State Route 37 Integrated Traffic, Infrastructure and Sea Level Rise Analysis: Final Report

Road Ecology Center
University of California, Davis
http://hwy37.ucdavis.edu

State Route 37 Integrated Traffic, Infrastructure and Sea Level Rise Analysis: Summary

Fraser M. Shilling, Kevin Ward, & David Waetjen

Road Ecology Center; University of California, Davis

Justin Vandever, Joy Villafranca , Kris May, Sarah Kassem, and Mark Lightner

AECOM

Author Note

This is the executive summary to the final project report, which includes Task-specific reports. It completes the tasks and deliverables for Contract # 74A0728 between the California Department of Transportation and The Regents of the University of California. The people listed on this page all contributed to the content of this report and the corresponding web-site: http://hwy37.ucdavis.edu

"*The most painful and expensive way to deal with global climate change will be to ignore it until something happens that elicits powerful public demands for immediate and Draconian action.*"

Jonathan Lash.
"As the earth heats up."
Journal of Commerce, August 16, 1996.

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16. Abstract
Sea level rise (SLR) and shoreline change in response to anthropogenic climate change is likely to fundamentally change coastal communities and ecosystems. Appropriate adaptive responses and resilience will determine how well these systems function in the future. Coastal highways and other infrastructure are both potentially vulnerable to these changes and adjacent to highly-regulated natural systems (e.g., tidal marshes, beaches). Understanding potential changes and the costs of adapting to changes allows agencies to plan a gradual vertical or inland retreat of critical infrastructure and potential abandonment of other structures. This project focused on State Route 37 (SR 37) to investigate the best approach for conducting an integrated evaluation of impacts of sea level rise on transportation and adaptive responses, while protecting ecosystem features and processes. It pioneered a stakeholder-inclusive approach that could be used for other routes/areas with similar needs. The team of UC Davis, Road Ecology Center and AECOM scientists, engineers and other staff (the Team) interacted with Caltrans, county congestion management agencies (CMAs), conservation and regulatory agencies, landowners, and other stakeholders to implement a 4-step process: Involve stakeholders in a multi-way discussion of future scenarios; model potential risks to SR 37 and associated shoreline; develop conceptual diagrams, costs, and visualizations of adaptive structures; and share text resources, data, and project findings through a web-system. This report provides background information, describes the approaches used, and shows possible future scenarios that area adaptive to SLR.

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Executive Summary

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The team of UC Davis, Road Ecology Center and AECOM scientists, engineers and other staff (the Team) interacted with Caltrans, county congestion management agencies (CMAs), conservation and regulatory agencies, landowners, and other stakeholders to implement a 4-step process: Involve stakeholders in a multi-way discussion of future scenarios; model potential risks to SR 37 and associated shoreline; develop conceptual diagrams, costs, and visualizations of adaptive structures; and share text resources, data, and project findings through a web-system. This report provides background information, describes the approaches used, and shows possible future scenarios that area adaptive to SLR.

Climate Change and Sea Level Rise

Identifying infrastructure that is both exposed now or in the future to the ocean and vulnerable to SLR and increased storminess is a complicated and potentially expensive process for local and state transportation agencies (Rowan et al., 2014). The physical structures themselves are vulnerable to SLR, which is likely to result in increased costs for maintenance, repair, replacement of facilities and materials, and eventual adaptation (Mallick et al., 2014; Lu et al., 2012). In addition, the function of linked, regional transportation systems may be vulnerable to disruption if a SLR-vulnerable link (e.g., a shoreline highway) fails (Testa et al., 2015; Chen et al., 2015).

Sea Level Rise and SR 37

State Route 37 (SR 37) constitutes a major regional east-west vehicular transportation corridor in the northern San Francisco Bay Area (hereafter “Bay Area”) and was used as a case study to understand adaptive transportation planning in the face of SLR. Like many coastal highways in the US, this corridor is under threat from SLR. In fact it is one of the lowest-lying highway (in terms of elevation relative to mean higher high water, MHHW) in California and was considered by Caltrans to be the best case study with which to develop an adaptive planning process to deal with SLR. The projected SLR of 1 – 1.7 m in the next 90 years (NRC, 2012) poses a potential threat to the highway. Because of its position upon a berm passing through existing marshes and marshes under restoration, SR 37 also poses a threat to the ability of nearby coastal-marsh systems to adapt to SLR. These marshes are nationally important as habitat for endangered species, so the role of the highway in their adaptation must be considered in corridor planning. Many animal and plant species are threatened or endangered as a result of loss of 85% of historical Bay Area wetlands (Marshall and Dedrick, 1994).

Sea Level Rise to Date

Sea level has already risen by 8 inches along the California coast and by 2100 may be 36” to 66” above present levels (Nicholls, R.J. and A. Cazenave, 2010; NRC 2012). Climate change is expected to result in accelerated rates of sea level rise (Cayan et al., 2008) and changing seasonal wave conditions (Bromirski et al., 2013), further exposing the shorelines to impacts (Heberger et al., 2011; King et al., 2011). Infrastructural and living systems adaptations will need to occur to avoid a wholesale change in the marshes, estuarine systems, low-lying urban areas, and exposed highway infrastructure along the US coast. Transportation system and coastal ecosystem changes occur slowly and may not adapt at the rates necessary to keep up with increased sea levels and storminess. Many coastal communities and infrastructural features face risks from storms in the form of flooding, erosion, and shoreline retreat. A longitudinal survey of coastal managers in California found SLR and related problems among the most challenging issues (Finzi Hart et al., 2012).

Projected Sea Level Rise

There is a growing number of predictions of sea level rise and shoreline change in response to anthropogenic climate change. One of the most recent and alarming is from a large group of climate scientists (Clark et al., 2016) who positioned the changes in carbon dioxide, temperature and sea level within Ice Age time-scales (+ 10,000 years). They suggested that focusing on 2100 was an unnecessarily short-sighted target for planning as impacts would extent well-beyond the end of the century, affecting future generations. They positioned this long-term thinking in contrast to the conventional economic practice of discounting future impacts (resulting in little incentive to act soon) and suggested that permanent displacement of current shoreline communities should be thought about now, while we are busy creating and benefiting from the circumstances resulting in displacement. In addition, the highest rate of change is in the next few centuries, with a rate this century of almost 2 m 100 yr^{-1} (increasing to 4 m 100 yr^{-1} by 2500; Figure 1b), implying that children and grandchildren being born now will see many of the impacts in their lifetimes.

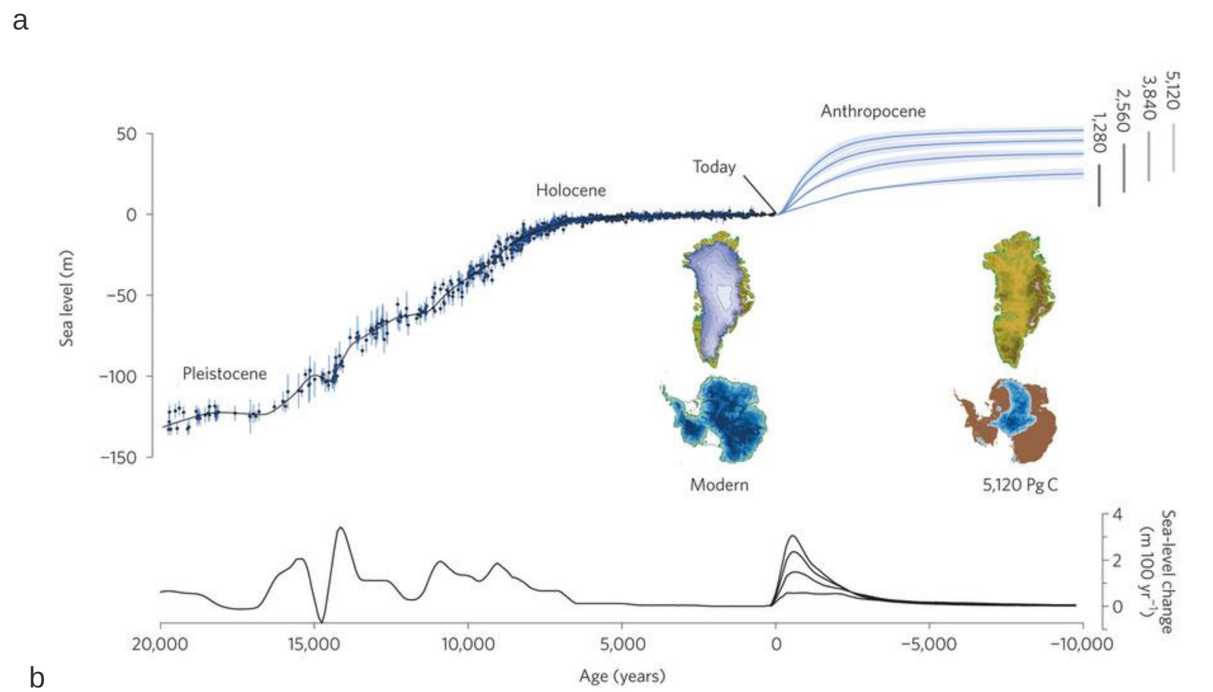

Figure 1. a) Long-term changes in sea level in response to various carbon-emission scenarios (1,280 to 5,120 Pg C) and b) change in rate of sea level rise (m 100 yr^{-1}) for the same emission scenarios (source: Clark et al., 2016).

There is also a growing number of national and local tools to visualize the predicted inland extent of sea level rise and shoreline change. One of these is the Climate Central Surging Seas tool (http://ss2.climatecentral.org). This tool uses the same underlying shoreline elevation dataset that was used for the present study – high-resolution LiDAR data developed by the USGS and NOAA. However, the SLR scenarios presented by this tool are a little different from those of the present study, possibly because our study had more local information to draw from. For example, according to our study, SR 37 between the Petaluma River and Lakeville highway would be flooded at or less than 24" of SLR, while the Surging Seas tool suggests this could happen at 12" SLR (circled areas, Figure 2). This is an important difference, but difficult to resolve.

An important aspect of adaptive planning for climate change and sea level rise is the creation of maps of potential SLR exposure, which overlay future potential sea level and wave run-up

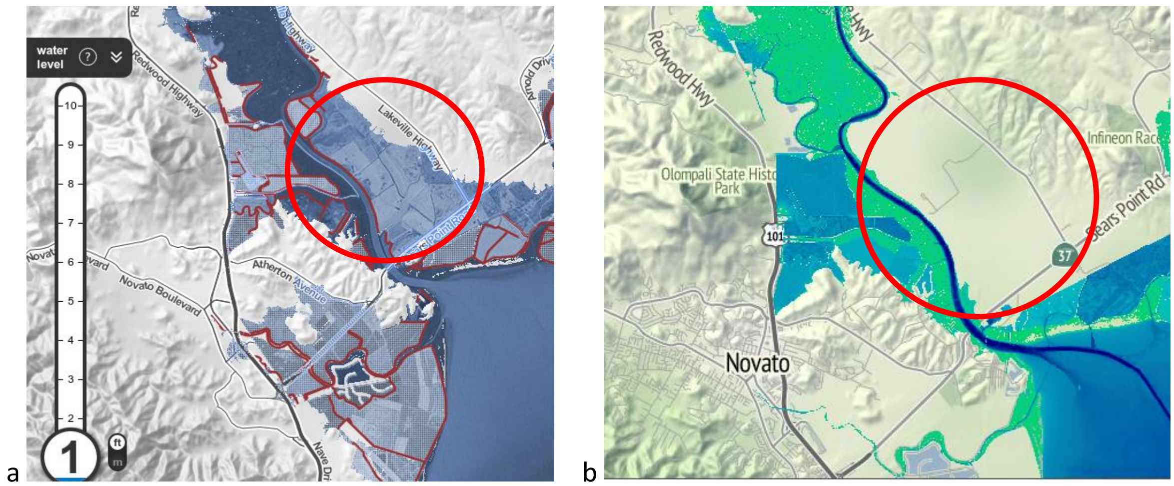

Figure 2. Potentially-flooded areas with 12" SLR (a) Climate Central's Surging Seas tool and (b) the present study.

hazard areas on existing infrastructure and natural features to assess SLR vulnerability (AECOM et al., 2011; BCDC, 2011). The public seems to find these maps of sea level rise and potential impacts, including interactive maps online, the most useful way to understand climate change effects (Schnotz, 2002; Retchless, 2014a,b; Monmonier, 2008; Kostelnick, 2013). Because there is considerable uncertainty in how much sea levels might rise, the types and costs of impacts, and when certain elevations and impacts will occur, many modeling and mapping projects attempt to display uncertainty and variability (Retchless, 2014b). At the same time, there is variation in how SLR maps are received by the public, which may be based upon scientific expertise, or trust in scientists (Retchless, 2014b).

Potential Impacts of Sea Level Rise

The most immediate impact of sea level rise is to newly flood lands that did not previously experience tidal or storm-based inundation. In addition, changes in wave height and run-up, as well as wave action on newly-eroded lands will impact shoreline areas as sea levels rise. In terms of SR 37 and surrounding lands, the most immediate and obvious impact will be to increase salinity and erosive pressure on tidal, brackish and freshwater marshes. As sea levels rise greater than 12" above current levels, several points along SR 37 face increasing temporary flooding from wave action and storm-related flooding (e.g., at Novato Creek), while the stretch of SR 37 between the Petaluma River and Lakeville Highway faces permanent inundation if the levees near the Eastern end of the Petaluma Bridge are overtopped.

Important Project Assumptions

Several important assumptions were made during this project, limiting and framing the findings presented here:

1) Only expansion of the number of lanes was considered, from 2 to 4 for segment B. No consideration was given of restricting travel on the primary re-constructed segments (A and B) to 2 lanes, or 3 lanes, where 2-lane travel would take place during directional rush-hour, with the center lane serving one direction and then the other. Both approaches would reduce cost and environmental impact.

2) No consideration was given to moving the highway alignment inland, or combining with existing highways with less exposure to SLR. This option was discussed in Phase I and was seen as impractical, primarily because it is not typically done. However, Caltrans is currently considering moving SR 1 inland in coastal areas because of regular flooding and slope failure. It is likely that consolidation of vehicle-travel routes inland would be less expensive than adapting shoreline structures to the continuously moving target of SLR and increased storm energy.

3) Similarly, no consideration was given to building a tunnel or bridge structure across San Pablo Bay (at its narrowest point) to provide the travel opportunity, but without retaining an alignment across the marshes. These scenarios were considered in Phase I, but were not included in this Phase.

4) Although transit was considered for multi-modal travel along the corridor, only bus transit was noted. Other forms of transit were briefly discussed, but serious analysis of transit remains to be carried out.

5) SLR is often thought of as a predictably-changing process where impacts will linearly increase with time/SLR. However, impact costs increase faster than the rate of SLR (Boettle et al., 2016), which includes storm-related impacts to areas that were previously unprotected. In CA over the last year (2015-2016), sea elevations have been up to 10” higher than expected due to the El Nino. This sudden rise in sea levels and increased storminess that accompanies El Nino events means that new areas on the CA shoreline will become exposed faster than expected. This will continue to happen.

6) Finally, analysis was limited to a SLR of 36”, a rate of rise of 3-6”/year, and a timeframe of 2075-2100. Although SLR will continue indefinitely, this frame was chosen to provide more familiar sidebars for planners and the public. However, future analyses should consider a broader range of conditions.

Task-Specific Summaries

The next few sections provide summaries of activities and findings under each task. We describe potential inundation from SLR, risk to and vulnerability of each SR 37 segment, potential adaptive structures, potential costs of each scenario, impacts and benefits of adaptive action, and the stakeholder process. The information associated with each task is also on the website (http://hwy37.ucdavis.edu).

Task 1: Potential Inundation of Shoreline Areas

In recognition of the potential effects of sea level rise on State Route 37 (SR 37) and surrounding marshes and communities, Caltrans engaged the Team to assist with initial stages of planning for adaptive actions associated with the highway. One critical analysis for planning adaptation is understanding the potential inundation due to sea level rise (SLR) and storm surges. A model was developed of the potentially-affected areas and stretches of highway from SLR and elevation changes due to storm surges.

The modeling approach relied on a combination of high-resolution elevation data obtained by light detection and ranging (LiDAR) by the US Geological Survey (USGS) and the National Oceanic and Atmospheric Administration's (NOAA) California Shoreline Mapping Project (CSMP). The model uses a "contagion" method which basically means that for any area on the landscape, if it is immediately adjacent to an area that is inundated and is lower elevation than that area, it will also become inundated. Mean higher high water ("high tide") elevations in the San Pablo Bay were used to describe current conditions. Additional water elevations due to SLR or storm surge were added to these elevations to indicate a potential future condition. These potential water elevations were then used to project potential inundation inland from the shoreline. Certain areas are protected by levees or berms and remain protected until the water elevation is higher than the lowest point on the levee or berm, at which point water enters the protected area and inundation proceeds until land elevations are higher than the water elevation. One consequence of this approach is that the inundated area may be over-estimated at lower than high-tide, unless water remains behind after the high-tide recedes.

The inundation modeling and mapping was the first step in understanding extent and magnitude of potential risks to SR 37 and surrounding landscapes and infrastructure. The vulnerability of SR 37 to SLR and the risks to continuing use of SR 37 were assessed (see Report 2) based on the inundation modeling and mapping step described here. The following memorandum describes the methods and results from the modeling and mapping. Maps corresponding to different SLR and storm surge scenarios are also available here:

http://hwy37.ucdavis.edu/resource/potential-inundation-maps-various-scenarios.

Task 2: Sea Level Rise Vulnerability and Risk Assessment

The vulnerability of each SR 37 segment was scored according to its exposure to SLR effects, sensitivity to SLR, and adaptive capacity (ability of other roadways to absorb traffic). The risk to each segment from SLR was determined by estimating and aggregating impacts to costs of improvement, recovery time (from impacts), public safety impacts, economic impact on commuters and goods transport, impacts on transit routes, proximity to communities of concern, and impacts on recreational activities.

Vulnerability Assessment Findings: Vulnerability was assessed by evaluating the exposure, sensitivity, and adaptive capacity of each reach of the highway to SLR impacts. Exposure of each reach was evaluated by examining the depth and extent of inundation, length of overtopped highway, and vulnerability of shoreline protection features. Sensitivity of each reach was evaluated by examining indicators such as age, level of use, historical performance during storm events, seismic sensitivity, and liquefaction susceptibility. The adaptive capacity of the regional transportation system was evaluated by examining the existence and viability of alternate routes in the event of SR 37 closure due to flooding. For each component of vulnerability – exposure, sensitivity, and adaptive capacity – a low/moderate/high rating was assigned to develop a composite vulnerability rating for each reach of the highway. Based on the results of the vulnerability assessment, Reaches A1, A2, and B1 (from Novato to Sonoma Creek) were assigned a high vulnerability rating, primarily due to their relatively low elevation, vulnerability to present day flood levels, widespread SLR impacts, and reliance on flood protection features maintained by other landowners. Reaches B2 and C (from Sonoma Creek to I-80) were assigned a moderate vulnerability rating due to their relatively higher elevation and lesser SLR impacts (see Figure 1 for reach definitions).

Risk Assessment Findings: Risk was assessed by evaluating the likelihood and consequence of SLR impacts to the highway to develop risk ratings for each reach. Potential consequences of inundation or flooding by SLR include costs to restore service, public safety impacts, economic impacts to goods transport and commuters, proximity to communities of concerns, and impacts to recreational activities. Based on the results of the risk assessment, Reaches A1 and A2 (from Novato to SR 121) were assigned a moderate risk rating, Reaches B1 to B2 (from SR 121 to Mare Island) were assigned a high risk rating, and Reach C (from Mare Island to I-80) was assigned a moderate rating.

The results of the vulnerability and risk assessment can help prioritize adaptation options along the most vulnerable and at-risk reaches of SR 37. In a subsequent stage of the project, conceptual engineering design and cost estimates were developed for adaptation options to elevate the highway and protect it from existing and future SLR-induced inundation and flooding hazards.

Task3: Designs and Cost Estimates for Possible Resilient Structures

Based upon the model of potential inundation, the assessment of risk and vulnerability, and previous recommendations of appropriate structures to consider, we developed conceptual engineering scenarios for SR 37 and cost estimates for each scenario. These scenarios included 1) the highway on top of a berm/embankment, raised to accommodate sea level rise, 2) the route on top of a causeway with box girder design, and 3) the highway on top of a causeway with concrete slab and pier design. Each was designed based on the Caltrans Highway Design Manual, input from stakeholders and Caltrans staff, and previous experience of the team. Cost estimates for each scenario were developed and are summarized below.

Table 1. Cost estimates for each engineered concept by reach

Segment	**Scenario Costs (in $millions)**		
	1 – Levee/ Embankment	**2 – Box Girder Causeway**	**3 – Slab Bridge Causeway**
A	$460	$1,400	$1,300
B	$650	$2,500	$2,200
C	$150	$400	$340
Total	**$1,260**	**$4,300**	**$3,840**

Task 4: Community and Environmental Benefits of SR 37 Scenarios

As planning to modify State Route SR 37 (SR 37) goes forward, it will be important to understand and plan for the best outcomes for society and the environment. In order to do that, indicators of these outcomes must be developed, broadly accepted and measured. One way to talk about outcomes is as benefits to society, either directly through tangible goods and services to members or the whole of society, or indirectly through benefits to the environment, which in turn benefits society. Not all transportation projects are automatically good for society and to make good decisions about them, the benefits they provide must be compared to the impacts (the opposite of benefits) and the financial cost of the project. The report for this task describes the types of benefits and impacts that could result from modifying SR 37 in response to sea level rise and associated impacts. Because almost every transportation agency and municipal government involved in planning associated with this highway claims to want to act sustainably, this principle is used to the frame the discussion. In this case, sustainability is defined primarily as the set of actions that support meeting the needs of current and future generations in the areas of community (equity, economy) and environment.

Task 5: Stakeholder Involvement to Improve Sustainability

In order to improve the inclusion of a broad array of opinions in planning for State Route 37 (SR 37), an extensive stakeholder process was carried out. Participation was continued from Phase I of the SR 37 project with many of the same organizations attending meetings. Large, quarterly stakeholder meetings were combined with more focused meetings and web-based sharing of information to make sure that everyone from the public to regulatory agencies had a chance to offer their opinions. Five stakeholders meetings were held throughout Phase II, as well as 5 focused meetings. Information about potential sea level rise and potentially inundated marsh and highway areas was shared at the first two meetings. Later meetings focused more on the constructed scenarios that were adaptive and resilient to the impacts of sea level rise and that minimized impacts to the surrounding environment.

Task 6: Technical Reporting

Besides the final report and component reports, the primary reporting tool was the project website: http://hwy37.ucdavis.edu. The website contains menu tabs that can be used to access meeting agendas/minutes, a data depot (spatial/GIS data), resources (previous reports/presentations), a mapping tool, and an image library. The information contained is intended for public education and to report on project progress.

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