SCC Climate Ready Grant #13-107
Economic Impacts of Climate Adaptation Strategies
for Southern Monterey Bay

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Marina State Beach, Photo credit: Kelly Leo

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Executive Summary

Local governments along Monterey Bay's shores are undertaking a number of initiatives for which sea level rise adaptation planning is required. Governor Schwarzenegger's 2008 Executive Order S-13-08 and the 2011 Resolution of the California Ocean Protection Council on sea level rise led to the proliferation of individual agency guidance documents (e.g., CalTrans (2011), BCDC (2011), CCC (2015)) that require emerging best available science (e.g., Pacific Institute Report (Heberger et al. 2009), NRC Report (2012)). These guidance documents stipulate that sea level rise and coastal hazards need to be considered in planning (e.g., Climate Action Compact, Climate Action Plans, Integrated Regional Water Management Plans, Local Hazard Mitigation Plans, Local Coastal Programs). Moreover, the California Coastal Commission has recently issued guidance indicating that sea level rise adaptation planning will be a critical piece of Local Coastal Programs going forward. As Ocean Protection Council (OPC)/California Coastal Commission (CCC) Local Coastal Program Update grantees, Monterey and Santa Cruz Counties serve as important pilots for the rest of California's coastal communities as the state moves toward climate-ready planning.

For years, scientists have emphasized the need to put detailed, dynamic inundation information in the hands of decision-makers in order to support this planning. This information should characterize the physical risk of sea level rise and storms in order to inform coastal managers. Detailed economic analysis, while not completely absent, has lagged behind. Many past studies have focused on the cost of sea level rise, or in some cases estimated the economic benefits of a single adaptation strategy (armoring).[1]

The southern Monterey Bay shore is, on average, the most erosive sandy shore in California (Hapke et al. 2006). The purpose of this study is to provide decision makers in the region with the tools they need to compare a suite of possible adaptation strategies to combat accelerating coastal erosion for their coastline. The physical process modeling projects how the coast would change in response to the implementation of each of these strategies, considering different rates of coastal erosion and flood hazards as well as sea level rise under several different sea level rise projections. This study also analyzes the economic costs and benefits of each

[1] A small number of studies have examined the costs of sea level rise (SLR) in California specifically. Heberger (2009) found that $100 billion in California property is at risk of inundation from a 1.4-m increase in sea level. King et al. (2015) combine data on the recreational value of beaches with estimates of property/infrastructure losses in several California coastal cities in order to examine optimal SLR adaptation strategies. Ng and Mendelsohn (2005) estimated the tradeoff between coastal "protection" (armoring) and "inundation" (doing nothing) in Singapore and determined that armoring was the most effective approach. Hallegatte et al. (2011) examined potential insurance losses and reductions in economic output caused by SLR in Copenhagen. They found that adapting to sea level rise is far more cost-effective than doing nothing. However, their adaptation strategies focused on traditional "hard" armoring methods.

adaptation approach, allowing decision makers to compare how the different management strategies will impact their jurisdiction economically as well as physically.

This study provides a detailed, integrated analysis of the costs and benefits of a range of coastal climate change adaptation strategies at four reaches in southern Monterey Bay (Figure 1), given a range of sea level rise projections. We consider a wide range of costs and benefits including losses to private property, to public goods such as recreational resources, and to the ecological function of coastal habitats. With extensive stakeholder input, we chose realistic alternative shoreline management strategies specific to discrete reaches of coastline in the study area. By combining projections of coastal hazard impacts (such as sea level rise, erosion, storm surge, wave impacts, etc.) with economic analyses of the impact on both at-risk human-made infrastructure (buildings, roads, etc.) and natural capital (ecological function and recreational assets), we estimated the value of various adaptation approaches for each reach. This information will give coastal managers the information they need to compare the benefits and impacts of different adaptation approaches and develop adaptation plans for their jurisdictions.

Figure 1: Study area divided in reaches based on geomorphology

Previous economic assessment of shoreline management strategies in Monterey Bay (ESA PWA 2012) examined various erosion-control alternatives using three of the same reaches as this study (this study added Moss Landing) and found that armoring strategies were generally not cost-effective. In Ventura County, a recent study reached similar conclusions: proactive adaptation yields more benefits than costs, and the degree to which a nature-based adaptation strategy becomes more economically preferable to a shoreline armoring strategy depends largely upon how much the community values its natural resources and the ecological services they provide to the community (Environ & ESA PWA 2015).

At the outset of this project, stakeholder input was used to define the scenarios and adaptation strategies that would be included in the analysis; agreed-upon strategies for analysis are listed in Table 1 below (See Table 11 for additional information about upland land use strategies).

Table 1: Adaptation management strategies modeled for each shoreline reach

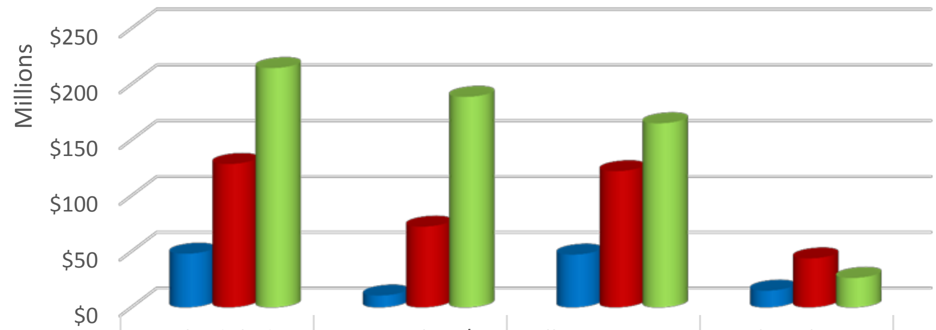
Reach	Management Strategy
Del Monte	**Opportunistic/scheduled beach Nourishment**: smaller local beach nourishment projects scheduled every 10 years
	Shoreline Armoring: Revetment constructed continuously across reach along backshore; stops erosion of back shore but allows beach to narrow and the structure to be overtopped
	Managed Retreat (Fee Simple Acquisition): erosion continues unimpeded; property purchased at fair market value
	Medium scale Nourishment as Needed with Groins: groins installed, beach nourished to 25% wider than current (2010) conditions
	Elevating Structures
Sand City	**Large scale Nourishment as Needed**: large scale nourishment needed to maintain 25% wider beach
	Managed Retreat (Conservation Easements): easements are acquired to allow erosion of upland property
	Shoreline Armoring: Revetment constructed continuously across reach along backshore; stops erosion of back shore but allows beach to narrow and the structure to be overtopped
	Elevating Infrastructure: HWY 1 elevated to column-supported causeway
Marina	**Rolling Easements**: allows erosion to continue naturally; coastal property boundaries move landward with high water lines
	Managed Retreat (Fee Simple Acquisition): erosion continues unimpeded; property purchased at fair market value
	Shoreline Armoring: Revetment constructed continuously across reach along backshore; stops erosion of back shore but allows beach to narrow and the structure to be overtopped
Moss Landing	**Do nothing**: erosion
	Shoreline Armoring: Revetment constructed continuously across reach along backshore; stops erosion of back shore but allows beach to narrow and the structure to be overtopped; rough estimate for estuarine / harbor water level management (e.g. lock)
	Managed Retreat (Conservation Easements): easements are acquired to allow erosion of upland property

In order to determine the costs and benefits of each strategy for each reach, we first examined the physical impact of these strategies. We modeled expected shoreline changes for each proposed adaptation strategy under a range of sea level rise projections (using the High and Medium projections recommended by the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC 2013)) and time horizons (2010, 2030, 2060 and 2100). We analyzed data sets and previous models to project the dynamics of beach erosion, beach nourishment, and other physical processes. The economic costs of each strategy were estimated by gathering information on the engineering costs of sand placement, construction of groins, and implementation of the various adaptation measures. These results were coupled with an economic analysis of the recreational and ecological value of coastal and upland resources that could be affected by coastal hazards. This part of the analysis involved conducting coastal user surveys to determine the value of beach and coastal recreation. We ranked the relative ecological condition of the beach within the study area using several metrics to score the physical, biotic, and human impacts conditions of km^2 blocks of Monterey beaches. The resulting beach ecological index score was then combined with estimates of beach restoration (replacement) costs to provide a monetized ecological value. In all, more than 100 distinct scenarios were analyzed.

We combined the estimates for all these costs and benefits and expressed them in terms of net present value using a 1% discount rate, which is appropriate for long-term climate change modeling. Results were expressed as net present value of the shoreline.

In all cases the least economically beneficial alternative, especially over the long-term, involved shoreline armoring.

For example, results for the Del Monte reach are shown in Figure 2 below. “Net Present Value” refers to the sum of all the benefits (e.g., the recreational and ecological value of beaches) minus the costs (e.g., engineering costs of armoring and nourishment). Loss of land, buildings, roads, and other infrastructure, as well as the cost of adaptation (e.g., elevating roads), were incorporated as costs in the analysis.



	Scheduled Nourish	Nourish w/ Groins	Allow Erosion	Shoreline Hardening
2030 (22 cm)	$48,100,000	$10,600,000	$47,300,000	$15,000,000
2060 (72 cm)	$128,600,000	$72,400,000	$122,100,000	$43,900,000
2100 (159 cm)	$214,500,000	$188,700,000	$165,000,000	$26,400,000

Figure 2: Economic benefits of adaptation approaches for the Del Monte reach

For all time horizons, the Scheduled Nourishment option, which involves smaller local beach nourishment projects scheduled every 10 years, results in the highest net present value (NPV). Our results indicate that, in some cases, Nourishment may be the most cost effective option, depending on the value of the coastal infrastructure at risk as well as the value that the community places on those at-risk assets. In the Del Monte reach (Figure 2), Scheduled Nourishment has a slightly higher net NPV. However, this outcome depends crucially on the availability of sand and the assumptions employed. The Allow Erosion and Beach Nourishment alternatives yield NPVs that are very close and well within the margin of error. Under different sets of plausible assumptions, as when nourishment costs increase, Allow Erosion yields a higher NPV than Nourishment. Given this margin of error, it is most accurate to state that Nourishment and Allow Erosion result in NPVs that are statistically indistinguishable.

For 2030, the NPVs of Allow Erosion and Scheduled Beach Nourishment are within 2% of each other, which is well within the margin of error. For the 2060 and 2100 time horizons, both nourishment options offer the most economic benefits. **In all time frames except 2030, Shoreline Armoring is the worst option.**

For the Sand City reach, the adaptation scenarios we considered were to Allow Erosion through Conservation Easements and Elevating Infrastructure, to Nourish as Needed (nourish the beaches based on a trigger point when the beach hits a particular width), and Shoreline Armoring (building a revetment across the entire reach). In all scenarios, Allowing Erosion – and particularly the implementation of Conservation Easements – resulted in the greatest net present value, while Shoreline Armoring yielded negative benefits, meaning it would cost more to build the revetment than the sum of the benefits the revetment would provide.

For the Marina reach, the adaptation scenarios we considered were to Allow Erosion in conjunction with Fee Simple Property Acquisition or Rolling Easements, and Shoreline Armoring. Allowing Erosion yields significant benefits, while Shoreline Armoring, again, costs more than it is worth in all scenarios. Both Fee Simple Property Acquisition and Rolling Easements yield significant benefits in all time horizons considered.

For the Moss Landing reach, the adaptation scenarios we analyzed were to Allow Erosion – either by taking No Action and letting nature run its course or through Conservation Easements – and Shoreline Armoring. In all time frames considered, Allow Erosion had a significantly higher net present value than Shoreline Armoring, meaning the costs of building and maintaining the revetments are greater than the benefits they provide. Investing in Conservation Easements yields significantly greater benefits than Doing Nothing.

As with any economic modeling, results are based on certain assumptions. To understand the relative role of each of these assumptions in our analysis, we conducted a sensitivity analysis—running the model using a range of values for key parameters to determine how sensitive the model is to changes in that parameter. We focused on the parameters that we believed were the most uncertain or where experts could disagree. **In most cases, we found that our results were quite robust.** The exception was in the Del Monte reach, where the two Beach Nourishment options and Allow Erosion are close enough that the assumptions matter.

This analysis is meant to provide coastal managers and decision makers in the region with general guidelines for assessing various adaptation options for sea level rise and coastal hazard mitigation. These methods and data can help inform coastal adaptation efforts, including Local Coastal Program sea level rise updates, coastal development permitting, and even regional and parcel level coastal protection, restoration, and development opportunities. Further, our results highlight how commonplace approaches to shoreline protection (i.e., shoreline armoring) are often not the most economically or environmentally sound choices.

Our results call into question the conventional wisdom that shoreline armoring is the best response to coastal erosion. In most scenarios analyzed, shoreline armoring yielded significantly lower net present values (NPVs) than other options. While southern Monterey Bay is not representative of the *entire* California coast, some extrapolation of results is possible. For example, even in the more urbanized Del Monte reach, which includes parts of

the City of Monterey, our analysis indicates that armoring yields significantly lower NPVs; this result could be applicable to other urbanized stretches of the California coastline with similar levels of exposure to coastal hazards.

Economic Impacts of Climate Adaptation Strategies for Southern Monterey Bay

Introduction

Sea level rise resulting from human-induced climate change is a serious problem for many coastal communities throughout the world. Today, 600 million people live within ten miles of an ocean coast and three-quarters of the world's megacities are at sea level (Tebaldi et al. 2012). The synthesis report for the fifth Intergovernmental Panel on Climate Change (IPCC 2013) concluded that:

> "… human influence on the climate system is clear and growing, with impacts observed across all continents and oceans. Many of the observed changes since the 1950s are unprecedented over decades to millennia. The **IPCC is now 95 percent certain that humans are the main cause of current global warming.** In addition, the [synthesis report] finds that the more human activities disrupt the climate, the greater the risks of severe, pervasive and irreversible impacts for people and ecosystems, and long-lasting changes in all components of the climate system. " (emphasis added)

Coastal Climate Change Adaptation in California

Adaptation to the changes that sea level rise will bring to coastal communities is critical, and the State of California has been a leader in this arena, making substantial progress in promoting sea level rise science and adaptation. The California Coastal Commission has provided very specific guidance on how communities should plan and adapt (August 2015 California Coastal Commission Sea Level Rise Guidance), and several state agencies have policies that guide their own activities in the face of sea level rise. The Ocean Protection Council, the California Coastal Commission, and the State Coastal Conservancy are granting funding support for vulnerability assessments, Local Coastal Program updates to incorporate consideration of sea level rise, and other activities targeted at developing climate readiness. As a result, a growing number of coastal communities now have access to high-resolution vulnerability information that can provide a strong foundation for their adaptation planning.

Among the most significant issues driving coastal management and policy in the face of sea level rise is the need to protect private property. Sea level rise and associated flooding will threaten nearly $100 billion worth of property along the California coast by 2100 (Heberger et al. 2009), and coastal landowners and planners will inevitably act to protect their assets from these losses. Landowners overwhelmingly default to standard risk-mitigation techniques to sea level rise-induced problems – specifically, coastal armoring solutions (seawalls, revetments, dikes, and levees). While armoring may be the right choice in some locations, it has well-documented adverse consequences, many of which are incompatible with maintaining a natural beach system that supports the local tourism economy and coastal ecosystem. On a natural shore, beach width is generally maintained as the shore erodes. However, when structures are built on an eroding shore, passive erosion occurs in which the beach in front of the structure becomes drowned over time as the adjacent shore continues to erode. This results in the structure projecting out into the ocean like a peninsula, which blocks lateral (alongshore) beach access and increases the exposure of the structure to wave impacts and overtopping. The before and after photographs of Stillwell Hall in Figure 3 illustrate this issue and the potential for beach recovery following the removal of such a structure. Nature-based strategies that enhance the natural flood mitigation benefits of coastal ecosystems could be an effective alternative, avoiding the adverse consequences of coastal armoring. However, few California jurisdictions have policies that prioritize nature-based strategies, and individual property owners rarely choose them.

Building upon an existing body of work

A substantial body of research and policy thought has already been dedicated to considering erosion mitigation alternatives for southern Monterey Bay; this study builds and improves on those previous projects.

Managers in the southern Monterey Bay region recognized that coastal assets were experiencing unusually high rates of erosion, and worked with partners at the Monterey Bay National Marine Sanctuary, the Association of Monterey Bay Area Governments, and the California Coastal Sediment Management Workgroup to form the Southern Monterey Bay Coastal Erosion Workgroup to address these issues collaboratively.

In 2008, PWA (now ESA (Environmental Science Associates)) completed a Coastal Regional Sediment Management Plan (CRSMP) for Southern Monterey Bay for the Association of Monterey Bay Area Governments (AMBAG) and the Coastal Sediment Management Workgroup. The CRSMP for southern Monterey Bay recommended additional research into beach restoration and protection strategies to decrease the severe erosion within the region.

In 2012, ESA PWA (now ESA (Environmental Science Associates)) conducted an “Evaluation of Erosion Mitigation Alternatives for Southern Monterey Bay” in response to recommendations in the CRSMP for the Monterey Bay Sanctuary Foundation and the Southern Monterey Bay Coastal Erosion Working Group. This study provided an assessment of various erosion mitigation measures to support development of a regional strategy to address coastal erosion hazards in southern Monterey Bay. Through a technical evaluation of various erosion mitigation measures, a cost benefit analysis was performed for a number of adaptation measures, and recommendations were made on subregional approaches for effectively addressing coastal erosion in the study area.

This study expands upon and extends this previous work in Monterey Bay in several ways:

1. we collected primary data on beach/coastal attendance and recreation;
2. we collected data on the ecological functions, goods and services of the beaches and coastal ecosystems in the study area;
3. our analysis of property boundary data – or parcel data – has been updated and fact-checked to ensure accuracy;
4. we examined the feasibility and cost of beach nourishment in great detail based on new data on sand availability and grain sizes; and
5. our analysis includes detailed consideration of sea level rise and coastal hazards, data which was not available for incorporation into previous studies.

The coastal hazards mapped in this study vary with time and include increased flooding and erosion due to sea level rise, in addition to accounting for beach width, backshore erosion, sand grain size, and sand volume changes. These improved mapping methods were applied to the study area in the Monterey Bay Sea Level Rise Vulnerability Study (MBSLR), which developed baseline coastal erosion and flooding hazard zones to understand the implications of sea level rise under a no-action scenario (ESA PWA 2014)[2]. MBSLR considers the hazards of wave run-up, overtopping, and coastal inundation that were not included in the Erosion Mitigation Alternatives study. Building on the MBSLR hazard modeling methods, and the introduction of an articulated beach width model, this analysis develops a suite of coastal hazards that considers future sea level rise and examines different adaptation strategies, enabling a more complete assessment of the costs and benefits associated with each strategy.

[2] MBSLR Baseline coastal hazard maps can be viewed by visiting The Nature Conservancy website: http://maps.coastalresilience.org/california/#, selecting the Monterey geography, and opening the Flood and Sea Level Rise layer menu on the left panel. The technical methods report (ESA PWA 2014) can be viewed through the "View Technical Report" link at the bottom of the Flood and Sea Level Rise layer menu.

Stakeholder Engagement for this analysis

Stakeholder engagement is a critical step in coastal adaptation planning. At the outset of this project, The Nature Conservancy (TNC) worked in coordination with a project team consisting of coastal ecologists, economists, engineers, and geomorphologists, as well as with key adaptation partners in the region to identify key stakeholders and decision-makers. Stakeholders were invited to a one-day workshop at the Elkhorn Slough National Estuarine Research Reserve on June 26, 2014. The primary objective of the workshop was to solicit stakeholder and local decision maker involvement in the identification of the sea level rise adaptation strategies to be considered in this analysis. Presentations from the project team on physical modeling and economic methodology prompted a lively and productive question and answer session with stakeholders; feedback from the discussion was used in refining the methodological approaches later used in the analysis. Workshop participants were then asked to note areas, assets, and issues of particular concern on large maps of the study area illustrating sea level rise and coastal hazard flooding projections for 2100. This information was collected and added to the Coastal Resilience Monterey web tool (http://maps.coastalresilience.org/california/#) within the Map Layers application. These priority assets were also taken into consideration in the economic analysis.

Based on the "Erosion Mitigation Alternatives for Southern Monterey Bay" study, which identified and ranked the most feasible management strategies for each stretch of shoreline, the study area was divided into four reaches (see Figure 1) based on similar geomorphological characteristics and with consideration of political boundaries. Workshop attendees separated into small groups, each focusing on one of the four shoreline reaches. Each group was given several strategies to consider with the goal of selecting three to five coastal climate adaptation strategies to be modeled and analyzed for each of the four reaches. To facilitate this discussion, the Project Team presented an overview of the most commonly considered adaptation strategies, explicitly weighing the documented advantages and disadvantages of each.

Several key stakeholders were unable to attend the workshop, so members of the Project Team (principally The Nature Conservancy's staff) met with these stakeholders in person throughout September and October 2014. With robust stakeholder input, the final suite of adaptation strategies was selected. In order to model the scenarios, we then detailed how each of the strategies would be applied, as realistically as possible based on historical management practices (see Table 1).

In autumn of 2015, the Project Team was invited to present preliminary results at a meeting of the Association of Monterey Bay Area Governments (AMBAG). On January 9, 2016, TNC and several members of the Project Team presented the results to the Technical Advisory Committee for the Coastal Hazards Vulnerability Assessment, currently being undertaken by Monterey and Santa Cruz Counties, which includes many of the original project stakeholders.

The southern Monterey Bay shore is on average the most erosive sandy shore in California (Hapke et al. 2006). Although only a very small proportion of the shore is armored at this time, there are several examples of passive erosion occurring, associated with the rip-rap seawall fronting Stillwell Hall in Fort Ord (since removed, see Figure 3) and the rip-rap at the end of Tioga Avenue in Sand City. In addition, shore access is currently blocked at high tide at the Monterey Beach Resort and the Ocean Harbor House condominiums seawalls during the winter when the beach is seasonally reduced. This situation is expected to worsen due to continued erosion, and increased erosion rates attributed to sea level rise. The existing seawalls will eventually project into the ocean as the sea level rises, subsuming beach habitat and blocking recreational access (Figure 3). This anticipated loss of the beach in southern Monterey Bay is a prime example of the need for better alternatives to traditional engineering structures that aim to preserve recreational and ecological resources, as well as protect upland property and infrastructure.

2003 2015

Figure 3: Stillwell Hall before and after removal of armoring and building in 2004
photo credit: Copyright © 2013 Kenneth & Gabrielle Adelman, California Coastal Records Project, www.californiacoastline.org

Modeling Shoreline Changes resulting from Adaptation Scenarios

As threats to coastal development have increased, so has the pressure to protect coastal property with various types of coastal armoring such as seawalls and revetments. In response to this, and as part of its revised management plan, the Monterey Bay National Marine Sanctuary (MBNMS) developed the Coastal Armoring Action Plan. The goal of this action plan is to minimize additional armoring in the coastal areas near the MBNMS through proactive regional planning, project tracking, and comprehensive permit analysis and compliance. The Coastal Armoring Action Plan recommends developing a more proactive and comprehensive regional approach that minimizes the negative impacts of coastal armoring on a sanctuary-wide basis (MBNMS 2008).

Our analysis supports that recommendation by applying improved methods to model the response of beach width, coastal erosion and storm event hazards through time under a range of sea level rise projections and various adaptation scenarios chosen with stakeholder input, as described above. A model that analyzes the coupled impact of sea level rise and coastal flooding hazards is essential in order to fully understand the potential range of future impacts, while the incorporation of beach width modeling improves our estimates of the recreational and ecological value lost or gained and the future implications of different adaptation strategies.

Coastal Hazards

Four separate hazard categories were analyzed: chronic erosion, chronic flooding, event wave impacts, and event flooding. Erosion was estimated in tandem with a beach width model that tracked erosion of the shoreline and backshore through time and adjusted erosion rates based on the existing beach buffer and actions of each adaptation scenario. These physical processes and the modeling approaches used are briefly discussed below, while more detailed methods can be found in Appendix A.

Chronic Erosion

Chronic erosion, or long-term erosion due to sea level rise (not taking into account erosion from a large storm), results in a loss of property and infrastructure seaward of the eroded dune location. We used baseline erosion results from the ESA PWA 2014 study as input into a two-line model that tracks movement of both the shoreline and backshore. The distance between these two reference features is the beach width. Erosion of the backshore is mapped in GIS as a buffer from the current backshore location, representing the future dune crest for the year mapped.

Chronic Flooding

Chronic flooding hazard zones are areas that will be regularly flooded (once per month, on average) by high tides under future sea level rise, not considering storm events, erosion, or river discharge. Two types of chronic flooding datasets were developed: extent of inundation and depth. The depth grids were used by the economists to determine the damage to properties from chronic flooding, using standard depth/damage curves from USACE. The elevation of inundation chosen for chronic flooding was Extreme Monthly High Water (EMHW), calculated by averaging the maximum monthly water level for every month recorded at the Monterey Bay tide gauge (EMHW = 2.0 meters (6.5 feet) NAVD88) over the most recent tidal epoch. Sea level rise projections were added to the EMHW for each sea level rise and planning horizon and mapped over the terrain. Chronic erosion areas have been erased from chronic flood zones so as not to double-count damages.

Event Wave Impacts

The event wave zone is where water could rush inland due to waves breaking at the coast, damaging structures, moving cars, etc. This zone takes into account both erosion and inland extent of wave run-up during a large coastal storm. In addition to chronic coastal erosion hazards, wave induced impacts of storm erosion and coastal flooding from a 100-year coastal storm wave event were mapped, using results from the Monterey Bay Sea Level Rise Vulnerability (MBSLR) study as a baseline. Reach-averaged storm erosion distances were calculated and then modified to reflect the impacts of the various adaptation strategies on the beach width zones. Throughout the analysis, beach widths varied based on the proposed adaptation management scenario; for example, some of the beach nourishment scenarios include beach widths that are narrower or wider than existing beach widths. Storm erosion impacts respond to the changes in beach widths, with the beach essentially reducing storm erosion of the backshore and dune. If the beach is wider than it was under existing conditions, the storm erosion distance is smaller and vice versa. Wave run-up distances were calculated for the various adaptation scenarios by modifying the run-up distance with beach width. Similar to storm erosion distance, the inland extent of run-up was reduced if the beach widened and increased if the beach narrowed. Detailed explanations of the event wave impact methods can be found in Appendix A.

Event Flooding

Similar to storm wave event impacts, flooding due to a 100-year coastal storm event was calculated and mapped for each adaptation scenario. The modeling results from MBSLR were used as the baseline, with wave overtopping and 100-year tidal inundation being the dominant flood types along the southern Monterey Bay coastline. Processes considered included storm surge, wave overtopping (waves running up and over the beach and flooding low-lying areas), extreme lagoon water levels in the Salinas River, and additional flooding caused by future rising sea level. The dominant hazard type changes with differences in shoreline morphology. Wave overtopping was used as the dominant type in places where low-lying areas are separated from the ocean by dunes, coastal armoring structures, or other obstructions. The 100-year tide water level (2.48 m NAVD88) was assumed to be the dominant flood type in predominantly open tidal systems (e.g., Elkhorn Slough) and was then raised by sea level for future planning horizons. More information on the modeling methods for event flooding impacts can be found in Appendix A.

Beach Width Zones

A quantitative model was developed to track shoreline location, backshore location and beach width through time in response to sea level rise and adaptation scenario. The beach width is the distance between the shoreline[3] and the backshore. A starting beach width was estimated for each reach by taking the average distance between the mean high water line[4] and the backshore location as observed in the 2009 - 2011 California Coastal Conservancy Coastal LiDAR Project Hydro-Flattened Bare Earth DEM (collected in spring 2010 in this area). Subsequent beach widths are calculated based on the relative movement of the shoreline and backshore. If the shoreline erodes more quickly than the backshore, then the beach narrows, and vice versa. Three components contribute to shoreline movement in this quantified conceptual model: landward movement due to sea level rise, shoreline erosion caused by other coastal processes (e.g., waves, wind, changes in sediment supply), and seaward movement of the shore due to sand placement activities. The components of backshore movement are similar except that the beach nourishment adjustment (which only changes the shoreline) is replaced with a placement loss distance (which only affects the backshore when armor is constructed).

Adaptation Scenarios & Assumptions

Two sea level rise scenarios, High and Medium, were examined for this study, as well as three planning horizons (2030, 2060, and 2100) consistent with MBSLR (ESA PWA 2014) and the recommendations provided to planners by the IPCC and NRC (IPCC 2013, NRC 2012).

Table 2: Sea Level Rise Projections

Year	Medium Sea Level Rise Projection	High Sea Level Rise Projection
2030	10 cm (4 in)	22 cm (8.8 in)
2060	33 cm (12.8 in)	72 cm (28.3 in)
2100	88 cm (34.5 in)	159 cm (62.6 in)

[3] Assumed to be located at Mean High Water (1.455 m NAVD88, from NOAA Monterey tide gage).

[4] The mean high water line was extracted from the 2009 - 2011 California Coastal Conservancy Coastal LiDAR Project Hydro-Flattened Bare Earth DEM.

Adaptation scenarios

Five management scenarios, as suggested and refined by the stakeholder participation process, were considered for southern Monterey Bay. Three to five of these scenarios were assessed for each of the four study reaches (Moss Landing, Marina, Sand City, and Del Monte; see Figure 1), as summarized in Table 3 below. A scenario may combine multiple management actions to create a "hybrid" approach. Each of the potential management actions and the associated model input parameters are described below. These descriptions focus on the physical implications of each management scenario, specifically the evolution of beach width and erosion of the backshore. A detailed explanation of the methods used to calculate the various hazards resulting from each scenario can be found in Appendix A.

Table 3: Description of adaptation management approaches by shoreline reach

Reach	Management Scenario	Scenario Description	Beach Model
Del Monte	Opportunistic (beach) Nourishment	A "small" local beach nourishment addressed in terms of incremental benefits and costs. (50,000 CY every 10 years)	Beach Nourishment (Set Schedule)
	Shoreline Armoring	Engineered coastal structure (revetment) constructed continuously along the back shore. This stops erosion of the back shore but allows the beach to narrow and the structure to be overtopped.	Hold the Line
	Managed retreat with Fee Simple Acquisition	Assumes that erosion is allowed to continue unhindered and that upland property is purchased at fair market value.	Allow Erosion
	Medium scale Nourishment as Needed with Groins	A medium scale nourishment project (400,000 CY as needed to maintain 25% wider beach). In addition, groins are also included to retain the nourished sand and extend the life of the nourishment project.	Beach Nourishment (As Needed) + Groins
	Elevating Structures	Assumes that erosion is allowed to continue unhindered and that new structures are built at higher elevations.	Allow Erosion
Sand City	Large scale Nourishment as Needed	A large scale nourishment project (2M CY as needed to maintain 25% wider beach)	Beach Nourishment (As Needed)
	Managed Retreat with Conservation Easements	Assumes that erosion is allowed to continue unhindered and that conservation easements are acquired at 70% Fair Market Value to allow erosion of upland property to continue.	Allow Erosion
	Shoreline Armoring	Engineered coastal structure (revetment) constructed continuously along the back shore. This stops erosion of the back shore but allows the beach to narrow and the structure to be overtopped. Include a depreciation factor based on a 30-year life.	Hold the Line
	Elevating Infrastructure	Specific to Hwy 1 requires elevating highway onto a column-supported causeway and allowing erosion to continue.	Allow Erosion

Reach	Management Scenario	Scenario Description	Beach Model
Marina	Managed Retreat with Rolling Easements	Allows erosion to continue using a rolling easement; (See Table 11 for more information)	Allow Erosion
	Managed Retreat with Fee Simple Acquisition	Allows erosion to continue with acquisition of upland properties at fair market value	Allow Erosion
	Shoreline Armoring	Engineered coastal structure (revetment) constructed continuously along the back shore. This stops erosion of the back shore but allows the beach to narrow and the structure to be overtopped. Include a depreciation factor based on a 30-year life.	Hold the Line
Moss Landing	Do nothing	Allows erosion to continue.	Allow Erosion
	Shoreline Armoring	Engineered coastal structure (revetment) constructed continuously along the back shore. This stops erosion of the back shore but allows the beach to narrow and the structure to be overtopped. Includes a depreciation factor based on a 30-year life. Also includes estimated costs of estuarine / harbor water level management (e.g. lock).	Hold the Line
	Managed Retreat with Conservation Easements	Assumes that erosion is allowed to continue unhindered and that conservation easements are acquired at fair market value to allow erosion of upland property to continue. Baseline with beach width modeling and easement costs.	Allow Erosion

Shoreline Armoring (at the backshore, aka "Hold the Line")

In this scenario, existing coastal protection infrastructure (e.g., seawalls, revetments) is maintained where it currently exists and constructed continuously across the reach where it does not yet exist; "holding the line" represents the current default coastal management approach. This scenario is modeled by assuming the backshore erosion rate is zero. A portion of the beach is converted to coastal armor, resulting in a placement loss (beach narrows initially due to the footprint of the structure). The structure is assumed to protect the area behind it from erosion hazards; however, with continued shoreline erosion and the additional impact of sea level rise, the beach in front of the structure narrows. The loss of the buffer that the beach provides to the backshore from wave action eventually leads to increased wave run-up and overtopping hazards behind the structures. The structural life of the revetment is assumed to be 30 years initially, but is reduced to 20 years once the backshore is exposed in the beach width model (no beach buffer with higher sea levels and more intense events result in higher wave loading and more rapid degradation of structures).

Allow Erosion

Under this management scenario, the shoreline and backshore are allowed to erode at a natural rate accelerated by sea level rise. This model was applied to scenarios of Managed Retreat, Fee Simple Acquisition, Conservation Easements, and Elevating Infrastructure, all of which allow erosion to continue. Since the dunes are permitted to erode, the beach erodes at a slower rate with backshore dunes than without them.

Beach Nourishment

Beach nourishment maintains beach widths for a longer time, preserving recreational, ecological, and buffer functions in the process. The following sections describe the three types of beach nourishment scenarios selected for the two southernmost reaches in this study:

1. Beach Nourishment as Needed (in Sand City)
2. Beach Nourishment as Needed with Groins (in Del Monte)
3. Scheduled Beach Nourishment (in Del Monte)

These reaches, Del Monte and Sand City, are lower in elevation, less exposed to waves, and more developed than the other two considered in this study (Marina and Moss Landing). In general, beach nourishment frequency was chosen to mitigate increasing erosion due to sea level rise but still allow the background erosion rate to continue. In general, beach nourishment results in lower backshore erosion rates and less wave impact because the wide beach acts as a buffer. The beach nourishment scenarios are generally modeled such that the backshore erosion by 2100 is equal to the backshore erosion that would have occurred by 2100 without sea level rise (simply from ongoing erosion). The only exception is the “scheduled beach nourishment” scenario, as described below.

We assumed that the supply of coarse beach-sized sand in southern Monterey Bay is finite; accordingly, some adjustments were made to the beach nourishment scenarios to reflect the fact that finer sand would need to be used for nourishment over time. Specifically, the use of finer sand results in: (1) increased erosion from sea level rise due to a flatter shoreface slope and (2) higher diffusion rate of placed sediment (and therefore an increase in background erosion rate). The increasing complexity of importing sand during the later time horizons caused the cost of beach nourishment used in the analysis to increase with time. See Appendix A for additional information on modeling beach nourishment.

Beach Nourishment as Needed (Sand City)

Beach nourishment (as needed) is implemented in the model by moving the shoreline seaward by the sand placement width of 100 feet, which was determined based on a placed volume of 2 million cubic yards along the Sand City reach. Beach nourishments are assumed to commence at the beginning of the model and are then repeated as necessary to maintain this beach width under long term sea level rise erosion. Beach nourishment modeling methods and notes describing selection of model parameters are presented in Appendix A.

Beach Nourishment as Needed with Groins (Del Monte)

The beach nourishment component of this management option is treated in the same manner as described in *Beach Nourishment as Needed*, above but with a sand placement volume of 400,000 cubic yards for the Del Monte reach. Groins are implemented in the model by adjusting the empirical relationship between erosion rate and beach width, historic erosion rate, and ambient beach width. Groins are able to retain sand and maintain a wider beach where wave conditions are ideal. The beach reaches a new, wider equilibrium. This is implemented in the conceptual model by increasing the “ambient beach width” in the empirical relationships used, and is further described in Appendix A. It is assumed that the groins would be reconstructed as part of each beach nourishment project.

Scheduled Beach Nourishment (Del Monte)

Beach nourishment with a set schedule is implemented in the model by specifying a beach nourishment width and schedule. Beach nourishments are triggered at the beginning of the model and then on the specified schedule (e.g., every 10 years). Because the intent of beach nourishment is to maintain beach width and slow backshore erosion, the backshore is still allowed to erode (but at a slower rate due to the wider beach). The volume of nourishment, 50,000 cubic yards, was selected to represent a hypothetical "opportunistic" sand nourishment, in which a small amount of sand becomes available. Therefore, unlike the other beach nourishment scenarios, the driving factor in this scenario is the nourishment schedule, not maintaining a designated beach width. Beach nourishment parameters and descriptions of how these parameters were selected can be found in Appendix A.[5]

Adaptation Scenario Engineering Cost Estimates

To enable analysis of the economic benefits of each shoreline adaptation scenario, we developed engineering cost estimates associated with the modeled coastal hazards for various management scenarios. Engineering cost estimates were prepared for:

- Unit costs associated with various shore protection measures and structural modification of roads and buildings;
- Replacement costs for Monterey Regional Water Pollution Control Agency (MRWPCA) sewer line and pump stations;
- Construction costs for each adaptation scenario for each study reach, as defined and previously modeled.

The cost estimates drew from multiple sources, for which ESA escalated the relevant costs to 2015 dollars using the published Engineering News Record cost index. Table 4 shows the escalation factors that were applied to costs for the different years of the source information.

Table 4: Cost escalation factors determined from Engineering News Record (ENR) cost index

Year	ENR Cost Index	Escalation Factor
1996	5620	1.78
2004	7115	1.40

5 These estimates do not include all possible costs, such as design, environmental review, permitting, construction administration, monitoring, property purchase and other costs. In particular, significant costs can be expected for sand mitigation fees for coastal armoring projects. Please note that in providing opinions of probable costs, we have no control over the actual costs at the time of construction. The actual cost of construction may be impacted by the availability of construction equipment and crews, and fluctuation of supply prices at the time the work is bid. Neither TNC nor its contractors make any warranty, expressed or implied, as to the accuracy of these estimated costs.

These estimates do not consider all possible benefits including indirect, consequential, and aesthetic benefits, and contributions to community health and well-being. Estimation of benefits is less certain than construction costs. Higher confidence is afforded recreational economics, while ecological values are inherently uncertain. Neither TNC nor its contractors make any warranty, expressed or implied, as to the accuracy of these estimates.

The information provided herein is intended to provide a standard basis for comparison among different coastal adaptation scenarios for the benefit of coastal zone management conceptual planning. The information provided herein is neither intended nor authorized for any other use and should not be used for any purpose without prior written approval of TNC.

Year	ENR Cost Index	Escalation Factor
2009	8570	1.17
2010	8799	1.14
2011	9070	1.10
2015 (Jan-Jul)	9993	1.00

Unit Costs

In a previous study funded by the Monterey Bay National Marine Sanctuary, PWA (now ESA) conducted a cost benefit analysis for the Southern Monterey Bay Technical Evaluation of Erosion Mitigation Alternatives Study (ESA PWA 2012). Most erosion mitigation measures that were considered previously are still applicable to this analysis; the selected measures are shown in Table 3. Some key assumptions not listed in Table 3 are:

- *Managed Retreat and Structural Adaptation* measures assume that erosion processes continue unimpeded.
- *Opportunistic (small) nourishment* – 75,000 CY placed every 5 years.
- *Shoreline armoring (building revetments)* – Includes placement losses which reduce beach width at time of construction. Includes active erosion effects which accelerate beach loss when beach width narrows and wave run-up frequently reaches structure.
- *(Scheduled) Large Beach Nourishment* – Two million cubic yards placed every 25 years.
- *Groins* –The effect of groins is modeled as a reduction in beach width loss, using the concept of sand diffusion. Groins are assumed to be rebuilt with each subsequent beach nourishment.

Prior analyses of erosion management options for the southern Monterey Bay region used constant erosion rates and considered erosion only. The new sea level rise hazard projections analyze how hazards vary with time and include increased flooding and erosion due to sea level rise, as well as account for beach width, backshore erosion, sand grain size and sand volume changes. Cost estimates for beach nourishment were also updated based on new data on sand availability and grain sizes.

The unit costs in 2015 dollars for shore protection and structural modification measures are shown in Table 5. A range of values was used to convey the sensitivity of the cost evaluation to construction costs for structural measures. We defined the High cost as 50% higher than the Low cost. With the exception of sand placements, unit costs in Table 5 include a 35% contingency.

After reviewing the large sand placement cost estimate from the 2008 Regional Sediment Management plan for the same region, and considering the approach of Moffatt & Nichol (2009) of dredging from the Monterey Canyon, we updated the cost of large sand placement from the previous study to reflect the higher cost, and more realistic methods, of Moffatt & Nichol (2009). These unit costs consider use of a hopper dredge and 8-mile barge to transport sand from the Elkhorn-Salinas delta to beaches south. The sand costs in Table 5 are for the 2010-2030 time horizons and are escalated in future horizons to reflect increasing cost of sand, as described in the Adaptation Scenario Engineering Cost Estimates section above. The High costs were used to develop the engineering cost estimates.

Table 5: Unit costs for shore protection and structural modification measures

Item	Cost	
	Low	High
Rock revetment	$17M / km	$20M / km
Groins (with sand placement)	$19M / km	$30M / km
Sand placement, large (about 2,000,000 CY)*	$10 / CY	$20 / CY
Sand placement, opportunistic (about 50,000 CY)	$6 / CY	$12 / CY
Structure elevation in wave zone	$230 / SF	
Structure elevation in flood zone	$140 / SF	
Elevation of roadway (bridge/trestle)	$570 / SF	
Reconstruction of secondary roadway (demo and rebuild)	$280 / LF	
Values include 35% contingency, except sand placements * Large sand placement unit cost determined from Moffatt & Nichol (2009); we assume it included an appropriate contingency.		

The estimated cost per linear foot of demolition and reconstruction of secondary roads is derived from RSMeans Heavy Construction Cost Data (RSMeans 2011). The values were escalated to 2015 using the Engineering News Record (ENR) cost index values in Table 4. The cost assumes a 24-foot wide road with curbs and gutters, removal of existing/damaged road, preparation of the subgrade, aggregate base layer, asphalt concrete road surface, asphalt emulsion layers, striping, and includes a 35% contingency. If a road is much wider or narrower than 24 feet, the modified cost should consider $12 per square foot.

Monterey Regional Water Pollution Control Agency Sewer Line and Pump Stations

As a part of the Erosion Mitigation Alternatives Analysis for the region (PWA 2004), the Monterey Regional Water Pollution Control Agency (MRWPCA) provided estimated replacement and failure costs for their sanitary sewer facilities along the shore. We used prior studies to identify when each component of the MRWPCA facilities would be impacted, triggering a cost. The selected threshold was a minimum protective summer/fall beach width of 20 meters (65 feet), in order to provide an adequate buffer for winter conditions and severe erosion due to storms. A single width was selected for simplicity although different widths could be selected for each facility based on type of damage (e.g., wave impact to a manhole or buoyant breakout of the pipeline due to reduced depth of cover) and location. We escalated the cost estimates for pipeline and pump station replacement to 2015 dollars using the ENR cost index; costs are presented below (Table 6).

Table 6: MRWPCA Sewer line and pump station damage and relocation cost estimates

	Feature	Length	Cost ($ M)
Interceptor Pipeline from South to North	Wharf II to Monterey Pump Station	~1 mile	$5.7-11.4M
	Monterey Pump Station to Tide Ave	~900 feet (private properties)	$1.1-2.3M
	Tide Ave (Ocean Harbor House) to Monterey Bay Beach Hotel	~3600 feet	$5.7M
	Monterey Bay Beach Hotel to Seaside Pump Station	~2900 feet	$4.5M
	To North, interceptor on seaward side of Highway 1	per mile	$5.7M
	Subtotal		$22.7-29.5M
Pump Stations	Monterey Pump Station	(estimate to relocate and rebuild)	$77.2M
	Reeside Pump Station	(estimate to relocate and rebuild)	$77.2M
	Seaside Pump Station	(estimate to relocate and rebuild)	$77.2M
	Subtotal		$231.6M
Failures	Minor – roughly 2 weeks to repair	fines per day	$3.4K
	Catastrophic - Double cost estimate for emergency repairs	(estimate to relocate and rebuild)*2	$154.4M

Impact costs for each scenario were computed based on when, and to what extent, mapped hazard zones overlapped facility locations. Two damage modes were applied (wave impacts and chronic erosion), each with a damage trigger defined by an offset distance from the backshore or shore line.

Adaptation Scenario Costs

Utilizing the unit costs from Table 5, escalated as described above and in Table 4, we developed cost estimates for the coastal engineering adaptation scenarios (revetments and sand placement with or without groins, NOT managed retreat) and utilized the results from the hazard mapping and beach width tracking analysis to determine revetment replacement timing.

The unit costs in Table 5 were used as current costs of structures, with the modifications described above to account for sand availability into the future. Several assumptions were made based on professional judgment, observations, and experiences in southern Monterey Bay and other places in California, as described below.

Revetments

Construction of revetments result in placement losses which reduce beach width at time of construction, and we adjusted the unit cost of these scenarios accordingly. Our cost estimates also include active erosion effects, which accelerate beach loss when beach width narrows and wave run up frequently reaches structures. Each reach length is used to calculate the cost of a new revetment at the backshore. There are a few segments of existing revetment (300-650 feet) that are not considered. The functional life of a revetment is assumed to be 30 years as long as there is a beach in front of the structure. Beach widths used to determine structure performance are in accordance with the previous beach width analysis and are dependent on the sea level rise scenario (High or Medium). If the beach disappears before 30 years have passed, the life of the structure is downgraded to 20 years. Long term erosion and sea level rise induced recession will induce failure more rapidly. After the beach width reaches zero, a 20-year functional lifespan is used. The repair cost after failure is assumed to equal the cost for construction.

The revetment adaptation alternative for the Moss Landing reach includes the construction of a protection system for Moss Landing Harbor. The system would include a lock at the harbor mouth, 6,000 feet of clay levees (10 feet high, 3:1 side slopes, and a 20-foot top width) on the west and east sides of the harbor extending to Sandholdt Road, and a hydraulic control structure at Sandholdt Road crossing. We provide an allowance for these components (not a thorough engineering estimate) in Table 7. The lock cost was taken from a previous economic analysis of nature-based adaptation alternatives for Ventura County (ENVIRON and ESA PWA 2015). Levee costs from that study were doubled due to land use, utilities and coastal access issues that will affect the construction, and increased to include a 35% contingency. The cost of a hydraulic control structure was chosen as an allowance, and is not a thorough engineering estimate. We assume that the lock and levee system is designed to accommodate the High sea level rise projection scenario with a 100-year lifespan. Annual operations and maintenance (O&M) costs could be considered equal to 1% of the cost of construction. These O&M costs are not included in the allowance in Table 7.

Table 7: Cost allocation for lock and levee system for Moss Landing Harbor

Feature	Cost
Tidal Barrier/Lock at Moss Landing Harbor	$200M
Levees along west and east sides of harbor (6000 FT total)	$15M
Hydraulic control structure at Sandholdt Road	$20M
Total Cost	$235M

Large scale beach nourishment

Beach nourishment follows the schedule resulting from an analysis of beach width (Appendix A). Prior reports have assumed that sand will be readily available from coarse sand deposits exposed on the seabed offshore of Sand City (PWA 2010, ESA PWA 2012). This assumption has resulted in relatively low construction cost estimates and a favorable assessment of beach nourishment feasibility. However, dredging of sand from the seabed in the Monterey Bay National Marine Sanctuary is presently not allowed. Recent research by the USGS has not found suitable sand deposits as previously thought in the Sand City vicinity. Also, several California projects have concluded that beach-sized sand is not readily available in some areas (Davis 2013, ESA 2014). In addition, ongoing coastal erosion is expected to increase the demand for sand for beach nourishment. Consequently, the TNC technical team has concluded that we should examine potential cost differences within the engineer's estimates of beach nourishment to account for sand scarcity and multiple source locations. The chosen approach is outlined below. The cost of sand was escalated over time in order to represent progressive scarcity for beach nourishment[6]. Our estimates, sources, and assumptions are as follows:

- **2010-2030 – The cost of $20 per cubic yard (CY) is assumed,** taken from Table 5 and described in the Unit Costs section. Assumes that the coarse sands on the seabed offshore of Sand City will be available. Assumes contingency is included.

- **2030-2060 – The cost of $26 per CY is assumed.** Assumes that sand will be dredged from the vicinity of the Elkhorn Slough mouth and Monterey Canyon at a higher cost

[6] We also considered recent sand grain size sampling and seafloor mapping data (see Appendix A). The sand grain size analysis across the surf zone (Chambers 2015) supports our characterization of the existing beach sands, and was generally consistent with prior work (PWA, 2008). Recent seafloor mapping by the USGS (2015) identified a thick sand deposit off the Salinas River mouth which could be a large source for beach nourishment. However, the USGS did not have sand grain size data and other data indicate that these sands may be finer than the relatively coarse beach sands of southern Monterey Bay (personal communication, Dr. Ed Thornton, June 2015). Use of the Salinas River delta sand would have a cost comparable to the Monterey Canyon source, and hence the distinction between these sites as sources for sand is apparently not substantive at the resolution of this study. Further, the feasibility of dredging sand from the Elkhorn / Canyon site has been analyzed and published, providing a reasonable basis for this study. The USGS mapping also indicated relatively thin sand deposits off of Sand City, thereby supporting our team's assumption of sand scarcity, and limiting the use of this source.

due to farther distances than offshore seabed deposits at Sand City. The cost is based on escalation of applied costs from the previous case study in Monterey Bay Canyon (Moffatt & Nichol, with Everts Coastal 2009), with additional barge-miles added to reach the southernmost reaches. Assumes contingency is included.

- **2060-2100 – The cost of $45 per CY is assumed.** Assumes that sand is obtained from inland sources such as the San Clemente Dam reservoir. Based on escalation of costs of dredging and bypassing of sediment behind Carmel Dam (Moffatt & Nichol 1996). Trucking and barging the sand in the Carmel study yielded similar unit costs. It is assumed that the Carmel Dam removal project is completed by 2060. Cost includes contingency from Moffat & Nichol (1996).

Groins + medium scale beach nourishment

The unit cost per kilometer of groins plus sand placement from Table 5 is assumed at 2010 costs, scaled to the full length of the Del Monte reach (1.7 km). Future beach nourishment follows the schedule determined in the previous beach width analysis. We assume that future beach nourishment would be carried out simultaneously with groin rebuilding (at the 2010 cost plus an adjustment for increased sand cost). The adjustments for future sand prices follow the incremental cost increases for large scale beach nourishment. For example: medium sand nourishment in 2050 costs an additional $6 per CY on top of the 2010 construction cost; medium sand nourishment in 2070 costs an additional $25 per CY.

Opportunistic beach nourishment

Opportunistic beach nourishment assumes the small-scale sand placement unit cost from Table 5 at 2010 rates of $12 per CY. These costs were verified as 'in the ballpark', but perhaps a bit low, based on the experience of Monterey Harbor dredging and beach placement (about $15 per CY, personal communication, Stephen Scheiblauer, Harbormaster, October 2015). Future beach nourishment follows the schedule determined in the beach width analysis (every 10 years). Future sand prices are increased according to the incremental cost increases for large scale beach nourishment, and are added to the initial unit cost from 2010. For example, opportunistic beach nourishment in 2050 costs $18 per CY; opportunistic beach nourishment in 2070 costs $37 per CY.

Adaptation scenario engineering cost tables

Utilizing the compiled engineering costs for various adaptation measures, separate cost schedules for each adaptation scenario were developed for the High and Medium sea level rise scenarios and are provided in Appendix A. Reach lengths of the four study areas that were used in the analyses are specified in the appendices.

Economic Analysis

The goal of the economic analysis portion of this study was to determine the costs and benefits of utilizing the adaptation strategies for each reach, considering both market and non-market goods and services. Market goods are valued by their price when sold. In the case of real estate, where sales are infrequent, we estimated the current market price based on comparable market values. Another novel consideration of our study is that we accounted for the fact that structures near the coast have a higher replacement cost per square foot than inland structures. Infrastructure, such as roads and wastewater pumps, was valued at replacement cost (see discussion below).

In addition to market goods, the coast also provides substantial non-market goods and services. For example, southern Monterey Bay's beaches provide recreational value for hundreds of thousands of visitors per year. Beaches also provide significant ecological functions, goods and services.

Methods

Economic Value of Beach Recreational Resources

Although beach spending is a useful metric, economists measure the non-market value of beach recreation by beach-goers' willingness to pay to recreate at a beach. Our estimates for the economic value of beach recreation are based on attendance estimates and an economic valuation model developed by Dr. Philip King for the State of California and the U.S. Army Corps of engineers, the California Sediment Benefits Analysis Tool (CSBAT), a benefits transfer model. The CSBAT model allows estimation of the change in recreational value as beach width decreases (e.g., due to erosion) or increases (e.g., due to nourishment). For a fuller discussion, see King and Symes (2004). The model was calibrated for beach width using survey data collected for this study (discussed below).

Recreation

The four coastal reaches examined in this study are largely comprised of sandy beaches that provide recreational opportunities for visitors. State beaches are required by law to estimate attendance. However, King and McGregor (2012) found that the methods used to estimate beach attendance vary greatly and the accuracy of "official" beach attendance estimates is suspect, typically overestimating actual attendance by up to an order of magnitude.

While there have been attempts to collect robust data on beach attendance in California, most of these efforts have been focused on the Southern California region where beach tourism plays a larger role in the economies of coastal communities. To address the limitations of existing attendance data, our analysis included the following for each reach during both high season (defined as June, July, and August) and low season (other months):

(1) Periodic counts of recreational activity estimating the number of people participating in water, beach and bluff activities at discrete times and days, and
(2) Intercept surveys designed to estimate the spending, beach width preferences, and demographic characteristics of beach visitors.

We used these user count and survey data and applied estimates of recreational value per visitor per day from other studies (an economic metric known as "benefits transfer").

Coastal User Periodic Counts

We developed coastal user periodic counts to collect data about common recreational activities at southern Monterey Bay beaches and other coastal recreational sites. We recorded the date/time, temperature, wind, cloud cover, and tide. Recreational activities were classified into three main categories: on-shore activities (walking; picnicking; fishing; etc.); off-shore activities (swimming/wading; surfing; kayaking; etc.); and bluff activities (walking/running; biking; marine/other life observation; etc.). Counts were conducted between June and August 2014 (high season) and between February and April 2015 (low season).

Intercept Survey

Randomly-selected beach visitors were asked to fill out a four-page intercept survey (see Appendix B) to gather information about beach activities and demographic characteristics. Respondents were given a choice between filling out the survey themselves (which most did) or having the surveyor read the survey and fill it out. Our past experience indicates that this method yields a high rate of response (80-90%) as compared to surveys where respondents are asked to mail back their responses (33-50%). Since any sampling strategy can have a potential selection bias (e.g., perhaps the 33-50% of respondents mailing back surveys were more affluent or more likely to come from out of town) a high response rate is preferable.

The intercept survey included questions about group size, origin of the trip, mode of transportation, etc. For overnight visitors, the survey inquired about the length of stay and type of lodging. In order to estimate attendance, the survey also enquired about the respondents' arrival and expected departures that day.

Also included in this section were questions about respondent's perception of different beach armoring alternatives and their effects on the quality of beach visitor's experience. The next two sections asked respondents about trip expenditures, and perceptions regarding the potential impacts of reduction/expansion of beach width on willingness to visit the beach.

Finally, the last section asked standard demographic information (age, gender, place of residence, race, education, employment status, household size and household income).

Summary Statistics

Table 8 below summarizes the key findings of the survey, which are consistent with other, similar surveys conducted in California (e.g., see King and Symes 2004). In particular, just under 40% of visitors were from Monterey County, and roughly half (51%) were on overnight trips. The typical party size was 3.5 and close to 80% of visitors arrived by car. Overnight visitors typically spent just under $50 per person per day while day-trippers spent $12 per person per day. The complete results of the survey are presented in Appendix B.

Table 8: Selected Summary Statistics from Survey of Beach Visitors

Item	Survey Estimates
Percentage of visitors from Monterey County	38.7%
Percentage of visitors on overnight trips	51%
Average party size	3.5
Percentage arriving by car	78.4%
Average expenditures per visitor – overnight	$48.66
Average expenditures per visitor – day tripper	$12.32

We used both count and survey data to estimate yearly attendance and spending at the Del Monte, Sand City and Marina reaches. Attendance estimates for Moss Landing are from State Parks-collected data. Given a distribution of arrival and departure times, we estimated the number of people on a beach for a given day based on a specific periodic count. Since the length of stay also depends upon arrival time, the "turnover factor" varies with count time and ranged from 1.75 (2-3 pm) to 5.1 (8-10am). Table 9 below summarizes our aggregate estimates for each reach.

Table 9: Estimated Yearly Attendance and Spending

Reach	Attendance	Annual Spending
Del Monte	88,000	$2,710,000
Sand City	90,000	$2,770,000
Marina	50,000	$1,540,000
Moss Landing	197,000	$6,060,000

Economic Value of Shoreline Ecological Resources

Beach and Coastal Ecosystems

Although California's beaches are often primarily considered for their recreational and aesthetic value, they also provide significant ecosystem services and are critical habitats for many plants and animals (Schlacher et al. 2007, 2014). The beaches and associated dunes of Monterey County provide habitat for a diversity of plants and animals including several insect, reptile, and plant species protected under the Endangered Species Act. Monterey beaches also provide grunion spawning habitat and critical nesting habitat for the federally-threatened Western snowy plover. Monterey beaches and dunes have been found to be critically important habitats for migratory birds along the Pacific flyway, providing expansive and productive feeding and resting grounds (Neuman et al. 2008). Beaches and dunes also provide considerable ecosystem services or benefits to humans in four main categories: i) provisioning of products used directly by people, ii) regulating natural functions and processes such as erosion, storm damage, water filtration and carbon sequestration, iii) supporting other services, and iv) cultural or aesthetic value. Consequently, preserving healthy beaches is critical to maintaining the habitat value and ecosystem services they provide.

Evaluating the ecological condition of beaches, however, is challenging (Schlacher et al. 2014). Collecting and evaluating the necessary data to evaluate the ecological condition of beaches can be incredibly time consuming and expensive. However, thoughtful consideration of metrics that show ecological condition, and their appropriate evaluation, can provide empirical evidence of ecological condition (Schlacher et al. 2014). Ideally, the data needed to inform these metrics will be publically available, spatially explicit, and locally applicable. A further challenge is placing a dollar value on the ecological functions that beaches provide.

We used a two-step approach for calculating a dollar value associated with the ecological condition of southern Monterey Bay beaches. First, we applied a replacement cost analysis based on reported costs of nearby coastal restoration. Second, we developed a relative ranking of ecological value for each beach within the study area. This ecological ranking was scored for present conditions and then calculated for resulting future ecological conditions arising from each adaptation strategy.

Table 10: Examples of costs for restoration of beach ecosystems in California[7]

Beach	Linear Feet	Area (acres)	Cost ($2015)	Cost Linear/Ft	Cost Square/Ft	Project Elements
Pacifica State Beach	2000	4	$6,960,000	$3480	$40	Parking lot, Revetment removed; Nourishment; Dune restoration
Surfer's Point	1100	2.1	$4,670,000	$4245	$50	Removal of paving; Beach/dune restoration; New road & parking lot; New storm drains
Ocean Beach	4000	13.5	$200,000,000	$50,000	$340	Removal of fill, revetment roadway, parking Native vegetation; Construction of public facilities farther inland
Goleta Beach	700	1	$3,650,000	$5214	$84	Protect of sewer outfall; Removal of parking, Revetment; Relocation of utilities, bike path
Average	**1950**	**4.03**	**$53,820,000**	**$15,735**	**129**	
Average w/o Ocean Beach	**1267**	**2.37**	**$5,093,333**	**$4,313**	**58**	

[7] Source: Memo from ESA on Beach Restoration costs. See Appendix A. Note that costs for acquisition or permission, easements, permitting, planning, monitoring etc., are not included in these estimates

Replacement Cost Analysis

To inform the value of beaches' relative ecological condition we used costs from recent proposed or implemented beach restoration projects (provided by Environmental Science Associates (ESA), see Appendix A). Table 10 above summarizes these costs and provides uniform metrics that could be applied: cost per linear foot and cost per square foot. For this project, we decided to use cost per square foot as beach ecological condition varies by, and is therefore better assessed by, area rather than length. Since beach widths vary over time due to erosion, sea level rise, and various policies such as nourishment and coastal armoring, our approach can account for these impacts on beach ecosystems.

Ecological Assessment

To assess the ecological score – or relative ecological health and quality – of southern Monterey Bay beaches, we divided the study area into $1km^2$ blocks, providing replication within study reaches (See Figure 4 below). Each block was centered on the shoreline to capture ecological functions and processes from both the terrestrial and marine realms. We then used best available geospatial data to inform the ecological value, or detraction from ecological value, resulting from human impacts.

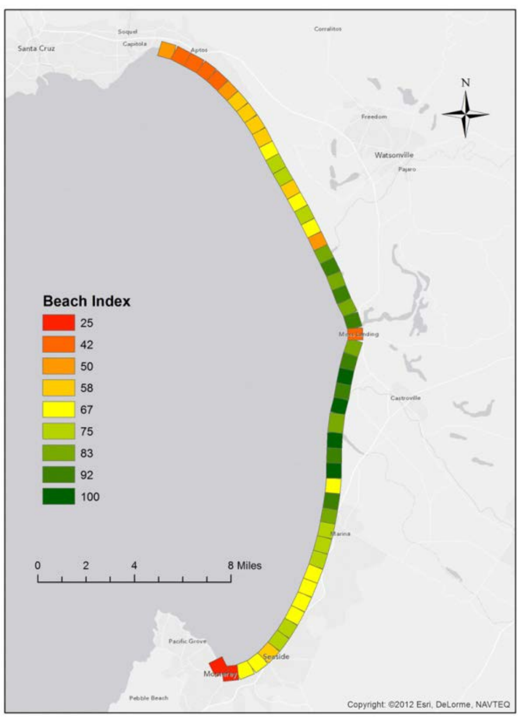


Figure 4: Beach ecological index evaluation

Beach ecological condition was scored according to three attributes: 1) Physical Condition, 2) Biotic Condition, and 3) Human Impact Condition, each measured using specific metrics described below. We sought the strongest metrics (Schlacher et al. 2014) using the highest quality empirical data from Monterey Beaches to score the Biotic Condition attribute for project beaches. Data for each metric were classified into quartile scores using Natural Breaks (the Jenks optimization method) in ArcGIS. Thus each metric was equally comparable, equally weighted, and provided a relative ranking of beach block from best attainable to worst observed within the study area given current conditions.

Physical Condition

To score beaches for the Physical Condition attribute we combined quartile scores for four metrics: long-term erosion rates, area of sandy beach, area of unvegetated dunes, and area of vegetated dunes. We used long-term erosion from 14,562 transects used to calculate long-term rates between the 1800s and 1998/2001 (Hapke et al. 2006) as a good indicator of whether project beaches were growing or diminishing through time. We used Calveg data (U.S. Forest Service) to quantify the area of sandy beach, area of unvegetated dunes, and area of vegetated dunes.

Biotic Condition

We sought metrics on biotic condition that were readily available, able to be entered as geodata, and recognized as strong indicators of ecological function. We chose three of the four types of broadly applicable metrics discussed by Schlacher et al. (2014): 1) abundance and diversity of birds, 2) breeding performance of obligate beach species, and 3) distribution and population parameters of vertebrates (primarily birds and turtles) (the fourth metric discussed in that review, population and assemblage measures of abundance/cover/biomass for plants and animals, was already included in our analysis as part of the calculation of the Physical Condition attribute). Elkhorn slough and the beaches of Monterey are recognized as important to a diversity of birds (Neuman et al. 2008) with high abundances relative to other parts of California (Neuman pers comm). Further, Point Blue has excellent quality data of the breeding performance of Western snowy plover, an obligate beach species listed as threatened under the Endangered Species Act (USFWS 2007). We used data from Neuman et al.'s (2008) rigorous study that surveyed shorebirds simultaneously among all forty-five kilometers of Monterey's beaches each spring low and high tide for an entire season. Our first Biotic Condition metric was total mean shorebird abundance for each $1km^2$ beach segment (Neuman et al. 2008). Our second metric characterized the mean total number of shorebird species for each beach segment (Neuman et al. 2008). Our third metric ranked the density of snowy plover nests within each beach segment (data courtesy of Point Blue).

Human Impact Condition

For our Human Impact Condition attribute we chose two clear measures of human degradation already available in GIS format: shoreline armoring and area of developed land. We used measures of shoreline armoring (NOAA Environmental Sensitivity Index Maps (ESI)), a metric shown to degrade resilience and ecological function of beaches (Dugan et al. 2006, Defeo et al. 2009) as our first metric ranking Human Impact Condition. For our second metric of Human Impact Condition we ranked the area of developed land using Calveg data (U.S. Forest Service), a metric commonly used to measure degree of human degradation to landscapes (Booth and Jackson, 1997; Schueler et al., 2009), other coastal habitats (Heady et al. 2015), and beaches (Dugan et al. 2008).

We summed and standardized metric scores as quartiles of 25, 50, 75, and 100 within each attribute. Thus, each 1km^2 block received a relative ranking for each of the four attributes. Attribute scores were averaged to produce a continuous index of ecological condition, referred to as the Beach Ecological Index Score, ranging from 25 (the worst attainable) to 100 (the best attainable) for each 1km^2 block:

Beach Ecological Index Score =
(Physical Condition + Biotic Condition + Human Impact Condition) / 3.

The Beach Ecological Index Score provides a relative ranking of each 1km^2 block within the project area. This relative ranking provides a baseline of current conditions from which to assess any changes associated with different adaptation strategies.

In order to estimate ecological condition associated with future scenarios we made several adjustments to our methodology. For the Physical Condition attribute, we applied ESA's modeled beach profiles for each adaptation scenario adjusting the area of sandy beach and the area of sand dunes metrics. We also removed the long-term erosion metric, as this was already incorporated into the future beach profiles. There is no way of predicting future biotic response to modeled physical conditions resulting from each adaptation strategy. However, examining our baseline data, we found a very strong correlation (80%) between the Biotic Condition attribute and the Physical Condition attribute. Therefore, we applied a linear regression model to generate a proxy for the Biotic Condition attribute scores given future Physical Condition attribute scores for each adaptation strategy for each time horizon and sea level curve (Appendix B). We did not make any changes to the Human Impact Condition attribute, and assume no changes to the amount of development within 500 meters of today's shoreline. This is likely an unrealistic assumption, but the estimation of future development trends and demographic patterns is beyond the scope of this project.

Beach nourishment degrades the ecological condition of beaches (Defeo et al. 2009, Schlacher et al. 2012, Peterson et al. 2014). Placing large amounts of sand on beaches can impact important nesting habitat as well as lead to complete mortality of the invertebrate community, thereby disrupting important prey sources for shore birds, fish, and crabs (Peterson and Bishop 2005, Schlacher et al. 2012). The impacts depend upon the method and amount of sand placement; recovery times can range from within one year to over four years (Schlacher et al. 2012, Peterson et al. 2014). To model the impacts of nourishment we reduced the biotic condition attribute score to 25 for large nourishment projects with a 10% recovery of score per year; for small nourishments we reduced the biotic condition attribute score to half of the value prior to nourishment and used a 15% recovery rate per year.

Monetizing Beach Ecological Value

There is no standard offset ratio for beach mitigation, however there is a large literature on wetlands mitigation offsets. The general consensus in the literature (e.g., see Zedler 1991, Castelle 1992, Moilanen et al. 2009) is that the offset ratio should be higher than one. The State of Washington, which has adopted a no-net-loss of ecological services policy for coastal ecosystems, uses wetlands mitigation ratios greater than 1:1 (Castelle 1992). Moilanen et al. (2009) conclude that the offset ratio may need to be much higher, possibly several hundred to one. Given the variability, we applied a 3:1 ratio; however, we also conducted a sensitivity analysis using a variety of ratios, including a ratio less than 1:1.

To monetize beach ecological value we combined Beach Ecological Index Scores with our beach restoration cost data. We assumed a 3:1 replacement cost for a beach with a "perfect" beach ecological index score of 100 and we scaled beaches with lower scores proportionately. For example, if a beach has a score of 100, the replacement cost would be:

Beach Ecological Value
= Beach Offset Ratio * Beach Replacement Cost *Beach Ecological Index Score/100
= 3 * $4313 * Beach Ecological Index Score/100
= $12,939 * Beach Ecological Index Score/100

So, for example, a beach with a score of 75 would be worth 75% of $12,939 or $9704.25 per linear foot. Please note that we used replacement cost per linear foot rather than by area since the Beach Ecological Index Score already incorporates the ecological value of increased beach width.

Economic Value of Upland Resources

In order to define an appropriate baseline to which costs and benefits could be compared, we used a number of public and commercial regional data sets. First, the Monterey County Assessor's parcel database represents the most useful, detailed inventory of property (i.e., land and buildings) in the area. However, public infrastructure such as roads and utilities are not included in the County Assessor's database. To fill this gap, we used data from local agencies that administer these assets. We used GIS to evaluate the exposure of these assets to the hazards described above, under current and future conditions, and under each adaptation scenario. These GIS analyses were used to develop an asset exposure inventory to support evaluation of economic damages.

The asset exposure inventory contains attributes (e.g., land use, land size, building size, land value, building value) of assets at risk of current and future damages. In some cases there are monetary values associated with these assets, and in other cases there are not. Even when there is a monetary value assigned to an asset, it may not be the appropriate value from which to measure economic damage. For example, when analyzing flooding damages to residential property, the structure - not the land - is at risk. Further, the structure value embedded in the County Assessor's data reflects the appraised value of the structure at the date of purchase with 2% annual increases (in most cases) to that assessed value (Prop 13). Because flooding will damage a property but in most cases not make it permanently uninhabitable, the appropriate economic unit of measurement is the replacement or reconstruction cost of the damaged structure, not the assessed value. For the same residential property that is at risk to erosion, there is no opportunity for replacing the structure or the land. In this case the market value of the structure and the land would be the appropriate economic unit of analysis.

Another important consideration in measuring damages to assets at risk is to define the thresholds at which damages are triggered by high tide, flooding and erosion. Just because an asset intersects with a hazard zone does not necessarily mean that economic damages will occur. Consider again the example of residential property that is subject to erosion. Erosion may only expose a small fraction of the property and not infringe on the footprint of the structure. In this scenario, only a small amount of the land is subject to damage, thereby leaving intact a majority of the land's utility and, by extension, the value of the property. On the other hand, if a majority of the property is exposed to erosion it would be reasonable to assume that a significant portion of the property value is compromised. Damage functions to account for these dynamics were established with consideration of the physical extent of the exposure and its potential effect on the economic use of the asset. These damage functions draw from past studies in the region (MBSLR, ESA 2012) and elsewhere in the state.

Property Analysis

Coastal Flooding Damages from Event Storms and Waves

Economic damages from storm events were estimated using US Army Corps of Engineers (USACE) depth-damage curves. The curves used in this study (USACE 2003a, USACE 2003b, GEC 2006) account for various types of flooding events (e.g., short duration, long duration, freshwater, saltwater) and structure types (e.g., residential, commercial, governmental). The curves were linked to structure values that were estimated with cost per square foot replacement values (RSMeans 2015) that most closely matched the type of building documented in the Monterey County Assessor parcel database.

Chronic Flood and Chronic Erosion Damages

Economic damages from coastal erosion were estimated by relating the landward extent of erosion to the market value of the land and/or structure at each exposed parcel. There are no widely used damage curves for assessing coastal erosion losses. Prior studies used simple rules of thumb that attempt to address the way in which the current land use may be compromised. For instance, if half of a residential property is subject to erosion, it is likely that the home would no longer be inhabitable and the potential use of both the structure and land for residential purposes would be lost. This rationale was used to develop damage functions for this study that were then applied to the market value of at risk property.

To identify the market value of land and structures at risk to erosion, efforts were taken to adjust valuations from the Assessor database so they reflect market values. In California, county assessors identify a property owner's tax burden by totaling the land and improvement (generally structure) value. Because of Proposition 13 (CABOE 1978), a property's land and structures are only re-assessed at the current market rate when they change ownership through sale, except when improvements are made to the property. Without incurring a change of ownership, the assessor's recorded value can only be increased up to two percent annually. This can lead to significant under-estimation in actual market value.

Further, the market values of properties in certain communities have increased at a much higher rate than other communities because of factors such as development and changes in employment sectors. A housing price index was used to adjust the assessor valuations of residential property to reflect current market rates. A consumer price index was used in a similar fashion for all other types of properties (e.g., commercial, industrial).

A number of non-taxable public properties are listed in the Assessor database as having both land and improvement value at $0. A review of these public records revealed that they were in many cases undeveloped, open-space parcels. It was assumed that these public parcels are likely constrained in their opportunity for development; however this assumption does not mean this land holds no economic value. Scenic and conservation easements recorded in the Assessor database were determined to be the closest proxy for an undeveloped, open space parcel. The land values of these property interests were analyzed; we contacted local organizations that have purchased these types of property to determine a conservative value per square foot that could be applied to these non-taxable public parcels. It was assumed that these parcels will remain undeveloped, though it is possible that some of this land could be sold on the open market for a value greatly exceeding the value we used for this study. For public non-taxable parcels where no information was available to determine the fair market value of land, a conservative proxy value was determined of $0.30 per square foot by analyzing sale price information from scenic and open space easements in Monterey County as well as land use purchases from the Elkhorn Slough Foundation.

Infrastructure

The two most important types of infrastructure examined in this project are roads and water treatment equipment. We assumed that all roads/infrastructure would need to be replaced when threatened by erosion. We determined the timeline and "trigger points" where replacement would occur. We assumed that the trigger point occurred when any part of the infrastructure (e.g., a road) is impacted by erosion. Our analysis does not include the additional costs of finding a new site for rebuilding. We assumed that major roads (in particular Hwy 1) would need to be elevated to avoid flood damages that are exacerbated by sea level rise. For minor roads, we used simple replacement cost. Details of the metrics used and assumptions made are contained in Appendix B.

Costs of Adaptation Alternatives

We estimated the costs of a range of risk-reducing land use and structural adaptation alternatives. The land use alternatives require the purchase of property or a right to that property at full and partial market value, respectively, while we estimated structural adaptation costs to be the cost of constructing and maintaining the structure. Tables 11 and 12 below summarize the assumptions used for the land-use alternatives.

Land Use Adaptation Costs

The Nature Conservancy (TNC) personnel from the West Coast, the Atlantic Coast and the Gulf Coast were contacted to help identify the costs of fee simple and conservation easement transactions. These types of transactions were focused on private property within the study area and include upfront purchase of the property as well as additional annual legal and stewardship fees.

Fee simple transactions were estimated at the fair market value or the closest proxy when direct market values were not applicable or data were lacking to infer a direct market value. TNC staff indicated that, without additional information on the terms of a conservation easement (which was outside the scope of this analysis and challenging to infer with Assessor Roll Call data), 70 percent of the market value of a parcel is a fair rule of thumb to apply. They did note that this would change if other rights are bundled with the parcel, such as permissible use of agriculture. We applied this rule of 70 percent of market value for the conservation easement scenario.

TNC staff also provided the following **annual** costs **per parcel** that we incorporated in the analyses:

- *Property insurance (fee simple and conservation easements):* 0.0003 percent of the purchase price of the parcel.
- *Monitoring (fee simple and conservation easements):* $78 per parcel in personnel operations, supervisor support and travel, occupancy, supplies and materials, in conformity with accreditation with the Land Trust Alliance (LTA) that requires that each easement be monitored annually.
- *Taxes (fee simple only):* $100 per parcel; this includes only special assessment fees.

It is also important to note that the above costs do not account for restoration and long-term ecological maintenance, taxes, or welfare exemptions that could produce income and cover some of the above costs, and any additional infrastructure maintenance.

In the case of rolling easements where structures on public or private properties would need to be removed, a rate of $10 per square foot was applied based on conversations with engineering subject matter experts. More information can be found in Table 11: Methodology for calculating upland land use adaptation alternative costs.

Structural Adaptation Costs

ESA provided structural adaptation costs for elevating structures and infrastructure which can be found in Appendix A.

Table 11: Methodology for calculating upland land use adaptation alternative costs

Alternative to Chronic Erosion	Definition	Damage Function	Economic Assumptions	Relevant Reaches
Do Nothing (Hold the Line)	Purchase of property at market value or closest proxy	If less than 50% of property is within hazard zone then 50% of property value is lost; Purchase of entire property is triggered if greater than 50% of parcel falls within hazard zone.	Loss of market value or closest equivalent for the provided land use as detailed in the Assessor roll call. For public non-taxable parcels scenic price per square foot values are applied based on scenic easements as a proxy.	Moss Landing
Fee simple	Purchase of vacant or developed property	Purchase of entire property is triggered if greater than 50% of parcel falls within hazard zone.	Purchase of private property at fair market value or closest proxy as determined in the Baseline scenario. Includes annual fees for insurance, monitoring, and taxes.	Del Monte Marina
Conservation easements	Assumes that there would be some public cost to secure an easement on private property	Purchase of entire property is triggered if greater than 50% of parcel falls within hazard zone.	Purchase of private property at 70% of the market value or closest proxy as determined in the Baseline scenario. Includes annual fees for insurance and monitoring.	Sand City Moss Landing

Alternative to Chronic Erosion	Definition	Damage Function	Economic Assumptions	Relevant Reaches
Rolling easements	As the coast retreats the easement line migrates along with it, inland on a parcel, then any development is removed and becomes part of that easement.	Structure demolition and removal cost is triggered if greater than 50% of parcel falls within hazard zone.	Cost to remove private or public structure based on price per square foot factor.	Marina
Elevating structures	Raising structures to elevate them above coastal hazard zones.	Install new foundations to public and private structures if greater than 50% of parcel falls within hazard zone.	Cost to install new foundations based on price per square foot factor.	Del Monte
Elevating infrastructure	Specific to Hwy 1. Modification of Hwy by installation of column foundation.	Installed in time to avoid intersection of backshore hazard zone with Hwy.	Cost to install new foundations based on price per linear foot factor.	Sand City

Table 12: Abbreviated methodology for calculating upland economic damages

Hazard	Damage Function	Economic Methodology by Property Type
Chronic erosion area	If less than 50% of property is within hazard zone then 50% of property value is lost; If greater than 50 % of property is within hazard zone then 100% of property value is lost.*	▪ *Residential:* Adjust assessor land and improvement value with home price index. ▪ *Commercial, Industrial, Miscellaneous:* Adjust assessor value with consumer price index. ▪ *Public/Institutional Taxable:* Adjust assessor value with consumer price index. ▪ *Public/Institutional Non-Taxable*:* Apply price per square foot values derived from scenic easement transactions in Monterey County to percent of parcel in hazard zone.
Chronic flood area	If less than 50% of property is within hazard zone then 50% of property value is lost; If greater than 50% of property is within hazard zone then 100% of property value is lost.	▪ *Residential:* Adjust assessor land and improvement value with home price index. ▪ *Commercial, Industrial, Miscellaneous:* Adjust assessor value with consumer price index. ▪ *Public Taxable:* Adjust assessor value with consumer price index. ▪ *Public Non-Taxable:* Apply price per square foot values derived from scenic easement transactions in Monterey County to percent of parcel in hazard zone.
Event flood hazard area	Depth of water at center of parcel related to USACE structure and content depth damage curves.	▪ *Residential with Information on Building Size:* Apply RS Means cost per square foot values to structure characteristics. ▪ *Residential with no Information on Building Size:* Adjust assessor structure value with home price index. ▪ *Commercial, Industrial, Miscellaneous:* Adjust assessor value of structure with consumer price index. ▪ *Public Taxable with Structures:* Adjust assessor value with consumer price index
Event wave flood hazard area	If less than 50% of property is within hazard zone then 50% of property value is lost; If greater than 50 % of property is within hazard zone then 100% of property value is lost.*	▪ *Residential:* Adjust assessor land and improvement value with home price index. ▪ *Commercial, Industrial, Miscellaneous:* Adjust assessor value with consumer price index. ▪ *Public/Institutional Taxable:* Adjust assessor value with consumer price index. ▪ *Public/Institutional Non-Taxable*:* Apply price per square foot values derived from scenic easement transactions in Monterey County to percent of parcel in hazard zone. ▪ Additional damage factor applied to parcels at risk, 50% greater than event flood up to but not exceeding total structure cost. ▪ Additional cost assigned to elevate structures.

Other Economic Considerations

Future Demand for Beach Recreation

We have generally assumed that the real costs and benefits of various adaptation strategies are constant; in particular, once corrected for inflation, the prices/costs of most property and engineering solutions will stay constant. However, for beach recreation, this assumption is quite limiting since existing demographic projections by the State of California indicate that both the state and county will experience population growth. In addition, state/county forecasts indicate that real per capita income will grow. Our knowledge of future trends in the demand for beaches or the future willingness to pay for beaches is limited; we assumed that attendance increases with population growth and that demand for beach recreation in southern Monterey Bay has an income elasticity of one -- that is, if a household's income increases by 5%, its willingness to pay increases by 5%. We believe these assumptions are reasonable.

Population and Income Projections

The State of California's Department of Finance's (DOF) Demographic division compiles projections for future population growth in the state by county. Table 13 below presents the DOF projections. For this study we assumed that attendance at coastal recreational sites (primarily beaches) will grow at the same rate as an average of the county and state growth rates.

Table 13: Population forecast 2010-2100

Year	California Population	California Population: % Change from Decade Prior	Monterey County Population	Monterey County Population: % Change from Decade Prior
2010	37,341,978	-	416,141	-
2020	40,619,346	8%	446,258	7%
2030	44,085,600	8%	476,874	6%
2040	47,233,240	7%	500,194	5%
2050	49,779,362	5%	520,362	4%
2060	51,663,771	4%	533,575	2%
2070*	54,047,807	4%	567,200	6%
2080*	56,999,104	5%	591,244	4%
2090*	59,950,402	5%	615,288	4%
2100*	62,901,700	5%	639,332	4%

Data Source: California Department of Finance, Linear Trend Estimate (2014)*

State and county level real per capita income forecasts from 2010 to 2040 from the California Department of Transportation were extrapolated to 2100. As with population, we assumed an average of the county and statewide projections.

Discount Rate

To account for the discount rate phenomenon (i.e., the fact that a dollar received today is considered more valuable than a dollar received in the future, because a dollar received today could be invested to produce additional wealth), it is important to identify the period of time over which most of the relevant benefits and costs will accrue. The choice of an appropriate discount rate is even more critical in this analysis since a higher discount rate implies that future benefits and costs are weighted lower. For most private projects the choice of a discount rate is relatively simple — it is set to the appropriate market rate. For example, if a private company is considering a $100 million investment in a new factory that would yield a future stream of returns (profit), the firm would use their cost of capital; if they can borrow money at a 5% rate of interest, then 5% would be the discount rate.

For public projects, the discount rate is often tied to something similar: the cost of government bonds over the appropriate time horizon. For example, on a federal project lasting 30 years, one can apply the interest rate on a 30-year treasury bond (3.8% on January 10, 2014).

Given the potentially enormous costs of climate change to future generations and the longer time scale, many environmental economists have proposed applying lower discount rates when analyzing the economic impacts of climate change. One of the most widely cited reports, the Stern Review (2007), applied a 1.4 % discount rate. Arrow et al. (2014) point out that climate change modeling presents a unique set of issues given the uncertainty involved and the potential for catastrophic outcomes (even if the probability of such outcomes is low). Consequently, many climate change models use a declining discount rate over time, implying that a longer time horizon should receive a lower discount rate. Our analysis uses a 1% discount rate, which is consistent with Arrow et al. (2014) and others.

Cost-Benefit Analysis

Table 14 below summarizes the models, methods, and metrics used in this study, discussed in previous sections. Most of the methods used are standard in these types of analyses; for example, the CSBAT beach recreation model has been employed by a range of researchers across the California Coast. We valued lost property and infrastructure at current replacement cost, as described above. The main innovation here is our valuation of coastal ecosystems, discussed in the Ecological Assessment section above.

Table 14: Method for Estimating Benefits and Costs

Item	Method for Estimating	Final Metric
Beach Recreation	CSBAT	Recreational Value for given Beach Width
Ecological Value	Beach ecological index score	Cost of Replacement
Land	Commercial Data	Market Value
Buildings	FEMA	Replacement Cost
Flood Damages	USACE	Depth Damage Curves
Water Infrastructure	ESA	Replacement Cost
Roads	ESA	Replacement Cost
Nourishment	ESA	Cost of Hopper Dredge, etc.
Revetments	ESA	Construction Cost

Table 15 summarizes the data sources used in the report. Recreational data were obtained from counts and surveys. We used heavily modified parcel level data to estimate the value of land and structures, the beach ecological index score with replacement cost to estimate ecological value, and engineering costs for nourishment, revetments and infrastructure.

Table 15: Data Sources used in this Report

Item	Data Source	Method
Beach Attendance	Periodic Human Counts	King/McGregor (2012)
Recreational Value per Visitor	Various Academic Studies	Benefits Transfer
Change in Rec Value w Beach Width	Survey	CSBAT
Value of Land/Structures	County Parcel data	Modified
Flooding of Structures	Modified County Parcel Data	USACE Depth Damage Curves
Ecological Replacement Cost	ESA	Examined Restoration Projects
Ecological Value	TNC	Beach Ecological Evaluation
Infrastructure	ESA	Replacement Cost

Results

For this study, we estimated the benefits and costs for each of four reaches for 2030, 2060 and 2100, using the IPCC High and Medium sea level rise projections. In all, we analyzed more than 100 distinct scenarios: four reaches, three time horizons, various adaptation scenarios, and two sea level rise projections. All results were calculated in 2015 dollars.

In the figures below, the "Net Present Value" represents the sum of the benefits and costs for each reach/scenario/time horizon. All dollar amounts are discounted at a rate of 1% a year from the year in which the benefit or cost occurs. Thus the Net Present Values depicted in the figures below are the sums of these corresponding benefits and costs for each reach, discounted for the appropriate time period.

Del Monte

For the Del Monte reach, the adaptation scenarios we considered were:

- Scheduled Nourishment (nourishing every ten years)
- Nourishment with Groins (add groins and nourish when beach width reaches a trigger point);
- Allow Erosion (beaches and other coastal ecosystems are allowed to retreat, through both fee simple acquisition & elevating structures); and
- Shoreline Armoring (revetments across the entire reach).

Selected, but representative, results are shown for each reach. Table 16 breaks down benefits and costs for the Del Monte, High sea level rise projection, adaptation strategies into three primary sources. First, recreational and ecological benefits are expressed in (positive) dollars, per year, and summed over the three time horizons. Predictably, those strategies in which the sandy beach erodes more quickly produce smaller benefits. Second, the (negative) losses of land, buildings, roads and other infrastructure, as well as the cost of adaptation (e.g., elevating roads) is expressed in terms of replacement costs. Since Allow Erosion, by definition, allows for greater property damage, private losses are greater in 2060, though only by 5.5%. By 2100, private losses are significantly higher under the Allow Erosion scenario, but still much smaller than the public gains from the other strategies, which is why Shoreline Armoring has the lowest overall net benefits. Finally, the (negative) costs of the strategies themselves (e.g., nourishment costs) are also included. Nourishment with Groins and Shoreline Armoring both entail very expensive construction projects and thus incur significant costs.

Table 16: Distribution of Costs and Benefits: Del Monte (using High Sea Level Rise projection)

Year	Scheduled Nourish	Nourish w/ Groins	Allow Erosion	Shoreline Armoring
Public Benefits (recreational and ecological value)				
2030	$62,600,000	$76,800,000	$59,900,000	$52,600,000
2060	$147,600,000	$177,900,000	$137,400,000	$111,000,000
2100	$250,800,000	$308,300,000	$229,100,000	$145,200,000
Property Losses/Damages (infrastructure, MRWPCA, public and private property)				
2030	-$12,600,000	-$12,600,000	-$12,600,000	-$1,900,000
2060	-$14,500,000	-$14,500,000	-$15,300,000	-$4,900,000
2100	-$28,900,000	-$28,700,000	-$64,100,000	-$20,800,000
Adaptation Costs (nourishment, groins, revetments)				
2030	-$2,000,000	-$53,600,000	$0	-$35,700,000
2060	-$4,500,000	-$90,900,000	$0	-$62,200,000
2100	-$7,400,000	-$90,900,000	$0	-$98,000,000

Figure 5 below presents our results for the High sea-level rise projection. Results for the Medium sea-level rise projections are similar and presented in Appendix B.

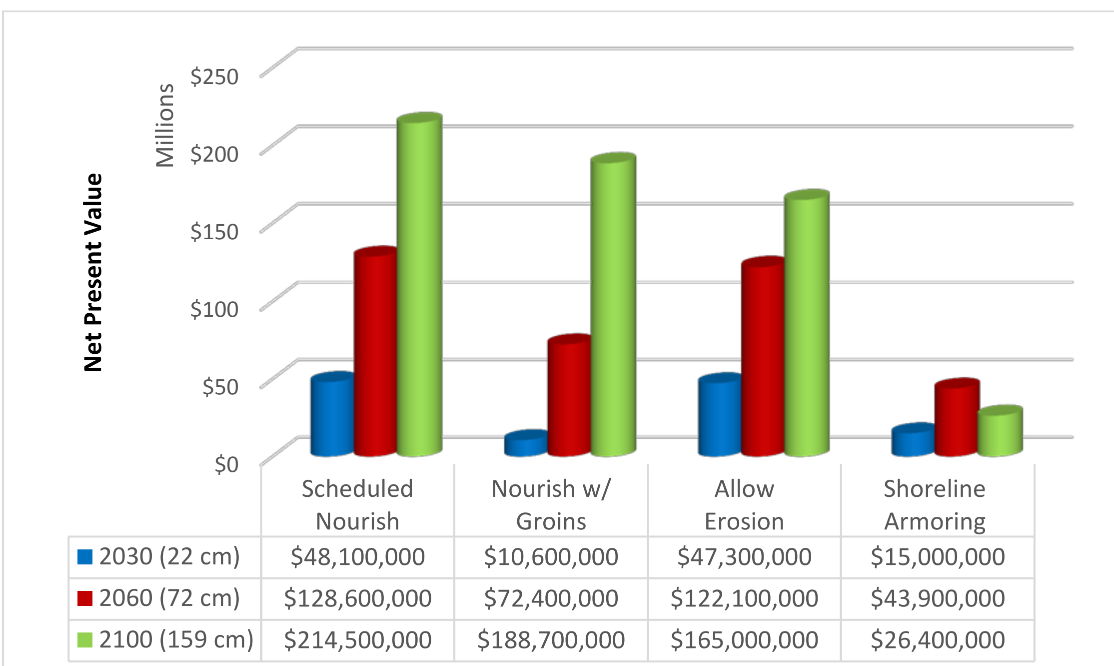


Figure 5: Net Present Value of Shoreline Management Options: Del Monte (using High sea level rise projection)

For the Del Monte reach, Scheduled Nourishment represents the option with the highest net present value assuming that sand is available. By 2100, the two non-armoring strategies (Nourishment and Allow Erosion) yield net benefits of over $150 million dollars. By way of comparison, this is significantly larger than the City of Monterey's Annual Budget of $108 million. (http://monterey.org/Portals/1/finance/budget/2014-15/AdoptedBudgetDocFY15.pdf).

For 2030, Allow Erosion and Scheduled Nourishment are within 2% of each other, which is well within the margin of error. In the 2060 and 2100 time horizons, both nourishment options have comparatively higher net present values. However, as our sensitivity analysis later indicates, these differences are well within the margin of error given our assumptions and given the inherent uncertainty in predicting the future. **In all time frames except 2030, Shoreline Armoring yields the lowest net present value.**

	Fee Simple	Elevate Structures
2030 (10 cm)	$49,100,000	$49,100,000
2060 (33 cm)	$126,400,000	$126,400,000
2100 (88 cm)	$168,100,000	$156,600,000

Figure 6: Net Present Value of Managed Retreat, comparing Fee Simple Property Acquisition with Elevating Structures: Del Monte (using High sea level rise projection)

This project also considered various upland (as compared with shoreline) adaptation strategies as part of the analysis. For the Del Monte reach, we considered Elevating Structures (residential and non-residential buildings and major roads such as Highway 1) as an alternative. In 2030 and 2060, these strategies yield the same net present value since the trigger point for elevating structures does not occur until after 2060. By 2100, the Elevating Structures strategy yields a lower net present value ($168 million vs. $157 million) than Fee Simple Acquisition, which indicates that the cost of elevating these structures does not reap sufficient benefits to justify the expense. Please note that our analysis aggregated the costs of elevating all roads and structures, and it is quite possible – even likely – that some structures (e.g., Hwy 1) might be worth elevating individually.

Sand City

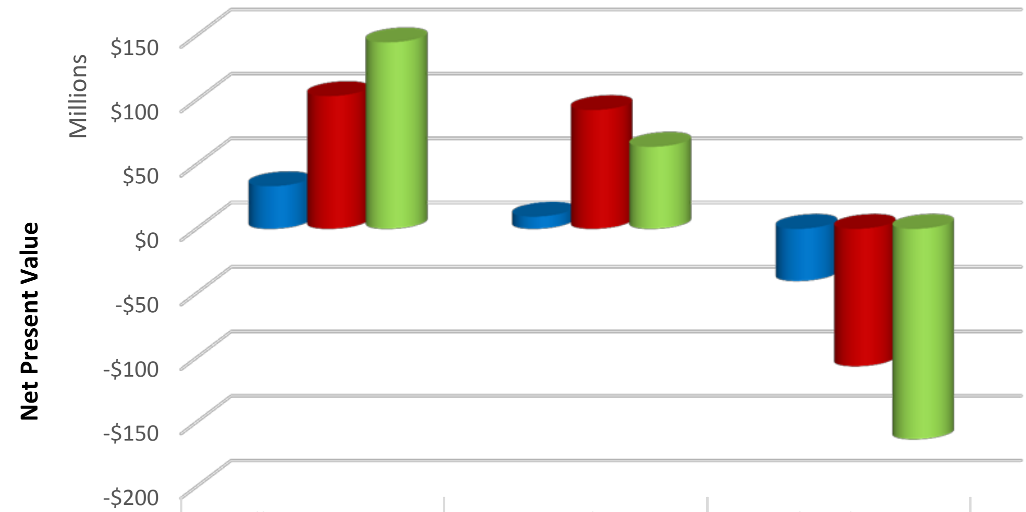
For the Sand City reach, the adaptation scenarios we considered were:

- Allow erosion;
- Nourishment as Needed (nourish when beach width reaches a trigger point); and
- Shoreline Armoring (revetment across the entire reach).

Table 17 (below) shows the distribution of costs and benefits for the three shoreline adaptation strategies considered. As in the case of Del Monte, the Nourishment as Needed strategy preserves the largest amount of sandy beach. Shoreline Armoring prevents the most property loss/damages but once again, these are small in comparison to the substantial costs of the armoring adaptation itself.

Table 17: Distribution of Costs and Benefits for Sand City (using High Sea Level Rise projection)

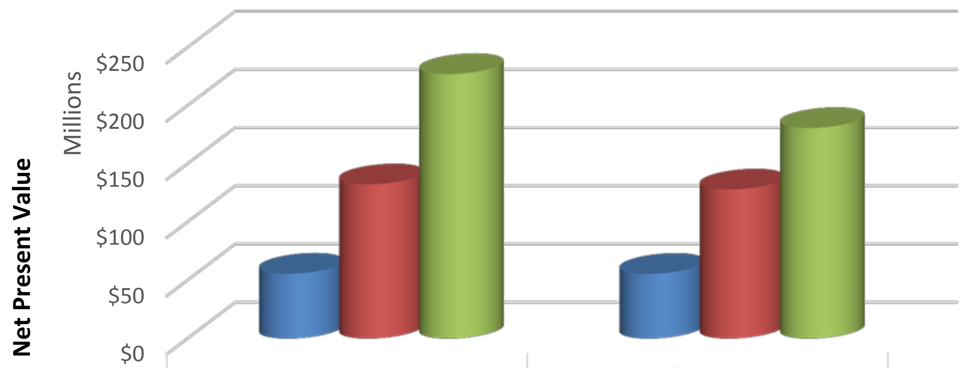
Year	Nourish as Needed	Allow Erosion	Shoreline Armoring
Public Benefits (recreational and ecological value)			
2030	$73,879,019	$55,517,865	$46,714,719
2060	$156,974,550	$128,161,523	$88,872,613
2100	$258,312,180	$215,278,285	$105,318,207
Property Losses/Damages (infrastructure, MRWPCA, public and private property)			
2030	-$22,317,371	-$22,405,393	-$7,307,244
2060	-$22,656,590	-$25,107,555	-$7,768,865
2100	-$57,879,464	-$70,474,388	-$8,435,046
Adaptation Costs (nourishment, groins, revetments)			
2030	-$42,040,402	$0	-$79,876,764
2060	-$42,040,402	$0	-$187,707,339
2100	-$136,692,248	$0	-$260,132,083



	Allow Erosion	Nourish as Needed	Shoreline Armoring
2030 (22 cm)	$33,100,000	$9,500,000	-$40,500,000
2060 (72 cm)	$103,100,000	$92,300,000	-$106,600,000
2100 (159 cm)	$144,800,000	$63,700,000	-$163,200,000

Figure 7: Net Present Value of Shoreline Management Options: Sand City (using High sea level rise projection)

For the Sand City reach, Allow Erosion represents the best option for all time frames. The net benefits from Nourishment are positive, but significantly lower than Allow Erosion for all timeframes. Shoreline Armoring yields negative net benefits, implying that the benefits from revetments are lower than the cost of construction/maintenance.



	Conservation easements	Elevating Infrastructure
2030 (22 cm)	$55,600,000	$55,500,000
2060 (72 cm)	$132,300,000	$127,900,000
2100 (159 cm)	$227,100,000	$180,700,000

Figure 8: Net Present Value of Other Management Options: Sand City (using High sea level rise projection)

For the Sand City reach, we also modeled the use of Conservation Easements. After analyzing sales data in the area, we concluded that the land acquisition prices for conservation easements are approximately 70% of the market value. However, it should be noted that estimation of benefits and costs is very assumption-dependent for this approach. In the case of conservation easements, someone, typically a government agency or NGO, must acquire the land. Further, there must be a willing seller. In contrast, under the Allow Erosion scenario, the cost of the land loss is often borne by the landowner (public or private) though it is possible an NGO or government agency could buy the land at market prices.

In Figure 8 above, Elevating Structures yields a lower net present value than Conservation Easements, but a higher value than Fee Simple Acquisition. In other words, it depends on how one values the land. We caution the reader from drawing any strong conclusions without further analysis.

Marina

For the Marina reach, the adaptation scenarios we considered were:

- Allow Erosion: Beaches and other coastal ecosystems are allowed to retreat; and
- Shoreline Armoring (revetment across the entire reach)

Table 18 (below) provides estimates of the benefits and costs broken down by type for the two options. While the public benefits of the Allow Erosion option are somewhat higher than those of Shoreline Armoring, the property losses/damages of the former are moderately higher than the latter. However, the costs of adaptation for Shoreline Armoring (essentially the costs of building and maintaining revetments) are much higher than any potential benefits.

Table 18: Distribution of Costs and Benefits: Marina (using High Sea Level Rise projection)

Year	Allow Erosion	Shoreline Armoring
Public Benefits (recreational and ecological value)		
2030	$77,252,329	$73,521,261
2060	$169,190,596	$150,380,476
2100	$266,362,964	$207,965,869
Property Losses/Damages (infrastructure, MRWPCA, public and private property)		
2030	-$44,943,649	-$30,802,090
2060	-$49,501,308	-$31,411,863
2100	-$58,789,820	-$37,666,832
Adaptation Costs (nourishment, groins, revetments)		
2030	$0	-$305,937,579
2060	$0	-$718,941,606
2100	$0	-$996,337,057

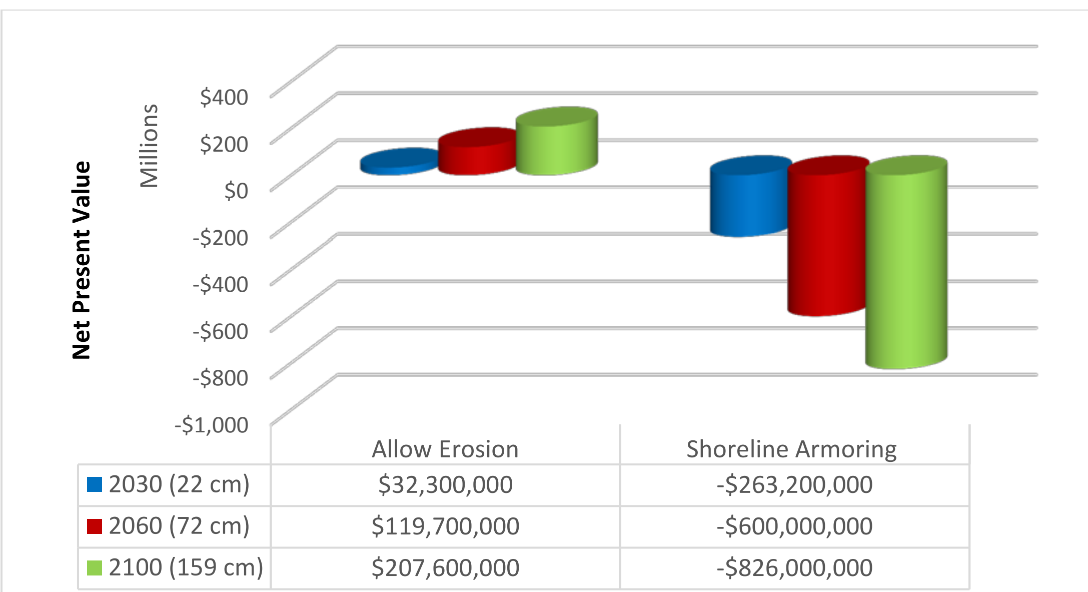
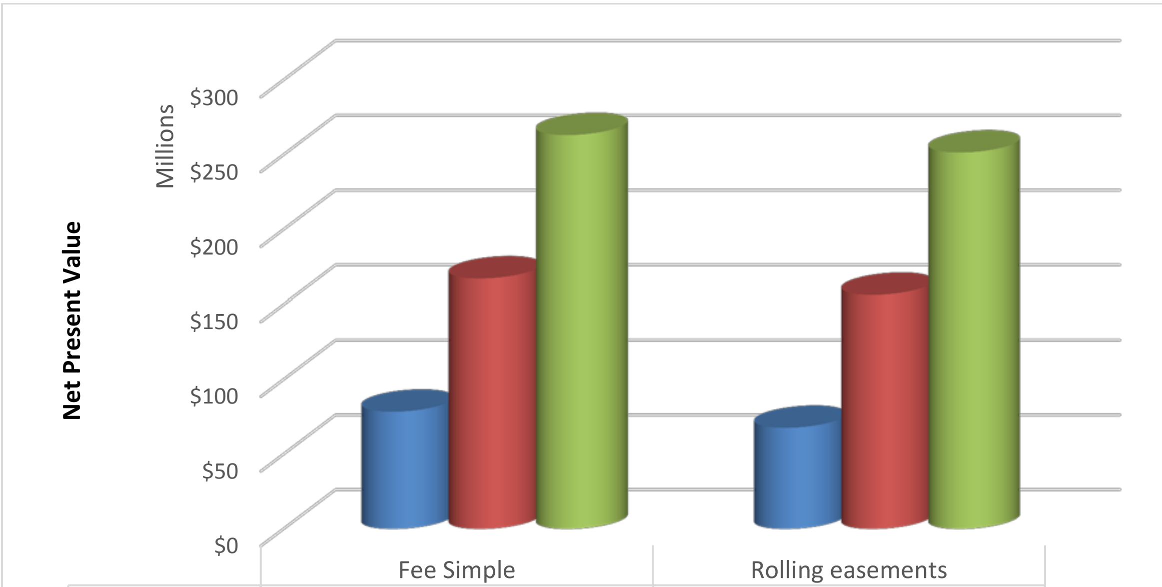


Figure 9: Net Present Value of Shoreline Management Options for Marina (using High sea level rise projection)

For the Marina reach, Allow Erosion had the greatest net benefits for all time frames. Shoreline Armoring yields negative net benefits, implying that the (storm/erosion) benefits from revetments are lower than the cost of construction/maintenance. **Indeed, between now and 2100, Allow Erosion yields net benefits that are over one billion dollars greater than Shoreline Armoring**.



	Fee Simple	Rolling easements
2030 (22 cm)	$78,500,000	$67,700,000
2060 (72 cm)	$167,300,000	$156,400,000
2100 (159 cm)	$263,200,000	$251,500,000

Figure 10: Net Present Value of Shoreline Management Options: Marina (using High sea level rise projection)

For the Marina reach we also considered Rolling Easements, where land use is restricted to exclude coastal armoring. In Figure 10 above, Fee Simple Acquisition yields higher net present value than Rolling Easements. However, the differences here are well within the margin of error.

Moss Landing

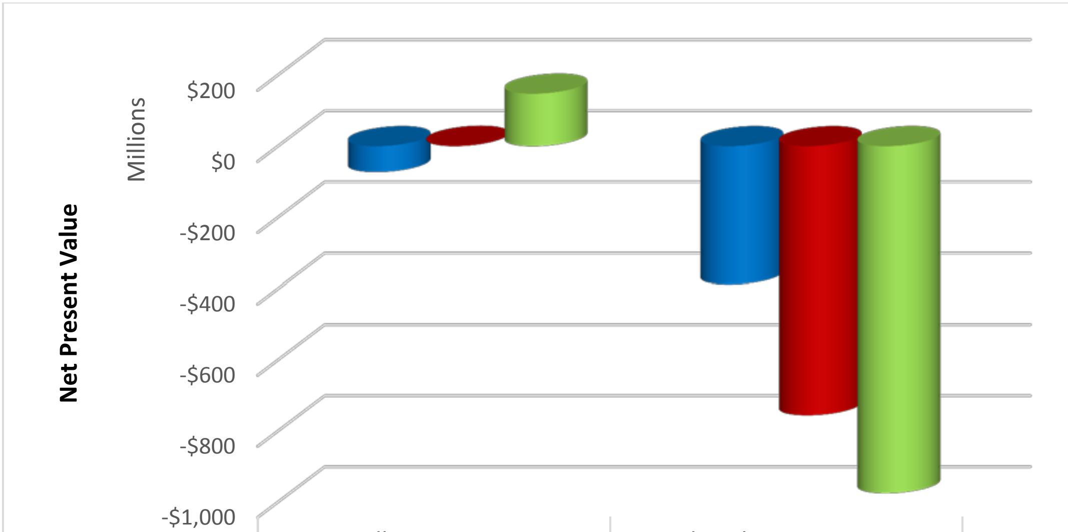
For the Moss Landing reach, we considered:

- Allow Erosion: Beaches and other coastal ecosystems are allowed to retreat
- Shoreline Armoring (revetment across the entire reach)

Table 19 (below) presents a breakdown of the costs and benefits. The public benefits of Allowing Erosion at Moss Landing are greater than those of Shoreline Armoring, while the property losses/damages are higher for Allow Erosion as one approaches 2100. Again, however, the high costs of armoring the Moss Landing shoreline make this option economically unviable.

Table 19: Distribution of Costs and Benefits: Moss Landing (using High sea level rise projection)

Year	Allow Erosion	Shoreline Armoring
Public Benefits (recreational and ecological value)		
2030	$87,398,194	$80,863,547
2060	$200,467,085	$146,028,145
2100	$408,866,543	$217,344,218
Property Losses/Damages (infrastructure, MRWPCA, public and private property)		
2030	-$160,192,822	-$159,906,088
2060	-$199,415,747	-$175,687,006
2100	-$261,334,259	-$186,020,350
Adaptation Costs (nourishment, groins, revetments)		
2030	$0	-$308,996,955
2060	$0	-$726,131,022
2100	$0	-$1,006,300,428



	Allow Erosion	Shoreline Armoring
2030 (22 cm)	-$72,800,000	-$388,000,000
2060 (72 cm)	$1,100,000	-$755,800,000
2100 (159 cm)	$147,500,000	-$975,000,000

Figure 11: Net Present Value of Shoreline Management Options: Moss Landing (using High sea level rise projection)

Figure 11 above compares the net present value for Allow Erosion and Shoreline Armoring. As with the Marina, the differences are significant. Indeed by 2100, the difference in net present value is $1.1 billion.

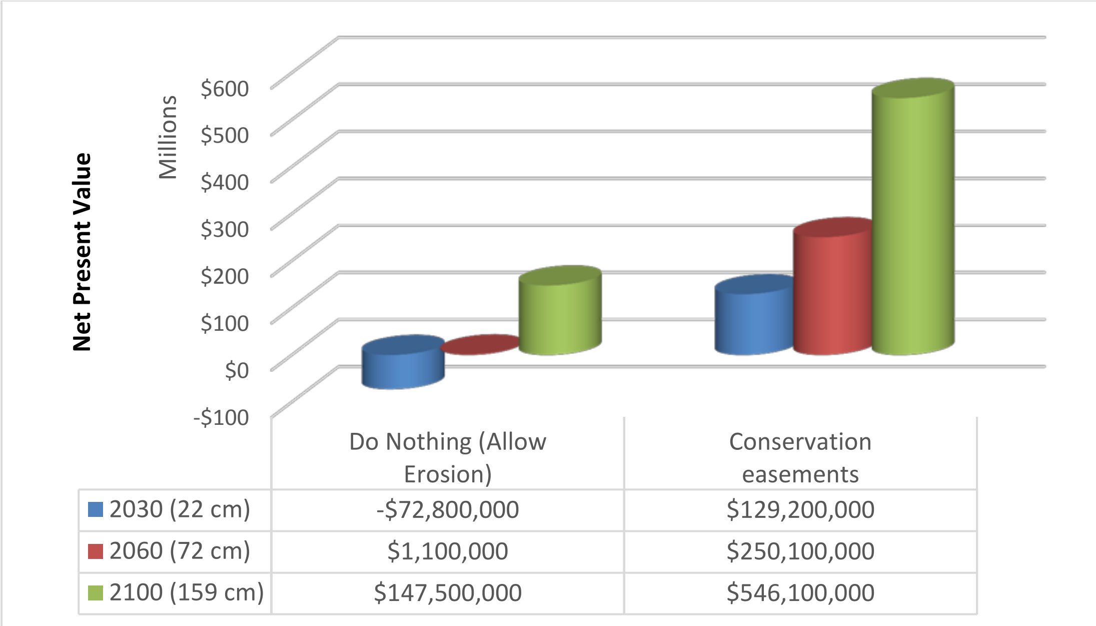


Figure 12: Net Present Value of Upland Management Options: Moss Landing (using high sea level rise projection)

For the Moss Landing reach, Conservation Easements have a significantly higher net present value than Doing Nothing, since land is valued at 70% of the market value—hence the dollar value of these losses are lower with Conservation Easements. However, once again, these results should be taken in context. In the case of conservation easements, someone must acquire the land, typically an NGO or government agency. Further, there must be a willing seller. In contrast, under the Allow Erosion scenario, the cost of the land loss is often borne by the landowner (public or private) though it is possible an NGO or government agency could buy the land at market prices.

Sensitivity Analysis Results

As with any economic modeling, the results presented above are based on certain assumptions. To understand the role of each of these assumptions in our analysis, we conducted a sensitivity analysis, which involves running the model using a range of values for key parameters to determine how sensitive the model is to changes in that parameter. We focused on the parameters that we believed were the most uncertain or where experts could disagree, namely:

- The discount rate
- The recreational value of beaches per person per day (i.e., day use value)
- Beach attendance
- The ecological value of beaches
- The recreational value of increasing/decreasing beach width
- The frequency of 100 year storms
- The costs of nourishment.

A summary of the results of the sensitivity analysis is contained in Table 20. **In most cases, we found that our results were quite robust, meaning that the relative ranking was not affected by the range of parameters considered in the sensitivity analysis.** The exception was in the Del Monte reach, where the two Nourishment options and Allow Erosion are close enough that the assumptions matter. A more complete discussion and analysis with more charts and tables is contained in the full economic report, Appendix B.

Discount Rate

We used a 1% discount rate for our analysis. However, there is still controversy in the economics profession about the appropriate discount rate to use (see discussion above). Consequently, we conducted a sensitivity analysis using higher and lower rates. In general, our results are robust with respect to changing the discount rate. For the Del Monte reach, Scheduled Nourishment remains the option with the highest net present value (NPV) over a wide range of discount rates (0.125% to 8%). However, as the discount rate increases Allow Erosion has a higher NPV relative to Nourishment with Groins.

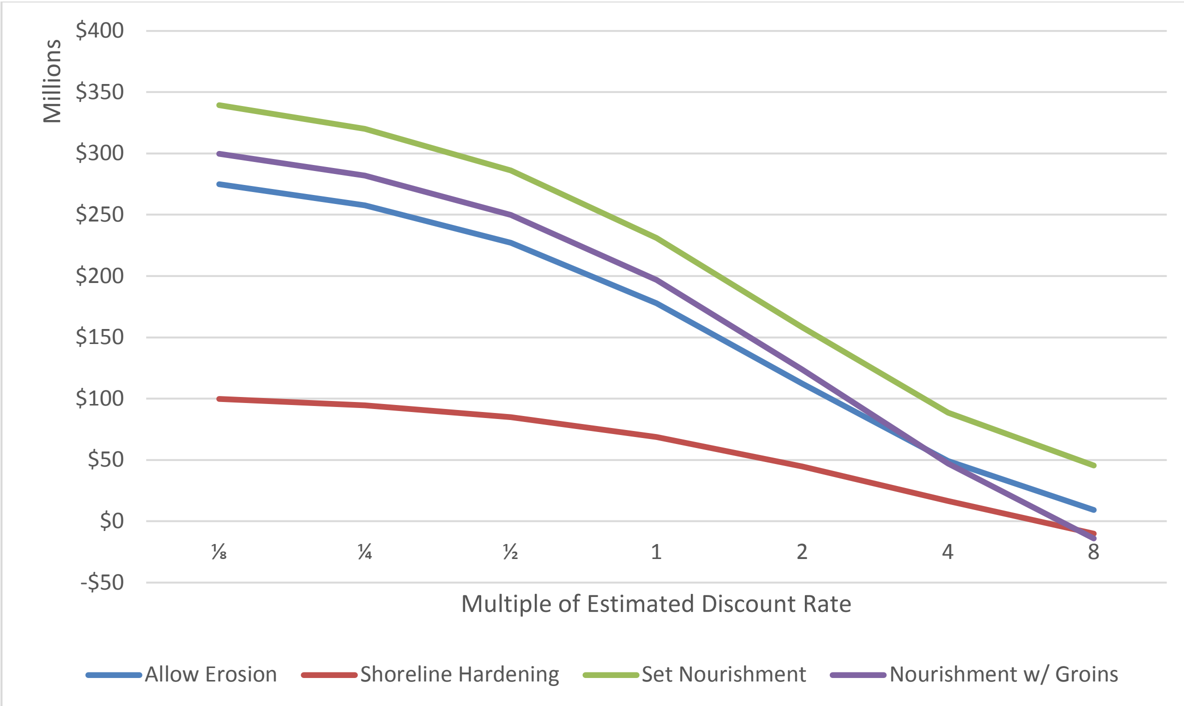


Figure 13: Sensitivity Analysis of discount rate using Net Present Value of Shoreline Management Options: Del Monte

Flood Frequency

ESA provided 100-year flood maps based on current storm probabilities (i.e., the probability of a 100 year flood occurring in any given year is 1/100). We estimated the additional flood costs from a 100-year event. Further, we performed an analysis assuming that the probability of a 100-year storm increased or decreased. Figure 13 presents the result of this analysis. **Although an increase in flood probability increases flood damages and therefore lowers the net present value (NPV), the relative ranking of adaptation strategies does not change.**

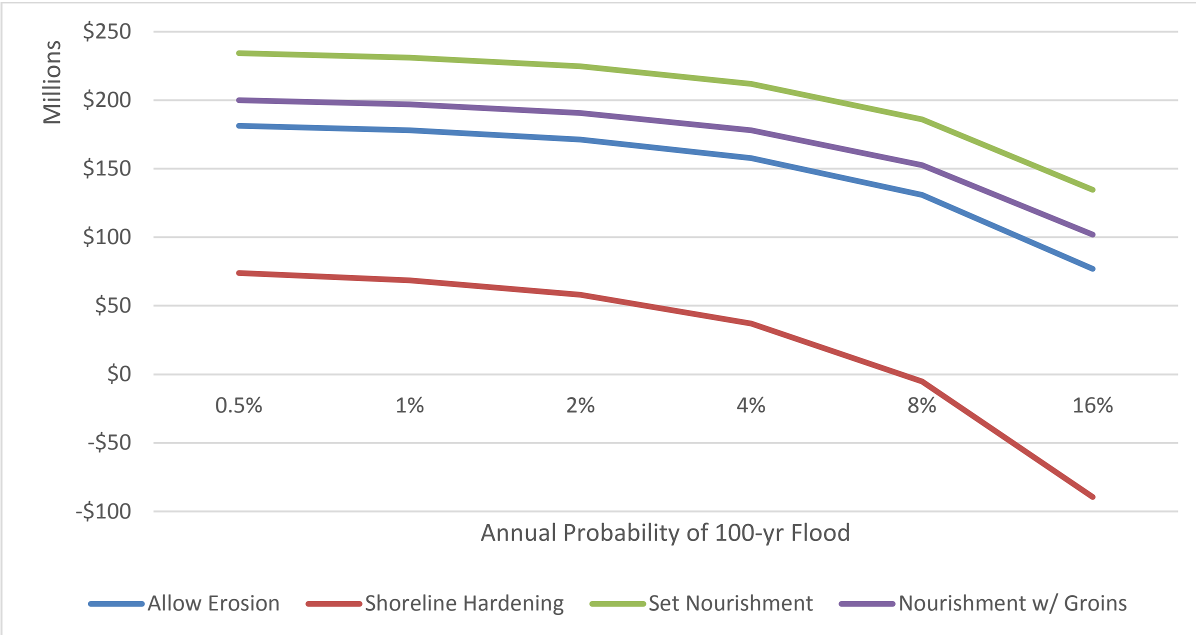


Figure 14: Sensitivity Analysis of 100-year Flood Probability using Net Present Value of Shoreline Management Options: Del Monte

Ecological Value

A 3:1 ratio is typical for the costs of wetlands mitigation – in other words, mitigation projects require the restoration of three acres for everyone one impacted. We assumed a similar cost ratio: for every acre impacted, the cost is three times the restoration value of that single acre. We have assumed this same ratio in estimating the costs associated with restoring lost ecological value due to the erosion and nourishment of southern Monterey County beaches. Figure 15 (below) illustrates the robustness of our results with respect to this ratio at each of the reaches through the year 2100. To use Marina as one of the clearer examples, Allow Erosion is clearly superior to Shoreline Armoring in all scenarios in which the cost of mitigation is between ⅛ and 8 times our assumed 3:1 ratio. The same can be said for Sand City and Moss Landing. While there is some sensitivity to this ecological value at the Del Monte reach, the net benefits of Shoreline Armoring remain well below those of the other response strategies for all ecological values.

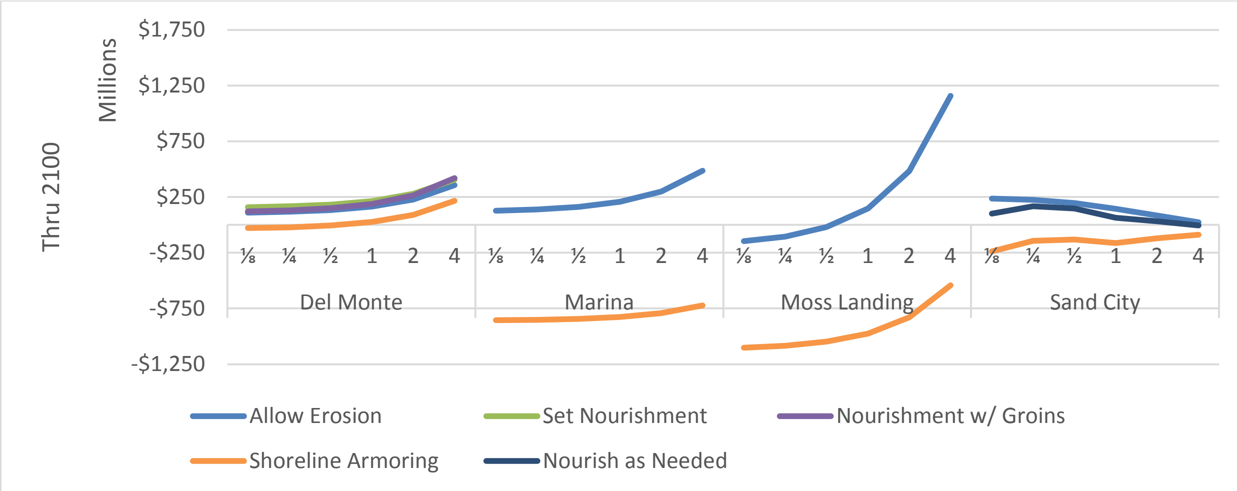


Figure 15: Sensitivity analysis of 3:1 restoration cost assumptions

Other Robustness Checks

Table 20 below summarizes our sensitivity analyses and robustness checks for each reach, timeline, and High and Medium sea level rise projections (24 in all). **With the exception of 2030 and 2060 in the Del Monte reach, the Shoreline Armoring options yield the lowest net present values. This result is quite robust even when varying significant parameters by a factor of two or more. In other words, within plausible ranges of our assumptions, we can be reasonably certain that Shoreline Armoring is a poor management or adaptation choice for these reaches.**

Given our assumptions, Nourishment yields the highest net present value in the Del Monte reach. However, Nourishment with Groins becomes a better option if the recreational value of beaches increases. In the Sand City reach, Allow Erosion yields the highest net present value, unless Nourishment becomes significantly less expensive (50% less) or if the recreational value of these beaches increases by over 200%.

Table 20: Sensitivity/Robustness Check for Economic Analysis

Reach	Year	SLR Scenario	Best Option	Worst Option	Robustness
Del Monte	2030	Med	Scheduled Nourishment/ Allow Erosion	Nourish w/Groins	Very robust
Del Monte	2030	High	Scheduled Nourishment/ Allow Erosion	Nourish w/Groins	Very robust

Reach	Year	SLR Scenario	Best Option	Worst Option	Robustness
Del Monte	2060	Med	Scheduled Nourishment	Shoreline Armoring	Nourishment w/ Groins beats Scheduled Nourishment if: Annual Attendance or Day Use Value is more 175%, Costs of Nourishment less than 50%
Del Monte	2060	High	Scheduled Nourishment	Shoreline Armoring	Very robust
Del Monte	2100	Med	Scheduled Nourishment	Shoreline Armoring	Nourishment w/ Groins beats Scheduled Nourishment if: Annual Attendance or Day Use Value is more than 200%, Costs of Adaptation less than 50%
Del Monte	2100	High	Scheduled Nourishment	Shoreline Armoring	Nourishment w/ Groins beats Scheduled Nourishment if: Annual Attendance or Day Use Value is more than 175%, Costs of Nourishment less than 75%
Sand City	2030	Med	Allow Erosion	Shoreline Armoring	Nourish as Needed beats Allow Erosion if: Day Use or Attendance are greater than 225%, Costs of Nourishment less than 50%
Sand City	2030	High	Allow Erosion	Shoreline Armoring	Nourish as Needed beats Allow Erosion if: Day Use or Attendance are over 225%, Costs of Nourishment are less than 50%
Sand City	2060	Med	Allow Erosion	Shoreline Armoring	Nourish as Needed beats Allow Erosion if: Day Use or Attendance is over 150%, costs of nourishment is less than 75%, Ecological value above 175%
Sand City	2060	High	Allow Erosion	Shoreline Armoring	Nourish as Needed beats Allow erosion if: Day Use or Attendance are over 150%, Costs of Nourishment are less than 75%, Ecological value is above 175%

Reach	Year	SLR Scenario	Best Option	Worst Option	Robustness
Sand City	2100	Med	Allow Erosion	Shoreline Armoring	Nourish as Needed beats Allow Erosion if: Annual Attendance or Day Use Value is more 200%, if the costs of nourishment are less than 50%.
Sand City	2100	High	Allow Erosion	Shoreline Armoring	Very robust
Marina	2030	Med	Allow Erosion	Shoreline Armoring	Very robust
Marina	2030	High	Allow Erosion	Shoreline Armoring	Very robust
Marina	2060	Med	Allow Erosion	Shoreline Armoring	Very robust
Marina	2060	High	Allow Erosion	Shoreline Armoring	Very robust
Marina	2100	Med	Allow Erosion	Shoreline Armoring	Very robust
Marina	2100	High	Allow Erosion	Shoreline Armoring	Very robust
Moss Landing	2030	Med	Allow Erosion	Shoreline Armoring	Very robust
Moss Landing	2030	High	Allow Erosion	Shoreline Armoring	Very robust
Moss Landing	2060	Med	Allow Erosion	Shoreline Armoring	Very robust
Moss Landing	2060	High	Allow Erosion	Shoreline Armoring	Very robust
Moss Landing	2100	Med	Allow Erosion	Shoreline Armoring	Very robust
Moss Landing	2100	High	Allow Erosion	Shoreline Armoring	Very robust

Future Work

This study integrates property values, ecological values, and the recreational value of coastal resources in order to estimate the benefits and costs of various adaptation strategies. However, like any other economic study, we relied on a number of assumptions, and although we used the best available data, more data in certain cases (discussed below) would have been helpful. We are confident in our results since our robustness/sensitivity analysis indicates that changing key parameters significantly generally does not change the rank ordering of results (see previous section).

Recreational Analysis

For this study, we relied on local survey data, counts, as well as measures of willingness to pay from other areas. Future work would benefit from additional study of beach recreation in the area, which would refine the analysis. Our use of the CSBAT model is consistent with many other studies in California. Fortunately, the limited availability of data on beach recreation in the study area did not influence our results, as indicated in the sensitivity analysis.

Ecological Analysis

We believe that our modeling of the ecological benefits of beaches and other coastal habitats represents a significant step forward from previous studies. However, more work is needed here. In particular, future studies should consider which of the outstanding details from the economic analysis, listed below, might be worthy of additional analysis.

- A non-linear economic model to describe beach ecological function (e.g., a Cobb-Douglas function) might be employed.
- Where feasible, future studies should include consideration of other ecological indicators (e.g., wrack), for which data were not available for this study, to estimate the value of beach ecology.
- There is a general agreement that nourishment harms coastal ecosystems, but that these systems can, and often do, recover in time (as conceptually modeled in this study). However, the timeframe for this recovery is unknown and almost certainly varies by site, type of nourishment, grain size, etc.; a closer look into the impacts of nourishment and ecological recovery time based on beach characteristics would allow for a more nuanced analysis.
- The profile modeling provided intertidal width and slope changes, which indicated degradation by coastal structures. However, these physical responses were not used. Future analysis could be improved by applying conceptual modeling of ecological responses to these intertidal changes. Similarly, other habitat “bands” could be included in the ecological response modeling.

- Our beach restoration cost estimates are based on a small number of projects, many hypothetical. If this method is used in future applications, the beach restoration cost metrics need refining.
- Our restoration cost approach did not include the potential recreational value or increased recreational value of these sites.
- While we believe this paper makes a significant advance in valuing coastal ecosystems, we did not place a value on upland ecosystems that would be modified/eliminated/degraded by the alternatives in this study. In future studies, we would attempt to fill this gap.

Flooding and Erosion

Future studies should consider which of the outstanding details resulting from flooding and erosion, listed below, might be worthy of additional analysis.

- While we did incorporate the primary damages from flooding (i.e., to buildings and structures), we did not incorporate the costs of cleaning up after flooding events (e.g., cleaning debris).
- Although we used replacement cost for infrastructure, we did not look at the potential costs of land to place this infrastructure on. Since we assumed major roads like Hwy 1 would be elevated, we think this assumption would not alter our conclusions.
- We did not model transportation delays caused by road flooding, removal, etc. These damages could be significant in some cases (e.g., closure of Hwy 1).
- We did not estimate the potential costs of hazardous materials cleanup that could result from coastal flooding. A recent analysis of coastal hazards for the City of Goleta indicated that hazardous materials mitigation/remediation could be a significant cost (Revell Coastal 2015).
- Future work should consider regional economic impacts (i.e., direct, indirect and induced) from businesses that temporary shutter their operations.
- Future work should consider the vulnerability of critical facilities such as hospitals and community centers.
- A sensitivity analysis on the range of possible physical scenarios such as storms at different frequencies (e.g., 20-year event, 500-year event) should be conducted.
- Future work should consider the loss of recreational value on coastal bluff trails subject to erosion.
- Future studies may want to examine the trade-offs between nourishment and managed retreat, including analyzing a range of options and assumptions about the future.

Our analysis also assumes that relative property values do not change with coastal adaptation strategies, which is unlikely. As the coast erodes, land adjacent to the coast will become less valuable as the market incorporates the probability that this land will disappear or be unusable. If the coastline is armored, this land might become less valuable due to the loss in aesthetic/recreational/ecological value of an armored coastline. Finally, if the coast erodes, some parcels/properties will become closer to the coast or on the coast, which might increase their market value. On the other hand, if expectations about future erosion are incorporated, this land might also decrease in value. All of these issues are important, but beyond the scope of this report.

Conclusion

This study of southern Monterey Bay builds upon previous work and integrates the economic value of inland property and human-made infrastructure with estimates of the value of coastal recreation and ecology. Our results are quite striking and robust. Within these reaches, coastal armoring is generally not a cost effective solution under a wide range of reasonable assumptions.

Our results call into question the conventional wisdom that coastal armoring is the best response to coastal erosion. Although southern Monterey Bay is not necessarily representative of the entire California coast, in most cases coastal armoring yielded significantly lower net present values (NPVs) than other options. Even in the more urban Del Monte reach, which includes parts of the City of Monterey, our analysis indicates that armoring the shoreline yields significantly lower NPVs than beach nourishment.

The analysis provided here compares the potential economic costs and benefits associated with the shoreline changes brought about through the implementation of a suite of stakeholder-selected coastal climate change adaptation approaches tailored to a series of reaches of the southern Monterey Bay coastline. The analysis is meant to provide coastal managers and decision makers in the region with the data they need to inform coastal adaptation efforts, including Local Coastal Program (LCP) sea level rise updates, Coastal Development Permits (CDPs), and even regional and parcel level coastal protection, restoration, and development opportunities.

With advance planning and careful consideration of how our coastal management approaches not only alter our shorelines physically, but impact economic sustainability, the suite of reasonable adaptation approaches narrows significantly. Traditional approaches to coastal management, when considered from a holistic socio-economic perspective, are actually less economically viable and more environmentally and economically damaging than their alternatives. What we think of as non-traditional approaches, such as managed retreat, have actually been implemented for centuries on coasts around the world. Analyses like these, that consider our coastal adaptation management options comprehensively, are changing the paradigm by showing the true cost to the community of adaptation solutions that do not account for long-term impacts and ancillary consequences.

Coastal adaptation to climate change presents many new challenges that can only be addressed through thoughtful collaborations among scientists, managers, and community members. We already have tried-and-true adaptation tools and approaches at our fingertips, but we need to ensure that we apply innovative and forward-thinking combinations of our "traditional" and "non-traditional" approaches as we work together to protect our coastal resources and communities into the future.

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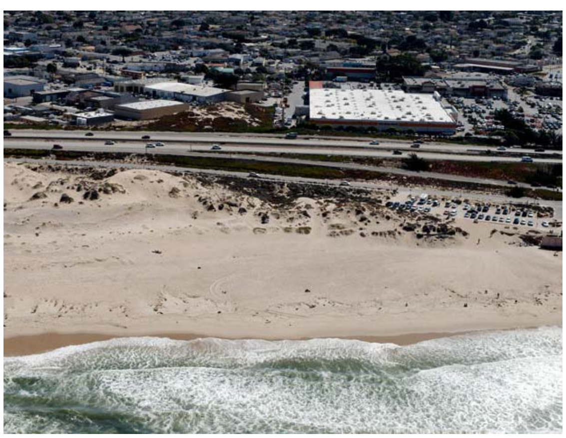
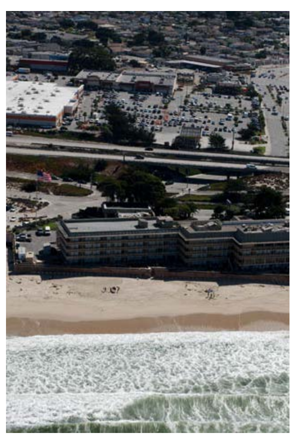
APPENDIX A:
CLIMATE READY – SOUTHERN MONTEREY BAY

Coastal Hazards Analysis to Assess Management Actions
Technical Methods Report

Prepared for
The Nature Conservancy
California Oceans Program
99 Pacific Street, Suite 200G
Monterey, CA 93940

January 2016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Cover Photos: View of Monterey Tides Hotel and adjacent shoreline

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1 INTRODUCTION

In 2014, ESA PWA, the Monterey Bay Sanctuary Foundation (MBSF), and others worked with local communities to assess Monterey Bay's vulnerability to potential future impacts of sea level rise on coastal erosion and flooding with funding from the California State Coastal Conservancy. The study "Monterey Bay Sea Level Rise Vulnerability Study" (MBSLR)[1] modeled and mapped coastal erosion and flood hazards under various future climate scenarios for the Monterey Bay. The hazard mapping results of MBSLR serve as a baseline "no action" scenario set of hazards in this study that are either directly applied or modified to develop new hazard maps for adaptation scenarios considered in the current study. Consistent with MBSLR, the sea level rise scenarios used in this project are based on the recent study by the National Research Council (NRC 2012) which are listed in Table 1 and curves shown in Figure 1. The low, medium, and high sea level rise scenarios use the "Average of Models, Low," "Projection," and "Average of Models, High," regional sea level rise amounts for San Francisco (NRC 2012, Table 5.3). The planning horizons of 2030, 2060, and 2100 are again used in the current study. The low sea level rise scenario was not considered in the current study.

Table 1. Sea Level Rise Projections from MBSLR, relative to 2010

Year	Low SLR	Medium SLR	High SLR
2030	3 cm (1.1 inches)	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)

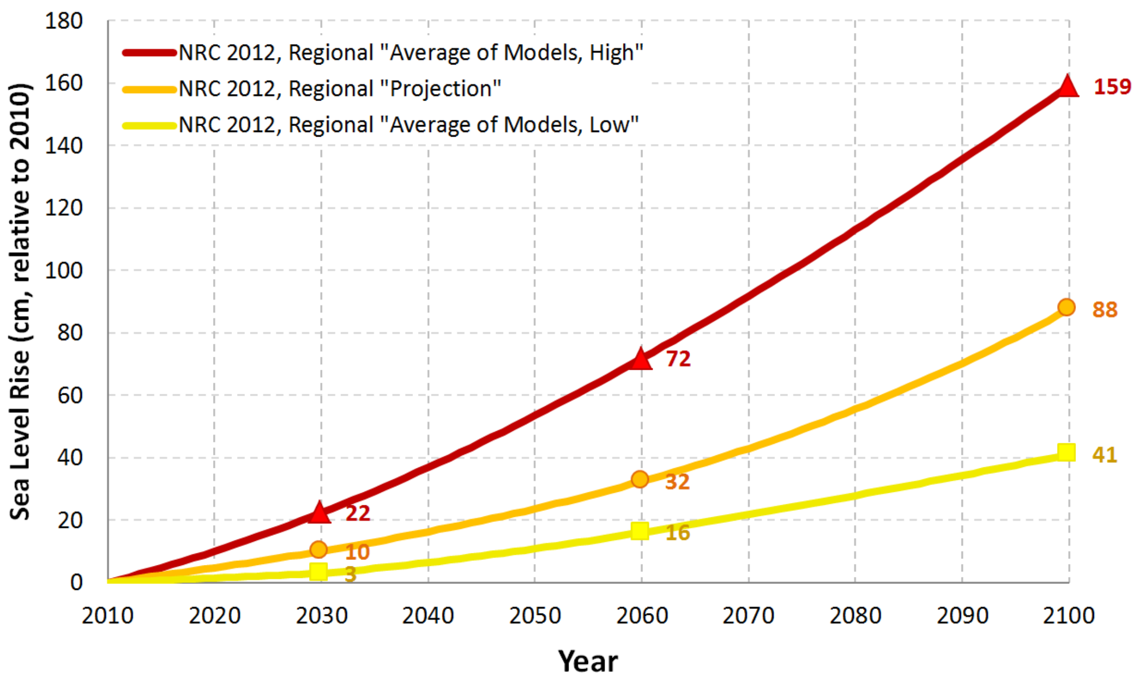

Figure 1. Sea Level Rise Scenarios.

[1] MBSLR Baseline coastal hazard maps can be viewed by visiting The Nature Conservancy website: http://maps.coastalresilience.org/california/# and selecting the Monterey geography, and opening the Flood and Sea Level Rise layer menu on the left panel. The technical methods report (ESA PWA 2014) can be viewed through the "View Technical Report" link at the bottom of the Flood and Sea Level Rise layer menu.

To assess the ability of management actions to address coastal erosion and flooding along the Southern Monterey Bay coastline, a quantified conceptual model of beach width and erosion was developed. The outputs of the beach width and erosion model were then used to adjust flooding hazards along southern Monterey Bay. This memo summarizes the methods and results associated with this beach width and erosion model as well as the adjustments made to coastal flooding hazards resulting from the model. The project study area includes four study reaches: Moss Landing, Marina, Sand City, and Del Monte (Figure 2). Table 2 provides a list of the study reaches and adaptation scenario descriptions. The beach width, erosion, and flooding results of this analysis were provided to the economics team along with relevant engineering cost estimates to compare the economic costs and opportunities associated with each adaptation management strategy.

This work builds upon several prior studies. The Coastal Regional Sediment Management Plan for Southern Monterey Bay (PWA, 2008) characterized the shore including specifically defining the reaches (shore segments) used to organize the analysis. A follow-on study called Evaluation of Erosion Mitigation Alternatives for Southern Monterey Bay (ESA PWA, 2012) addressed the benefits and costs associated with alternative measures to mitigate coastal erosion, and provided the precursor to the present study. Both of these prior studies benefited from participation by and guidance of the Southern Monterey Bay Coastal Erosion Working Group as described in these prior reports. The sea level rise scenarios and "no action" hazard mapping were developed in the Monterey Bay Sea Level Rise Vulnerability Assessment (ESA PWA, 2014).

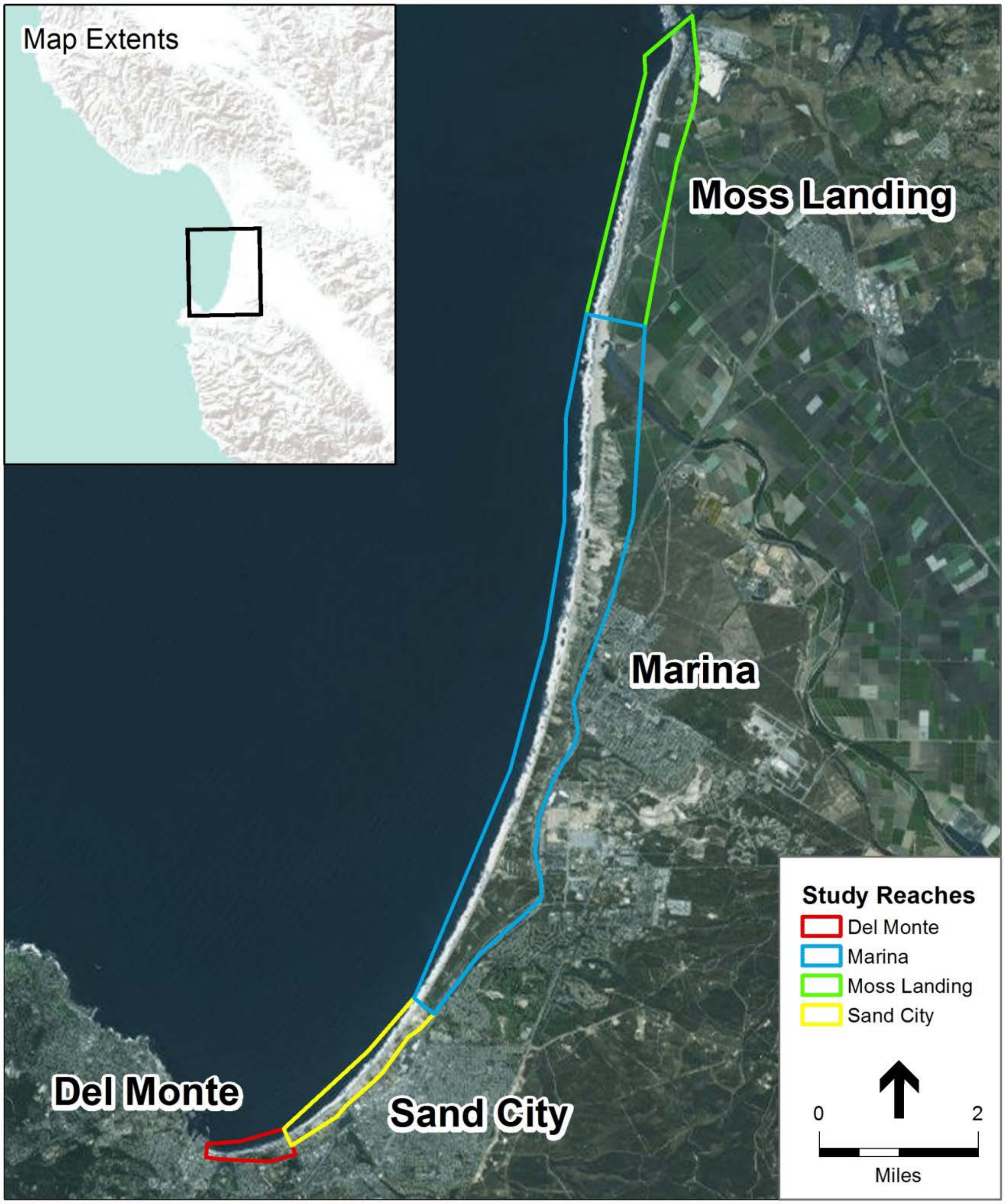

Figure 2. Southern Monterey Bay Study Reaches.

Table 2. Analysis Reaches and Scenario Descriptions

Reach	Management Scenario	Scenario Description	Beach Model
Del Monte (1.6 km)	Opportunistic beach nourishment (50,000 CY every 10 years)	This will be a "smallish" local beach nourishment and will be addressed in terms of incremental benefits and costs.	Beach Nourishment (Set Schedule)
	Revetments	Everywhere along back shore. Allow beach to narrow and structure to overtop. Include a depreciation factor based on a 30-year life (20 years when beach disappears).	Hold the Line
	Managed retreat (fee simple)	This is our previously completed baseline SLR modeling work with this study including additional beach width modeling.	Allow Erosion
	Groins + medium scale nourishment (400,000 CY as needed to maintain 25% wider beach)	Compute sand placement to maintain existing beach width with sand deficit and SLR sand demand, then model. Sand volume and placement frequency will vary with sea level rise curve (and accelerated erosion) as a function of time.	Beach Nourishment (As Needed) + Groins
	Elevating structures	Baseline, similar to managed retreat, but with different costs (new foundations instead of structure damages).	Allow Erosion
Sand City (4.1 km)	Large scale beach nourishment (2M CY as needed to maintain 25% wider beach)	Compute sand placement rate to maintain existing beach width and then model. Sand volume and placement frequency will vary with sea level rise curve (and accelerated erosion) as a function of time.	Beach Nourishment (As Needed)
	Managed retreat – cons. easements	Baseline with beach width modeling and easement costs.	Allow Erosion
	Revetments	Everywhere along back shore. Allow beach to narrow and structure to overtop. Include a depreciation-type annual maintenance cost based on a 30-year life or other simple model.	Hold the Line
	Elevating infrastructure	Specific to Hwy 1: same as managed retreat, but with Hwy 1. column foundation installed in time to avoid damages: intervention when backshore reaches roadway.	Allow Erosion
Marina (14.5 km)	Rolling easements	Baseline (from previous SLR modeling) with beach width modeling and easement costs.	Allow Erosion
	Fee simple	Baseline with beach width modeling and easement costs.	Allow Erosion
	Revetments	Everywhere along back shore. Allow beach to narrow and structure to overtop. Include a depreciation-type annual maintenance cost based on a 30-year life (20 years when beach disappears).	Hold the Line
Moss Landing (6.0 km)	Do nothing	Baseline (from previous SLR modeling) with additional beach width modeling.	Allow Erosion
	Revetments	Defend in place revetments everywhere along back shore. Allow beach to narrow and structure to overtop. Include a depreciation factor based on a 30-year life (20 years when beach disappears). Plus rough estimate for estuarine / harbor water level management (e.g. lock).	Hold the Line
	Managed retreat with conservation easements	Baseline (from previous SLR modeling) with additional beach width modeling.	Allow Erosion

1.1 Objectives

To expand the applicability of hazard modeling and mapping from MBSLR, the objectives of this study are to develop and implement a beach width and erosion projection model with the following attributes:

1. Ability to differentiate between coastal management alternatives.
2. Automated process that can be efficiently applied to multiple reaches while still being flexible enough to address unique situations and exceptions.
3. Ability to incorporate impact of sea level rise.
4. Use historic erosion trends and shoreform characteristics specific to each study reach.
5. Output a set of useful, quantified results that can be input to an economic model.

1.2 Study Resolution

In MBSLR, baseline coastal erosion hazard zones were developed to understand the implications of sea level rise under a no-action scenario (ESA PWA 2014). This prior study was conducted at a resolution of 500-m "blocks" along the entire Monterey Bay shoreline. This resolution was maintained for input to and output from a reach-based analysis using averaged shore profile geometry and other averaged parameters and reach-block transfer functions. The reaches were established based on physical processes by prior studies (PWA 2008; ESA PWA 2012). The shore lengths of these reaches ranged from 1.6 to 14.5 km, with 53- 500 m blocks for the total southern Monterey Bay shore length of 26.5 km (16.3 miles).

2 COASTAL EROSION MODELING

The current "Allow Erosion" management scenario corresponds, in principal, to the MBSLR Baseline scenario in which no actions are taken and the shoreline and backshore respond naturally to sea level rise and ongoing erosion. However, the beach width modeling conducted as part of the current study is more sophisticated and takes into account more factors than the baseline modeling done for the prior MBSLR (2014). Therefore, the hazard zones and erosion distances do not match between the two studies. The benefit of using this more detailed model is that it allows us to model the effects of adaptation strategies (holding the line, beach nourishment) on beach width, backshore erosion, and storm hazards. The following list of changes to the erosion modeling explains the differences between MBSLR and the current study:

- **Beach width modeling** – Now we are modeling beach width through time. In the model, a wider beach results in less erosion at the dunes, while a narrower beach results in more rapid dune erosion. This results in a difference between the MBSLR Baseline and the current "Allow Erosion" scenarios.
- **Storm Erosion** – In a similar vein, the storm erosion is assumed to be reduced when the beach is widened and vice versa. Therefore, the storm erosion values differ between the two studies.
- **Reach-Based Modeling** – The beach width modeling is done on a reach -- rather than block -- basis. This means that the results need to be prorated to bring them back to the 500-m block level of detail. This proration inherently introduces differences between MBSLR Baseline and the current Allow Erosion scenario
- **Modified Bruun Rule for dune erosion** –MBSLR used a standard Bruun rule, which assumes that the entire beach profile shifts up and inland with sea level rise. This does not, however, account for the large amount of sediment released when large dunes erode. Therefore, any scenarios which allowed backshore erosion to occur were modified to account for this additional sediment in the system. The result is less backshore erosion in the Allow Erosion scenario compared with the MBSLR Baseline modeling.

2.1 Beach Zones Modeling

This model tracks the shoreline location, backshore location, and beach width. For beaches backed by dunes or structures, the backshore location represents the toe of the dune or structure. Backshore erosion results in a total loss of property. Using a 1-year time step, the shoreline movement and backshore erosion are calculated using relationships described in the following sections.

2.1.1 Beach Width

The beach width is the distance between the shoreline[2] and the backshore. A starting beach width was estimated for each reach by taking the average distance between the mean high water line[3] and the

[2] Assumed to be located at Mean High Water (MHW=1.455 m NAVD88, from NOAA Monterey tide gage).

backshore location as observed in the 2009 - 2011 California Coastal Conservancy Coastal LiDAR Project Hydro-Flattened Bare Earth DEM (collected in Spring 2010 in this area). Subsequent beach widths are calculated based on the relative movement of the shoreline and backshore. If the shoreline erodes more quickly than the backshore, then the beach narrows, and vice versa.

2.1.2 Shoreline Movement

Three components contribute to shoreline movement in this quantified conceptual model: landward movement due to sea level rise (SLR), shoreline erosion caused by other coastal processes (e.g., waves, wind, changes in sediment supply), and seaward movement of the shore due to sand placement activities:

$$Shoreline\ Movement = SLR\ transgression + Ongoing\ erosion + Beach\ nourishment$$

2.1.2.1 Sea Level Rise Transgression

The impact of sea level rise on shoreline movement is incorporated by assuming that the shoreline will move inland based on the shape of the beach profile and the amount of sea level rise:

$$Sea\ Level\ Rise\ Transgression = \frac{increase\ in\ sea\ level}{shoreface\ slope}$$

The shoreface slope used in this equation depends on whether or not the backshore is eroding. Figure 3 shows how the sea level rise erosion changes with beach width. When the backshore is not allowed to erode, or the beach is so wide that backshore erosion is not occurring (like when the beach is widened after beach nourishment), the shoreline erodes according to a standard Bruun slope, which is the slope between the depth of closure and the backshore toe location (shoreface height/active profile length).

However, if the backshore is allowed to erode, it will release sand into the system that will slow future erosion. In this case, a modified Bruun slope is used, which accounts for the eroding dune height. This slope is calculated as: (shoreface height + dune height)/(active profile length). Therefore, if the dune is very high, the slope increases and the sea level rise transgression is reduced. The taller the dune, the more the sea level rise transgression is reduced. In the beach nourishment scenarios, the shoreface slope is changed over time to reflect decreasing availability of beach-sized sediments. See the discussions about beach nourishment in Section 4 below for more detail.

The model assumes a linear transition between when a regular Bruun slope is used and when the modified Bruun slope is used (Figure 3). When the beach is more than 2x wider than the stable beach slope, the Bruun slope is used. When the beach is narrower than the stable beach slope and the backshore is allowed to erode, the modified Bruun slope is used. In between these two beach widths, the erosion is linearly interpolated between the two methods.

[3] The MHW line was extracted from the 2009 - 2011 California Coastal Conservancy Coastal LiDAR Project Hydro-Flattened Bare Earth DEM.

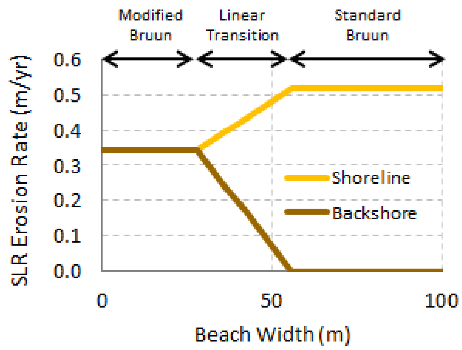

Figure 3: Example of empirical relationships between sea level rise-induced erosion rate and beach width. In this example the existing beach width is 28 meters. The sea level rise erosion rate for the standard Bruun slope is 0.52 m/yr, while the modified Bruun slope, which takes into account sediments released by the eroding dune, is 0.34 m/yr. In between the two conditions, a linear transition is assumed.

Two sea level rise curves are assessed in this study[4]. The curves are based on recent NRC 2012 guidance. These curves predict 0.88 m and 1.59 m of sea level rise by 2100, relative to 2010. As the rate of sea level rise increases towards the end of the century, the contribution of sea level rise to shoreline movement will likely be greater than ongoing erosion.

2.1.2.2 Background Erosion

All four reaches have a historic shoreline trend – either erosion or accretion. If no action is taken, and the beach and dunes are allowed to erode, this component of erosion will remain constant. However, if actions are taken that modify the beach's behavior (like beach nourishment or building a seawall), this component of erosion can increase or decrease. In this model, shoreline erosion is specified as a function of beach width. When the beach is nourished, the beach widens and the shoreline moves seaward. In this unusually wide beach configuration, the shoreline erosion rate is expected to increase (Dean 2002). If the beach narrows (either due to sea level rise or background erosion combined with holding the line), shoreline erosion decreases. An exponential empirical relationship was established between shoreline erosion rate and beach width for each reach that reflects this conceptual model.

$$E_{shoreline}(t) = \min(E_{shoreline,historic} * e^{a\left(\frac{BW(t)}{BW_{stable}}-1\right)}, E_{shoreline,max})$$

Where:

$E_{shoreline}$ (t)	= Shoreline erosion at time t
$E_{shoreline, historic}$	= Historic shoreline erosion rate
$E_{shoreline,max}$	= Maximum shoreline erosion rate
BW (t)	= Beach width at time t
$BW_{ambient}$	= "Ambient" beach width
a	= calibration parameter for erosion rate responsive to beach width

[4] The Monterey Bay Sea Level Rise Vulnerability Study considered three sea level rise curves. The current study uses the medium and high curve from the previous study. The low sea level rise projection (0.41 m by 2100, relative to 2010) is not carried forward in the current study.

Similar exponential relationships have been proposed for existing sand placement projects (Dean 2002). One assumption is that sand placements are self-similar. Previous studies have shown that an exponential relationship may overestimate the erosion rates (Dette et al. 1994). Because very little data exist related to response of shoreline erosion to sand placement, the decay parameter was selected based on wave exposure. A value of 1 at Sand City resulted in erosion rates that matched quite well with the prior coastal erosion study (ESA PWA et al 2012). Then, the value of (a) was increased in areas with higher wave exposure, like Marina, and decreased in reaches with lower wave exposure, like Del Monte. When a groin is implemented, the decay parameter is reduced by 50%, to account for the reduced potential sediment transport. In the beach nourishment scenarios, the decay parameter is increased over time to reflect decreasing availability of beach-sized sediments (finer sediments are removed from the system more quickly). See the discussions about beach nourishment in Section 4 below for more detail.

An example of this relationship is plotted in Figure 4. When the beach width is equal to the ambient beach width, the erosion rate is equal to the long-term historic erosion rate. The equation is capped with a maximum erosion rate to acknowledge that there is a limit to how quickly sand can be removed from the beach. A high value of the calibration parameter (a) leads to erosion rates being more responsive to beach width. A value of 0 would result in a constant erosion rate equal to the historic erosion rate, regardless of beach width.

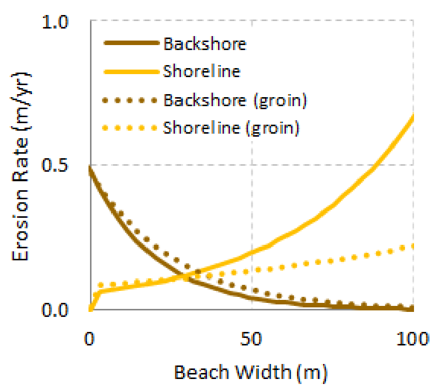

Figure 4: Example of empirical relationships between erosion rate and beach width. In this example, the existing beach width is 29 meters. The historic shoreline and backshore erosion rates are both 0.12 m/year. When a groin is added, the ambient beach width is assumed to widen by 25% to 36 meters; the shoreline erosion rates for beaches wider than the ambient beach with are reduced compared to no-groin conditions.

2.1.2.3 Beach Nourishment

This component of the equation applies during beach nourishment scenarios. Each time beach nourishment is implemented, it widens the beach by shifting the shoreline seaward. The amount the shoreline is shifted seaward depends on the volume of sand placed on the beach, the profile characteristics, and sand quality.

2.1.3 Backshore Erosion

The backshore location is tracked using a similar empirical relationship as the shoreline. The basic equation is similar except that the beach nourishment adjustment (which only changes the shoreline) is replaced with a placement loss distance (which only affects the backshore when armor is constructed).

$$Backshore\ Movement = SLR\ transgression + Ongoing\ erosion - Placement\ Loss$$

2.1.3.1 Sea Level Rise Transgression

As with the shoreline, the impact of sea level rise on backshore movement is incorporated by assuming that the backshore toe will move inland based on the shape of the beach profile and the amount of sea level rise:

$$Sea\ Level\ Rise\ Transgression = \frac{increase\ in\ sea\ level}{shoreface\ slope}\ or\ 0$$

The sea level rise component of backshore erosion is plotted on Figure 3 along with the shoreline erosion. If the backshore is allowed to erode and the beach is narrower than the stable beach width, a modified Bruun slope is used in this equation. This slope is calculated as:

$$Modified\ Bruun\ Slope = \frac{shoreface\ height + dune\ height}{active\ profile\ length}$$

If the scenario is to hold the line or the beach is wider than twice the stable beach width, the backshore does not erode. The backshore erosion is linear between 0 and the modified Bruun transgression when the beach is between the stable beach width and 2x the stable beach width.

2.1.3.2 Background Erosion

Bluff erosion is expected to have the opposite response to beach width: when the beach is wide, the backshore is expected to erode more slowly than if the beach is narrow, due to the additional protection from waves provided by the wide beach. When the beach becomes narrow, the backshore is expected to erode more quickly due to more frequent wave contact at the backshore toe. Once again, the erosion rate is capped by the maximum backshore erosion rate to acknowledge that the backshore (bluff/cliffs in particular) should have a maximum erosion rate which is a function of geology. This relationship is plotted, along with the similar relationship for shoreline erosion, in Figure 4.

$$E_{backshore}(t) = \min(E_{backshore,historic} * e^{-b\left(\frac{BW(t)}{BW_{stable}}-1\right)}, E_{backshore,max})$$

Where:

$E_{backshore}$ (t)	= Backshore erosion at time t
$E_{backshore,\ historic}$	= Historic backshore erosion rate
$E_{backshore,max}$	= Maximum backshore erosion rate
BW (t)	= Beach width at time t
$BW_{ambient}$	= "Ambient" beach width
b	= calibration parameter for erosion rate responsive to beach width

In this case we calculate the decay parameter (b) using the ratio:

$$b = \frac{shoreface\ height + dune\ height}{shoreface\ height}$$

which is derived from a modified Bruun profile. This value could be modified in more detailed studies with additional information about how the backshore responds to narrower or wider beaches. Most reaches were relatively insensitive to this parameter.

It is important to note that this model does not address backshore erosion due to terrestrial processes (e.g., ground water levels, seismic forces, geology, land use, etc.) that are independent of coastal processes and outside the scope of this study.

2.1.3.3 Placement Loss

Placement loss refers to the space taken up by construction of a coastal protection structure like a revetment or seawall. These structures are usually placed at the back of the beach and cover part of the existing beach width, effectively shifting the backshore line seaward. For the current study, a placement loss of 7.6 meters (25 feet) was assumed for all Hold the Line scenarios.

2.2 Estimating Future Intertidal Habitat

In addition to the beach width and backshore, the intertidal width and slope was estimated over time for each reach and adaptation scenario. The intertidal width is assumed to be the horizontal distance between Mean High Water (MHW, 1.46 m NAVD88) and Mean Lower Low Water (MLLW, 0.043 m NAVD88). A representative profile, shown in Figure 5, was developed to compare how the intertidal area evolves under an “Allow Erosion” (at -3 fpy) and a “Seawall” (i.e., Hold the Line) scenario. For the allow erosion scenario, the beach profile simply moves inward and upward with sea level rise and background erosion. For the seawall scenario, the backshore is not allowed to move, so over time the beach in front of the seawall scours deeper. First the beach is lost, and eventually the intertidal area is lost as well.

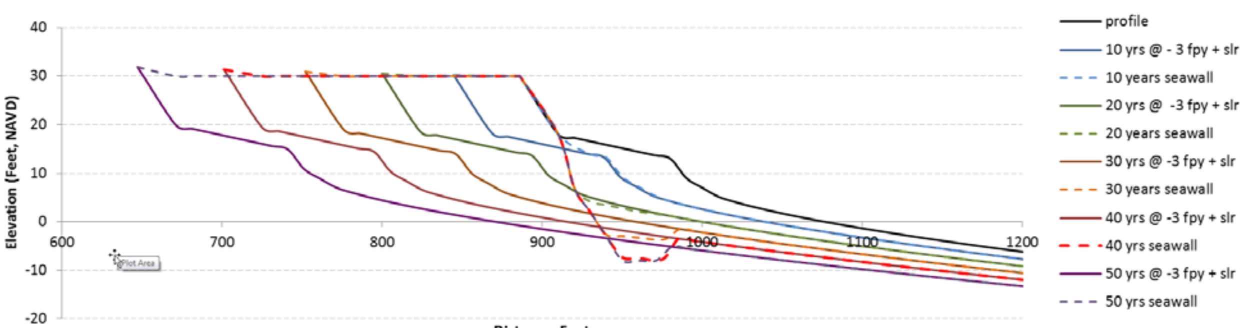

Figure 5. Representative Profile Comparing two Adaptation Scenarios

From these profiles, a look-up table was developed for the seawall (hold the line) scenario that was used to apply these changes to the four SMB reaches. The look-up table (Table 3) relates the percent intertidal width remaining to the amount that the shoreline (MHW line) would have eroded past the backshore toe, had the seawall not been present. We assume that no significant change to the intertidal width would occur under beach nourishment or allow erosion scenarios. This table was used to calculate the intertidal width remaining for each reach and adaptation scenario. The results can be seen (by reach) in Appendix 1a-1h. The results of intertidal width were used by the ecologists to quantify habitat through time.

Table 3. Percent Intertidal Width Remaining vs. Potential Erosion

Distance Eroded Past Toe (m)	% Intertidal Width Remaining
0	100%
0	100%
0	100%
10	16%
25	16%
42	16%
143	9%

The intertidal slope was then calculated by dividing the vertical elevation band (1.41 meters, MLLW to MHW) by the intertidal width remaining. Intertidal parameters were not scaled down to the block-level due to lack of data in the intertidal zone.

2.3 Converting Reach-Averaged Results to Block Scale

The final results were post-processed to develop block-level (500-m) beach widths, long-term erosion, and storm erosion metrics to be used as inputs to the economic modeling. Adaptation scenarios in this study are specific to each of four reaches, each of which was modeled by a representative transect. In order to translate the future response of the representative transect to all blocks in a reach, we used relative ratios that relate the attributes of a block to the average within its reach. Relative ratios were calculated for beach width, backshore erosion, and storm erosion impact distance, which were used to apply the geomorphic response of a reach under different adaptation strategies. For example, the calculated erosion at time 2030 for the Del Monte reach representative transect was scaled to each block in the Del Monte reach based on the ratio of the background erosion rate for that block (computed in a previous study) to the average of all blocks in the reach. Table 4 below is an example of the previously computed erosion distances and newly calculated ratios for blocks in the Del Monte Reach under future time horizons.

Table 4. Relative ratios used to prorate reach average erosion to block scale.

Backshore Erosion Distance (X) by Block					
Reach	BlockID	Er2010	Er2030	Er2060	Er2100
Del Monte	264	-	7.9	23.1	48.1
Del Monte	265	-	2.8	8.7	30.2
Del Monte	266	-	2.2	5.5	25.7
Del Monte	267	-	6.8	20.4	42.8
Del Monte	268	-	6.1	18.0	37.5
Reach Average Erosion X					
Reach	BlockIDs	Er2010	Er2030	Er2060	Er2100
Del Monte	264 to 268	-	5.2	15.1	36.9
Relative Ratios = (Block Erosion X) / (Reach Average Erosion X)					
Reach	BlockID	Er2010	Er2030	Er2060	Er2100
Del Monte	264	-	1.5	1.5	1.3
Del Monte	265	-	0.5	0.6	0.8
Del Monte	266	-	0.4	0.4	0.7
Del Monte	267	-	1.3	1.3	1.2
Del Monte	268	-	1.2	1.2	1.0

2.3.1 Beach Width

The beach width model described in this memo provided beach widths over time as computed on representative transects for each of the four study reaches. The results for the reaches were prorated to the 500-meter blocks using the average existing beach width. The ratio of existing block beach width to existing (average) reach beach width was used to scale the future beach widths, as follows:

$$Beach\ Width_{Block,\ Scen,Future} = Beach\ Width_{Reach,Scen,\ Future} * \frac{Beach\ Width_{Block,\ 2010}}{Beach\ Width_{Reach,\ 2010}}$$

2.3.2 Backshore Erosion

The backshore erosion results for the reaches were prorated to the 500-meter blocks using the baseline erosion rates computed in MBSLR. For context, the baseline (MBSLR) erosion rates assumed the beach profile retreated as one unit, which is distinguished from the newly computed rates from the quantified conceptual beach erosion model that erodes the shore and backshore separately and considers the beach width as a buffer to backshore erosion. The ratio of future block backshore erosion to future reach average backshore erosion was used to scale the future reach backshore erosion for each management scenario, as follows:

$$Erosion_{Block,Scen,Future} = Erosion_{Reach,Scen,Future} * \frac{Erosion_{Block,\ \mathbf{Baseline},Future}}{Erosion_{Reach,\ \mathbf{Baseline},Future}}$$

2.3.3 Storm Erosion Impact Distance

The storm erosion impact distances for the reaches were prorated to the 500-meter blocks using the baseline storm erosion distances for each block. Similar to backshore erosion, the newly computed erosion impacts articulate with changing beach width, described in the modeling methods above. The ratio of future block storm erosion to future reach storm erosion was used to scale the future reach storm erosion for each management scenario, as follows:

$$Storm_{Block,Scen,Future} = Storm_{Reach,Scen,Future} * \frac{Storm_{Block,\,\boldsymbol{Baseline},Future}}{Storm_{Reach,\,\boldsymbol{Baseline},Future}}$$

2.4 Converting Projected Erosion into GIS Beach Zones

The processed block-level results were converted into GIS shapefiles which represent four zones:

- Offshore: seaward of the shoreline (Mean High Water)
- Beach: Shoreline (Mean High Water) to the dune/revetment toe
- Dune Face: Dune toe to the dune crest. Includes revetment footprint, if applicable
- Storm Erosion Zone: Dune crest to the inland extent of storm hazard.

A separate set of zones exists for each adaptation scenario, planning horizon, and sea level rise scenario. These zones represent the beach during a winter/spring condition. This section describes how the mapped zones are derived from the block level results (described in the previous section).

An offshore baseline was derived from the 2010 MHW shoreline by buffering the line offshore by 70 meters[5]. The distance between the reference line and the backshore toe location was calculated for each block using up to five along-shore transects (100-meter spaced).

First, to estimate the location of the backshore toe, the offshore reference line was buffered as follows:

$$buffer\ distance = offset\ to\ backshore\ toe + backshore\ erosion - placement\ loss$$

Second, to estimate the location of the shoreline, the beach width was subtracted from the above buffer distance.

Third, to estimate the dune crest location, the dune face width was added to the above buffer distance. Each study block has an average dune toe and crest elevation. The difference in this elevation was divided by the tangent of a typical dune angle of repose (0.625) to obtain the dune face width. If the adaptation scenario being mapped includes a placement loss, this is included in the “dune face” zone (and removed from the beach zone).

Finally, to estimate the inland extent of storm erosion impacts, both the dune face width and the pro-rated storm distance were added to the above buffer distance. Notice in Figure 6 that the hold the line scenario does not show storm erosion, because the armoring is assumed to prevent erosion, however wave runup and overtopping still occur.

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[5] This reference line differs slightly from the reference line that was used in MB SLR 2014. The previous study used a reference line from a 2009 state-wide study (PWA 2009), which derived its reference line from an older (1978) shoreline inventory. Since Southern Monterey Bay experiences high erosion rates, this reference line was no longer parallel and offshore of the shoreline in some places, so a new up-to-date reference line was developed for this study.

These four locations were overlapped in GIS to develop polygons that include the four zones: offshore, beach, dune face, and storm erosion impact area (Figure 6).

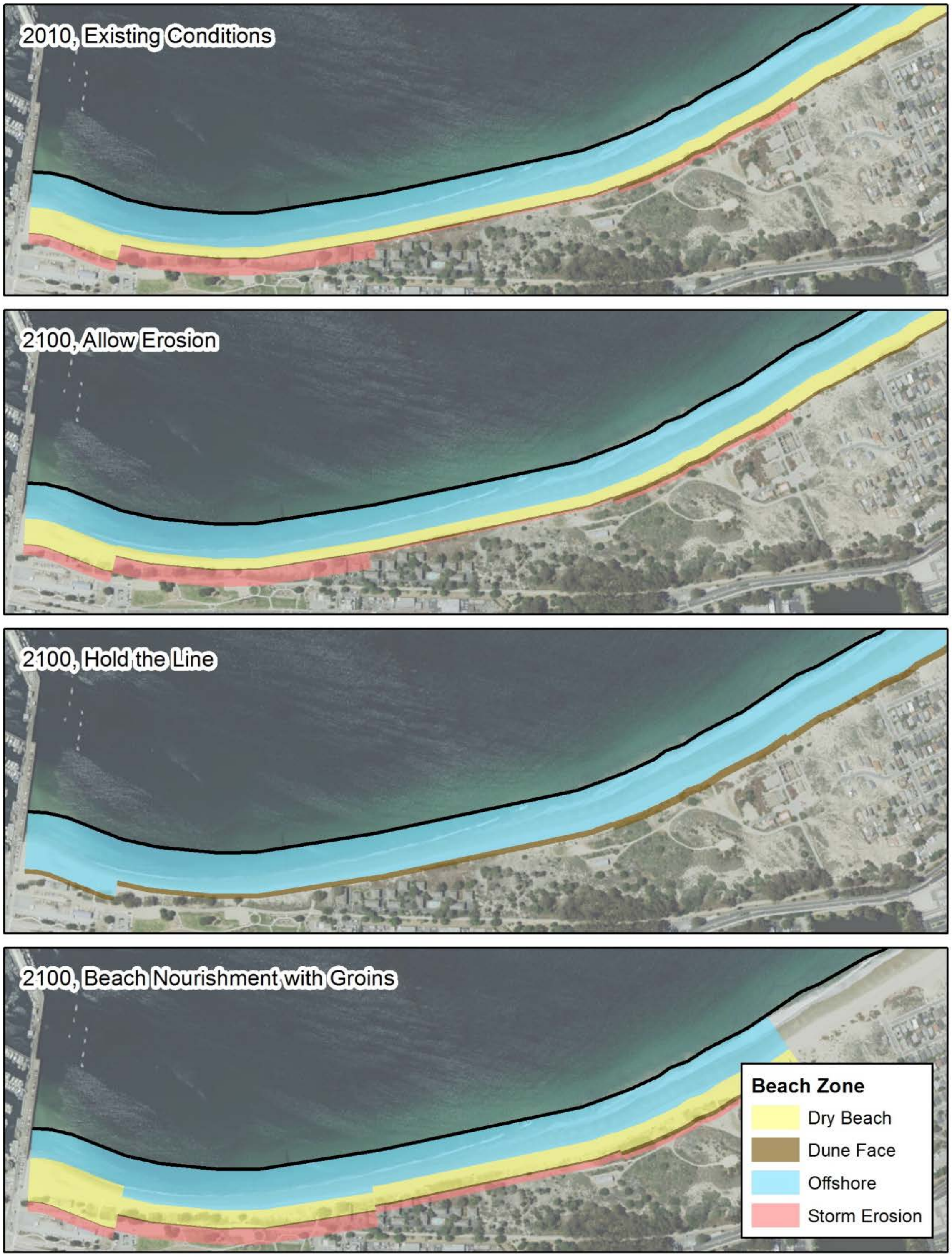

Figure 6. Example of erosion results shapefiles showing beach zones in Del Monte reach (not all adaptation scenarios are shown, High SLR scenario).

3 COASTAL FLOOD MODELING

Using the outputs from the sophisticated beach width and erosion model, coastal flooding caused by a coastal storm was remodeled for the scenarios considered in each study reach. The flooding processes considered include (1) storm surge (a rise in the ocean water level caused by waves and pressure changes during a storm), (2) wave overtopping (waves running up over the beach and flowing into low-lying areas, calculated using the maximum historical wave conditions), (3) extreme lagoon water levels which can occur when lagoon mouths are closed and fill up during rainfall events, and (4) additional flooding caused by rising sea level in the future. This hazard zone takes into account areas that are projected to erode in the future, sometimes leading to additional flooding through new hydraulic connections between the ocean and low-lying areas. The more sophisticated beach width and erosion model thus enables the articulation of wave runup and overtopping with each adaptation management scenario. The methods used to produce coastal flooding hazard zones for each adaptation management scenario are described in the following sections.

3.1 Chronic Flooding Hazard Zones

Chronic flooding hazard zones were previously mapped for MBSLR (2014) and are directly applied in this study for all management scenarios. These hazard zones show which areas will be regularly flooded (once per month, on average) by high tides under future sea level rise (not considering storm events). Two types of chronic flooding datasets were developed: a general inundation area and a depth grid (or raster).

The monthly Extreme Monthly High Water (EMHW) was estimated by averaging the maximum monthly water level for every month recorded at the Monterey Bay tide gage (EMHW = 2.0 meters (6ft 6 inches) NAVD88) and raised with sea level rise projections for each planning horizon and mapped over the 2009 – 2011 CA Coastal Conservancy DEM. Flooding depths were calculated and used as input to depth-damage curves to estimate costs associated with each scenario. Details on the mapping methods are explained in MBSLR Technical Methods Report (ESA PWA 2014).

3.2 Event Wave Hazard Zones

This study modifies the MBSLR baseline event wave impacts resulting from a 100-year coastal storm in order to articulate the wave hazards with each adaptation scenario. Under the different management scenarios, storm erosion was calculated in the beach width and erosion model, while the maximum inland extent and maximum elevation of wave runup were calculated using outputs from the beach width and erosion model. Storm erosion and wave runup were then mapped and merged to create the event wave hazard zones.

3.2.1 Storm Erosion Impact Zones

After the beach erosion model was run, and beach width and backshore erosion estimated through time, a storm erosion impact distance was estimated. In the MBSLR study (ESA PWA 2014), baseline 100-year storm erosion distances were estimated for each block. Using these baseline results, a reach-averaged storm erosion distance was calculated for each of the four reaches. Then, the storm distance was modified to reflect the various adaptation strategies, as follows:

$$Storm\ Erosion_{Reach,Scen,Future} = \min(\max(0, Storm\ Erosion_{Reach,Baseline,Exist} - change\ in\ beach\ width), 1.5 * Storm\ Erosion_{Reach,Baseline,Exist})$$

First, the change in beach width was subtracted from the existing storm distance. This means that if the beach is wider than it was under existing conditions, the storm distance is smaller. If the beach is narrower, then the backshore storm distance increases. However, the storm distance is not allowed to go negative. Additionally, the storm distance is capped at 1.5 times the existing storm distance. The storm impact zones are then mapped for each management scenario, sea level rise scenario, and planning horizon using a one-sided buffer in ESRI's ArcGIS software with an ArcINFO® license.

3.2.2 Wave Runup Impact Zones

Wave runup was recomputed using the composite slope method on transects that exhibited overtopping of the back beach barrier (dune crest) in the MBSLR study. The new results for wave runup were applied locally to the block that is intersected by the composite slope transect and to adjacent blocks that had similar crest elevations and wave exposure as the transect block. The extents were applied to a maximum of three blocks away from the composite slope transect in either direction. Details on the wave runup computation methods can be found in the Monterey Bay Sea Level Rise Vulnerability Study Technical Methods Report (ESA PWA 2014). The methods used to modify the new runup values to consider beach and backshore erosion for the different modeled scenarios are described below.

The computed wave runup described above represents existing conditions, and had to be adjusted for each adaptation scenario and future time horizons. Future wave runup distance was prorated based on dune toe erosion and change in beach width associated with each adaptation alternative. At any time for a particular block, the inland extent of wave runup projected from the baseline was calculated as follows:

$$WR_{Block}(t) = WR_{Block,Present} + E_{Block,Backshore}(t) - (BW_{Block}(t) - BW_{Block,Present})$$

Where:

$WR_{Block}(t)$ = Wave Runup distance at time t
$WR_{Block,Present}$ = Wave Runup distance for existing conditions
$E_{Block,Backshore}(t)$ = Backshore erosion distance at time t
$BW_{Block}(t)$ = Beach width at time t
$BW_{Block,Present}$ = Beach Width for existing conditions

Thus, wave runup will reach further inland with an eroding dune toe as well as respond to changes in beach width. Because the beach acts as a natural buffer to wave runup, a wider beach would reduce the wave energy that reaches the backshore and therefore reduces wave runup. Conversely, a narrow beach provides less of a buffer and runup would increase with a shrinking beach width. Maximum inland distance wave runup zones were then mapped for each management scenario, sea level rise scenario, and planning horizon using a one-sided buffer in ESRI's ArcGIS software with an ArcINFO® license.

In the areas where the backshore is comprised of steep dunes, the inland extents of wave runup were limited by the topography up to the maximum runup elevation. Using the existing maximum runup computed, future maximum wave runup elevation was prorated based on change in beach width associated with each adaptation alternative. At any time for a particular block, the maximum elevation of wave runup was calculated as follows:

$$WRz_{Block}(t) = (WRz_{Block,Present} - DWL_{Block,Present}) * \left(\frac{WRx_{Block,Present}}{WRx_{Block,Present} + (BW_{Block}(t) - BW_{Block,Present})}\right) + DWL_{Block,Present}$$

Where:

WRz_{Block} (t)	= Wave Runup elevation at time t
$DWL_{Block,Present}$	= Dynamic water level (wave setup) elevation for existing conditions
$WRz_{Block,Present}$	= Wave Runup elevation for existing conditions
$WRx_{Block,Present}$	= Wave Runup distance for existing conditions
BW_{Block} (t)	= Beach Width at time t
$BW_{Block,Present}$	= Beach Width for existing conditions

A bathtub projection of the maximum runup elevation was then mapped for each composite slope transect using ESRI's ArcGIS software with an ArcINFO® license. The extents of the bathtub projection were then clipped by the associated inland extent buffer described above. The result is an extent of wave runup that is limited both by the maximum elevation and inland distance calculated with the above equations.

3.3 Event Flooding Zones

Flooding caused by the 100-year coastal storm was previously modeled and mapped in MBSLR. For that study, the shoreline was broken into regions based on the geomorphology and dominant process driving coastal flood levels. The flood processes considered are: 100-year tide, wave runup (explained above in 3.2.2 Wave Runup Impact Zones), overtopping, and elevated berm crest of seasonally closed lagoons. Brief descriptions are provided below, while detailed modeling and mapping methods can be found in MBSLR Technical Methods Report (ESA PWA 2014).

3.3.1 100-year Tide

The 100-year tide water level (2.48 m NAVD88) was assumed to be the major coastal flood process in Elkhorn Slough. No variations in extreme water levels were considered (no tidal muting or amplification). As with the chronic flooding zones, the 100-year water level was raised by sea level rise for future planning horizons.

3.3.2 Overtopping

This method was used in places where low-lying areas are separated (disconnected) from the ocean by dunes, coastal armoring structures, or other obstructions. During large wave events, wave run-up can overtop these structure and flow into low-lying areas. Because these areas are disconnected from the ocean, flood waters cannot easily drain, causing persistent flooding. Using the maximum wave runup elevations and eroded future dune crests calculated for each management scenario, sea level rise scenario, and planning horizon, overtopping volumes were generated and resulting inundation elevation and extents were mapped in the low-lying basins using hypsometry curves.

3.3.3 Berm Crest of Seasonally Closed Lagoons (Bar Built Estuaries)

The third flood mechanism considered in this study applies to coastal lagoon systems, which occur at confluences between creeks/rivers and the ocean. Unlike open tidal systems, these seasonally closed lagoons often experience the highest water levels during closed conditions, when a high beach berm develops and there is enough runoff to fill the lagoon but not breach. The Salinas River lagoon was considered in the current study. The estimated maximum potential beach berm elevation of 16 feet NAVD88 was used from MBSLR. In the future, the sediment supply is assumed to be consistent with existing conditions to allow the "maximum beach berm elevation" to rise in equilibrium with sea level (i.e., the maximum flood elevation in the closed lagoon rises at the same rate as sea level). The existing and future maximum flood elevations were mapped over existing topography to identify the flood hazard zone for the Salinas River seasonally closed lagoon system.

4 MODEL APPLICATION

4.1 Management Actions

The quantified conceptual model described above was used to analyze five types of management actions. Up to four of these scenarios were assessed for each study area, summarized in Table 2. A scenario may combine multiple management actions for a "hybrid" approach. Each of the potential management actions and the associated model input parameters are described below. These descriptions focus on the physical implications of each management action rather than economic implications (e.g., costs, which will be discussed in a later memo).

4.1.1 Hold the Line

This action maintains existing coastal protection infrastructure (seawalls, revetments) where it currently exists and constructs coastal protection infrastructure where it does not yet exist. With continued shoreline erosion and the additional impact of sea level rise, the beach will continue to narrow. This action is implemented by setting backshore erosion rate to zero. A portion of the beach is converted to coastal armor, resulting in a placement loss (beach narrows initially). The structure is assumed to protect the area behind it from erosion hazards, however, wave run-up and overtopping hazards may still remain behind the structures.

4.1.2 Allow Erosion

The shoreline and backshore are allowed to erode at a natural rate. This model was applied to scenarios of managed retreat, fee simple acquisition, conservation easements, and elevating infrastructure, all of which allow erosion to continue. Since the dunes are permitted to erode, the beach erodes at a slower rate than when the backshore is not allowed to erode due to additional sand being released into the system.

4.1.3 Beach Nourishment

The following sections describe how three types of beach nourishment scenarios are implemented in the model. In general, the model handled frequency of beach nourishment by mitigating increasing erosion due to sea level rise but allowing the background erosion rate to continue. So, most of the beach nourishment scenarios are modeled such that the backshore erosion by 2100 is equal to the backshore erosion that would have occurred by 2100 without sea level rise (simply from ongoing erosion). The exception is "beach nourishment with a set schedule," as described below.

There is not an infinite supply of coarse, beach-sized sand in southern Monterey Bay, so some adjustments were made to the beach nourishment scenarios to reflect finer sand being used over time. This manifests itself in two ways: (1) increased erosion from sea level rise due to a flatter shoreface slope and (2) higher diffusion rate of placed sediment (increase in background erosion rate).

The flatter shoreface slope was estimated using a Dean equilibrium profile, which derives a profile from a grain size. The Dean profile was used to estimate a percent change in shoreface slope with a specified change in grain size. First, the existing shoreface composite grain sizes for Sand City and Del Monte (the two reaches with beach nourishment scenarios) were estimated to be 0.4 and 0.3 mm, respectively. Then, future available grain sizes were selected using judgement for the 2030 – 2060 time horizon (0.3 mm) and the 2060 – 2100 time horizon (0.2 mm). A percent change in shoreface slope was estimated using the Dean equilibrium profiles derived from the changing grain size. This percent change was then applied to the existing shoreface slopes. The new shoreface slopes were used to calculate new Bruun sea level rise recession rates. The sand grain sizes for beaches were selected based on prior studies (PWA 2008; Chambers 2014). Sand sources (locations where sand for beach nourishment would be obtained) were identified and characterized using prior studies (PWA 2008; M&N and Everts 2009; USGS 2015).

A higher diffusion rate (due to smaller future grain size) was implemented by using a larger a-value. The a-value is described above in Sections 2.1.2 and 2.1.3. For Sand City, the a-value was increased from 1 to 1.2 during 2030-2060 and to 1.5 during 2060 – 2100. For Del Monte, the a-value was increased from 0.7 to 1.1 during 2060 – 2100 (no change for 2030 – 2060 because the available grain size matches existing shoreface grain size).

4.1.3.1 Beach Nourishment as Needed (Sand City)

Beach nourishment (as needed) is implemented in the model by moving the shoreline seaward by the sand placement width, which depends on the reach. Beach nourishments are triggered at the beginning of the model and as necessary to mitigate the sea level rise component of erosion. Beach nourishment parameters and notes describing how these parameters were selected are summarized in Table 5 for each reach.

4.1.3.2 Beach Nourishment with Groins (Del Monte)

The beach nourishment component of this management option is treated in the same manner as described in *Beach Nourishment as Needed*, above. Groins are implemented in the model by adjusting the empirical relationship between erosion rate and beach width, historic erosion rate, and ambient beach width. Groins have successfully demonstrated the ability to maintain a wider beach where wave conditions are ideal. The beach reaches a new, wider equilibrium. This is implemented in the conceptual model by increasing the "ambient beach width" in the empirical relationships described previously (25% wider).

Limited data exist to quantify the extent to which groins would change shoreline movement rates, especially with the contribution of sea level rise. Table 5 shows the input parameters selected for each reach with the rationale for choosing each parameter.

4.1.3.3 Beach Nourishment with a Set Schedule (Del Monte)

Beach nourishment (set schedule) is implemented in the model by specifying a beach nourishment width and schedule. Beach nourishments are triggered at the beginning of the model and then at the specified schedule (e.g., every 10 years). Because the intent of beach nourishment is to maintain a beach and slow backshore erosion, the backshore is still allowed to erode (but erodes at a slower rate due to a wider beach). The volume of nourishment, 50,000 cubic yards, was selected to represent an "opportunistic" sand nourishment, in which a small amount of sand becomes available. Therefore, unlike the other beach nourishment scenarios, the driving factor in this scenario is the nourishment schedule, not preventing additional erosion due to sea level rise. Beach nourishment parameters and notes describing how these parameters were selected are summarized in Table 5 for each reach.

Table 5: Input Parameters for each Reach and Scenario

	Monterey	Sand City	Marina	Moss Landing	Notes
All Scenarios					
starting beach width (m)	29	28	46	38	*May/June 2010 beach width, averaged across all blocks*
ambient beach width (m)	29	28	46	28	*Only different for Moss Landing*
shoreline erosion rate (m/yr)	-0.12	-0.5	-1.17	0.21	*Shoreline erosion rate averaged across all blocks*
backshore erosion rate (m/yr)	-0.12	-0.5	-1.17	0.21	*Assumed to be equal to shoreline erosion rate over long time periods*
max bckshr erosion rate (m/yr)	-2	-2	-2	-2	*Default*
max shoreline erosion rate (m/yr)	-4	-4	-4	-4	*Default*
bluff attenuation factor (unitless)	1.38	1.52	1.74	0.00	*Based on modified Bruun profile*
beach attenuation factor (unitless)	0.7	1	1.2	0	*Based on wave exposure*
reach length (m)	1621	4092	14500	6000	*Total reach length*
shoreface height (m)	8.6	12.2	16.4	17.0	*Average value for all blocks*
overall profile slope (m/m)	0.052	0.046	0.035	0.019	*From depth of closure to dune toe*
modified Bruun slope (m/m)	0.072	0.070	0.061	0.022	*From depth of closure to dune crest*
Hold the Line					
armor placement loss (m)	7.6	7.6	7.6	7.6	*Assumed 25 feet - all revetments*
Beach Nourishment (As Needed)					
nourishment volume (CY)	#N/A	2,000,000	#N/A	#N/A	
sand placement width (m)	#N/A	30.5	#N/A	#N/A	*Derived from volume + profile shape + reach length*
minimum beach width (m)	#N/A	24.5 or 27	#N/A	#N/A	*Selected to prevent accelerated backshore erosion from Medium or High SLR, respectively*
Beach Nourishment (Set Schedule)					
nourishment volume (CY)	50,000	#N/A	#N/A	#N/A	
sand placement width (m)	6	#N/A	#N/A	#N/A	*Derived from volume + profile shape + reach length*
time between nourishments (yrs)	10	#N/A	#N/A	#N/A	
Beach Nourishment with Groins					
nourishment volume (CY)	400,000	#N/A	#N/A	#N/A	
sand placement width (m)	22.0	#N/A	#N/A	#N/A	
new stable/ambient beach width (m)	36.3	#N/A	#N/A	#N/A	*25% larger than starting beach width*
min permitted beach width (m)	43.5	#N/A	#N/A	#N/A	*50% more than existing beach width*
bluff attenuation factor (unitless)	1.38	#N/A	#N/A	#N/A	
beach attenuation factor (unitless)	0.35	#N/A	#N/A	#N/A	*50% less than no groins*

4.2 Model Limitations

While the conceptual model enabled the technical team to link adaptation scenarios to beach and backshore erosion, there are some inherent limitations to the model.

1. Lack of site-specific data to use as inputs and to calibrate the conceptual model. In particular:
   - Impact of groins on erosion rates, especially in combination with sea level rise.
   - Relationship of beach width to shoreline backshore and erosion was qualitatively observed, but limited data exist to calibrate the empirical relationships.
   - Maximum erosion rates for shorelines and dunes. This likely depends on sediment supply and wave processes (see limitation #2).
2. Not a hydrodynamic or sediment transport model.
3. Does not address erosion caused by terrestrial processes.
4. Hazard zone algorithm is fairly simple.

4.3 Outputs

The following outputs are extracted from the quantified conceptual model and provided in a summary table for each reach and scenario (Appendix 1a-h). These outputs were chosen for their utility as inputs to the economic assessment.

- *Reach Name*
- *Modeling Approach*: Brief description of the model scenario (see **Error! Reference source not found.**).
- *Sand Placement Frequency*: Number of sand placements triggered between 2010 and 2100, and the years that those placements are triggered.
- *Long Term Backshore Erosion*: Erosion that occurs at the back of the beach in 10 year increments.
- *Average Beach Width*: The average beach width in 10-year increments. The beach widths are averaged over these 10-year time periods because nourishment activities lead to significant beach width variation from year to year, so taking the beach width for a single year might not be representative of the average conditions.
- *Storm-Induced Erosion*: Amount of erosion that could occur at the back of the beach during a large (i.e., 100-year) erosion event.
- *Total Coastal Erosion Hazard Zone*: The distance from the reference toe line (backshore toe location in year 2010) to the inland extent of the erosion hazard. This value is calculated from the backshore erosion, storm-induced erosion, and offset using the method described below.
- *Intertidal Width and Slope*: The width and slope of the intertidal zone (between MLLW and MHW) over time in 10-year increments.
- Plots of shoreline and backshore locations, beach width, and intertidal width over time.

5 RESULTS, SUMMARIES, AND MAPS

5.1 Beach Zones

Results from the quantified conceptual model were compiled for each reach under both sea level rise scenarios (Medium and High) and are presented in Appendix 1a-1h.

For each reach/SLR scenario, the following information is presented:

- Graph of **beach width over time** for each adaptation scenario. [Note: beach width is simply the distance between the shoreline (based on 2010 Mean High Water line) and the backshore (dune or seawall toe) locations].
- Graph of **shore and backshore location over time** for each adaptation scenario [Note: a location of 0 corresponds to the starting (2010) shoreline location. Negative values correspond to locations onshore of the starting shoreline. Therefore, the backshore line begins at a negative distance equal to the beach width.]
- **Beach width** averaged across three time horizons for each adaptation scenario.
  [Note: these horizons can be tailored to match the needs of the economic study – the beach width modeling is done on a 1-year time-step. The beach widths were averaged over time to remove some of the variability induced by beach nourishments, which can be seen in the beach width graphs.]
- Amount of **backshore erosion** at three time horizons for each adaptation scenario.
  [Note: this is a long-term backshore change and does not include storm damages. Storm damage distances will be included in the final results and also reflected in the relevant erosion hazard zone shapefiles.]
- Years **when beach nourishment occurs**, and the assumed sand volume and beach widening.
  [Note: only for the Monterey and Sand City reaches, where nourishments are proposed as adaptation strategies.]

The final results were post-processed to develop block-level (500-m) beach widths, long-term erosion, and storm-erosion that can be used as inputs to the economic modeling. These block-level results were converted into GIS shapefiles (Figure 6) which represent 4 zones:

- **Offshore**: seaward of the shoreline (Mean High Water)
- **Beach**: Shoreline (Mean High Water) to the dune/revetment toe
- **Dune Face**: Dune toe to the dune crest. Includes revetment footprint, if applicable
- **Storm Erosion Hazard Zone**: Dune crest to the inland extent of storm hazard.

A separate set of zones exists for each adaptation scenario, planning horizon, and sea level rise scenario (see naming convention below). These zones represent the beach during a winter/spring condition. GIS beach zones are presented for each reach, adaptation scenario and SLR scenario in Appendix 2a-2v. Wave runup is also displayed in these appendices.

5.2 Flooding and Erosion

Shapefiles were produced for the flooding and erosion hazards as a result of the direct application of MBSLR hazard results or the modification of MBSLR hazards due to the QCM outputs for backshore erosion and beach width. Chronic flooding and erosion, as well as 100-year event based wave runup and flooding were mapped in GIS. Example results along the Del Monte oceanfront are shown in Figure 7. These hazards were subsequently intersected with parcel data and the terrain to produce flooding depths for each hazard and scenario for the economic analysis.

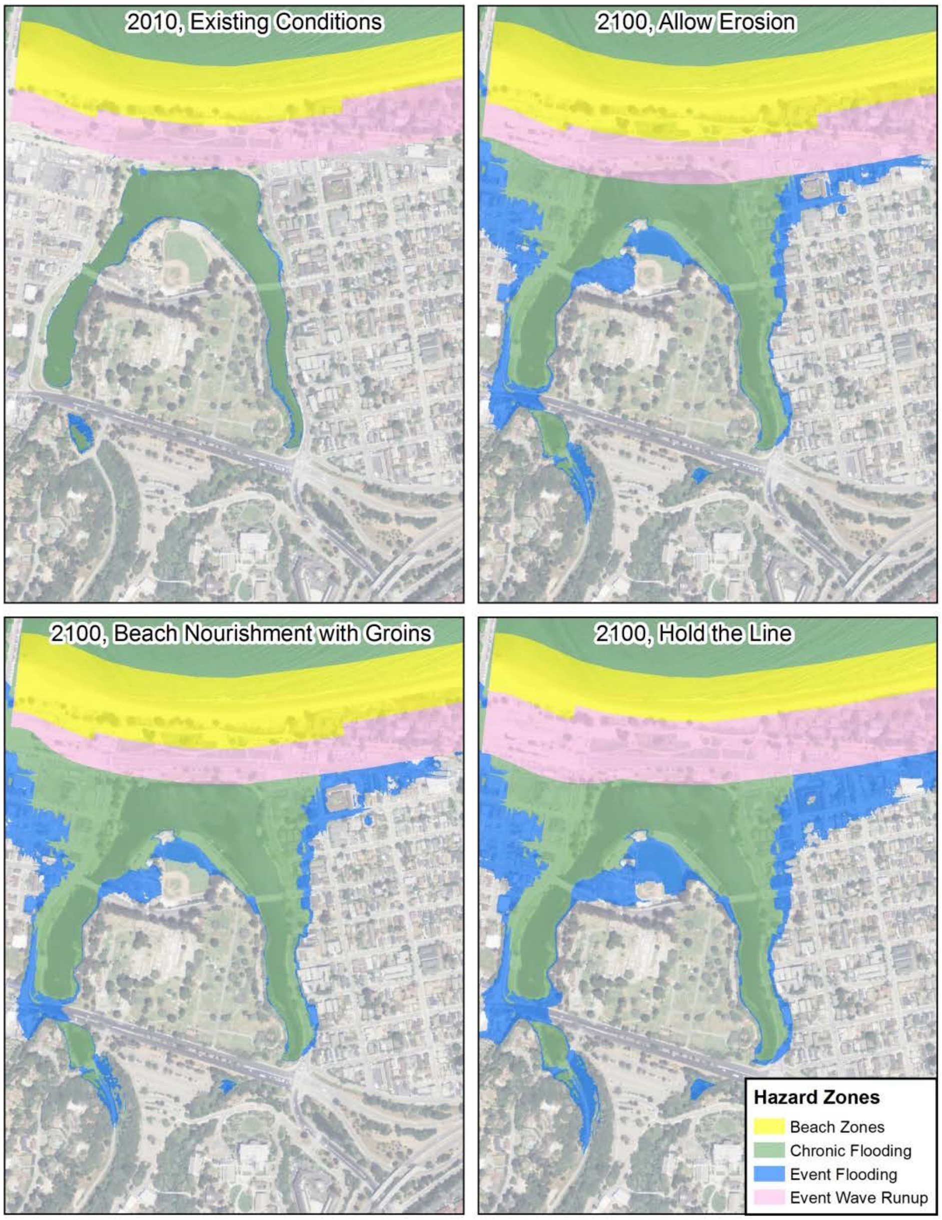

Figure 7. Example of erosion and flooding results shapefiles showing zones in Del Monte reach (not all adaptation scenarios are shown, High SLR scenario). Beach zones include offshore, beach, dune face and storm erosion.

5.3 Output Shapefile Naming Convention

"***hazard zone***" + _ + ***adaptation scenario*** + _+ **sea level rise scenario** + **planning horizon** + .shp

Hazard zones
beach_zones
chronic_erosion
chronic_flood
event_flood
event_wave

Adaptation scenarios
AER – Allow Erosion
HTL – Hold the Line
BNN – Beach Nourishment as Needed
BNS – Beach Nourishment with a Set Schedule
BNG – Beach Nourishment as Needed with Groins

Sea level rise scenario*
ec – Existing conditions (2010 water level)
s2 – Medium sea level rise (88 cm by 2100)
s3 – High sea level rise (158 cm by 2100)
**s1 is skipped because this study does not use the "low" sea level rise curve from the MB SLR study*

Planning horizon*
2010 – Existing Conditions
2030
2060
2100
**beach widths, backshore erosion, and storm hazard distances are computed at a 10-year time step, but shapefiles are only produced for the listed planning horizons.*

Example
The **beach zone** representing the offshore area, beach, dune face, and storm hazard zone for a **hold the line** scenario under **high sea level rise** in **2060** would be named: **beach_zones_HTL_s32060.shp**

A table of all coastal hazard GIS deliverables for this study are listed in Appendix 3.

6 ENGINEERING COST ESTIMATES

6.1 Disclaimer

The information provided herein was developed to provide a standard basis for comparison among different shore erosion mitigation scenarios for the benefit of coastal zone management discussions. The information provided herein is neither intended nor authorized for any other use and should not be used for any purpose without prior written approval by ESA.

For planning purposes we have provided order of magnitude estimates to allow comparison of alternative erosion mitigation scenarios. These estimates are intended to provide an approximation of shore erosion, benefits and costs appropriate for the conceptual level alternatives comparison.

These estimates do not explicitly include consideration of all possible costs, such as design, environmental review, permitting, construction administration, monitoring, property purchase and other costs. In particular, significant costs can be expected for sand mitigation fees for coastal armoring projects. Please note that in providing opinions of probable costs, ESA has no control over the actual costs at the time of construction. The actual cost of construction may be impacted by the availability of construction equipment and crews and fluctuation of supply prices at the time the work is bid. ESA makes no warranty, expressed or implied, as to the accuracy of such opinions as compared to bids or actual costs.

These estimates do not consider all possible benefits and costs including indirect, consequential, aesthetic and community health and well-being. Estimation of benefits is less certain than construction costs. Higher confidence is afforded recreational economics, while ecological values are inherently uncertain. ESA makes no warranty, expressed or implied, as to the accuracy of opinions of erosion rates. In particular, the erosion rates are not consistent with existing guidance on sea level rise which would tend to increase the rates of erosion.

6.2 Background

To enable economists to analyze the benefits of each shoreline erosion adaptation, ESA developed engineering cost estimates associated with the modeled coastal hazards for various management scenarios in the SMB-TNC Climate Ready project. Engineering cost estimates were prepared for the following:

- Unit costs associated with various shore protection measures and structural modification of roads and buildings
- Replacement cost information on Marin Regional Water Pollution Control Agency (MRWPCA) sewer line and pump stations
- Adaptation scenario costs for each study reach, as defined and previously modeled.

The cost estimates draw from multiple sources, for which ESA escalated the relevant costs to 2015 dollars using the published Engineering News Record cost index. Table 6 shows the escalation factors that were applied to costs for the different years of the source information.

Table 6. Cost escalation factors determined from ENR cost index.

Year	ENR Cost Index	Escalation Factor
1996	5620	1.78
2004	7115	1.40
2009	8570	1.17
2010	8799	1.14
2011	9070	1.10
2015 (Jan-Jul)	9993	1.00

6.3 Unit Costs

In a previous study funded by the Monterey Bay National Marine Sanctuary, PWA (now ESA) conducted a cost benefit analysis for the Southern Monterey Bay Technical Evaluation of Erosion Mitigation Alternatives Study (PWA 2010). The erosion mitigation measures that were considered previously and are still applicable to SMB Climate Ready project are listed below.

1. Managed Retreat
   - Rolling Easements
   - Conservation Easements
   - Fee Simple Acquisition
2. Structural Adaptation
3. SCOUP (Sediment Compatibility and Opportunistic Use Program)
4. Revetments
5. Groins
6. Beach Nourishment (in RSM)

These mitigation measures used the following assumptions (adjusted for this study where stated):

- *Managed Retreat and Structural Adaptation* measures assume that erosion processes continue unimpeded.

- *SCOUP* – The smaller nourishment described in the RSM plan of ~75,000 CY which adds three feet of beach width every five years.

- *Revetments and Seawalls* – Includes placement losses which reduce beach width at time of construction. Includes active erosion effects which accelerate beach loss when beach width narrows and wave run up frequently reaches structure.

- *Beach Nourishment* – The large nourishment described in the RSM plan of ~2MCY adds 100 feet of beach every 25 years.

- *Groins, Artificial Reefs, Breakwaters* – Large coastal engineering structures are used in conjunction with large beach nourishment to increase sand retention. The retention structures essentially slow the rate of sand transport away from the nourishment area, thereby slowing the rate of beach width reduction. This effect is modeled as a reduction in width loss, using the concept of sand diffusion. Offshore breakwaters are considered the most effective because wave sheltering and diffraction reduces sand transport directly. Offshore reefs are considered less effective because the wave sheltering is reduced by the low crest height which allows wave overtopping. Groins are considered the least effective because wave climate is not reduced and rip current formation causes offshore transport, bypassing any edge effects.

PWA investigated the costs of structural measures to mitigate erosion in southern Monterey Bay. Construction costs were estimated per kilometer of shore as agreed upon with the SMBCEW. The Sand City Erosion Study[6] provided estimates for confinement structures to enhance beach nourishment (breakwaters and groins), as well as seawalls and revetments. These costs were escalated using construction cost index data published by Engineering News Record. The Coastal Regional Sediment Management Plan[7] for the study area provides a conceptual description of large scale beach nourishment consisting of about two million cubic yards deposited over a 3- to 4-mile section (southernmost, Monterey through Sand City). This report also includes a description of smaller nourishment characterized as “opportunistic” beneficial reuse of sand excavated for other purposes. A 75,000 cubic yard volume from the Monterey Marina dredging project was used, but other inland sources of similar scale are also represented by the “SCOUP” measure. PWA also contacted design firms to inquire about the costs of revetments, seawalls and artificial reefs, and reviewed available construction costs from recent projects. These other firms consulted included Haro Kucinich, Power Engineering, and ASR, Ltd.

The current SMB Climate Ready work is not simply an update of the PWA (2010) study, primarily because the prior work used constant erosion rates and considered erosion only. The new sea level rise hazard maps show hazards varying with time and include increased flooding and erosion due to sea level rise. Starting with the unit costs from the previous 2010 economic analysis, ESA escalated the relevant costs to 2015 dollars using the published Engineering News Record cost index (shown in Table 6 above). The unit costs in 2015 dollars for shore protection and structural modification measures are shown in Table 7. A range of values was used to convey the sensitivity of the cost evaluation to construction costs for structural measures. We defined the high cost as 50% higher than the low cost; the low cost is about 67% of the high cost. High costs inform the adaptation scenario costs. With the exception of sand placements, unit costs in Table 7 include a 35% contingency.

After reviewing the large sand placement cost estimate from the 2008 RSM plan and the approach of Moffatt and Nichol (2009) of dredging from the Monterey Canyon, ESA decided to update the cost of large sand placement to reflect the higher cost and more realistic methods of Moffatt and Nichol (2009). These unit costs consider a hopper dredge and 8-mile barge to transport sand from the Elkhorn-Salinas delta to beaches south. This is more applicable to the approach in this study: dredge sand from deeper waters offshore of Sand City and transport and pump to shore from a barge. The sand costs in Table 7 are for the 2010-2030 time horizon and are escalated in future horizons to reflect increasing cost of sand, described in the Adaptation Scenario Costs section.

6 Battalio & Everts, 1990, Moffatt & Nichol Engineers, Sand City Erosion Study.

7 PWA, 2008, Coastal regional Sediment Management Plan for southern Monterey Bay.

Table 7. Unit costs for shore protection and structural modification measures.

Item	Cost	
	Low	**High**
Rock revetment	$17M / km	$20M / km
Groins (with sand placement)	$19M / km	$30M / km
Sand Placement Large (about 2,000,000 CY)*	$10 / CY	$20 / CY
Sand Placement Opportunistic (about 75,000 CY)	$6 / CY	$12 / CY
Structure Underpinning (elevation on piles) in Wave Zone	$230 / SF	
Structure Underpinning (elevation on piles) in Flood Zone	$140 / SF	
Elevation of roadway (bridge/trestle)	$570 / SF	
Reconstruction of secondary roadway (demo and rebuild)	$280 / LF	

Values include 35% contingency, except sand placements.
* Large sand placement unit cost determined from Moffatt and Nichol (2009), and assume included contingency.

Estimated for this project, the cost per linear foot of demolition and reconstruction of secondary roads uses costs from RSMeans Heavy Construction Cost Data published in 2011. The values were escalated to 2015 using the ENR cost index values in Table 6. The cost assumes a 24-foot wide road with curbs and gutters, removal of existing/damaged road, preparation of the subgrade, aggregate base layer, asphalt concrete road surface, asphalt emulsion layers, striping, and includes a 35% contingency. If a road is much wider or narrower than 24 feet, the modified cost should consider $12 per square foot.

6.4 MRWPCA Sewer Line and Pump Stations

As a part of the PWA 2010 study referenced in the Unit Costs section, the Monterey Regional Water Pollution Control Agency (MRWPCA) provided estimated replacement and failure costs for their sanitary sewer facilities along the shore. PWA used prior studies to identify when each component of the MRWPCA facilities would be impacted, triggering a cost[8]. The selected threshold was a minimum protective summer / fall beach width of 65 feet, in order to provide an adequate buffer for winter conditions and severe erosion due to storms. A single width was selected for simplicity although different widths could be selected for each facility based on damage mode and location. ESA escalated the cost estimates for pipeline and pump station replacement to 2015 dollars using the ENR cost index, and are presented below (Table 8).

[8] PWA, 2004; Southern Monterey Bay Coastal Erosion Study, Memorandum to Robert Jaques, PE, PWA, Ref. # 1729, Nov. 24, 2004.

Table 8. MRWPCA Sewer line and pump station damage and relocation cost estimates.

	Feature	Length	Cost ($ M)
Interceptor Pipeline from South to North	Wharf II to Monterey Pump Station	~1 mile	$5.7-11.4M
	Monterey Pump Station to Tide Ave	~900 feet (private properties)	$1.1-2.3M
	Tide Ave (Ocean Harbor House) to Monterey Bay Beach Hotel	~3600 feet	$5.7M
	Monterey Bay Beach Hotel to Seaside Pump Station	~2900 feet	$4.5M
	To North, interceptor on seaward side of Highway 1	per mile	$5.7M
	Subtotal		**$22.7-29.5M**
Pump Stations	Monterey Pump Station	(estimate to relocate and rebuild)	$77.2M
	Reeside Pump Station	(estimate to relocate and rebuild)	$77.2M
	Seaside Pump Station	(estimate to relocate and rebuild)	$77.2M
	Subtotal		**$231.6M**
Failures	Minor – roughly 2 weeks to repair	fines per day	$3.4K
	Catastrophic - Double cost estimate for emergency repairs	(estimate to relocate and rebuild)*2	$154.4M

Impact costs for each adaptation scenario were computed by intersecting erosion layers with the MRWPCA facilities shapefiles, representing nodes in the interceptor network and pump locations. To estimate damages to pipes from erosion, contributing pipe lengths were assigned to each node by attributing half of the pipe length entering and exiting each node. The backshore line was used to trigger damages for most MRWPCA facilities, with the exception of nodes in Del Monte reach that are already seaward of the backshore location. Damages to these MRWPCA facilities between the Wharf II and Monterey Pump Station are triggered by an offset of the shoreline instead of the backshore line. In a past evaluation of the MRWPCA facilities, vulnerability was assessed using a 20-m offset from the shoreline as the trigger for damage to the interceptor pipeline. This same offset was employed for these MRWPCA facilities that are already located seaward of the back beach.

Locations of the MRWPCA sewer facilities were provided by ESA for the team’s geospatial analysis. These locations were determined with the assistance of MRWPCA for a prior assessment of erosion-induced vulnerability (PWA 2004).

6.5 Adaptation Scenario Costs

Utilizing the escalated unit costs from Table 7, ESA developed cost estimates for the adaptation scenarios that were determined and modeled previously. ESA only formed estimates for coastal engineering adaptation scenarios (revetments and sand placement with or without groins, NOT managed retreat) and utilized the results from the hazard mapping and beach width tracking analysis conducted previously. The unit costs in Table 7 were used as current costs of structures and some modifications were made based on sand availability into the future, following discussions with the SMB technical team. Additional assumptions were made for some parameters that were required for the analysis but were uncertain or unknown. In many cases, less than optimal data exist to conduct a complete and robust cost estimate. To complete the assessment, several assumptions were made based on professional judgment, observations, and experiences in southern Monterey Bay and other places in California. The assumptions relevant to each scenario are listed below.

6.5.1 Revetments

Initial adjustments include placement losses which reduce beach width at time of construction. Results include active erosion effects which accelerate beach loss when beach width narrows and wave runup frequently reaches structure. Each reach length is used to calculate cost of new revetment at the backshore. There are a few segments of existing revetment (300-650 feet) that are not considered. The functional life of a revetment is assumed to be 30 years as long as a positive beach width is maintained in front of the structure. Beach widths used to determine structure performance are in accordance with the previous beach width analysis and are dependent on sea level rise scenario (High or Medium). If the beach disappears before 30 years have passed, the life of the structure is downgraded to 20 years. Long term erosion and SLR-recession will induce failure more rapidly. After the beach width reaches zero, a 20-year functional lifespan is used. The repair cost after failure is assumed to equal the cost for construction.

Not originally scoped, the revetment adaptation alternative for the Moss Landing reach includes the construction of a protection system for Moss Landing Harbor. The system would include a lock at the harbor mouth, 6000 feet of clay levees (10 feet high, 3:1 side slopes and a 20-foot top width) on the west and east sides of the harbor extending to Sandholdt Road, and a hydraulic control structure at Sandholdt Road crossing. We provide an allowance for these components (not a thorough engineering estimate) in Table 9. The lock cost was taken from a previous economic analysis of nature-based adaptation alternatives for Ventura County (ENVIRON and ESA PWA 2013). Levee costs from the ENVIRON (2013) study were doubled due to land use, utilities and coastal access issues that will affect the construction and increased to include a 35% contingency. The cost of a hydraulic control structure was chosen as an allowance, and is not a thorough engineering estimate. We assume that the lock and levee system is designed to accommodate the high sea level rise scenario with a 100-year lifespan. Annual operations and maintenance costs could be considered equal to 1% of the cost of construction. These O&M costs are not included in the allowance in Table 9.

Table 9. Cost allocation for lock and levee system for Moss Landing Harbor

Feature	**Cost**
Tidal Barrier/Lock at Moss Landing Harbor	$200M
Levees along west and east sides of harbor (6000 FT total)	$15M
Hydraulic control structure at Sandholdt Road	$20M
Total Cost	**$235M**

6.5.2 Large scale beach nourishment

Beach nourishment follows the schedule resulting from the previously conducted beach width analysis. Prior reports have assumed that sand will be readily available from coarse sand deposits exposed on the sea bed offshore of Sand City[9,10]. This assumption resulted in relatively low construction cost estimates and a favorable assessment of beach nourishment feasibility. However, dredging of sand from the seabed in the Monterey Bay National Marine Sanctuary is presently not allowed. Also, several California

[9] PWA, 2008. Coastal Regional Sediment Management Plan for Southern Monterey Bay.
[10] ESA PWA, 2012. Evaluation of Erosion Mitigation Alternatives for Southern Monterey Bay.

projects have concluded that beach-sized sand is not readily available in some areas[11,12]. Also, ongoing coastal erosion is expected to increase the demand for sand for beach nourishment. Consequently, the TNC technical team has concluded that we should examine potential cost differences within the engineer's estimates of beach nourishment to account for sand scarcity and multiple source locations. This document outlines the chosen approach. The cost of sand will be escalated over time in order to represent progressive scarcity for beach nourishment. Our estimates, resources considered and assumptions are as follows:

- **2010-2030 – The cost of $20 per CY is assumed,** taken from Table 7 and described in the Unit Costs section. Assumes that the coarse sands on the sea bed offshore of Sand City will be available. Assumes contingency is included.

- **2030-2060 – The cost of $26 per CY is assumed.** Assumes that sand will be dredged from the vicinity of the Elkhorn River delta at a higher cost due to farther distances than offshore seabed deposits at Sand City. The cost is based on escalation of applied costs from the previous case study in Monterey Bay Canyon (Moffatt & Nichol and Everts 2009), with additional barge-miles added to reach the southernmost reaches. Assumes contingency is included.

- **2060-2100 – The cost of $45 per CY is assumed.** Assumes that sand is obtained from inland sources such as the San Clemente Dam reservoir. Based on escalation of costs of dredging and bypassing of sediment behind Carmel Dam (Moffatt & Nichol 1996). Trucking and barging the sand in the Carmel study yielded similar unit costs. It is assumed that the Carmel Dam removal project is completed by 2060. Cost includes contingency from Moffat & Nichol (1996).

6.5.3 Groins + medium scale beach nourishment

The unit cost per kilometer of groins plus sand placement from Table 7 is assumed at 2010, scaled to the full length of the Del Monte reach (1.7 km). Future beach nourishment follows the schedule determined in the previous beach width analysis. At the same time as future beach nourishments, we assume the groins are also rebuilt at the 2010 cost plus an adjustment for increased sand cost. The adjustments for future sand prices follow the incremental cost increases for large scale beach nourishment. For example: medium sand nourishment in 2050 costs an additional $6 per CY on top of the 2010 construction cost; medium sand nourishment in 2070 costs an additional $25 per CY.

6.5.4 Opportunistic beach nourishment

Assumes small sand placement unit cost from Table 7 at 2010 equaling $12 per CY. Future beach nourishment follows the schedule determined in the beach width analysis (every 10 years). Future sand prices are increased according to the incremental cost increases for large scale beach nourishment, and are added to the initial unit cost from 2010. For example, opportunistic beach nourishment in 2050 costs $18 per CY; opportunistic beach nourishment in 2070 costs $37 per CY.

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[11] Davis, Jessica, "Environmental Groups Question Plan to Protect Homes at Broad Beach," Malibu Patch, http://malibu.patch.com/groups/politics-and-elections/p/environmental-groups-question-plan-for-broad-beach-prc79a4b66f2, last visited August, 2013.

[12] ESA, 2014, Coastal Regional Sediment Management Plan for the San Francisco Littoral Cell, Draft.

6.5.5 Adaptation scenario engineering cost tables

Utilizing the compiled engineering costs for various adaptation measures, separate cost schedules for each adaptation scenario were developed for the High and Medium SLR scenarios and are provided in Appendix 4a and 4b, respectively. Reach lengths of the four study areas that were used in the analyses are specified in these appendices as well as in Table 2. These reach lengths are consistent with the beach reaches polygon shapefile that was provided to Walter Heady for ecological analysis.

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- Bob Battalio, PE (Chief Engineer) – Directed 2-line beach erosion model development, provided technical oversight and review of modeling and mapping and engineering cost estimates.
- Elena Vandebroek, PE (Associate Hydrologist) – Developed 2-line beach erosion model, modeled and mapped erosion and flooding hazards.
- James Jackson, PE (Associate Hydrologist) – Modeled and mapped revised wave runup hazard zones, assisted with 2-line beach erosion modeling, developed engineering cost estimates.
- Louis White, PE (Managing Associate) – Led development of engineering cost estimates.
- To Dang, PhD (Technical Expert) – Modeled wave runup.

With technical input and review provided by:

- David Revell, PhD – Led development of adaptation strategies for each reach, provided review and comments on hazard modeling/mapping.

Appendix 1a. Reach Summary

Del Monte (Medium Sea Level Rise)

The Del Monte reach includes two types of beach nourishment scenarios, with the following inputs and outputs:

Beach Nourishment (Set Schedule)

Nourishment volume: 50,000 CY

Nourishment years before 2100: 2010, 2020, 2030, 2040, 2050, 2060, 2070, 2080,

Beach Nourishment (As Needed) + Groins

Nourishment volume: 400,000 CY

Nourishment years before 2100: 2010, 2089

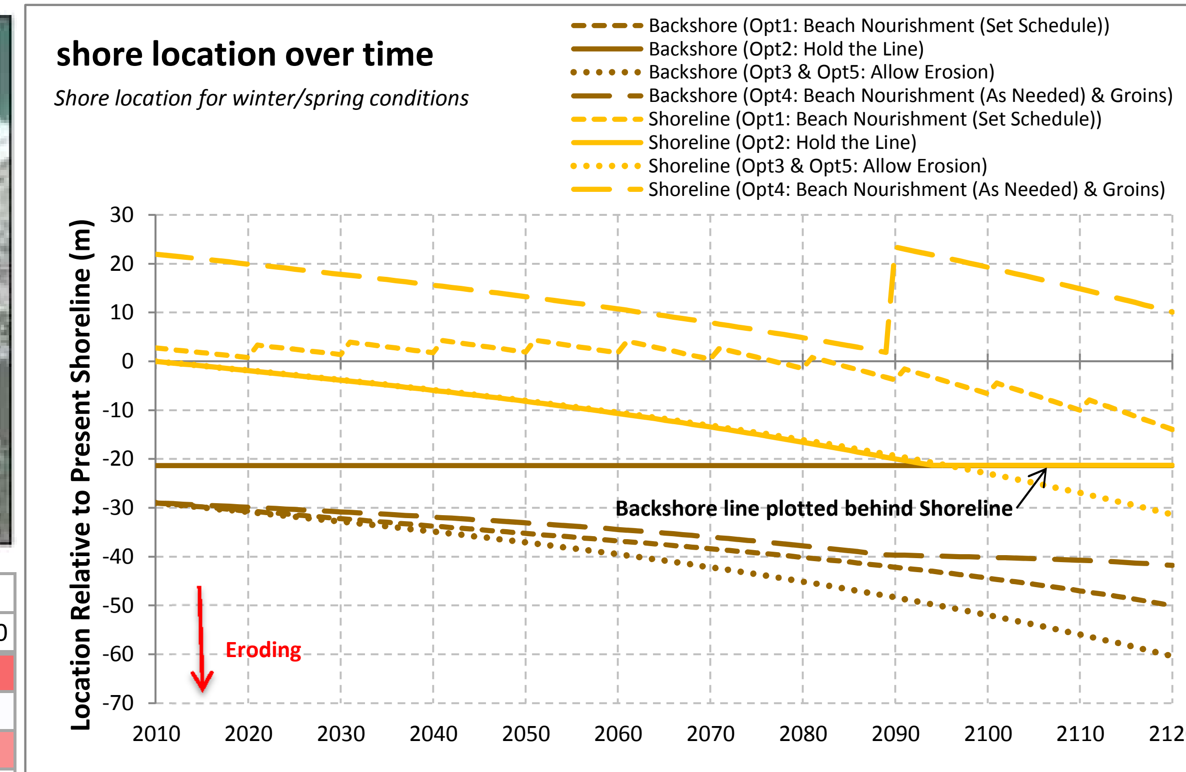
Long-Term Coastal Evolution Results

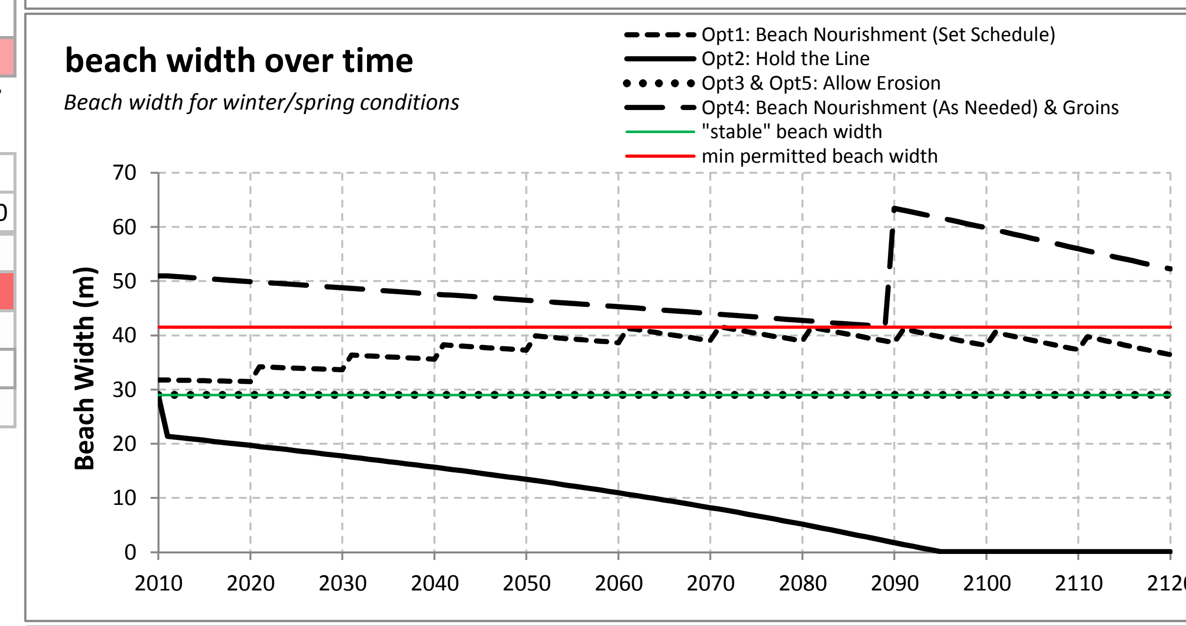
Scenario	Average Beach Width (m)										Long Term Backshore Erosion (m)*									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	29	29	29	29	29	29	29	29	29	29	0	2	4	6	8	11	13	16	19	23
Hold the Line	21	20	19	17	14	12	9	6	3	0	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
Beach Nourishment (Set Schedule)	32	32	34	36	38	39	40	40	40	39	0	2	3	5	6	8	9	11	13	15
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	51	50	49	48	47	46	45	43	42	61	0	1	2	3	4	5	7	9	11	11

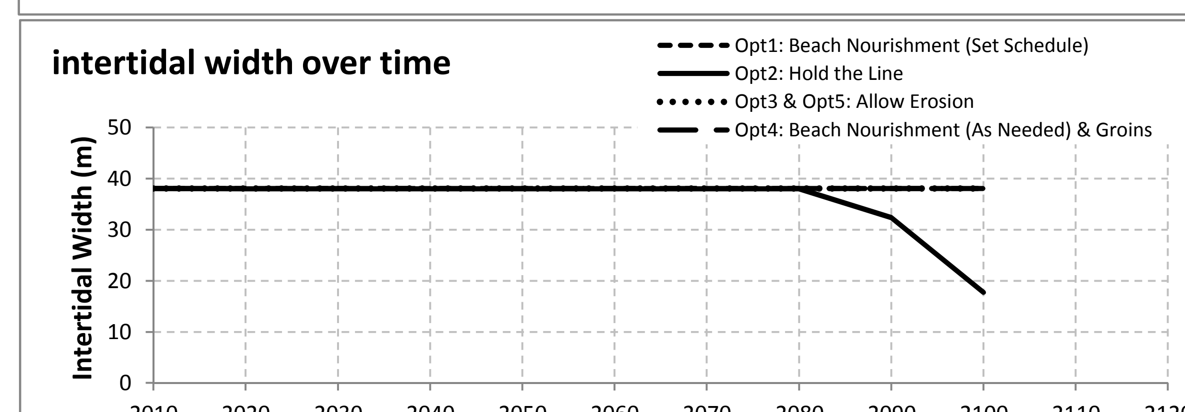
**Hold the line scenario produces negative backshore erosion due to the encroachment of the revetment onto the beach.*

Scenario	Storm-Induced Erosion Distance (m)**										Intertidal Width (m)									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	17	17	17	17	17	17	17	17	17	17	38	38	38	38	38	38	38	38	38	38
Hold the Line	0	0	0	0	0	0	0	0	0	0	38	38	38	38	38	38	38	38	32	18
Beach Nourishment (Set Schedule)	14	14	12	10	8	6	5	5	6	6	38	38	38	38	38	38	38	38	38	38
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	17	17	18	19	21	22	23	24	25	6	38	38	38	38	38	38	38	38	38	38

***Hold the line scenario assumes no erosion past structure. However, high velocity run-up can still occur over structure (see flood maps).*







Appendix 1b. Reach Summary

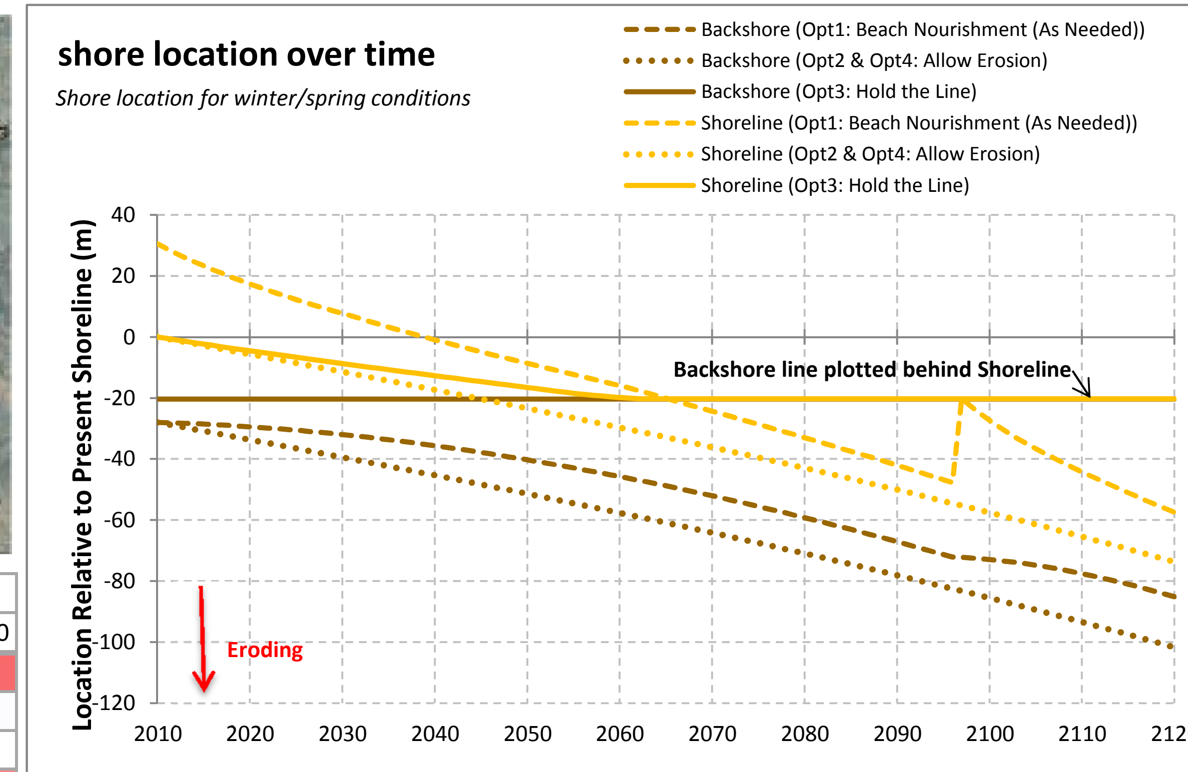
Sand City (Medium Sea Level Rise)

The Sand City reach includes one beach nourishment scenario, with the following inputs and outputs:

Beach Nourishment (As Needed)

Nourishment volume: 2,000,000 CY

Nourishment years before 2100: 2010, 2096



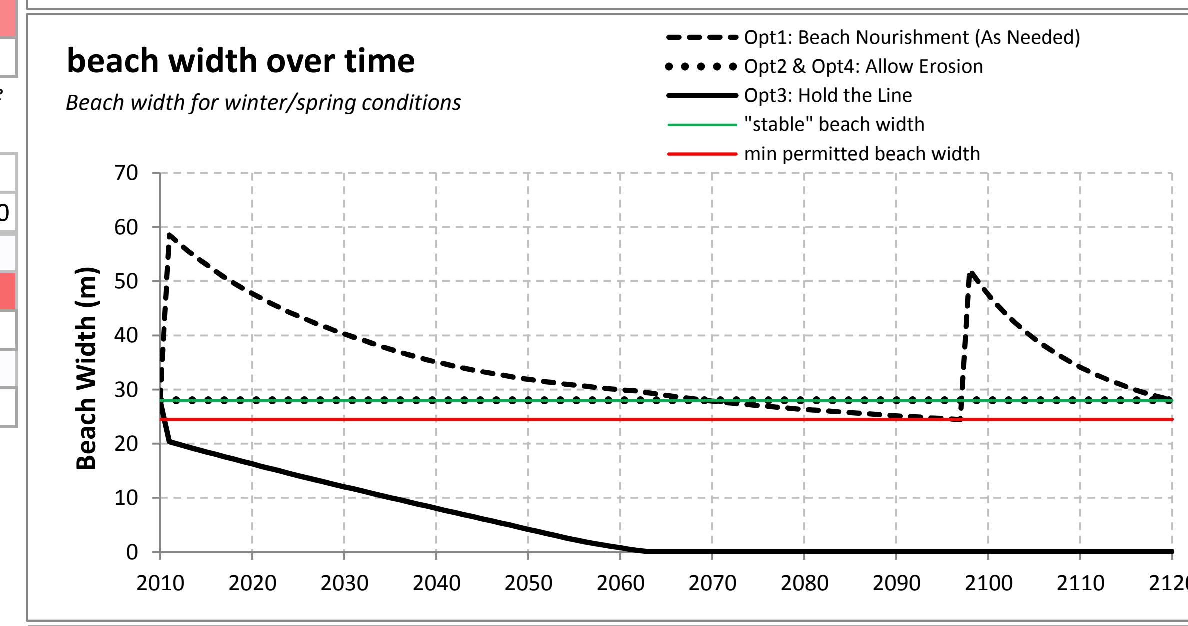
Long-Term Coastal Evolution Results

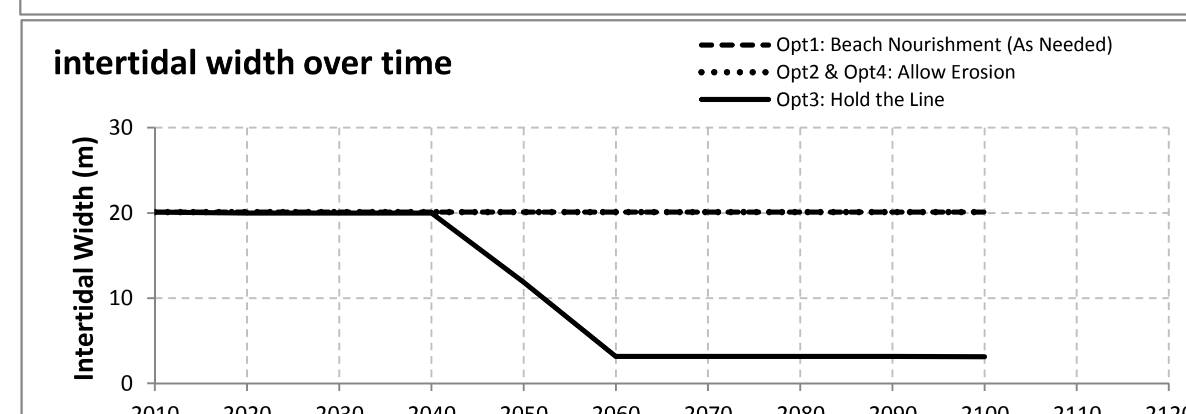
Scenario	Average Beach Width (m)										Long Term Backshore Erosion (m)*									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	28	28	28	28	28	28	28	28	28	28	0	6	11	17	23	30	36	43	50	58
Hold the Line	20	18	14	10	6	2	0	0	0	0	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	59	52	43	37	33	31	29	27	26	33	0	1	4	8	12	18	24	31	39	45
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

**Hold the line scenario produces negative backshore erosion due to the encroachment of the revetment onto the beach.*

Scenario	Storm-Induced Erosion Distance (m)**										Intertidal Width (m)									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	22	22	22	22	22	22	22	22	22	22	20	20	20	20	20	20	20	20	20	20
Hold the Line	0	0	0	0	0	0	0	0	0	0	20	20	20	20	12	3	3	3	3	3
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	22	28	33	33	33	33	33	33	33	33	20	20	20	20	20	20	20	20	20	20
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

***Hold the line scenario assumes no erosion past structure. However, high velocity run-up can still occur over structure (see flood maps).*





Appendix 1c. Reach Summary

Marina (Medium Sea Level Rise)

The Marina reach does not include any beach nourishment scenarios.

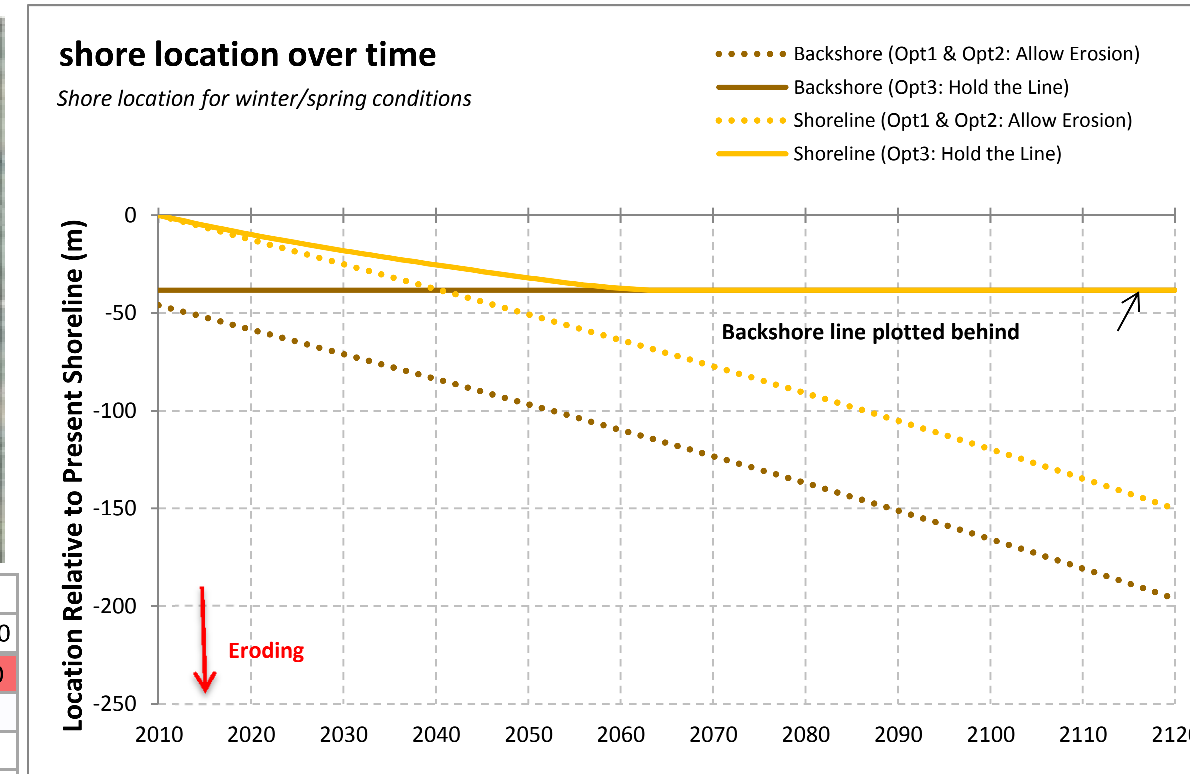
Long-Term Coastal Evolution Results

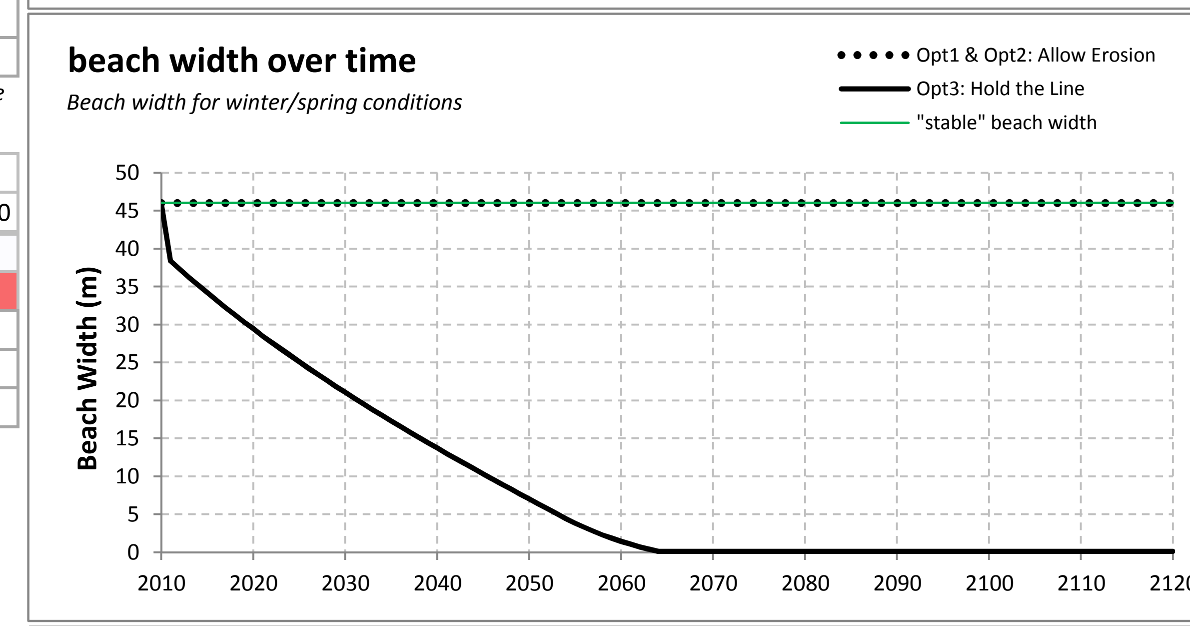
Scenario	Average Beach Width (m)										Long Term Backshore Erosion (m)*									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	46	46	46	46	46	46	46	46	46	46	0	12	25	38	51	64	77	91	105	120
Hold the Line	38	33	24	17	10	3	0	0	0	0	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

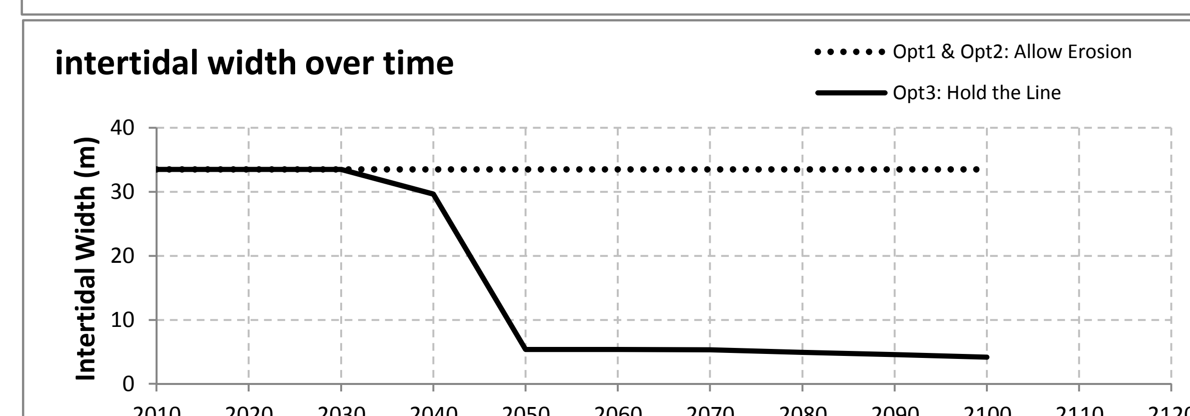
**Hold the line scenario produces negative backshore erosion due to the encroachment of the revetment onto the beach.*

Scenario	Storm-Induced Erosion Distance (m)**										Intertidal Width (m)									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	27	27	27	27	27	27	27	27	27	27	34	34	34	34	34	34	34	34	34	34
Hold the Line	0	0	0	0	0	0	0	0	0	0	34	34	34	30	5	5	5	5	5	4
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

***Hold the line scenario assumes no erosion past structure. However, high velocity run-up can still occur over structure (see flood maps).*



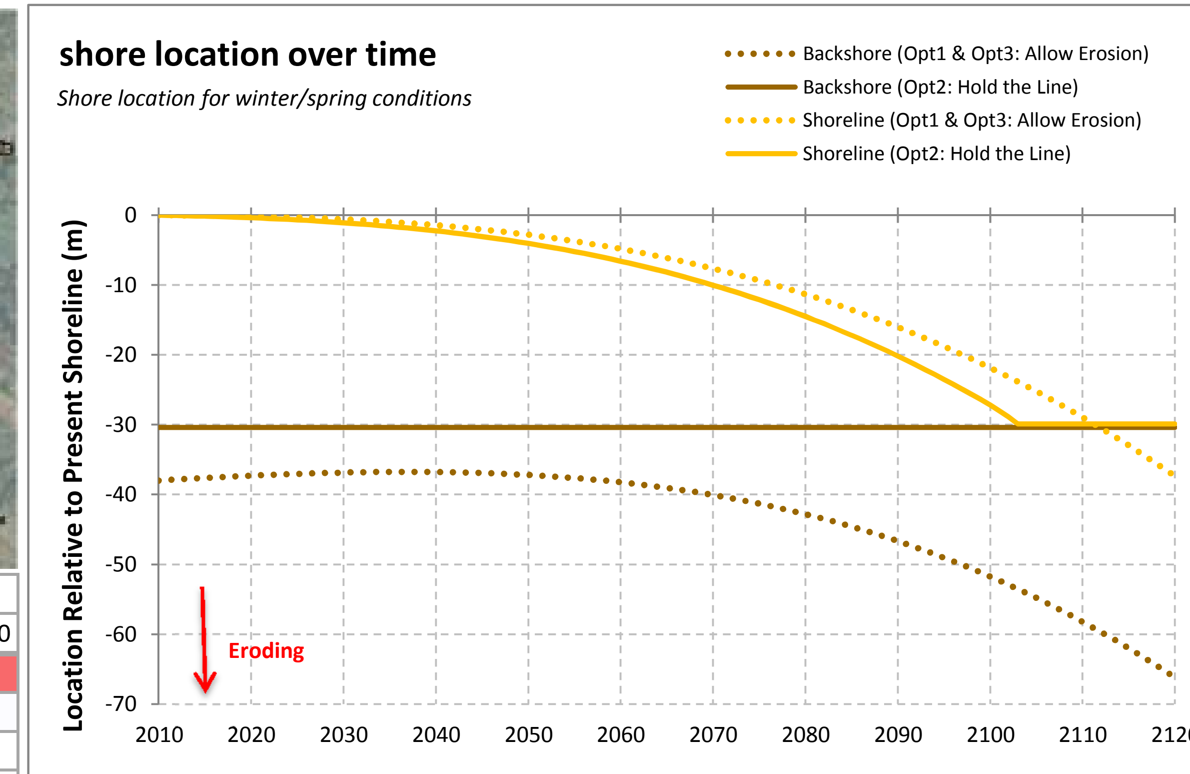


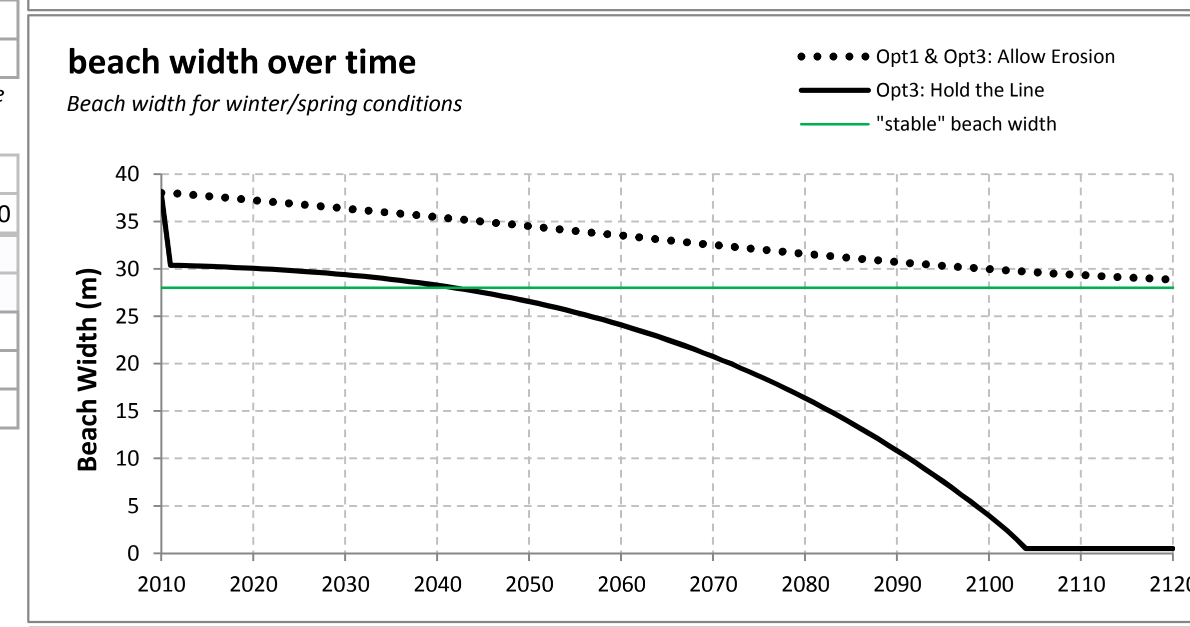


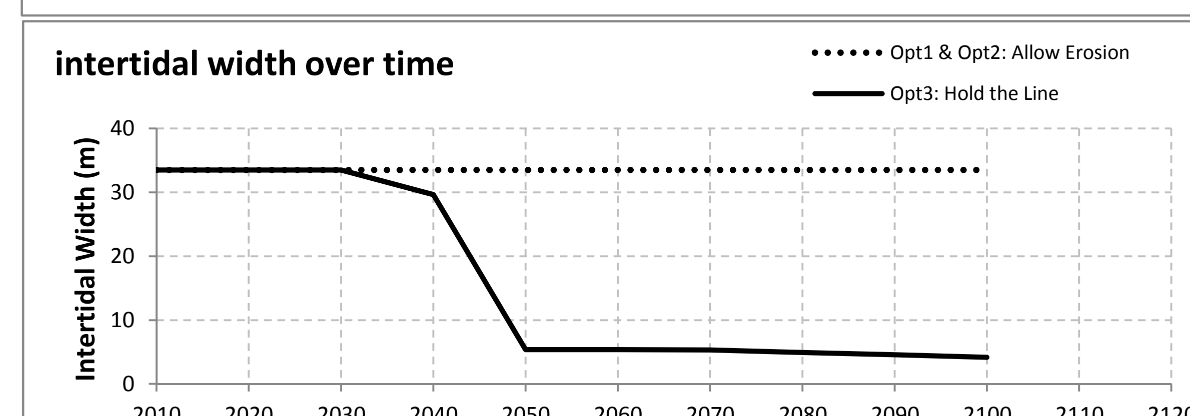
Appendix 1d. Reach Summary

Moss Landing (Medium Sea Level Rise)

The Moss Landing reach does not include any beach nourishment scenarios.







Long-Term Coastal Evolution Results

	Average Beach Width (m)										Long Term Backshore Erosion (m)*									
Scenario	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	38	38	37	36	35	34	33	32	31	30	0	-1	-1	-1	-1	0	2	5	9	14
Hold the Line	30	30	30	29	27	25	22	18	13	7	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

**Hold the line scenario produces negative backshore erosion due to the encroachment of the revetment onto the beach.*

	Storm-Induced Erosion Distance (m)**										Intertidal Width (m)									
Scenario	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	20	20	21	22	23	24	25	26	27	27	41	41	41	41	41	41	41	41	41	41
Hold the Line	0	0	0	0	0	0	0	0	0	0	41	41	41	41	41	41	41	41	41	41
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

***Hold the line scenario assumes no erosion past structure. However, high velocity run-up can still occur over structure (see flood maps).*

Appendix 1e. Reach Summary

Del Monte (High Sea Level Rise)

The Del Monte reach includes two types of beach nourishment scenarios, with the following inputs and outputs:

Beach Nourishment (Set Schedule)

Nourishment volume:	50,000 CY
Nourishment years before 2100:	2010, 2020, 2030, 2040, 2050, 2060, 2070, 2080,

Beach Nourishment (As Needed) + Groins

Nourishment volume:	400,000 CY
Nourishment years before 2100:	2010, 2051

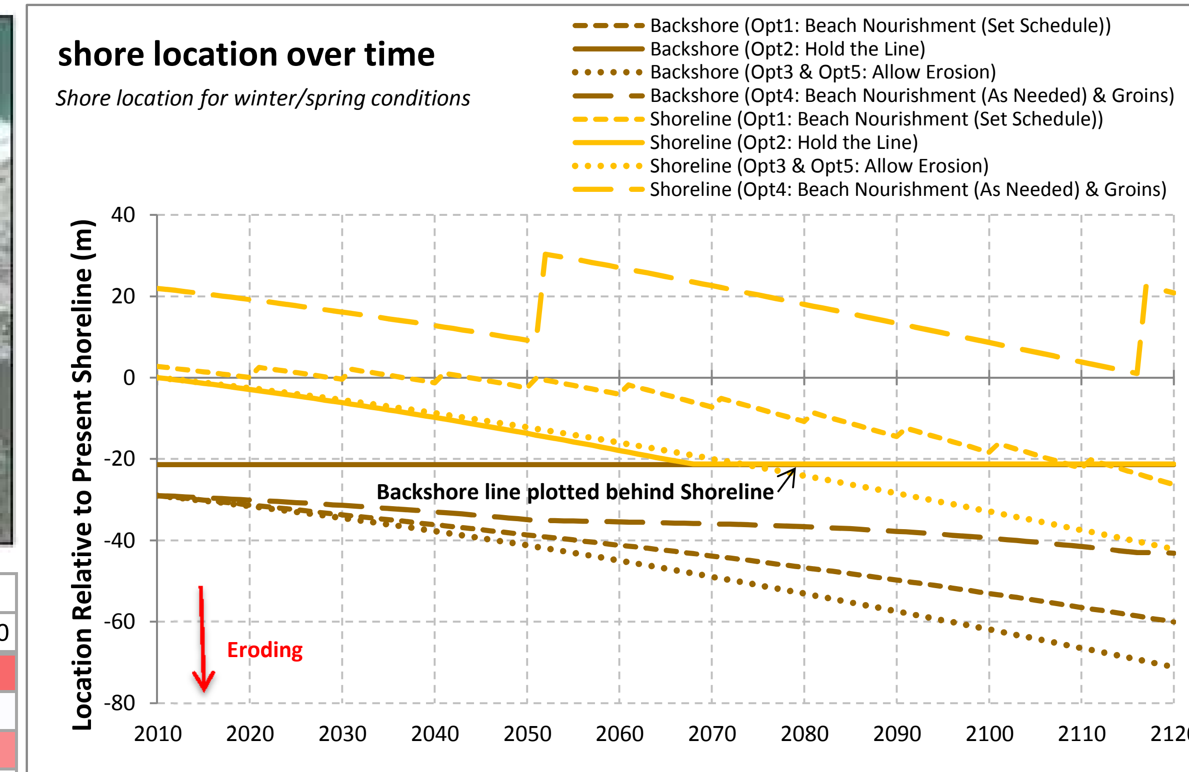
Long-Term Coastal Evolution Results

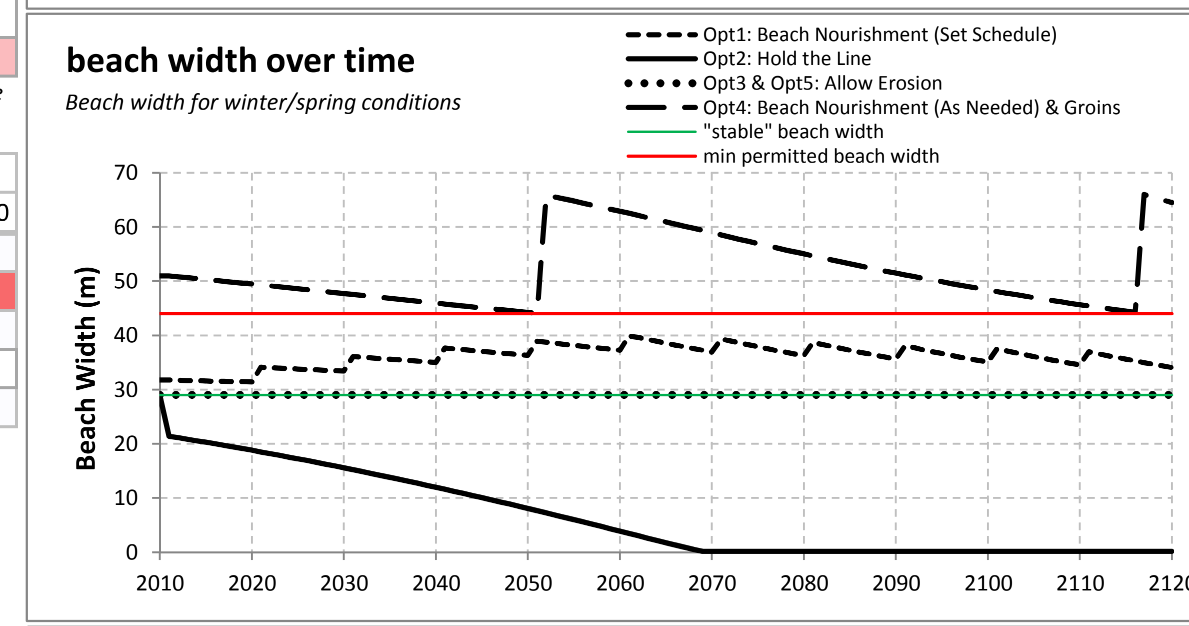
Scenario	Average Beach Width (m)										Long Term Backshore Erosion (m)*									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	29	29	29	29	29	29	29	29	29	29	0	3	6	9	12	16	20	24	28	33
Hold the Line	21	20	17	13	10	6	1	0	0	0	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
Beach Nourishment (Set Schedule)	32	32	34	35	37	38	38	38	37	36	0	2	5	7	10	12	15	18	21	24
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	51	50	48	47	45	62	61	57	53	50	0	1	2	4	6	6	7	8	9	10

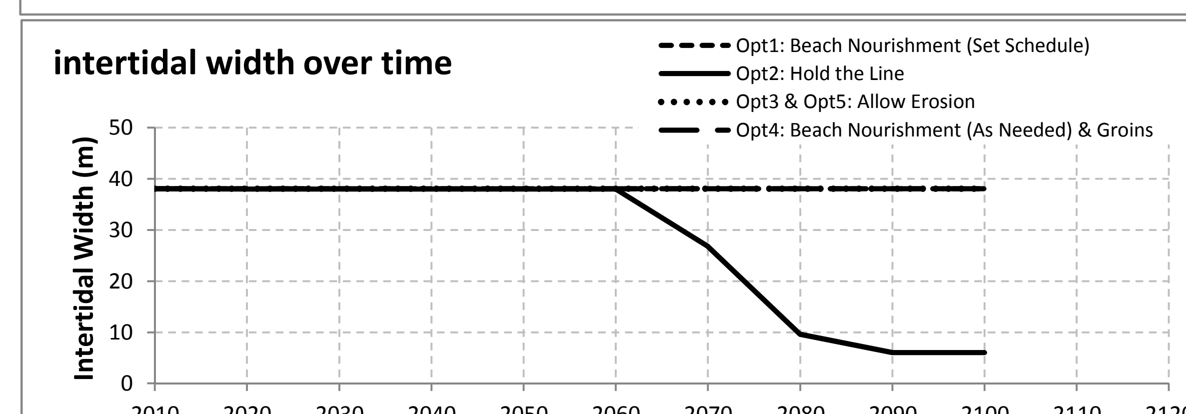
**Hold the line scenario produces negative backshore erosion due to the encroachment of the revetment onto the beach.*

Scenario	Storm-Induced Erosion Distance (m)**										Intertidal Width (m)									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	17	17	17	17	17	17	17	17	17	17	38	38	38	38	38	38	38	38	38	38
Hold the Line	0	0	0	0	0	0	0	0	0	0	38	38	38	38	38	38	27	10	6	6
Beach Nourishment (Set Schedule)	14	14	12	10	9	8	7	8	9	9	38	38	38	38	38	38	38	38	38	38
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	17	17	19	21	23	6	7	11	15	18	38	38	38	38	38	38	38	38	38	38

***Hold the line scenario assumes no erosion past structure. However, high velocity run-up can still occur over structure (see flood maps).*







Appendix 1f. Reach Summary

Sand City (High Sea Level Rise)

The Sand City reach includes one beach nourishment scenario, with the following inputs and outputs:

Beach Nourishment (As Needed)

Nourishment volume: 2,000,000 CY

Nourishment years before 2100: 2010, 2067, 2094

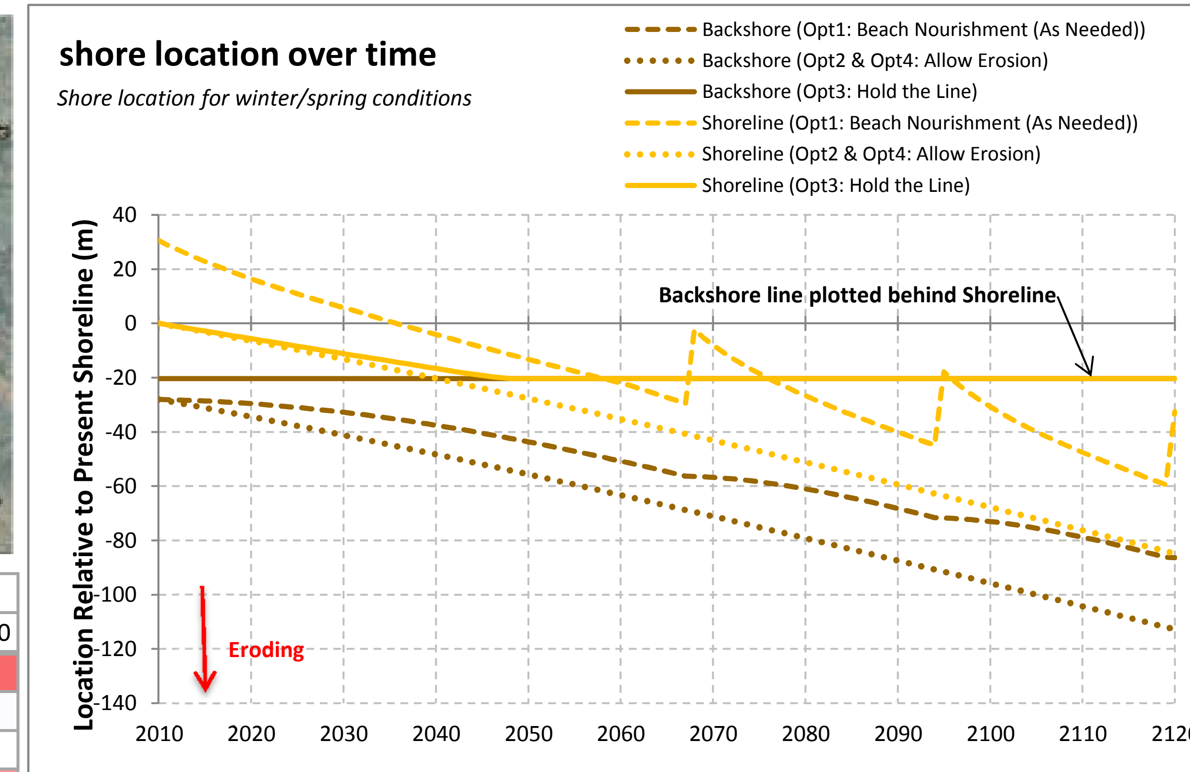
Long-Term Coastal Evolution Results

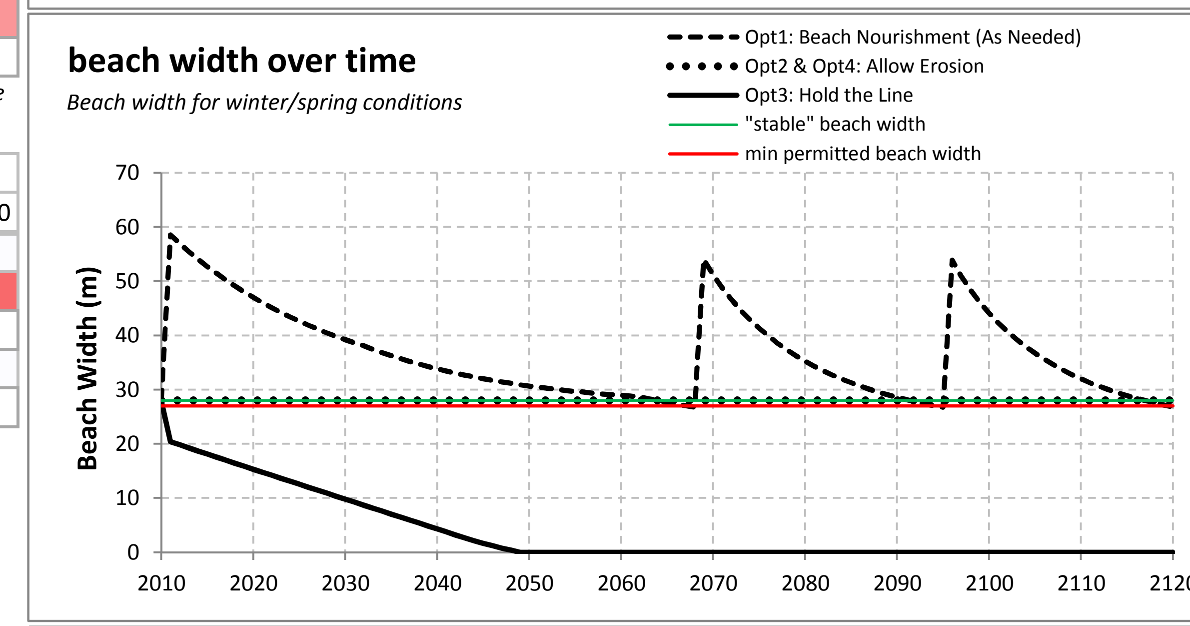
Scenario	Average Beach Width (m)										Long Term Backshore Erosion (m)*									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	28	28	28	28	28	28	28	28	28	28	0	6	13	20	28	35	43	51	59	68
Hold the Line	20	18	12	6	1	0	0	0	0	0	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	59	52	42	36	32	30	33	40	31	39	0	2	5	10	16	23	29	33	40	45
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

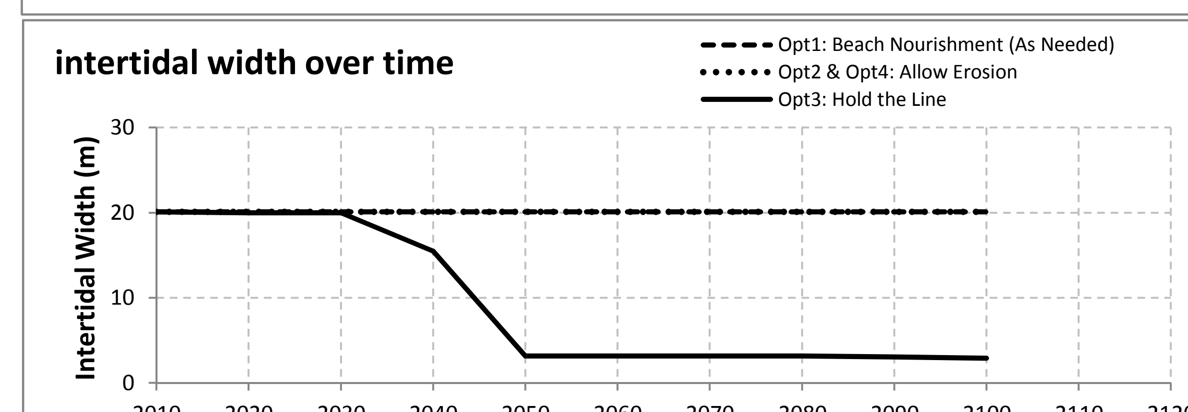
**Hold the line scenario produces negative backshore erosion due to the encroachment of the revetment onto the beach.*

Scenario	Storm-Induced Erosion Distance (m)**										Intertidal Width (m)									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	22	22	22	22	22	22	22	22	22	22	20	20	20	20	20	20	20	20	20	20
Hold the Line	0	0	0	0	0	0	0	0	0	0	20	20	20	15	3	3	3	3	3	3
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	22	29	33	33	33	33	33	33	33	33	20	20	20	20	20	20	20	20	20	20
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

***Hold the line scenario assumes no erosion past structure. However, high velocity run-up can still occur over structure (see flood maps).*







Appendix 1g. Reach Summary

Marina (High Sea Level Rise)

The Marina reach does not include any beach nourishment scenarios.

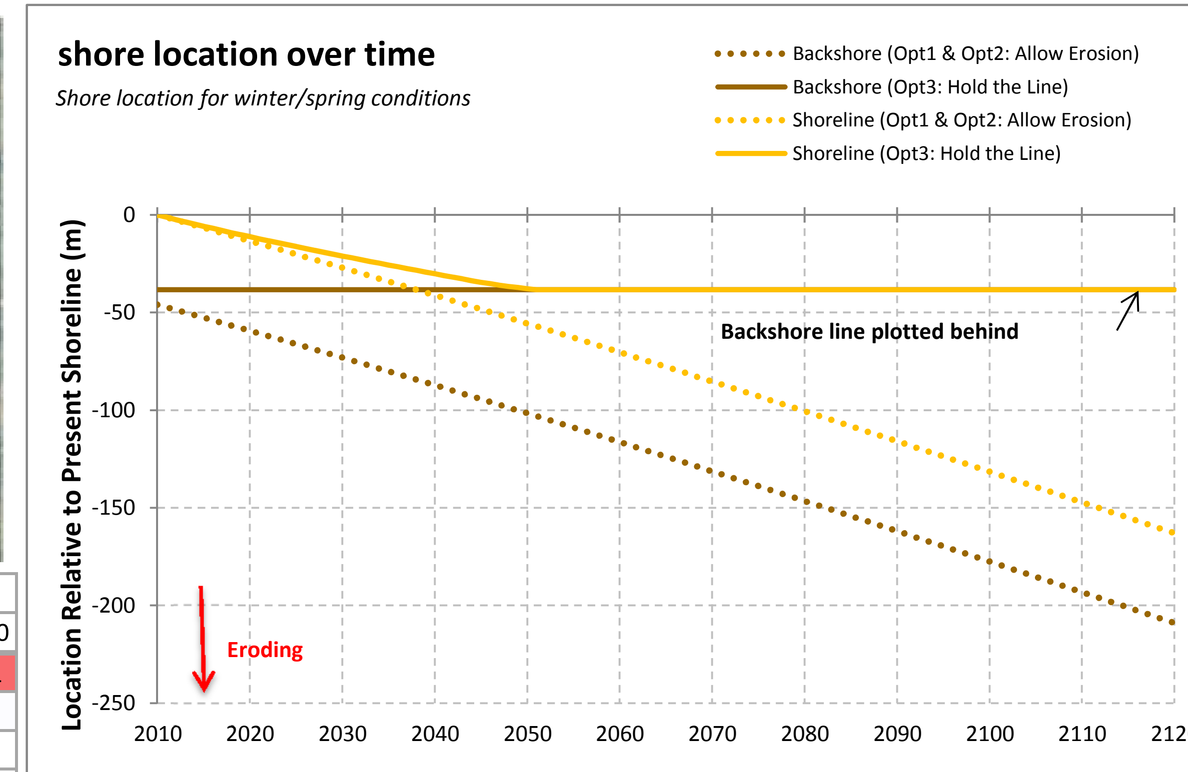
Long-Term Coastal Evolution Results

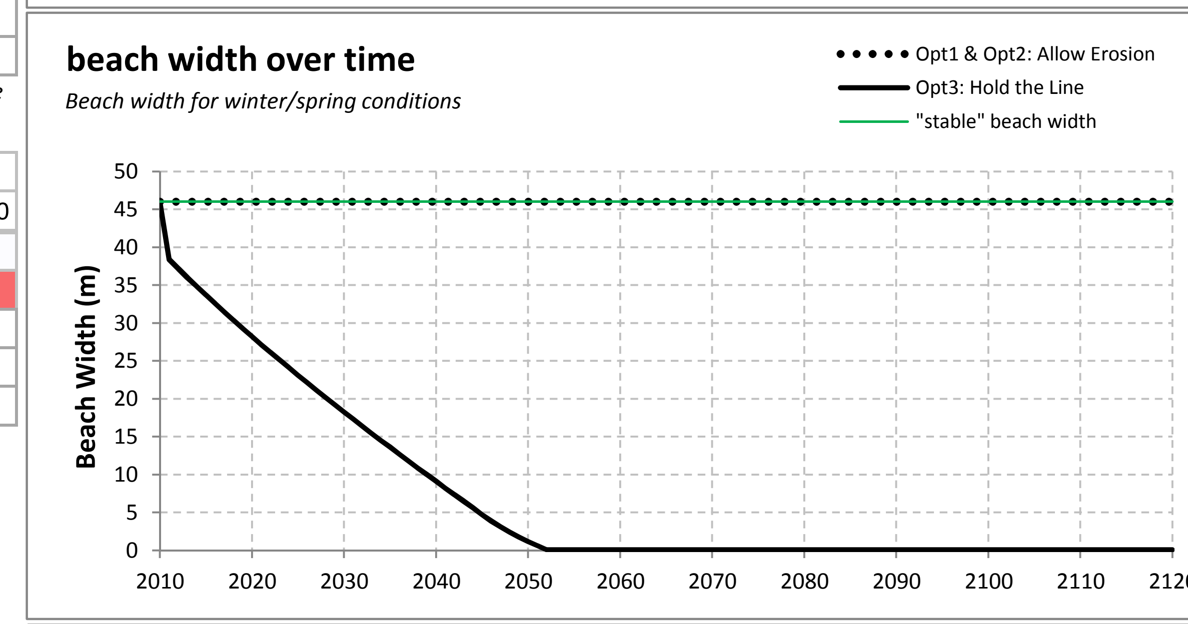
Scenario	Average Beach Width (m)										Long Term Backshore Erosion (m)*									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	46	46	46	46	46	46	46	46	46	46	0	13	27	41	56	70	85	101	116	131
Hold the Line	38	33	22	13	4	0	0	0	0	0	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

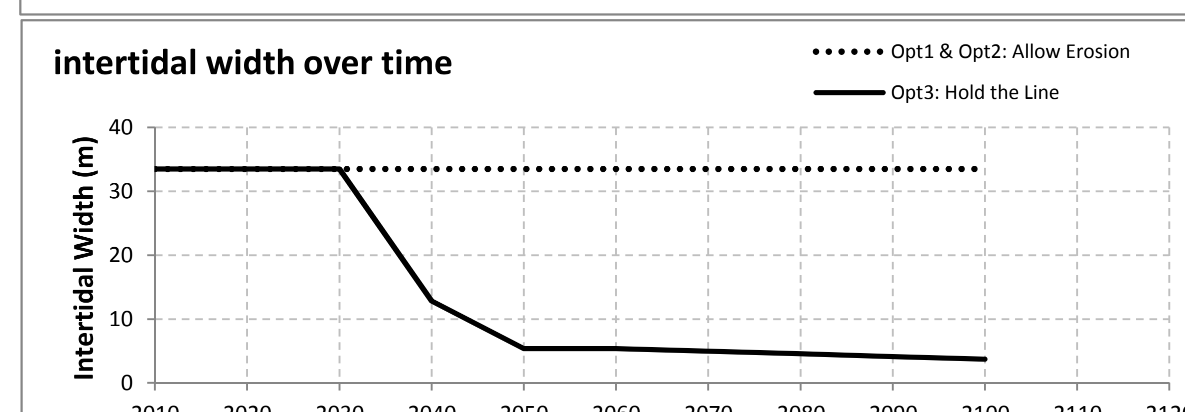
**Hold the line scenario produces negative backshore erosion due to the encroachment of the revetment onto the beach.*

Scenario	Storm-Induced Erosion Distance (m)**										Intertidal Width (m)									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	27	27	27	27	27	27	27	27	27	27	34	34	34	34	34	34	34	34	34	34
Hold the Line	0	0	0	0	0	0	0	0	0	0	34	34	34	13	5	5	5	5	4	4
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

***Hold the line scenario assumes no erosion past structure. However, high velocity run-up can still occur over structure (see flood maps).*







Appendix 1h. Reach Summary

Moss Landing (High Sea Level Rise)

The Moss Landing reach does not include any beach nourishment scenarios.

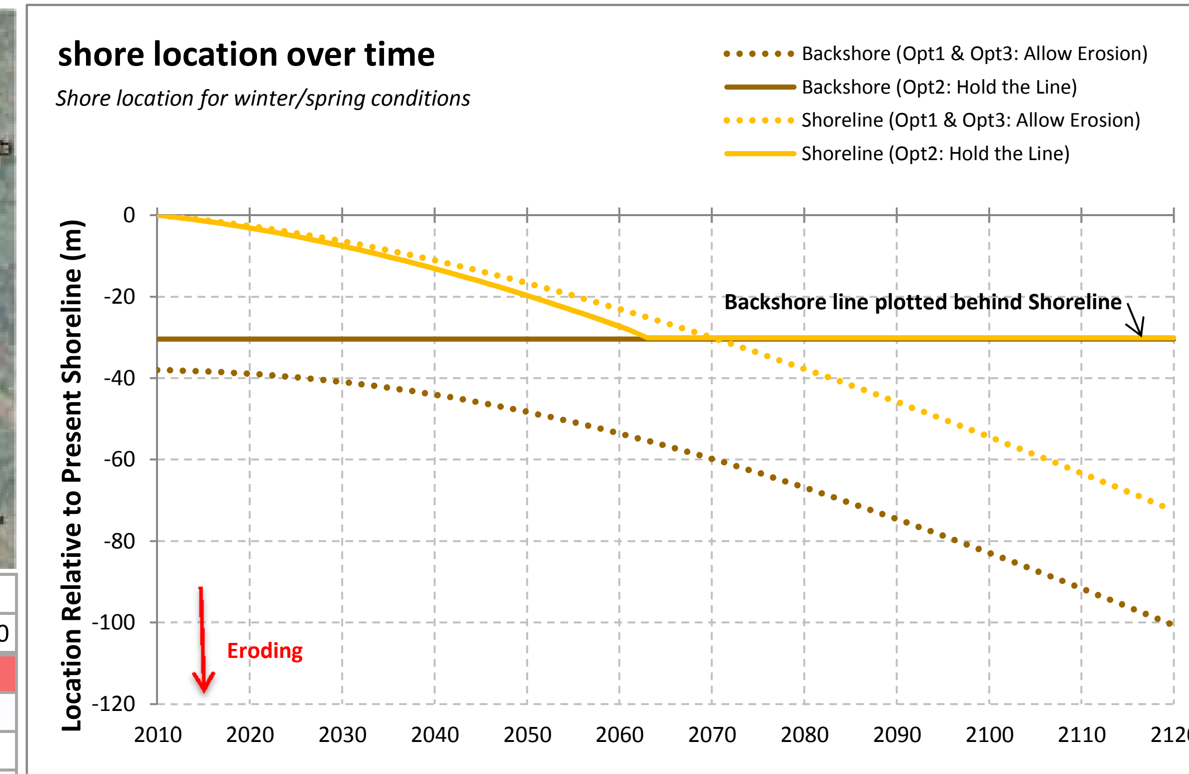
Long-Term Coastal Evolution Results

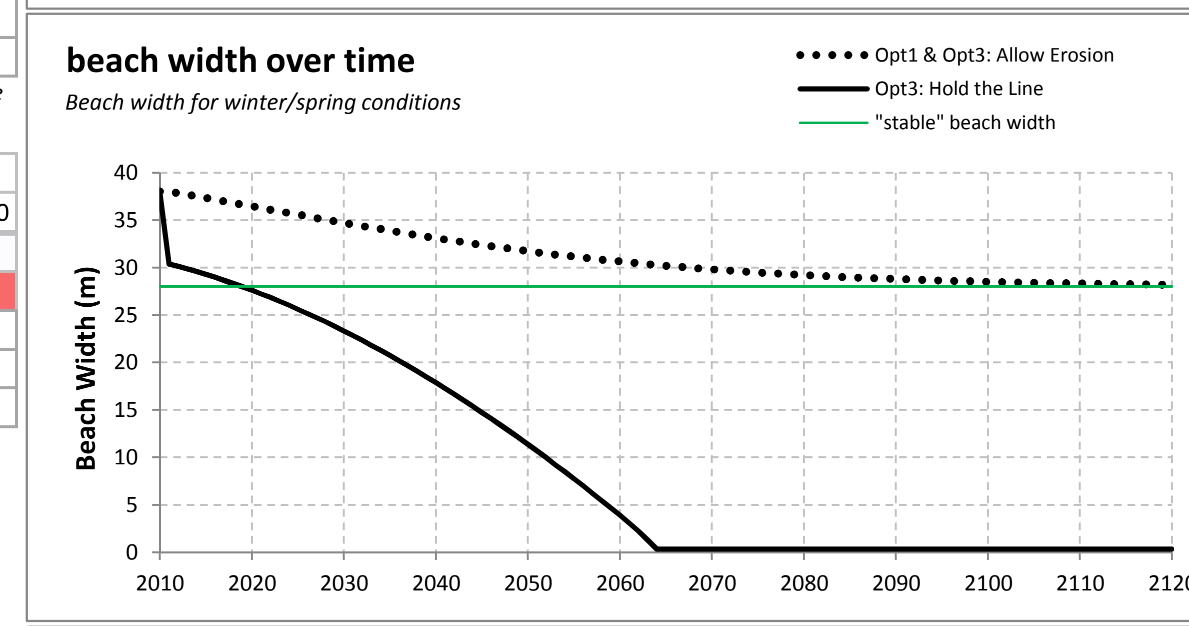
Scenario	Average Beach Width (m)										Long Term Backshore Erosion (m)*									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	38	37	35	34	32	31	30	29	29	29	0	1	3	6	10	16	22	29	37	45
Hold the Line	30	29	25	20	14	7	1	0	0	0	-8	-8	-8	-8	-8	-8	-8	-8	-8	-8
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

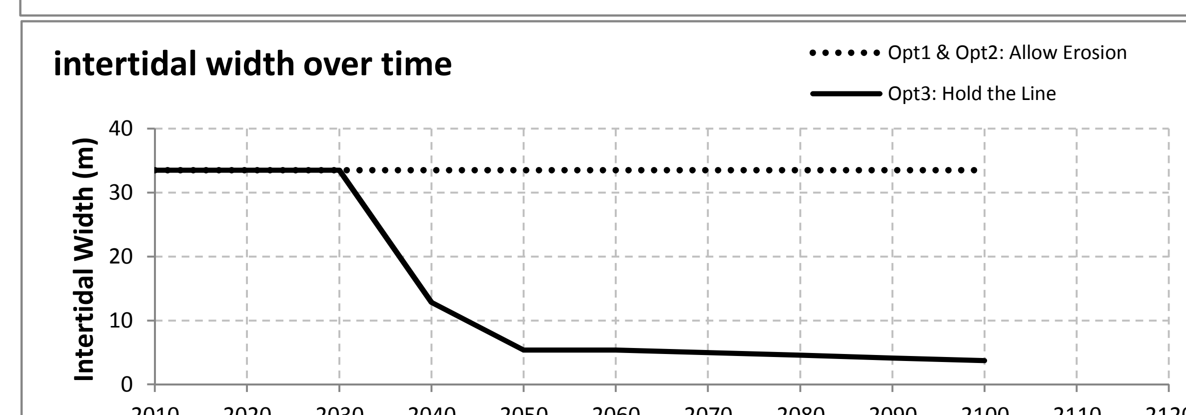
**Hold the line scenario produces negative backshore erosion due to the encroachment of the revetment onto the beach.*

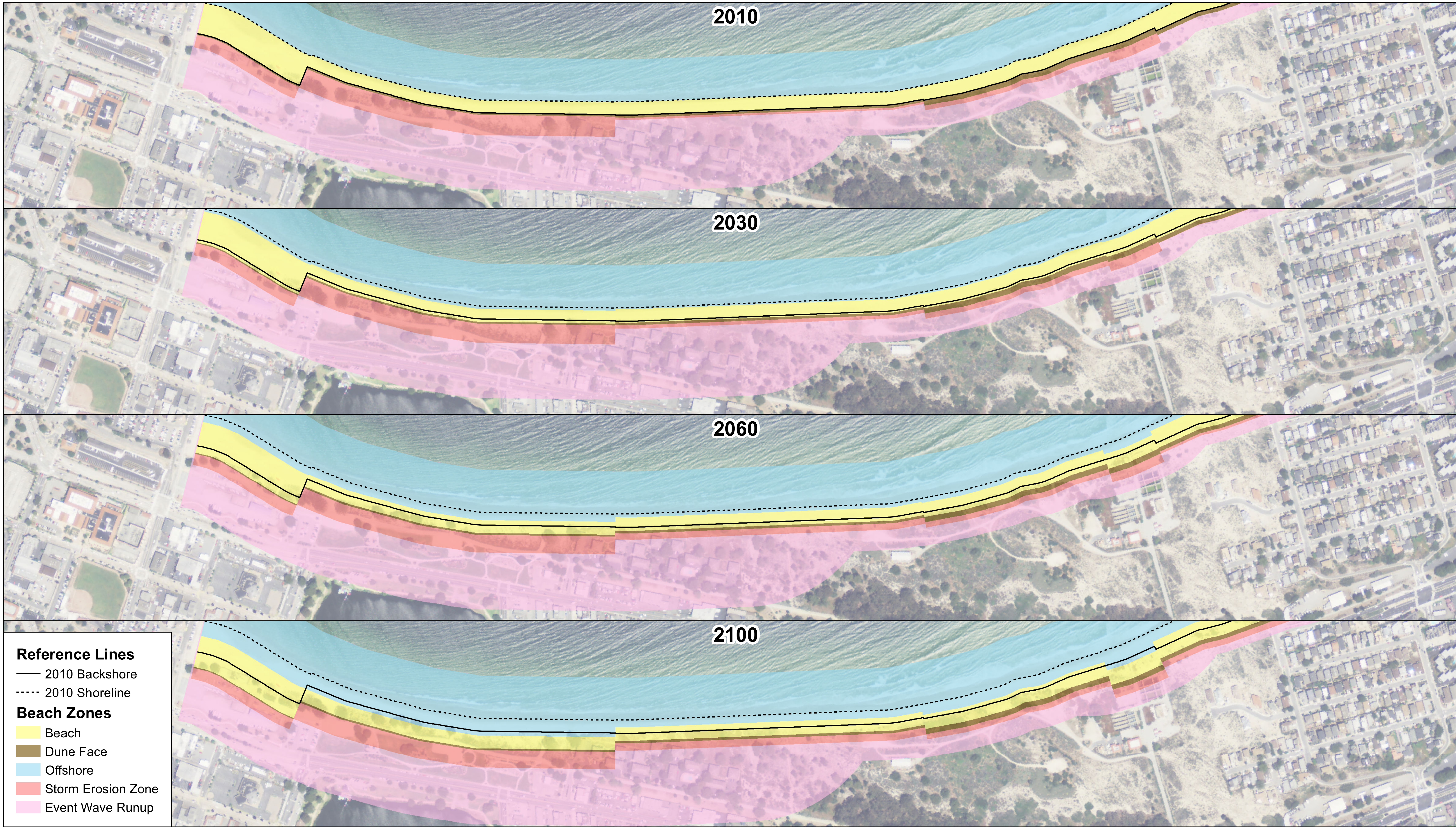
Scenario	Storm-Induced Erosion Distance (m)**										Intertidal Width (m)									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Allow Erosion	20	20	22	24	25	27	27	28	29	29	41	41	41	41	41	41	41	41	41	41
Hold the Line	0	0	0	0	0	0	0	0	0	0	41	41	41	41	41	41	23	7	6	6
Beach Nourishment (Set Schedule)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed)	*This adaptation action is not a scenario for this reach.*																			
Beach Nourishment (As Needed) + Groins	*This adaptation action is not a scenario for this reach.*																			

***Hold the line scenario assumes no erosion past structure. However, high velocity run-up can still occur over structure (see flood maps).*









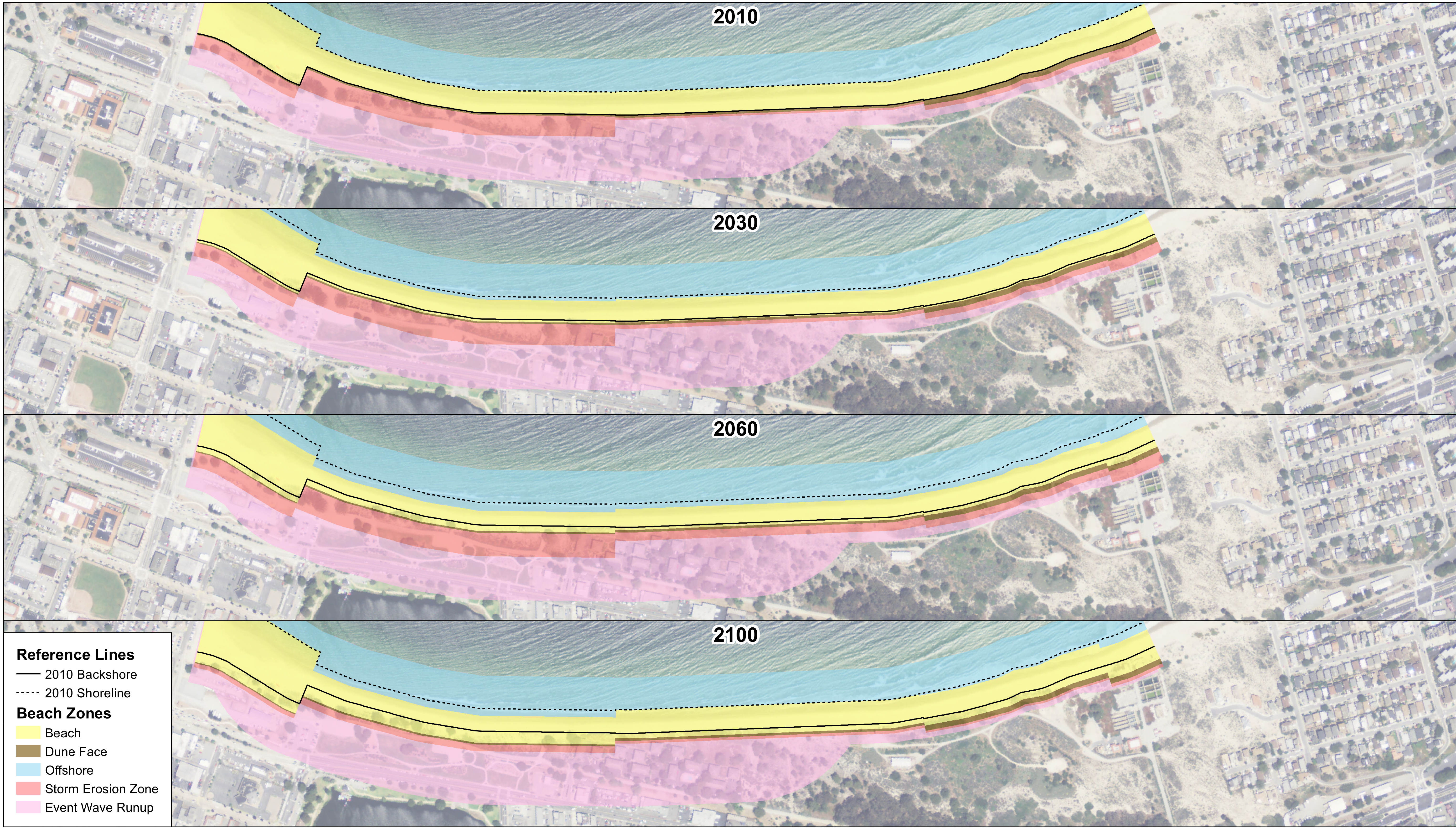
SOURCE:

SMB Climate Ready . 130604

Appendix 2a

Del Monte Beach Zones

Allow Erosion, Medium SLR



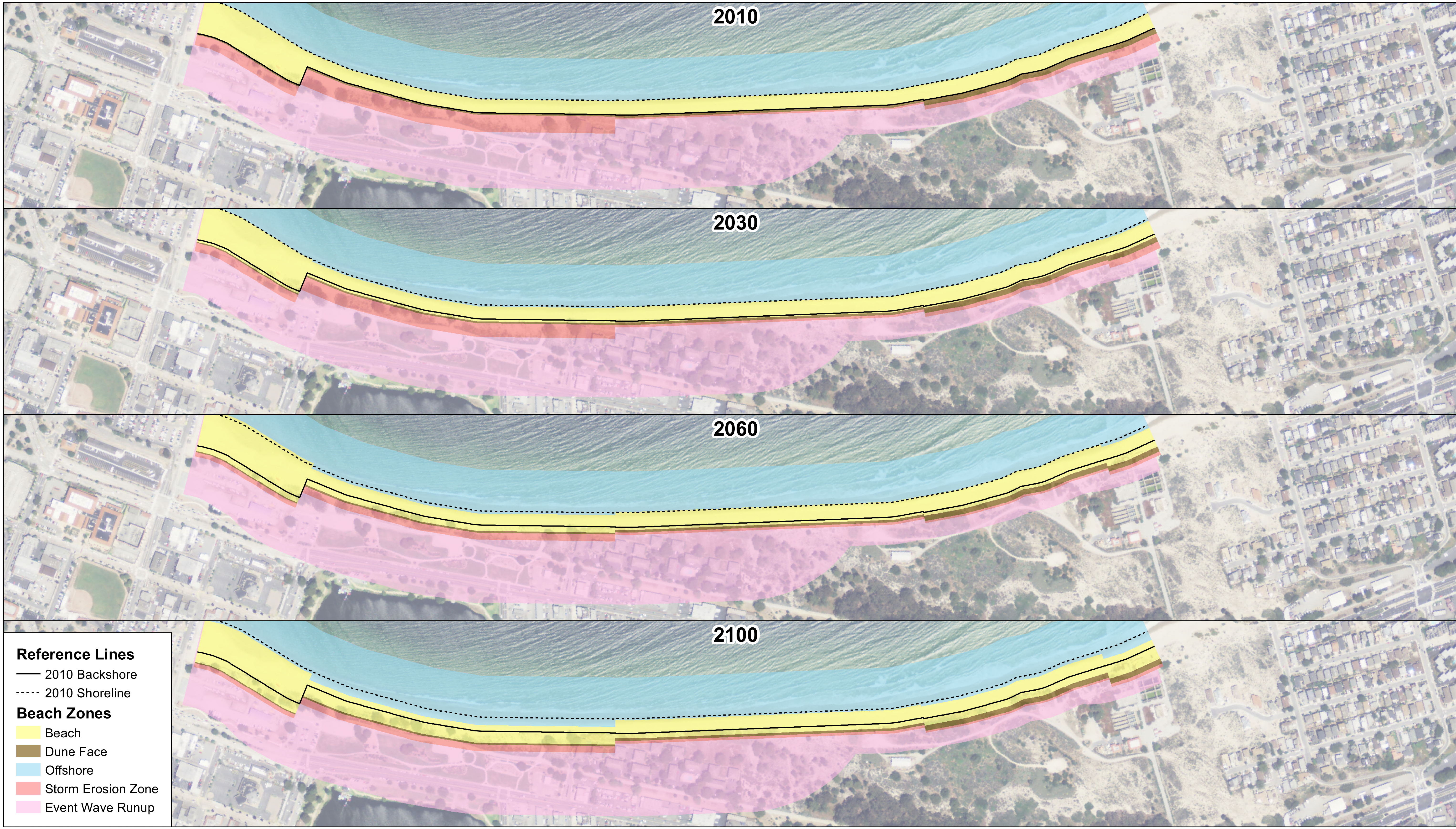
SOURCE:

SMB Climate Ready . 130604

Appendix 2b

Del Monte Beach Zones

Beach Nourishment with Groins, Medium SLR



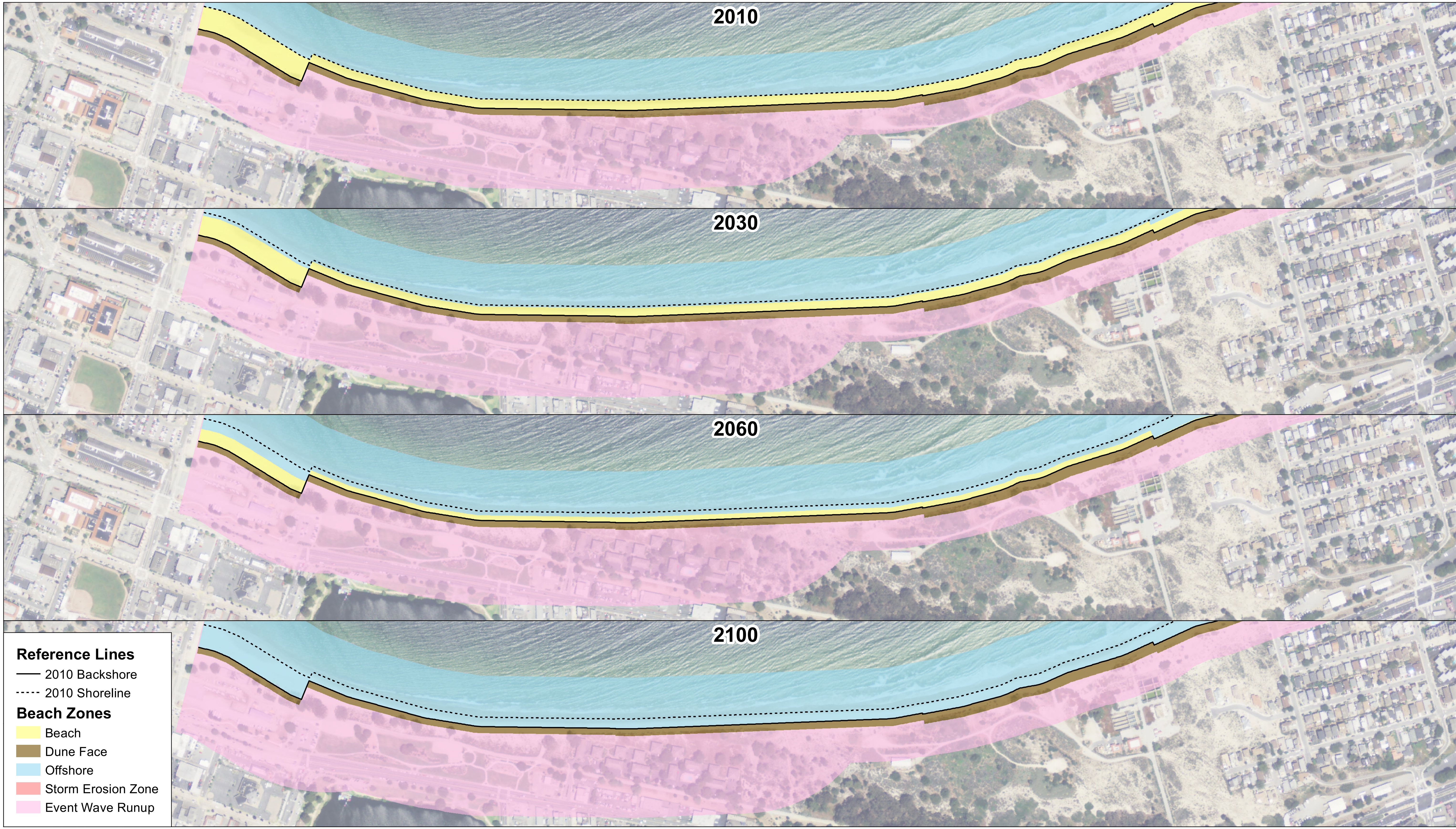
SOURCE:

SMB Climate Ready . 130604

Appendix 2c

Del Monte Beach Zones

Beach Nourishment Set Schedule, Medium SLR



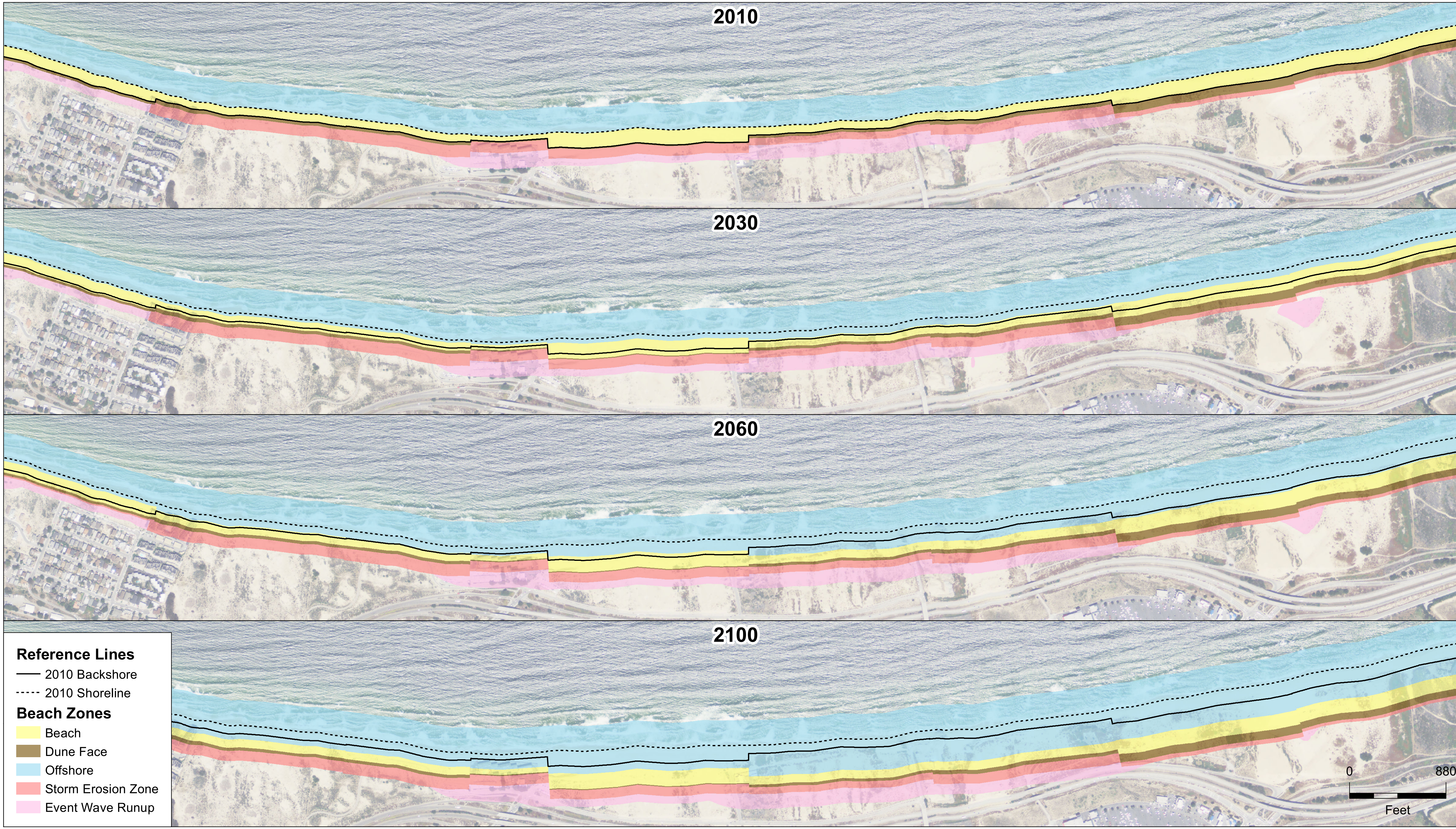
SOURCE:

SMB Climate Ready . 130604

Appendix 2d

Del Monte Beach Zones

Hold the Line, Medium SLR



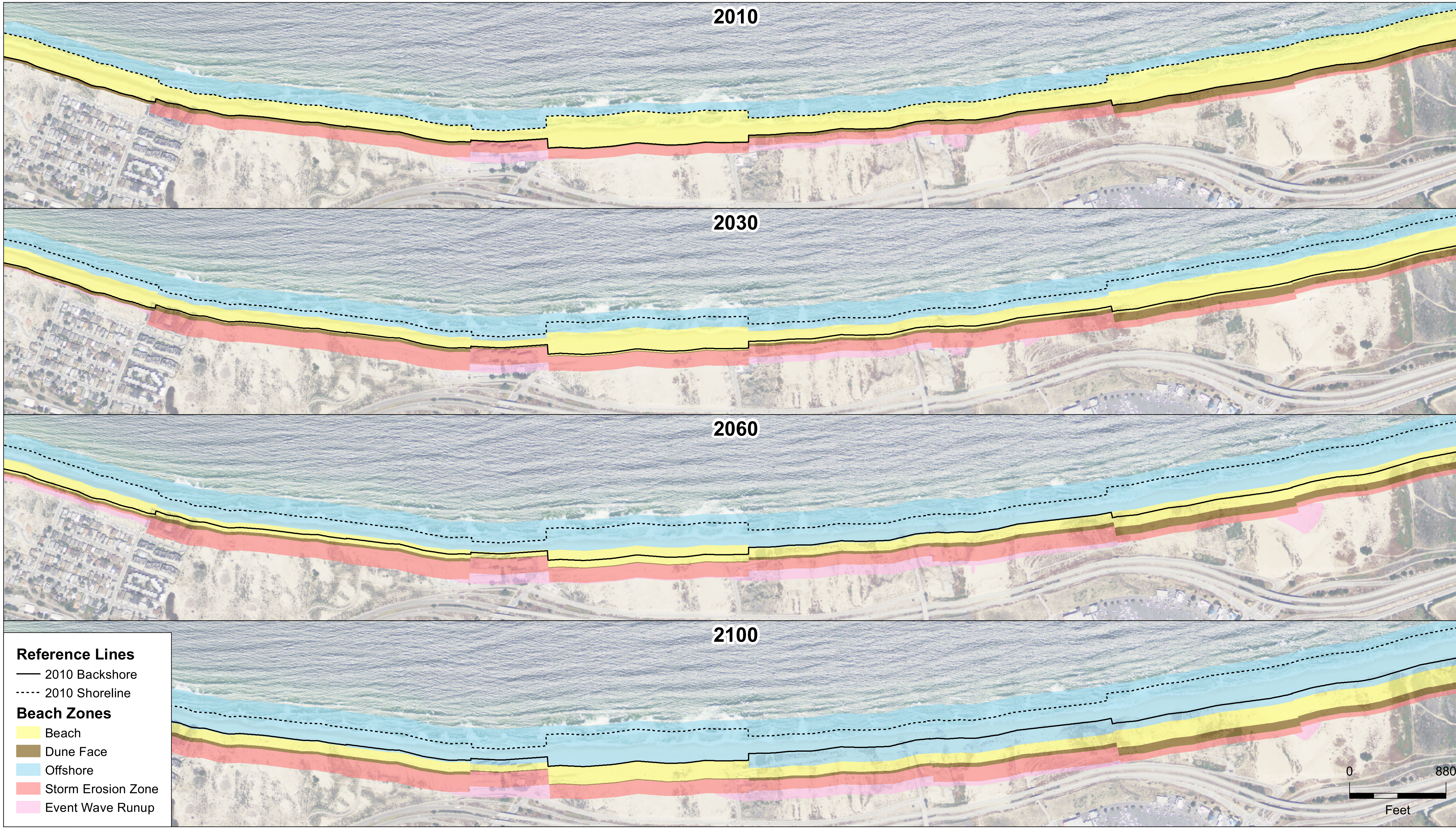
SOURCE:

SMB Climate Ready . 130604

Appendix 2e

Sand City Beach Zones

Allow Erosion, Medium SLR



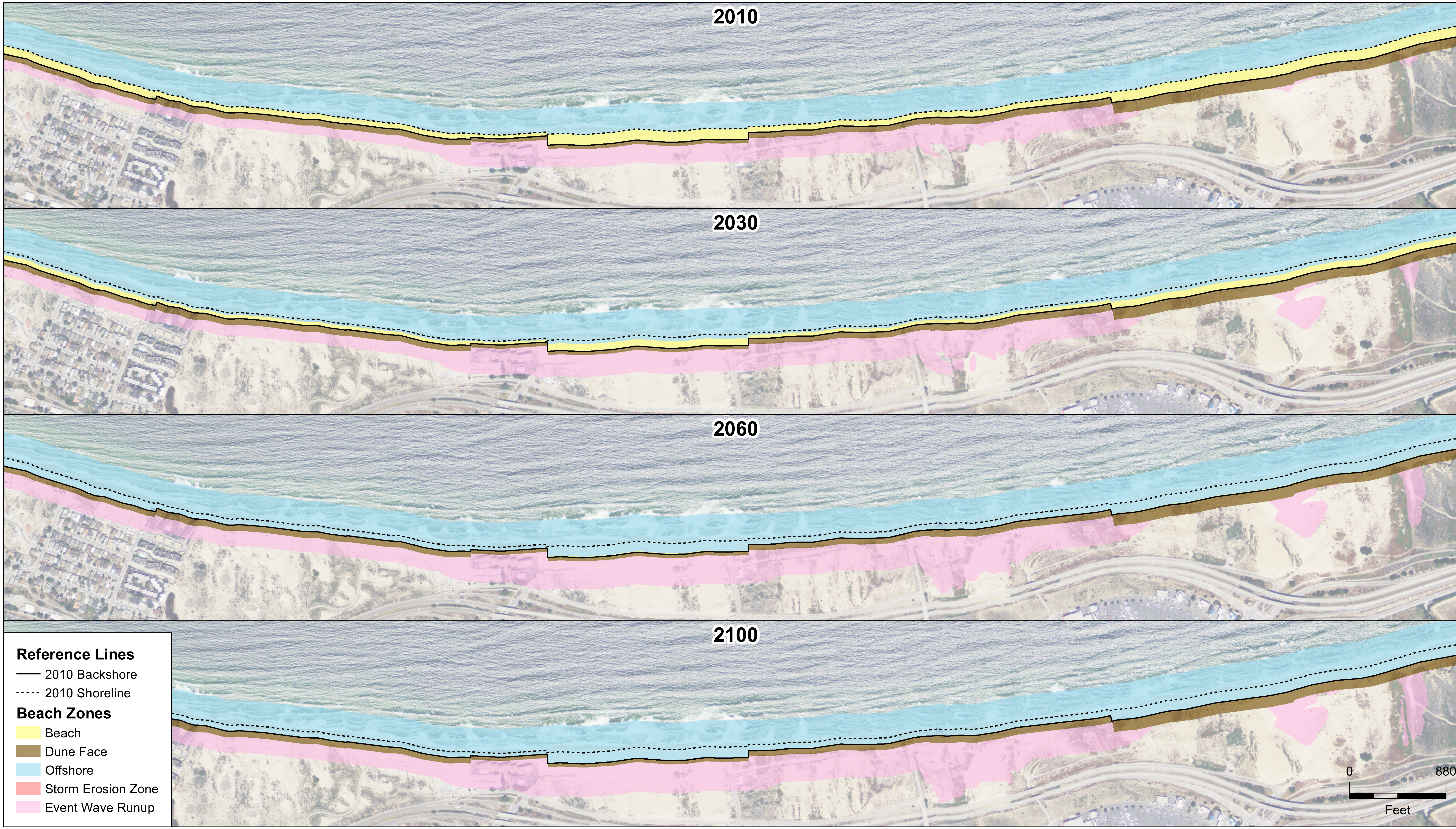
SOURCE:

SMB Climate Ready . 130604

Appendix 2f

Sand City Beach Zones

Beach Nourishment As Needed, Medium SLR



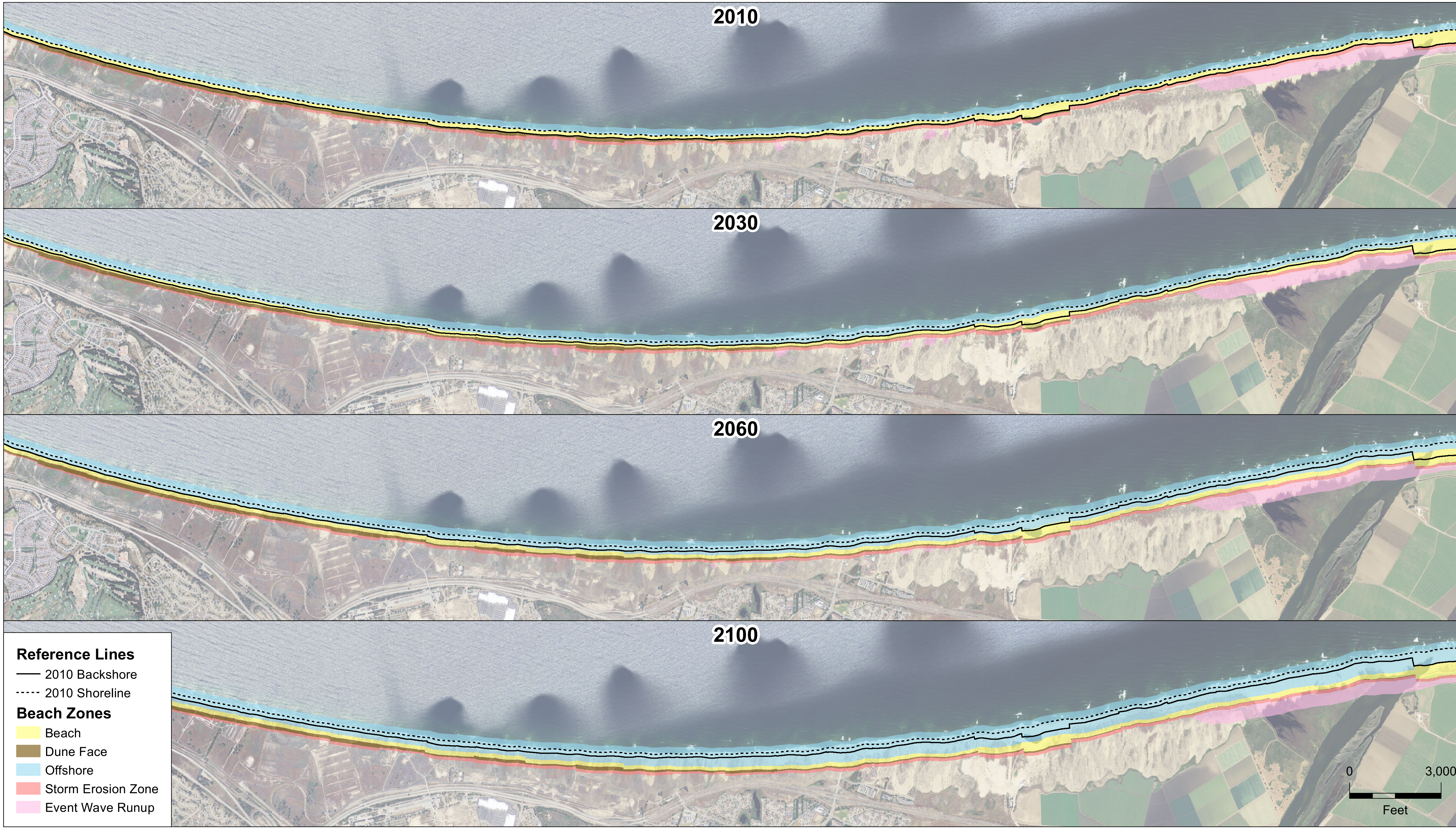
SOURCE:

SMB Climate Ready . 130604

Appendix 2g

Sand City Beach Zones

Hold the Line, Medium SLR



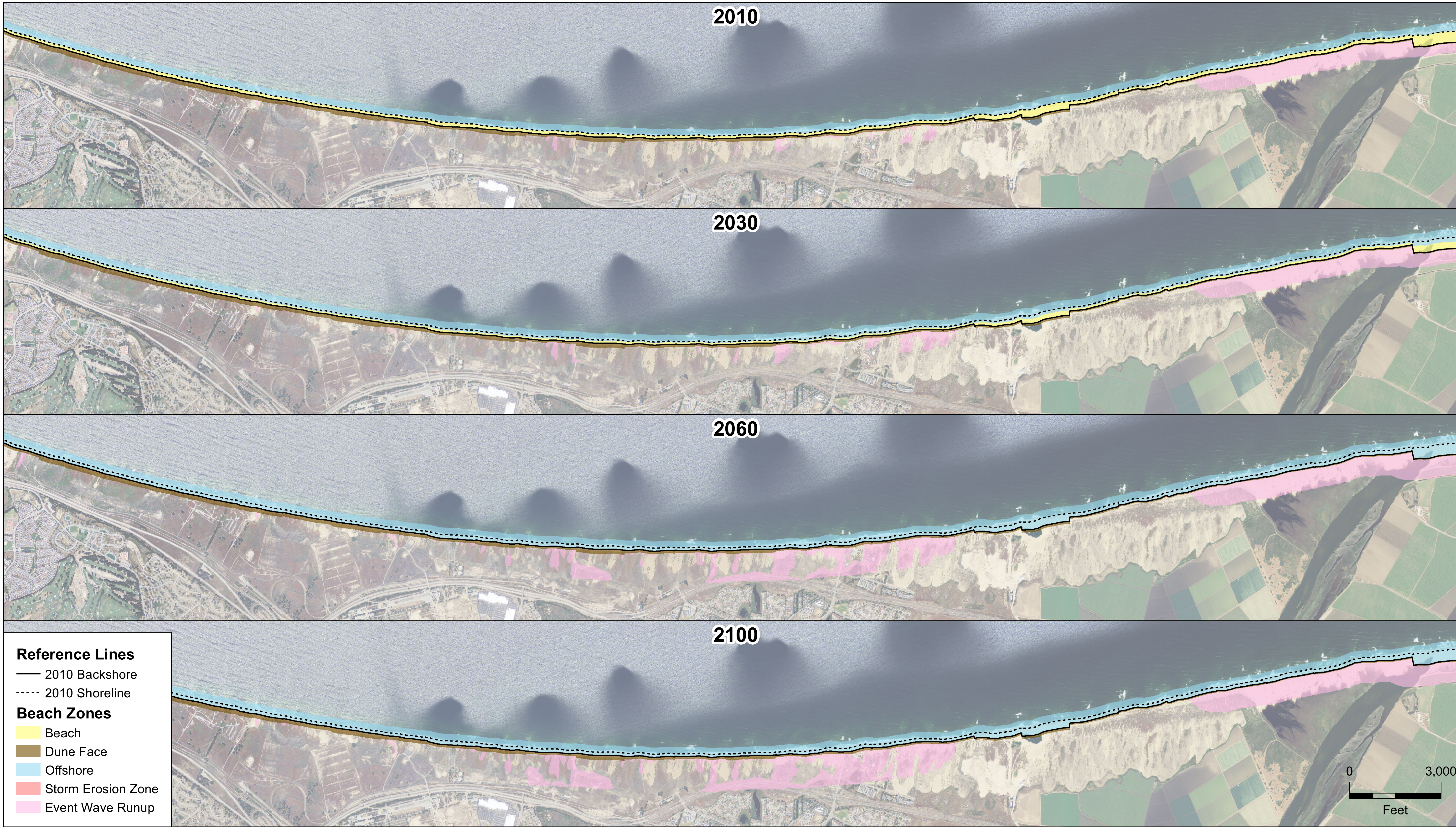
SOURCE:

SMB Climate Ready . 130604

Appendix 2h

Marina Beach Zones

Allow Erosion, Medium SLR



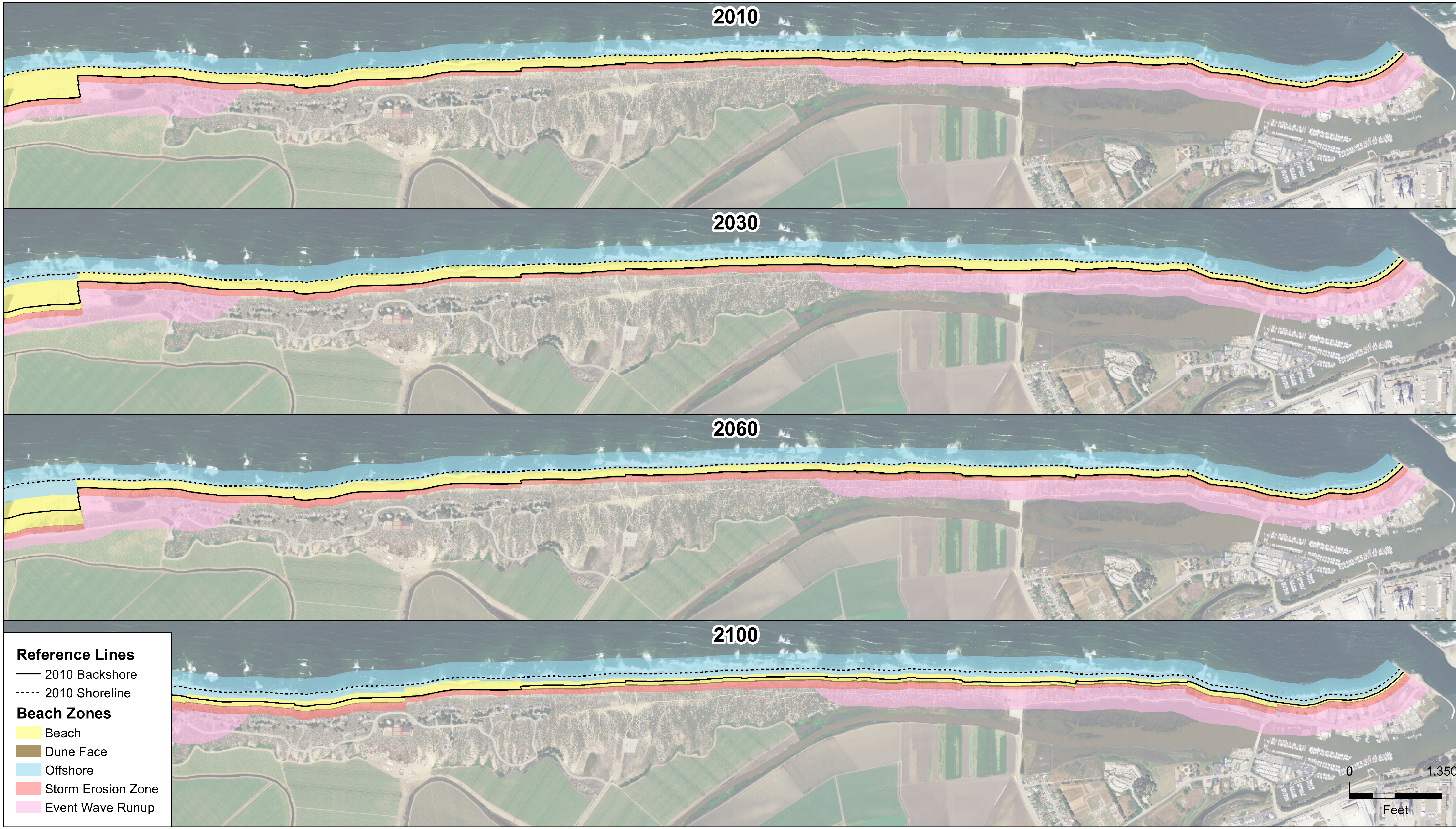
SOURCE:

SMB Climate Ready . 130604

Appendix 2i

Marina Beach Zones

Hold the Line, Medium SLR



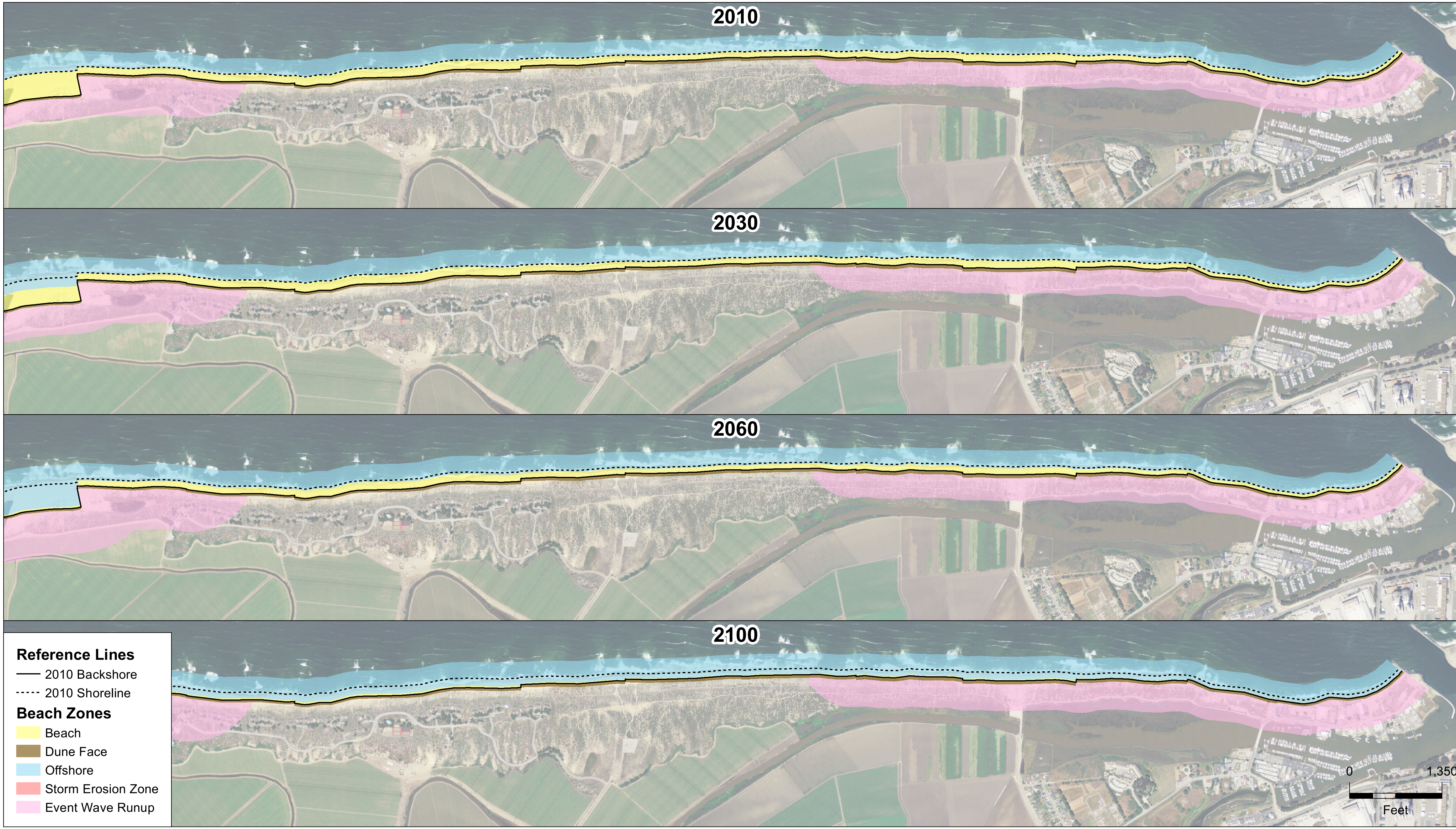
SOURCE:

SMB Climate Ready . 130604

Appendix 2j

Moss Landing Beach Zones

Allow Erosion, Medium SLR



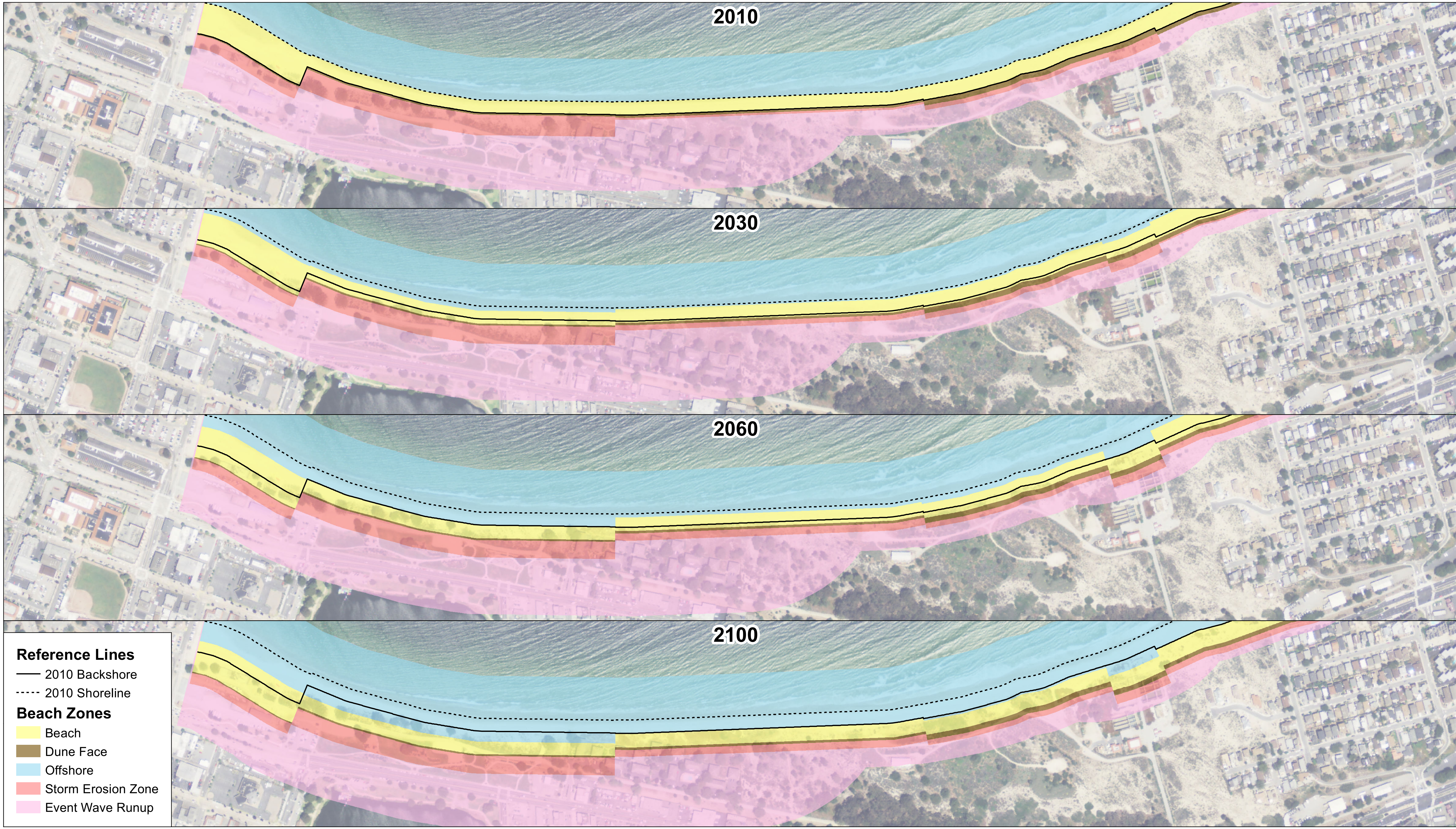
SOURCE:

SMB Climate Ready . 130604

Appendix 2k

Moss Landing Beach Zones

Hold the Line, Medium SLR



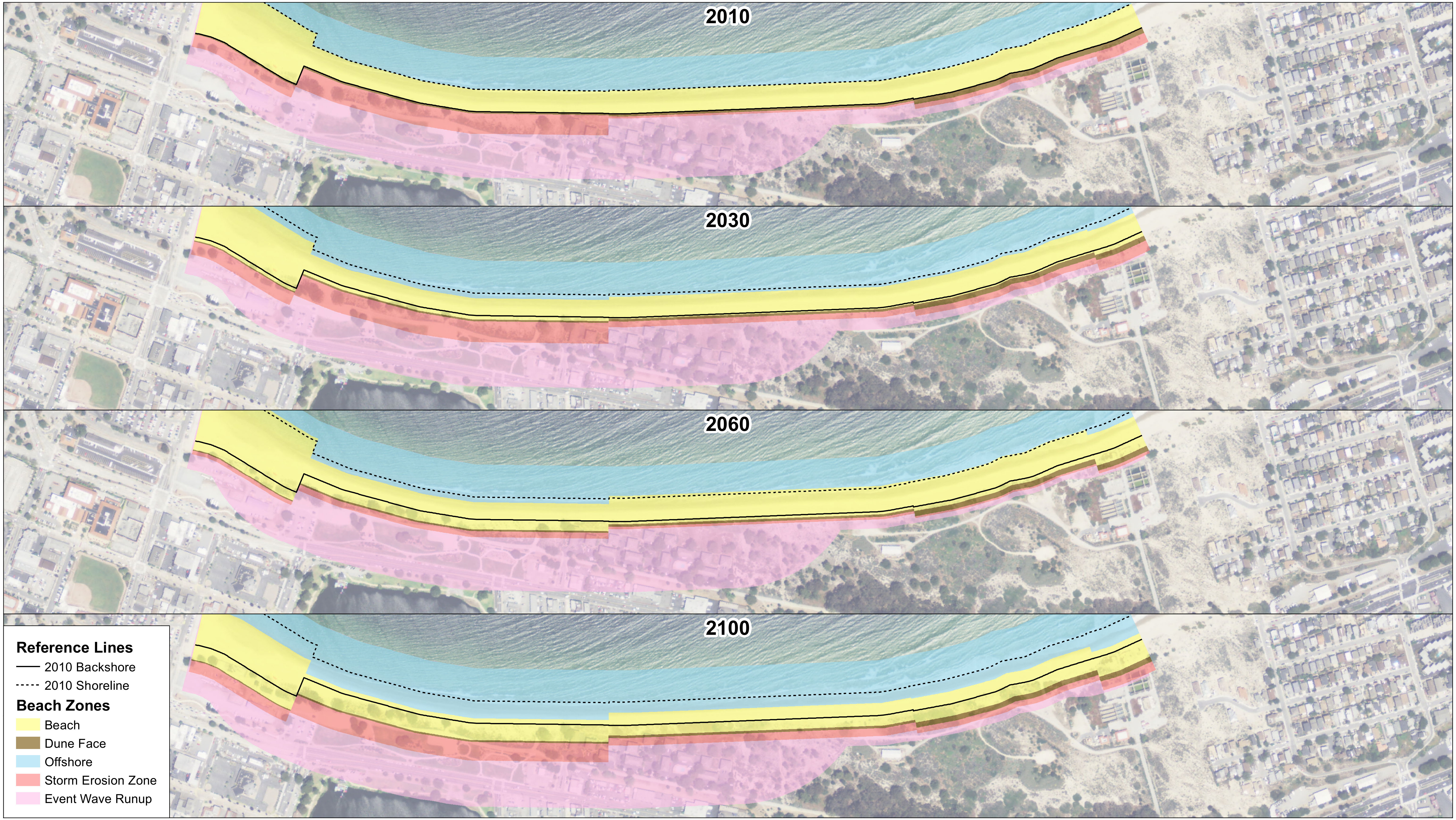
SOURCE:

SMB Climate Ready . 130604

Appendix 2I

Del Monte Beach Zones

Allow Erosion, High SLR



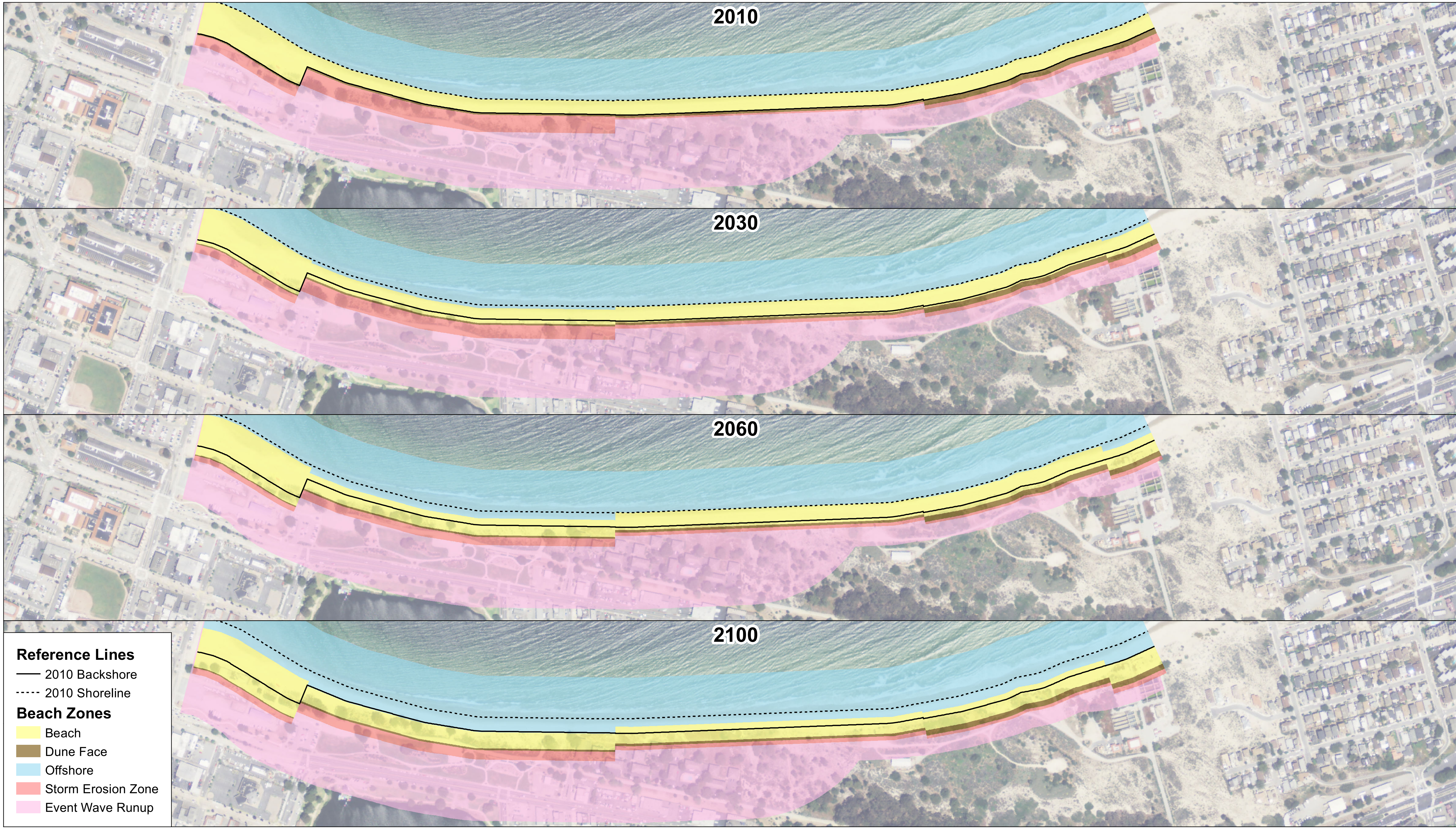
SOURCE:

SMB Climate Ready . 130604

Appendix 2m

Del Monte Beach Zones

Beach Nourishment with Groins, High SLR



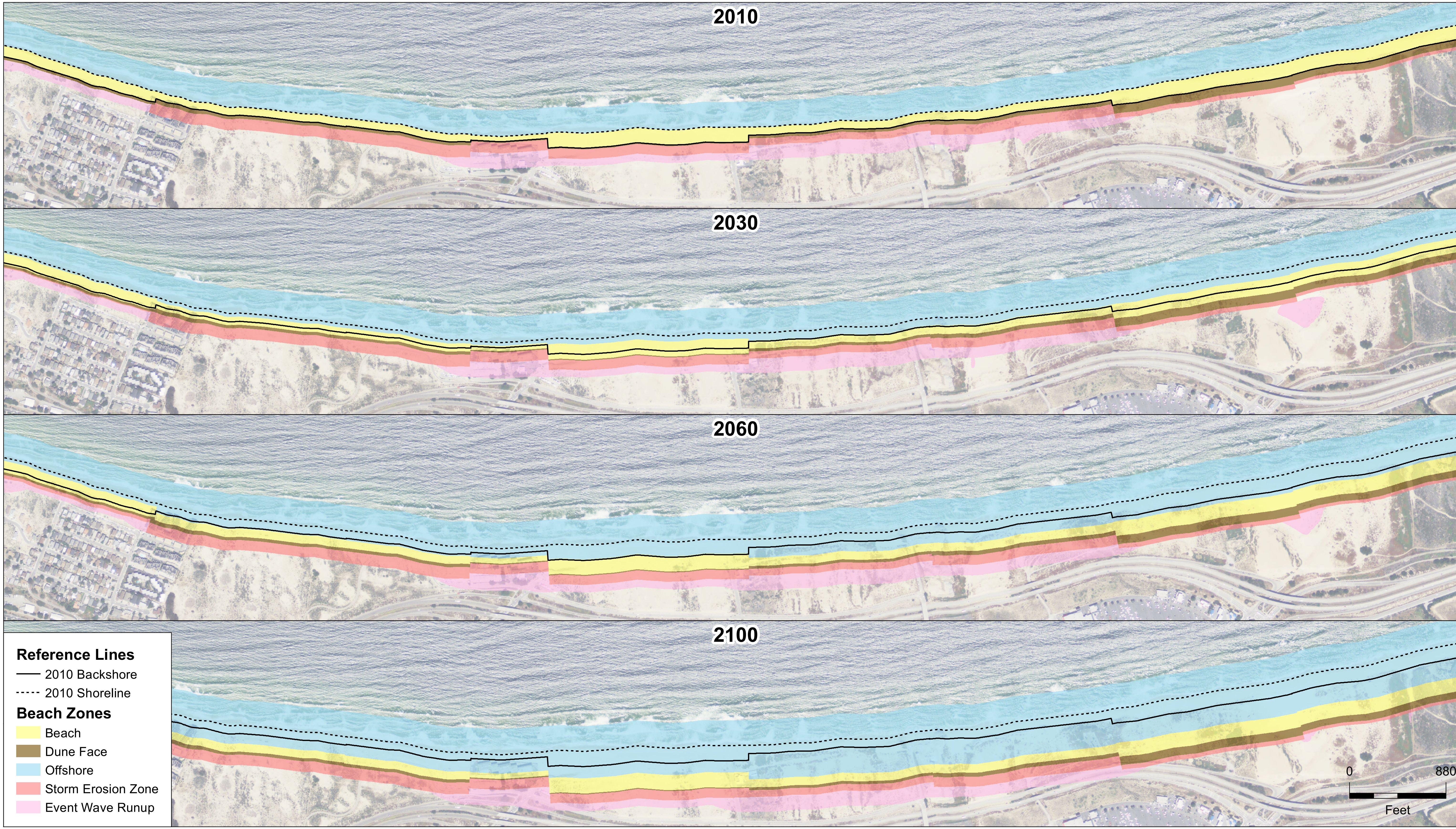
SOURCE:

SMB Climate Ready . 130604

Appendix 2n

Del Monte Beach Zones

Beach Nourishment Set Schedule, High SLR



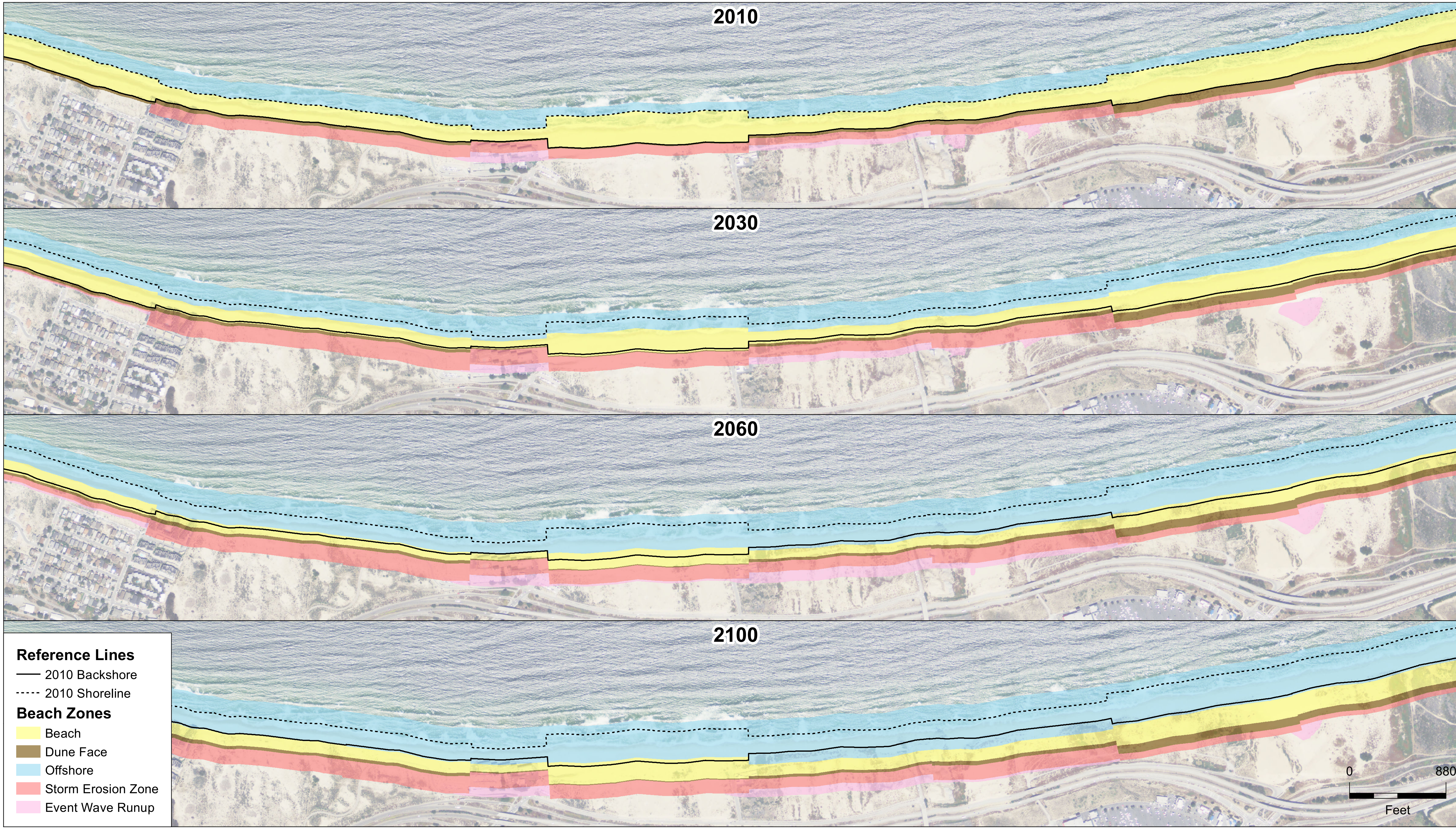
SOURCE:

SMB Climate Ready . 130604

Appendix 2o

Sand City Beach Zones

Allow Erosion, Hgih SLR



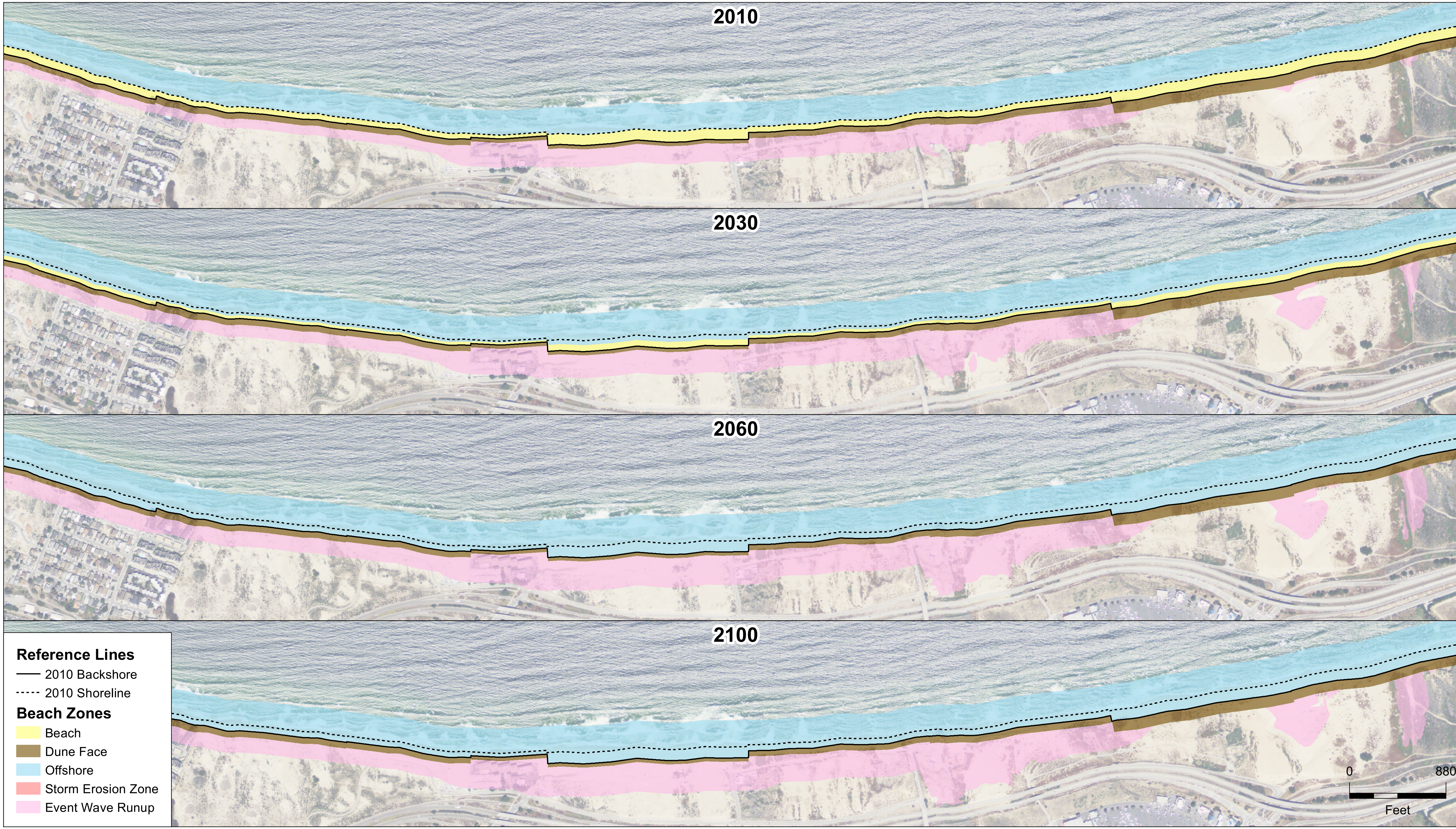
SOURCE:

SMB Climate Ready . 130604

Appendix 2p

Sand City Beach Zones

Beach Nourishment As Needed, Hgih SLR



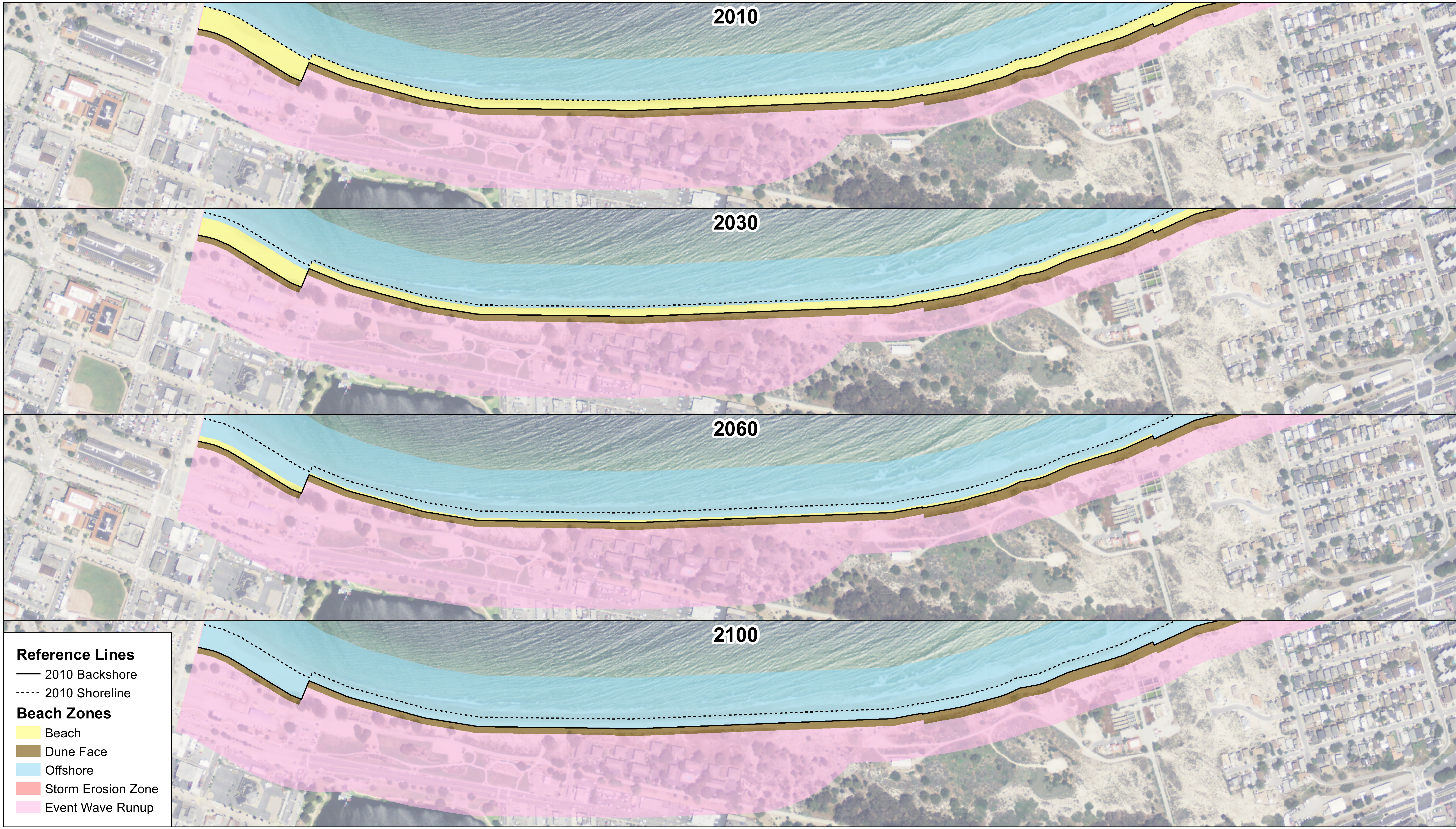
SOURCE:

SMB Climate Ready . 130604

Appendix 2q

Sand City Beach Zones

Hold the Line, Hgih SLR



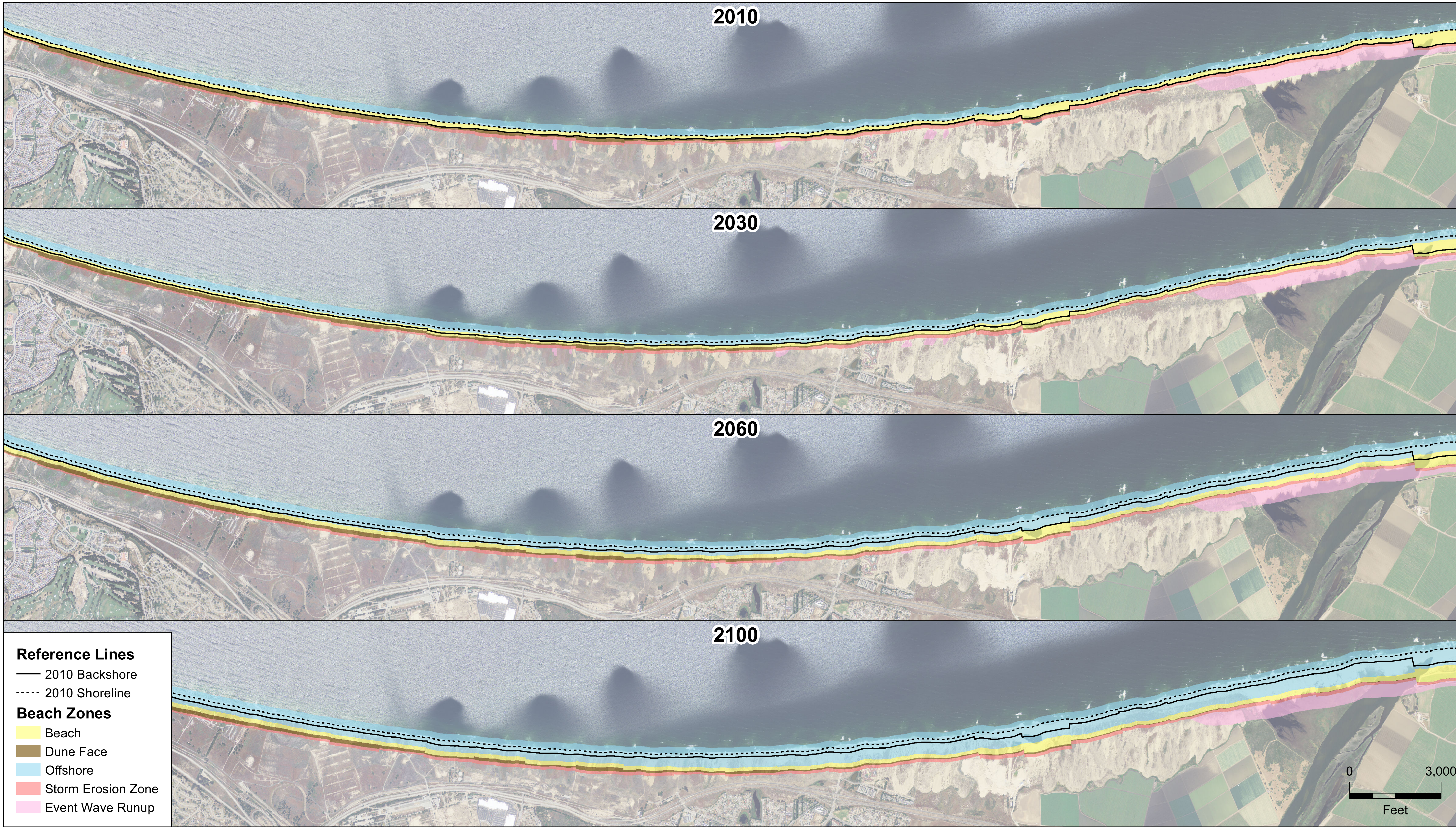
SOURCE:

SMB Climate Ready . 130604

Appendix 2r

Del Monte Beach Zones

Hold the Line, High SLR



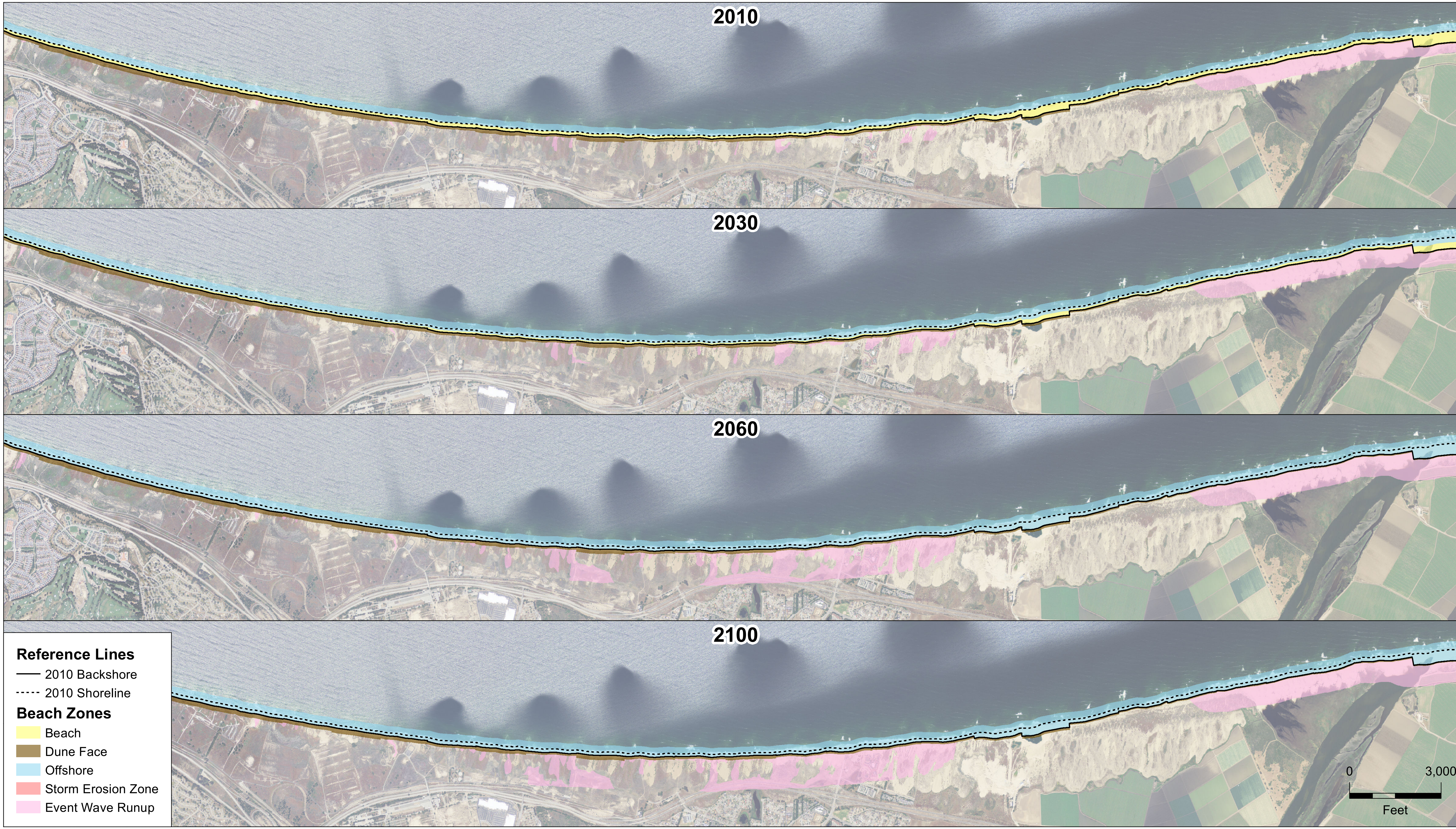
SOURCE:

SMB Climate Ready . 130604

Appendix 2s

Marina Beach Zones

Allow Erosion, High SLR



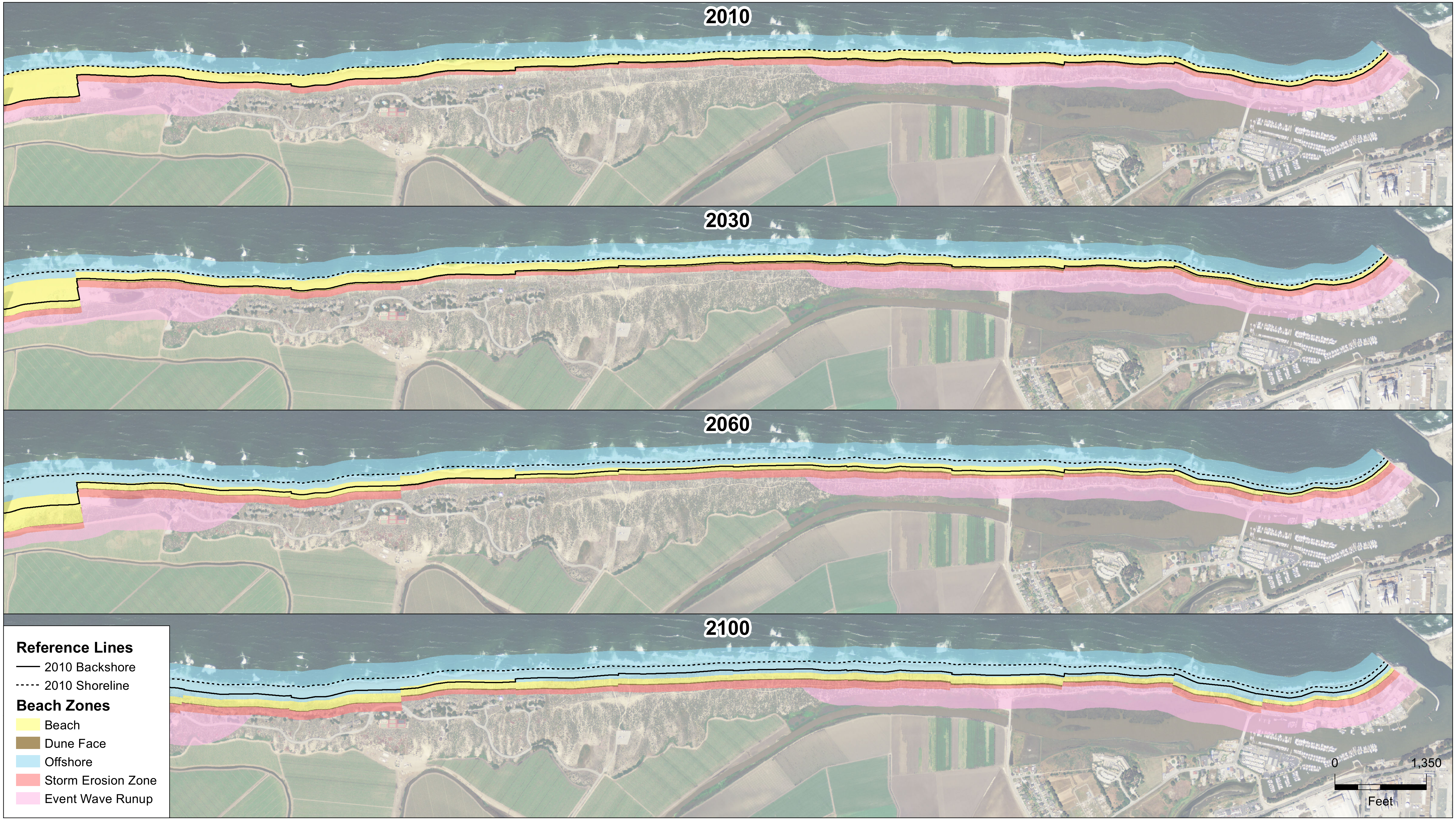
SOURCE:

SMB Climate Ready . 130604

Appendix 2t

Marina Beach Zones

Hold the Line, High SLR



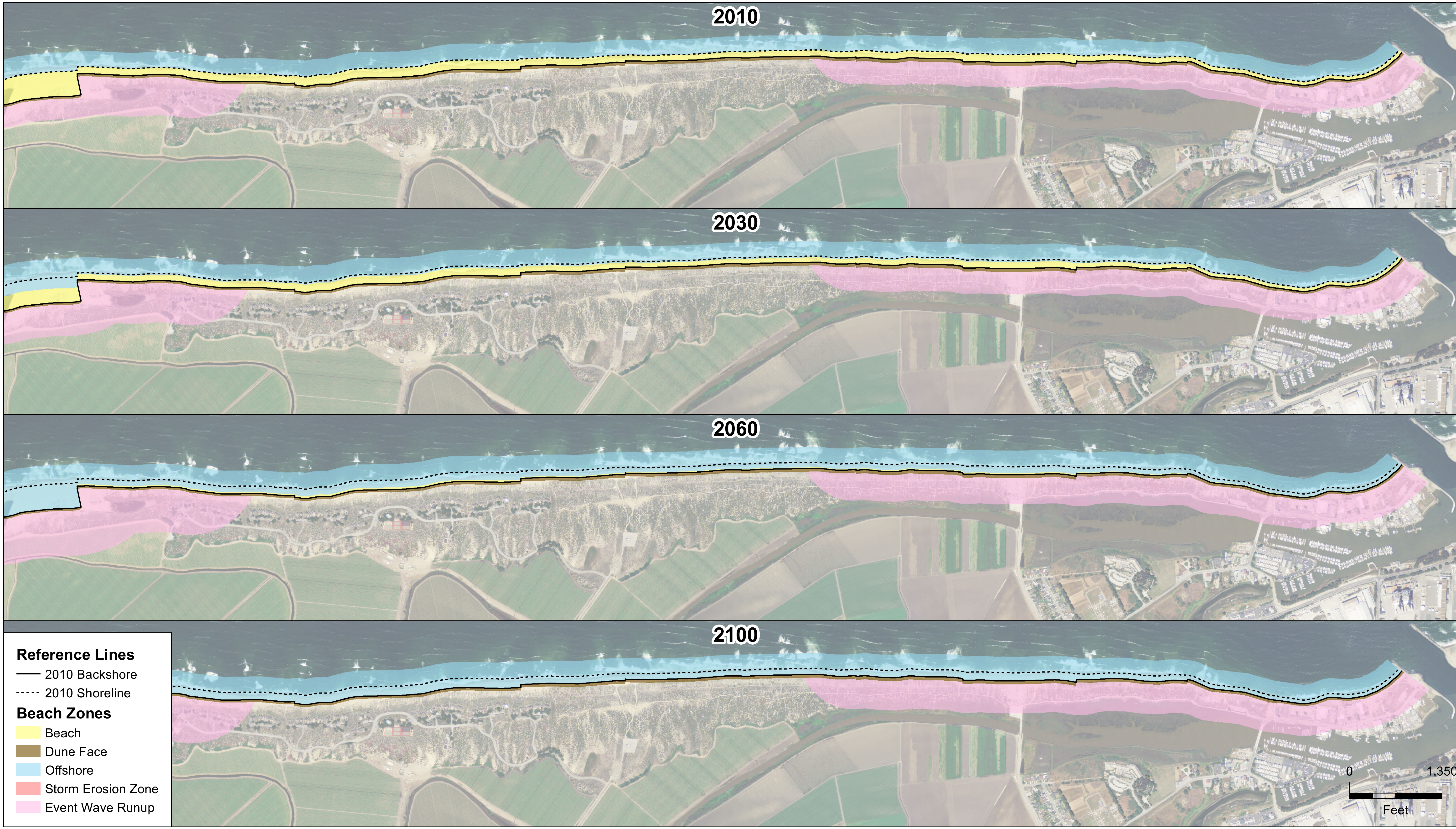
SOURCE:

SMB Climate Ready . 130604

Appendix 2u

Moss Landing Beach Zones

Allow Erosion, High SLR



SOURCE:

SMB Climate Ready . 130604

Appendix 2v

Moss Landing Beach Zones

Hold the Line, High SLR

Appendix 3. List of Coastal Hazard GIS Files

File Name	Folder	File Type	Hazard Zone Type	Prefix	Management Scenario*	Sea Level Rise	Planning Horizon
beach width zones							
beach_zones_AER_ec2010.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	AER	ec	2010
beach_zones_AER_s22030.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	AER	s2	2030
beach_zones_AER_s22060.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	AER	s2	2060
beach_zones_AER_s22100.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	AER	s2	2100
beach_zones_AER_s32030.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	AER	s3	2030
beach_zones_AER_s32060.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	AER	s3	2060
beach_zones_AER_s32100.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	AER	s3	2100
beach_zones_HTL_ec2010.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	HTL	ec	2010
beach_zones_HTL_s22030.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	HTL	s2	2030
beach_zones_HTL_s22060.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	HTL	s2	2060
beach_zones_HTL_s22100.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	HTL	s2	2100
beach_zones_HTL_s32030.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	HTL	s3	2030
beach_zones_HTL_s32060.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	HTL	s3	2060
beach_zones_HTL_s32100.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	HTL	s3	2100
beach_zones_BNN_ec2010.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNN	ec	2010
beach_zones_BNN_s22030.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNN	s2	2030
beach_zones_BNN_s22060.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNN	s2	2060
beach_zones_BNN_s22100.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNN	s2	2100
beach_zones_BNN_s32030.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNN	s3	2030
beach_zones_BNN_s32060.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNN	s3	2060
beach_zones_BNN_s32100.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNN	s3	2100
beach_zones_BNS_ec2010.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNS	ec	2010
beach_zones_BNS_s22030.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNS	s2	2030
beach_zones_BNS_s22060.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNS	s2	2060
beach_zones_BNS_s22100.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNS	s2	2100
beach_zones_BNS_s32030.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNS	s3	2030
beach_zones_BNS_s32060.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNS	s3	2060
beach_zones_BNS_s32100.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNS	s3	2100
beach_zones_BNG_ec2010.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNG	ec	2010
beach_zones_BNG_s22030.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNG	s2	2030
beach_zones_BNG_s22060.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNG	s2	2060
beach_zones_BNG_s22100.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNG	s2	2100
beach_zones_BNG_s32030.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNG	s3	2030
beach_zones_BNG_s32060.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNG	s3	2060
beach_zones_BNG_s32100.shp	1_BeachZones\v06	polygon shapefile	Beach Width Zones	beach_zones	BNG	s3	2100

**AER = Allow Erosion, HTL = Hold the Line, BNN = Beach Nourishment as Needed, BNS = Beach Nourishment with a Set Schedule, and BNG = Beach Nourishment as Needed with Groins*

Appendix 3. List of Coastal Hazard GIS Files

File Name	Folder	File Type	Hazard Zone Type	Prefix	Management Scenario*	Sea Level Rise	Planning Horizon
chronic erosion zones							
chronic_erosion_AER_ec2010.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	AER	ec	2010
chronic_erosion_AER_s22030.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	AER	s2	2030
chronic_erosion_AER_s22060.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	AER	s2	2060
chronic_erosion_AER_s22100.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	AER	s2	2100
chronic_erosion_AER_s32030.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	AER	s3	2030
chronic_erosion_AER_s32060.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	AER	s3	2060
chronic_erosion_AER_s32100.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	AER	s3	2100
chronic_erosion_HTL_ec2010.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	HTL	ec	2010
chronic_erosion_HTL_s22030.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	HTL	s2	2030
chronic_erosion_HTL_s22060.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	HTL	s2	2060
chronic_erosion_HTL_s22100.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	HTL	s2	2100
chronic_erosion_HTL_s32030.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	HTL	s3	2030
chronic_erosion_HTL_s32060.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	HTL	s3	2060
chronic_erosion_HTL_s32100.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	HTL	s3	2100
chronic_erosion_BNN_ec2010.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNN	ec	2010
chronic_erosion_BNN_s22030.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNN	s2	2030
chronic_erosion_BNN_s22060.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNN	s2	2060
chronic_erosion_BNN_s22100.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNN	s2	2100
chronic_erosion_BNN_s32030.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNN	s3	2030
chronic_erosion_BNN_s32060.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNN	s3	2060
chronic_erosion_BNN_s32100.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNN	s3	2100
chronic_erosion_BNS_ec2010.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNS	ec	2010
chronic_erosion_BNS_s22030.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNS	s2	2030
chronic_erosion_BNS_s22060.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNS	s2	2060
chronic_erosion_BNS_s22100.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNS	s2	2100
chronic_erosion_BNS_s32030.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNS	s3	2030
chronic_erosion_BNS_s32060.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNS	s3	2060
chronic_erosion_BNS_s32100.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNS	s3	2100
chronic_erosion_BNG_ec2010.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNG	ec	2010
chronic_erosion_BNG_s22030.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNG	s2	2030
chronic_erosion_BNG_s22060.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNG	s2	2060
chronic_erosion_BNG_s22100.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNG	s2	2100
chronic_erosion_BNG_s32030.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNG	s3	2030
chronic_erosion_BNG_s32060.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNG	s3	2060
chronic_erosion_BNG_s32100.shp	2_ChronicErosion\v06	polygon shapefile	Chronic Erosion Hazard Zone	chronic_erosion	BNG	s3	2100

**AER = Allow Erosion, HTL = Hold the Line, BNN = Beach Nourishment as Needed, BNS = Beach Nourishment with a Set Schedule, and BNG = Beach Nourishment as Needed with Groins*

Appendix 3. List of Coastal Hazard GIS Files

File Name	Folder	File Type	Hazard Zone Type	Prefix	Management Scenario*	Sea Level Rise	Planning Horizon
chronic flood zones (monthly flooding)							
chronic_flood_AER_ec2010.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	AER	ec	2010
chronic_flood_AER_s22030.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	AER	s2	2030
chronic_flood_AER_s22060.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	AER	s2	2060
chronic_flood_AER_s22100.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	AER	s2	2100
chronic_flood_AER_s32030.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	AER	s3	2030
chronic_flood_AER_s32060.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	AER	s3	2060
chronic_flood_AER_s32100.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	AER	s3	2100
chronic_flood_HTL_ec2010.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	HTL	ec	2010
chronic_flood_HTL_s22030.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	HTL	s2	2030
chronic_flood_HTL_s22060.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	HTL	s2	2060
chronic_flood_HTL_s22100.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	HTL	s2	2100
chronic_flood_HTL_s32030.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	HTL	s3	2030
chronic_flood_HTL_s32060.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	HTL	s3	2060
chronic_flood_HTL_s32100.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	HTL	s3	2100
chronic_flood_BNN_ec2010.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNN	ec	2010
chronic_flood_BNN_s22030.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNN	s2	2030
chronic_flood_BNN_s22060.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNN	s2	2060
chronic_flood_BNN_s22100.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNN	s2	2100
chronic_flood_BNN_s32030.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNN	s3	2030
chronic_flood_BNN_s32060.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNN	s3	2060
chronic_flood_BNN_s32100.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNN	s3	2100
chronic_flood_BNS_ec2010.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNS	ec	2010
chronic_flood_BNS_s22030.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNS	s2	2030
chronic_flood_BNS_s22060.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNS	s2	2060
chronic_flood_BNS_s22100.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNS	s2	2100
chronic_flood_BNS_s32030.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNS	s3	2030
chronic_flood_BNS_s32060.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNS	s3	2060
chronic_flood_BNS_s32100.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNS	s3	2100
chronic_flood_BNG_ec2010.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNG	ec	2010
chronic_flood_BNG_s22030.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNG	s2	2030
chronic_flood_BNG_s22060.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNG	s2	2060
chronic_flood_BNG_s22100.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNG	s2	2100
chronic_flood_BNG_s32030.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNG	s3	2030
chronic_flood_BNG_s32060.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNG	s3	2060
chronic_flood_BNG_s32100.shp	3_ChronicFlood\area	polygon shapefile	Chronic Flood Hazard Zone	chronic_flood	BNG	s3	2100

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Appendix 3. List of Coastal Hazard GIS Files

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event_wave_AER_s22030.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	AER	s2	2030
event_wave_AER_s22060.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	AER	s2	2060
event_wave_AER_s22100.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	AER	s2	2100
event_wave_AER_s32030.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	AER	s3	2030
event_wave_AER_s32060.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	AER	s3	2060
event_wave_AER_s32100.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	AER	s3	2100
event_wave_HTL_ec2010.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	HTL	ec	2010
event_wave_HTL_s22030.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	HTL	s2	2030
event_wave_HTL_s22060.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	HTL	s2	2060
event_wave_HTL_s22100.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	HTL	s2	2100
event_wave_HTL_s32030.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	HTL	s3	2030
event_wave_HTL_s32060.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	HTL	s3	2060
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event_wave_BNS_ec2010.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	BNS	ec	2010
event_wave_BNS_s22030.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	BNS	s2	2030
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event_wave_BNS_s32060.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	BNS	s3	2060
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event_wave_BNG_s32060.shp	4_EventWaveHazard	polygon shapefile	Event Wave and Erosion Hazard Zone	event_wave	BNG	s3	2060
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event_flood_HTL_s32030.shp	5_EventFlooding	polygon shapefile	Event Flood Hazard Zone	event_flood	HTL	s3	2030
event_flood_HTL_s32060.shp	5_EventFlooding	polygon shapefile	Event Flood Hazard Zone	event_flood	HTL	s3	2060
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event_flood_BNS_s22060.shp	5_EventFlooding	polygon shapefile	Event Flood Hazard Zone	event_flood	BNS	s2	2060
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event_flood_BNG_ec2010.shp	5_EventFlooding	polygon shapefile	Event Flood Hazard Zone	event_flood	BNG	ec	2010
event_flood_BNG_s22030.shp	5_EventFlooding	polygon shapefile	Event Flood Hazard Zone	event_flood	BNG	s2	2030
event_flood_BNG_s22060.shp	5_EventFlooding	polygon shapefile	Event Flood Hazard Zone	event_flood	BNG	s2	2060
event_flood_BNG_s22100.shp	5_EventFlooding	polygon shapefile	Event Flood Hazard Zone	event_flood	BNG	s2	2100
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Appendix 4a

High SLR - Time Table for Adaptation Scenario Costs ($M)

Reach	Scenario Name	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100	Note
Del Monte (1.6 km)	Opportunistic beach nourishment (50,000 CY every 10 years)	$0.60		$0.60		$0.90		$0.90		$0.90		$1.85		$1.85		$1.85		$1.85			Cost of 50,000 CY of nourishment every 10 years.
	Revetments	$32.00						$32.00						$32.00				$32.00			Cost of constructing and maintaining rock revetment. Beach Width = 0 in 2068
	Managed retreat (fee simple)	To be determined by economists																			
	Groins + medium scale nourishment (400,000 CY as needed to maintain 25% wider beach)	$48.00								$50.40											Cost of Groins and 400,000 CY of nourishment at year 2010 and 2051.
	Elevating structures	To be determined by economists																			
Sand City (4.1 km)	Large scale beach nourishment (2M CY as needed to maintain 25% wider beach)	$40.00											$90.00						$90.00		Cost of 2,000,000 CY of nourishment at year 2010, 2067, 2094.
	Managed retreat – cons. easements	To be determined by economists																			
	Revetments	$82.00						$82.00				$82.00				$82.00				$82.00	Cost of constructing and maintaining rock revetment. Beach Width = 0 in 2047
	Elevating infrastructure	To be determined by economists																			
Marina (14.5 km)	Managed Retreat (rolling easements)	To be determined by economists																			
	Managed retreat (fee simple)	To be determined by economists																			
	Revetments	$290.00						$290.00				$290.00				$290.00				$290.00	Cost of constructing and maintaining rock revetment. Beach Width = 0 in 2051
Moss Landing (6.0 km)	Do nothing	To be determined by economists																			
	Revetments	$355.00						$120.00					$120.00				$120.00				Cost of constructing and maintaining rock revetment. Plus 2010 construction of lock-levee system at Moss Landing Harbor. Beach Width = 0 in 2063
	Managed retreat with conservation easements	To be determined by economists																			

Red cells = Beach Width reaches 0, determined in previous beach width modeling.

Appendix 4b

Medium SLR - Time Table for Adaptation Scenario Costs ($M)

Reach	Scenario Name	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080	2085	2090	2095	2100	Note
Del Monte (1.6 km)	Opportunistic beach nourishment (50,000 CY every 10 years)	$0.60		$0.60		$0.90		$0.90		$0.90		$1.85		$1.85		$1.85		$1.85			Cost per 50,000 CY of nourishment every 10 years.
	Revetments	$32.00						$32.00						$32.00					$32.00 (red)		Cost of constructing and maintaining rock revetment. Beach Width = 0 in 2093
	Managed retreat (fee simple)	To be determined by economists																			
	Groins + medium scale nourishment (400,000 CY as needed to maintain 25% wider beach)	$48.00																$58.00			Cost of Groins and 400,000 CY of nourishment at year 2010 and 2089.
	Elevating structures	To be determined by economists																			
Sand City (4.1 km)	Large scale beach nourishment (2M CY as needed to maintain 25% wider beach)	$40.00																	$90.00		Cost of 2,000,000 CY of nourishment at year 2010 and 2096.
	Managed retreat – cons. easements	To be determined by economists																			
	Revetments	$82.00						$82.00					$82.00 (red)				$82.00				Cost of constructing and maintaining rock revetment. Beach Width = 0 in 2061
	Elevating infrastructure	To be determined by economists																			
Marina (14.5 km)	Managed Retreat (rolling easements)	To be determined by economists																			
	Managed retreat (fee simple)	To be determined by economists																			
	Revetments	$290.00						$290.00					$290.00 (red)				$290.00				Cost of constructing and maintaining rock revetment. Beach Width = 0 in 2062
Moss Landing (6.0 km)	Do nothing	To be determined by economists																			
	Revetments	$355.00						$120.00						$120.00						$120.00	Cost of constructing and maintaining rock revetment. Plus 2010 construction of lock-levee system at Moss Landing Harbor.
	Managed retreat with conservation easements	To be determined by economists																			

Red cells = Beach Width reaches 0, determined in previous beach width modeling.

Appendix B
Economic Impact of Climate Adaptation Strategies for Southern Monterey Bay: ECONOMIC ANALYSIS

Prepared by:

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March 2015

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Introduction

The goal of this economic appendix is to determine the costs and benefits of utilizing the adaptation strategies for each reach, considering both market and non-market goods and services. Market goods are valued by their price when sold. In the case of real estate, where sales are infrequent, we estimated the current market price based on comparable market values. Unlike previous studies (e.g., Environs 2015) we also accounted for the fact that structures near the coast have a higher replacement cost per square foot than inland structures. Infrastructure such as roads and wastewater pumps were valued at replacement cost (see discussion below).

In addition to market goods, the coast also provides substantial non-market goods and services. For example, southern Monterey Bay beaches provide recreational value for hundreds of thousands of visitors per year. Beaches also provide significant ecological functions, goods and services, but quantifying the economic value of such things is challenging. Our previous study of southern Monterey Bay used a generic estimate for the value of beach ecosystems that relied on a modified value per hectare (e.g., see Costanza, et. al., 2006). This study, by contrast, uses existing data on ecological functions to rate each beach/reach for its ecological value. All values are real 2015 dollars.

Sea Level Rise Literature Review

Yohe et al. were the first to compare the costs and benefits of allowing sea level to rise unimpeded with those of introducing protective measures for the purpose of preventing property inundation (Yohe 1989; Yohe et al. 1996; Yohe and Schlesinger 1998). These authors argued that a property would be protected if and only if its value was greater than the cost of intervention at the time of inundation. Other authors (e.g., Hanemann 2008; Heberger et al. 2009) have, however, identified several limiting assumptions that are native to this approach. First, it failed to take into account damages due to a combination of sea-level rise and extreme storm events. Second, it is highly unlikely that property owners would be able or choose to take preventive actions at the point in time when sea-level rise posed a risk. Third, the approach taken by Yohe et al. did not include economic damages beyond those of private property losses, such as business interruptions, travel delays, etc.

A number of more recent studies have, however, remedied some of the conceptual limitations described above. In 2009, the Pacific Institute built on prior analyses by evaluating the impacts of a sea level rise of 1.4 meters in combination with a 100-year flood event across the entire California open coast (Heberger et al. 2009; Gleick and Maurer 1990). Neumann et al. (2003) illustrated the range of impacts that could be experienced over larger geographies by exploring the relationship between changes in sea-level and coastal economies/populations along the California coast.

King et al. (2013) employed a much more particularistic approach, arguing that, if one considers soft and hard engineering solutions to public/private property, recreational and habitat value, and beach related spending/tax revenues across multiple time horizons and a range of sea-level rise scenarios, there is no single best strategy for adaptation to apply across the diverse array of coastal communities. Finally, Environ and ESA (2015) analyzed both engineering and nature-based adaptation strategies in Ventura County, California, concluding that the former yielded slightly higher net benefits than the latter only when the additional ecosystem services are not accounted for. When ecological functions, goods and services were taken into account, the nature based strategy generated the most benefits.

Economic Value of Beach Recreational Resources

Although beach spending is a useful metric, economists measure the non-market value of beach recreation by beach-goers' willingness to pay to recreate at a beach. Our estimates for the economic value of beach recreation are based on attendance estimates and an economic valuation model developed by Dr. Philip King for the State of California and the U.S. Army Corps of engineers, the California Sediment Benefits Analysis Tool (CSBAT), a benefits transfer model. The CSBAT model estimates the change in recreational value as beach width decreases (e.g., due to erosion) or increases (e.g., due to nourishment). For a fuller discussion, see King and Symes (2004). The model was calibrated for beach width using survey data collected for this study (discussed below).

Recreation

The four coastal reaches examined in this study are largely comprised of sandy beaches that provide recreational opportunities for visitors. State beaches are required by law to estimate attendance. However, King and McGregor (2012) found that the methods used to estimate beach attendance vary greatly and the accuracy of "official" beach attendance estimates is suspect, typically overestimating actual attendance by up to an order of magnitude.

While there have been attempts to collect robust data on beach attendance in California, most of these efforts have been focused on the Southern California region where beach tourism plays a larger role in the economies of coastal communities. To address the limitations of existing attendance data, our analysis included the following for each reach during both high season (defined as June, July, and August) and low season (other months):

(1) Periodic counts of recreational activity estimating the number of people participating in water, beach and bluff activities at discrete times and days, and
(2) Intercept surveys designed to estimate the spending, beach width preferences, and demographic characteristics of beach visitors.

We used these user count and survey data and applied estimates of recreational value per visitor per day from other studies (an economic metric known as "benefits transfer").

Coastal User Periodic Counts

We developed coastal user periodic counts to collect data about common recreational activities at southern Monterey Bay beaches and other coastal recreational sites. We recorded the date/time, temperature, wind, cloud cover, and tide. Recreational activities were classified into three main categories: on-shore activities (walking; picnic; fishing; etc.); off-shore activities (swimming/wading; surfing, kayaking; etc.); and bluff activities (walking/running; biking; marine/other life observation; etc.). Counts were conducted between June and August 2014 (high season) and between February and April 2015 (low season).

Intercept Survey

Randomly-selected beach visitors were asked to fill out a four-page intercept survey to gather information about beach activities and demographic characteristics. Respondents were given a choice between filling out the survey themselves (which most did) or having the surveyor read the survey and fill it out. Our past experience indicates that this method yields a high rate of response (80-90%) as compared to surveys where respondents are asked to mail back their responses (33-50%). Since any sampling strategy can have a potential selection bias (e.g., perhaps the 33-50% of respondents mailing back surveys were more affluent or more likely to come from out of town) a high response rate is preferable.

The intercept survey included questions about group size, origin of the trip, mode of transportation, etc. For overnight visitors, the survey inquired about the length of stay and type of lodging. In order to estimate attendance, the survey also enquired about the respondents' arrival and expected departures that day.

Also included in this section were questions about respondent's perception of different beach armoring alternatives and their effects on the quality of beach visitor's experience. The next two sections asked respondents about trip expenditures, and perceptions regarding the potential impacts of reduction/expansion of beach width on willingness to visit the beach. Finally, the last section asked standard demographic information (age, gender, place of residence, race, education, employment status, household size and household income).

The survey instrument and full survey results can be found in the appendices to this report.

Summary Statistics

Table 1 (below) summarizes the key findings of the survey, which are consistent with other surveys we have conducted (e.g., see King and Symes 2004). In particular, just under 40% of visitors were from Monterey County, and roughly half (51%) were on overnight trips. The typical party size was 3.5 and close to 80% of visitors arrived by car. Overnight visitors typically spent just under $50 per person per day while day-trippers spent $12 per person per day. The complete results of the survey are presented in Appendix A.

Table 1: Selected Summary Statistics from Survey of Beach Visitors

Item	Survey Estimates
Percentage of visitors from Monterey County	38.7%
Percentage of visitors on overnight trips	51%
Average party size	3.5
Percentage arriving by car	78.4%
Average expenditures per visitor – overnight	$48.66
Average expenditures per visitor – day tripper	$12.32

We used both count and survey data to estimate yearly attendance and spending at the Del Monte, Sand City and Marina reaches. Attendance estimates for Moss Landing are from State Parks-collected data. Given a distribution of arrival and departure times, we estimated the number of people on a beach for a given day based on a specific periodic count. Since the length of stay also depends upon arrival time, the "turnover factor" varies with count time and ranged from 1.75 (2-3 pm) to 5.1 (8-

10am). Table 2 (below) summarizes our aggregate estimates for each reach.

Table 2. Estimated Yearly Attendance and Spending

Reach	Attendance	Annual Spending
Del Monte	88,000	$2,710,000
Sand City	90,000	$2,770,000
Marina	50,000	$1,540,000
Moss Landing	197,000	$6,060,000

Economic Value of Shoreline Ecological Resources

Although from an economic or social perspective California's beaches are often primarily considered for their recreational and aesthetic value, they also provide significant ecosystem services and are critical habitats for many plants and animals (Schlacher et al. 2007, 2014). The beaches and associated dunes of Monterey County provide habitat for a diversity of plants and animals including several insect, reptile, and plant species protected under the endangered species act (ESA). Monterey beaches also provide grunion spawning habitat and critical nesting habitat for the federally-threatened Western snowy plover. Monterey beaches and dunes have been found to be critically important habitats for migratory birds along the Pacific flyway, providing expansive and productive feeding and resting grounds (Neuman et al. 2008). Beaches and dunes also provide considerable ecosystem services or benefits to humans in four main categories: i) provisioning of products used directly by people, ii) regulating natural functions and processes such as erosion, storm damage, water filtration and carbon sequestration, iii) supporting other services, and iv) cultural or aesthetic value. Consequently, preserving healthy beaches is critical to maintaining the habitat value and ecosystem services they provide.

We used a two-step approach for calculating a dollar value associated with the ecological condition of Southern Monterey Bay beaches. First, we applied a replacement cost analysis based on reported costs of nearby coastal restoration. Second, we developed a relative ranking of ecological value for each beach within the study area. This ecological ranking was scored for present conditions and projected for the future ecological conditions resulting from each adaptation strategy.

The available scientific literature regarding the ecological functions, goods and services provided by beaches is limited and thus difficult to quantify in terms of a dollar amount without knowing exactly the scope of magnitude of these goods and services e.g., see Barbier,2011). The approach, developed by Dr. King and others for the California Coastal Commission, is to view California's beaches as critical natural capital. This approach assumes that any beach ecosystems which are damaged or destroyed need to be replaced, ideally within the same littoral cell. For this study, we used this restoration cost as a metric to economically valuate coastal ecosystems. This approach is largely analogous to the valuation metrics used in order to estimate the replacement cost of physical capital (residential, public and commercial buildings roads, etc.).

Replacement Cost Analysis

Costs from recently proposed or implemented beach restoration projects were used to estimate the value of each beaches relative ecological condition. Table 3 (below) summarizes these costs and provides uniform metrics in terms of cost per linear foot and cost per square foot. Since beach widths vary over time due to erosion, sea level rise, and various policies such as nourishment and coastal armoring, our approach evaluated beach ecosystems in terms of their square footage.

Table 3. Examples of costs for restoration of beach ecosystems in California[1]

Beach	Linear Feet	Area (acres)	Cost ($2015)	Cost/ Linear Ft.	Cost/ Sq.Ft.	Project Elements
Pacifica State Beach	2,000	4	$6,960,000	$3480	$40	Parking lot, Revetment removed. Nourishment. Dune restoration
Surfer's Point	1,100	2.1	$4,670,000	$4245	$50	Removal of paving Beach/dune restoration New road & parking lot New storm drains
Ocean Beach	4,000	13.5	$200,000,000	$50,000	$340	Removal of fill, revetment roadway, parking Native vegetation. Construction of public facilities farther inland
Goleta Beach	700	1	$3,650,000	$5214	$84	Protect of sewer outfall Removal of parking, Revetment. Relocation of utilities, bike path
Average	**1950**	**4.03**	**$53,820,000**	**$15,735**	**$129**	
Average w/o Ocean Beach	**1267**	**2.37**	**$5,093,333**	**$4,313**	**58**	

Ecological Assessment

To assess the ecological score – or relative ecological health and quality – of southern Monterey Bay beaches, we divided the study area into 1km^2 blocks, providing replication within study reaches (See Figure 1, below). Each block was centered on the shoreline to capture ecological functions and processes from both the terrestrial and marine realms. We then used the best available geospatial data to inform the ecological value or detraction from ecological value resulting from human impacts.

[1] Source: Memo from ESA on Beach Restoration costs, April 23, 2015. Note that costs for acquisition or permission, easements, permitting, planning, monitoring etc., are not included in these estimates

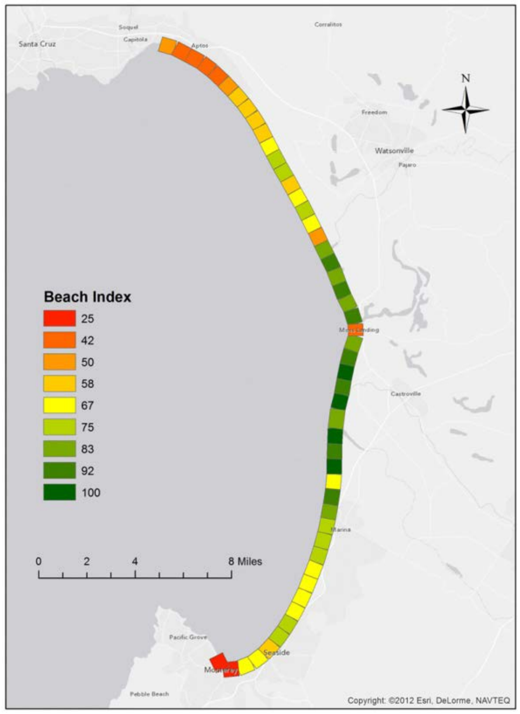


Figure 1. Beach Ecological Index Evaluation

Beach ecological condition was scored according to three attributes: Physical Condition, Biotic Condition, and Human Impact, each measured using the specific metrics described below. We sought the strongest metrics (Schlacher et al. 2014) using the highest quality empirical data from Monterey Beaches to score the Biotic Condition attribute for project beaches. Data for each metric were classified into quartile scores using Natural Breaks (the Jenks optimization method) in ArcGIS. Thus each metric was equally comparable, equally weighted, and provided a relative ranking of beach block from best available to worst observed within the study area given current conditions.

Physical Condition: To score beaches for the Physical Condition attribute we combined quartile scores for four metrics: long-term erosion rates, area of sandy beach, area of unvegetated dunes, and area of vegetated dunes. We used long-term erosion from 14,562 transects used to calculate long-term rates between the 1800s and 1998/2001 (Hapke et al. 2006) as a good indicator of whether project beaches were growing or diminishing through time. We used Calveg data (U.S. Forest Service) to quantify the area of sandy beach, area of unvegetated dunes, and area of vegetated dunes.

Biotic Condition: We sought metrics on Biotic Condition that were readily available, able to be entered as geodata, and recognized as strong indicators of ecological function. We chose three of the four types of broadly applicable metrics discussed by Schlacher et al. (2014) – the fourth metric (population and assemblage measures of abundance/cover/biomass for plants and animals) is included within the Physical Condition attribute. Our first Biotic Condition metric was total mean shorebird abundance for each 1km^2 beach segment (Neuman et al. 2008). Our second metric characterized the mean total number of shorebird species for each beach segment (Neuman et al. 2008). Our third metric ranked the density of snowy plover nests within each beach segment (data courtesy of Point Blue).

Human Impact: For the Human Impact attribute we chose two clear measures of human degradation already available in GIS format: shoreline armoring and area of developed land. We used NOAA's Environmental Sensitivity Index Maps (ESI) to estimate extent of shoreline armoring and Calveg data (U.S. Forest Service) to measure extent of developed land (Booth and Jackson, 1997; Schueler et al., 2009), other coastal habitats (Heady et al. 2015), and beaches (Dugan et al. 2008).

We summed and standardized metric scores as quartiles of 25, 50, 75, and 100 within each attribute. Thus, each 1km^2 block received a relative ranking for each of the four attributes. Attribute scores were averaged to produce a continuous index of ecological condition, referred to as the Beach Ecological Index Score, ranging from 25 (the worst attainable) to 100 (the best attainable) for each 1km^2 block:

Beach Ecological Index Score =
(Physical Condition + Biotic Condition + Human Impact) / 3.

The Beach Ecological Index Score provides a relative ranking of each 1km^2 block within the project area. This relative ranking provides a baseline of current conditions from which to assess any changes associated with different adaptation strategies.

In order to estimate ecological condition associated with future scenarios we made the following adjustments. For the Physical Condition attribute we applied ESA's modeled beach profiles for each adaptation scenario adjusting the area of sandy beach and the area of sand dunes metrics. We also removed the long-term erosion metric, as this was already incorporated into the future beach profiles. There is no way of predicting future biotic response to modeled physical conditions resulting from each adaptation strategy. However, examining our baseline data, we found a very strong correlation (80%) between the Biotic Condition attribute and the Physical Condition attribute. Therefore, we applied a linear regression model to generate a proxy for the Biotic Condition attribute scores given future Physical Condition attribute scores for each adaptation strategy for each time horizon and sea level curve. We did not make any changes to the Human Impact attribute, and assume no changes to the amount of development within 500 meters of today's shoreline. This is likely an unrealistic assumption, but the estimation of future development trends and demographic patterns is beyond the scope of this project.

Beach nourishment degrades the ecological condition of beaches (Defeo et al. 2009, Schlacher et al. 2012, Peterson et al. 2014). Placing large amounts of sand on beaches can impact important nesting habitat as well as lead to complete mortality of the invertebrate community, thereby disrupting important prey sources for shore birds, fish, and crabs (Peterson and Bishop 2005, Schlacher et al. 2012). The impacts depend upon the method and amount of sand placement; recovery times can range from within one year to over four years (Schlacher et al. 2012, Peterson et al. 2014). To model the impacts of nourishment we reduced the Biotic Condition attribute score to 25 for large nourishment projects with a 10% recovery of score per year; for small nourishments we reduced the Biotic Condition attribute score to half of the value prior to nourishment and used a 15% recovery rate per year.

Monetizing Beach Ecological Value

There is no standard offset ratio for beach mitigation, however there is a large literature on wetlands mitigation offsets. The general consensus in the literature (e.g., see Zedler 1991, Castelle 1992, Moilanen et al. 2009) is that the offset ratio should be higher than one. The State of Washington, which has adopted a no-net-loss of ecological services policy for coastal ecosystems, uses wetlands mitigation ratios greater than 1:1 (Castelle 1992). Moilanen et al. (2009) conclude that the offset ratio may need to be much higher, possibly several hundred to one. Given the variability, we applied a 3:1 ratio; however, we also conducted a sensitivity analysis using a variety of ratios including a ratio less than 1:1.

To monetize beach ecological value we combined beach ecological index scores with our beach restoration cost data. We assumed a 3:1 replacement cost for a beach with a "perfect" BEE score of 100 and we scaled beaches with lower BEE scores proportionately. For example, if a beach has a score of 100, the replacement cost would be:

Beach Ecological Value = Beach Offset Ratio * Beach Replacement Cost *BEE/100

= 3 * $4313 * BEE/100

= $12,939 *BEE/100

So, for example, a beach with a score of 75 would be worth 75% of $12,939 or $9704.25 per linear foot. Please note that we used replacement cost per linear foot rather than by area since our BEE score already incorporates the ecological value of increased beach width.

Economic Value of Upland Resources

In order to define an appropriate baseline to which costs and benefits could be compared, we used a number of public and commercial regional data sets. First, the Monterey County Assessor's parcel database represents the most useful detailed inventory of property (i.e., land and buildings) in the area. However, public infrastructure such as roads and utilities are not included in the County Assessor's database. To fill this gap, we used data from local agencies that administer these assets. We used GIS to evaluate the exposure of these assets to the hazards described above, under current and future conditions, and under each adaptation scenario. These GIS analyses were used to develop an asset exposure inventory to support evaluation of economic damages.

The asset exposure inventory contains attributes (e.g., land use, land size, building size, land value, building value) of assets at risk of current and future damages. In some cases, there are monetary values associated with these assets, and in other cases there are not. Even when there is a monetary value assigned to an asset, it may not be the appropriate value from which to measure economic damage. For example, when analyzing flooding damages to residential property, the structure - not the land - is at risk. Further, the structure value embedded in the County Assessor's data reflects the appraised value of the structure at the date of purchase with 2% annual increases (in most cases) to that assessed value (Prop 13). Because flooding will damage a property but in most cases not make it permanently uninhabitable, the appropriate economic unit of measurement is the replacement or reconstruction cost of the damaged structure, not the assessed value. For the same residential property that is at risk to erosion, there is no opportunity for replacing the structure or the land. In this case the market value of the structure and the land would be the appropriate economic unit of analysis.

Another important consideration in measuring damages to assets at risk is to define the thresholds at which damages are triggered by high tide, flooding and erosion. Just because an asset intersects with a hazard zone does not necessarily mean that economic damages will occur. Consider again the example of residential property that is subject to erosion. Erosion may only expose a small fraction of the property and not infringe on the footprint of the structure. In this scenario only a small amount of the land is subject to damage, thereby leaving intact a majority of the land's utility and, by extension, the value of the property. On the other hand, if a majority of the property is exposed to erosion it would be reasonable to assume that a significant portion of the property value is compromised. Damage functions to account for these dynamics were established with consideration of the physical extent of the exposure and its potential effect on the economic use of the asset. These damage functions draw from past studies in the region (SMB v1.0, ESA 2012) and elsewhere in the state (TNC 2014).

Property Analysis

Coastal Flooding Damages from Event Storms and Waves

Economic damages from storm events were estimated using US Army Corps of Engineers (USACE) depth-damage curves. The curves used in this study (USACE 2003a, USACE 2003b, GEC 2005) account for various types of flooding events (e.g., short duration, long duration, freshwater, saltwater) and structure types (e.g., residential, commercial, governmental). The curves were linked to structure values that were estimated with cost per square foot replacement values (RSMeans 2015) that most closely matched the type of building documented in the Monterey County Assessor parcel database.

Sensitivity of Flood Damages

One potential gap in this analysis relates to the potential damages to public structures at risk to flooding. The Assessor database generally does not include attribute information for public structures like a court house which is assessed at $0. Review of the Assessor data made it evident that there were some building characteristics associated with pubic parcels, making it possible to derive damages to these structures. But there were likely public structures that were not accounted for in the Assessor data, and thereby not included in the damage assessment. To gauge the sensitivity of our results to these potential data gaps we analyzed data from a statewide sea-level rise assessment (Heberger et al. 2009). The authors used generalized census block data collected by the National Institute of Building Sciences and stored in the FEMA HAZUS database to identify buildings and contents at risk. For Monterey County, only 2% of the total damages were considered public. Because some of these public assets are accounted for in the Assessor data, the extent damages to these structure types not accounted for the Assessor database is likely minimal.

The depth damage curves reflect riverine freshwater flooding for all structure types less residential where hurricane salt water curves have been published by the USACE. Based on review of freshwater and saltwater residential curves, the freshwater curves anticipate slightly less damage (on average approximately 5%) than the saltwater curves.

Chronic Flood and Chronic Erosion Damages

Economic damages from coastal erosion were estimated by relating the landward extent of erosion to the market value of the land and/or structure at each exposed parcel. There are no widely used damage curves for assessing coastal erosion losses. Prior studies used simple rules of thumb that attempt to address the way in which the current land use may be compromised. For instance, if half of a residential property is subject to erosion, it is likely that the home would no longer be inhabitable and the potential use of both the structure and land for residential purposes would be lost. This rationale was used to develop damage functions for this study that were then applied to the market value of at risk property.

To identify the market value of land and structures at risk to erosion, efforts were taken to adjust valuations from the Assessor database so they reflect market values[2]. In California, county assessors identify a property owner's tax burden by totaling the land and improvement (generally structure) value. Because of Proposition 13 (CABOE 1978), a property's land and structures are only re-assessed at the current market rate when they change ownership through sale, except when improvements are made to the property. Without incurring a change of ownership, the assessor's recorded value can only be increased up to two percent annually. This can lead to significant under-estimation in actual market value.

Further, the market values of properties in certain communities have increased at a much higher rate than other communities because of factors such as development and changes in employment sectors. A

[2] The upland damages from coastal flooding and erosion were assessed using existing replacement and market value prices. They were not adjusted for increases in construction costs (e.g., wages, material) or inflation to property values in the scenario years of 2030, 2060 and 2100 because there are few reliable information points on which to forecast these changes. Therefore, these damages should be considered conservative.

housing price index was used to adjust the assessor valuations of residential property to reflect current market rates. A consumer price index was used in a similar fashion for all other types of properties (e.g., commercial, industrial).

A number of non-taxable public properties are listed in the Assessor database as having both land and improvement value at $0. A review of these public records revealed that they were in many cases undeveloped, open-space parcels. It was assumed that these public parcels are likely constrained in their opportunity for development; however, this assumption does not mean this land holds no economic value. Scenic and conservation easements recorded in the Assessor database were determined to be the closest proxy for an undeveloped, open space parcel. The land values of these property interests were analyzed; we contacted local organizations that have purchased these types of property to determine a conservative value per square foot that could be applied to these non-taxable public parcels. It was assumed that these parcels will remain undeveloped, though it is possible that some of this land could be sold on the open market for a value greatly exceeding the value we used for this study. For public non-taxable parcels where no information was available to determine the fair market value of land, a conservative proxy value was determined of $0.30 per square foot by analyzing sale price information from scenic and open space easements in Monterey County as well as land use purchases from the Elkhorn Slough Foundation.

Infrastructure

The two most important types of infrastructure examined in this project are roads and water treatment equipment. We assumed that all roads/infrastructure would need to be replaced when threatened by erosion. We determined the timeline and "trigger points" where replacement would occur. We assumed that the trigger point occurred when any part of the infrastructure (e.g., a road) is impacted by erosion. Our analysis does not include the additional costs of finding a new site for rebuilding. We assumed that major roads (in particular Hwy 1) would need to be elevated to avoid flood damages that are exacerbated by SLR. For minor roads, we used simple replacement cost. Details of the metrics used and assumptions made are contained in Appendix B.

Costs of Adaptation Alternatives

We estimated the costs of a range of risk-reducing land use and structural adaptation alternatives. The land use alternatives require the purchase of property or a right to that property at full and partial market value, respectively, while we estimated structural adaptation costs to be the cost of constructing and maintaining the structure. Tables 12 and 13 below summarize the assumptions used for the land-use alternatives.

Land Use Adaptation Costs

TNC personnel from the West Coast, the Atlantic Coast and the Gulf Coast were contacted to help identify the costs of fee simple and conservation easement transactions. These types of transactions were focused on private property within the study area and include upfront purchase of the property as well as additional annual legal and stewardship fees.

Fee simple transactions were estimated at the fair market value or the closest proxy when direct market values were not applicable or data were lacking to infer a direct market value. TNC staff indicated that without additional information on the terms of a conservation easement (which was outside the scope of this analysis and challenging to infer with Assessor Roll Call data) that 70 percent of the market value of a parcel is a fair rule of thumb to apply. They did note that this would change if other rights are bundled with the parcel such as permissible use of agriculture. We applied this 70 percent of market value for the conservation easement scenario.

TNC staff also provided the following **annual** costs **per parcel** that we incorporated in the analyses:

- *Property insurance (fee simple and conservation easements):* 0.0003 percent of the purchase price of the parcel.
- *Monitoring (fee simple and conservation easements):* $78 per parcel in personnel operations, supervisor support and travel, occupancy, supplies and materials, in conformity with accreditation with the Land Trust Alliance (LTA) that requires that each easement be monitored annually.
- *Taxes (fee simple only):* $100 per parcel; this includes only special assessment fees.

It would be general practice that the above funds would be invested in an endowment and that the entity in control of the properties would only draw 4.5% of a 5-year average. It is also important to note that the above costs do not account for restoration and long-term ecological maintenance, taxes, or welfare exemptions that could produce income and cover some of the above costs, and any additional infrastructure maintenance.

In the case of rolling easements where structures on public or private properties would need to be removed, a rate of $10 per square foot was applied based on conversations with engineering subject matter experts.

More information can be found in Table 4. Methodology for calculating upland land use adaptation alternative costs.

Structural Adaptation Costs

ESA provided structural adaptation costs for elevating structures and infrastructure which can be found in Appendix 1.

Table 4. Methodology for calculating upland land use adaptation alternative costs

Alternative to Chronic Erosion	Definition	Damage Function	Economic Assumptions	Relevant Reaches
Do Nothing (Hold the Line)	Purchase of property at market value or closest proxy	If less than 50% of property is within hazard zone then 50% of property value is lost; Purchase of entire property is triggered if greater than 50% of parcel falls within hazard zone.	Loss of market value or closest equivalent for the provided land use as detailed in the Assessor roll call. For public non-taxable parcels scenic price per square foot values are applied based on scenic easements as a proxy.	Moss Landing
Fee simple	Purchase of vacant or developed property	Purchase of entire property is triggered if greater than 50% of parcel falls within hazard zone.	Purchase of private property at fair market value or closest proxy as determined in the Baseline scenario. Includes annual fees for insurance, monitoring, and taxes.	Del Monte Marina
Conservation easements	Assumes that there would be some public cost to secure an easement on private property	Purchase of entire property is triggered if greater than 50% of parcel falls within hazard zone.	Purchase of private property at 70% of the market value or closest proxy as determined in the Baseline scenario. Includes annual fees for insurance and monitoring.	Sand City Moss Landing
Rolling easements	As the coast retreats the easement line migrates along with it, inland on a parcel, then any development is removed and becomes part of that easement.	Structure demolition and removal cost is triggered if greater than 50% of parcel falls within hazard zone.	Cost to remove private or public structure based on price per square foot factor.	Marina
Elevating structures	Raising structures to elevate them above coastal hazard zones.	Install new foundations to public and private structures if greater than 50% of parcel falls within hazard zone.	Cost to install new foundations based on price per square foot factor.	Del Monte
Elevating infrastructure	Specific to Hwy 1. Modification of Hwy by installation of column foundation.	Installed in time to avoid intersection of backshore hazard zone with Hwy.	Cost to install new foundations based on price per linear foot factor.	Sand City

Table 5. Abbreviated methodology for calculating upland economic damages

Hazard	Damage Function	Economic Methodology by Property Type
Chronic erosion area	If less than 50% of property is within hazard zone then 50% of property value is lost; If greater than 50 % of property is within hazard zone then 100% of property value is lost.*	▪ *Residential:* Adjust assessor land and improvement value with home price index. ▪ *Commercial, Industrial, Miscellaneous:* Adjust assessor value with consumer price index. ▪ *Public/Institutional Taxable:* Adjust assessor value with consumer price index. ▪ *Public/Institutional Non-Taxable*:* Apply price per square foot values derived from scenic easement transactions in Monterey County to percent of parcel in hazard zone.
Chronic flood area	If less than 50% of property is within hazard zone then 50% of property value is lost; If greater than 50 % of property is within hazard zone then 100% of property value is lost.	▪ *Residential:* Adjust assessor land and improvement value with home price index. ▪ *Commercial, Industrial, Miscellaneous:* Adjust assessor value with consumer price index. ▪ *Public Taxable:* Adjust assessor value with consumer price index. ▪ *Public Non-Taxable:* Apply price per square foot values derived from scenic easement transactions in Monterey County to percent of parcel in hazard zone.
Event flood hazard area	Depth of water at center of parcel related to USACE structure and content depth damage curves.	▪ *Residential with Information on Building Size:* Apply RS Means cost per square foot values to structure characteristics. ▪ *Residential with no Information on Building Size:* Adjust assessor structure value with home price index. ▪ *Commercial, Industrial, Miscellaneous:* Adjust assessor value of structure with consumer price index. ▪ *Public Taxable with Structures:* Adjust assessor value with consumer price index
Event wave flood hazard area	If less than 50% of property is within hazard zone then 50% of property value is lost; If greater than 50 % of property is within hazard zone then 100% of property value is lost.*	▪ *Residential:* Adjust assessor land and improvement value with home price index. ▪ *Commercial, Industrial, Miscellaneous:* Adjust assessor value with consumer price index. ▪ *Public/Institutional Taxable:* Adjust assessor value with consumer price index. ▪ *Public/Institutional Non-Taxable*:* Apply price per square foot values derived from scenic easement transactions in Monterey County to percent of parcel in hazard zone. ▪ Additional damage factor applied to parcels at risk, 50% greater than event flood up to but not exceeding total structure cost. ▪ Additional cost assigned to elevate structures.

Other Economic Considerations

Future Demand for Beach Recreation

We have generally assumed that the real costs and benefits of various adaptation strategies are constant; in particular, once corrected for inflation, the prices/costs of most property and engineering solutions will stay constant. However, for beach recreation, this assumption is quite limiting since existing demographic projections by the State of California indicate that both the state and county will experience population growth. In addition, state/county forecasts indicate that real per capita income will grow. Our knowledge of future trends in the demand for beaches or the future willingness to pay for beaches is limited; we assumed that attendance increases with population growth and that demand for beach recreation in southern Monterey Bay has an income elasticity of one -- that is, if a household's income increases by 5%, its willingness to pay increases by 5%. We believe these assumptions are reasonable.

Population and Income Projections

The State of California's Department of Finance's (DOF) Demographic division compiles projections for future population growth in the state by county. Table 6 below presents the DOF projections. For this study we assumed that attendance at coastal recreational sites (primarily beaches) will grow at the same rate as an average of the county and state growth rates.

Table 6. Population forecast 2010-2100

Year	California Population	California Population: % Change from Decade Prior	Monterey County Population	Monterey County Population: % Change from Decade Prior
2010	37,341,978	-	416,141	-
2020	40,619,346	8%	446,258	7%
2030	44,085,600	8%	476,874	6%
2040	47,233,240	7%	500,194	5%
2050	49,779,362	5%	520,362	4%
2060	51,663,771	4%	533,575	2%
2070*	54,047,807	4%	567,200	6%
2080*	56,999,104	5%	591,244	4%
2090*	59,950,402	5%	615,288	4%
2100*	62,901,700	5%	639,332	4%

Data Source: California Department of Finance, Linear Trend Estimate 2015*

State and county level real per capita income forecasts from 2010 to 2040 from the California Department of Transportation were extrapolated to 2100. As with population, we assumed used an average of the county and statewide projections.

Discount Rate

To account for the discount rate phenomenon (i.e., the fact that a dollar received today is considered more valuable than a dollar received in the future, because a dollar received today could be invested to produce additional wealth), it is important to identify the period of time over which most of the relevant benefits and costs will accrue. The choice of an appropriate discount rate is even more critical in this analysis since a higher discount rate implies that future benefits and costs are weighted lower. For most private projects the choice of a discount rate is relatively simple — it is set to the appropriate market rate. For example, if a private company is considering a $100 million investment in a new factory that would yield a future stream of returns (profit), the firm would use their cost of capital; if they can borrow money at a 5% rate of interest, then 5% would be the discount rate.

For public projects, the discount rate is often tied to something similar: the cost of government bonds over the appropriate time horizon. For example, on a federal project lasting 30 years, one can apply the interest rate on a 30-year treasury bond (3.8% on January 10, 2014).

A number of economists have argued that using market interest rates when analyzing social costs and benefits is inappropriate for a variety of reasons. First, the social rate of time preference – that is, the rate at which society values present consumption over future consumption — is not necessarily given by the market interest rate (Zhuang et al. 2007). Empirical studies of the social rate of discount estimate rates ranging from 0.1% to 3% per year (Liang et al.).

Standard discounting practices face another critical problem: rates that are typically employed discount future generations heavily. Applying a discount rate of 3%, for example, implies that benefits or costs borne in 100 years are only weighted 5% (1/20) of current costs and benefits; if one uses a 2% rate, the weighting changes to (a still low) 14%. Even applying a rate as low as 1%, as we used in this analysis, implies that benefits/costs 100 years from now are only weighted at 37% of today's benefits.

Given the potentially enormous costs of climate change to future generations and the longer time scale, many environmental economists have proposed applying lower discount rates when analyzing the economic impacts of climate change. One of the most widely cited reports, the Stern report (2006), applied a 1.4 % discount rate. Arrow et al. (2014) point out that climate change modeling presents a unique set of issues given the uncertainty involved and the potential for catastrophic outcomes (even if the probability of such outcomes is low). Consequently, many climate change models use a declining discount rate over time, implying that a longer time horizon should receive a lower discount rate. A number of European countries have already adopted such an approach. For example, Great Britain has adopted a declining rate formula for climate change projects where the discount rate can reach 0.75% after 300 years (Arrow et al., 2014). Our analysis uses a 1% discount rate, which is consistent with Arrow et al. (2014) and others.

Cost-Benefit Analysis

Table 7 below summarizes the models, methods, and metrics used in this study, discussed in previous sections. Most of the methods used are standard in these types of analyses; for example, the CSBAT beach recreation model has been employed by a range of researchers across the California Coast. We valued lost property and infrastructure at current replacement cost, as described above. The main innovation here is our valuation of coastal ecosystems, discussed above in the *Ecological Assessment* section.

Table 7. Method for Estimating Benefits and Costs

Item	Method for Estimating	Final Metric
Beach Recreation	CSBAT	Recreational Value for given Beach Width
Ecological Value	Beach ecological index score	Cost of Replacement
Land	Commercial Data	Market Value
Buildings	FEMA	Replacement Cost
Flood Damages	USACE	Depth Damage Curves
Water Infrastructure	ESA	Replacement Cost
Roads	ESA	Replacement Cost
Nourishment	ESA	Cost of Hopper Dredge, etc.
Revetments	ESA	Construction Cost

Table 8 summarizes the data sources used in the report. Recreational data were obtained from counts and surveys. We used heavily modified parcel level data to estimate the value of land and structures, the beach ecological index score with replacement cost to estimate ecological value, and engineering costs for nourishment, revetments and infrastructure.

Table 8. Data Sources used in this Report

Item	Data Source	Method
Beach Attendance	Periodic Human Counts	King/McGregor (2012)
Recreational Value per Visitor	Various Academic Studies	Benefits Transfer
Change in Rec Value w Beach Width	Survey	CSBAT
Value of Land/Structures	County Parcel data	Modified
Flooding of Structures	Modified County Parcel Data	USACE Depth Damage Curves
Ecological Replacement Cost	ESA	Examined Restoration Projects
Ecological Value	TNC	Beach Ecological Evaluation
Infrastructure	ESA	Replacement Cost

Results

For this study, we estimated the benefits and costs for each of four reaches for 2030, 2060 and 2100, using the IPCC high and medium SLR projections. In all, we analyzed more than 100 distinct scenarios: four reaches, three time horizons, various adaptation scenarios, and two SLR projections. All results were calculated in 2015 dollars.

In the figures below, the "Net Present Value" represents the sum of the benefits and costs for each reach/scenario/time horizon. All dollar amounts are discounted at a rate of 1% a year from the year in which the benefit or cost occurs. Thus the Net Present Values depicted in the figures below are the sums of these corresponding benefits and costs for each reach, discounted for the appropriate time period.

Del Monte

For the Del Monte reach, the adaptation scenarios we considered were:

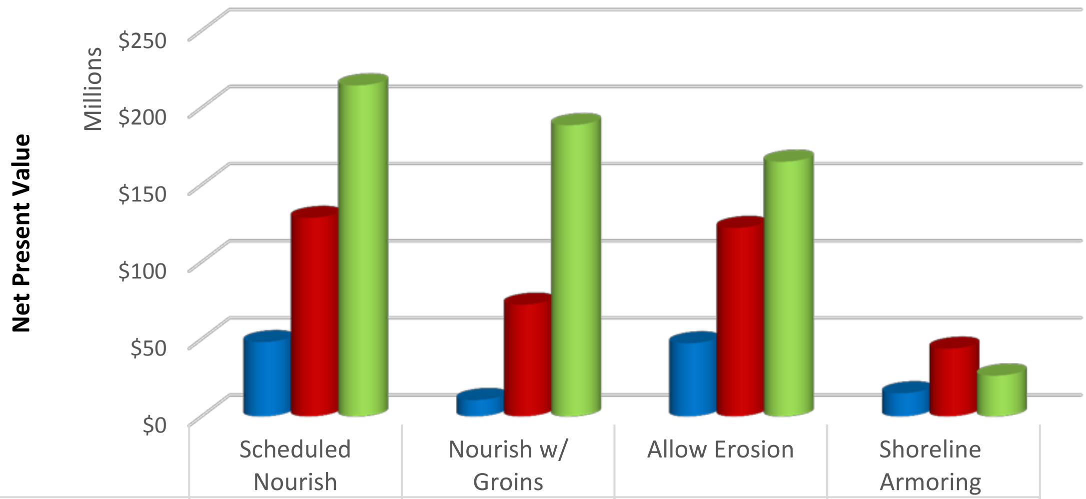
- Scheduled Nourishment (nourishing every ten years)
- Nourishment with Groins (add groins and nourish when beach width reaches a trigger point);
- Allow Erosion (beaches and other coastal ecosystems are allowed to retreat, through both fee simple acquisition & elevating structures); and
- Shoreline Armoring (revetments across the entire reach).

Selected, but representative, results are shown for each reach. Table 9 breaks down benefits and costs for the Del Monte, High SLR adaptation strategies into three primary sources. First, recreational and ecological benefits are expressed in (positive) dollars, per year, and summed over the three time horizons. Predictably, those strategies in which the sandy beach erodes more quickly produce smaller benefits. Second, the (negative) losses of land, buildings, roads and other infrastructure, as well as the cost of adaptation (e.g., elevating roads) is expressed in terms of replacement costs. Since allow erosion, by definition, allows for greater property damage, private losses are greater in 2060, though only by 5.5%. By 2100, private losses are significantly higher under allow erosion, but still much smaller than the public gains from the other strategies, which is why armoring has the lowest overall net benefits. Finally, the (negative) costs of the strategies themselves (e.g., nourishment costs) are also included. Nourishment with groins and shoreline armoring both entail very expensive construction projects and thus incur significant costs.

Table 9. Distribution of Costs and Benefits for Del Monte: High SLR.

Year	Scheduled Nourish	Nourish w/ Groins	Allow Erosion	Shoreline Armoring
Public Benefits (recreational and ecological value)				
2030	$62,600,000	$76,800,000	$59,900,000	$52,600,000
2060	$147,600,000	$177,900,000	$137,400,000	$111,000,000
2100	$250,800,000	$308,300,000	$229,100,000	$145,200,000
Property Losses/Damages (infrastructure, MRWPCA, public and private property)				
2030	-$12,600,000	-$12,600,000	-$12,600,000	-$1,900,000
2060	-$14,500,000	-$14,500,000	-$15,300,000	-$4,900,000
2100	-$28,900,000	-$28,700,000	-$64,100,000	-$20,800,000
Adaptation Costs (nourishment, groins, revetments)				
2030	-$2,000,000	-$53,600,000	$0	-$35,700,000
2060	-$4,500,000	-$90,900,000	$0	-$62,200,000
2100	-$7,400,000	-$90,900,000	$0	-$98,000,000

Figure 2 (below) presents our results for the high sea-level rise scenario:



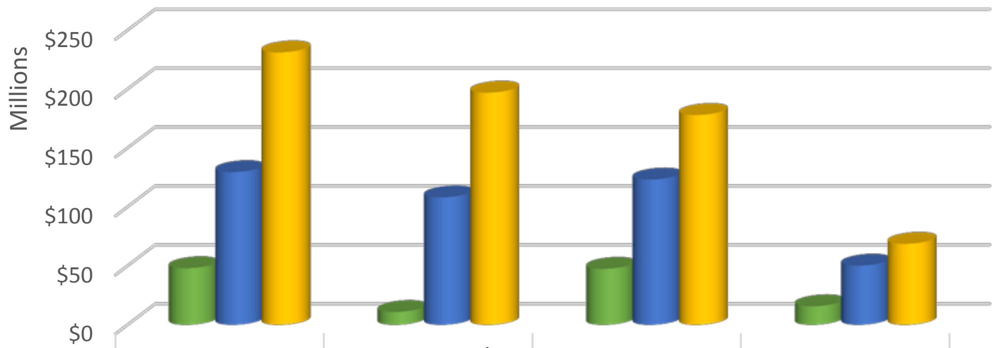
	Scheduled Nourish	Nourish w/ Groins	Allow Erosion	Shoreline Armoring
2030 (22 cm)	$48,100,000	$10,600,000	$47,300,000	$15,000,000
2060 (72 cm)	$128,600,000	$72,400,000	$122,100,000	$43,900,000
2100 (159 cm)	$214,500,000	$188,700,000	$165,000,000	$26,400,000

Figure 2. Net Present Value of Shoreline Management Options: Del Monte (high sea-level rise scenario)

For the Del Monte reach, scheduled nourishment represents the option with the highest net present value assuming that sand is available. By 2100, the two non-armoring strategies (nourishment and allow erosion) yield net benefits of over $150 million dollars. By way of comparison, this is significantly larger than the City of Monterey's Annual Budget of $108 million. (http://monterey.org/Portals/1/finance/budget/2014-15/AdoptedBudgetDocFY15.pdf).

For 2030, allow erosion and scheduled nourishment are within 2% of each other, which is well within the margin of error. In the 2060 and 2100 time horizons, both nourishment options have comparatively higher net present values. However, as our sensitivity analysis later indicates, these differences are well within the margin of error given our assumptions and given the inherent uncertainty in predicting the future. **In all time frames except 2030, shoreline armoring yields the lowest net present value.**

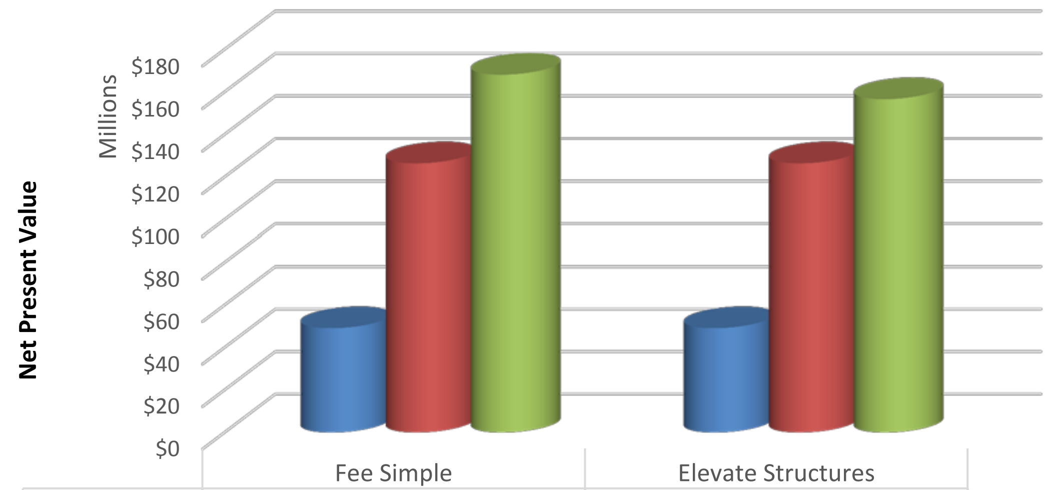
Figure 3 (below) presents the net benefits for the same reach, but within a medium sea-level rise scenario. Predictably, the slightly smaller sea-level rise estimates (next to the years within each table) which define the medium sea-level rise scenario produce slightly higher net present values (underneath the bars) than are found within the high sea-level rise scenario (Figure 2, above).



	Scheduled Nourish	Nourish w/ Groins	Allow Erosion	Shoreline Armoring
2030 (10 cm)	$47,900,000	$10,800,000	$47,400,000	$15,600,000
2060 (33 cm)	$129,400,000	$108,000,000	$123,100,000	$50,100,000
2100 (88 cm)	$231,100,000	$196,900,000	$177,900,000	$68,600,000

Figure 3. Net Present Value of Shoreline Management Options: Del Monte (medium sea-level rise scenario)

This project also considered various upland (as opposed to shoreline) adaptation strategies as part of the analysis. For the Del Monte reach, we considered elevating structures (residential and non-residential buildings and major roads such as Highway 1) as an alternative within the high sea-level rise scenario. Figure 4 (below) illustrates how, in 2030 and 2060, these strategies yield the same net present value since the trigger point for elevating structures does not occur until after 2060. By 2100, the elevating structures strategy yields a lower net present value ($168 million vs. $157 million) than "fee simple" which indicates that the cost of elevating these structures does not reap sufficient benefits to justify the expense. Please note that our analysis aggregated the costs of elevating all roads and structures and it is quite possible, even likely that some structures (e.g., Hwy 1) might be worth elevating individually.



	Fee Simple	Elevate Structures
2030 (10 cm)	$49,100,000	$49,100,000
2060 (33 cm)	$126,400,000	$126,400,000
2100 (88 cm)	$168,100,000	$156,600,000

Figure 4. Net Present Value of Upland Management Options: Del Monte (using high sea level rise projections)

Sand City

For the Sand City reach, the adaptation scenarios we considered were:

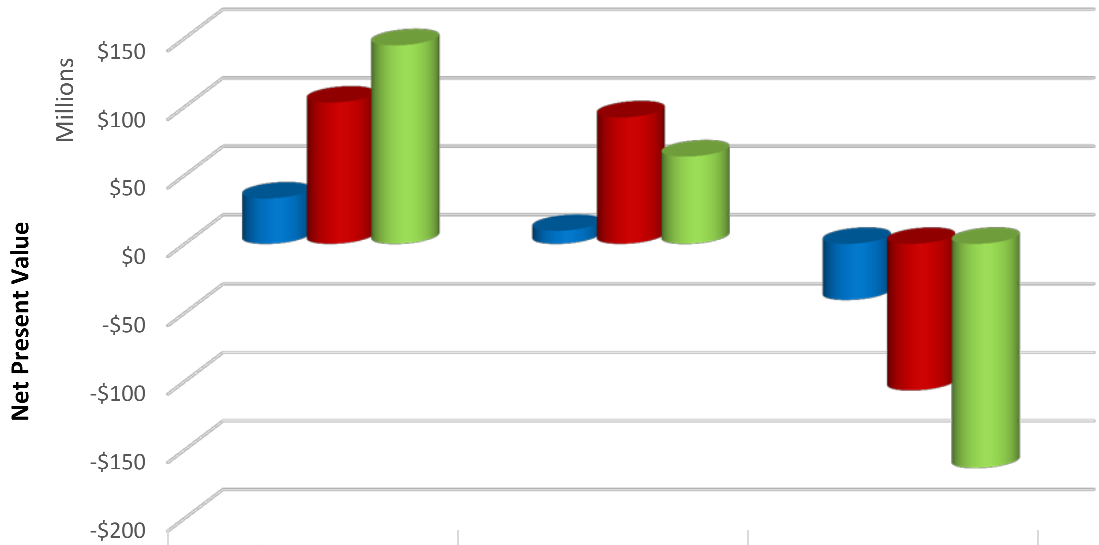
- Allow erosion;
- Nourishment as Needed (nourish when beach width reaches a trigger point); and
- Shoreline Armoring (revetment across the entire reach).

Table 10 (below) shows the distribution of costs and benefits for the three shoreline adaptation strategies considered. As in the case of Del Monte, the nourishment strategy preserves the largest amount of sandy beach. Shoreline armoring prevents the most property loss/damages but once again, these are small in comparison to the substantial costs of the armoring adaptation itself.

Table 10. Distribution of Costs and Benefits for Sand City: High SLR.

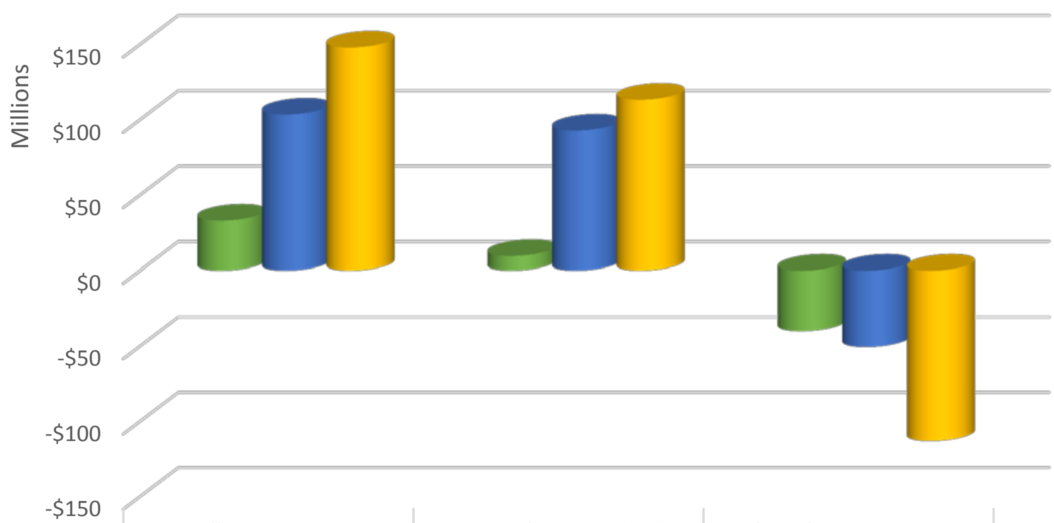
Year	Nourish as Needed	Allow Erosion	Shoreline Armoring
Public Benefits (recreational and ecological value)			
2030	$73,879,019	$55,517,865	$46,714,719
2060	$156,974,550	$128,161,523	$88,872,613
2100	$258,312,180	$215,278,285	$105,318,207
Property Losses/Damages (infrastructure, MRWPCA, public and private property)			
2030	-$22,317,371	-$22,405,393	-$7,307,244
2060	-$22,656,590	-$25,107,555	-$7,768,865
2100	-$57,879,464	-$70,474,388	-$8,435,046
Adaptation Costs (nourishment, groins, revetments)			
2030	-$42,040,402	$0	-$79,876,764
2060	-$42,040,402	$0	-$187,707,339
2100	-$136,692,248	$0	-$260,132,083

Figure 5 (below) illustrates how, under conditions of high sea-level rise **at the Sand City reach, allow erosion represents the best option for all time frames**. Figure 6 (below) indicates that the same holds within the medium sea-level rise scenario. The net benefits from nourishment are positive, but significantly lower than allow erosion for all timeframes. Shoreline Armoring yields negative net benefits, implying that the benefits from revetments are lower than the cost of construction/maintenance.



	Allow Erosion	Nourish as Needed	Shoreline Armoring
2030 (22 cm)	$33,100,000	$9,500,000	-$40,500,000
2060 (72 cm)	$103,100,000	$92,300,000	-$106,600,000
2100 (159 cm)	$144,800,000	$63,700,000	-$163,200,000

Figure 5. Net Present Value of Shoreline Management Options: Sand City (high sea level rise projection)

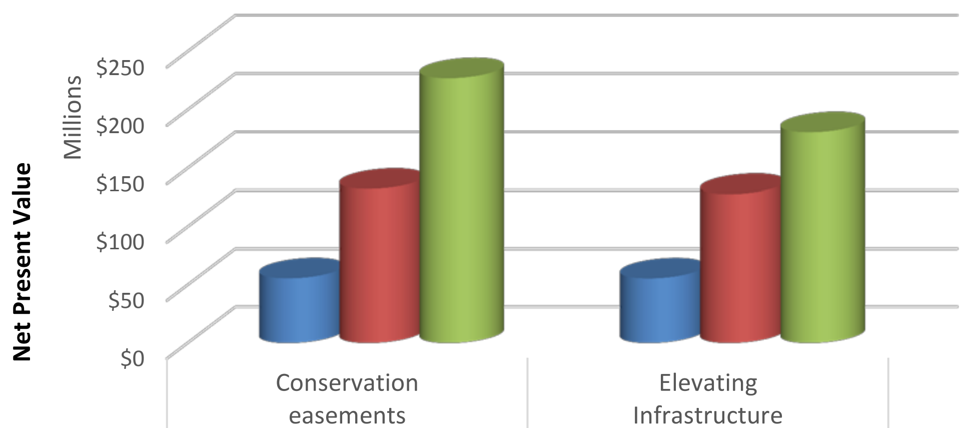


	Allow Erosion	Nourish as Needed	Shoreline Armoring
2030 (10 cm)	$33,100,000	$9,700,000	-$40,000,000
2060 (33 cm)	$103,500,000	$92,900,000	-$50,500,000
2100 (88 cm)	$148,000,000	$113,300,000	-$113,000,000

Figure 6. Net Present Value of Shoreline Management Options: Sand City (medium sea level rise projection)

For the Sand City reach, we also modeled the use of conservation easements. After analyzing sales data in the area, we concluded that the land acquisition prices for conservation easements are approximately 70% of the market value. However, it should be noted that estimation of benefits and costs is very assumption-dependent for this approach. In the case of conservation easements, someone, typically a government agency or NGO, must acquire the land. Further, there must be a willing seller. In contrast, under the "allow erosion" scenario the cost of the land loss is often borne by the landowner (public or private) though it's possible an NGO or government agency could buy the land at market prices.

In Figure 9 (below), elevating structures yields a lower net present value than conservation easements, but a higher value than fee simple. In other words, it depends on how one values the land. We caution the reader from drawing any strong conclusions without further analysis.



	Conservation easements	Elevating Infrastructure
2030 (22 cm)	$55,600,000	$55,500,000
2060 (72 cm)	$132,300,000	$127,900,000
2100 (159 cm)	$227,100,000	$180,700,000

Figure 7. Net Present Value of Upland Management Options: Sand City (high SLR projection)

Marina

For the Marina reach, the adaptation scenarios we considered were:

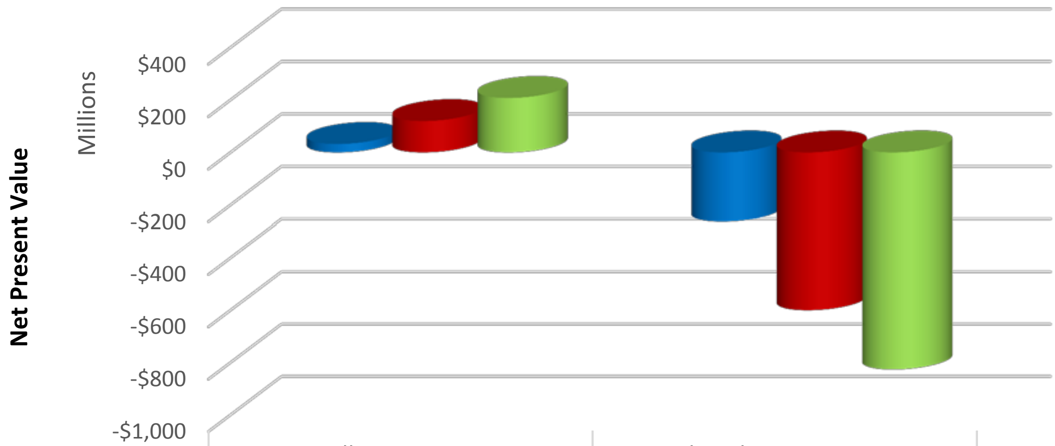
- Allow Erosion: Beaches and other coastal ecosystems are allowed to retreat; and
- Shoreline Armoring (revetment across the entire reach)

Table 11 (below) provides estimates of the benefits and costs broken down by type for the two options. While the public benefits of the allow erosion option are somewhat higher than those of shoreline armoring, the property losses/damages of the former are moderately higher than the latter. However, the costs of adaptation for shoreline armoring (essentially the costs of building and maintaining revetments) are much higher than any potential benefits.

Table 11. Distribution of Costs and Benefits for Marina: High SLR.

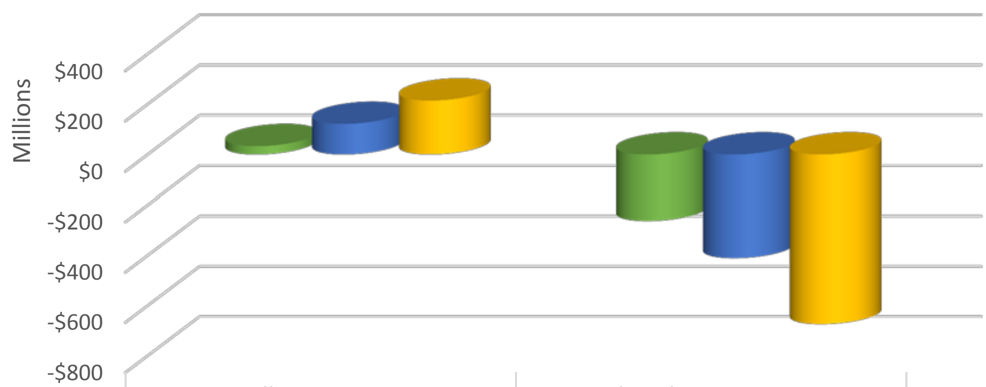
Year	Allow Erosion	Shoreline Armoring
Public Benefits (recreational and ecological value)		
2030	$77,252,329	$73,521,261
2060	$169,190,596	$150,380,476
2100	$266,362,964	$207,965,869
Property Losses/Damages (infrastructure, MRWPCA, public and private property)		
2030	-$44,943,649	-$30,802,090
2060	-$49,501,308	-$31,411,863
2100	-$58,789,820	-$37,666,832
Adaptation Costs (nourishment, groins, revetments)		
2030	$0	-$305,937,579
2060	$0	-$718,941,606
2100	$0	-$996,337,057

Figure 8 (below) indicates that allow erosion had the greatest net benefits for all time frames at Marina reach. Shoreline Armoring yields negative net benefits, implying that the (storm/erosion) benefits from revetments are lower than the cost of construction/maintenance. **Indeed, between now and 2100 Allow Erosion yields net benefits that are over one billion dollars greater than shoreline armoring**. Figure 9 (below) tells a very similar story for Marina reach within the medium sea-level rise scenario.



	Allow Erosion	Shoreline Armoring
2030 (22 cm)	$32,300,000	-$263,200,000
2060 (72 cm)	$119,700,000	-$600,000,000
2100 (159 cm)	$207,600,000	-$826,000,000

Figure 8. Net Present Value of Shoreline Management Options: Marina (high sea level rise projection)

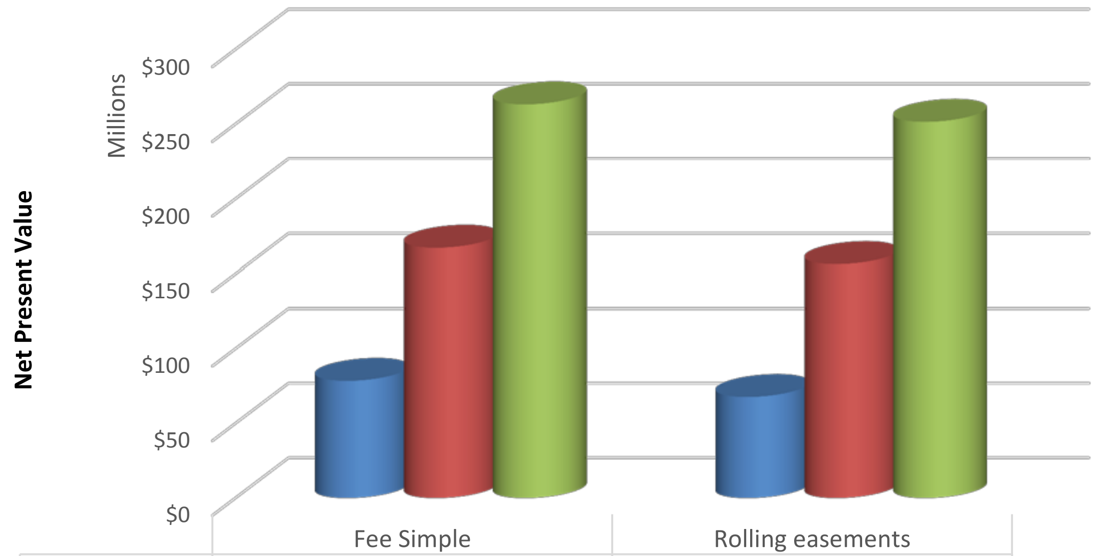


	Allow Erosion	Shoreline Armoring
2030 (10 cm)	$33,100,000	-$263,100,000
2060 (33 cm)	$121,600,000	-$410,900,000
2100 (88 cm)	$214,500,000	-$674,000,000

Figure 9. Net Present Value of Shoreline Management Options: Marina

(medium sea level rise projection)

For the Marina reach we also considered rolling easements, where land use is restricted to exclude coastal armoring. In Figure 10 below, fee simple yields higher net present value than rolling easements. However, the differences here are well within the margin of error.



	Fee Simple	Rolling easements
2030 (22 cm)	$78,500,000	$67,700,000
2060 (72 cm)	$167,300,000	$156,400,000
2100 (159 cm)	$263,200,000	$251,500,000

Figure 10. Net Present Value of Upland Management Options: Marina (high SLR projection)

Moss Landing

For the Moss Landing reach, we considered:

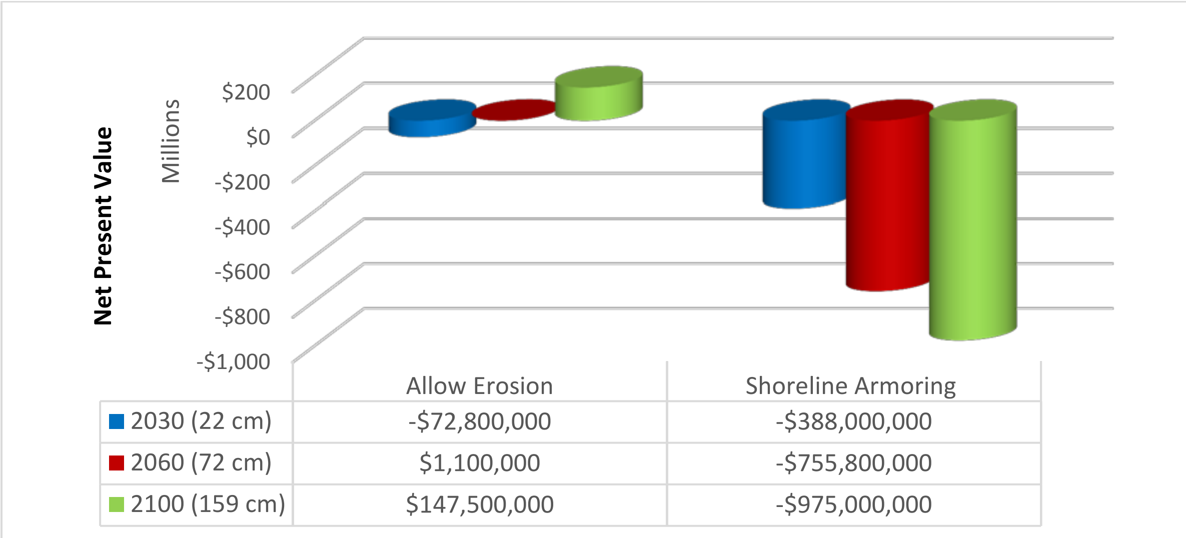
- Allow Erosion: Beaches and other coastal ecosystems are allowed to retreat
- Shoreline Armoring (revetments across the entire reach)

Table 12 (below) presents a breakdown of the costs and benefits. The public benefits of allowing erosion at Moss Landing are greater than those of armoring the shoreline, while the property losses/damages are higher for allow erosion as one approaches 2100. Again, however, the high costs of armoring the Moss Landing shoreline make this option economically unviable.

Table 12. Distribution of Costs and Benefits for Moss Landing: High SLR.

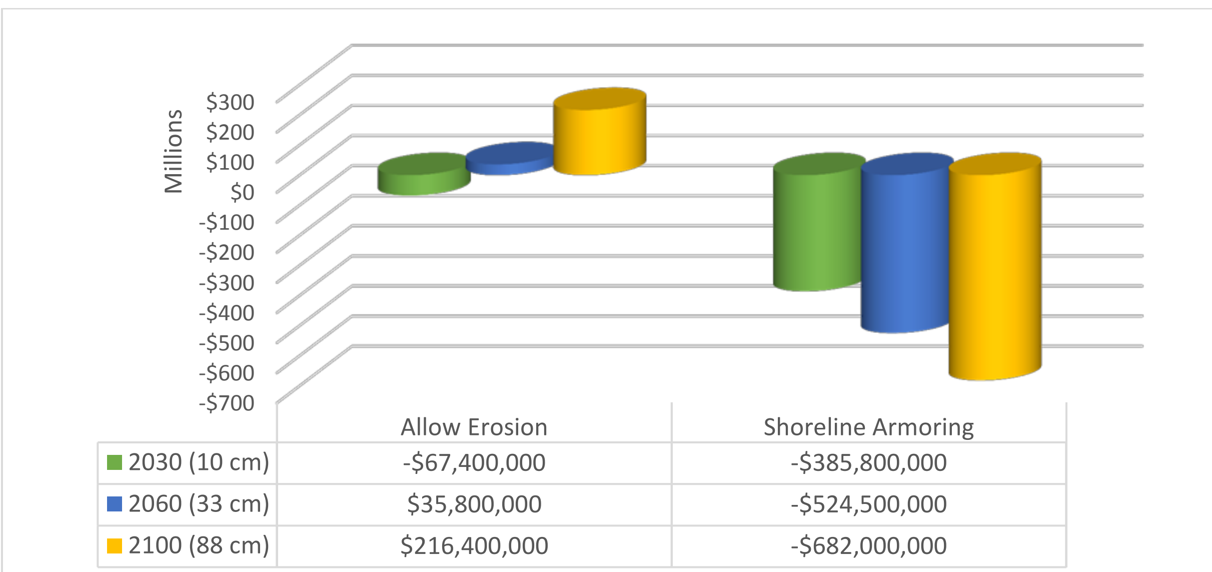
Year	Allow Erosion	Shoreline Armoring
Public Benefits (recreational and ecological value)		
2030	$87,398,194	$80,863,547
2060	$200,467,085	$146,028,145
2100	$408,866,543	$217,344,218
Property Losses/Damages (infrastructure, MRWPCA, public and private property)		
2030	-$160,192,822	-$159,906,088
2060	-$199,415,747	-$175,687,006
2100	-$261,334,259	-$186,020,350
Adaptation Costs (nourishment, groins, revetments)		
2030	$0	-$308,996,955
2060	$0	-$726,131,022
2100	$0	-$1,006,300,428

Figure 11 below compares the net present value for “allow erosion” and “shoreline armoring” within the high sea-level rise scenario. As with the Marina, the differences are significant. Indeed, by 2100, the difference in net present value is $1.1 billion. Figure 12 (below) indicates that this difference barely shrinks to $900,000 within the medium sea-level rise scenario.



	Allow Erosion	Shoreline Armoring
2030 (22 cm)	-$72,800,000	-$388,000,000
2060 (72 cm)	$1,100,000	-$755,800,000
2100 (159 cm)	$147,500,000	-$975,000,000

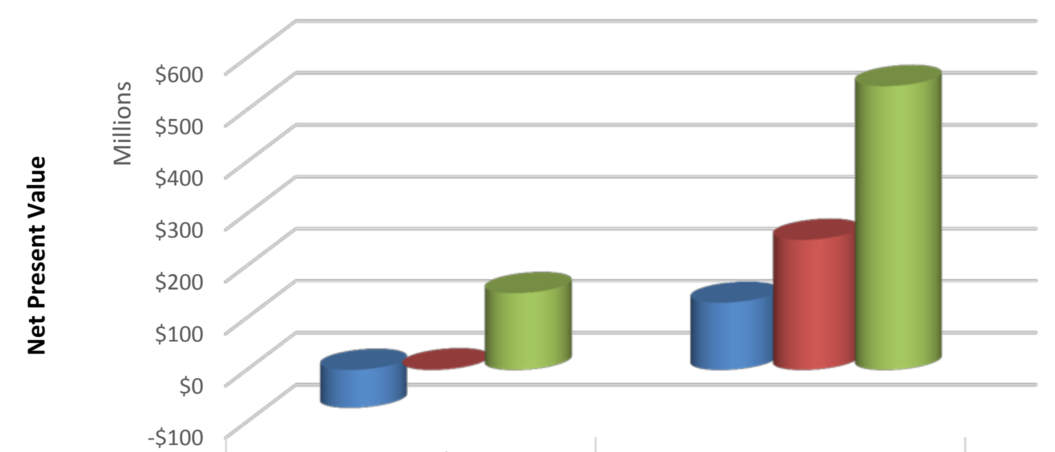
Figure 11. Net Present Value of Shoreline Management Options: Moss Landing (high sea-level rise projection)



	Allow Erosion	Shoreline Armoring
2030 (10 cm)	-$67,400,000	-$385,800,000
2060 (33 cm)	$35,800,000	-$524,500,000
2100 (88 cm)	$216,400,000	-$682,000,000

Figure 12. Net Present Value of Shoreline Management Options: Moss Landing (medium sea-level rise projection)

For the Moss Landing reach, conservation easements have a significantly higher net present value than doing nothing, since land is valued at 70% of the market value—hence the dollar value of these losses are lower with conservation easements. However, once again, these results should be taken in context. In the case of conservation easements, someone must acquire the land, typically an NGO or government agency. Further, there must be a willing seller. In contrast, under the “allow erosion” scenario the cost of the land loss is often borne by the landowner (public or private) though it's possible an NGO or government agency could buy the land at market prices.



	Do Nothing (Allow Erosion)	Conservation easements
2030 (22 cm)	-$72,800,000	$129,200,000
2060 (72 cm)	$1,100,000	$250,100,000
2100 (159 cm)	$147,500,000	$546,100,000

Figure 13. Net Present Value of Upland Management Options: Moss Landing (high SLR projection)

Sensitivity Analysis Results

As with any economic modeling, the results presented above are based on certain assumptions. To understand the role of each of these assumptions in our analysis, we conducted a sensitivity analysis—applying other values for key parameters. We focused on the parameters that we believed were the most uncertain or where experts could disagree. We determined these were the key parameters:

- The discount rate
- The frequency of 100 year storms
- The recreational value of beaches per person per day (i.e., day use value)
- Beach Attendance
- The Ecological Value of beaches
- The recreational value of increasing/decreasing beach width
- The costs of nourishment.

A complete discussion and analysis with more charts and tables is contained in appendix X. **In most cases, we found that our results were quite robust.** The exception was in the Del Monte reach, where the two nourishment options and allow erosion are close enough that the assumptions matter.

Discount Rate

When considering benefits and costs that are incurred over a number of years, the dollar values must be adjusted to reflect the fact that a dollar received today is considered more valuable than a dollar received in the future. One important reason for this is the fact that a dollar received today could be invested to produce additional wealth. To do this, it is important to identify the period of time that will account for most of the relevant benefits and costs and to select a discount rate that will account for the diminishing value of benefits received in the future.

The choice of an appropriate discount rate is generally even more critical in the analysis since a higher discount rate implies that future benefits and costs are weighted lower. For most private projects the choice of a discount rate is relatively simple—whatever the appropriate market rate is. For example, if a private company is considering a $100 million investment in a new factory that would yield a future stream of returns (profit), the firm would use their cost of capital. If they can borrow money at a 5% rate of interest, then 5% would be the discount rate.

For social projects, the discount rate is often tied to something similar—the cost of government bonds over the appropriate time horizon. For example, on a federal project lasting 30 years, one can apply the interest rate on a 30-year treasury bond (3.8% on January 10, 2014).

A number of economists have argued that using market interest rates when analyzing social costs and benefits is inappropriate for a variety of reasons. First, the social rate of time preference –that is the rate at which society values present consumption over future consumption—is not necessarily given by the market interest rate (Zhuang, Liang, Lin, & Guzman, 2007). A number of economists have conducted empirical studies of the social rate of discount and have found rates ranging from 0.1% to 3% (Liang, Lin, & Guzman, p.6).

Standard discounting practices face another critical problem in that the rates that are typically used discount goods and services to future generations. Applying a discount rate of 3%, for example, implies that benefits or costs born in 100 years are only weighted 5% (1/20) of current costs and benefits; if one uses a 2% rate, the weighting changes to (a still low) 14%. Even applying a rate as low as 1% implies that benefits/costs 100 years from now are only weighted at 37% of today's benefits.

Given the potentially enormous costs of climate change to future generations and the longer time scale, many environmental economists have proposed applying lower discount rates when analyzing the economic impacts of climate change. One of the most widely cited reports, the Stern report (2006), applied a 1.4 % discount rate. Arrow et al. (2014) point out that climate change modeling presents a unique set of issues given the uncertainty involved and the potential for catastrophic outcomes (even if the probability of such outcomes is low). Consequently, many climate change models use a declining discount rate over time—implying that a longer time horizon should receive a lower discount rate. A number of European countries have already adopted such an approach. For example, Great Britain has adopted a declining rate formula for climate change projects where the discount rate can reach 0.75% after 300 years (Arrow et. al., 2014, p. 11). Our analysis uses a 1% discount rate, which is consistent with Arrow and others, but we also conducted a sensitivity analysis using other discount rates.

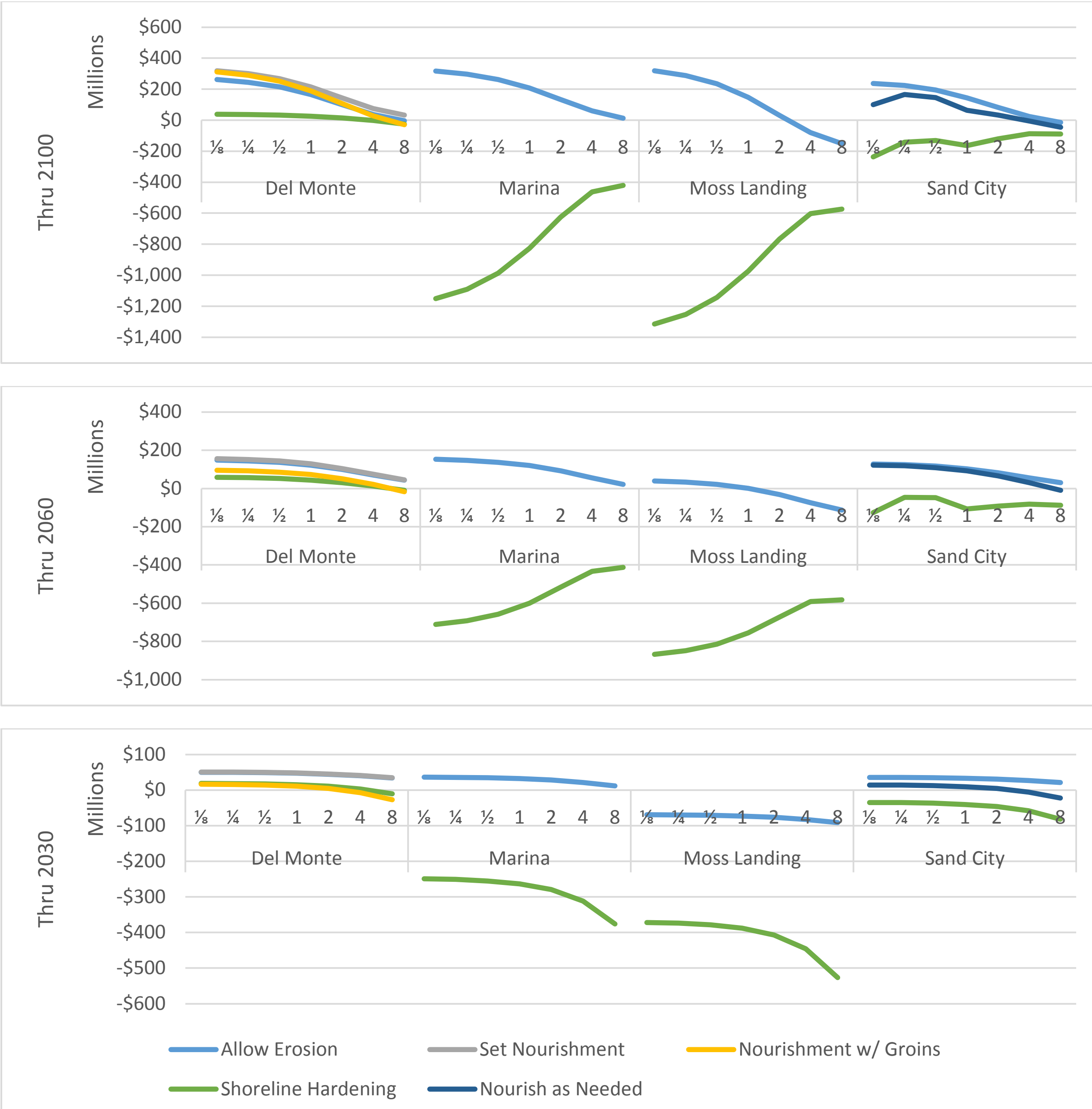


Figure 14: Sensitivity to Discount Rate (High SLR)

Storm Frequency

In addition to other data/analyses provided in this study, ESA also provided 100-year flood maps based on current storm probabilities (i.e., the probability of a 100-year flood occurring in any given year is 1/100). WE estimated the additional flood costs from a 100-year event. Further, we also performed an analysis assuming that the probability of a 100-year storm increased or decreased. Figure 15 presents the result of this analysis for Moss Landing within the high sea-level rise scenario. **Although an increase in flood probability increases flood damages and therefore lowers the NPV, the relative ranking does not change.** Furthermore, this is true for all reaches within all scenarios and timelines.

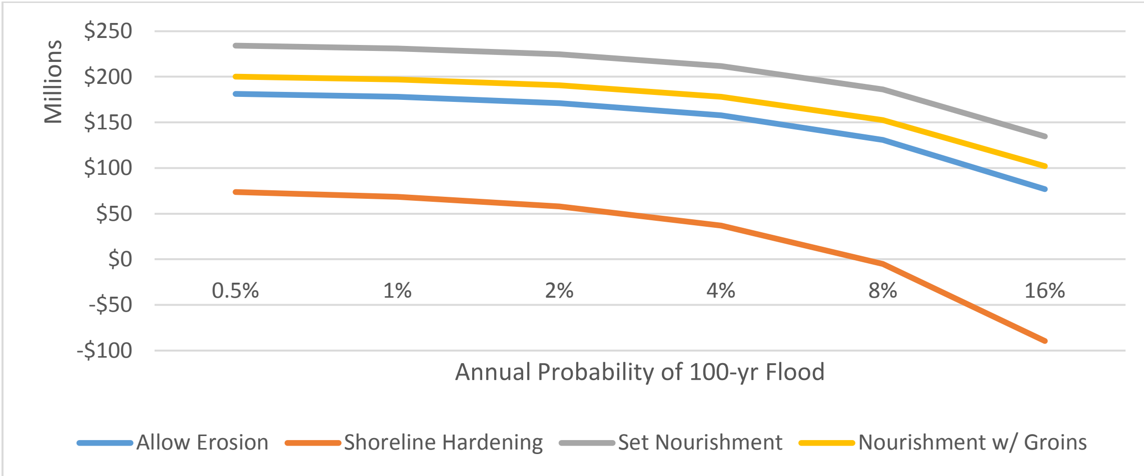


Figure 15. Net Present Value of Shoreline Management Options: Del Monte

Day Use Value and Attendance

Since the total recreational benefits for any reach just are its the day use value multiplied by the annual number of visits to that beach, the sensitivity analyses for these two variables are exactly the same. Figure 16 (below) illustrates the sensitivity of all reaches, across all time horizons within the high sea-level rise scenario to day use value, annual attendance or some combination of the two. Our results for the reaches at Marina and Moss Landing are very robust: no change in the total recreational value makes shoreline armoring preferable to allowing erosion. At Sand City, allow erosion remains the preferable option across all three time horizons, but nourish as needed is a close second. The results at Del Monte, however, are somewhat sensitive to these variables. As total recreational benefits increase past 4 times larger than our current measurements, nourishment with groins become more preferable, especially within the larger time horizon. If, by contrast, total recreational benefits grow smaller than those measured using the CSBAT model, set nourishment become preferable. Under no conditions is shoreline armoring the preferred response.

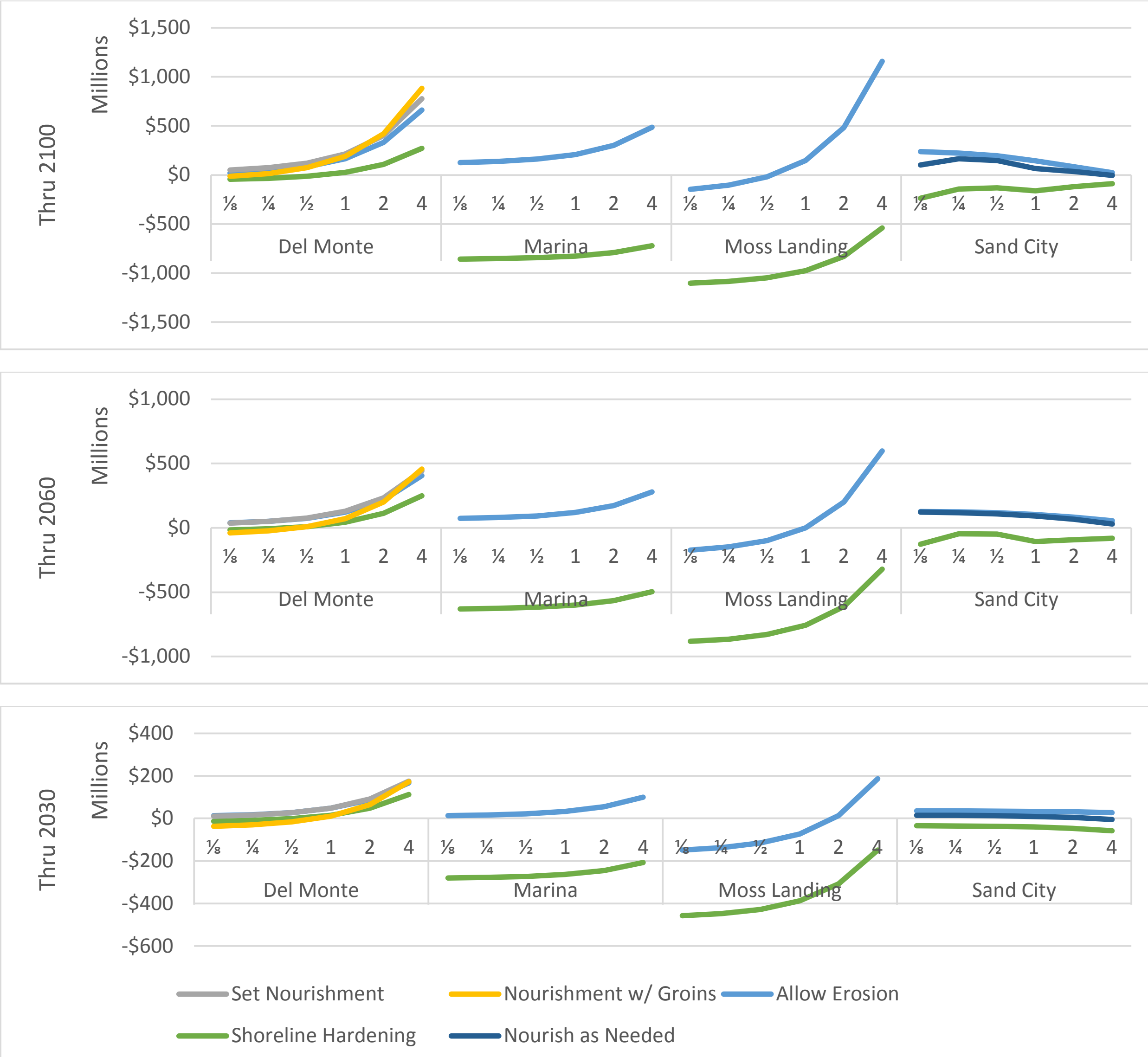


Figure 16: Sensitivity to Day Use Value (High SLR)

Ecological Valuation

Figure 17 (below) depicts the sensitivity of our results to the economic appraisal of the ecological functions, goods and services at each reach. As noted above, our model assumed an ecological valuation of 3 times the beach replacement costs. The sensitivity of our analysis to ecological valuation is very similar to that of total recreation benefits. For no ecological valuation is shoreline armoring preferable to allowing erosion at the Marina or Moss Landing reaches. At Sand City, allow erosion is slightly preferable to nourish as needed while at Del Monte a high ecological valuation favors nourishment with groins while a low ecological valuation favors set nourishment. Shoreline armoring is never the preferred adaptation strategy.

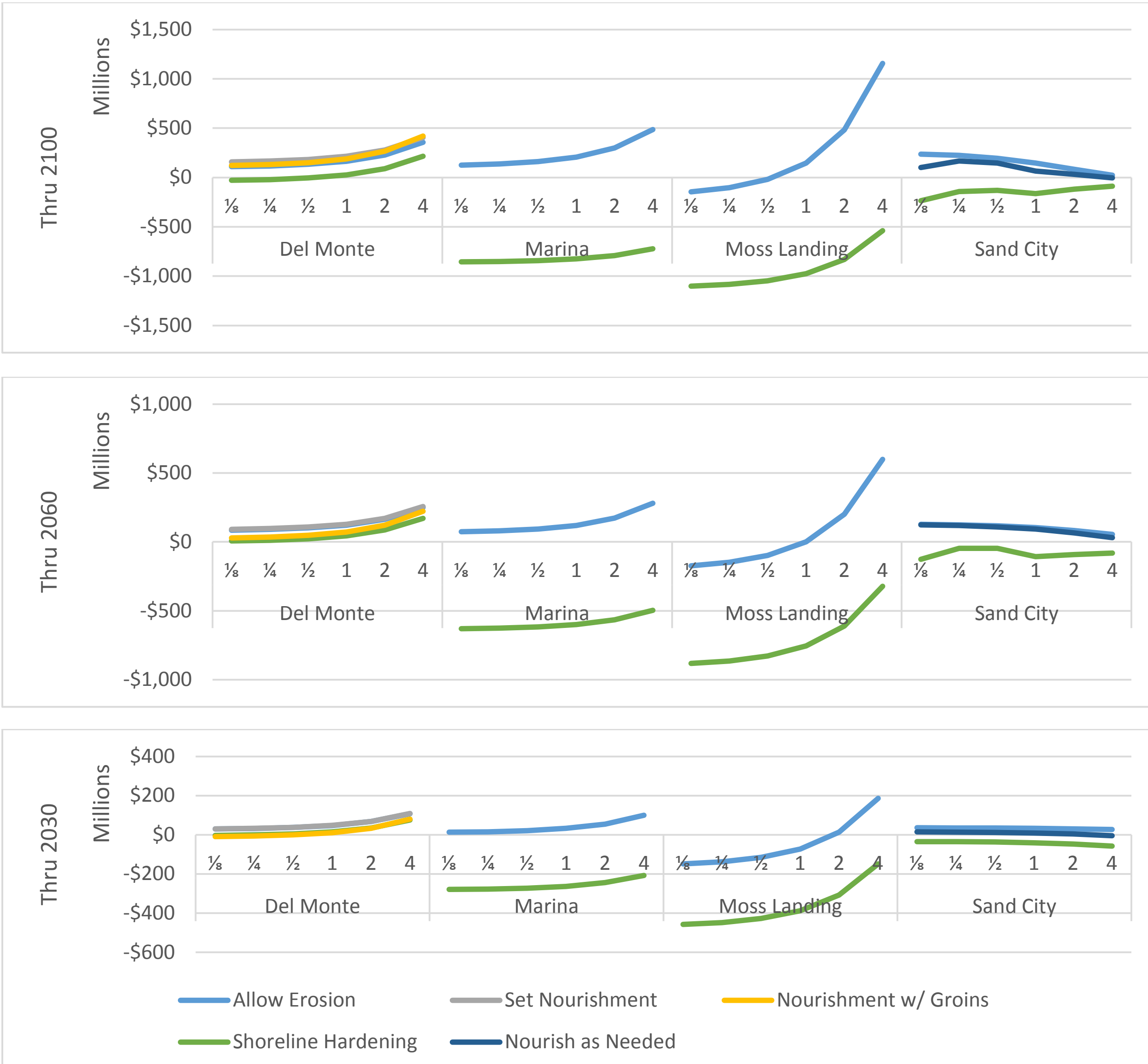


Figure 17: Sensitivity to Ecological Valuation (High SLR)

Beach Width Preference

Figure 18 (below) shows the sensitivity of our analysis to visitor preferences in beach width. Since beach goers prefer a wider beach, annual attendance estimates are a function of changes in beach width due to erosion and nourishment. Again, allowing erosion at the Marina and Moss Landing reaches is strongly preferred to shoreline armoring. At Sand City, nourish as need approaches, but does not quite overtake allow erosion as the best strategy as beach goers react more strongly to beach widths. At Del Monte, set nourishments are preferable through the short and medium time horizons, but, given strong preferences for beach width, nourishment with groins is preferable over the longest time horizon. Again, shoreline armoring is never the preferred option.

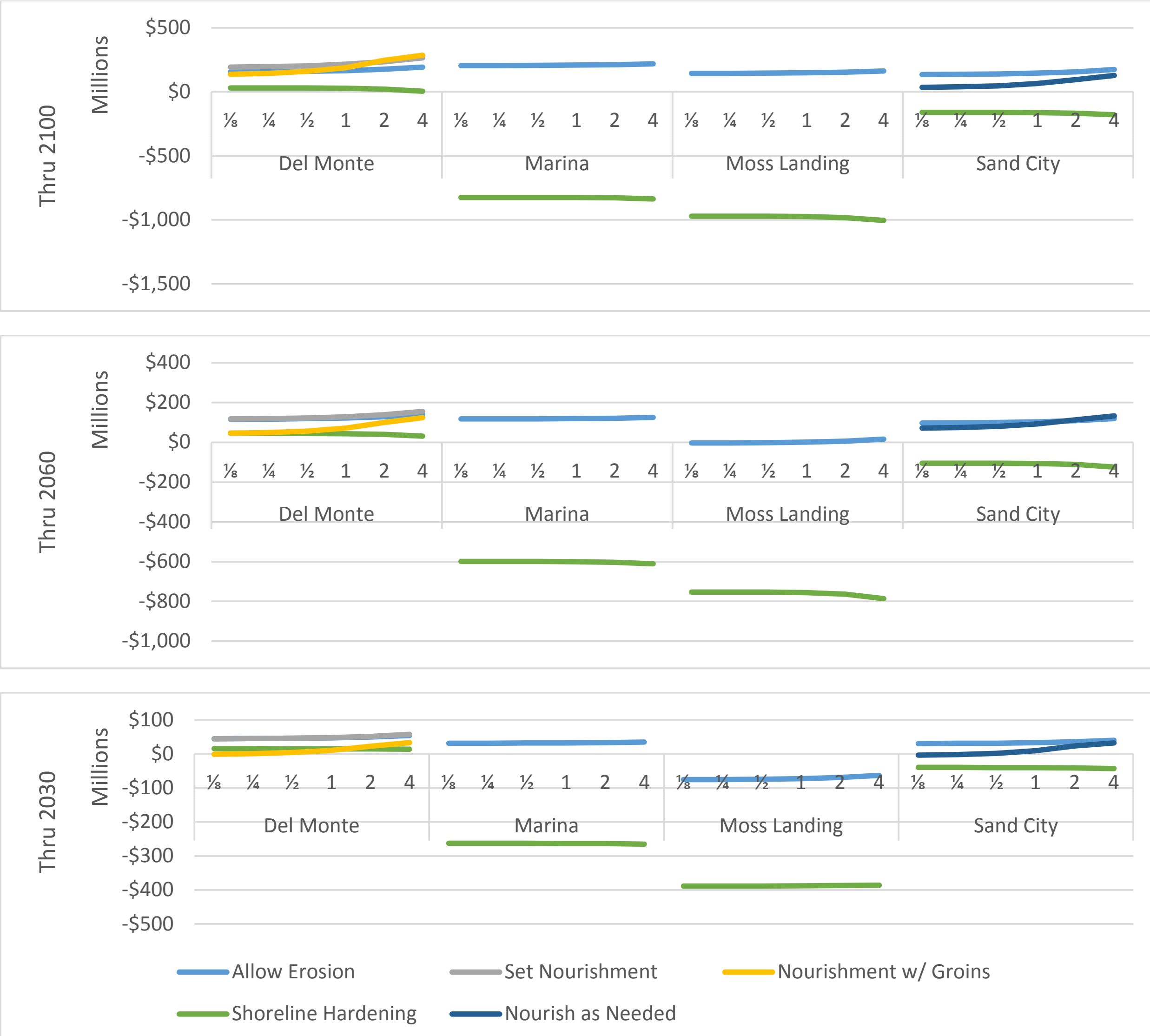


Figure 18: Sensitivity to Beach Width Preference (High SLR)

Nourishment Costs

Figure 19 (below) shows the sensitivity of our analysis to the costs of nourishment and shoreline armoring. Predictably, as these costs rise, allowing erosion become more preferable by comparison. Even when these costs are half of those assumed within this report, allow erosion is still preferable at the Marina and Moss Landing reaches. At Sand City, larger nourishment costs tend to bias toward allowing erosion, while nourish as needed approaches and slightly exceeds allow erosion for smaller nourishment costs. At Del Monte, set nourishment is either equal to or slightly preferable to allow erosion for all nourishment costs, although for very small costs, nourishment with groins comes to dominate these other strategies. Under no set of nourishment costs is shoreline armoring a preferable strategy.

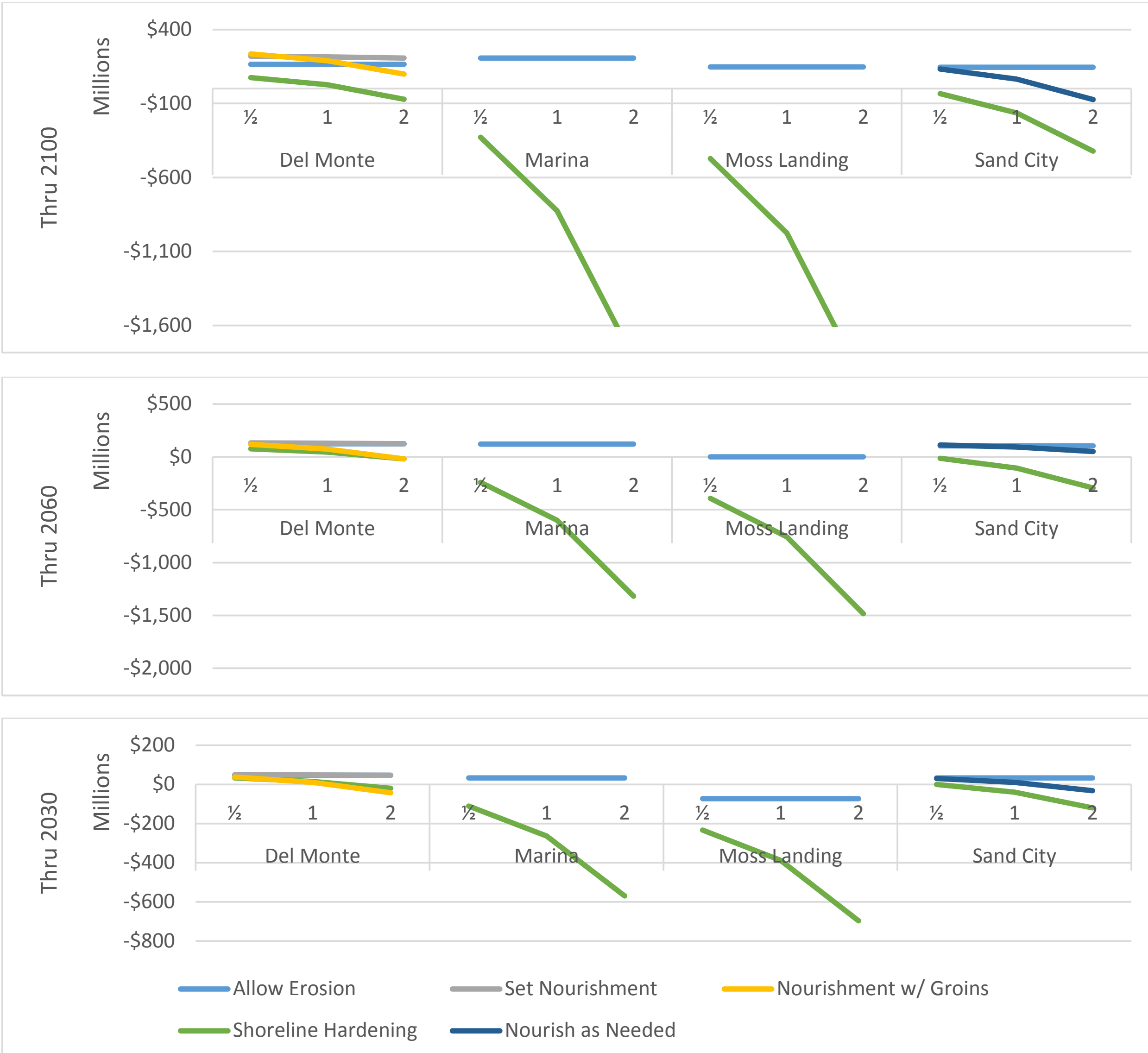


Figure 19: Sensitivity to Nourishment Costs (High SLR)

Table 13 (below) summarizes our sensitivity analyses and robustness checks for each reach, timeline and high and medium SLR projections (24 in all). **With the exception of 2030 and 2060 in the Del Monte reach, the shoreline hardening options yield the lowest net present values and under no scenario does it yield the highest net benefits. This result is quite robust, even varying significant parameters by a factor of two or more. In other words, even if our assumptions are somewhat inaccurate, we can be reasonably certain that shoreline armoring is a poor policy choice for these reaches, at least in the aggregate.**

Given our assumptions, nourishment yields the highest net present value in the Del Monte reach. However, nourishment with groins becomes a better option if the recreational value of beaches increases or the costs of nourishment decrease. In the Sand City reach, allow erosion yields the highest net present value, although nourish as needed is very close to it, especially in nourishment costs are very low or beach-width preferences are relatively strong. Allow erosion strongly dominates shoreline nourishment under all scenarios at both Marina and Moss Landing.

Table 13. Sensitivity/Robustness Check for Economic Analysis

Reach	Year	SLR Scenario	Best Option	Worst Option	Robustness
Del Monte	2030	Med	Scheduled Nourishment/ Allow Erosion	Nourish w/ Groins	Very robust.
Del Monte	2030	High	Scheduled Nourishment/ Allow Erosion	Nourish w/ Groins	Very robust.
Del Monte	2060	Med	Scheduled Nourishment	Shoreline Hardening	Nourishment w/ Groins beats Scheduled Nourishment if: Annual Attendance or Day Use Value is more 175%, Costs of Nourishment less than 50%
Del Monte	2060	High	Scheduled Nourishment	Shoreline Hardening	Very robust.
Del Monte	2100	Med	Scheduled Nourishment	Shoreline Hardening	Nourishment w/ Groins beats Scheduled Nourishment if: Annual Attendance or Day Use Value is more 200%, Costs of Adapation less than 50%
Del Monte	2100	High	Scheduled Nourishment	Shoreline Hardening	Nourishment w/ Groins beats Scheduled Nourishment if: Annual Attendance or Day Use Value is more 175%, Costs of Nourishment less than 75%
Sand City	2030	Med	Allow Erosion	Shoreline Hardening	Nourish as Needed beats Allow Erosion if: Day Use or Attendance are greater than 225%, Costs of Nourishment less than 50%
Sand City	2030	High	Allow Erosion	Shoreline Hardening	Nourish as Needed beats Allow Erosion if: Day Use or Attendance are over 225%, Costs of Nourishment are less than 50%
Sand City	2060	Med	Allow Erosion	Shoreline Hardening	Nourish as Needed beats Allow Erosion if: Day Use or Attendance is over 150%, costs of nourishment is less than 75%, Ecological value above 175%
Sand City	2060	High	Allow Erosion	Shoreline Hardening	Nourish as Needed beats Allow erosion if: Day Use or Attendance are over 150%, Costs of Nourishment are less than 75%, Ecological value is above 175%
Sand City	2100	Med	Allow Erosion	Shoreline Hardening	Nourish as Needed beats Allow Erosion if: Annual Attendance or Day Use Value is more 200%, if the costs of nourishment are less than 50%.
Sand City	2100	High	Allow Erosion	Shoreline Hardening	Very robust.
Marina	2030	Med	Allow Erosion	Shoreline Hardening	Very robust.
Marina	2030	High	Allow Erosion	Shoreline Hardening	Very robust.

Marina	2060	Med	Allow Erosion	Shoreline Hardening	Very robust.
Marina	2060	High	Allow Erosion	Shoreline Hardening	Very robust.
Marina	2100	Med	Allow Erosion	Shoreline Hardening	Very robust.
Marina	2100	High	Allow Erosion	Shoreline Hardening	Very robust.
Moss Landing	2030	Med	Allow Erosion	Shoreline Hardening	Very robust.
Moss Landing	2030	High	Allow Erosion	Shoreline Hardening	Very robust.
Moss Landing	2060	Med	Allow Erosion	Shoreline Hardening	Very robust.
Moss Landing	2060	High	Allow Erosion	Shoreline Hardening	Very robust.
Moss Landing	2100	Med	Allow Erosion	Shoreline Hardening	Very robust.
Moss Landing	2100	High	Allow Erosion	Shoreline Hardening	Very robust.

Future Work

This study integrates property values, ecological values, and the recreational value of coastal resources in order to estimate the benefits and costs of various adaptation strategies. However, like any other economic study, we relied on a number of assumptions, and although we used the best available data, more data in certain cases (discussed below) would have been helpful. We are confident in our results since our robustness/sensitivity analysis indicates that changing key parameters significantly generally does not change the rank ordering of results (see previous section).

Recreational Analysis

Our knowledge of recreation in the study area is quite limited. For this study we relied on survey data, counts, as well as measures of willingness to pay from other areas. Further study of beach recreation in the area would refine our analysis. Our use of the CSBAT model is consistent with many other studies in California. However, our knowledge of the relationship between recreational value and beach width is still limited. Fortunately, this limitation did not influence our results, as indicated in the sensitivity analysis.

Ecological Analysis

We believe that our modeling of the ecological benefits of beaches and other coastal habitats represents a significant step forward from previous studies. However, more work is needed here. In particular future studies should consider the following:

- Using a non-linear economic model to describe beach ecological function (e.g., a Cobb-Douglas function);
- The inclusion of other ecological indicators (e.g., wrack), for which data were not available for this study, to estimate the value of beach ecology;
- Our knowledge of the ecological impacts of nourishment is scanty. There is a general agreement that nourishment harms coastal ecosystems, but that these systems can and often do recover in time (as conceptually modeled in this study). However, the timeframe for this recovery is unknown and almost certainly varies by site, type of nourishment, grain size, etc.
- The profile modeling provided intertidal width and slope changes, which indicated degradation by coastal structures. However, these physical responses were not used. Future analysis could be improved by applying conceptual modeling of ecological responses to these intertidal changes. Similarly, other habitat “bands” could be included in the ecological response modeling.
- Our beach restoration cost estimates are based on a small number of projects, many hypothetical. If this method is used in future applications, the beach restoration cost metrics need refining.
- Our restoration cost approach did not include the potential recreational value or increased recreational value of these sites.
- While we believe this paper makes a significant advance in valuing coastal ecosystems, we did not place a value on upland ecosystems that would be

modified/eliminated/degraded by the alternatives in this study. In future studies, we would attempt to fill this gap.

Flooding and Erosion

Future studies should consider the following:

- While we did incorporate the primary damages from flooding (i.e., to buildings and structures), we did not incorporate the costs of cleaning up after flooding events (e.g., cleaning debris);
- Although we used replacement cost for infrastructure, we did not look at the potential costs of land to place this infrastructure on. Since we assumed major roads like Hwy 1 would be elevated, we think this assumption would not alter our conclusions;
- We did not model transportation delays caused by road flooding, removal etc. These damages could be significant in some cases (e.g., closure of Hwy 1)
- We did not estimate the potential costs of hazardous materials cleanup that could result from coastal flooding. A recent analysis of coastal hazards for the City of Goleta indicated that hazardous materials mitigation/remediation could be a significant cost (Revell Coastal 2015);
- Future work should consider regional economic impacts (i.e., direct, indirect and induced) from businesses that temporary shutter their operations;
- Future work should consider the vulnerability of critical facilities such as hospitals and community centers;
- A sensitivity analysis on the range of possible physical scenarios such as storms at different frequencies (e.g., 20-year event, 500-year event) should be conducted;
- Future work should consider the loss of recreational value on coastal bluff trails subject to erosion.
- Future studies may want to examine the trade-offs between nourishment and managed retreat, including analyzing a range of options and assumptions about the future.

Our analysis also assumes that relative property values do not change with coastal adaptation strategies, which is unlikely. As the coast erodes, land adjacent to the coast will become less valuable as the market incorporates the probability that this land will disappear or be unusable. If the coastline is armored, this land might become less valuable due to the loss in aesthetic/recreational/ecological value of an armored coastline. Finally, if the coast erodes, some parcels/properties will become closer to the coast or on the coast, which might increase their market value. On the other hand, if expectations about future erosion are incorporated, this land might also decrease in value. All of these issues are important, but beyond the scope of this report.

Future Demand for Beach Recreation

In this report, we have generally assumed that the real costs and benefits of various adaptation strategies is constant. Put simply, once one corrects for inflation the prices/costs of most property and engineering solutions will stay constant. However, for beach recreation, this assumption is quite limiting since existing demographic/population projections by the State of California indicate that both the State and County will experience population growth. In addition, State/County forecasts indicate that real per capita income will grow.

We have little or no data/information on the growth of demand for beaches over time. State Parks does keep annual records with official attendance counts, but as shown by King and McGregor (2012) the official counts are suspect. For example, conversations with lifeguards indicate that in many cases they have an idea of how many people visit on a "busy" day or a "slow" day, but this estimate may not change over time. Our knowledge of the relationship between income and the willingness to pay is also limited. While it may seem reasonable to assume that the willingness to pay increases with income, it's also possible that wealthier individuals substitute other recreational activities as their income increases, or they may use the additional income to visit beaches elsewhere, such as southern California or Mexico.

To simplify, we assumed that attendance increased with the population growth and that the demand for beach recreation in southern Monterey Bay has an income elasticity of one--that is if a household's income increases by 5%, its willingness to pay increases by 5%. We believe these assumptions are reasonable. Fortunately, with the exception of the Del Monte reach, our sensitivity/robustness analysis indicates that our results generally do not change even with significant changes in the recreational value of beaches.

Discount Rate

When considering benefits and costs that are incurred over a number of years, the dollar values must be adjusted to reflect the fact that a dollar received today is considered more valuable than a dollar received in the future. One important reason for this is the fact that a dollar received today could be invested to produce additional wealth. To do this, it is important to identify the period of time that will account for most of the relevant benefits and costs and to select a discount rate that will account for the diminishing value of benefits received in the future.

The choice of an appropriate discount rate is generally even more critical in the analysis since a higher discount rate implies that future benefits and costs are weighted lower. For most private projects the choice of a discount rate is relatively simple—whatever the appropriate market rate is. For example, if a private company is considering a $100 million dollar investment in a new factory that would yield a future stream of returns (profit), the firm would use their cost of capital. If they can borrow money at a 5% rate of interest, then 5% would be the discount rate.

For social projects, the discount rate is often tied to something similar—the cost of government bonds over the appropriate time horizon. For example, on a federal project lasting 30 years, one can apply the interest rate on a 30-year treasury bond (3.8% on January 10, 2014).

A number of economists have argued that using market interest rates when analyzing social costs and benefits is inappropriate for a variety of reasons. First, the social rate of time preference –that is the rate at which society values present consumption over future consumption—is not necessarily given by the market interest rate (Zhuang, Liang, Lin, & Guzman, 2007). A number of economists have conducted empirical studies of the social rate of discount and have found rates ranging from 0.1% to 3% (Liang, Lin, & Guzman, p.6).

Standard discounting practices face another critical problem in that the rates that are typically used discount goods and services to future generations. Applying a discount rate of 3%, for example, implies that benefits or costs born in 100 years are only weighted 5% (1/20) of current costs and benefits; if one uses a 2% rate, the weighting changes to (a still low) 14%. Even applying a rate as low as 1% implies that benefits/costs 100 years from now are only weighted at 37% of today's benefits.

Given the potentially enormous costs of climate change to future generations and the longer time scale, many environmental economists have proposed applying lower discount rates when analyzing the economic impacts of climate change. One of the most widely cited reports, the Stern report (2006), applied a 1.4 % discount rate. Arrow et al. (2014) point out that climate change modeling presents a unique set of issues given the uncertainty involved and the potential for catastrophic outcomes (even if the probability of such outcomes is low). Consequently, many climate change models use a declining discount rate over time—implying that a longer time horizon should receive a lower discount rate. A number of European countries have already adopted such an approach. For example, Great Britain has adopted a declining rate formula for climate change projects where the discount rate can reach 0.75% after 300 years (Arrow et. al., 2014, p. 11). Our analysis uses a 1% discount rate, which is consistent with Arrow and others, but we also conducted a sensitivity analysis using other discount rates.

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Appendix A: Coastal User Survey Results

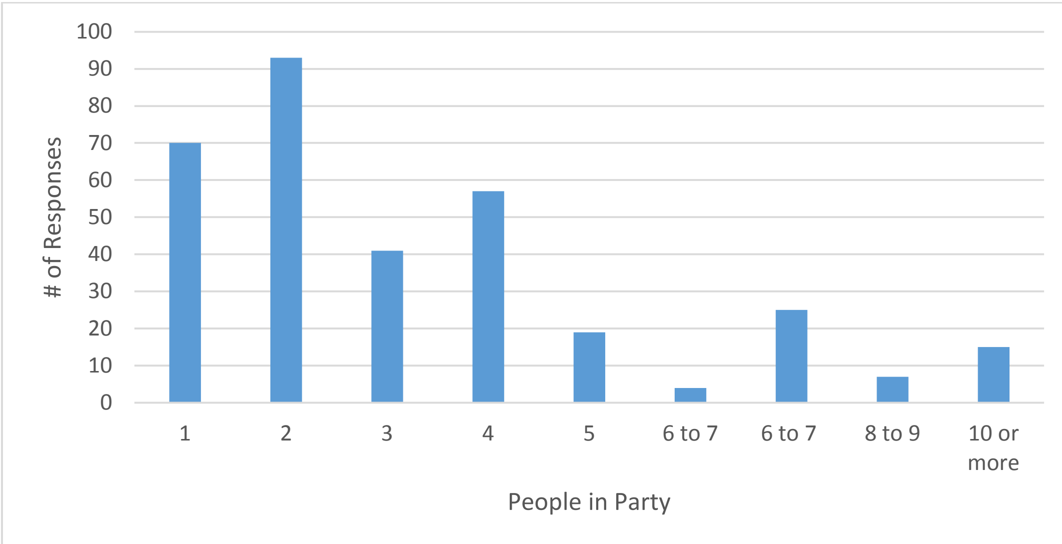

Figure 20: Including yourself, how many people are in your party today?

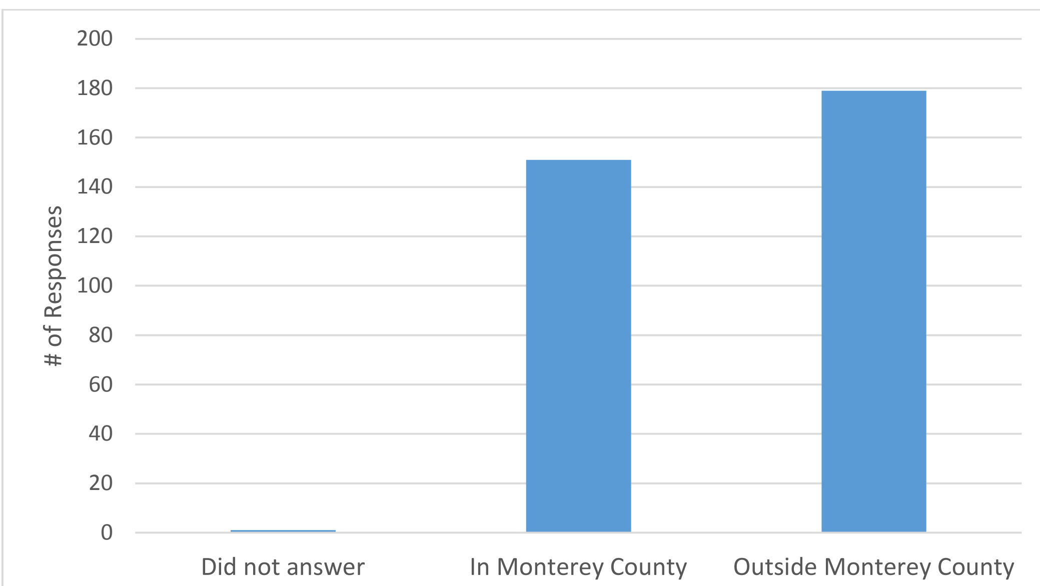

Figure 21: Where did you start your trip from?

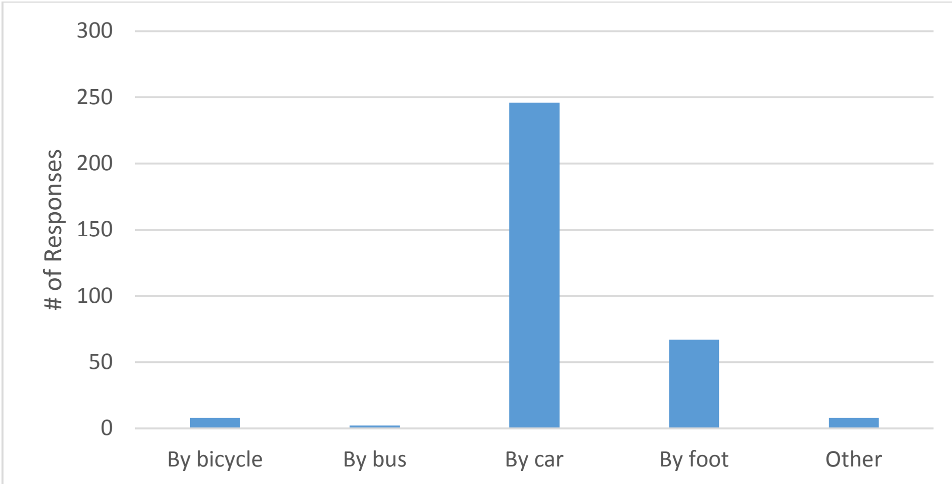

Figure 22: How did you get to the beach today?

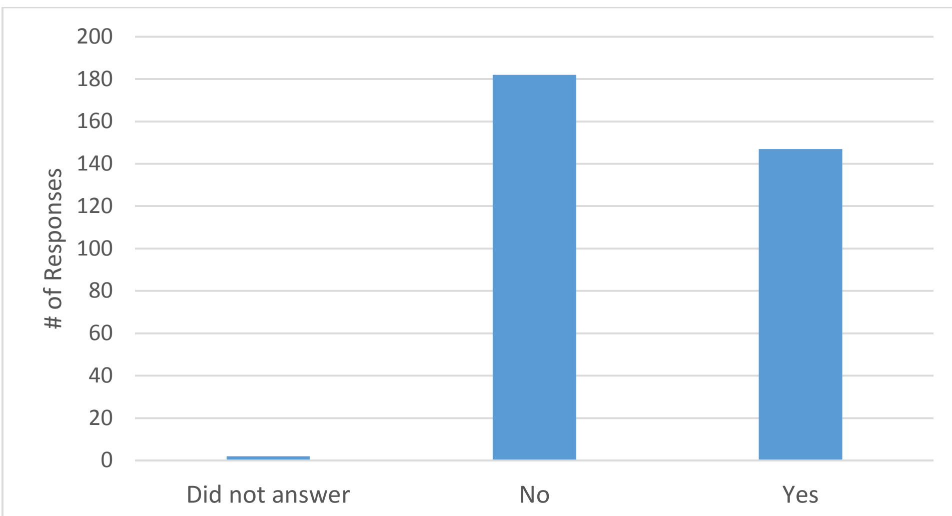

Figure 23: Is this an overnight trip away from your primary residence?

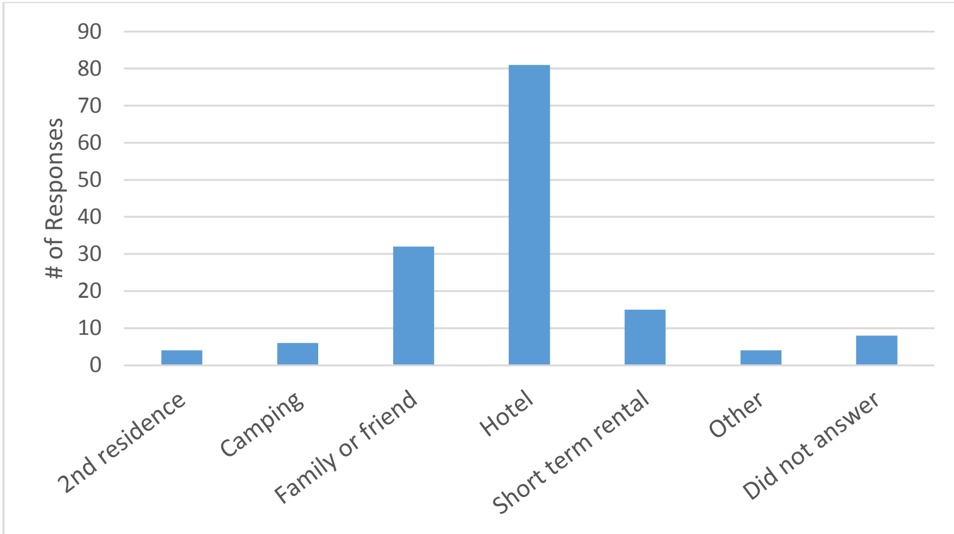

Figure 24: What type of lodging will you be using?

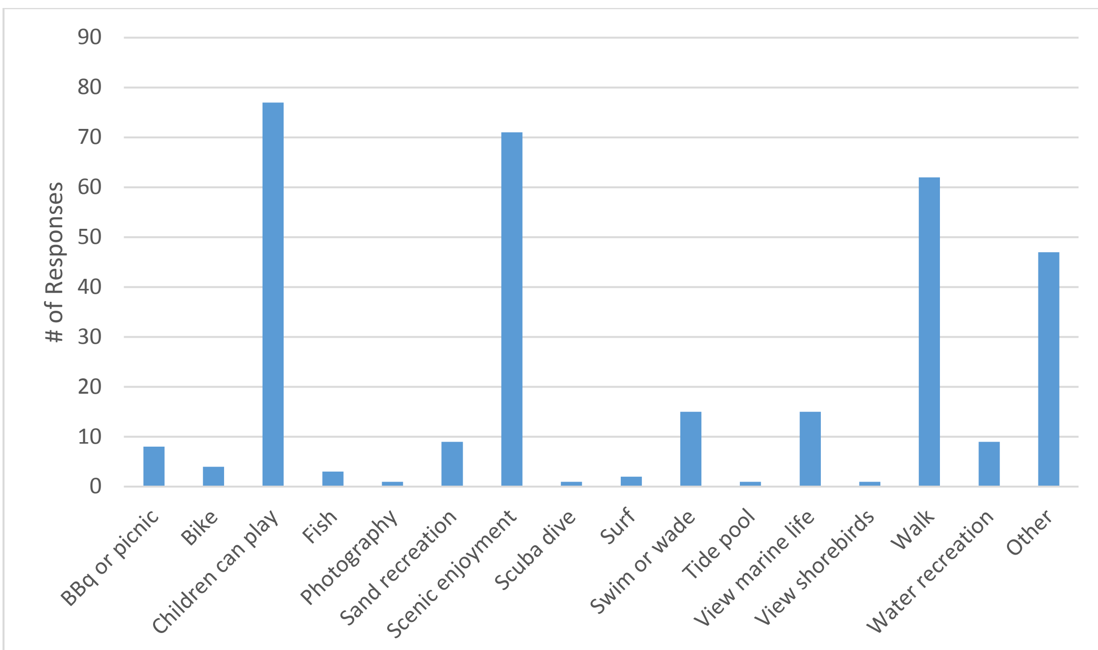

Figure 25: What is the main reason for your party's trip today (choose one)?

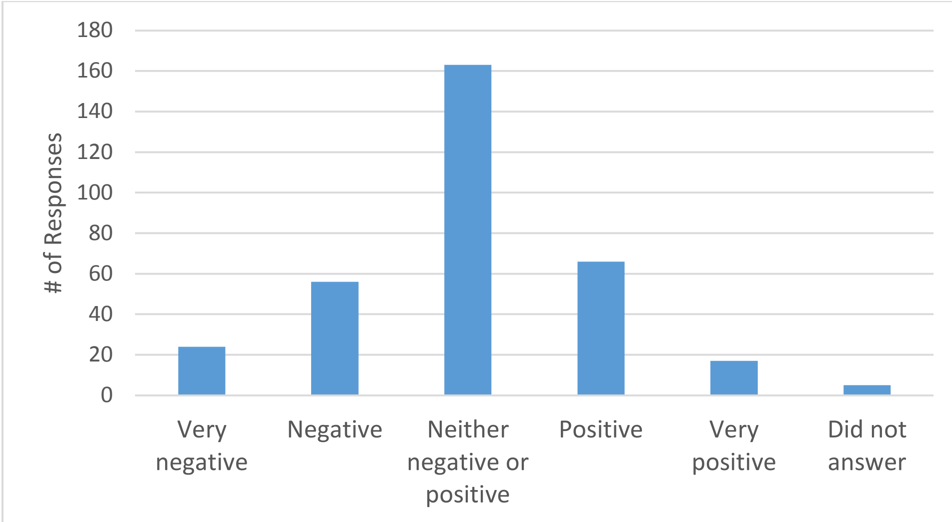

Figure 26: What effect do seawalls (vertical concrete walls generally at the back of the beach) have on your beach going experience?

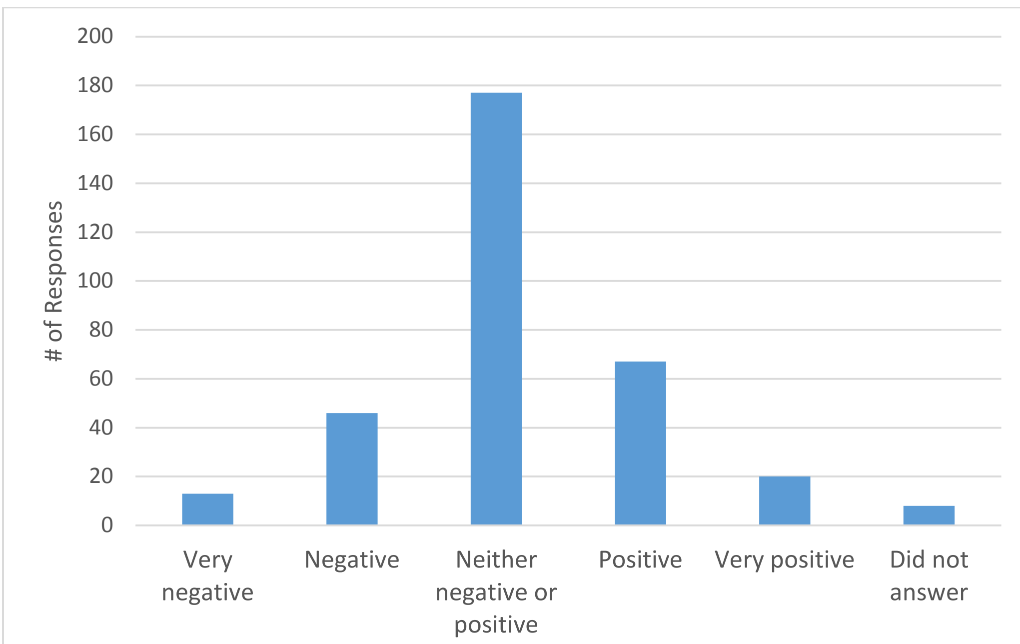

Figure 27: What effect do revetments/riprap (rock boulders or stones generally at the back of the beach) have on your beach going experience?

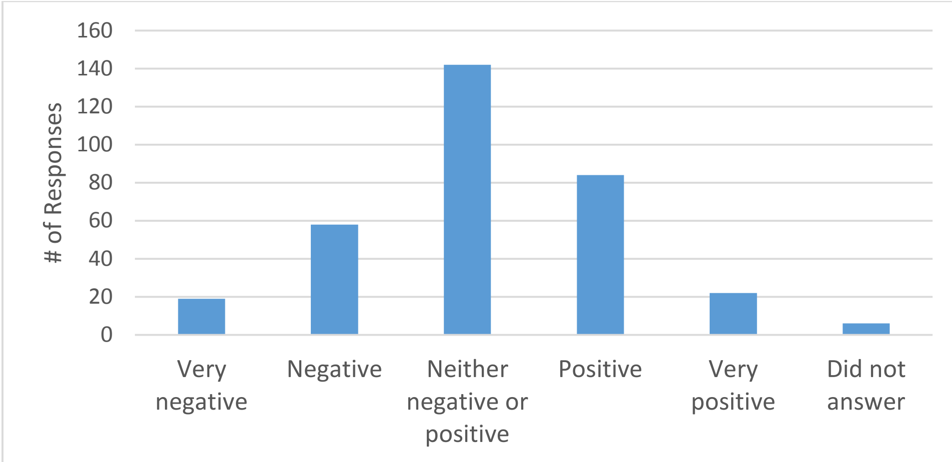

Figure 28: What effect do jetties/groins (wood, stone, or rock structures that extend from the beach into the water) have on your beach going experience?

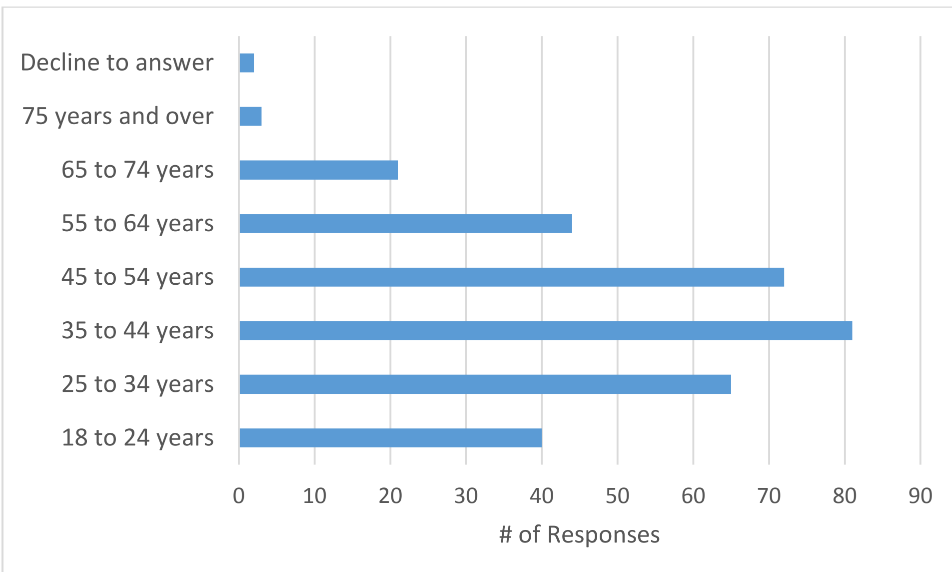

Figure 29: What is your age?

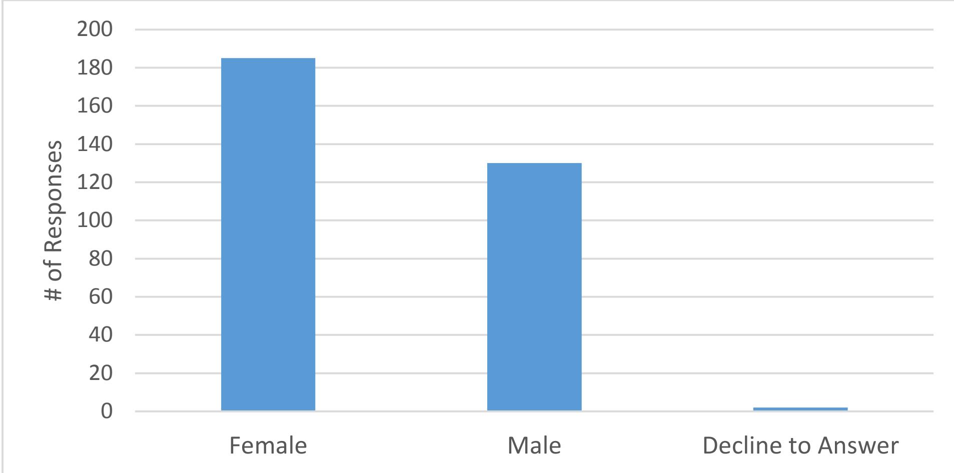

Figure 30: What is your gender?

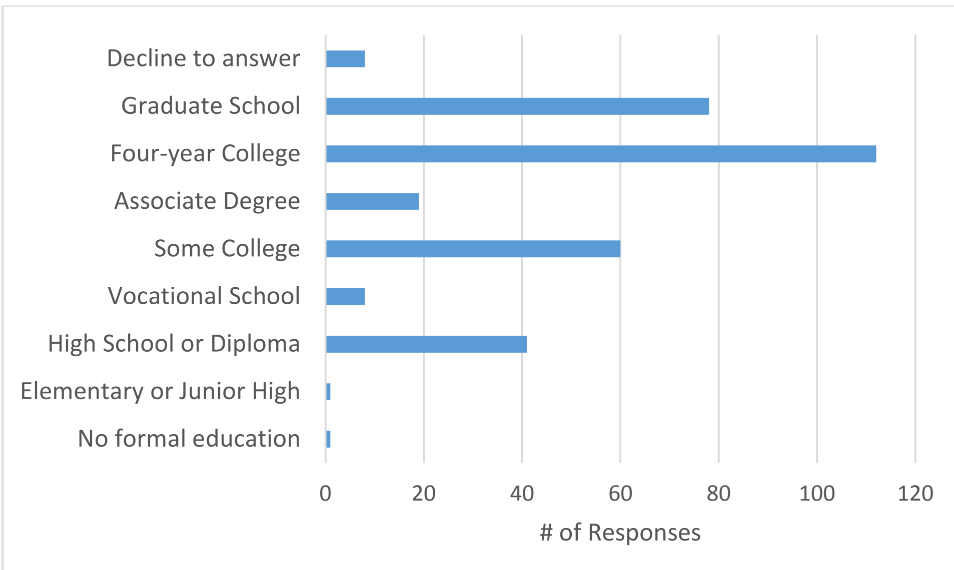

Figure 31: Highest level of education completed (choose only one)?

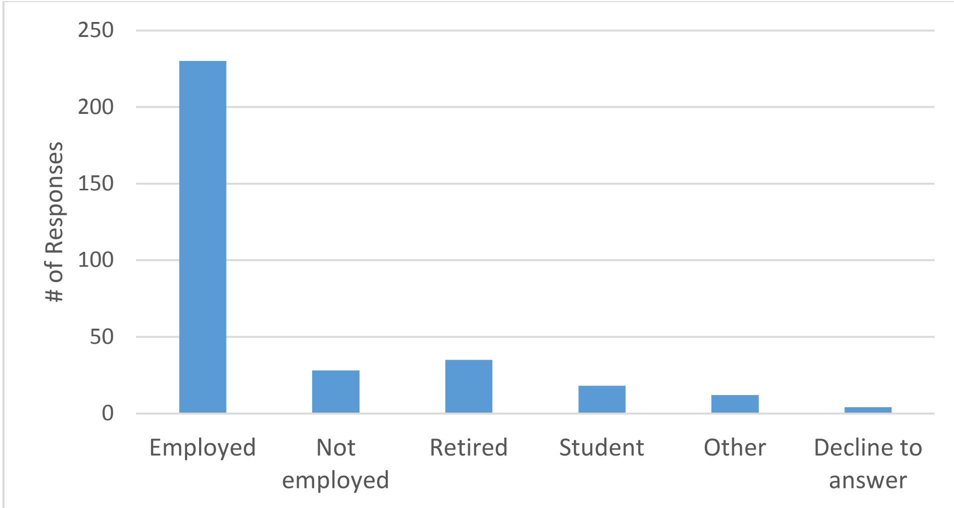

Figure 32: Employment status (choose only one)?

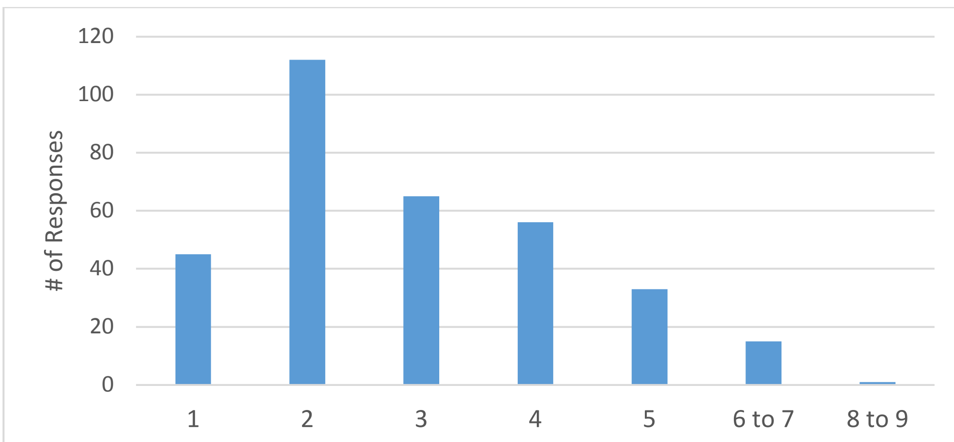

Figure 33: Including yourself, how many people are in your current household (i.e., people you live and share financial resources with)?

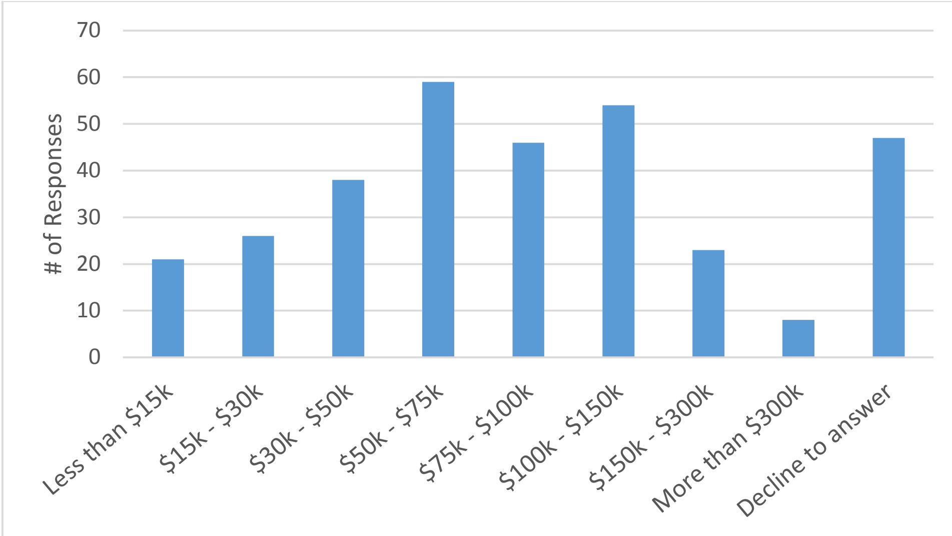

Figure 34: Total annual household income for last year before taxes (from all sources)?

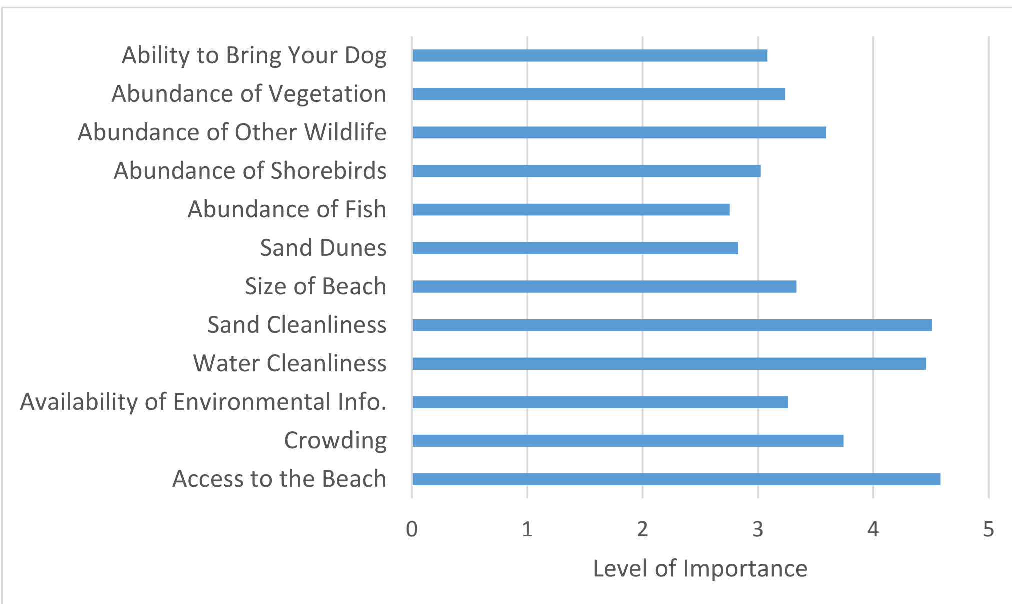

Figure 35: In general, how important are the following factors to your beach going experience? (1 = Not at all important, 5 = Extremely important)

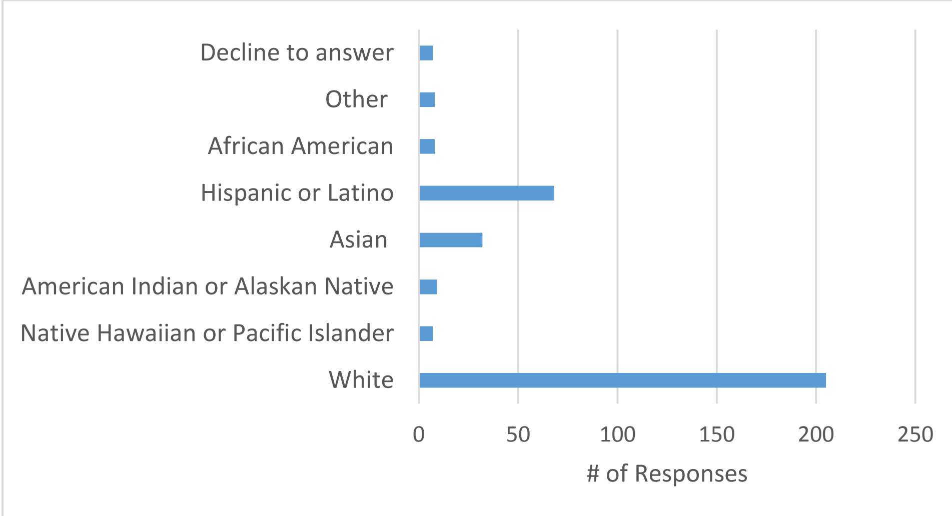

Figure 36: Race (choose all that apply)?

Appendix B: Southern Monterey Bay Coastal Survey

We are conducting this survey as part of a project funded by the State of California Coastal Conservancy. Our goal is to learn about you the activities you will participate when you are in Monterey Bay. We would appreciate your help by taking a few minutes to complete this survey.

All responses are confidential. *Thank you very much for your participation.*

1. **<u>Including yourself,</u> how many people are in your party today?**

   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6-7 ☐ 8-9 ☐ 10 or more

2. **Where did you start your trip from?**

   ☐ In Monterey County ☐ Outside Monterey County

3. **How did you get to the beach today?**

   ☐ By Car ☐ By foot ☐ By Bicycle ☐ By Bus ☐ Other ___________

4. **Is this an overnight trip away from your primary residence?** ☐ Yes ☐ No → **If 'NO', skip to Question 5**

   4a. How many nights will you stay in <u>Monterey County</u> on this trip?

   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8-14 ☐ 15 or more

   4b. What type of lodging will you be using?

   ☐ Hotel ☐ Short term rental ☐ Family or friend ☐ Camping ☐ 2nd Residence ☐Other___________

5. **<u>Not including this trip</u>, how many days have you visited <u>this beach</u> in the past 12 months?**

   ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6-12 ☐ 13-51 ☐ Once a week ☐ More than once a week

6. **<u>Not including this trip</u>, how many days have you visited <u>other beaches in Monterey County</u> over the past 12 months?**

   ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6-12 ☐ 13-51 ☐ Once a week ☐ More than once a week

7. **When did you arrive at the beach today?**

   ☐ Before 8am ☐ 8am-10am ☐ 10am-11am ☐ 11am-12pm ☐ 12pm-1pm

   ☐ 1pm-2pm ☐ 2pm-3pm ☐ 3pm-5pm ☐ After 5pm

8. **When do you plan to leave the beach today?**

   ☐ 10am-11am ☐ 11am-12pm ☐ 12pm-1pm ☐ 1pm-2pm ☐ 2pm-3pm

   ☐ 3pm-4pm ☐ 4pm-5pm ☐ After 5pm

9. **Have you left the beach today or do you plan to leave the beach and return later today?** For example, to go get something to eat or go retrieve something from a car.

   ☐ Yes ☐ No → **If 'NO', skip to Question 10**

9a. How long do you think you will be away from this beach today if leave and then return?

☐ 30 minutesor less ☐ 30-60 minutes ☐ 1-2 hours ☐ 2-3 hours ☐ 3-4 hours ☐ 4 hours or more

10. What is the main reason for your party's trip today (choose one)?

☐ Children can play	☐ Walk	☐ Sand recreation (e.g., volleyball)	☐ BBQ or picnic
☐ Swim/wade	☐ Surf	☐ Water recreation (e.g., kayak)	☐ View shorebirds
☐ View marine life	☐ Fish	☐ Snorkel or free dive	☐ Scuba dive
☐ Tide pooling	☐ Sail	☐ Hang glide/parasail	☐ Photography
☐ Scenic Enjoyment	☐ Bike	☐Golf	☐Other________________

11. Which other activities will your party engage in today (choose as many as apply)?

☐ Children can play	☐ Walk	☐ Sand recreation (e.g., volleyball)	☐ BBQ or picnic
☐ Swim/wade	☐ Surf	☐ Water recreation (e.g., kayak)	☐ View shorebirds
☐ View marine life	☐ Fish	☐ Snorkel or free dive	☐ Scuba dive
☐ Tide pooling	☐ Sail	☐ Hang glide/parasail	☐ Photography
☐ Scenic Enjoyment	☐ Bike	☐Golf	☐Other________________

12. In general, how important are the following factors to your beach going experience?

Factors for your consideration	**Level of Importance**				
r wildlife	1	2	3	4	5
Abundance of vegetation	1	2	3	4	5
Ability to bring your dog	1	2	3	4	5

13. What effect do the following features have on your beach going experience?

a. Seawalls (vertical concrete walls generally at the back of the beach):

☐ Very Negative ☐ Negative ☐ Neither negative or positive ☐ Positive ☐ Very Positive

b. Revetments/Riprap (rock boulders or stones generally at the back of the beach):

☐ Very Negative ☐ Negative ☐ Neither negative or positive ☐ Positive ☐ Very Positive

c. Jetties/groins (wood, stone, or rock structures that extend from the beach into the water):

☐ Very Negative ☐ Negative ☐ Neither negative or positive ☐ Positive ☐ Very Positive

14. What is your best estimate of the amount of money spent on the following items on <u>this entire trip</u>? <u>If you spend nothing on an item please put $0.</u>

Expense Item	Cost	Number of People Covered
Parking		
Food and beverages from a store		
Food and beverages at a restaurant or bar		
Souvenirs (t-shirts, posters, gifts, etc.)		
Sundries (sunscreen, surf wax, motion sickness pills, batteries, film, etc.)		
Boat rental, fuel and other fees (e.g., ramp)		
Car rental		
Gas		
Kayak rental		
Board sport rental		
Bike rental		
Lodging (if you stayed overnight)		
Charter fee (whale watching, etc.)		
Museum, aquarium, or other entrance fee		
Golf		

15. Suppose this beach was HALF its current width (from the ocean to the bluff or first infrastructure). Would this change your experience at this beach:

☐ Have no real effect one way or another → **go to Question 16**

☐ Worse → **go to Question 15a**

☐ Better → **go to Question 15b**

15a. If worse, about how many fewer days would you spend at this beach over the next 12 months?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6-12 ☐ 13-51 ☐ 52 or more

15b. If better, about how many more days would you spend at this beach over the next 12 months?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6-12 ☐ 13-51 ☐ 52 or more

16. Suppose this beach was TWICE its current width (from the ocean to the bluff or first infrastructure). Would this make your experience at this beach:

☐ Have no real effect one way or another → **go to Question 17**

☐ Worse → **go to Question 16a**

☐ Better → **go to Question 16b**

16a. If worse, about how many fewer days would you spend at this beach over the next 12 months?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6-12 ☐ 13-51 ☐ 52 or more

16b. If better, about how many more days would you spend at this beach over the next 12 months?

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6-12 ☐ 13-51 ☐ 52 or more

Demographic Information: The following questions are designed to give us a better idea of the characteristics of visitors. *Please note that your responses are anonymous and you are not identified in any way with this information.*

17. What is your age:

☐ 18 to 24 years ☐ 25 to 34 years ☐ 35 to 44 years ☐ 45 to 54 years

☐ 55 to 64 years ☐ 65 to 74 years ☐ 75 years and over ☐ Decline to answer

18. Are you: ☐ Male ☐ Female ☐ Decline to answer

19. Home (primary residence) zip code: __________

19a. If not living in the United States, where do you live: ___________________________

20. Race (<u>choose all that apply</u>):

☐ White ☐ Native Hawaiian or Pacific Islander ☐ American Indian or Alaskan Native

☐ Asian ☐ Hispanic or Latino ☐ African American

☐ Other ☐ Decline to answer

21. Highest level of education completed (<u>choose only one</u>):

☐ No formal education ☐ Elementary/Junior High ☐ High School or Diploma

☐ Vocational School ☐ Some College ☐ Associates Degree

☐ Four-year College ☐ Graduate School ☐ Decline to answer

22. Employment status (<u>choose only one</u>):

☐ Employed ☐ Not employed ☐ Retired ☐ Student ☐ Other ☐ Decline to answer

23. Including yourself, how many people are in your current household (i.e., people you live and share financial resources with)?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6-7 ☐ 8-9 ☐ 10 or more

24. Total annual household income for last year before taxes (<u>from all sources</u>):

☐ Less than $15,000 ☐ $15,000 to under $30,000 ☐ $30,000 to under $50,000

☐ $50,000 to under $75,000 ☐ $75,000 to under $100,000 ☐ $100,000 to under $150,000

☐ $150,000 to under $300,000 ☐ More than $300,000 ☐ Decline to answer

Appendix C: Southern Monterey Bay Coastal Visitor Count Survey

Surveyor Initials: ___________ Date: __________________

Site Name: _________________ Survey Start Time: ___________ Survey End Time: ___________

Temperature:	Hot	Warm	Cool	Cold
Wind:	Calm	Breezy	Windy	
Sky:	Sunny	Hazy	Cloudy	Rainy
Tide:	Low	Medium	High	

On-Shore Activities	
Beach Going (e.g., sitting, sand castles)	
Walking/Running	
Recreation (e.g., volleyball)	
BBQ/Picnic	
Fishing	
Other (write description)	

Off-Shore Activities	
Swimming/Wading	
Surfing	
Kayaking/Canoeing	
Other (e.g., diving; write description)	

Trail Activities	
Walking/Running	
Biking	
Viewing Wildlife (e.g., birds, whales, dolphins)	
Other (e.g., hang-gliding; write description)	

Other Comments (Special events, beach closure)	

Note: This survey is being completed as part of a project funded by the State of California Coastal Conservancy. These data will help us to better understand the number of people who visit the coastal zone in the Southern Monterey Bay

Appendix D: Southern Monterey Bay Survey Methods and Protocols

Survey Mechanics

- Survey administration will be broken into two periods:
  - High season: June 2014 through August 2014
  - Low season: February 2015 through April 2015
- On average, three days of the week and both weekend days will be surveyed each week to allow the surveyor to work five out of seven days per week while still surveying weekdays evenly.
- Time blocks for conducting coastal visitor counts and proctoring intercept surveys where feasible include: 10-12pm (time slot 1), 12:30-2:30pm (time slot 2), and 3:00-5:00pm (time slot 3) to allow for travel between sites and accommodate a short lunch if necessary.
- Days, time blocks and corresponding locations are chosen using the Excel random number generator where feasible.

Administration Protocol

Coastal Visitor Counts

- Based on the survey schedule, the research assistant will go to the assigned site and walk to the designated vista point and fill in the metadata (e.g., Name, Date, Transect ID, Start Time, Weather)
- The time spent observing at each vista point should be the smallest amount of time needed to count all activities.
- If there is visibility problems and the research assistant needs to walk the chosen transect to collect data, the protocol is to only count people in front of them. Do not count any activity that is happening behind you. People's activities can change from the time you first see them until the time you pass them, so to maintain consistency, you should strive to only record the activity you initially see them. Take effort not to double-count people if their activity changes or for people that are coming towards you (e.g., someone running on the beach towards you).
- The research assistant will record the user in the appropriate activity tally group. In some cases it will be important to provide written comments for activities that do not fall into one of the major categories, or for unique events (e.g., volleyball tournament, school field trip).
- Transfer the data from your survey to the online database within one week of it being collected

Intercept Survey

- The research assistant will proctor surveys from strategically identified locations (e.g., Wharf, bike path, beach access point) or at intervals across the beach/shoreline. At the beach, the research assistant will zig-zag and approach every nth group, where n depends on the number of surveys they expected to collect at that site, and the density of the crowd.
- When approaching a coastal user, the research assistant will introduce the survey by asking if they were 18 years old.
- The research assistant will introduce the survey by saying something along the lines of: "Hello, my name is _____. I'm sorry to bother you, but I was wondering if you would be willing to take a few

minutes to complete this survey that is being conducted on behalf of the State of California (i.e., California Coastal Conservancy). Our goal is to learn about your trip to Monterey Bay. All responses are anonymous and confidential and you will not be identified in any way with the information collected."

- If the coastal users wants to know more about the survey, the research assistant is instructed to say something similar to: "This survey would provide local resource managers with additional information on their users (e.g., what activities you do, how far you travel to the beach) and that such information could inform decision-making." Proctors should not introduce bias to the survey by saying things like: "This information will help the beach."
- If an individual agreed to participate in the survey, the research assistant will ask them if they would be willing and able to take the survey as a handout. If they say no for any reason, the research assistant will offer to interview the respondent (i.e., dictate the questions and record answers).
- For respondents taking the handout, research assistant will provide a clipboard with an attached survey and ballpoint pen.
- The research assistant will note that the survey is 3 (or 4) single-sided pages, and that they will be close-by if any questions arise.
- If the respondent hesitates during the demographic section, the research assistant will respond along the lines of "This portion of the survey asks some simple demographic questions and the information is completely anonymous. You can select the 'Decline to Answer' option for any questions that you would prefer to not answer."
- If feasible, the research assistant will review the survey to check if all questions have been answered. The
- When the survey has been completed the research assistant will fill out the survey metadata (e.g., Name, Date, Transect ID, Start Time, Weather)
- Transfer the data from your survey to the online database within one week of it being collected.

Other Things to Consider

- Fill out a separate data sheet for EACH survey site/transect.
- Do not compromise your personal well-being to collect data
- Dress appropriate, and wear a hat or sunscreen when warranted.
- People may approach you. If they do, be friendly and tell them that this
- Be aware of people approaching you. Be cordial and don't hesitate if they ask what you are doing that this is a project funded by the State of California (i.e., California Coastal Conservancy) to develop a further understanding of coastal users in Monterey Bay. All responses are anonymous and confidential and you will not be identified in any way with the information collected.
- There is no need to draw extra attention to yourself. This could influence the behavior of coastal users, thereby biasing the data and/or result in negative attention to the project.

- This is a team project, so don’t hesitate to communicate directly to your supervisor if you have any questions, comments or problems. Your continued work and perspectives are integral to conducting this important work in the region.