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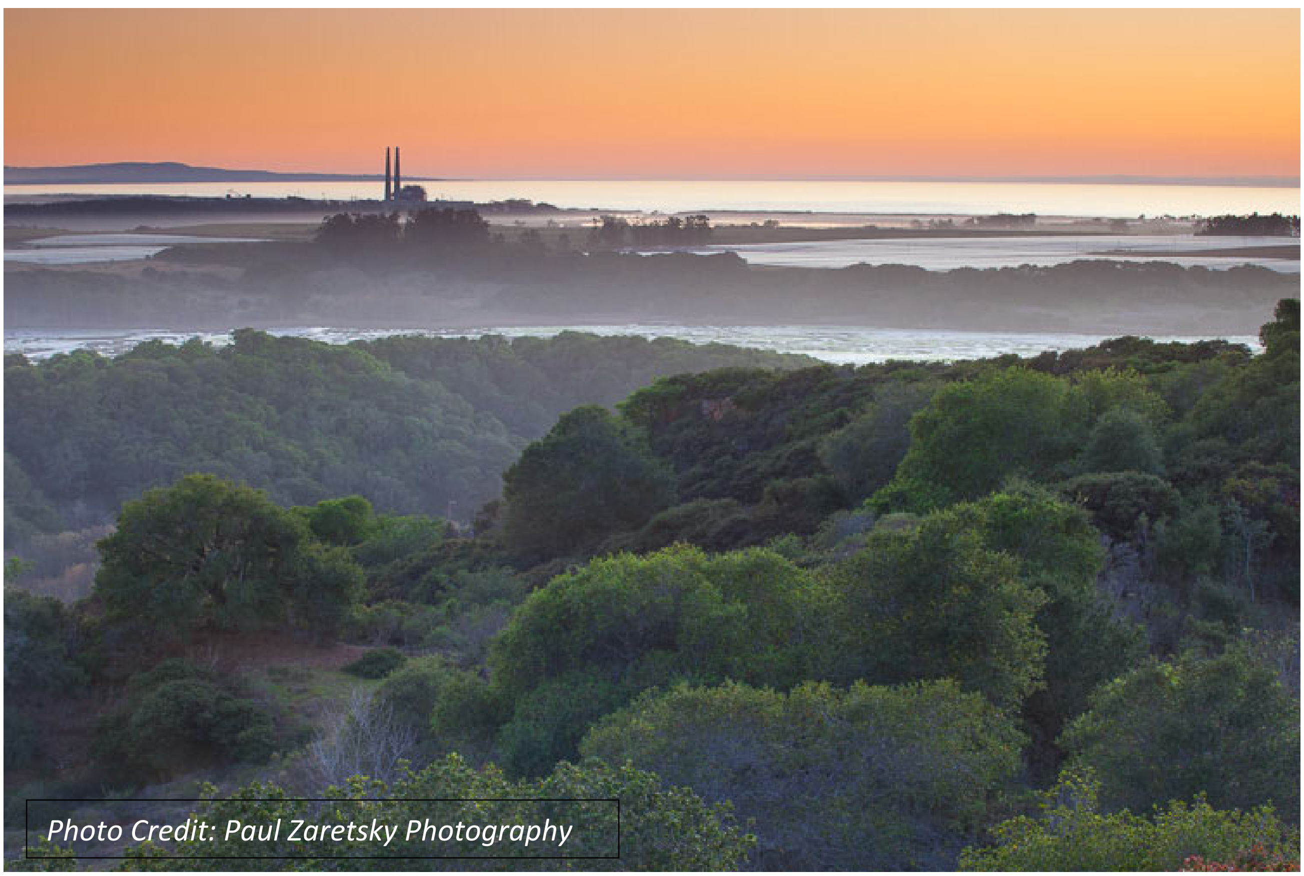
Final

CENTRAL COAST HIGHWAY 1 CLIMATE RESILIENCY STUDY

Study Report

Prepared for
Association of Monterey Bay Area Governments (AMBAG)

July 2020



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CHAPTER 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. Tidal estuarine habitats within the Slough and the ecosystem services they provide are at risk to substantial degradation and losses from 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 current marsh habitat area in the face of sea level rise. Presently, Elkhorn Slough holds the third largest extent of estuarine marsh in California and is well conserved. However, largely due to the surrounding steep topography, approximately 85% of this marsh is projected to be degraded or converted to tidal flats or open water with sea level rise without concerted restoration and conservation efforts. As sea levels rise, each acre of salt marsh now becomes that much more important to conserve or restore. Ensuring that Elkhorn Slough will perpetually host healthy salt marshes into the future is a high priority for the region (Fountain et al. 2020).

Transportation assets in this region are also vulnerable to sea level rise impacts. The eight-mile stretch of Highway 1 through Elkhorn Slough is a critical transportation asset for the region and beyond. It provides local access to Moss Landing, is essential to freight movement and the economy, and is a major commuting route connecting two regionally important cities, Santa Cruz and Monterey. With 2 feet of sea level rise, major disruptions to Highway 1 transportation function are anticipated. The railway, which runs along the main stem of 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 1 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, and Environmental Science Associates (ESA) to develop and evaluate adaptation strategies for Highway 1 and the railway to improve resilience of transportation infrastructure in a manner that most benefits the surrounding ecosystems throughout 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 Caltrans via a Senate Bill (SB) 1 Adaptation Planning grant, a Sustainable Communities Planning grant, with additional funding provided by AMBAG, TNC and the CBE.

The Project Team coordinated with a wide range of local, regional and state 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 (Haasnoot, 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 that could be implemented. 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:

	2-Lane Elevated Highway 1 (C1)	**Improve G12 Inland Corridor as Main Route (C2)**	**4-Lane Elevated Highway 1 (C3)**
	Highway 1 remains 2 lanes and is elevated in place, on piles or fill, as appropriate	Through traffic re-direct inland to the G12 corridor and Highway 1 unmodified for local only access	Highway 1 expanded to 4 lanes and is elevated in place, on piles or fill, as appropriate
Road Features	Highway 1 remains 2 lanes	G12 Widened to 4-lane and Highway 1 traffic diverted	Highway 1 widens to 4 lanes
Road Features	Highway elevated on piles or fill	Only local access to Highway 1	Highway elevated on piles or fill
Road Features	Road ecotone marsh planting		Road ecotone marsh planting
Road Features	Highway operational and access improvements		Highway operational and access improvements
Road Features	Express transit service		Express transit service
Road Features	Enhanced bicycle and pedestrian facilities	Enhanced bicycle and pedestrian facilities	Enhanced bicycle and pedestrian facilities
Rail Features	Hourly rail service on elevated single track	Hourly rail service on elevated single track	Hourly rail service on elevated single track
Rail Features	Marsh restoration east of railway	Marsh restoration east of railway	Marsh restoration east of railway

The roadway and railway adaptation scenarios were evaluated using best available locally specific data to inform a series of modeling tools investigating systemic changes to hydrology, transportation, and ecology triggered by sea level rise and 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. Further, we provide an examination of when adaptation action needs to be taken to provide resilience benefits to both transportation infrastructure and surrounding ecosystems given probabilities of sea level rise. The major takeaways from each portion of the evaluation are briefly described here.

1.1 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 solutions to enable needed transportation function for the study area. The results of the modeling for each scenario were compared to each 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:

- Allowing the roadway to flood (No Action Scenario) would not only increase congestion and delay in the study area, it would also limit access to transportation for disadvantaged communities within the Moss Landing and Elkhorn Slough area.

- Scenario C3 (4-Lane Elevated Highway 1) would best suit the transportation needs of the corridor, allowing for increased capacity on a road that is already overburdened by demand. Widening Highway 1 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.

- Scenario C2 (Improve G12 Inland Corridor as Main Route) presents the same problems as a no action scenario in that it limits access for disadvantaged communities, and does not outperform Scenario C3 (4-Lane Elevated Highway 1) under any transportation metric.

- Scenario C1 (2-Lane Elevated Highway 1) does not provide relief to the demand on Highway 1 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.

1.2 Flood Hazards Modeling

The Coastal Resilience Monterey Bay (CRMB) hazard mapping resource was applied to assess the extents of Highway 1 at risk to flooding, resulting in identification of four sections of Highway 1, 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. CRMB are the best available flood hazard mapping for the Monterey region and are being used by municipalities for vulnerability assessments and adaptation planning. We crosswalk CRMB sea level rise curves (2.4 ft by 2060 and 5.2 ft by 2100) with the most recent (2018) California guidance for reference and planning purposes. The CRMB (2014) maps were then updated 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-affected sea levels and runoff from the Reclamation Ditch - Gabilan Creek drainage. The refined flood hazard mapping indicates Highway 1 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).

1.3 Hydrodynamic Modeling

The Delft3D hydrodynamic model was applied 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 1 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 sea level rise.

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. Marsh restoration of the complexes east of the railway (about 700 acres of intertidal areas) proposed within this project will reduce the overall increase in tidal prism associated with sea level rise, thereby reducing marsh loss.

1.4 Habitat Modeling

The Sea Level Affecting Marshes Model (SLAMM) was applied to predict wetland habitat evolution within the Slough for each roadway and railway adaptation scenarios compared to a no action scenario on decadal time steps as sea levels rise. While a majority of Elkhorn Slough is conserved for habitat values, much of the periphery of the estuary is too steep to allow the migration of its extensive marsh habitats as sea levels rise. SLAMM modeling also assessed how much additional wetland habitat could be provided from proposed marsh restoration east of the railway, compared to a no action scenario, which would strengthen habitat resilience through the Slough.

Ecotone levees were incorporated into all scenarios of adapting Highway 1 in place. An ecotone levee utilizes a much more gradual slope (up to 20H:1V) than typically used which creates intertidal habitat area as well as an “ecotone,” an area of transition between tidal habitats and upland habitats. This ecotone provides a buffer between the roadway and sensitive estuarine habitats and also provides migration space for tidal marsh habitats to move upwards into as sea levels rise thereby enhancing resilience.

Proposed grading by Reach 2 for levee ecotone creation for Scenarios C1A (2-Lane Elevated Highway 1 with Reach 2 on Piles), C1B (2-Lane Elevated Highway 1 with Reach 2 on Fill), C3A (4-Lane Elevated Highway 1 with Reach 2 on Piles) and C3B (4-Lane Elevated Highway 1 with Reach 2 on Fill) will produce between 72 to 83 acres of estuarine marsh habitat, assuming construction by mid-century. The total number of estuarine marsh habitat acreages will likely be refined and could potentially be greater than this planning study has included. Scenarios C1B (2-Lane Elevated Highway 1 with Reach 2 on Fill) and C3B (4-Lane Elevated Highway 1 with Reach 2 on Fill) result in the greatest area of estuarine marsh habitat from the associated restoration adaptation actions among the different scenarios (607 acres remaining at 2100, compared to 260 acres from the no action scenario).

Adaptation for the railway differed from adaptation of Highway 1. Because the railway is currently within the main stem of Elkhorn Slough, elevating on fill is predicted to subside. We took this as an opportunity for restoration of large extents of tidal habitat in this part of the Slough. The rail would be elevated on trestle, and the existing railway could then be used as grade control to allow elevating the marsh plain of approximately 700 acres to mean higher high water (MHHW) in year 2050 for Parsons Slough, North/ Estrada Marsh and Azevedo Ponds. This approach is supported by the Elkhorn Slough Reserve’s strategy for conservation, restoration, and enhancement and was pioneered with the recent construction of Hester Marsh within Elkhorn Slough (Fountain et al. 2020).

According to SLAMM modeling, 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. Around 290 acres of additional restored estuarine marsh habitat remain at year 2100 (5 ft of sea level rise) as a consequence of proposed marsh restoration. As much of the area of estuarine marsh habitats throughout the Slough are converted to flats and open water under sea level rise, the importance of these marsh 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 substantially, given that many habitat acres may have already converted to estuarine open water. This highlights the need for adaptation and restoration actions beginning now and by mid-century to minimize loss of marsh habitat, secure resilience and maintain the benefits these habitats provide to people and nature.

The habitat modeling results strongly support action to create and sustain estuarine marsh habitat acreages with any infrastructure adaptation and other restoration projects throughout the Slough. Habitat modeling also urges the need to deploy such adaptation and restoration before mid-century. 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. Strategic land acquisition, in the context of enabling marsh migration, is a critical strategy to sustaining future marsh habitat (Heady et al. 2018). This is further supported by Fountain et al. 2020. 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.

1.5 Benefit Cost Analysis

Sea level rise presents a significant challenge to maintaining both the transportation system of Highway 1 and the ecological systems of Elkhorn Slough. A major part of that challenge is that the costs of adapting to sea level rise are likely be very large, but the costs of not adapting could be even higher. Decisions must be made about whether to adapt, and if the decision to adapt is made, then a choice must be made of which option should be selected. Benefit cost analysis is a tool to help make these choices. It can show whether the threats from sea level rise are likely sufficient to justify action, and which options have the greatest likelihood of providing more in social benefits than the social costs incurred. Equally importantly, benefit cost analysis works with a common metric of economic values that permits comparison of the changes in both transportation and the environment resulting from sea level rise and the options being considered for response.

The analysis conducted for this study considers:

- The expenditures on transportation system adaptation and wetlands enhancement/ restoration
- The value of time spent in transportation for both passengers and freight
- The economic costs of highway accidents
- Expenditures on motor vehicle operations
- The value of recreation in Elkhorn Slough
- The value of ecosystem services from Elkhorn Slough other than recreation.

Costs and benefits are defined by context. Costs are defined as reductions in economic values, while benefits are defined as gains in economy valuation. Losses and gains are always measured by comparison with a reference scenario. Taking no action with respect to sea level rise risks losses of valuable time, ecosystem services, safety, etc., but saves money for use elsewhere. Adaptation, by contrast, must incur the costs of altering infrastructure and ecosystems but these costs are offset by gains in other social values measured in time, safety, etc. that would be cost. Thus, the costs and benefits of the adaptation scenarios are the inverse of the costs and benefits of taking no action.

The results of this analysis, as shown below, indicate that the option to adapt with a 4-Lane Elevated Highway 1, which includes investments in expanding and restoring wetlands (C3) is the only option whose benefits exceed its costs (adjusted to present value). The No Action and other scenarios, 2-lane elevated highway (C1) or shifting north-south traffic to inland routes (C2/Improve G12 Inland Corridor as Main Route) all show substantially more costs than benefits. The choice of whether to use fill or piles for an elevation of Highway 1 does not affect the benefit cost conclusions.

TABLE 1
SUMMARY OF BENEFIT COST ANALYSIS

Millions of $			C1		C2	C3	
		No Action	On Piles	On Fill		On Piles	On Fill
TOTAL	Costs	-$1,459.02	-$773.91	-$765.10	-$899.02	-$913.34	-$904.54
	Benefits	$858.86	$234.17	$235.87	$149.41	$1,008.95	$1,012.94
Net Present Value		-$600.17	-$539.74	-$529.23	-$749.61	$95.61	$108.40
Cost Benefit Ratio		0.59	0.30	0.31	0.17	1.10	1.12

The analysis also examines how to deal with the large uncertainties surrounding the actual pace and extent of sea level rise in Monterey Bay. The California Ocean

Protection Council recommends using a risk averse approach to planning for sea level rise adaptation. That is, plans should be based on the expectation of large amounts of sea level rise, even if such amounts have low probabilities based on best available science. Planning for worst case (or near worst case) scenarios creates an economic dilemma: moving ahead too soon may mean large expenditures that are ultimately not needed or not needed for many years in the future. Moving ahead too late risks enduring unacceptable losses until action is taken.

Finding a point where the decision to act is more likely to result in net gains requires an analysis of the probabilities of sea level rise. This was done in the benefit cost analysis, with the result that a decision to commit large scale resources should be made no later than the early 2040s, a point at which the data indicates that sea level rise-enhanced storms are more likely than not to begin damaging Highway 1. That decision point will be followed by at least 10 years of project development, evaluation, and construction.

The benefit cost analysis also considered the sensitivity of the analysis to the discount rate (the mechanism for equating distant future benefits with near term costs). It was found that the results were sensitive to the discount rate, with net present values for C3 (4-Lane Elevated Highway 1) approach zero at about a 4% discount rate in contrast to the 3% discount rate used. This indicates that future economic evaluation of Highway 1 adaptation options should include examination of lower cost alternatives, particularly in wetlands restoration, which in the current analysis comprises a large a portion of costs.

1.6 Major Takeaways and Considerations for Future Planning

While not an exhaustive list, summarized below are key takeaways and considerations for future planning drawn from the study process, approach, methodologies and results from the analyses.

Major Takeaways:

- **Choosing not to adapt to sea level rise will result in widespread loss of coastal habitat, significant transportation impacts and economic losses.** Following a no action pathway, or 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 an economically viable option for Moss Landing and Elkhorn Slough.
- **Adaptation of the highway with nature-based elements helps to reduce the loss of marsh habitat.** Marsh habitat is the most at-risk habitat type with sea level rise. Every acre of marsh habitat that can be conserved and restored will be critical to ensure Elkhorn Slough can continue to support healthy wetland habitat. The ecotone proposed for highway adaptation and the marsh restoration for Parsons

Slough, North/Estrada Marsh Complexes and Azevedo Ponds, will make significant contributions to reducing habitat loss in the Slough.

- **Adaptation needs to be in place by 2050 to ensure benefits to transportation and habitats.** The benefits of implementing adaptation actions, such as large-scale marsh restoration, are greater the earlier they happen in the century. The results of the evaluation emphasize the importance of planning for Highway 1 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- 21^{st} century.
- **Multi-sector cooperation and planning is key.** Integrating transportation and ecosystem resilience planning from the beginning can provide better outcomes for both sectors. It is critical to have a multi-sectoral team of transportation planners, scientists, conservationists, engineers and economists together at the same table, pursuing coequal goals for transportation and ecology, and working to identify pathways to long-term adaptation to achieve multiple benefits.
- **Planning for ecosystem migration is critical to increase future habitat and overall resilience of Elkhorn Slough.** This study revealed the need to also pursue conservation and restoration strategies to ensure migration of coastal habitat with sea level rise. Habitat migration could mitigate approximately half of projected habitat losses with sea level rise.

Considerations for Future Planning (See Section 7.3 Considerations for Future Planning)**:**

- Integrate study results into Regional, Metropolitan and State Transportation Plans and prioritize further planning for this critical transportation corridor.
- Continue planning processes that combine multi-objective and multi-benefit focus in each stage of adaptation planning.
- Future analysis should integrate best available science and modeling, including considering higher sea level rise scenarios when projections are available.
- Integration and consistency with other ongoing and future climate change adaptation planning efforts is critical, including the Moss Landing Community Plan, Local Coastal Plan and Monterey County General Plan.
- The economic benefit cost analysis developed in this project provides a framework for planners to assess when adaptation is needed and should be applied to future efforts.
- Pathways, triggers and strong partnerships must be in place now to ensure effective climate change adaptation for the Moss Landing area and Elkhorn Slough.