicates that some time during the 2040-2050 decade the likelihood of storm caused disruptions will exceed 50% and so planning for the projects analyzed here could begin in earnest at some point in the decade of the 2030s.

6.5.4 Conclusions

The benefit-cost analysis does clearly point to beginning to plan for adaptation of Highway One in the early to mid-2030s and, unless some alternative to reduce delays on an elevated but 2-lane is found, a widening of Highway One to 4 lanes would be economically justified. The value of reductions in delay and other travel costs will be sufficient to cover the costs of the investments in wetlands protection and restoration analyzed. Much more detailed analysis of this option will be required, including many environmental dimensions not covered here. Benefit-cost analysis can only screen out options that are very unlikely to be economically viable and point to issues needing further investigation before a final decision can be made.

All analyses of complex systems such as this are subject to issues of measurement and to issues of inadequate data. Appendix E contains a discussion of known issues in this analysis and whether those issues are likely to raise or lower the estimates of costs and benefits. Improvements in precision of estimates are possible but are generally unlikely to alter the conclusions with respect to Scenario C0 (No Action) or Scenario C2 (Managed Retreat/Widening G-12). More analysis of Scenario C1 (2-Lane Elevated Highway) and Scenario C3 (4-Lane Elevated Highway) may alter the conclusions, particularly if it is possible to significantly reduce delays in Scenario C1 (2-Lane Elevated Highway). A major shift of travel to alternate modes or technological changes in motor vehicle transportation permitting higher volumes and speeds on the same capacity roads may make Scenario C1 (2-Lane Elevated Highway) economically viable; this analysis has assumed no major changes in technology since those are too uncertain at this point.

7. ADAPTATION STRATEGIES MOVING FORWARD

7.1 Strategies Moving Forward

The study presents a range of roadway and railway adaptation strategies over time in order to facilitate action now towards meaningful climate change adaptation for the transportation infrastructure and habitats of Elkhorn Slough. Near-term actions for transportation and ecological resilience, such as replacements/modifications of existing hydraulic structures, operational restrictions for use of railway during high water conditions and continuing marsh restoration efforts around the Slough, were presented in Section 4. The efficacy of these interim strategies will diminish as sea-level rises, simply because it will become necessary to adapt infrastructure to a new normal.

According to sea-level rise, flooding response, ecological response, and benefit-cost modeling, adaptation implemented not later than 2050 is critical to the resilience of transportation infrastructure and particularly to minimize habitat loss and the services ecosystems provide. Given the scope of the adaptation required, action toward implementation (e.g. planning, environmental review, design, approvals) must be initiated in the near term. The consequences of taking no action to improve either would be extremely costly and result in devastating losses in habitat area and disruption to commuter function. The hydrodynamic modeling (Delft3D) conducted show that new flood pathways develop in the study area by 1) Moss Landing Wildlife Area, Struve Pond and Bennett Slough, as well as 2) Highway One Reaches 3, 4 and Moro Cojo Slough under a future extreme monthly high water and additional sea-level rise of 2 to 3 feet (2050 to 2070 timeframe). With a coastal storm, the flood hazard modeling results show that portions of the roadway alignment (Reaches 1 and 2) will be impacted even earlier (2030 to 2040). Modifications made to the roadway will have decreasing control over flood protection for landward areas, which underlines the importance of defining triggers for adaptation actions now.

The habitat modeling (SLAMM) portion of the evaluation shows that up to 85% of existing estuarine marsh habitat in the Slough will be lost under sea-level rise at 2100. About half of existing tidal flat habitat will be permanently submerged at that time horizon. Marsh restoration of the complexes east of the railway at mid-century would help mitigate some of this habitat area loss, providing an additional 290 acres of wetland habitat at 2100. The cost and difficulty of conducting a large-scale restoration would drastically increase as water levels rise. The modeling also shows opportunity areas by Highway One and Moss Landing Wildlife Area to create between 72 to 83 acres

of estuarine marsh habitat at mid-century using a levee ecotone approach. At a synoptic scale, the agricultural lands by Highway One Reaches 3 and 4 and Moro Cojo Slough could potentially mitigate a greater portion of estuarine habitat loss (up to 460 acres), if allowed to convert to wetlands.

Overall, the results of the economic assessment and transportation evaluation indicate that Scenario C3 would be considered economically justified and meet the transportation, mobility and accessibility needs in the corridor. However, many of the components of the Scenario C3 are very long term and require a large amount of funding to be secured in order to be implemented. Some of the operational components from Scenario C1 could be considered in the near-term for improvements in the corridor. In this time frame, additional analysis could be conducted to see how adverse impacts on wetland habitat from construction of a new highway facility could be minimized. It may be possible that demographic changes and patterns in using the transportation infrastructure could shift significantly in the future, as climate change drives larger impacts in the wider Monterey Bay Area. The nuances of this conclusion point towards the limitations of existing data in being able to perfectly predict options for the future.

This study will not be the last to investigate the dual issues of transportation and ecological resilience for Moss Landing and Elkhorn Slough. New information (e.g. technology shifts in transportation, planned large-scale ecological action, projected commuter use of the corridor and other factors) may become available and should be incorporated into the adaptation planning for the future of the roadway, railway and adjacent habitats, as part of an adaptive management approach. Overall, the analyses performed in this study confirm that planning and action in the next decade to prepare for future sea-level rise will be critical and must be taken sooner rather than later and that the benefits of doing so earlier will be greater.

7.2 Potential Future Funding Sources

This section lists potential sources of federal and state funding and potential matching local funds to support adaptation strategies investigated in this study.

Federal Funding Sources

- Federal Highway Administration
- U.S. Army Corps of Engineers
 - Section 204 Beneficial uses of dredged material
 - Section 206 Aquatic system restoration
- National Oceanic and Atmospheric Administration
- Environmental Protection Agency
- Federal Emergency Management Agency (FEMA)
 - Building Resilient Infrastructure and Communities (BRIC)
 - Hazard Mitigation Grant Program
 - Pre-Disaster Mitigation Program
- U.S. Fish and Wildlife Service
 - National Coastal Wetlands Conservation Program

State Funding Sources

- California State Coastal Conservancy
- California Department of Water Resources
 - Integrated Water Resource Management Program
- California Department of Fish and Wildlife
 - Wetland Restoration for Greenhouse Gas Reduction Program
- Wildlife Conservation Board
- Climate Ready Grants
- Senate Bill 1 (SB 1) - SB 1 Competitive Programs

Local/Regional Matching Funds

The transportation and ecological adaptation actions constitute large capital investments, encompassing further study, planning, design and construction. Revenue streams at the local/regional level will have to be developed in order to leverage state and federal funds. Cost-sharing amongst project beneficiaries may also be a potential strategy.

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