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Economic Impacts of Climate Adaptation Strategies for Southern Monterey Bay

Kelly Leo

Sarah Newkirk

Walter Heady

Brian Cohen

Juliano Calil

See next page for additional authors

Authors
Kelly Leo, Sarah Newkirk, Walter Heady, Brian Cohen, Juliano Calil, Philip King, and Fernando DePaolis

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Marina State Beach, Photo credit: Kelly Leo

Prepared for:
the California State Coastal Conservancy
1330 Broadway, 13th Floor
Oakland, CA 94612

Prepared by: The Nature Conservancy's California Coastal Program: Kelly L. Leo, Sarah G. Newkirk, Dr. Walter N. Heady, Brian Cohen, and Ecological Consultant: Juliano Calil; Economic Consultants: Dr. Philip King, Aaron McGregor, Dr. Fernando DePaolis, Dr. Ryan Vaughn, & Jeffrey Giliam; Physical Hazard Modeling & Engineering Consultants: Environmental Science Associates (ESA): Bob Battalio; Elena Vandebroek; James Jackson; & Dr. David Revell (now of Revell Coastal)

Edited by: Nancy Steinberg

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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

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[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

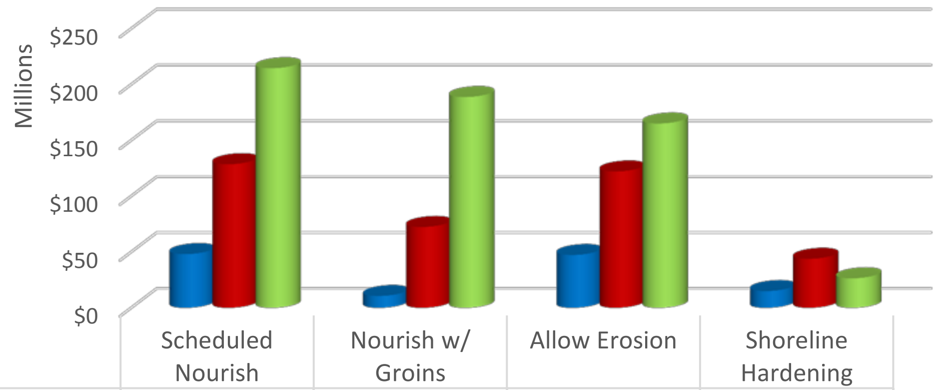
Reach	Management Strategy
Del Monte	**Opportunistic/scheduled beach Nourishment**: smaller local beach nourishment projects scheduled every 10 years
	Shoreline Armoring: Revetment constructed continuously across reach along backshore; stops erosion of back shore but allows beach to narrow and the structure 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.

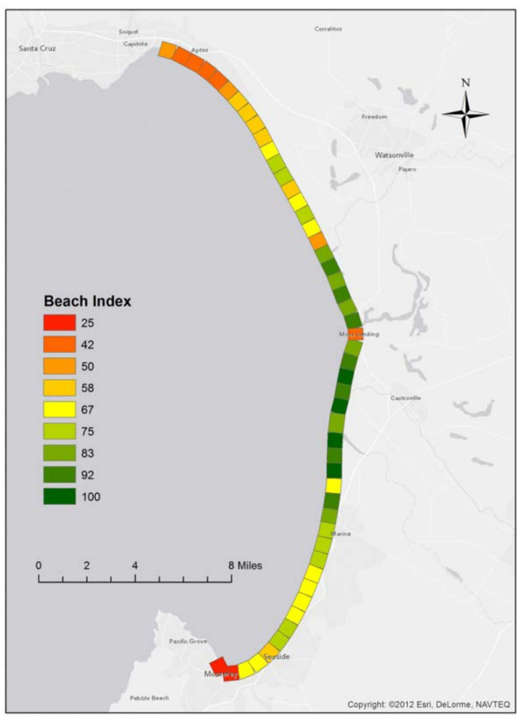


Figure 4: Beach ecological index evaluation

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.

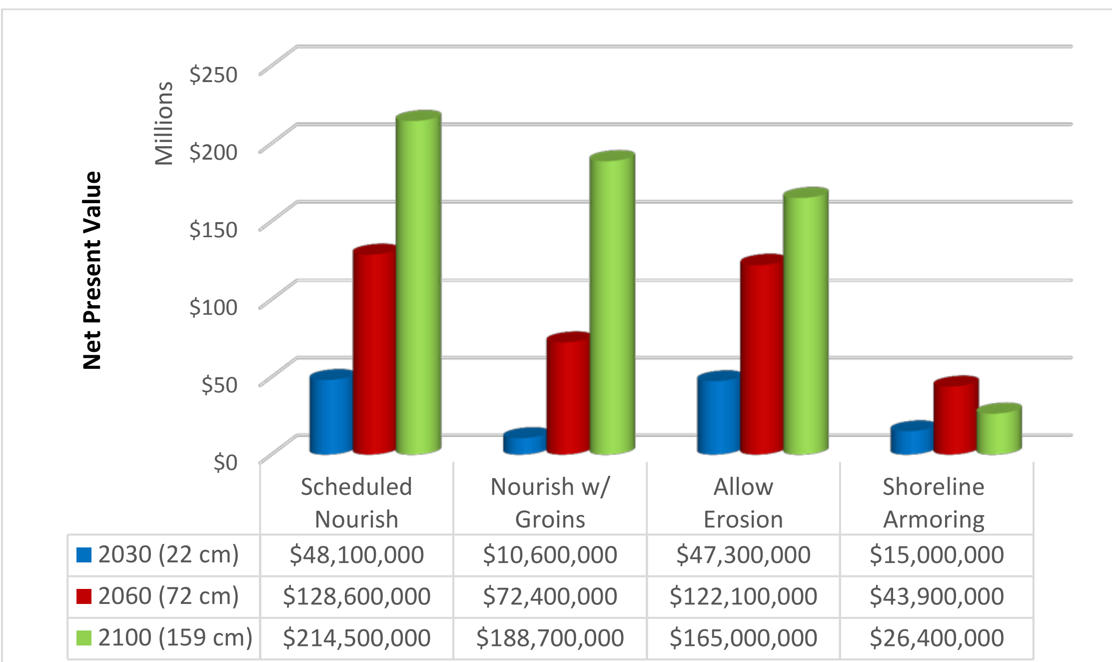
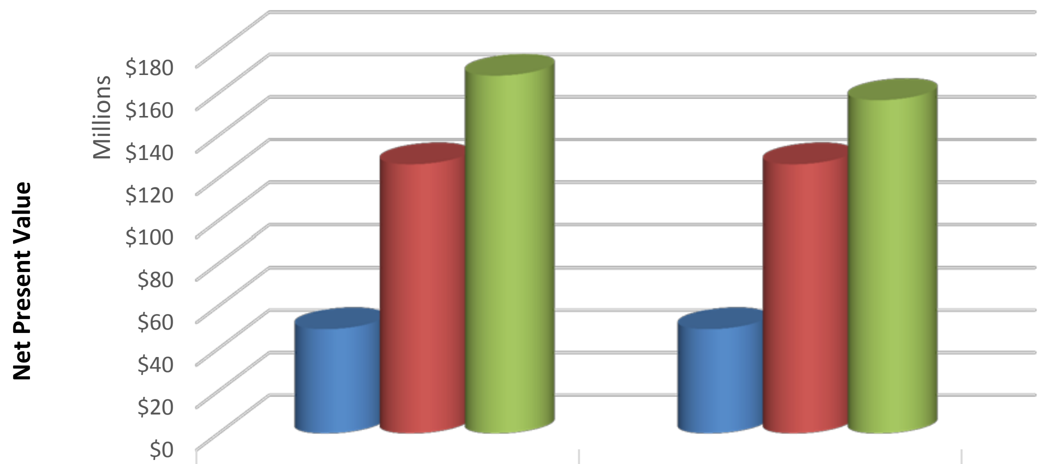


Figure 5: Net Present Value of Shoreline Management Options: Del Monte (using High sea level rise projection)

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

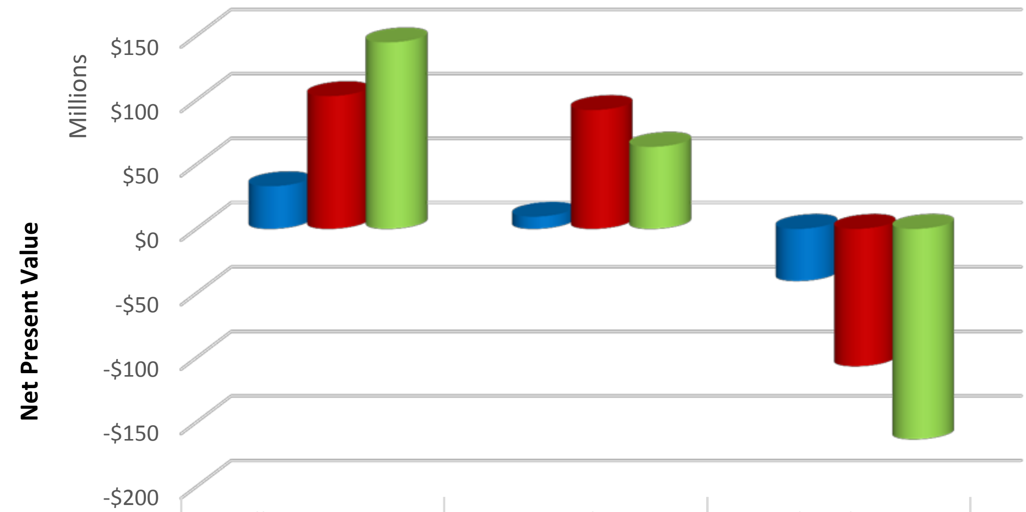
For the Sand City reach, the adaptation scenarios we considered were:

- 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)

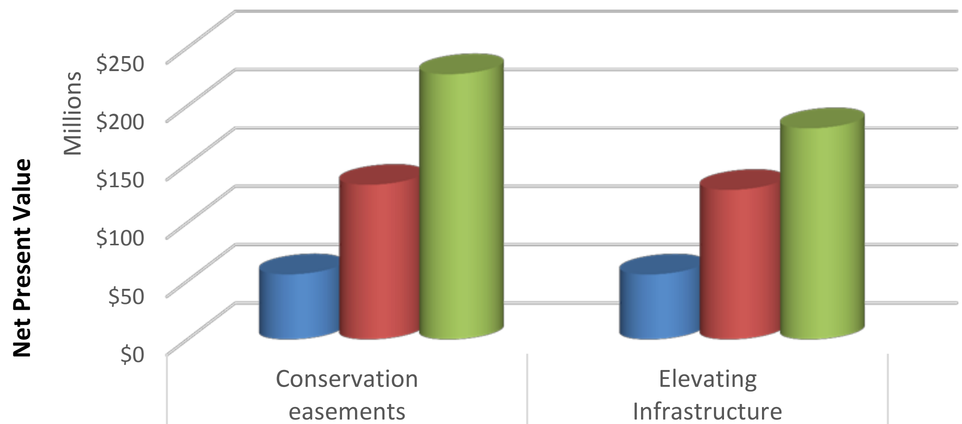
Year	Nourish as Needed	Allow Erosion	Shoreline Armoring
Public Benefits (recreational and ecological value)			
2030	$73,879,019	$55,517,865	$46,714,719
2060	$156,974,550	$128,161,523	$88,872,613
2100	$258,312,180	$215,278,285	$105,318,207
Property Losses/Damages (infrastructure, MRWPCA, public and private 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

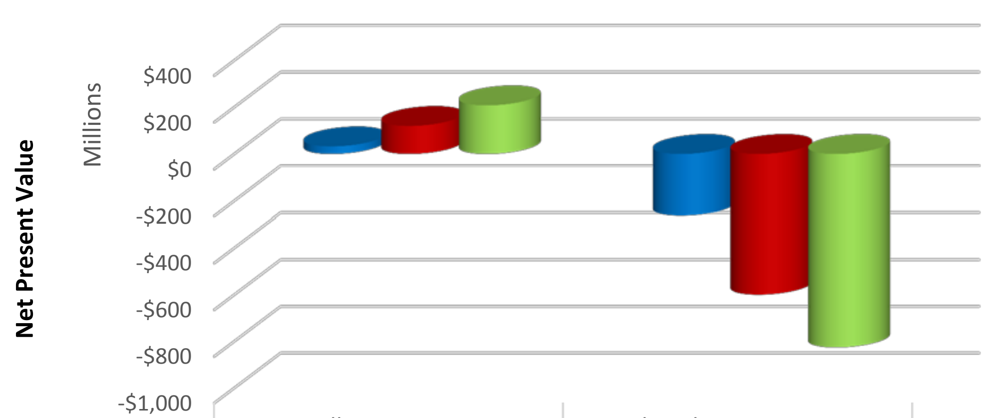
For the Marina reach, the adaptation scenarios we considered were:

- 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)

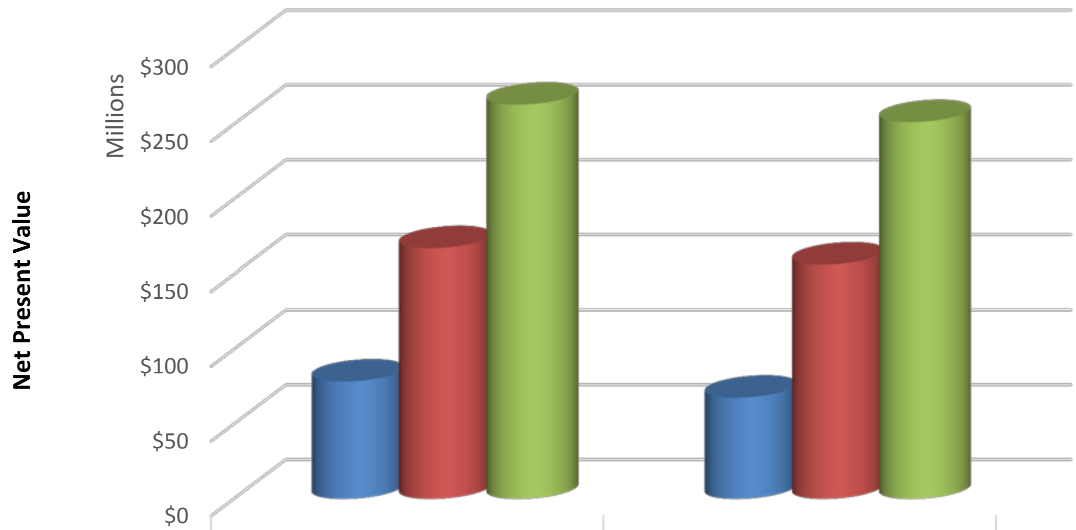
Year	Allow Erosion	Shoreline Armoring
Public Benefits (recreational and ecological value)		
2030	$77,252,329	$73,521,261
2060	$169,190,596	$150,380,476
2100	$266,362,964	$207,965,869
Property Losses/Damages (infrastructure, MRWPCA, public and private property)		
2030	-$44,943,649	-$30,802,090
2060	-$49,501,308	-$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



	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 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

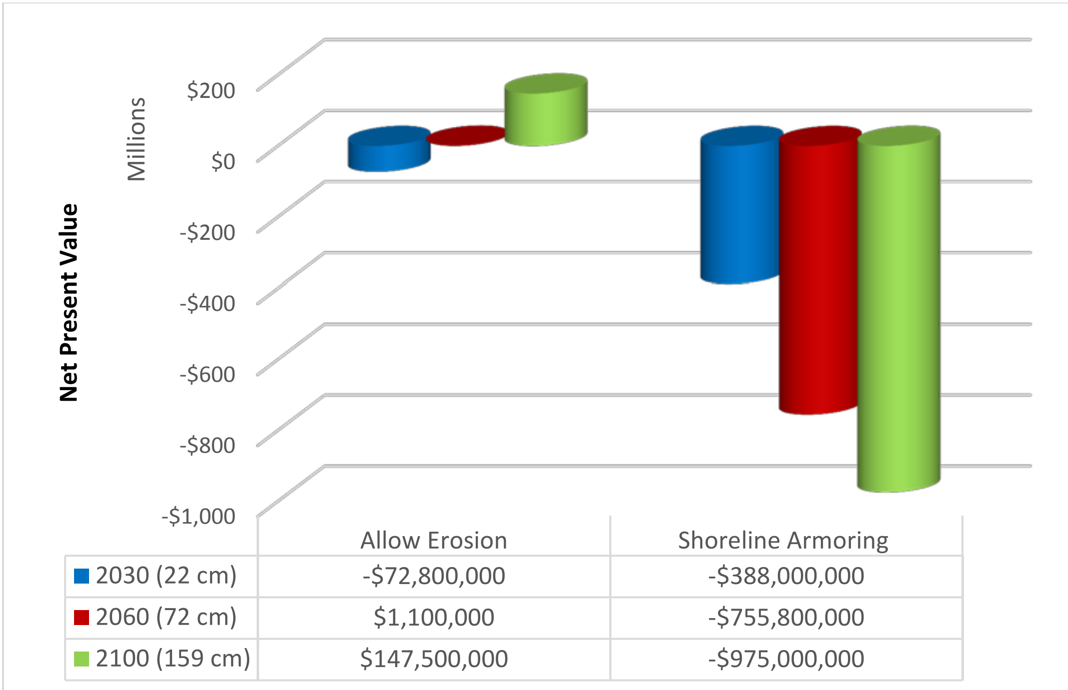
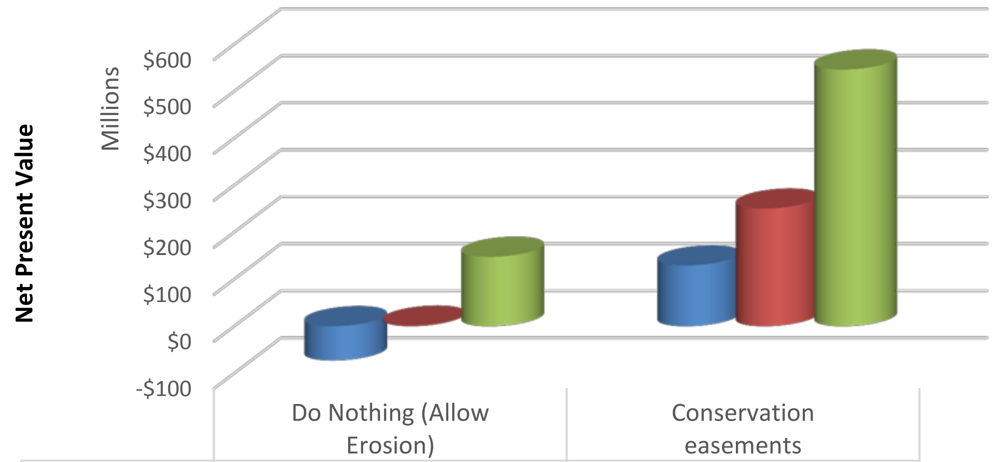


Figure 11: Net Present Value of Shoreline Management Options: Moss Landing (using High sea level rise projection)

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.



	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 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.

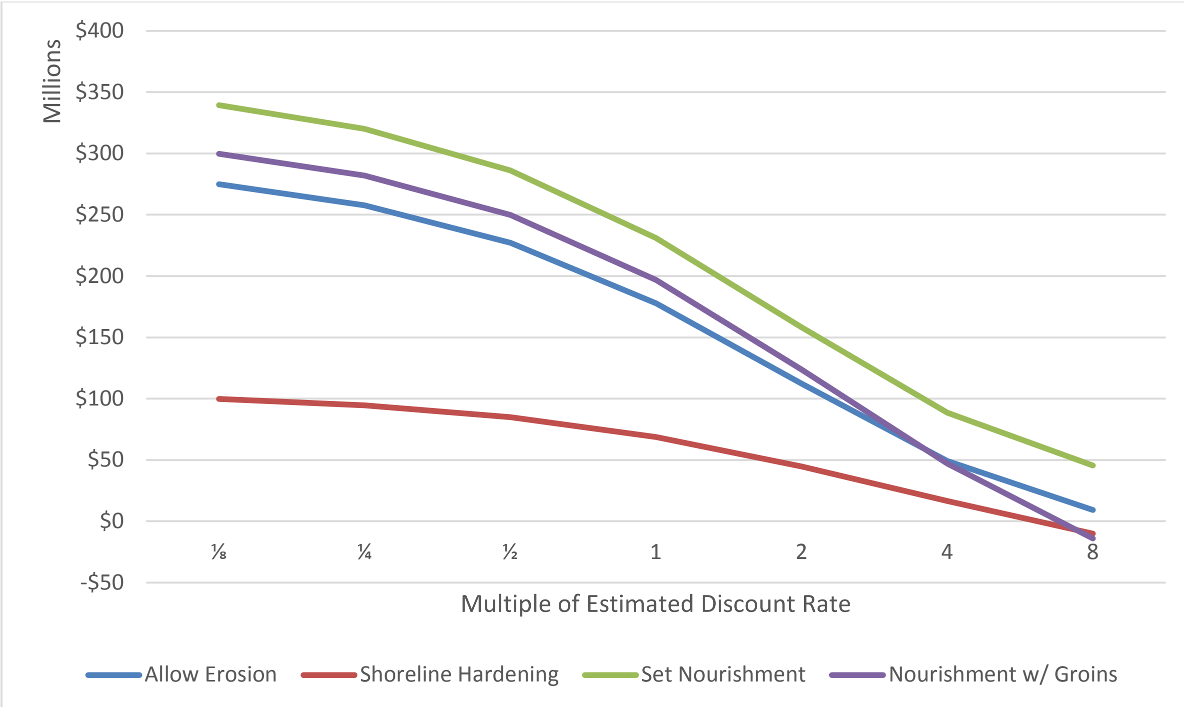


Figure 13: Sensitivity Analysis of discount rate using Net Present Value of Shoreline Management Options: Del Monte

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.**

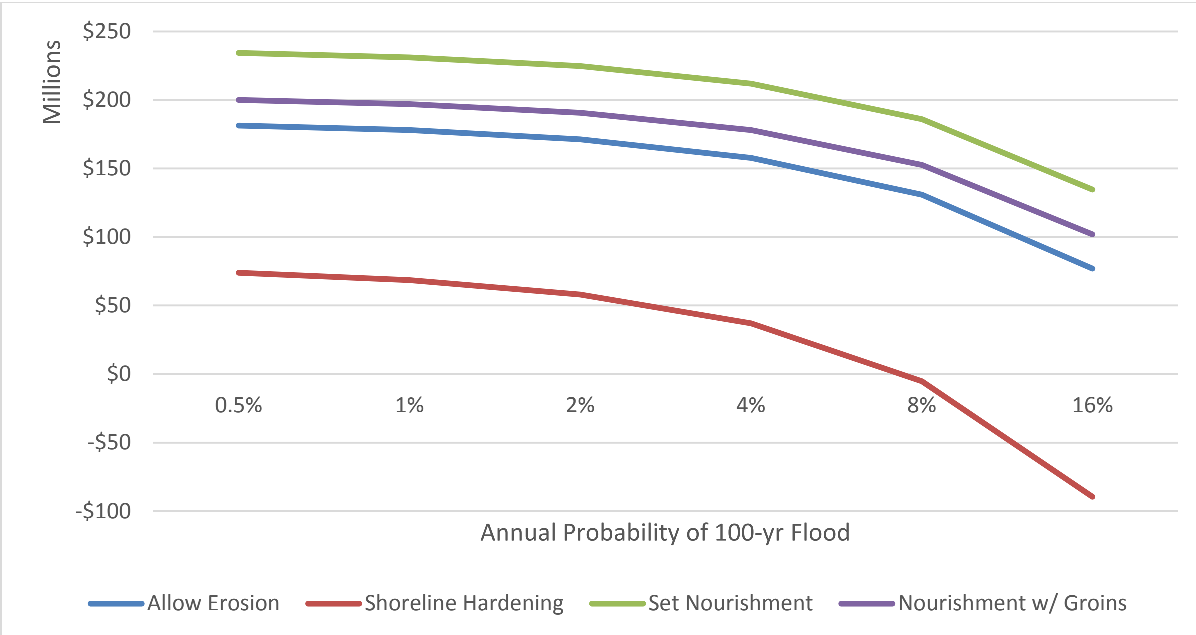


Figure 14: Sensitivity Analysis of 100-year Flood Probability using Net Present Value of Shoreline Management Options: Del Monte

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.

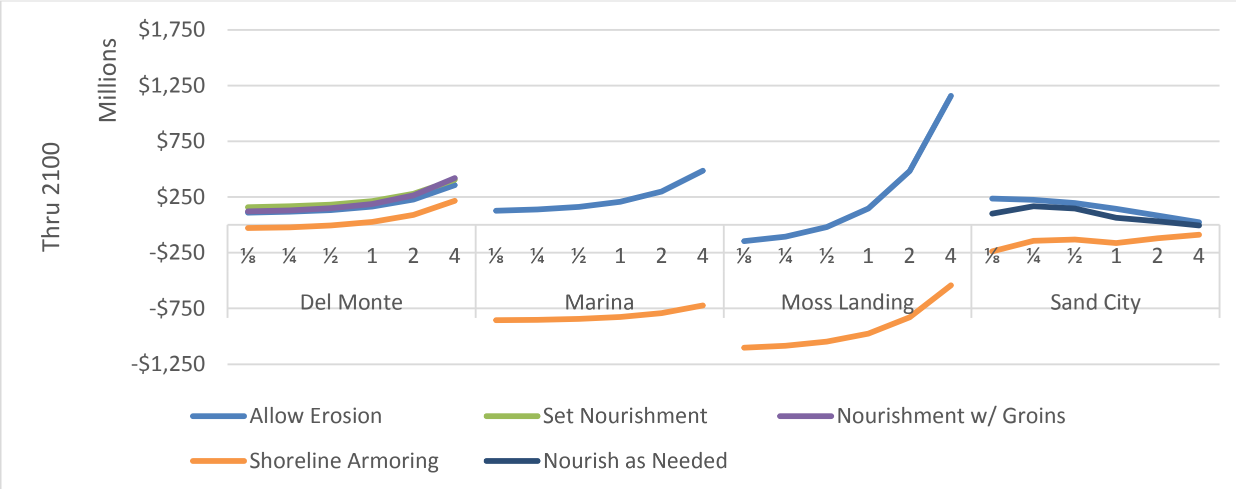


Figure 15: Sensitivity analysis of 3:1 restoration cost assumptions

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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