THE ECONOMIC COSTS OF SEA-LEVEL RISE TO CALIFORNIA BEACH COMMUNITIES

A Paper From:

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PREFACE

Sea-level rise places the California coast at increasing risk to damages in the coming century. Responding to the threats posed by sea-level rise, Governor Arnold Schwarzenegger issued Executive Order S-13-08, mandating the California Resource Agency to head a sea-level rise assessment for the state of California. The four primary elements to be included in the final assessment report follow (Office of the Governor 2008):

1) *Sea-level rise projections for the state of California that evaluate impacts from coastal erosion, tidal events, El Niño and La Niña events, storm surges and land subsidence;*
2) *Assessments on the level of uncertainty for all sea-level rise projections;*
3) *Evaluations of sea-level rise impacts to state infrastructure, landward coastal zones, and coastal and marine ecosystems; and*
4) *Considerations of future mitigation and adaptation strategies that will increase the resiliency of California's coastal zone from sea-level rise.*

Executive Order S-13-08 further mandates state agencies with administrative responsibilities along California's coastline to include site-specific research in their long-range planning efforts.

California's shorelines are ecologically, economically and socially important. Coastal erosion, which is projected to accelerate in the coming century, threatens ecosystem services, reduces shoreline storm buffering capacities, and limits recreational opportunity.

Sections 65 through 67.3 of the Harbors and Navigation authorizes the California Department of Boating and Waterways (DBW) to "study erosion problems; act as shore protection advisor to all agencies of government; and plan, design and construct protective works when funds are provided by he Legislature" (DBW 2010). To provide information on methods to limit future shoreline erosion, DBW continues to dedicate funding for environmental studies, including waves, sea level and related coastal processes, and research on how these processes might be altered by climate change.

More information on the California Department of Boating and Waterways and its past and ongoing research efforts can be found at: www.dbw.ca.gov.

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EXECUTIVE SUMMARY

California's coast faces ever-increasing risks from sea-level rise. In the near future, sea-level rise is expected to exacerbate the impacts of high tides, storm surges and erosion. In the more distant future, sea-level rise could permanently inundate some coastal areas. Sea-level rise will result in valuable infrastructure, ecosystems and recreational areas facing increased risk. Policymakers and coastal administrators will be charged with making critical mitigation and adaptation decisions (e.g., armor the coast, nourish shorelines, abandon and/or relocate infrastructure) to limit the impacts of sea-level rise; the cost of adaptation, while expensive, may be less costly than responding after the fact.

Previous studies estimating the economic losses from sea-level rise have been primarily "macro" in form—relying on highly aggregated data sets and methods for evaluating damages over large spatial scales (e.g., county, state). Additionally, existing studies primarily evaluate future impacts on a singular temporal scale (e.g., damages in 2100). While macro-scale damage assessments provide valuable information for regional, state and national policymakers, such studies generally fail to provide local jurisdictions with a clear understanding of the site-specific risks posed to their constituencies. Further, since most scientific studies emphasize the highly site-specific nature of climate change and sea-level rise, developing methodologies to estimate economic damages at the community level is imperative; decisions on how to manage the shoreline may be made at the parcel level (e.g., the seawall at Ocean Harbor House in Monterey).

We believe that the methodologies outlined in this study can help local communities make first-order evaluations of the economic impacts of sea-level rise. In particular, we estimated the economic costs of sea-level rise on a more disaggregated, "micro" level, including assessments, where applicable, at the parcel scale. We employ methods that are scalable and reproducible with secondary data inputs.

We evaluate sea-level rise impacts to five representative sites on the California coast: Ocean Beach, San Francisco; Carpinteria City and State Beach, Carpinteria; Zuma and Broad Beach, Malibu; Venice Beach, Los Angeles; and Torrey Pines City and State Beach, San Diego. Sea-level rise scenarios of 1.0 m, 1.4 m, and 2.0 m by 2100[1] are modeled to estimate economic losses/reductions in the following categories:[2]

[1] The State of California Sea Level Rise Interim Guidance Document (CO-CAT 2010) endorses a range of sea-level rise scenarios, including 1.0 and 1.4 m by 2100, to encourage uniformity in interagency coordination. In light of this guidance document and conversations with coastal scientists, we adopt these official low and high scenarios, as well as a 2.0 m sea-level rise scenario to comparatively examine potential sea-level effects from catastrophic ice melting and other upper-bound effects.

[2] We do not model permanent inundation to coastal land following a rise in sea level. Beyond wetlands where data limitations prevented us from modeling damages, our sites were immune from permanent inundation under the modeling scenarios. Yet, many areas of California, highlighted by the San Francisco Bay, are at risk to permanent

- **Temporary flooding from a 100-year coastal storm**:
    - Structures and contents
- **Sandy beach erosion from the berm to the backbeach**:
    - Recreation value, habitat value, beach-related spending and tax revenue
- **Upland erosion landward from the backbeach (where cliffs or dunes are present)**:
    - Land, structures and transportation infrastructure

Previous studies generally evaluate damages at a larger scale (e.g., census block, county level), make use of generalized building inventories, and estimate damages for assets intersecting a hazard zone at full replacement value. Imprecise valuation methods can result in significant over- or underestimation of damages, depending on the location and concentration of assets at risk of flooding and/or erosion. For example, if the most valuable infrastructure within a census block is concentrated near the coast, use of a census block average property value could underestimate flood damages. Conversely, if the coast is fronted by parkland or other open space, use of a census block average could overestimate damages.

In this study, we outline methods to estimate sea-level rise impacts at a finer scale; where feasible, damages are evaluated on a parcel-by-parcel basis. To more closely reflect the types of assets at risk, parcel-specific characteristics are used. Since legislation like Proposition 13 limits the reassessment of real property in California, we provide estimates of the actual market value for structures and land at risk. Further, we introduce multiple damage functions to determine if assets' values are at partial or full risk.

To simplify the analysis, our socioeconomic projections assume current (2010) population, real prices and incomes. Since population and income are likely to grow, our estimates should be considered lower-bound (conservative) estimates. Modeling future coastal hazards with existing socioeconomic conditions provides a baseline damage inventory that can allow local policymakers to identify community aspects (e.g., recreation, habitat, residential, commercial and industrial facilities, transportation infrastructure) vulnerable to climate change impacts and areas of adaptive capacity.

Since planning for sea-level rise requires a comprehensive assessment of potential damages, we include sea-level rise impacts to sandy beach recreation value, habitat value, and beach tourism-related spending. These damages are more indirect than losses to upland structures and land, yet are also vital to understanding the true economic impact of sea-level rise. Most of California's coastal economies depend on beach visitation; economic losses from sandy beach erosion reverberate throughout these communities in the form of diminished recreation value

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inundation from a rise in sea level in the coming century. Future studies should account for permanent coastal inundation where relevant.

to beachgoers, lower attendance, lost spending, forgone tax revenue, and diminished ecological value.

The tables below present sea-level rise impacts (in 2010 dollars) to a 100-year coastal flood, upland erosion and beach erosion[3]. Modeling a baseline scenario allows evaluation of the incremental damages caused by sea-level rise. For example, Ocean Beach flood damages are $6.5 million in the baseline scenario (absent sea-level rise), and $19.6 million in 2100 after a 1.4 m sea-level rise, thereby resulting in $13.1 million in damages directly from sea level effects.

Table E1: 100-Year Coastal Flood Impacts

100-Year Coastal Flood Impacts (millions of dollars)

Scenario	Baseline	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2000	2050	2100	2050	2100	2050	2100
Ocean Beach	6.5	9.1	14.6	9.8	19.6	11.4	36.4
Carpinteria	1.5	2.4	6.9	4.0	10.7	4.6	19.5
Zuma	12.6	17.1	24.6	18.2	28.5	20.8	37.1
Venice	7.0	12.6	31.6	15.1	51.6	19.4	96.2
Torrey Pines	3.0	3.4	3.9	3.4	5.0	3.7	6.7

Note: Damages (in millions of 2010 dollars) from a 100-year coastal flood in year 2000 followed by three respective sea-level rise scenarios (1.0 m, 1.4 m, and 2.0 m by 2100) in 2050 and 2100.

Table E2: Upland Erosion Impacts

Upland Erosion Impacts (millions of dollars)

Scenario	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise	
	2050	2100	2050	2100
Ocean Beach	49.5	177.1	99.5	540.3
Carpinteria	0.1	0.3	0.1	0.3
Torrey Pines	4.0	338.9	4.0	353.3

Note: Damages (in millions of 2010 dollars) from upland erosion (landward from the backbeach) under two sea-level rise scenarios (1.0 m and 1.4 m by 2100) in 2050 and 2100. To avoid inconsistencies, the more extreme 2.0 m sea-level rise scenario was not modeled at all sites. These results do not net out the potential impacts from historical erosion projected overtime.

[3] Upland erosion damages are not presented at each site due to varying backbeach profiles. See Section 5.0 for accumulated beach erosion damages (in present value dollars 2050 and 2100), accumulated nourishment costs (in present value dollars 2050 and 2100) and mitigation costs for armoring (in constant 2010 dollars).

Table E3: Annual Beach Benefits: 2000, 2050, and 2100

Annual Beach Benefits: 1.4m Sea-Level Rise				(millions of dollars)
Site	**Category**	**Year 2000 Value**	**Year 2050 Value**	**Year 2100 Value**
Ocean Beach	**% Beach Area**	**100%**	**69%**	**7%**
	Recreational Value	3.4	2.6	0.00
	Habitat Value	0.09	0.06	0.01
	Spending	22.3	18.4	0.00
	Tax Revenue	1.7	1.4	0.00
Carpinteria	**% Beach Area**	**100%**	**85%**	**65%**
	Recreational Value	15.7	14.0	10.0
	Habitat Value	0.06	0.05	0.03
	Spending	114.0	105.3	81.7
	Tax Revenue	9.7	9.0	6.9
Zuma	**% Beach Area**	**100%**	**89%**	**67%**
	Recreational Value	71.0	65.4	52.7
	Habitat Value	0.10	0.09	0.07
	Spending	390.6	369.0	315.0
	Tax Revenue	29.3	27.7	23.6
Venice	**% Beach Area**	**100%**	**95%**	**83%**
	Recreational Value	78.2	76.1	71.4
	Habitat Value	0.33	0.31	0.28
	Spending	884.5	860.9	808.0
	Tax Revenue	66.3	64.6	60.6
Torrey Pines	**% Beach Area**	**100%**	**75%**	**23%**
	Recreational Value	5.6	4.6	1.3
	Habitat Value	0.01	0.01	0.00
	Spending	35.5	30.6	10.6
	Tax Revenue	2.7	2.3	0.8

Note: Annual snapshots of economic value (in millions of 2010 dollars) of recreation, habitat, beach-related spending and tax revenue in 2000, 2050, and 2100 under a sea-level rise scenario of 1.4 m by 2100. As sea level rises and beaches erode more rapidly, the annual economic benefits of each beach face reductions. Results represent a hold the line strategy where the backbeach is fixed.

This study has its limitations. While we are confident that our methods result in more comprehensive damage estimates than prior first order studies, the accuracy of these estimates depends upon the geophysical assumptions and models applied. All three of the sea-level rise parameters used in this study are subject to significant uncertainty. Similarly, existing geophysical and geomorphological models for 100-year coastal floods, sandy beach erosion and upland erosion are based on limited response data and also subject to uncertainty.

However, while the economic damages presented in this report are contingent upon the geophysical scenarios/models, we have developed an adaptable framework that allows damages to be re-assessed as more and better geophysical information is obtained and modeled for use in spatial formats.

The 2.0 m scenario used in this study is considered a maximum rate of change, and has not been adopted officially by the State of California. While the current consensus is that a 2.0 m sea-level rise is unlikely by 2100, mean sea level will continue to rise beyond 2100, a reality that policymakers and planners should consider when making land use decisions that have long-term implications.

In this report, we do not implicitly or explicitly recommend the implementation of particular coastal adaptation response strategies. The site-specific consequences, positive and negative, of these strategies vary too greatly on a case-by-case basis for a study of this scope to sufficiently address. Rather, these results indicate the scale and nature of the economic risks that coastal California communities will face in the coming century and beyond, and highlight the economic aspects of coastal adaptation options. For example, a seawall can protect property from periodic storm flooding, but unarmored, nourished sandy beaches can raise recreation value, bolstering tourism and beach economies. Appropriate responses vary on a site-specific basis, but serious consideration of sea-level rise is essential to all short- and long-term coastal planning in California.

The economic risks in this report, presented conservatively, demonstrate the scale and importance of sea-level rise impacts in a local planning context. Unlike many engineering feasibility studies (e.g., those conducted by the US Army Corps of Engineers) our methodology, by using a variety of publicly available sources, provides a relatively low-cost way to help policymakers and managers consider potential local threats and identify where additional, engineering-scale studies should be conducted. We believe continued collaboration between economists, scientists, and policymakers will allow for informed decisions regarding the management, health, and sustainability of both our natural coast and our coastal economies.

Keywords: Climate change, sea-level rise, 100-year coastal flood, erosion, El Niño, adaptation, beach nourishment, seawalls, recreation.

1.0 Introduction

Past studies of sea-level rise have focused on macro-scale analyses, aggregating economic damages for large regions. These studies generally incorporate first-order assessment techniques that forfeit precision by incorporating generalized rather than detailed data inputs. Macro-scale planning studies are valuable to federal and state policymakers since they provide aggregate estimates of the amount and type of damages that may occur. However, these studies fail to provide local jurisdictions with a clear understanding of the site-specific risks posed to their constituencies.

Providing localized and disaggregated information on the potential economic costs of sea-level rise is a time-consuming and costly exercise. Agencies like the United States Army Corps of Engineers (USACE) conduct micro-level shoreline hazard assessments. Such assessments, generally known as feasibility studies, often take years to complete and can cost millions of dollars. Feasibility studies can provide valuable, site-specific information concerning the costs and benefits of shoreline risk management techniques. Yet, given limited public expenditures to fund these detailed studies, many coastal communities lack the information they need to start formulating climate adaptation plans. Further, it was not until recently that agencies like the USACE introduced sea-level rise impacts into their shoreline hazard assessments, limiting the application of prior localized studies that failed to account for projected climate change impacts. Similarly, the Federal Emergency Management Agency (FEMA) has just begun to address the limitations of their existing flood insurance maps, which do not account for the impacts of sea-level rise (Board on Earth Sciences and Resources 2007).

Given the scientific consensus on climate change and associated sea-level rise impacts, coastal communities must be actively formulating adaptation plans that can frame the need for more detailed risk management studies. Planning for sea-level rise is a highly site-specific exercise. Community-by-community variations in geography and land use present disparities in the potential type and amount of damages, and differing adaptation strategies will be needed to prepare for a rapidly changing climate.

This study models a range of sea-level rise scenarios for years 2050 and 2100 and imposes potential impacts upon year 2010 socioeconomic conditions. Modeling efforts are directed at uncovering the economic costs of sea-level rise on a) a 100-year coastal flood; b) sandy beach erosion; and c) upland bluff/cliff erosion. In particular, this study evaluates the incremental economic losses from these phenomena at five California coastal communities. To complement our economic damage assessment, we provide baseline estimates for adaptation strategies (e.g., beach nourishment, seawalls) at our study sites.

We believe the methods used in this study are feasible, comprehensive and scalable. While our streamlined approach may forfeit some level of precision and accuracy, given the uncertainty over climate change, we believe our methodology, properly applied, can provide reasonable baseline estimates of the potential economic damages attributable to a rise in sea level in the coming century. These estimates can be used to identify where full-level feasibility studies are needed. Indeed, with further study and additional resources, these techniques could be refined further.

2.0 Background

2.1. Climate Change

There is a wide consensus among scientists that climate change—long-term changes in regional and global weather patterns due to the net warming of the earth's surface—is unequivocal and substantially influenced by human activity (IPCC 2007). The effects of a warming climate, detailed in many reports, for example the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007), are wide reaching, and consideration of these effects is increasingly pertinent to long-term planning efforts.

Greenhouse gases (GHG) trap infrared radiation (heat) in the earth's atmosphere, and existing climate data makes clear the relationship between GHG concentrations and increasing global surface temperature (IPCC 2007). Anthropogenic emissions of carbon dioxide (CO_2), largely from fossil fuel combustion and large-scale deforestation, have increased global CO_2 concentrations to nearly 390 parts per million (ppm), 40 percent higher than pre-industrial revolution levels (Tans 2010; Tans 2008).

Figure 1: Historical atmospheric CO_2 concentrations (ppm), 1700-2000
Source: Tans 2008
Note: Green dots are data acquired from Siple ice core samples. The pink and blue lines are observed data from the South Pole and Mauna Loa, respectively.

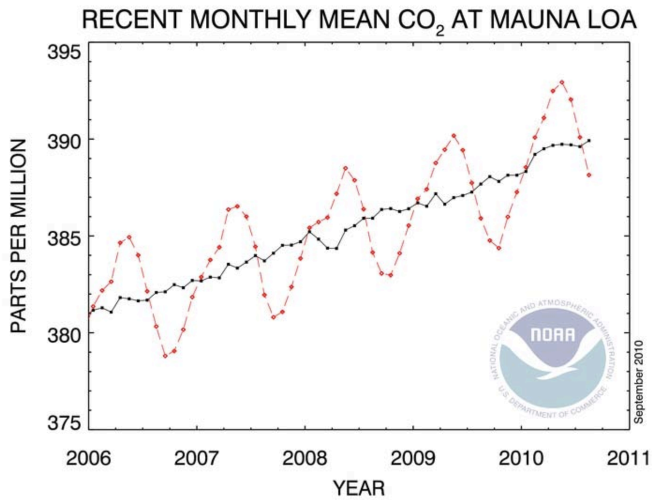

Figure 2. Monthly mean CO_2 concentrations at Mauna Loa: Jan. 2006 - Sep. 2010
Source: Tans 2010
Note: This figure exhibits an approximate CO_2 increase of 2ppm. The dashed red line (larger variance) with diamond symbols represents the monthly mean values, centered on the middle of each month. The black line with the square symbols represents the same, after correction for the average seasonal cycle.

The future of GHG emissions, and thereby the severity of climate change, depends on many variables. The IPCC considers a range of possible emissions scenarios to predict climate impacts over the 21st century. The six GHG emissions storylines illustrated in Figure 3 represent differing assumptions about the demographic, social, economic, technological, environmental, and policy future (IPCC 2007).

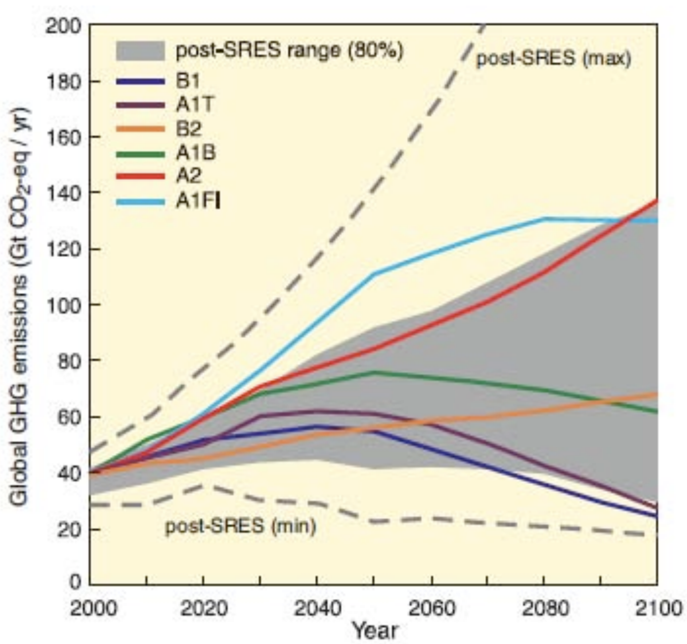

Figure 3. IPCC GHG emissions storylines from 2000 to 2100
Source: IPCC 2007

2.2. Sea-Level Rise

The absorbed infrared radiation from increasing atmospheric GHG concentrations in turn increases oceanic temperatures, causing thermal expansion of the world's oceans (Lombard et al. 2005). The thermally increased volume of the oceans raises mean sea level worldwide. Additionally, higher temperatures increase glacial melting in high latitude regions, further contributing to ocean volume and sea-level rise. The relationship between GHG emissions and sea level led the IPCC to develop sea-level rise scenarios that correspond with each of the six emissions storylines (IPCC 2007). The IPCC sea-level rise scenarios are outlined in Table 1, predicting sea-level rise between 0.18 and 0.59 m by year 2100.

Table 1. Projected global average warming and sea-level rise (meters) by 2100

Case	Temperature change[a]		Sea level rise[b, c]
	Best estimate	Likely range	Model-based range
Year 2000[d]	0.6	0.3 - 0.9	Not available
B1	1.8	1.1 - 2.9	0.18 - 0.38
A1T	2.4	1.4 - 3.8	0.20 - 0.45
B2	2.4	1.4 - 3.8	0.20 - 0.43
A1B	2.8	1.7 - 4.4	0.21 - 0.48
A2	3.4	2.0 - 5.4	0.23 - 0.51
A1F1	4.0	2.4 - 6.4	0.26 - 0.59

Source: Adapted from IPCC 2007 [a,b,c,d]

IPCC reports, while largely considered the principle authority on climate change impacts, have received criticism for failing to include essential inputs (e.g., ice-melt contributions) to sea-level rise predictions. IPCC reports represent consensus findings of a large body of scientists, and understandably present rather conservative figures, omitting more extreme or dissenting viewpoints. More recent and specific reports estimate significantly higher sea-level rise.

Factoring in observational ice-melt data from the Greenland and Antarctic ice sheets—unaccounted for by the IPCC due to data uncertainty at that time—and addressing uncertainties in the linearity of the relationship between temperature and sea level, Rahmstorf et al. (2007) projected a range of eustatic (global mean) sea-level rise scenarios ranging between 0.5 and 1.4 meters by 2100. Cayan et al. (2008) utilized the Rahmstorf method to develop sea-level rise projections specific to the California coast, accounting not only for ice melt scenarios but also water stored in dams and reservoirs. Cayan et al. (2008) predict mean sea level in California to rise between 1.0 m and 1.4 m by 2100.

[a,] °C at 2090-2099 relative to 1980-1999

[b] Meters at 2090-2099 relative to 1980-1999

[c] Model-based range excluding rapid changes in ice flow

[d] Constant year 2000 concentrations

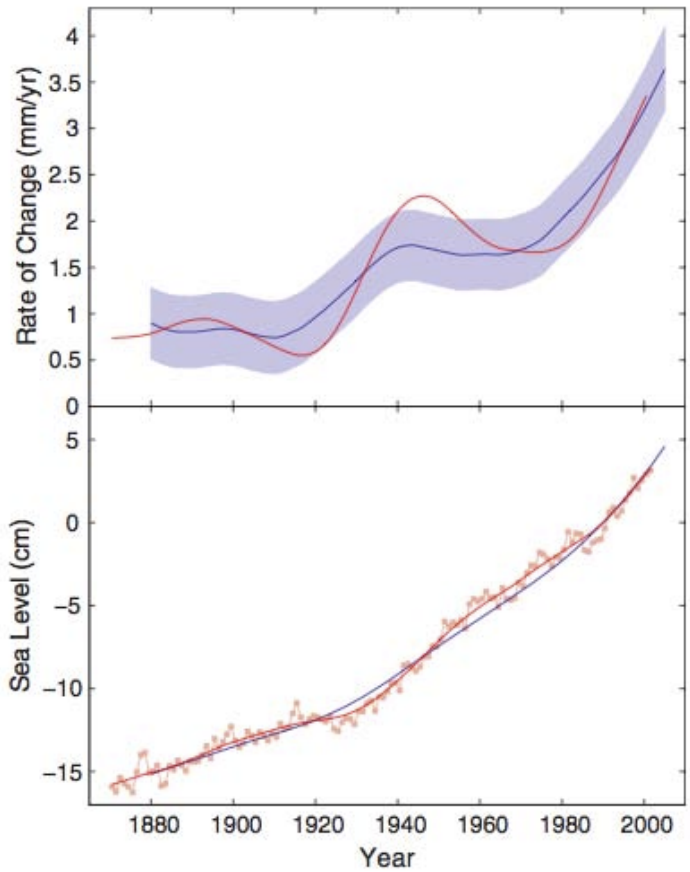

Figure 4. Observed and predicted rate of sea-level rise
Source: Rahmstorf 2007
Note: The top graph illustrates the observed rate of sea-level rise (red) and that forecast using the simple empirical model (blue), trained using data for the period 1880 to 1940. The bottom graph represents observed sea level (red) and that predicted using the empirical model (blue), by integrating the blue curve from the top panel forward in time.

More recently, scientific literature has begun addressing even higher sea-level rise scenarios. Vermeer and Rahmstorf (2009) published an updated study on the relationship between global sea level and global temperature, using global climate model data and accounting for known anthropogenic hydrologic contributions to sea level. For the global temperature scenarios from the IPCC Fourth Assessment report, the relationship projects sea-level rise of up to 1.9 m by 2100 (baseline of 1990). Pfeffer et al. (2008) modeled upper bound ice-melt scenarios, projecting eustatic sea-level rise of 2.0 m by 2100, and have called for sea-level rise studies to include such higher scenarios.

Further, Bromirski et al. (2011) reported that sea-level change along the Pacific Coast of North America has been suppressed since the mid-1970s, when a shift took place in wind patterns. A subsequent shift back to the previous wind regime could cause resumption of sea-level rise along the U.S. West Coast to global or even higher rates.

2.3. Peak Tides, Coastal Storms and ENSO

While sea level itself undoubtedly affects the land-ocean interface, the most significant coastal damages are often witnessed during extreme storms and episodic events, which are projected to occur more frequently under a changing climate. The El Niño-Southern Oscillation (ENSO), a recurring but irregular cycle of shifting ocean and atmospheric conditions, is a key consideration of coastal management and damage projections on the Pacific coast. During El Niño events, higher than normal sea surface temperatures in the equatorial eastern and central Pacific Ocean shift rainfall production eastward, toward the California coast, as well as shifting wave direction southward (Wang 1999). Further, ENSO-related oceanic and atmospheric mechanisms can elevate sea level on the California coast during by as much as a foot for several months (Cayan et al. 2008). Such a raised water level can flood the upper beach, allowing wave runup to attack sea cliffs and inflict damage at high tide (Wang 1999).

Conditions for El Niño are set up irregularly about every 2-7 years, and the ENSO pattern can persist anywhere from 6-18 months (Liu et al. 2000). Californians experienced the most damaging coastal inundation and erosion from El Niño storms in the winter of 1982-83, when large waves coincided with high astronomical tides to cause over $200 million (in 2009 dollars) in damages to California's central coast. Another major El Niño event in 1997-98 caused significant damages, but less than 1982-83 storms (due in part new protective structures and less significant coincidence between peak tides and storm waves). Both these winters exceeded 1984-1995 mean sea surface elevation by more than 25 cm (Storlazzi et al. 2000) (see Figure 5). If sea level projections prove correct over the next century, significant storm damages can be expected to occur more frequently and more severely.

2.4. Coastal Wetlands

Coastal wetlands, such as salt marshes, estuaries, and intertidal areas, are highly sensitive to long-term changes in sea level, as their location is largely determined by sea level. Wetlands provide numerous services such as flood protection, water treatment, recreation, and carbon sequestration, and are vital for maintaining biodiversity and wildlife habitat (Semlitsch et al. 1998).

Historically, wetlands are among the land types most threatened by human development and infringement. Less than half of historical wetlands in the continental United States remain, and in California, more than 90 percent of wetlands have been lost to development (EPA 2001). While protection and restoration efforts for remaining wetlands have increased dramatically in recent times, sea-level rise represents another serious threat.

As sea level rises, vertical accretion of sediment and organic matter may increase, allowing a coastal wetland to grow upwards in place. If the rate of vertical accretion is less than the rate of sea-level rise, however, wetland vegetation is submerged by tidal cycles for progressively longer periods, and may die from waterlogging (Nicholls et al. 1999). If surrounding dry land is sufficiently low-lying and undeveloped, wetlands may migrate landward and maintain critical function. In highly developed coastal areas, however, adjacent dry land is often unsuitable for wetland migration, causing a “squeeze” likely to drown wetland vegetation, resulting in a landscape of bare sediment or open water.

2.5. Beach Erosion and Sand Supply

Beaches protect the coastline from direct wave attack by acting as shock absorbers, and dissipating wave energy. Most beach sand in California comes from river and stream runoff, with a lesser amount contributed from eroding cliffs and bluffs (Griggs et al. 2005; Slagel and Griggs 2008). However, Flick and Ewing (2009) estimate that even little or no net sea-level rise, southern California’s sand supply levels are insufficient to maintain current beach widths everywhere. This deficit is due in part to decreases in natural sand supply from rivers, insufficient and isolated contribution from cliff and terrace erosion, and cessation of large-scale sand contributions from construction projects (Flick and Ewing 2009; Flick 1993). Increased protection of coastal development by shoreline armoring, largely in the form of seawalls and rock revetments, has fixed the backbeach position at many beaches, particularly in southern California. The combined factors of sand supply deficiency, coastal armoring and sea-level rise, cause beaches that would typically migrate landward to become narrowed between the fixed backbeach and the landward movement of the shoreline. Many will eventually disappear, impeding access to and along the coast and exposing the backshore (whether cliffs or development) to increased threats of wave damage and flooding (Flick and Ewing 2009).

2.6. Economic Value of Beaches

Beaches provide a variety of services that have economic value, including recreational value to beachgoers, storm-buffering capacity, and provision of biological and ecological diversity. Since beaches (below the mean high tide line) in California are in the public trust, there is no market price for the land. Thus, it proves somewhat difficult to estimate the value of beaches to society, and economists rely on a variety of techniques to estimate the “non-market value” of beaches. Such non-market values fall into a number of distinct categories, depending upon the type of economic service. Economists have devised an overall framework to group these services. Total economic value is first divided into use value and non-use value, and then subdivided further, as illustrated in Figure 6 below (NOAA Coastal Services Center 2009). Though in theory, non-use values are important, in practice they are difficult to measure and are, for now, largely theoretical constructs.

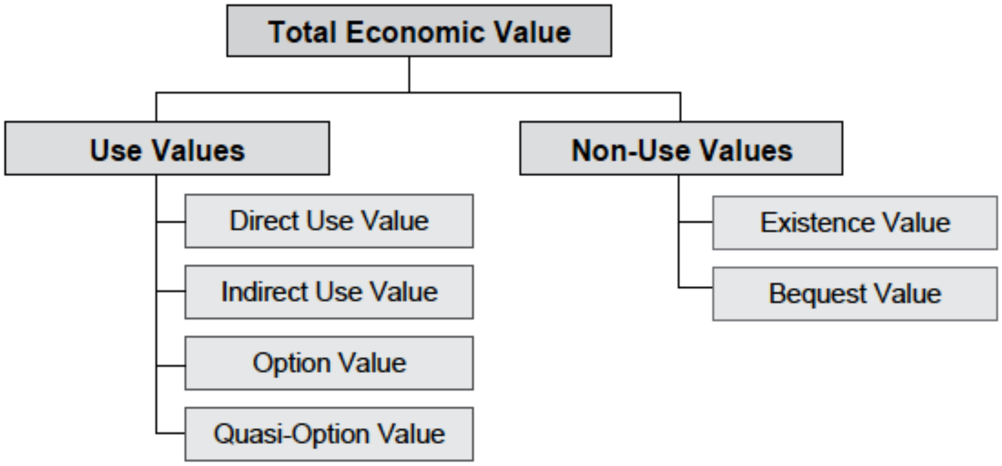

Figure 5. Total economic value of a natural resource

Source: NOAA Coastal Services Center 2009.

A great deal of attention has been paid to estimating the use value of natural resources. As the name implies, direct use value (Figure 6) measures services that flow directly from the resource, for example timber from a forest, or bird watching at a wetland. Indirect use values are more difficult to define and measure, but generally involve ecological services. In practice, the distinction between direct and indirect use values is sometimes arbitrary. Figure 7 illustrates how one might divide the services of a wetland into direct and indirect use value.

USE BENEFITS			**NON-USE BENEFITS**
Direct Use Benefits	**Indirect Use Benefits**	**Option Benefits**	**Existence Benefits**
Recreation	Nutrient Retention	Potential future uses	Biodiversity
* boating	Water Filtration	(as per direct and	
* birding	Flood Control	indirect)	Cultural
* wildlife viewing	Shoreline Protection		
* walking	Groundwater Recharge	Future value of	Heritage
* fishing	External Ecosystem Support	information (e.g.,	
Trapping-Hunting	Micro-Climate Stabilization	pharmaceuticals,	Bequest Value
Commercial Harvests	Erosion Control	education)	
* nuts	Associated Expenditures		
* berries	* travel		
* grains	* guides		
* fish	* gear		
* peat			
* forestry			

Figure 6. Direct and indirect benefits of a wetland

Source: Adapted from Environment Canada - Canadian Wildlife Service, 2001.

For beaches, the most significant economic direct use value is likely to be recreation, though other direct use values may also exist, such as sand mining). Although estimating a concrete value for non-market activities like beach recreation is more challenging than measuring the value of market goods that are bought and sold, there are a number of standardized techniques that can be applied, and general agreement exists among economists (within a reasonable range) of what the appropriate value is for a day at the beach (USACE 2003b; King 2001; Pendleton et al. 2011). Economists consider beach recreation a consumer good, however the State of California provides beaches for free (although some beaches charge a small fee for parking). Consequently, there are no explicit prices that can be used to compute either the value an individual receives from visiting a beach or the total economic benefit (consumer surplus) that accrues to all visitors to that beach (Pendleton et al. 2011).

Economists have developed several techniques for estimating the economic value of a day at the beach. The two most common estimation techniques are:

1. *Stated preference*, where people are asked how much they are willing to pay (in this case, to go to a specific beach for the day); and

2. *Revealed preference*, where economists analyze actual behavior to estimate one's willingness to pay.

Contingent valuation (CV) is the general methodology for estimating stated preferences, and is implemented by conducting surveys. The chief criticism of CV is that people may not state what their actual preferences are, or may misunderstand the question. Further, designing a sophisticated CV study tends to be expensive (Diamond and Hausman 1994).

Revealed preference models vary in sophistication. The simplest models use travel cost (time and expense) to estimate consumers' willingness to pay (WTP). For example, King (2001a; 2001b) finds that a day at the beach at Carpinteria or San Clemente is worth between $30 and $45. A downside of the travel cost method is the difficulty in adequately accounting for substitution—if San Clemente beach were to close (i.e., due to an oil spill) many people would simply go to a different beach. Random Utility Models (RUMs) represent a more sophisticated version of travel cost modeling, analyzing trips to multiple beaches and accounting for such substitution effects. Since most beaches in California have reasonably close substitutes, estimates of WTP from RUMs tend to be lower than simple travel cost methods. A serious weakness of RUMs, however, is that they only account for individual substitutions (e.g., if one person decides to go to Santa Monica rather than Venice Beach). However, should a large beach close, thousands of people will need to make alternative plans, and the capacity of nearby beaches to absorb all of the substitution—in particular, increased parking and traffic congestion—is questionable. Thus, it is possible, even likely, that welfare estimates made with RUMs for such circumstances are too low.

To date, the most comprehensive examination of consumers' valuation of beach visitation was the Southern California Beach Valuation study (Hanemann et al. 2005), which used a RUM to examine beach visitation in Orange and Los Angeles Counties. Their results are consistent with an earlier valuation made for the American Trader case (Chapman and Hanemann 2001), and not inconsistent with the day use valuations employed by the USACE (2004). None of these models, however, consider impacts to valuation stemming from changes in beach width.

Pendleton et al. (2011) estimate welfare benefits of enhanced beach width in a RUM based on data from the southern California beach project (Orange and Los Angeles counties). They find significant welfare benefits from enhanced beach width. Further, they find that water users (e.g., swimmers and surfers) as well as people on the pavement also benefit from increased beach width, though after a point, the marginal benefit of increased beach width diminishes. In a related paper, Pendleton et al. (2010) use the same data set to estimate welfare losses at southern California beaches when beach width decreases due to erosion.

A small number of studies also examine the welfare benefits of increased beach width at beaches on the east coast of the US. Huang and Poor (2004) use stated preference methods to examine the value of protecting against beach loss in the states of Maine and New Hampshire. Although they focus on preserving the status quo rather than changing beaches, they find the public generally dislikes many of the consequences of beach armoring (i.e., building seawalls or sand retention structures such as groins). Landry et al. (2003) examine a Georgia island community, using a hedonic model to quantify benefits to property owners, and stated preference techniques to determine the benefits of beach preservation and enhancement strategies. They find that, in general, people prefer wider beaches and also dislike armoring strategies.

Parsons et al. (2000) used revealed preference data to examine beaches in New Jersey and Delaware, using models that account for familiarity and favorites, and consider three categories of beach width. They find that, in general, people prefer wider beaches, but only up to a point (about 250 feet, or 76 m). Whitehead et al. (2006) use a random effects Poisson model—combining revealed preference and stated preference data—and find that people prefer increased beach width, although width is only examined using the stated preference data.

2.7. Indirect Uses and Ecological Value of Beaches

Although beaches are best known for their recreational value, it is by no means clear that other non-use and ecological values are less important or less valuable—particularly considering the fact that many beaches in California (especially in central and northern California) do not provide the extensive recreational services of, say, Huntington Beach. California's beaches provide habitat for a number of threatened species of flora and fauna such as the Least Tern, Snowy Plover, and Tidewater Goby. Beaches also provide spawning opportunities in the intertidal zone for grunion and other species. Reducing the size of beaches reduces this habitat and potentially reduces biodiversity. Schlacher et al. (2007) find that human activity on beach habitats has already significantly reduced their capacity to provide ecological services.

In addition, beaches provide important storm-buffering services. Wider beaches protect upland public and private property from wave attack, reduce upland erosion, and prevent or limit potential damages to inland habitat such as lagoons and coastal wetlands. Unfortunately, few studies exist about these benefits or how to properly measure them. They must not, however, be completely ignored. One common parameter used in many studies of beaches, wetlands and other natural resources providing ecological and other services is to place a value per hectare (or per acre) and tally the total area of the resource to derive an economic value. This methodology is not without its problems, particularly when examining a change in the area of the resource. Ecosystem services may exhibit diminishing returns, or certain habitats may exhibit threshold effects—whereby reducing habitat below a certain level could lead to species extinction (for further discussion, see Brander et al. 2006).

Costanza et al. (2006) analysed 94 peer-reviewed papers and 6 other studies, while also employing hedonic analysis and spatial modelling to estimate the economic values of seven types of biomes (including beaches) and the cumulative ecosystem services of New Jersey. They estimate that New Jersey's beaches deliver $42,147 per acre per year in economic/ecological services. They further break these benefits down into recreational and aesthetic value ($14,847 per acre per year) and other services ($27,300 per acre per year).

Estimation of the dollar value of the biological/ecological services of beaches is in its infancy, and few studies have been conducted. However, wetland ecological services have been studied, and provide, at the least, a potential range for the ecological value of beaches. Costanza et al. (2006) provides an estimate of the ecological services of saltwater wetlands at $6527 per acre per year.

Brander et al. (2006) conducted the most comprehensive study of wetland valuation to date, examining over 200 studies of the economic value of wetlands. These studies include recreational value, water quality improvements, amenity improvements and habitat/biodiversity value. For our purposes, the biodiversity and habitat value are most important, since beaches do not hold the significance of wetlands in terms of water purification, and since recreational/amenity values are estimated separately using the Coastal Sediment Benefits Analysis Tool (CSBAT) model.

Brander et al. find that the average biodiversity value of a wetland per hectare per year is $17,000 (about $6800 per acre) and habitat value is about $2000 per hectare. They also estimate that wetlands provide $4000 per hectare per year in flood relief, a value that is likely low compared to beaches.

Considering that ecological valuation procedures as a whole are relatively new, our study conservatively adopts a $4000 per hectare ($1619 per acre) figure to encompass the biodiversity, habitat and additional ecosystem service values of beaches at our study sites. This value should be updated in future studies as more and better references become available.

2.8. Economic Sea-Level Rise Studies

Several previous studies have estimated economic potential costs of sea-level rise; many of these have their foundation in the Yohe approach (Yohe 1989; Yohe et al. 1996; Yohe and Schlesinger 1998), a cost-benefit model that weighs the cost of protecting a property (often through armoring) against the property's value at the time of inundation. The Yohe approach holds that property will be protected if the value of property exceeds the cost of protection at the time of inundation, and will be abandoned if protection costs outweigh property value.

While a widely applied method of economic analysis, the Yohe approach relies on a number of restrictive assumptions. First and foremost, the Yohe method only analyzes damages from changes in eustatic (global mean) sea level, ignoring the impacts climate change may have on extreme storm events and erosion. Yohe further assumes that property owners and policy makers have perfect foresight and thus will build protective structures in anticipation of sea-level rise. Finally, Yohe's approach only examines the net social cost of property values, ignoring not only transfer possibilities among property owners, but also various other economic impacts from sea-rise level: i.e., erosion impacts, damaged transportation infrastructure, wetland losses, oil spills and other pollution discharges, as well as various indirect reverberations like transport delays and lost spending and/or tax revenue (Hanemann 2008; Heberger et al. 2009).

In California, the Pacific Institute (PI) conducted an examination of impacts from a one-meter rise in sea level, including an elevated 100-year high tide elevation, on a regional scale (Gleick and Maurer 1990), identifying $48 billion of existing commercial, residential, and industrial structures at risk in the San Francisco Bay. The report addressed construction and maintenance costs for protective measures to safeguard existing high-value development, however did not quantify costs of protecting or restoring marshes, wetlands, or groundwater aquifers.

In 2009, the Pacific Institute partnered with Philip Williams and Associates (PWA) to expand the scope of the 1990 analysis, covering the entire 1100-mile California coast. The 2009 update (Heberger et al. 2009) represents one of the most comprehensive regional planning-level studies to date. Refining methods by using more comprehensive data and modern analytical tools such as Geographic Information Systems (GIS), economic damages from coastal flooding and erosion were estimated under a 1.4-meter sea-level rise in the year 2100. Utilizing FEMA's HAZUS model to estimate flooding damages, the PI report (2009) aggregated value at risk with census block resolution: i.e., if 30 percent of the area of a census block is flooded, it is assumed 30 percent of the property in that block is damaged in the flood. Key findings of the PI report follow: 480,000 people, 350,000 acres of wetlands, and nearly $100 billion (in 2000 dollars) of property at risk in the event of a 100-year coastal storm event following a sea-level rise of 1.4 m. Reinforcing and building new protective structures was estimated at $14 billion, with $1.4 billion per year in maintenance costs.

Our analysis employs many of the methods used in the PI report, however we sought a more precise approach to valuing assets at risk. Where applicable and feasible, we estimate damages on the parcel scale, as opposed to the more broad census block scale used previously.

Additionally, actual building stock is used rather than generalized structure inventories. We also employ the Bruun Rule—a highly criticized approach, yet one without an accessible alternative—to estimate sandy beach erosion and subsequently value several categories of benefits of the beach itself that could be lost to sea-level rise. Further, to guide understanding of the incremental effects of different scenarios, our report adds value by subtracting coastal flood damages in each scenario from damages incurred in a pre-sea-level rise, baseline scenario. By subtracting damages from a baseline 100-year flood, we allow for visualization and assessment of impacts directly linked to each sea-level rise scenario.

3.0 Study Sites

The following coastal areas—representing diverse infrastructure, ecology and recreational opportunities—were selected for this analysis: Ocean Beach, San Francisco; Carpinteria State Beach and City Beach, Carpinteria; Broad Beach and Zuma Beach, Malibu; Venice Beach, Los Angeles; Torrey Pines State Beach, San Diego.[4]

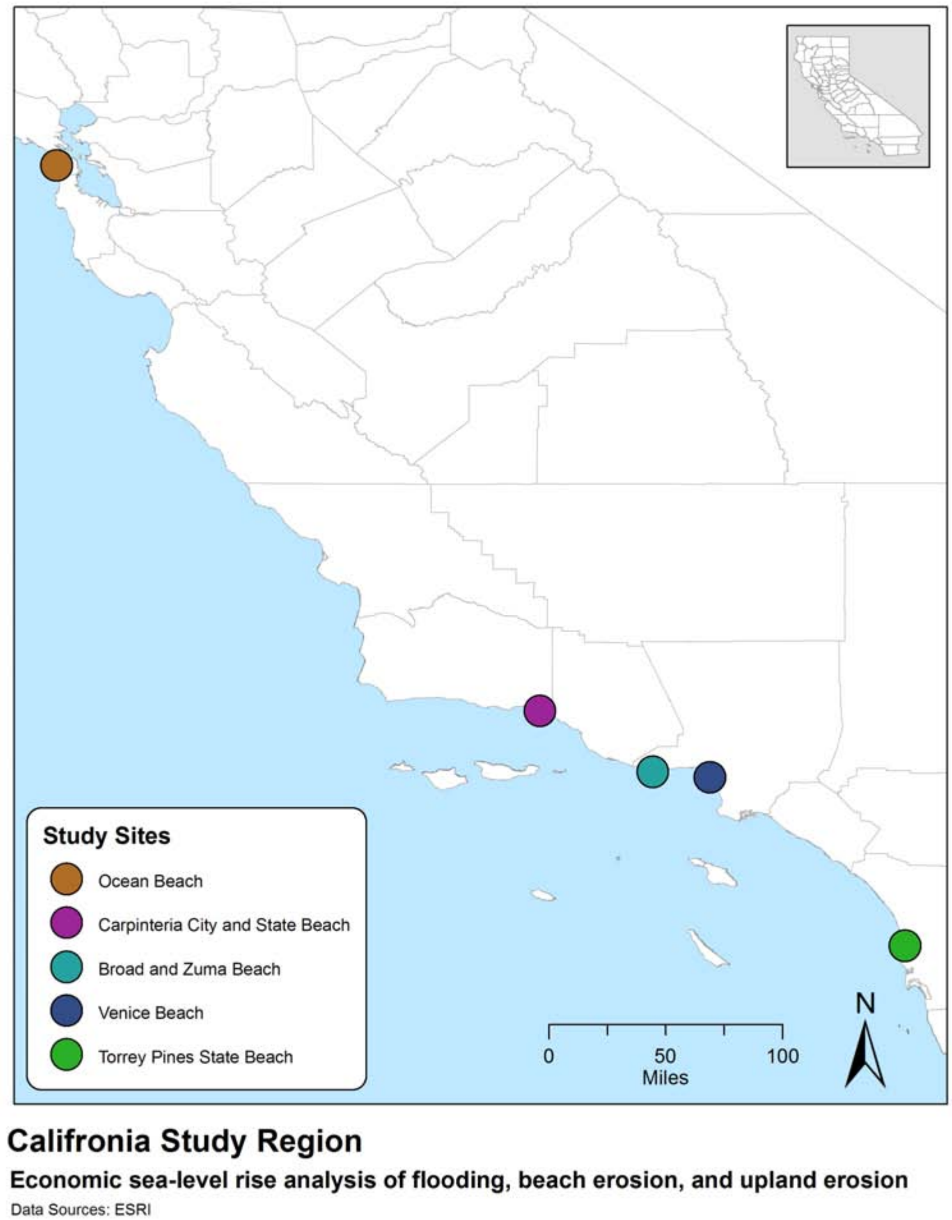

Figure 7. Study sites

[4] We initially modeled sea-level rise impacts to downtown Santa Cruz. Limitation in our coastal flood modeling (e.g., the inability to account for existing levees), data gaps for the Santa Cruz Beach Boardwalk and external consultation led us to exclude those initial results from this publication.

Ocean Beach, San Francisco

Ocean Beach extends four miles from the Cliff House in the north to the San Francisco Zoo in the south. This sandy reach of beach is backed by seawalls, sand dunes and pedestrian walkways. Ocean Beach is a multi-use beach that offers recreational opportunities for walking, sand activities, and surfing, though—like many northern California beaches—swimming and sun-bathing are limited. The air temperature at Ocean Beach is generally cooler than other areas of San Francisco and often windy. Ocean beach is also subject to many foggy days, particularly in the summer. Hazardous rip currents throughout the year, coupled with cold nearshore waters due to upwelling, provide unsafe and unpleasant swimming conditions. However, surfing has become much more popular in recent years, particularly just south of Seal Rock at Ocean Beach's north end and near Sloat Blvd. on the south end.

Ocean beach is easily accessible by car or by public transport and parking is generally available, though the parking lot at Sloat Blvd. has eroded and has a reduced number of spaces. Primarily San Francisco residents frequent the beach. Beach access is provided at parking lot staircases, pedestrian walkway outlets and multi-purpose paths. Directly upland of Ocean Beach is the Great Highway. Residential homes and the western end of Golden Gate Park are found landward of the Great Highway. We did not model damages south of Sloat Blvd.

Ocean Beach also provides habitat for a number of shorebirds including the Killdeer, Black-Bellied Plover, and the Sanderling. At a couple of places, the beach also provides habitat for the threatened Snowy Plover. The dunes behind portions of Ocean Beach also provide habitat for many sensitive plant species.

Carpinteria City Beach and Carpinteria State Beach, Carpinteria

Carpinteria City Beach extends one quarter-mile from the Carpinteria Salt Marsh in the north to Linden Avenue, the City's main downtown street, in the south. Condominiums and motels back this sandy reach of beach. Beach access is provided at a small parking lot at the western end of Linden Avenue or by pedestrian footpaths along the reach of the beach.

Carpinteria State Beach extends one mile from Linden Avenue in the north to Tar Pit Park in the south. The state camping parking lot backs the beach in the north. Small dunes back the beach in the south. A park and state-operated camping facilities are found slightly upland. The beach can be accessed at the Linden Avenue parking lot and State Park parking lot.

Generally weak wave activity makes these Carpinteria beaches some of the safest along the coast, and they are thereby popular with families. Recreational opportunities exist for both water and sand activities. Surfing is restricted to the southern end of the State beach.

The Carpinteria Salt Marsh, also know as the Ash Avenue Wetland, lies to the north of Carpinteria City Beach. This 230-acre reserve, bordered by homes, agriculture, nurseries, the railroad and Highway 101, hosts wetlands and sub-tidal habitats that support a diverse range of sensitive plant and animal species. In the last century, Carpinteria's Salt Marsh habitat has been altered due to human intervention. To address the vulnerable state of the marshland the Land Trust for Santa Barbra County, California Coastal Conservancy, City of Carpinteria, University of

California Natural Reserve System, County Flood Control District and Sandyland Homeowners Association purchased a majority of the marshland to protect and enhance the plants and wildlife that are found in the area.

Zuma Beach and Broad Beach, Malibu

Zuma Beach extends one and one-half miles from Broad Beach in the west to Westward Beach in the east. A large fee parking lot and Highway One back this wide sandy beach. Landward of Highway One is a steep hillside (the old seacliff) scattered with large residential lots. Zuma Beach is consistently one of the most popular beaches in southern California, touted for its clean water quality, good surf, and marine life sightings. Beach access is provided via fee parking lots or on-street parking along Highway One.

The Zuma Wetlands, a small freshwater marsh and creek, is found at the eastern end of Zuma Beach. These wetlands act as a wildlife corridor and nesting habitat for birds and small mammals. Past dumping of construction debris had a significant impact on the wetlands; The Santa Monica Bay Restoration Foundation, the National Park Service, and the Los Angeles County Department of Beaches and Harbors initiated a restoration plan to excavate construction fill, restore upland habitats, remove exotic plants and restore native plants in the late 1990s.

Broad Beach, Malibu, directly west of Zuma Beach, is a one-mile stretch of narrow sandy beach. This reach of shoreline has recently garnered public attention. Referred to as a “private beach with two public access points,” Broad Beach is backed by large, very expensive, single-family homes, many occupied by celebrities. These homes, which have been threatened by storm erosion, were granted an emergency permit by the California Coastal Commission (CCC) in January 2010 to build an 8-foot seawall extending 4,100 ft along the shoreline, estimated at $4 million. The seawall, which was paid for by at risk homeowners, is intended to be a short-term solution to a proposed long-term nourishment project designed to restore the beach to its original 100 ft width (Pool 2010). Public controversy continues over the potential erosion impacts of the seawall and continued delay for the two public access pathways to be reopened (seawall construction was completed in June 2010, and was yet to be reopened in November 2010).

Venice Beach, Los Angeles

Venice Beach extends two and one-half miles from the City of Santa Monica in the north to the Marina Del Rey channel in the south. A promenade and boardwalk backs the beach in the northern reach, while the southern reach is backed by residential development. A mix of residential and commercial infrastructure is hosted further upland. Venice Beach is one of the most iconic beaches in the country. The wide sandy beach provides a diverse range of sand and water recreational activities and unique sightseeing opportunities. The quarter-mile fishing pier, the Venice Breakwater, and an artificial reef provide above-average surfing conditions. Venice also provides less common beach recreation opportunities like a skate park, outdoor gymnasium, tennis and handball facilities and basketball courts.

The Venice pier closed in 1983 due to El Niño storm damage. It was not reopened until the mid-1990s. Again, in 2005, the pier experienced significant storm damage, resulting in a section of the pier falling into the ocean. The pier was not reopened until mid-2006 when engineers concluded that the pier was structurally sound. Venice Beach can be accessed by a number of fee parking lots and adjacent street access pathways.

Torrey Pines State Beach, San Diego

Torrey Pines State Beach stretches four and one-half miles from Del Mar Beach in the north to Blacks Beach in the south. Steep sandstone bluffs back a majority of this narrow sandy beach. Torrey Pines State Beach provides both sand and water recreational opportunities. High tides can swallow this narrow beach, leaving only wet sand to beachgoers. Beach patrons can access the sand by a fee parking lot or on-street parking.

The Los Peñasquitos Lagoon, which covers over 870 acres and hosts a diverse range of animal and plant species, divides Torrey Pines State Beach. This channel was once a bay; over time, sediment filled the bay, resulting in the existing lagoon. A single-track railway and Highway One intersect the lagoon, which has historically restricted the drainage capacity and the natural tidal ebb and flow to the lagoon. Responding to the vulnerable state of the lagoon, the Los Peñasquitos Lagoon Enhancement program was initiated in the early 1980s. Collaboration between the California Coastal Commission (CCC), the Coastal Conservancy and the Los Peñasquitos Lagoon Foundation resulted in Los Peñasquitos Lagoon becoming a State Preserve. In the recent decades, a new bridge has been constructed over the lagoon to enhance the transfer of both sediment from the lagoon to the ocean and the tidal currents. Further, pumping stations have been redeveloped to prevent the future discharge of effluents into the lagoon.

4.0 Methods

Coastal hazards are a fact of life. The most commonly assessed hazards, low-probability storm events and erosion, have shaped the worlds coastlines prior to the recent acceleration of sea-level rise. Sea-level rise is expected to increase the frequency and amplitude of flooding, and accelerate beach erosion processes, among other effects. This study seeks to address and, when possible, quantify the relationship between sea level rise and the aforementioned coastal hazards.

Most planning-level studies provide an overview of changes in coastal hazard risk from a single sea-level rise scenario at one point in time. Estimates paint a picture of potential damages in the year 2100, yet do not allow for a comparative evaluation of potential losses for a range of sea-level rise scenarios. Given the uncertainty in future sea-level rise, we model a range of scenarios (1.0 m, 1.4 m and 2.0 m rise from 2000 to 2100) in years 2050 and 2100, and quantify expected losses with existing 2010 socioeconomic baselines.

From a policy standpoint, comparing the economic losses for a range of scenarios at different points in time can provide information to weigh the costs and benefits of adaptation methods (such as erecting a seawall, nourishing the beach, or allowing the sea to migrate landward unimpeded). Multi-scenario assessments can provide planners and policymakers information to make reasoned, effective and timely adaptation decisions that will balance recreational and ecosystem services while safeguarding valuable infrastructure.

In this study, we adopt the following three sea-level rise scenarios: 1.0 m by 2100 (Cayan B1), 1.4 m by 2100 (Cayan A2), and 2.0 m by 2100 (Pfeffer). These scenarios are illustrated in Table 2. Intermediate (year 2050) sea-level rise estimations are adopted directly from Cayan et al. (2008) for the low and medium scenarios, and calculated for the high scenario by an NRC quadratic approximation function (USACE 2009):

$$\Delta E = E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + b(t_2^2 - t_1^2)$$

$E(t)$ = mean sea level at year t
t_1 = starting date – 1986
t_2 = future date – 1986
b is a linear coefficient

Table 2. Adopted sea level rise scenarios (meters), 2000-2100

Year	Cayan B1	Cayan A2	Pfeffer
2000	0.00	0.00	0.00
2025	0.15	0.18	0.23
2050	0.36	0.45	0.64
2075	0.63	0.84	1.23
2100	1.00	1.40	2.00

Note: Cayan B1 and A2 year-2100 approximations were rounded to 1.0 m and 1.4 m, respectively.

This report quantifies sea-level rise damages in three distinct categories, each of which require varied geographical and valuation analyses:

- **Temporary flooding from a 100-year coastal storm**:
  - Structures and contents
- **Sandy beach erosion from the berm to the backbeach**:
  - Recreation value, habitat value, beach-related spending and tax revenue
- **Upland erosion landward from the backbeach (where cliffs or dunes are present):**
  - Land, structures and transportation infrastructure

For upland losses, we estimate damages for each parcel intersecting a 100-year coastal flood and/or erosion hazard zone. For beach losses, we limit our analysis to passive impacts from a fixed backbeach, which is assumed to uniformly affect the entire reach at each study site.

4.1. Upland Damage Assessment

Valuing upland damages from a 100-year coastal flood and/or erosion processes following a rise in sea level is a multi-step processes that incorporates hazard modeling, land use data collection, valuation of at-risk assets and the estimation of respective asset damages.

4.1.1. 100-Year Coastal Flood Modeling

Many sea-level rise studies model changes to average conditions (i.e., the coastal impacts of a gradual rise in mean sea level). However, larger economic impacts, especially in the near future, will likely come from sea-level effects on extreme events, such as the coincidence of peak tides and wave storms. Our flood impact assessment examines the potential impacts of sea-level rise on a 100-year coastal flood; a parameter often used in shoreline hazard assessments. Similarly to Heberger et al. (2009), we model sea-level-associated increases to (year 2000) 100-year coastal base flood elevations.

The risk of a storm event in this context is often calculated by applying basic probability theory. In the simplest models, storms are viewed as a random event where the probability of a flood occurring in any given year is independent of prior conditions. For the purpose of this analysis, a 100-year coastal flood event, which has a one percent probability of occurring in any given year, was modeled in combination with adopted sea-level rise scenarios. It is important to recognize that a 100-year event can represent a joint probability. For example, a 100-year coastal flood could represent either a combined 10-year tide and 10-year wave event, or a one-year tide and 100-year wave event.

Recent climate and oceanographic studies indicate that a warming climate may increase the intensity, duration, and frequency of extreme storms (Cayan et al. 2008). Given the probabilistic definition of a 100-year coastal flood, we recognize that the face of the 100-year flood could change significantly by the end of the century. For simplicity and comparative purposes, this study models year 2000 100-year coastal floods in all years and scenarios. In this context, damage estimates may be considered conservative.

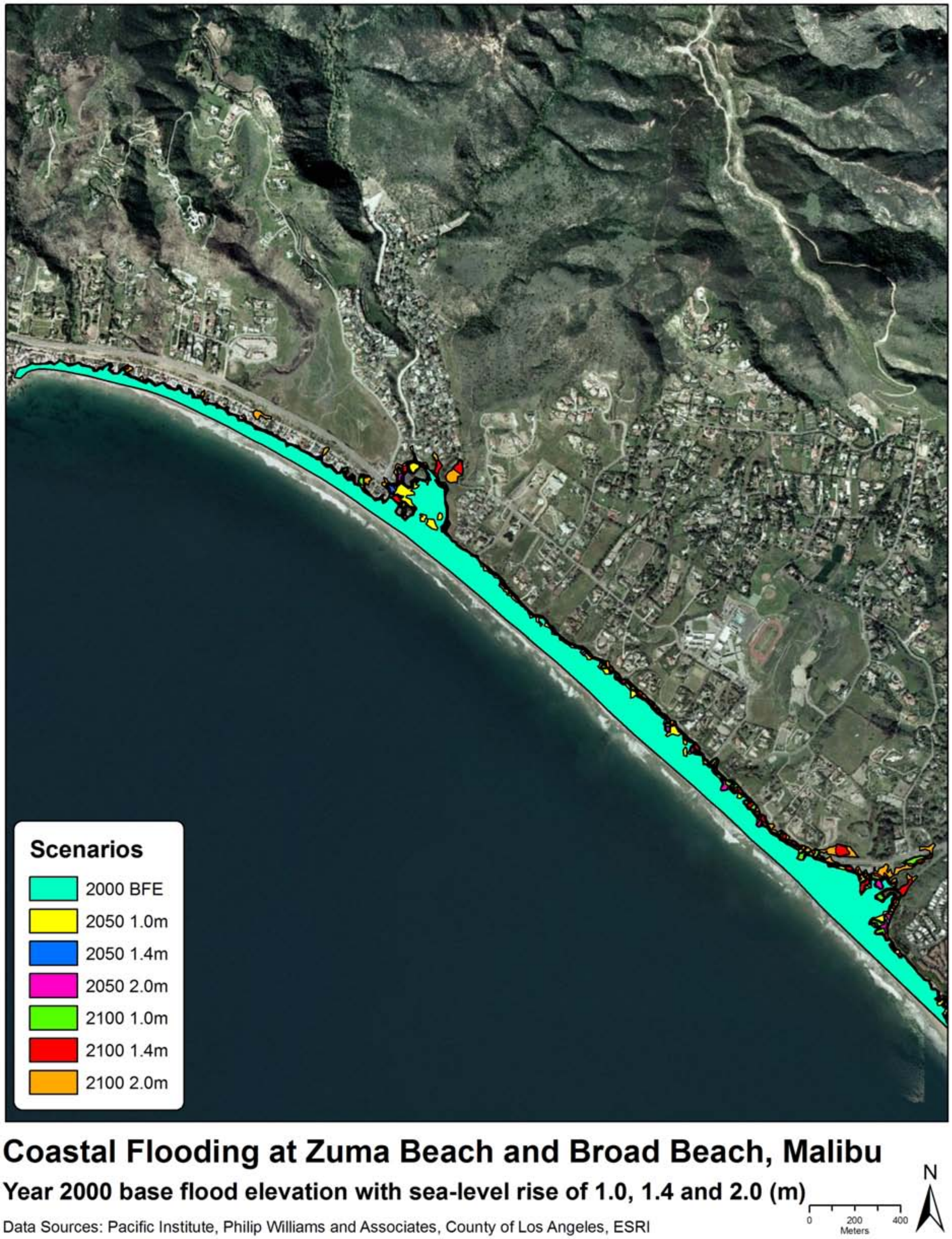

Figure 8: Marginal flood analysis

Note: Each respectively higher sea level scenario increases the reach of the flood zone.

To identify upland areas at risk to a 100-year coastal flood, we used GIS mapping methods to develop flood hazard zones and further isolate parcels intersecting the floodplain. A combination of digital elevation models (DEMs)[5] representing the elevation of the earth's surface and base flood elevation models (BFEs)[6] illustrating the elevation of a 100-year coastal flood (in the year 2000) were acquired from the Pacific Institute and Philip Williams and Associates. These BFEs and inundation scenarios are subject to uncertainties, and should be updated with future wave run-up studies.

The aforementioned elevation models were modified within GIS, using raster math to add the adopted sea-level rise scenarios to water levels corresponding with a year 2000 100-year coastal flood event. Figure 10 provides a theoretical visualization of the change in water surface elevation for current and future 100-year coastal flood elevations. The horizontal dash line represents the water surface elevation for a current 100-year coastal flood, and the horizontal solid line represents the water surface elevation for a future 100-year flood after sea level has risen. The future tide frequency adopts the assumption that the mean low water (MLW), mean high water (MHW), and mean higher-high water (MHHW) increase at the same rate as mean sea level (MSL). Evidence exists, however, that this relationship is not always proportional, thereby warranting the evaluation of regional tidal characteristics (Flick 1998; Flick et al. 1999; Flick et al. 2003; Flick 2008)

[5] Secured DEMs come from a variety of sources. For the southern California region, Interferometric Synthetic Aperture Radar (IFSAR) 3m resolution DEMs, which has an average vertical accuracy of ± 2.2 m and were produced by the National Oceanic and Atmospheric Administration (NOAA), were used. For the northern California region, Light Detection and Ranging (LIDAR) 3 m resolution DEMs with vertical accuracy of ± 0.07 m were used. The most landward section of our San Francisco study area, where the hazard zone went beyond the reach of the LIDAR data, required limited use of U.S. Geological Survey 10 m resolution DEMs with a vertical accuracy of ± 7.5 m.

[6] "Base Flood Elevations (BFEs) published by FEMA were collated into a GIS-based shapefile, and attributed to an offshore line paralleling the shoreline. Digital Flood Insurance Rate Maps (DFIRMs), provisional DFIRMS, and paper FIRMs along with tabulated flood elevations in Flood Insurance Studies (FISs) for communities in the northern California region were used to populate the GIS shapefile. Substantial gaps were filled using professional judgment, informed by considering published values for nearby areas or generally by local knowledge and experience regarding wave exposure and geography. Values were adjusted to the year 2000 North America Vertical Datum (NAVD) based on land and tidal datums for regional, primary tide stations published by the National Ocean Service (NOS). The conversion and rounding process varied depending on the data source and hence accuracy varies" (Revell et al. 2009).

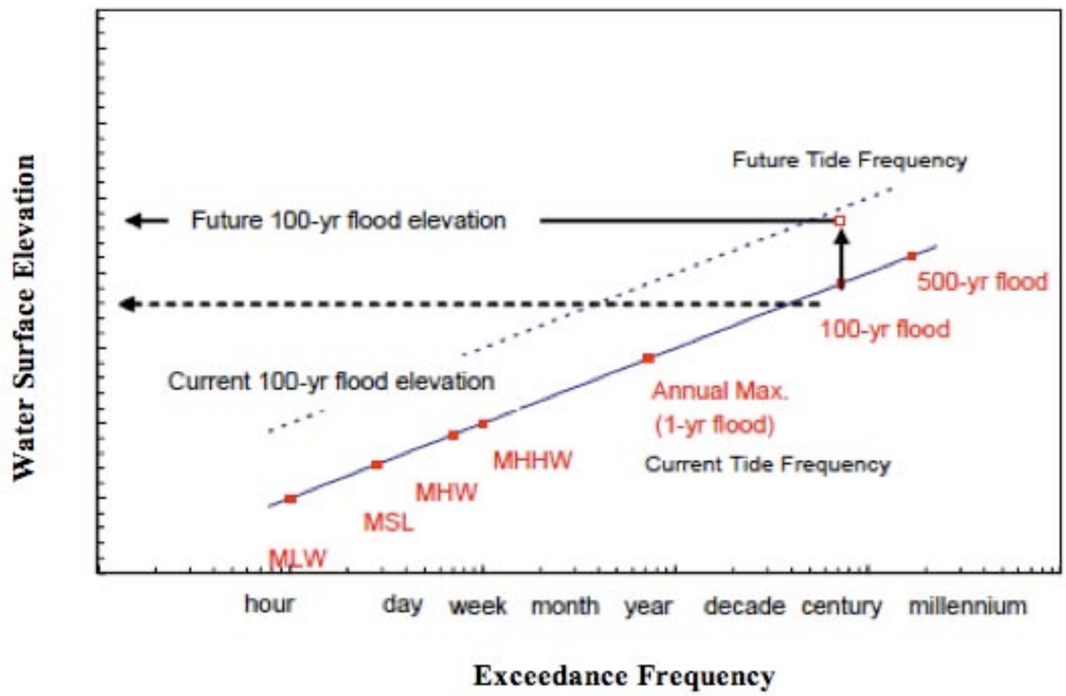

Figure 9: Theoretical overview of future coastal frequencies
Source: Heberger et al. 2009

The base flood elevation data used to model storm scenarios in this report do not fully account for existing flood protection structures. While existing flood barriers may provide sufficient protection for people living within the current 100-year coastal floodplain, such defenses are likely to become less suitable as sea levels rise in the coming century. Our framework is amenable to improved inputs, however, and as updated flood elevation data become available in the future, our results could be re-assessed rather painlessly.

Further, measuring damages with depth of flooding characteristics can overstate damages to land depressions, specifically low-lying objects to which there is no path for seawater to flow (See Figure 11). To partially address this limitation, we made an effort in our geospatial analysis to isolate and remove small ponds that did not represent realistic dynamics of flooding connectivity.

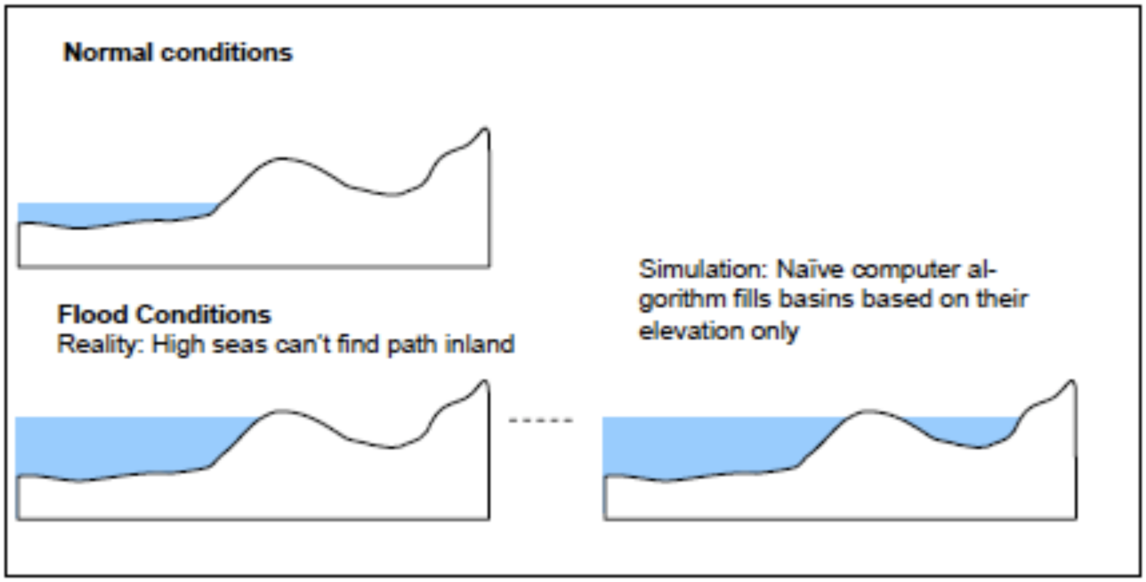

Figure 10. Limitations of the computer's ability to accurately map coastal flooding in areas protected by seawalls or levees or natural barriers
Source: Heberger et al. 2009

4.1.2. Coastal Erosion Modeling

To date, there is no consistent statewide dataset evaluating the expected acceleration in coastal upland (landward of the backbeach) erosion from a rise in sea level. Data limitations required us to use two distinct approaches for mapping erosion hazard zones in the coming century. For our study site in northern California (Ocean Beach) we evaluate damages with a combined dune and bluff erosion hazard zone developed by geomorphologists and coastal engineers from Philip Williams and Associates (PWA). The PWA dataset (Revell et al. 2009), which was developed for the Ocean Protection Council and used in the Pacific Institute report (Heberger et al. 2009), evaluates future erosion by considering three primary factors:

- Changes to total-water level (TWL) from a rise in sea level;
- Historic rates of shoreline change; and
- A 100-year storm event.

PWA's conceptual approach is premised on studies that suggest sea-level rise will accelerate erosion rates as shorelines are confronted with higher water levels and corresponding increases in wave energy. As TWL—the sum of mean sea level, tides, waves, wave run-up, storm surges and El Niño—increases, the face area of cliffs and dunes will be present with a heightened exposure to waves that may accelerate erosion processes (Heberger et al. 2009; Revell et al. 2009; Revell et al. in-press, Ruggiero et al. 1996; Ruggiero et al. 2001).

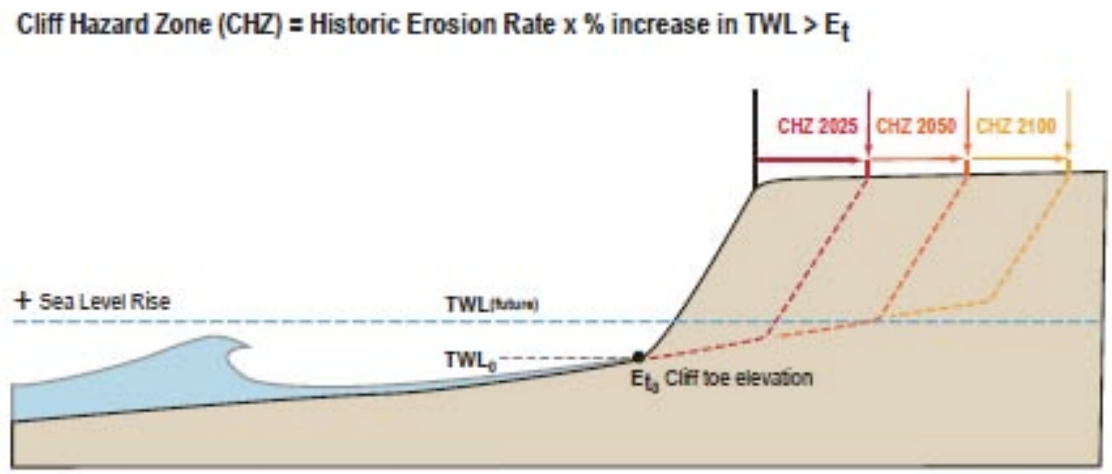

Figure 11. PWA conceptual framework for modeling cliff erosion hazard zones
Source: Revell et al. 2009

PWA produced GIS erosion hazard layers for a 1.0 m and 1.4 m sea-level rise by 2100. The PWA methodology does not consider existing armoring that could limit upland erosion on dune and cliff-backed beaches,[7] however at Ocean Beach, armoring is present along various reaches of the backbeach. We assume that existing armoring will be maintained in the coming century and result in no upland erosion directly landward of these structures. However, we can expect upland erosion to continue in the areas on either side of the armoring. To exclude armored sections, we modified PWA GIS layers to account for existing armoring with data from the California Coastal Commission, creating new erosion hazard zones by clipping out areas of upland erosion that back existing protective structures. To maintain consistency with the borrowed data, we modeled damages following a 1.0 m and 1.4 m sea-level rise in 2050 and 2100, but did not model the upper-bound, 2.0 m sea-level rise scenario in this section.[8]

[7] The PWA authors note that information on the material, geometry and condition of existing armoring was not readily available at the time of their analysis, making it difficult to evaluate future upland erosion where armoring exists (Revell et al. 2009).

Figure 12: Accounting for existing armoring in upland erosion analysis

Due to funding limitations and ongoing projects in southern California by the United States Geological Survey and the Scripps Institution of Oceanography, among others, PWA was not contracted to produce erosion layers south of Point Conception in northern Santa Barbara County. Ongoing southern California erosion studies that account for sea-level rise were not available for our analysis. After consulting with PWA staff, we developed a framework to interpolate the acceleration of long-term shoreline change rates as outlined in the 2009 California Climate Adaptation Strategy (CCAS) (California Natural Resources Agency 2009).

Our southern California sites are characterized by shallow sloped beaches backed by a combination of development, armoring and cliffs. In modeling upland erosion, we make the following assumptions:[9]

- Currently protected reaches of coast will continue to be protected, thereby fixing the backbeach.
- Development along non-cliff-backed beaches (e.g., Venice Beach) will be protected, thereby fixing the coast along such reaches.
- Unprotected cliff-backed beaches are subject to landward erosion.

According to the California Climate Adaptation Strategy (California Natural Resources Agency 2009), by 2100, southern California cliff erosion rates are expected to accelerate by 20 percent for a 1.0 m rise in sea level. Using this rate of change parameter, we extrapolate long-term cliff erosion rates for each respective sea-level rise scenario in 2050 and 2100.[10]

Table 3. Expected acceleration of erosion rates and total accumulated erosion to bluffs at Carpinteria State Beach

Sea-level rise scenario (m)	2000		2050		2100	
	Erosion rate (m/yr)	Total erosion (m)	Erosion rate (m/yr)	Total erosion (m)	Erosion rate (m/yr)	Total erosion (m)
0.0 m	-0.25	0.0	-0.25	-12.5	-0.25	-25.0
1.0 m	-0.25	0.0	-0.27	-12.9	-0.30	-26.9
1.4 m	-0.25	0.0	-0.27	-13.0	-0.32	-27.7
2.0 m	-0.25	0.0	-0.28	-13.1	-0.35	-28.8

Note: The *2000 Erosion rate (m/yr)* column reflects existing long-term cliff erosion rates at Carpinteria (Hapke et al. 2007). The *Total erosion (m)* column reflects estimates of accumulated erosion from a baseline bluff position at 0 m.

[9] While passive erosion may result in the landward retreat of adjacent landforms backing protective structures, modeling such complex geomorphological dynamics was beyond the scope and resources of this study.

[10] Since a change in the rate of erosion is provided for only one scenario (1.0 m), we extrapolate by multiplying the CCAS expected 20% acceleration-per-meter-sea-level-rise proportionally by sea level equations for each scenario, derived using the NRC (USACE 2009) method detailed in Section 4.0, producing an exponential integration of shoreline movement over time. We urge future study toward more sophisticated erosion acceleration predictions for multiple sea-level rise scenarios.

Using the accelerated erosion rates to buffer hazard zones within GIS, we identified all parcels that intersect with an erosion zone. Further efforts were made within GIS to evaluate at-risk transportation infrastructure (e.g., roads, railways) that were not inventoried in county assessor parcel shapefiles.

4.1.3. Valuing At-Risk Assets

Thoroughly estimating asset values (and subsequently, potential damages) required utilization of various data sources that detail the properties and infrastructure at risk. Property characteristic information can be collected from field surveys (primary data) or from pre-existing data sources (secondary data). Collection of primary data, which can be time-consuming and costly, was infeasible for this study, given that the at-risk properties in our study areas numbered in the thousands. We utilized secondary property data from county assessor agencies[11] to estimate property values and future damages. However, only in cases where we were deficient in physical attribute data did we rely on recorded assessor values. We re-estimated the replacement value of structures and contents for every type of property at risk (e.g., residential, commercial, industrial, institutional). Damage estimates for structures and their contents are expressed as depreciated replacement value – estimated cost of replacing an asset with a substitute of similar kind, utility, and condition. For land value, we focused our efforts on re-estimating the value of residential parcels and institutional open-space parcels, as approximately 95 percent of hazard zones at our study sites are zoned for these uses. Residential land is expressed in terms of market value, while institutional open-space land is referenced as the transaction cost between a private and/or public entity and a land trust. For all other land uses at risk to erosion (e.g., commercial, industrial) we present damages that reflect recorded assessor values.

Property Valuation in California

In California, a property's assessed value is divided into two categories: land value and improvement value. Land value is the total estimated value of the land, including any upgrades or improvements to the land. Improvement value is the total estimated value of buildings or structures generally attached to the land, including any upgrades or improvements to buildings or structures. Land value and improvement value are summed to calculate a property's total assessed value, which is used to assess a property's tax burden (CABOE 2009). Given California's division of assessed property value into land value and improvement value, extracting these values for at-risk parcels is the simplest and most direct method to evaluate structure and land value. This method, while convenient, does not guarantee an accurate appraisal of structure and land value since:

1. There can be systematic assessment protocols that vary from county to county.
2. In California, properties are not reassessed annually due to Proposition 13. Rather, property is assessed only when it changes ownership or with the

[11] County of San Francisco, County of Santa Barbara, County of Los Angeles, County of San Diego

completion of new and improved construction.[12] Barring the sale of a property, future increase to assessed value is capped at an annual inflation factor of 2 percent (CABOE 1978). For properties that have not been reappraised for some time, the 2 percent annual inflation factor can grossly underestimate the market value of land and structures (Schwartz 1997). Prior to the recent downturn, the inflation rate in residential property (land prices plus construction costs) was, on average, considerably higher than 2 percent a year, especially in coastal areas of California where land available for development is scarce, in part because of zoning restrictions.

3. County assessor recorded land and improvement values are developed for tax purposes. Because institutional properties (e.g., governmental, non-profit) are in many cases exempt from property taxes, county assessors may record such land and improvement values at $0 (CABOE 2009). Yet, these properties provide utility that is at risk to storm and/or erosion events.
4. Assessed value of structures is a form of depreciated valuation, which captures the remaining economic life and value of a good at the time it is damaged. This is not only a function of age, but also character and condition of assets.[13] This data was not readily available. In this report, we value property at risk to flooding and erosion using a constant depreciation factor of 25%.[14]
5. Estimating damages to structures and land requires distinct valuation methods. Depreciated replacement values are appropriate for estimating damages to structures, yet the market value of land (which literally falls into the ocean, and cannot be replaced) is a more appropriate estimation to account for land damages associated with upland erosion.

To provide an example, a multifamily residential parcel adjacent to Ocean Beach had four units. These units, all of similar physical characteristics (e.g., size, bed, bath) had significant variances in assessed value. Two of the units, both valued near $200,000, had not been reappraised since the late 1980s while the other two units, both valued near $600,000, had been reassessed in since 2000.

We do not mean to imply that assessors' data is necessarily unreliable. While disparities exist in assessed values, building characteristic data from many counties allowed us to utilize a different—and likely more precise—technique for valuing assets and potential damages, when compared to generalized building stock data.

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[12] The Assessor is required to add the value of the structure improvements to the assessment roll. However, the value of the existing property is not reappraised (CABOE 2009).

[13] Contacts at the USACE advised us to use a constant depreciation factor of 25%, the underlying concept being most structures reach a constant state where the annual maintenance spending and the annual rate of depreciation are equal.

[14] The USACE measures depreciated replacement costs while FEMA generally uses full replacement costs. The primary rationale fore FEMA's use of full replacement costs lies in FEMA's commission to allocate the finances required to repair or replace damages assets apart from an asset's existing economic condition (USACE 2010).

STRUCTURE VALUE

To calculate a base replacement value for a structure, we linked assessment building characteristic data (size, type, number of stories, year built) to mean cost-per-square-foot replacement values identified by the National Institute of Building Sciences (NIBS) (FEMA 2006).

The NIBS mean cost-per-square-foot values represent average nationwide construction costs. Building construction costs vary regionally, due to wage differences, material costs and transportation costs. We adjusted NIBS nationwide averages to account for inflation and to more closely reflect building costs at our study sites. To accomplish this, we evaluated historical region-specific building cost indices maintained by Engineering News Report (ENR) (ENR 2010).[15] For our southern and northern California sites, we adjust NIBS cost per sq ft factors with Los Angeles and San Francisco region-specific profiles, respectively. The NIBS cost-per-square-foot values increase by approximately 20 percent in the Los Angeles region and by approximately 30 percent in San Francisco, when adjusted for the region-specific building cost indices and for inflation from 2006 to 2010.

Overall, the assessment rolls we secured provided sufficient data coverage to estimate structure losses on a parcel-by-parcel basis. For parcels lacking data inputs necessary to calculate structure value, we performed cluster analyses, examining neighboring properties with similar profiles. When no building characteristic data were available, we used county appraised structure values, which are likely conservative estimates of replacement value.

RESIDENTIAL LAND VALUE

Residential land value is influenced by locale (e.g., urban/suburban/rural setting, nearby parks, roads, air quality), zoning classification (e.g., single family/multifamily, commercial, institutional, mixed use), and size, among many other variables. The relative contribution of each factor to the land value itself is complex, and relatively difficult to distinguish.

In coastal areas, land available for residential development is scarce, due to zoning regulations and a limited supply of land. The large consumer demand for a scarce supply of developable land gives residential land along the coast an often-significant price premium. As found by Glaeser and Gyourko (2003), land use classifications that designate the amount of development available per parcel (e.g., single-family, multi-family, mixed-use) have a direct effect on the value of land. Land values for identically sized single-family and multi-family lots are not identical; the multi-family lot typically elicits a higher land value from its ability to host more development and consumer demand.

To estimate the land component of a parcel's value, we use a hybrid "extraction" technique, where depreciated structure value (estimated in the same method as discussed above) is subtracted from the expected sale price of a property. Some county assessor rolls document

[15] The USACE also maintains building cost indices, yet these indices are often designated for public works project.

the most recent sale price for a property, yet many properties have not been sold for many years—or even decades—thereby failing to reflect a realistic current market value.

Due to a deficient amount of data to infer and relate residential land value by classification and lot-size, we turned our attention to a private company, Zillow, which provides estimates of residential property values. Zillow's "Zestimate" values are available at Zillow.com, a contemporary, web-based real estate interface. A Zestimate is calculated using an algorithm that evaluates the relationship between multiple physical characteristics and the current and past sale prices of homes in that area (Zillow 2010).

We identified the Zestimate for approximately 90 percent of at-risk parcels, and calculated land value by subtracting estimated structure value for each parcel from that parcel's Zestimate (Zillow 2010). When a Zestimate was not available, we used cluster analyses, estimating the mean cost-per-square-foot of land by relating similar, neighboring residential properties where Zestimates were available.

To investigate the accuracy of Zestimates at our study sites, we calculated cost-per-square-foot land values for all residential properties that were re-appraised in 2010. While this was only a small sample (approximately 10 out of 200 parcels at risk), we found a small variance—less than 5 percent—when comparing the average county assessor cost-per-square-foot land value (those re-appraised in 2010) to the average cost-per-square-foot land value (for all at risk residential parcels) calculated from the Zestimate.

The accuracy of a Zestimate is influenced by the amount and quality of accessible countywide physical characteristic data. Zillow estimates the accuracy of their Zestimates by comparing the final sale price of a property to the Zestimate on or before the sale date. Zestimates were only used to estimate land value adjacent to Ocean Beach, San Francisco (other study sites were not vulnerable to residential land losses from upland erosion).

According to Zillow, there is a high level of accuracy for their Zestimates in San Francisco. Zillow provides Zestimates for over 90 percent of residential properties in San Francisco. Approximately 55 percent of Zestimates were within 10 percent of the sale price and upward of 80 percent of Zestimates fell within 20 percent of the sale price. The accuracy of Zestimates varies greatly by site, however; future studies should examine statistics on local Zestimate accuracy and recent market sales data.

For areas of larger scale (investigation of residential land losses at our study sites encompassed only two half-mile stretches), one could re-appraise land value with alternative techniques such as *sales comparison* and *allocation*, which were not used in this analysis given the small geographic scale of analysis:

The sales comparison technique involves an analysis of market transactions for vacant parcels of similar type. The application of this appraisal technique is contingent on using comparable market or sales data within a relatively narrow window of time (Gwartney 1999). The sales comparison approach is an ideal method to use when there are limited market sales but accessible data detailing various site characteristics for all properties.

When there is difficulty locating recent sales data for vacant parcels, one can make use of the allocation approach. The allocation approach supports the premise that there is a general ratio of land value to property (combined value of land and buildings) for different categories of real estate that host similar characteristics in nearby locations. One can analyze recent sales and estimate proportional parameters for land and buildings. These factors can then be applied to the total market value for similar properties in a defined area to estimate parcel-specific land values (Gwartney 1999).

GOVERNMENTAL OPEN-SPACE LAND VALUE

Government-owned parcels at risk from upland erosion are primarily undeveloped. As previously discussed, due to tax exemptions, county assessors record the land value of these parcels as $0. Yet, from an economic framework, these undeveloped parcels provide utility that has monetary value.

It is well accepted that undeveloped land, particularly land backing the shoreline, provides numerous benefits, such as public access, scenic benefits to real estate values, and natural habitat value (Fausold and Lilieholm 1999). This recognition has led to formation of land trusts that assist in purchasing and managing land—primarily undeveloped, open space parcels—for the public's trust.

In some cases, the deed for property purchased by a public agency transferred to a land trust for future management, and vice versa. To estimate the value of publicly owned open space land, we evaluated recent land transactions along the California coast. We limited our evaluations to purchases of upland coastal areas by California land trusts.

The sale prices of land trust and public agency transactions were identified as ranging from $1 to $20 per square foot along coastal areas adjacent to our study sites or at coastal sites with similar physical and social profiles.[16] Often, land trusts and/or public agencies are able to secure the purchase of privately owned land for a price well below market value. We assume that open-space property currently managed by public agencies or land trusts will not be sold or leased to private agencies for consumptive uses in the future. Therefore, we do not estimate institutional land at market value—the most likely price that a property would be purchased at in an open and competitive market. Rather, we estimate land value at $2 per square foot. This value is assumed to conservatively reflect a cost to a land trust or a public agency, whereby an agency would recoup the original price it paid to secure the purchase of the land. It should be considered a possibility, notwithstanding existing land use provisions (e.g., development rights,

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[16] Land transactions were evaluated from a range of open space land organizations across the state. Transactions were merged and adjusted for inflation with records from the Big Sur Land Trust, Peninsula Open Space Trust, Citizens for the Carpinteria Bluffs, Bolsa Chica Land Trust and the San Elijo Lagoon Conservancy.

easements), such undeveloped land could be sold in an open and competitive market. If this were the case, the cost-per-square-foot would likely greatly exceed our estimate.

COMMERCIAL, INDUSTRIAL AND INSTITUTIONAL LAND VALUE

For commercial, industrial and institutional property types, we made use of county assessor recorded land values, noting that these values are prone to underestimating the market value of land and should therefore be considered conservative.

Due to the minimal number of commercial, industrial and institutional land parcels vulnerable to upland erosion at our study sites, we directed our resources toward re-estimating residential and governmental open space land value. However, many California communities host significant amounts of commercial, industrial and institutional land at risk to coastal hazards. To more closely reflect potential losses to these land use designations, future studies could introduce alternative appraisal methods, such as the *income approach* (known in some circles as the ground rent capitalization approach), a useful, transferable technique used primarily for re-estimating land value of commercial property:

The premise of the income approach is that land value can be calculated as a function of the rent that a property can collect. If one can determine the net operating income (NOI) and the capitalization rate of a property, the land value of the property can then be estimated. The income approach is a simple, straightforward estimation method, however significant resources may be required to secure location-specific capitalization rates and NOIs for various classes of commercial property (Gwartney 1999).

TRANSPORTATION INFRASTRUCTURE

All roads at risk in our study area fall into the categories of major or minor roads. The widths of a major and minor road are approximately the same, averaging 40 feet (most minor roads provide on-street parking not available on major roads). Because roads are at risk to erosion processes (where the shoreline will migrate landward of existing surface streets) we assume that structural adjustments (e.g., trestle bridges) will be required, estimated at $500 per square foot (ESA-PWA 2010).

At Torrey Pines, a railroad line falls within our erosion hazard zones. To estimate the replacement value to at-risk railways, we use a value identified by the Southern California Regional Rail Authority (SCRRA), listed in a USACE economic appendix (2007) that evaluates the economic impacts of coastal hazards in San Clemente, CA. The section of rail at risk in Torrey Pines is part of the Los Angeles to San Diego (LOSSAN) railroad corridor—the same corridor evaluated in the USACE (2007) study.[17]

[17] The USACE (2007) notes that LOSSAN is the only rail connector between San Diego and the rest of the United States for passenger, freight and military operations, second in passenger traffic to the Boston to Washington DC corridor in respect to Amtrak train ridership.

According to SCRRA, the replacement cost for a 50 m section of track and embankment (including new materials, labor, mobilization rates, and a 25 percent contingency factor) is approximately $408,000. The USACE notes that the actual cost would vary with the length, width and type of erosion. We used GIS to estimate the length of track at risk, and multiplied length by a mean replacement cost of $8,160 per linear meter ($480,000/50 m). The USACE assumes that existing railways will fix the position of the backbeach, acting as the landward hazard boundary. In our erosion analysis, we allow for erosion processes to migrate landward of railways. Onsite replacement of railways undercut by erosion would require structural adjustments (e.g., trestle bridges) that may be more costly than SCRRA estimates. However, structural adjustments could limit the need for capital investments in embankments and additional protective structures.

Surface parking lots are also at risk. The mean construction cost for an off-street surface parking space is $5,000 (Victoria 2010). Based on the size of a typical off-street parking spot, ranging from 144-200 sq ft, we estimate the replacement cost for an off-street parking lot at $30 per square foot.

4.1.4. Damage Functions

One cannot assume that the total value of a property (land, structure, contents) will be lost if that property intersects a coastal hazard zone; in other words, if only an edge or portion of the property is affected by erosion. Similarly, one foot of flooding is unlikely to result in complete loss of property value. While previous studies have aggregated all asset value at risk, we aim to increase the accuracy of economic damage estimates by employing stage damage curves that account for the impact of *flood depth* on structure and content damage. For erosion events, we introduce assumptions and employ a unique approach to calculate land and structure losses as a percentage of the total value of at-risk parcels.

Flooding

This study follows Heberger et al. (2009) and approximates future flooding impacts by adding sea-level rise projections to water levels from a current 100-year coastal flood event. Today's 100-year coastal flood elevations are increased by a respective 1.0 m, 1.4 m or 2.0 m to represent sea-level rise over the next century. The established principle follows that a rise in sea level will increase the base flood elevation and extend the area of the flood's reach, thereby threatening more properties.

Many planning-level studies employ a footprint approach to evaluate the cost of a 100-year coastal flood following a rise in sea level. The footprint approach maps a flood over a defined geographic area, such as a census block. The percent (surface area) of a census block at risk to flooding is used to make assumptions about the expected economic damages. Most first-order footprint analyses incorporate generalized building inventories, assuming that building stock is evenly distributed (spatially) in the damage zone; therefore, if 20 percent of a census block is flooded, 20 percent of the total assets in the census block are assumed to be at risk, regardless of the depth of flooding or the spatial distribution of assets.

We add value to this approach by accounting for exacerbated damages from the increased flood depth associated with sea-level rise. For example, when modeling a 100-year coastal flood following a 1.4 m rise in sea level, not only is the flood footprint area extended, but properties within the reach of the baseline flood also experience deeper flooding (assumedly by 1.4 m) than they did in the baseline flood. Realistically, damages would be much more extensive in the deeper flood. Generic footprint analyses that disregard depth of flooding can significantly over- or underestimate flooding damages.

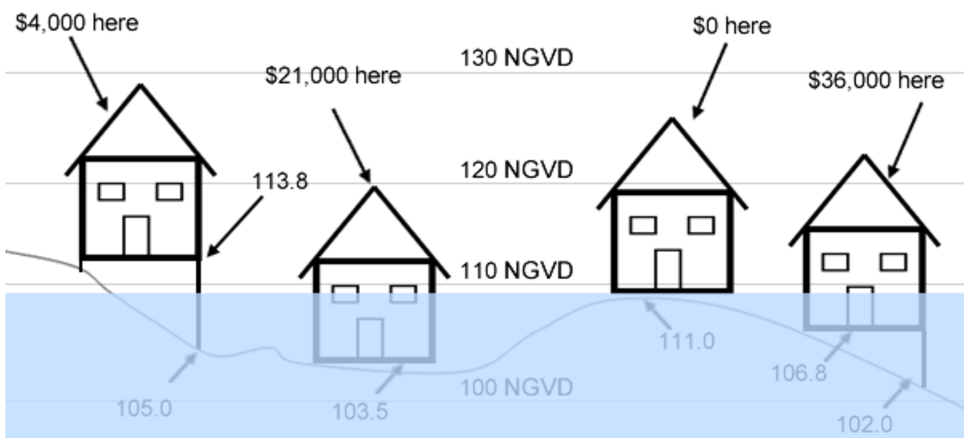

Figure 13. Economic damage overview for flood depth and structure elevation
Source: USACE 2010

The USACE has published depth-damage functions that relate flood depth to damage estimates for residential, commercial, industrial, agricultural, governmental and educational facilities. We approximated mean depth of flooding[18] at each threatened parcel, and using the USACE's Generic Depth-Damage Relationships (USACE 2003a, 2003b), calculated damages as an appropriate proportion of the full structure value.

USACE damage functions also exist for proportional damages to building contents. In the absence of estimates for total content value, the USACE provides generalized content-to-structure value ratios for various building types, representing content value as a percentage of structure value.

[18] USACE depth-damage curves measure flood depth in feet, so for this portion of the analysis, we converted and rounded flood depth to the nearest foot, or half-foot, where appropriate.

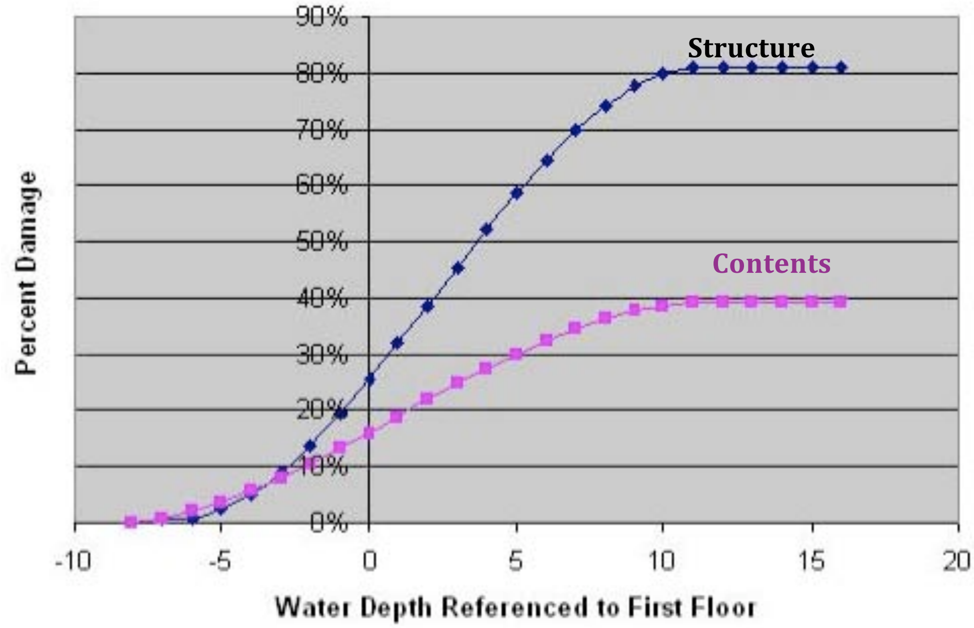

Figure 14. Generic example, USACE depth-damage functions
Source: USACE 2010
Note: The blue curve (top) references the relationship between the depth (feet) of water and damages as a percentage of the structure's value. The pink curve (bottom) represents content damages, also as a percentage of structure value.

UPLAND EROSION

Few studies evaluate the economic costs of coastal erosion events following a rise in sea level. The PI study (2009) is the most recent and applicable California-specific assessment of coastal erosion following a rise in sea level. Heberger et al. (2009) analyze erosion impacts from a 1.4 m rise in sea level from Del Norte County to Point Conception in Santa Barbara County. To quantify damages, the authors identify the number of parcels that entirely or partially intersect an erosion hazard zone developed by Philip Williams and Associates (PWA). Heberger et al. (2009) assume that each parcel intersecting the erosion zone results in $1.4 million in damages, reflecting the average value of a property along the California Coast.

The authors of the PI report call for more study of these damages and note the limitations to their approach; the one-size-fits-all valuation approach can result in an underestimation and/or overestimation of damages when considering that parcels vary in size, land use (open-space land, roads, residential, commercial, industrial and institutional facilities) and may contain multiple units of infrastructure. These drawbacks are evident when examining parcel characteristics within our erosion hazard zones. For example, upland parcels at risk from erosion at Torrey Pines State Beach range in size from approximately 7 thousand to 12 million square feet and contain anywhere from zero to 48 units of infrastructure.

To improve on past erosion damage assessments, we start by re-estimating the market value of land and depreciated value of structures at risk on a parcel-by-parcel basis. We calculate relative losses by assuming the following damage criteria:

- Developed parcels less than or equal to 5,000 square feet with a structure-to-lot size ratio of 0.5 or greater face a complete loss of structure and land value.
- Developed parcels greater than 5,000 square feet are evaluated on a case-by case basis. Structure and land losses are evaluated separately. If a structure intersects with the erosion hazard zone, the structure faces a complete loss of value. If a structure does not intersect with a hazard zone, only land losses are observed, estimated as a function of the percent surface area of the parcel within the hazard zone.
- Undeveloped (vacant) parcel damage is a function of the percent of parcel (surface area) within the erosion hazard zone, regardless of parcel size.

Our erosion damage functions address the limitations of past studies, which use a single default replacement value and assume total loss, regardless of the type of parcel or area of a parcel at risk to erosion. We calculate structure-to-lot size ratios assuming that structure square footage data are representative of surface area. This assumption results in overestimating the structure-to-lot size ratios for structures that contain basements and/or multiple levels. Building footprint shapefiles would further assist in delineating the surface area of at risk structures.

Episodic cliff- and bluff-erosion events place structures slightly landward of erosion hazard zones at risk, as evidenced by recent erosion events in Pacifica, CA, where a 30-foot wide section of cliff eroded into the sea. We did not introduce a setback parameter to our erosion hazard zones due to limited knowledge of site-specific evacuation protocols. In this context, our erosion damage outputs may be considered conservative.

4.2. Sandy Beach Damages

4.2.1. The Bruun Rule

As discussed previously, coastal hazards will result in different damages to sandy beaches and upland areas. Higher sea level, all else equal, will cause beaches to become narrower where the backbeach is fixed and not allowed to retreat. For the purpose of this analysis, we model linear landward shoreline retreat, using the Bruun model (1962) to calculate the area of beach eroded away passively due to rising sea levels.

Bruun (1962) designed a conceptual model relating rising sea level to changes in a beach and nearshore profile. Operating under a few key assumptions, The Bruun Rule may be summarized as follows: as sea level rises: (a) the foreshore is displaced landward as the upper beach is eroded, (b) the volume of sediments eroded from the upper beach is equal to the volume of sediments deposited on the nearshore bottom, and (c) due to this nearshore deposition, the increase in elevation of the nearshore bottom is equal to the increase in elevation of sea level, thus maintaining a constant water depth in the nearshore (Schwartz 1965; Dubois 2001; Davidson-Arnott 2005).

The explicit assumptions of the Bruun Rule, as outlined by Davidson-Arnott (2005) are:

- The Bruun Rule applies to a two-dimensional profile, normal to the shoreline. All net sediment transfers are along the profile (onshore-offshore) and longshore drift is not considered.
- The beach profile is assumed to be in equilibrium and developed entirely in sand. Mean profile form is assumed to reflect the wave climate and sediment size.
- Material landward of the beach berm is assumed to consist of easily erodible sand with characteristics similar to those in the nearshore.
- Wave climate is assumed to frequently produce waves of sufficient size to erode, transport, and redistribute sediment over the profile. Without wave action, sea-level rise would simply inundate the landward profile.

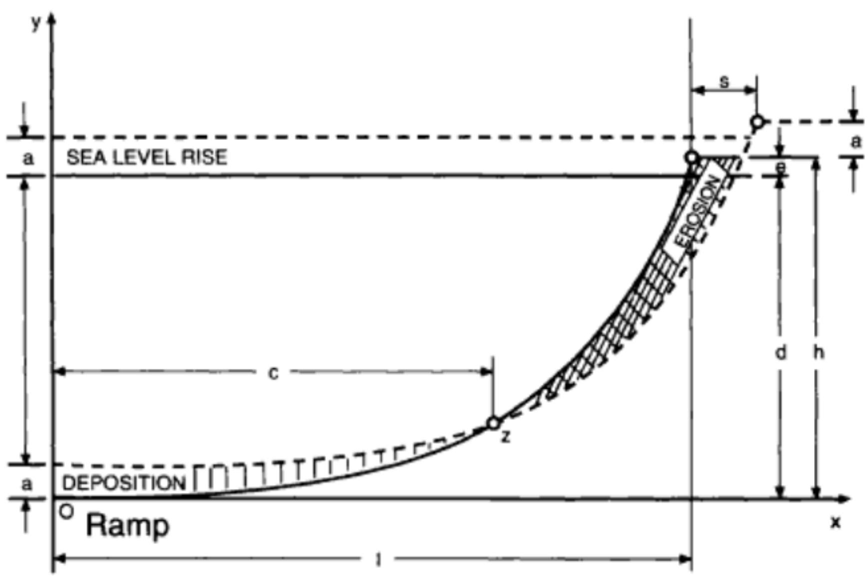

Figure 15. Schematic representation of Bruun's rule
Source: Bruun 1988

Wide application of the Bruun model has been criticized, largely due to the restrictive assumptions above, specifically the two-dimensionality (Pilkey and Cooper 2004). In general, however, shear stress on a profile due to wave action—and particularly during storms—is far greater than the shear stress originating from longshore currents (Bruun 1988). Further, the Bruun model always predicts future recession, while some areas may accrete with sea-level rise.

While a generalized method for predicting shoreline change, the Bruun Rule models only the effects from changes in mean sea level—that is, the gradual, long-term erosion of beaches due to ever-higher tides. El Niño winters and periodical major storm events typically strip much (if not all) sand from many of California's shallow-sloped, cliff-backed beaches. Thus, these estimates of gradual erosion damages could be considered conservative.

The Bruun Rule for shoreline movement remains one of the most widely used tools for modeling erosion in a sea-level rise context. The limited resources of this project prevented us from utilizing more advanced modeling techniques. Bearing this in mind, our methods for calculating economic impacts could fairly simply adapt to more accurate geomorphological data and modeling in future studies.

At each study site, we quantify shoreline retreat as a proportional decrease of baseline beach width values. Our utilization of the Bruun Rule required the following beach profile inputs:

- Beach width
- Beach berm elevation
- Depth of closure
- Foreshore slope

We utilized multiple sources to gather the best available inputs for each of the study sites. These varied sources include public agencies (SANDAG)[19], policy and academic literature (CA Coastal Sediment Master Plan; BEACON[20]; Maalouf et al. 2001; Lippman et al. 1996; Revell et al. 2009), and original data from local coastal researchers. Spatial mapping tools (e.g., GIS, Google Earth) were used to estimate the length of the beach at each study area.

These simple inputs provide us estimates of the beach profile length and depth at each of the study sites. These parameters, using the Bruun Rule, allow us to estimate future beach recession as a function of sea level increases under each scenario: 1.0 m, 1.4 m, and 2.0 m. This result is a linear, landward shoreline movement estimate, which we multiply by the length of sandy beach at each study area to estimate beach area lost to sea-level rise, assuming that the reach of shoreline is affected uniformly.

4.2.2. Beach Erosion Damages

As sea levels rise over the next century, coastal communities must consider the potential impacts that sand erosion and subsequent beach loss will have on the value of their beaches—the greatest assets to many tourist- and consumer-based beach economies in California.

Economic losses accrue as a function of lost beach width and area, in the form of:

- Recreational value to beachgoers;

[19] SANDAG stands for the San Diego Association of Governments.
[20] BEACON stands for Beach Erosion Authority for Clean Oceans and Nourishment.

- Economic spending and tax impacts from shoreline visitation; and
- Ecosystem services associated with shoreline habitat.

RECREATIONAL VALUE

In modeling losses to recreational value following sandy beach erosion, we use a standard model that is reasonably tractable—a benefits transfer (BT) approach, which allows one to apply estimates from previously analyzed sites to similar beaches. In practice, BT is much cheaper than other methods and also has the advantage of consistency.

For BT to work properly, consistent methodology must be used to assess the recreational value of a particular beach. Several federal agencies, most notable the USACE, have developed a scale from 1-100 to assess the value of a recreation day, with distinctive amenities each assigned a subtotal of the total 100 points, see Table 4 (USACE 2004).[21]

Table 4. USACE unit day value method – point values

Criteria	Total Possible Points
Recreation Experience	30
Availability of Opportunity	18
Carrying Capacity	14
Accessibility	18
Environmental	20
Total	**100**

The USACE criteria indicate how to assign point values to each beach (or other recreation site) One serious limitation of the USACE criteria is that beach width is not specifically accounted for, although "carrying capacity" depends in part on beach width. Another problem with the above scheme is that, since it is additive, a site can score a zero on a particular criterion and yet still earn a relatively high day use value. Realistically, however, if the recreational experience is zero or very low, it matters little whether the site is accessible or has an adequate carrying capacity. A further complication with the USACE methodology is that additional recreation points are given if multiple recreational opportunities are available. In practice, some beaches cater only to one type of recreation (e.g., surfing, bathing) but do so extremely well (e.g., Trestles for surfing or Carpinteria for family recreation) and the USACE methodology may undervalue the recreation experience.

[21] The USACE Unit Day Value (UDV) method is generally used for recreation sites where there are less than 750,000 annual visitors and recreation is not a deciding factor to endorse a project. For detailed feasibility studies, the USACE will generally perform a site-specific contingent valuation or travel cost study to value recreation. Further, the UDV method was not developed specifically for evaluating beach recreation given the limited number of beaches in the USACE project portfolio.

The Coastal Sediment Benefits Analysis Tool (CSBAT) approach used in this study is a benefits transfer model that avoids some of the above issues by assuming that the value of each amenity is multiplicative—that is, one should rate each amenity on an appropriately defined scale and then multiply each amenity's point value to derive a final index. The index can then be translated (as the USACE methodology is) to a day use value.

CSBAT uses the following six criteria to assess the recreational value of California beaches:

1. **Weather**: Typically California beaches are overcast early in the morning and clear before noon, though some beaches remain overcast for a significant number of days. In assessing the weather, many sub-criteria are considered: the number of sunny days, average temperature of the air and water, currents, and wind.
2. **Water Quality/Surf**: Water quality has become a critical issue for southern California, leading to the closure of many beaches. This factor will be revised in future studies and model updates since waves and water quality are quite different attributes.
3. **Beach Width and Quality**: While a wide beach is not crucial to high recreation value, all else equal, people generally prefer wider beaches. Beaches at our study sites all have good sand quality (and little cobble except near shore), so distinguishing sand quality was not a priority issue in this study.
4. **Overcrowding**: Previous surveys of beachgoers indicate that overcrowded beaches are considered less desirable (King 2001c). Crowding can be measured in a number of ways. Typically, it is measured by the amount of sand available per person, though crowding can also occur in the water, in parking lots, at snack bars, and elsewhere.
5. **Beach Facilities and Services**: Beachgoers generally prefer access to restrooms, trashcans, and lifeguards. Most (but not all) also prefer some food facilities and other shops.
6. **Availability of Substitutes**: Scarcity also affects the relative value of a beach. If similar beaches are available within a short distance, a beach is considered less valuable than if it were the only choice. From a planner's perspective, it may not make sense to nourish a beach if another similar beach is available nearby. However, in making an assessment of substitutes, one must keep in mind the differing preferences of beach users. For example, some prefer a city beach with an urban or tourist ambiance while other prefer a more "natural" beach. A critical issue often overlooked in studies of California beaches is congestion and availability of parking.

The functional form used in the CSBAT analysis is a Cobb-Douglas utility function—a standard practice in the economic field. The equation is of the general form:

$$\text{Value of a Beach Day} = M^* \quad A^a * A_2^b * A_3^c * A_4^d * A_5^e * A_6^f$$

Where:

M is the maximum value for a beach day

A_1 … A_n represent each beach amenity (rated on a scale of 0 to 1)

a … f are the weighting of each amenity value

$a + b + c + d + e + f = 1$.

The CSBAT model has been calibrated with data from existing studies. The Cobb-Douglas function exhibits diminishing marginal utility with respect to beach width (e.g., adding 50 ft of sand to a narrow beach has a larger welfare benefit, *ceteris paribus*, than adding 50 ft to a wider beach). This model behavior is consistent with empirical studies and anecdotal evidence. In addition, the CSBAT model employed in this study caps beach width benefits at 300 feet. This is consistent with a number of studies indicating that beaches can, in fact, be too wide (Landry et al. 2003). However, wider beaches also diminish crowding, the benefits of which are taken into account in the model.

The key issue in calibrating the CSBAT model for a sea-level rise study is how beach width increases (or decreases) visitors' willingness to pay for a day at the beach. Doubling the beach width of a typical (somewhat eroded) beach in southern California increases the value of a beach day by 15-20 percent (King 2001c). The maximum value for a beach day is $14, which is consistent with Chapman and Hanemann's (2001) estimate for the value of a day at Huntington Beach as well as the USACE (2004) BT protocol.

ECONOMIC IMPACTS

With so many coastal California communities relying on beaches, sea-level rise erosion impacts pose to reverberate throughout local economies, affecting spending and tax revenues in the communities. To address these risks, we use attendance estimates from the CSBAT model and spending estimates from King and Symes (2004). The key variable in estimating spending and revenue is the percentage of day-trip visitors versus out-of-town visitors (who spend more). For each site, we rely either on existing data or direct interviews with knowledgeable local coastal residents to estimate the percentage of day-trippers vs. overnighters.

In addition, we assume that spending per visitor does not change as beach width changes—thus, all of the economic and tax revenue impacts estimated in this study are a result of estimated changes in beach attendance. It is possible that changes in beach width could affect the composition of overnight/day-trip visitors, which would affect spending/tax estimates, but this impact was considered secondary and is not estimated in this study. Tax revenue impacts are based on spending estimates combined with data from the California Statistical Abstract, a collection of social, economic, and physical data for the State (2009). This area would benefit from future research, which we recommend.

ECOLOGICAL VALUE OF BEACHES

In estimating potential losses of ecological services provided by a beach, we aggregate losses per-area of beach lost to sea-level rise and erosion.

Following our earlier discussion (see 2.7), we adopt a conservative assumption that our beaches offer $4000 per hectare per year in economic benefits beyond recreational value. This estimate includes habitat value, biodiversity value and other ecological services as well as storm damage prevention benefits not included elsewhere in the study. Our estimate is significantly lower than those ones used by Costanza et al. (2006) for biodiversity/habitat value of wetlands and is equivalent to Brander et al. (2006) benefits per year in wetland flood protection. It is quite possible that our estimate is too low, but given the uncertainties in this realm of valuation, we thought these values to be appropriately conservative, capturing at the minimum storm protection. This area would benefit enormously from future research, which we recommend.

4.3. Coastal Protection Measures

The increasing vulnerability of coastal communities has resulted in the proposal of structural and non-structural measures to reduce the potential damages from sea-level rise, high tides, and wave runup. Structural and non-structural measures can be categorized as: soft solutions (e.g., beach nourishment); hard solutions, (e.g., seawalls and revetments); and passive solutions (e.g., managed retreat).

In an era of uncertainty, the threats posed by a retreating coastline necessitate responses that are as sustainable as they are cost-effective. Present attempts to address coastal retreat are insufficient, as valuable land and infrastructure continues to be lost (Griggs 2005). Further, there is contention over what are the best-fit approaches to respond to a retreating coastline in highly developed areas.

Decisions on which protection measure to implement are left in the hands of local coastal programs and the California Coastal Commission (CCC) and the San Francisco Bay Conservation and Development Commission (BCDC), where considerations are made for the profile of the beach, the nature of landward development, and the desired adaptation result. Our objective in this study is not to advocate for one adaptation response over another. We prefer to leave those conversations for the planners and policymakers responsible for making such decisions on a local, regional and statewide level. Rather, the following discussion is designed to provide an overview of the functions, advantages and disadvantages of commonly used coastal protection techniques.

4.3.1. Soft Solutions

Beach nourishment is the primary soft solution for shoreline management. Aimed at addressing sandy beach erosion and enhancing recreational value, beach replenishment projects nourish the beach with sediment from offshore and/or onshore sources. Another potential advantage of beach replenishment is enhanced real estate value for coastal properties (Dixon et al. 1996).

Beach nourishment projects are sometimes viewed, however, as unsustainable or short-term solutions. Beach nourishment projects are vulnerable to wave energy, primarily in winter months, that displaces sediment both offcoast and downshore. Recent discussion has been directed at the long-term availability of sufficient sand type and volume to meet the needs of the coast. Over the past fifty years, a majority of California's nourishment projects were made possible by the dredging of harbors and marinas (Griggs and Runyan 2005) though some recent projects, notably SANDAG's project rely on offshore sources and some others have used opportunistic inland sources such as debris basins.

Also, beach ecosystems provide habitat and resources for a diversity of species, ranging from invertebrates to birds, fish and marine mammals. While nourishment can create wider dry sand zones, the ecological value of nourished shorelines is not likely to scale with dry beach width. In addition, nourishment can cause disturbances and mortality of intertidal fauna associated with fill activities, including burial and the direct impacts of heavy equipment and sand manipulation (Speybroek et al. 2006). Recovery of ecological value of beaches may take years, even decades in some cases. Ecosystem recovery can be strongly inhibited, if the fill material is too fine, too coarse or poorly sorted compared to native sand (Peterson et al. 2006).

4.3.2. Hard Solutions

The most common coastal hazard response in California is the construction of seawalls and revetments. Seawalls are near-vertical shoreline structures to protect against storm waves, while revetments have a sloped profile that extends horizontally onto the beach profile to prevent backbeach erosion from storm waves (USACE 1984b).

While seawalls and revetments can assist in protecting landward areas from high tides and storm surge, there is concern over the direct and indirect impacts of these structures. The footprint of seawalls and revetments result in the placement loss of beach; the quantity of loss being a function of the seaward placement of the structure and its alongshore reach (Griggs 2005). Seawalls and revetments can also cause passive erosion. As sea levels rise, the shoreline will retreat. Since defenses like seawalls and revetments fix the position of the backbeach, a rise in sea level may result in the gradual loss of the beach fronting such structures (Griggs 2005). Further, concern exists about the visual impacts of seawalls and revetments on beachgoers, as well as the potential for such structures to reduce horizontal and vertical beach access. Coastal armoring is also likely to have negative ecological impacts beyond simply reducing the size of beaches. Seawalls and revetments create physical barriers to the movement of intertidal flora and fauna within the coastal ecosystem. For example, Dugan et al. (2008) found that coastal armoring reduced the diversity and abundance of seabirds.

The lifespan of beach nourishment project can be improved by the use of retention structures such as groins. Groins are constructed perpendicular to the shoreline and designed to trap longshore sediment drift. Sand deposits on the updrift side of a groin until it fills to capacity, allowing for longshore drift to pass downshore. Although groins retain sand, they can result in downdrift erosion, damaging downfield reaches (NRC 1987). Groins can be effective for retaining sand, yet the effectiveness is influenced by material composition and site-specific issues such as littoral cell positions (Griggs and Kinsman 2008).

4.3.3. Passive Solution: Managed Retreat

The need for sustainable and cost-effective shoreline responses has directed attention to the practice of “managed retreat.” Managed retreat removes threatened structures and facilities so the shoreline can advance landward unimpeded. As sea level rises and migrates landward, coastal infrastructure is either demolished or relocated inland (NOAA 2007).

Managed retreat requires that nearshore development be guided by use of land use policies like setbacks and rolling easements. Setbacks prohibit development near the shore, and can result in “takings” claims against property as the shoreline advances landward too close to development (NOAA 2011a). Rolling easements similarly prevent property owners from holding back the sea with stabilization structures, but allow any other type of use and activity on the land, with the owner’s understanding that they will not be able to protect their property from erosion (NOAA 2011b). Practicing managed retreat can reduce the risk of storm flooding, minimize erosion maintenance costs and assist in preserving land for open space uses. Yet, managed retreat can result in the depreciation of shoreline development that is planned for future relocation and/or abandonment.

Currently, managed retreat is not widely practiced, especially in the United States. Given the high value of coastal land, coastal property owners are generally affluent and politically organized. In the event that a coastal area is identified for managed retreat, mobilized property owners can exert significant amounts of influence on politicians responsible for approving coastal policy measures. Yet, there are an increasing number of sites, particularly in areas vulnerable to hurricanes and excessive wave energy, where managed retreat may be the only feasible option (Griggs 2005). In California, managed retreat strategies are ongoing in San Mateo County and at Surfer’s Point in Ventura County, and are being considered in Santa Barbara County. However, the California Coastal Act also limits the implementation of managed retreat strategies since it allows landowners to protect their property (e.g., build a seawall in some instances) when the threat of property loss is “imminent.”

As sea-level rise increases coastal erosion, it is likely that managed retreat will become a viable option, particularly on land that is relatively undeveloped or in areas where more artificial approaches such as nourishment and armoring are unpopular, costly or infeasible.

4.3.4. Protective Structure Costs

The costs of protective structures are highly site-specific. Heberger et al. (2009) synthesized recent literature on the costs to construct new levees, raise existing levees, introduce new seawalls and maintain such structures along the California coast. On average, the capital cost per linear foot (in year 2000 dollars) is $5,300 for a new seawall[22]. Annual maintenance costs range from 1 to 4 percent of the capital construction costs for seawalls and revetments.

To identify the cost of protecting landward development along our study reaches, we made use of a GIS dataset that contains information on existing coastal armoring along the California coastline. This dataset, provided by the CCC, allowed us to identify the placement and type (e.g., revetment, seawall) of existing armoring. However, data on the height, condition and life expectancy of these protective structures was not readily available. These data inputs are necessary for determining the need to strengthen and/or raise existing structures to account for a rise in sea level. Therefore, we assume existing revetments and seawalls are sufficient to protect landward development from a rise in sea level. This assumption may not necessarily be true, as recent events such as the 2011 Japanese tsunami have demonstrated that nature sometimes overcomes human engineering. For unarmored reaches at our study sites, we used GIS to map the backbeach and estimate the costs of protecting the remaining unarmored stretches of shoreline with seawalls.

We made use of Heberger et al. (2009) northern California and southern California regional cost profile, updating these costs to year 2010 dollars with USACE (2009) civil works construction cost indices. When seawall costs are adjusted for inflation and location, the cost per linear foot is approximately $7,200 in northern California and $6,250 in southern California. These default values should be considered conservative as costs can reach $10,000 per linear foot depending on the profile of the structure. Annual maintenance costs are 3 and 2.5 percent of the capital cost of construction for revetments and seawalls, respectively.

[22] These costs do not include permitting and mitigation fees, which will vary on a case-by-case basis, but can reach millions of dollars (e.g., Monterey seawall at Ocean Harbor House Condominiums).

5.0 Results

5.1. Flood Damages

Sea-level rise exacerbates coastal storm damage by both increasing the reach of a flood as well as the depth of flooding within the base hazard zone. These compounding effects (see Figure 17 below) result in damage increases (from a 100-year coastal flood absent sea-level rise to a 100-year coastal flood following a sea-level rise of 1.4 m) ranging between 70 percent at Torrey Pines to 640 percent at Venice Beach.

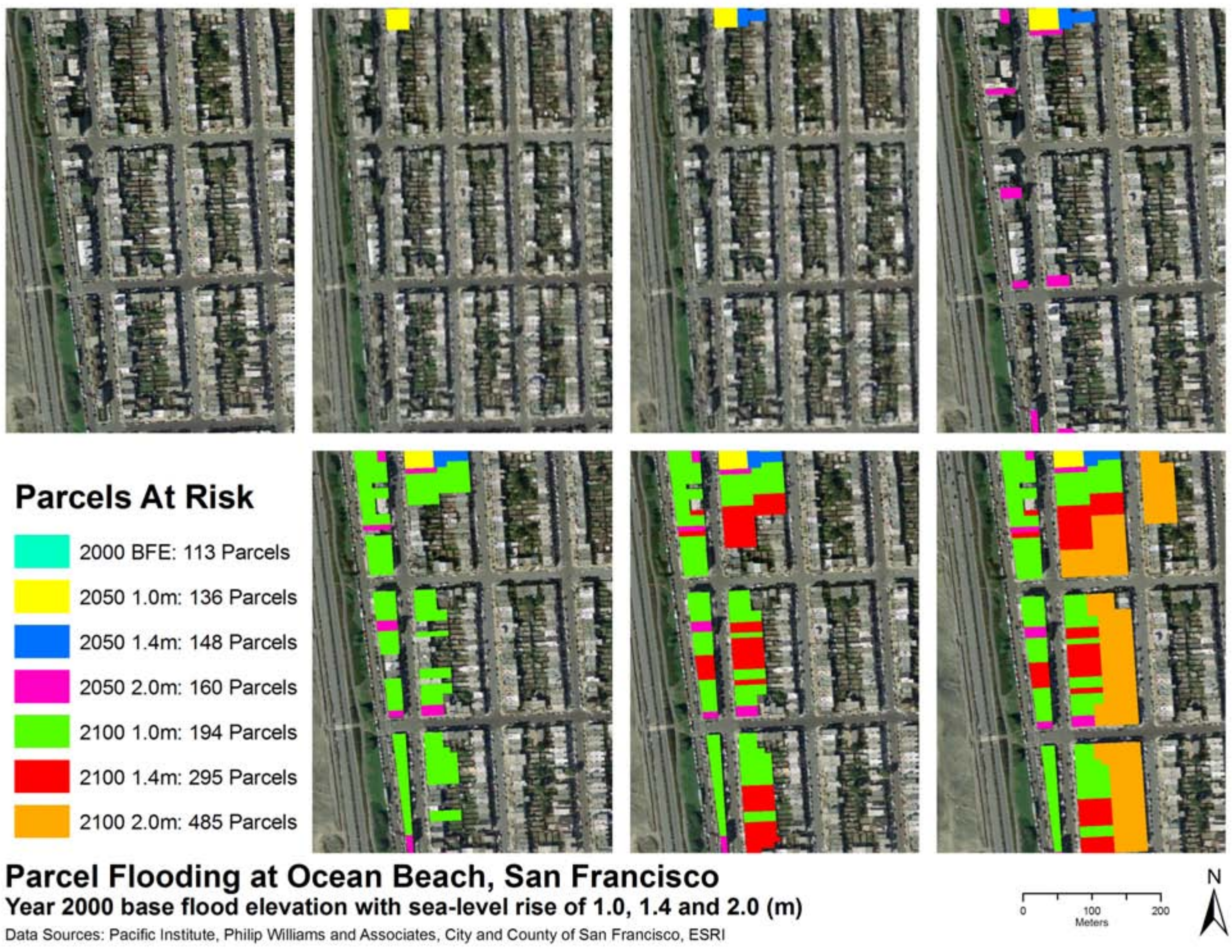

Figure 16. Incremental flood damages[23]

At our study sites, the majority of sea-level rise flooding impacts fall on residential structures and their contents. However, damages to commercial structures and contents can be affected by increased flood depths even more severely; only a meter or so of flooding in retail or grocery stores can damage contents in amounts totaling more than the value of the buildings themselves.

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[23] These structures are located landward of Highway One. The illustrated flooding impacts represent the parcels at risk per scenario, not the perimeter or full extent of the floodplain.

Our results indicate that absent sea-level rise, our study sites are vulnerable to a range of economic damages from a 100-year coastal flood. Sea-level rise exacerbates these flood damages by expanding the floodplain and increasing flood depth. Closer analysis of our results demonstrates that there is a non-linear relationship between the rate of sea-level rise and expected damages. Land elevation and the development beyond the 2000 base flood plain vary greatly by site. These factors, among others, result in "tipping points" or "thresholds" where an increase in the rate of sea-level rise (e.g. from 1.0 m to 1.4 m) results in non-linear increases in damages. For example, at Venice Beach the first m of sea-level rise causes an additional $25 million in damages beyond the base flood, while the next 0.4 m of sea-level rise causes an additional $20 million in damages.

Table 5. Ocean Beach flood damages[24]

Ocean Beach

100-Year Coastal Flood Impacts (millions of 2010 dollars)

Scenario	Baseline	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2000	2050	2100	2050	2100	2050	2100
Residential Structures	4.2	5.8	9.4	6.3	12.6	7.3	24.1
Residential Contents	2.3	3.3	5.2	3.5	7.0	4.1	12.3
Total Residential Damages	6.5	9.1	14.6	9.8	19.6	11.4	36.4
Total Flood Damages	**6.5**	**9.1**	**14.6**	**9.8**	**19.6**	**11.4**	**36.4**
Sea Level Rise Impact							
Damages Beyond Baseline	–	**2.5**	**8.1**	**3.3**	**13.1**	**4.8**	**29.9**
% Increase From Baseline	–	**39%**	**124%**	**50%**	**200%**	**74%**	**457%**

[24] While our study was in review, we received input that led us to adjust the base flood elevations at Ocean Beach. While we accounted for the change in the flood elevations when modeling damages to structures and contents, we did not have the resources to reproduce the footprint of the floodplain for from the ground up.

Table 6. Carpinteria City Beach and Carpinteria State Beach flood damages

Carpinteria

100-Year Coastal Flood Impacts (millions of 2010 dollars)

Scenario	Baseline	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2000	2050	2100	2050	2100	2050	2100
Residential Structures	1.0	1.6	3.4	1.9	5.8	2.3	11.7
Residential Contents	0.5	0.8	1.6	0.9	2.5	1.1	4.4
Total Residential Damages	1.5	2.4	5.0	2.8	8.3	3.4	16.1
Commercial Structures	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Commercial Contents	0.0	0.0	0.1	0.0	0.2	0.0	0.6
Total Commercial Damages	0.0	0.0	0.1	0.0	0.2	0.0	1.1
Institutional Structures	0.0	0.0	0.7	0.4	0.9	0.4	1.0
Institutional Contents	0.0	0.0	1.1	0.8	1.3	0.8	1.3
Total Institutional Damages	0.0	0.0	1.8	1.2	2.2	1.2	2.3
Total Flood Damages	1.5	2.4	6.9	4.0	10.7	4.6	19.5
Sea Level Rise Impact							
Damages Beyond Baseline	–	0.9	5.4	2.5	9.2	3.1	18.0
% Increase From Baseline	–	60%	360%	167%	613%	207%	1,200%

Table 7. Broad Beach and Zuma Beach flood damages

Zuma

100-Year Coastal Flood Impacts (millions of 2010 dollars)

Scenario	Baseline	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2000	2050	2100	2050	2100	2050	2100
Residential Structures	8.0	10.8	15.5	11.5	18.0	13.1	21.6
Residential Contents	4.6	6.3	9.1	6.7	10.5	7.7	12.5
Total Residential Damages	12.6	17.1	24.6	18.2	28.5	20.8	34.1
Commercial Structures	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Commercial Contents	0.0	0.0	0.0	0.0	0.0	0.0	2.4
Total Commercial Damages	0.0	0.0	0.0	0.0	0.0	0.0	3.0
Total Flood Damages	12.6	17.1	24.6	18.2	28.5	20.8	37.1
Sea Level Rise Impact							
Damages Beyond Baseline	–	4.5	12.0	5.6	15.9	8.2	24.5
% Increase From Baseline	–	36%	95%	44%	126%	65%	194%

Table 8. Venice Beach flood damages

Venice

100-Year Coastal Flood Impacts (millions of 2010 dollars)

Scenario	Baseline	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2000	2050	2100	2050	2100	2050	2100
Residential Structures	3.0	5.6	14.6	6.5	24.1	8.7	43.8
Residential Contents	1.3	2.5	6.4	2.9	10.5	3.8	19.0
Total Residential Damages	4.3	8.1	21.0	9.4	34.6	12.5	62.8
Commercial Structures	0.8	1.3	3.3	1.7	5.1	2.0	9.1
Commercial Contents	1.9	3.1	7.1	3.9	11.4	4.8	23.2
Total Commercial Damages	2.7	4.4	10.4	5.6	16.5	6.8	32.3
Institutional Structures	0.0	0.0	0.1	0.0	0.2	0.0	0.5
Institutional Contents	0.0	0.1	0.1	0.1	0.3	0.1	0.6
Total Institutional Damages	0.0	0.1	0.2	0.1	0.5	0.1	1.1
Total Flood Damages	**7.0**	**12.6**	**31.6**	**15.1**	**51.6**	**19.4**	**96.2**
Sea Level Rise Impact							
Damages Beyond Baseline	–	5.6	24.6	8.1	44.6	12.4	89.2
% Increase From Baseline	–	80%	351%	116%	637%	177%	1,274%

Table 9. Torrey Pines State Beach flood damages

Torrey Pines

100-Year Coastal Flood Impacts (millions of 2010 dollars)

Scenario	Baseline	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2000	2050	2100	2050	2100	2050	2100
Residential Structures	1.0	1.2	1.4	1.2	1.5	1.3	1.8
Residential Contents	0.4	0.5	0.6	0.5	0.7	0.6	0.8
Total Residential Damages	1.4	1.7	2.0	1.7	2.2	1.9	2.6
Commercial Structures	0.4	0.5	0.7	0.5	1.2	0.6	1.7
Commercial Contents	1.2	1.2	1.2	1.2	1.6	1.2	2.4
Total Commercial Damages	1.6	1.7	1.9	1.7	2.8	1.8	4.1
Total Flood Damages	**3.0**	**3.4**	**3.9**	**3.4**	**5.0**	**3.7**	**6.7**
Sea Level Rise Impact							
Damages Beyond Baseline	–	0.4	0.9	0.4	2.0	0.7	3.7
% Increase From Baseline	–	13%	30%	13%	67%	23%	123%

5.2. Upland Erosion Damages

In the coming century, accelerating rates of cliff and bluff erosion following a rise in sea level poses significant upland damages that vary in nature between sites. Upland damages are concentrated in residential structure and land losses at Ocean Beach, institutional land in Carpinteria and railway damage in Torrey Pines. Both Ocean Beach and Torrey Pines also experience damages to major and minor roads.

Similar to our flood results, damage thresholds and/or tipping points are observed when modeling coastal erosion following a rise in sea level. The LOSSAN rail corridor runs upland of Torrey Pines State Beach. If historical erosion rates continued to the end of the century, only $4.5 million of track would be at risk. However, an acceleration of historical erosion rates from a 1.0 m, 1.4 m and 2.0 m sea-level rise increases the amount of railway at risk by approximately $334, $349 and $374 million. The irregularity and non-linearity of the relationship between incremental rises in sea level and upland erosion damages is highlighted at Ocean Beach as well (see Figure 18 below).

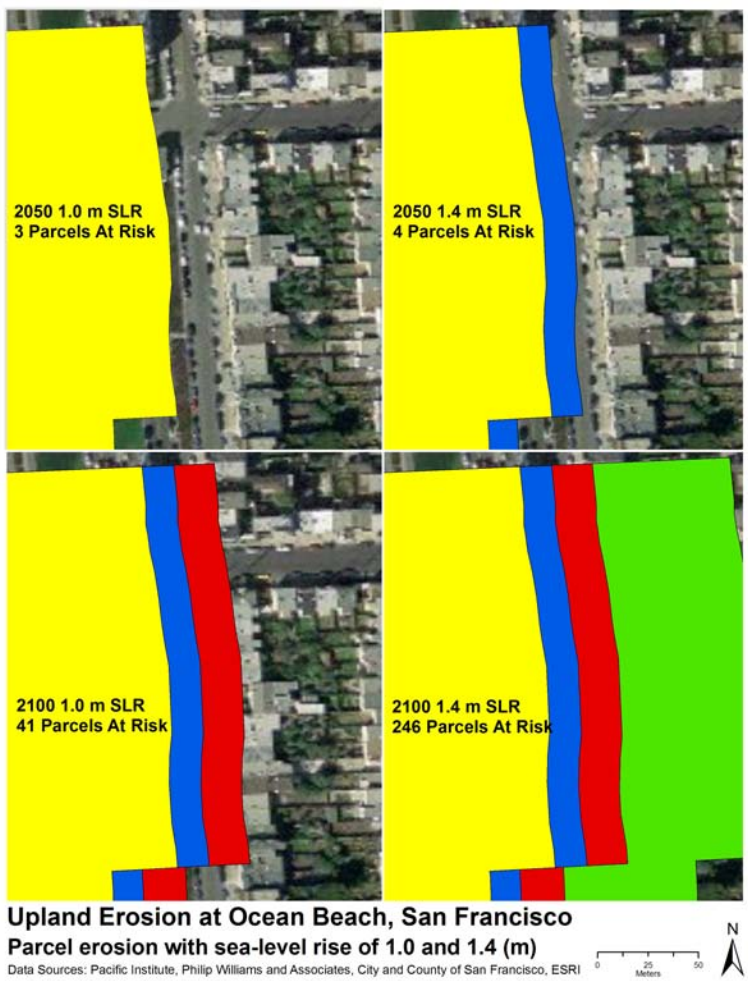

Figure 17. Incremental Upland Erosion Damages

Table 10. Ocean Beach upland erosion damages

Ocean Beach

Upland Erosion Impacts (millions of 2010 dollars)

Scenario	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise	
	2050	2100	2050	2100
Residential Land Damages	2.0	23.3	2.0	160.7
Residential Structure Damages	0.5	6.3	0.5	54.9
Commercial Land Damages	0.0	0.0	0.0	5.4
Commercial Structure Damages	0.0	0.0	0.0	4.0
Institutional Land Damages	0.0	0.0	0.0	1.4
Institutional Structure Damages	0.0	0.0	0.0	0.2
Miscellaneous Land Damages	0.0	0.0	0.0	1.7
Miscellaneous Structure Damages	0.0	0.0	0.0	0.1
Major Road Damages	47.0	133.1	95.0	264.7
Local Road Damages	0.0	14.4	2.0	47.2
Total Damages	**49.5**	**177.1**	**99.5**	**540.3**

Table 11. Carpinteria City Beach and Carpinteria State Beach upland erosion damages

Carpinteria

Upland Erosion Impacts (millions of 2010 dollars)

Scenario	Continued Historical Erosion		1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100	2050	2100
Institutional Land Damages	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.3
Sea Level Rise Impact								
Damages Beyond Baseline	–	–	**0.001**	**0.008**	**0.002**	**0.012**	**0.002**	**0.017**
% Increase From Baseline	–	–	**1%**	**3%**	**2%**	**4%**	**2%**	**5%**

Table 12. Torrey Pines State Beach upland erosion damages

Torrey Pines

Upland Erosion Impacts (millions of 2010 dollars)

Scenario	Continued Historical Erosion		1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100	2050	2100
Institutional Land Damages	3.9	4.1	4.0	8.4	4.0	8.7	7.8	9.0
Road Damages	0.0	0.0	0.0	0.0	0.0	0.2	0.0	5.1
Railroad Damages	0.0	0.4	0.0	330.5	0.0	344.4	0.0	364.8
Total Damages	3.9	4.5	4.0	338.9	4.0	353.2	7.8	378.9
Sea Level Rise Impact								
Damages Beyond Baseline	–	–	**0.1**	**334.4**	**0.1**	**348.7**	**3.9**	**374.4**
% Increase From Baseline	–	–	**3%**	**7,421%**	**4%**	**7,739%**	**101%**	**8,308%**

5.3. Beach Erosion Damages

Beach erosion can result in losses of recreation value, habitat value, tourism-related spending and tax revenue. A rise in sea level elevation can reduce beach width; this is particuarly the case for shorelines where the backbeach is fixed. Modeling beach erosion with the Bruun Rule allows one to calculate the area of beach eroded away passively due to rising sea levels where the backbeach is fixed by armoring.

Sandy beaches at our study sites experience varying amounts of erosion. At Ocean Beach and Torrey Pines State Beach, 100 percent of original sandy beach area will passively erode by 2100 following a 2.0 m sea-level rise. At Venice Beach, only 24 percent of beach area erodes under this scenario. The area of beach at risk to passive erosion is influenced by the existing width of the beach and beach profile characteristics such as berm elevation, depth of closure and foreshore slope.

Recreational value losses occur as reductions in beach width decrease visitors' willingness to pay for a day at the beach. Following a 1.4 m sea-level rise, aggregate recreational losses total $15 million at Ocean Beach, compared to $102 million at Zuma Beach. Higher damages occur at Zuma Beach due to higher attendance; on average, there are one-half million annual visitors to Ocean Beach, and over seven million annual visitors at Zuma Beach.

As beaches erode, habitat losses occur in the form of biodiversity value, ecological services and storm damage prevention benefits. Damages, a function of total beach area at risk to erosion, are most significant at Ocean Beach, where a 2.0 m sea-level rise by 2100 results in 57 acres of beach loss and habitat losses topping $700,000.

Spending and tax losses will occur as reductions in beach width limit the carrying capacity of beaches and reduce annual attendance loads. Similar to recreational losses, the most significant impacts are experienced at beaches that experience high levels of beach loss and host large numbers of annual visitors. Combined local and state spending losses amount to $608 million at Venice Beach following a 2.0 m sea-level rise by 2100. Corresponding local and state tax losses amount to $16 million.

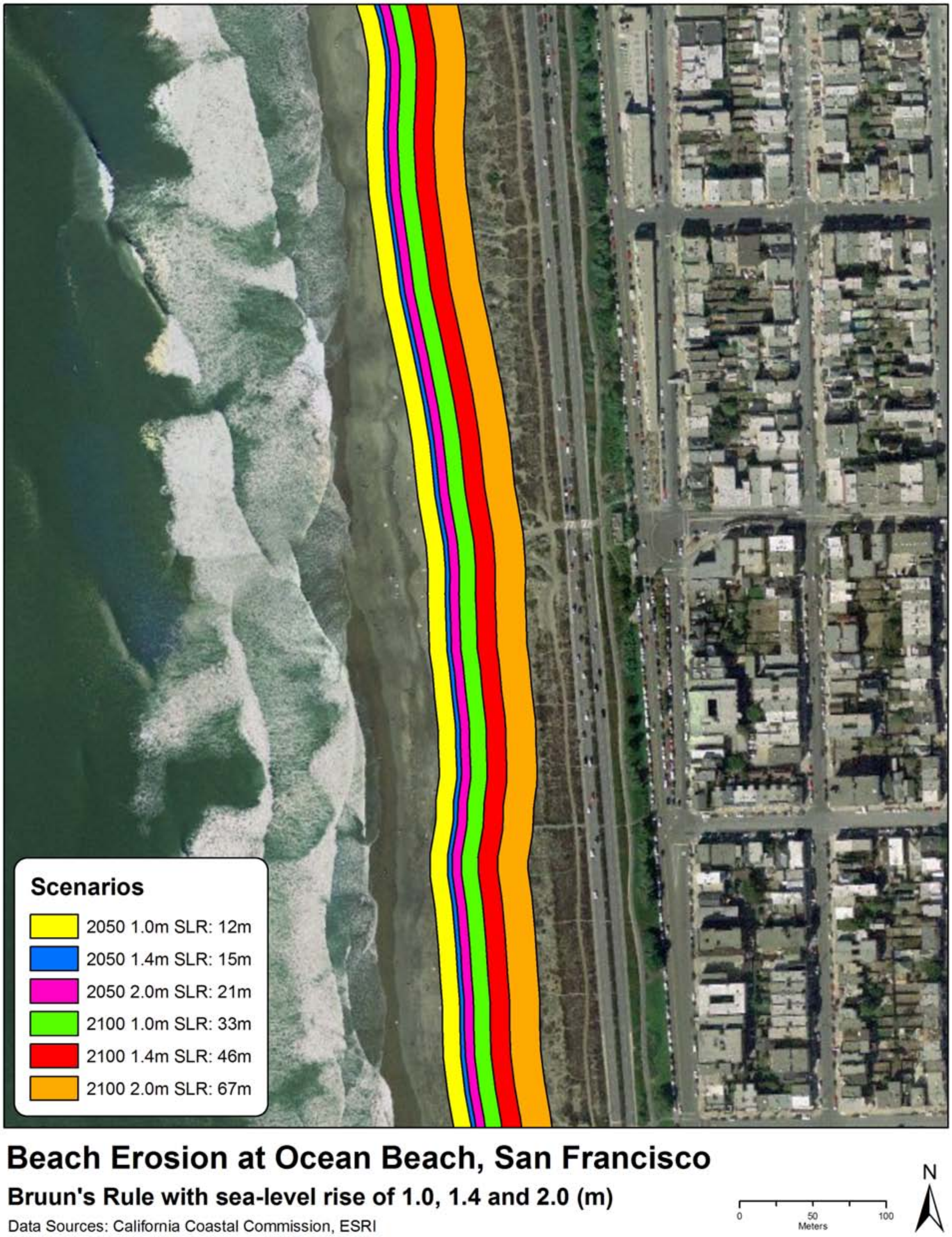

Figure 18. Beach erosion modeled using the Bruun rule

Table 13. Beach erosion damages at Ocean Beach

Ocean Beach

Annual Beach Benefits

(millions of 2010 dollars)

Scenario	Baseline	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2000	2050	2100	2050	2100	2050	2100
Beach Area Eroded	0.0 acres	13.8 acres	37.5 acres	17.2 acres	52.9 acres	24.6 acres	57.4 acres
Percent Area Eroded	0.0%	24.0%	65.3%	30.0%	92.0%	42.8%	100.0%
Recreation Value	3.4	2.8	1.3	2.6	0.0	2.2	0.0
Habitat Value	0.09	0.07	0.30	0.06	0.01	0.05	0.00
Total Annual Rec/Habitat Value	**3.5**	**2.9**	**1.6**	**2.7**	**0.0**	**2.3**	**0.0**
Direct Local Spending	9.9	8.7	4.7	8.2	0.0	7.3	0.0
Direct State Spending	12.4	10.9	5.9	10.2	0.0	9.1	0.0
Total Annual Spending	**22.3**	**19.6**	**10.6**	**18.4**	**0.0**	**16.4**	**0.0**
Direct Local Tax Revenue	0.2	0.2	0.1	0.2	0.0	0.2	0.0
Direct State Tax Revenue	1.4	1.3	0.7	1.2	0.0	1.0	0.0
Total Annual Tax Revenue	**1.6**	**1.5**	**0.8**	**1.4**	**0.0**	**1.2**	**0.0**

Ocean Beach

Discount Rate: 3%

Aggregate Beach Erosion Impacts

(millions of 2010 dollars)

Scenario	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Beach Area Eroded	13.8 acres	37.5 acres	17.2 acres	52.9 acres	24.6 acres	57.4 acres
Percent Area Eroded	24.0%	65.3%	30.0%	92.0%	42.8%	100.0%
PV Total Recreation Value Losses	4.5	10.5	6.0	15.2	8.4	21.9
PV Total Habitat Value Losses	0.2	0.4	0.2	0.5	0.3	0.7
Total Rec/Habitat Value Losses	**4.9**	**11.4**	**6.5**	**16.5**	**9.1**	**23.6**
PV Direct Local Spending Losses	9.2	23.0	12.5	35.5	17.9	54.5
PV Direct State Spending Losses	11.4	28.8	15.6	44.4	22.4	68.2
Total Spending Losses	**20.6**	**51.8**	**28.1**	**80.0**	**40.3**	**122.7**
PV Direct Local Tax Losses	0.2	0.6	0.3	0.9	0.4	1.4
PV Direct State Tax Losses	0.6	0.8	0.7	1.1	1.1	1.7
Total Tax Revenue Losses	**0.8**	**1.4**	**1.1**	**2.0**	**1.5**	**3.0**

Table 14. Beach erosion damages at Carpinteria City Beach and Carpinteria State Beach

Carpinteria

Annual Beach Benefits

(millions of 2010 dollars)

Scenario	Baseline	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2000	2050	2100	2050	2100	2050	2100
Beach Area Eroded	0.0 acres	2.2 acres	6.1 acres	2.8 acres	8.5 acres	4.0 acres	12.4 acres
Percent Area Eroded	0.0%	11.5%	31.4%	14.4%	44.2%	20.6%	64.1%
Recreation Value	15.7	14.5	11.8	14.0	10.0	13.0	5.9
Habitat Value	0.06	0.06	0.04	0.05	0.03	0.01	0.00
Total Annual Rec/Habitat Value	**15.8**	**14.6**	**11.8**	**14.1**	**10.0**	**13.0**	**5.9**
Direct Local Spending	38.0	35.9	31.0	35.1	27.2	33.8	19.5
Direct State Spending	76.0	71.9	62.0	70.2	54.4	67.7	38.9
Total Annual Spending	**114.0**	**107.8**	**93.0**	**105.3**	**81.6**	**101.5**	**58.4**
Direct Local Tax Revenue	1.0	0.9	0.8	0.9	0.7	0.8	0.5
Direct State Tax Revenue	8.7	8.3	7.1	8.1	6.3	7.8	4.5
Total Annual Tax Revenue	**9.7**	**9.2**	**7.9**	**9.0**	**7.0**	**8.6**	**5.0**

Carpinteria

Discount Rate: 3%

Aggregate Beach Erosion Impacts

(millions of 2010 dollars)

Scenario	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Beach Area Eroded	2.2 acres	6.1 acres	2.8 acres	8.5 acres	4.0 acres	12.4 acres
Percent Area Eroded	11.5%	31.4%	14.4%	44.2%	20.6%	64.1%
PV Total Recreation Value Losses	9.8	22.3	13.1	30.8	20.0	48.9
PV Total Habitat Value Losses	0.1	0.1	0.1	0.2	0.1	0.2
Total Rec/Habitat Value Losses	**9.9**	**22.7**	**13.3**	**31.3**	**20.3**	**49.6**
PV Direct Local Spending Losses	16.3	38.0	21.9	53.5	30.6	79.5
PV Direct State Spending Losses	32.5	76.0	43.8	107.0	61.1	159.1
Total Spending Losses	**48.8**	**113.9**	**65.6**	**160.4**	**91.7**	**238.6**
PV Direct Local Tax Losses	0.4	0.9	0.5	1.3	0.8	2.0
PV Direct State Tax Losses	1.6	2.2	2.1	3.0	2.9	4.3
Total Tax Revenue Losses	**2.0**	**3.1**	**2.7**	**4.3**	**3.7**	**6.2**

Table 15. Beach erosion damages at Broad Beach and Zuma Beach

Zuma

Annual Beach Benefits

(millions of 2010 dollars)

Scenario	Baseline	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2000	2050	2100	2050	2100	2050	2100
Beach Area Eroded	0.0 acres	4.2 acres	11.3 acres	5.2 acres	16.0 acres	7.4 acres	23.1 acres
Percent Area Eroded	0.0%	8.6%	23.4%	10.7%	32.9%	15.3%	47.7%
Recreation Value	71.0	66.9	58.3	65.4	52.7	63.0	43.3
Habitat Value	0.10	0.09	0.08	0.09	0.07	0.08	0.05
Total Annual Rec/Habitat Value	**71.1**	**67.0**	**58.4**	**65.5**	**52.8**	**63.1**	**43.4**
Direct Local Spending	173.6	166.7	151.1	164.0	140.0	159.8	120.0
Direct State Spending	217.0	208.3	188.8	205.0	175.0	199.8	150.0
Total Annual Spending	**390.6**	**375.0**	**339.9**	**369.0**	**315.0**	**359.6**	**270.0**
Direct Local Tax Revenue	4.3	4.2	3.8	4.1	3.5	4.0	3.0
Direct State Tax Revenue	25.0	24.0	21.7	23.6	20.1	23.0	17.2
Total Annual Tax Revenue	**29.3**	**28.2**	**25.5**	**27.7**	**23.6**	**27.0**	**20.2**

Zuma

Discount Rate: 3%

Aggregate Beach Erosion Impacts

(millions of 2010 dollars)

Scenario	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Beach Area Eroded	4.2 acres	11.3 acres	5.2 acres	16.0 acres	7.4 acres	23.1 acres
Percent Area Eroded	8.6%	23.4%	10.7%	32.9%	15.3%	47.7%
PV Total Recreation Value Losses	32.8	74.3	43.8	102.2	60.5	145.4
PV Total Habitat Value Losses	0.1	0.1	0.1	0.2	0.1	0.3
Total Rec/Habitat Value Losses	**32.9**	**74.5**	**43.9**	**102.3**	**60.6**	**145.6**
PV Direct Local Spending Losses	54.8	126.4	73.6	176.0	102.2	256.0
PV Direct State Spending Losses	68.6	158.0	92.0	220.1	127.8	320.0
Total Spending Losses	**123.4**	**284.5**	**165.5**	**396.1**	**230.1**	**576.0**
PV Direct Local Tax Losses	1.4	3.2	1.8	4.4	2.6	6.4
PV Direct State Tax Losses	3.4	4.6	4.5	6.2	6.2	8.8
Total Tax Revenue Losses	**4.7**	**7.8**	**6.3**	**10.6**	**8.7**	**15.2**

Table 16. Beach erosion damages at Venice Beach

Venice

Annual Beach Benefits

(millions of 2010 dollars)

Scenario	Baseline	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2000	2050	2100	2050	2100	2050	2100
Beach Area Eroded	0.0 acres	6.6 acres	18.0 acres	8.3 acres	25.3 acres	11.8 acres	36.7 acres
Percent Area Eroded	0.0%	4.3%	11.6%	5.3%	16.4%	7.6%	23.7%
Recreation Value	78.2	76.7	73.5	76.1	71.4	75.2	68.1
Habitat Value	0.33	0.32	0.29	0.31	0.28	0.31	0.25
Total Annual Rec/Habitat Value	**78.5**	**77.0**	**73.8**	**76.4**	**71.7**	**75.5**	**68.4**
Direct Local Spending	393.1	385.5	369.5	382.6	359.1	378.3	342.4
Direct State Spending	491.4	481.8	461.8	478.3	448.9	472.8	428.0
Total Annual Spending	**884.5**	**867.3**	**831.3**	**860.9**	**808.0**	**851.1**	**770.4**
Direct Local Tax Revenue	9.8	9.6	9.2	9.6	9.0	9.5	8.6
Direct State Tax Revenue	56.5	55.4	53.1	55.0	51.6	54.4	49.2
Total Annual Tax Revenue	**66.3**	**65.0**	**62.3**	**64.6**	**60.6**	**63.9**	**57.8**

Venice

Discount Rate: 3%

Aggregate Beach Erosion Impacts

(millions of 2010 dollars)

Scenario	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Beach Area Eroded	6.6 acres	18.0 acres	8.3 acres	25.3 acres	11.8 acres	36.7 acres
Percent Area Eroded	4.3%	11.6%	5.3%	16.4%	7.6%	23.7%
PV Total Recreation Value Losses	12.2	27.5	16.2	37.8	22.4	53.7
PV Total Habitat Value Losses	0.1	0.2	0.1	0.3	0.2	0.5
Total Rec/Habitat Value Losses	**12.4**	**28.1**	**16.6**	**38.6**	**22.9**	**54.8**
PV Direct Local Spending Losses	61.1	138.4	81.6	190.2	112.7	270.1
PV Direct State Spending Losses	76.4	173.0	102.0	237.7	140.9	337.6
Total Spending Losses	**137.5**	**311.5**	**183.6**	**427.9**	**253.5**	**607.7**
PV Direct Local Tax Losses	1.5	3.5	2.0	4.8	2.8	6.8
PV Direct State Tax Losses	3.7	5.1	5.0	6.9	6.8	9.5
Total Tax Revenue Losses	**5.3**	**8.6**	**7.0**	**11.6**	**9.6**	**16.3**

Table 17. Beach erosion damages at Torrey Pines State Beach

Torrey Pines

Annual Beach Benefits

(millions of 2010 dollars)

Scenario	Baseline	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2000	2050	2100	2050	2100	2050	2100
Beach Area Eroded	0.0 acres	11.3 acres	30.8 acres	14.1 acres	43.3 acres	20.2 acres	56.6 acres
Percent Area Eroded	0.0%	20.0%	54.3%	24.9%	76.5%	35.6%	100.0%
Recreation Value	5.6	4.9	3.0	4.6	1.3	4.1	0.0
Habitat Value	0.010	0.008	0.004	0.007	0.002	0.006	0.000
Total Annual Rec/Habitat Value	**5.6**	**4.9**	**3.0**	**4.6**	**1.3**	**4.1**	**0.0**
Direct Local Spending	15.8	14.2	9.8	13.6	4.7	12.5	0.0
Direct State Spending	19.7	17.8	12.2	17.0	5.9	15.6	0.0
Total Annual Spending	**35.5**	**32.0**	**22.0**	**30.6**	**10.6**	**28.1**	**0.0**
Direct Local Tax Revenue	0.4	0.4	0.2	0.3	0.1	0.3	0.0
Direct State Tax Revenue	2.3	2.0	1.4	2.0	0.7	1.8	0.0
Total Annual Tax Revenue	**2.7**	**2.4**	**1.6**	**2.3**	**0.8**	**2.1**	**0.0**

Torrey Pines

Discount Rate: 3%

Aggregate Beach Erosion Impacts

(millions of 2010 dollars)

Scenario	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Beach Area Eroded	11.3 acres	30.8 acres	14.1 acres	43.3 acres	20.2 acres	56.6 acres
Percent Area Eroded	20.0%	54.3%	24.9%	76.5%	35.6%	100.0%
PV Total Recreation Value Losses	6.1	14.2	8.2	20.1	11.4	30.0
PV Total Habitat Value Losses	0.02	0.03	0.02	0.04	0.03	0.06
Total Rec/Habitat Value Losses	**6.1**	**14.3**	**8.3**	**20.2**	**11.5**	**30.2**
PV Direct Local Spending Losses	11.9	29.0	16.1	42.9	22.9	63.7
PV Direct State Spending Losses	14.8	36.2	20.2	53.6	28.6	79.6
Total Spending Losses	**26.7**	**65.2**	**36.3**	**96.5**	**51.5**	**143.3**
PV Direct Local Tax Losses	0.3	0.7	0.4	1.1	0.6	1.6
PV Direct State Tax Losses	0.7	1.0	1.0	1.4	1.4	2.1
Total Tax Revenue Losses	**1.0**	**1.7**	**1.4**	**2.5**	**1.9**	**3.7**

5.4. Adaptation Costs

We modeled adaptation costs for armoring the shoreline and nourishing the beach. Modeling the adaptation costs for managed retreat strategies was beyond the scope of this project, requiring additional geophysical, ecological and economic modeling efforts. A comprehensive analysis of managed retreat options has yet to be fully modeled along most stretches of California's coastline. The most comprehensive analysis of shoreline erosion mitigation strategies, including several managed retreat strategies, was recently completed for the Southern Monterey Bay region (see PWA-ESA 2011).

5.4.1. Hard Stabilization Costs

Table 18 exhibits the initial capital costs of armoring currently unprotected reaches of shoreline at each study site with seawalls, totaling upward of $93 million at Zuma and Broad Beach. Seawalls also require annual maintenance, which, for four study sites, would cost more than $2 million per year.

Table 18. Capital costs and annual maintenance costs for seawalls and revetments

Coastal Armoring (millions of 2010 dollars)

Site	Capital Costs	Annual Maintenance Costs
Ocean Beach	55.7	2.8
Carpinteria	28.4	1.0
Zuma	92.9	2.3
Venice	67.9	2.1
Torrey Pines	68.5	2.1

5.4.2. Soft Stabilization Costs (Nourishment)

Some beaches, particularly in tourist-rich southern California, are periodically nourished with sand, to either replace eroded sand, increase a storm buffer, or both. Under accelerated beach erosion from sea-level rise, nourishment requirements will likely increase as water levels rise. For nourishment regimes to keep pace with increased erosion, coastal planners must incorporate sea-level rise into long-term planning.

Tables 19-23 (below) show the volume of nourishment required to replace future sand loss at each study site, and the net present value of the cost of annual nourishment (@ $10 per cubic meter) (Flick and Ewing 2009). It should be noted that the Bruun Rule does not account for longshore drift. Large wave events can pull sand offshore to depths of 30 m or more, which is beyond the normal closure depth for many beaches in California (Flick and Ewing 2009). These events can restart coastal conditions, and, similar to Flick and Ewing (2009), we assume that each large event strips offshore all past nourishment added to maintain beach. For illustrative purposes, three storm events were modeled in 2025, 2050 and 2075. The additional sand volume and corresponding costs to restore the pre-storm profiles were tabulated and are presented in tables 19-23 below. The dates of these storm events are hypothetical. The time when a storm event occurs directly influences the volume of sand needed for replenishment. For example, a storm event in the early part of the century would require less volume and have a smaller replenishment cost than a storm event occurring in the latter part of the century.

Also, it should be noted that to improve the effectiveness of nourishment projects, perpendicular shoreline structures such as groins could be introduced. Groins would result in larger capital costs, but could reduce the amount of nourishment needed to maintain beach width as sea level rises.

Table 19. Ocean Beach nourishment costs

Ocean

Discount Rate: 3%

Beach Nourishment Requirements

(millions of 2010 dollars)

No Storm Events	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Cubic Meters of Sand Loss	815,000	2,218,000	1,018,000	3,123,000	1,454,000	4,526,000
PV Sand Replenishment Cost	4.4	7.2	5.4	10.2	7.8	14.8

Three Storm Events	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Cubic Meters of Sand Loss	1,969,000	4,798,000	2,444,000	6,450,000	3,433,000	9,293,000
PV Sand Replenishment Cost	7.8	12.3	9.7	16.5	13.6	23.6

Table 20. Carpinteria City Beach and Carpinteria State Beach nourishment costs

Carpinteria

Beach Nourishment Requirements

Discount Rate: 3%

(millions of 2010 dollars)

No Storm Events	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Cubic Meters of Sand Loss	95,000	257,000	118,000	362,000	169,000	525,000
PV Sand Replenishment Cost	0.5	0.8	0.6	1.2	0.9	1.7

Three Storm Events	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Cubic Meters of Sand Loss	229,000	556,000	283,000	748,000	399,000	1,078,000
PV Sand Replenishment Cost	0.9	1.4	1.1	1.9	1.6	2.7

Table 21. Zuma Beach and Broad Beach nourishment costs

Zuma and Broad

Beach Nourishment Requirements

Discount Rate: 3%

(millions of 2010 dollars)

No Storm Events	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Cubic Meters of Sand Loss	219,000	596,000	274,000	840,000	391,000	1,217,000
PV Sand Replenishment Cost	1.2	1.9	1.5	2.7	2.1	4.0

Three Storm Events	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Cubic Meters of Sand Loss	529,000	1,290,000	657,000	1,734,000	923,000	2,499,000
PV Sand Replenishment Cost	2.1	3.3	2.7	4.4	3.7	6.4

Table 22. Venice Beach nourishment costs

Venice

Beach Nourishment Requirements

Discount Rate: 3%

(millions of 2010 dollars)

No Storm Events	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Cubic Meters of Sand Loss	348,000	947,000	435,000	1,334,000	621,000	1,933,000
PV Sand Replenishment Cost	1.9	3.1	2.3	4.3	3.3	6.3

Three Storm Events	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Cubic Meters of Sand Loss	841,000	2,049,000	1,044,000	275,500	1,466,000	3,969,000
PV Sand Replenishment Cost	3.4	5.2	4.2	7.1	5.8	10.1

Table 23. Torrey Pines State Beach nourishment costs

Torrey Pines

Beach Nourishment Requirements

Discount Rate: 3%

(millions of 2010 dollars)

No Storm Events	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Cubic Meters of Sand Loss	502,000	1,366,000	627,000	1,924,000	896,000	2,788,000
PV Sand Replenishment Cost	2.7	4.5	3.4	6.3	4.8	9.1

Three Storm Events	1.0 m Sea-Level Rise		1.4 m Sea-Level Rise		2.0 m Sea-Level Rise	
	2050	2100	2050	2100	2050	2100
Cubic Meters of Sand Loss	1,213,000	2,955,000	1,505,000	3,973,000	2,115,000	5,724,000
PV Sand Replenishment Cost	4.8	7.6	6.0	10.2	8.4	14.6

5.5. Discussion of Results

To keep this discussion manageable, this discussion is limited to an overview of damages following a respective 1.4 m sea-level rise in 2050 and 2100. See Section 5.0 for a detailed breakdown of hazard damages and adaptation costs following a respective 1.0, 1.4 and 2.0 m sea-level rise in 2050 and 2100. All damages estimates are derived from the methods and assumptions (e.g., it is possible for more than one large storm event to happen in the coming century, resulting in compounding damages) described in Sections 4.0 and 5.0 of this paper.

5.5.1. Ocean Beach, San Francisco

We limited our analysis to the reach of shoreline north of Sloat Avenue; the reach south of Sloat contains significant water treatment infrastructure and modeling these issues was beyond the scope and budget of this project.

At Ocean Beach, a 100-year storm following a 1.4 m rise in sea level could result in approximately $10 million and $20 million (2010 dollars) in damages to structures and their contents in 2050 and 2100, respectively. If a 1.4 m sea-level rise is realized, accelerated landward erosion at unarmored reaches of the backbeach could result in $100 to $540 million (2010 dollars) in damages in 2050 and 2100, respectively.

These damage estimates demonstrate that in the context of sea-level rise, backbeach erosion at Ocean Beach is of a greater economic concern than flooding in the coming decades. There are various adaptation strategies that can assist in minimizing flood and upland erosion damage, including armoring the shoreline and nourishing the beach. We estimate that Ocean Beach's shoreline could be fixed by armoring for a capital cost of $56 million (2010 dollars) and annual maintenance infusions of $3 million (2010 dollars).

It may appear that armoring the shoreline could result in net economic benefits; the capital costs could change substantially depending on the year of placement and maintenance costs would significantly increase as the beach and its ability to dissipate wave energy is lost. However, if one fixes the shoreline, sea-level rise will passively swallow the beach. By 2100, the coastal erosion following a 1.4 m sea-level rise could eliminate over 90 percent of the existing beach and produce losses to recreational and habitat value of $16.5 million (NPV), lost state and local spending totaling $80 million (NPV) and lost state and local sales tax totaling $2 million (NPV). Using nourishment projects to maintain the existing beach width would require at least $16 million (NPV). While nourishment could help to minimize losses related to recreational value, spending, and taxes, nourishment could also result in reductions to habitat value which we have not modeled in this analysis.

Allowing the beach to retreat landward unimpeded can help support the existing beach width without the added costs of nourishment, safeguarding the recreational and habitat services that are threatened when the backbeach is armored. Upland erosion damages increase from $100 million at mid-century to $540 million at the end of the century. Further, nearly 98% of damages associated with backbeach erosion at mid-century are directly tied to structural adjustment costs to ensure the continued operation of major and minor roads that fall in the hazard zone. Detailed transportation analyses of adjacent road networks could identify if structural adjustments could be forgone for more cost-effective mechanisms that will ensure the mobility of existing and future users. If more cost-effective mechanisms exist, managed retreat of the shoreline could result in significant economic benefits up to mid-century and potentially beyond; allowing for an adaptive planning framework as the hazard zone approaches other forms of critical infrastructure.

5.5.2. Carpinteria State Beach and Carpinteria City Beach, Carpinteria

At Carpinteria State and Carpinteria City Beach, a 100-year storm following a 1.4 m rise in sea level could result in approximately $4 million and $10 million (2010 dollars) in damages to structures and their contents in 2050 and 2100, respectively. If a 1.4 m sea-level rise is realized, accelerated bluff erosion at the southern end of the State campground could result in $0.1 to $0.3 million (2010 dollars) in damages in 2050 and 2100 respectively.

To evaluate various adaptation approaches, we assume that unarmored reaches of the backbeach that hosts structures, parking lots and dedicated open-space will be armored, the capital cost of taking such an action valued at approximately $28 million (2010 dollars) with annual maintenance infusions of $1 million (2010 dollars); the capital costs could change substantially depending on the year of placement and maintenance costs would significantly increase as the beach and its ability to dissipate wave energy is lost.

According to the analysis in this paper, the costs of armoring Carpinteria's shoreline outweighs the associated benefits of flood reduction (flooding risk can be traced to both the open coast and flood pathways connecting to the adjacent salt marsh) and bluff stabilization provided by fixing the backbeach with hard-engineering structures. Further, if one fixes the shoreline with armoring, a 1.4 m sea-level rise could passively reduce one-third of the beach profile by 2100, resulting in losses to recreational and habitat value reaching $31 million (NPV), lost state and local spending totaling $160 million (NPV) and lost state and local sales tax totaling over $4 million (NPV). Using nourishment projects to maintain the existing beach width would require almost $2 million (NPV). While nourishment presents an economically feasible way to counteract losses related to recreational value, spending, and taxes, nourishment could also result in reductions to habitat value not modeled in this paper.

Land uses along Carpinteria's shoreline are highly segregated. To the north, the City beach hosts residential structures. To the south, the State beach hosts a beach parking lot and State Park campgrounds. While the residential structures to the north have high market value, the campsites to the south also high economic value that may be underestimated here. Allowing the beach to migrate landward could result in significant economic impacts, especially as the shoreline approaches residential structures to the north and campsites to the south. Yet, impeding natural beach processes by armoring the beach, will allow for sea-level rise to passively swallow the beach profile, resulting in extensive losses related to recreational value, spending, and taxes.

A combination of armoring, nourishment, placement of winter berms and managed retreat along varying sections of the shoreline could assist in striking a balance of protecting public property and public trust resources while minimizing losses to recreational value, spending and taxes, and habitat services. Additional analysis of relocating parking lots, open space fields, and campsites would further bolster an incremental and adaptive management framework designed for instituting multiple planning approaches.

5.5.3. Zuma Beach and Broad Beach, Malibu

At Zuma Beach and Broad Beach, a 100-year storm following a 1.4 m rise in sea level could result in approximately $18.2 million and $28.5 million (2010 dollars) in damages to structures and their contents in 2050 and 2100, respectively.

To evaluate various adaptation approaches, we assume that unarmored reaches of the backbeach that host structures, parking lots and dedicated open-space will be armored, the capital cost of armoring is estimated to be approximately $93 million (2010 dollars) with annual maintenance infusions of at least $2 million (2010 dollars); the capital costs could change substantially depending on the year of placement and maintenance costs would significantly increase as the beach and its ability to dissipate wave energy is lost.

The total cost of armoring the shoreline at Zuma Beach and Broad Beach outweighs the associated benefits of flood reduction; an overwhelming majority of benefits are directly tied to protecting residential structures at the back of Broad Beach. Further, if one fixes the shoreline with armoring, sea-level rise will reduce beach size substantially. By 2100, the coastal erosion following a 1.4 m sea-level rise could result in combined losses to recreational and habitat value reaching $102 million (NPV), lost state and local spending totaling $396 million (NPV) and lost state and local sales tax totaling nearly $11 million (NPV). Using nourishment projects to maintain the existing beach width would require $4.4 million (NPV). While nourishment presents an economically feasible way to counteract losses related to recreational value, spending, and taxes, nourishment could also result in reductions to habitat value not estimated in this report.

Zuma Beach and Broad Beach present different thresholds to risk from low-probability storm events and beach erosion following a rise in sea level. Broad Beach maintains a narrow beach profile that fronts high-valued residential structures. These structures are already susceptible to wave attack, and are currently protected by a 4,100 ft emergency seawall that was constructed in the winter of 2010. If this seawall is maintained, nearly all of the recreational and habitat benefits associated with this stretch of shoreline will be lost in the near future as water levels rise.

Zuma Beach maintains a wide beach profile, but will also face losses to recreational and habitat services if armored. If a 1.4 m sea-level rise occurs, approximately 10 and 30 percent of the existing profile could be lost by 2050 and 2100, respectively. In the coming decades, nourishment could provide an economically feasible mechanism to maintain beach width absent the use of armoring, and the placement of winter berms could reduce the potential for flooding impacts to Highway One, a primary transportation corridor to Los Angeles in the south and Ventura in the north; both of these adaptation responses will have environmental and ecological consequences that should be further evaluated.

5.5.4. VENICE BEACH, LOS ANGELES

At Venice Beach, a 100-year storm following a 1.4 m rise in sea level could result in approximately $15.1 million and $51.6 million (2010 dollars) in damages to structures and their contents in 2050 and 2100, respectively. To evaluate various adaptation approaches, we assume that unarmored reaches of the backbeach that host structures, parking lots and dedicated open-space will be armored, the capital cost of taking such an action valued at approximately $70 million (2010 dollars) with annual maintenance infusions of at least $2 million (2010 dollars); the capital costs could change substantially depending on the year of placement and maintenance costs would significantly increase as the beach and its ability to dissipate wave energy is lost.

The cost of armoring the shoreline at Venice Beach outweighs the associated benefits of flood reduction. Further, if one fixes the shoreline with armoring, sea-level rise will passively swallow the beach. By 2100, the coastal erosion following a 1.4 m sea-level rise could result in losses to recreational and habitat value reaching $38.6 million (NPV), lost state and local spending totaling nearly $428 million (NPV) and lost state and local sales tax totaling nearly $11.6 million (NPV). Using nourishment projects to maintain the existing beach width would require over $7 million (NPV). While nourishment presents an economically feasible way to counteract losses related to recreational value, spending, and taxes, nourishment could also result in reductions to habitat value not estimated in this paper.

Venice Beach is an iconic destination for many California visitors. Due to large nourishment projects in the past, along with the placement of groins, this stretch of shoreline provides sufficient beach width to continue hosting millions of visitors per year as sea-level rises passively reduce beach width. Additional nourishment projects could help minimize recreational losses due to sea level rise; the placement of winter berms could also help reduce the impacts of flooding following large winter storms. Both of these adaptation responses will have environmental and ecological consequences that should be further evaluated.

5.5.5. TORREY PINES STATE BEACH, SAN DIEGO

At Torrey Pines, a 100-year storm following a 1.4 m rise in sea level could result in approximately $3.4 million and $5 million (2010 dollars) in damages to structures and their contents in 2050 and 2100, respectively. If a 1.4 m sea-level rise is realized, accelerated landward erosion at unarmored reaches of the backbeach could result in approximately $4 to $353 million (2010 dollars) in damages in 2050 and 2100, respectively.

These damage estimates demonstrate that in the context of sea-level rise, backbeach erosion at Torrey Pines is of a greater economic concern than flooding in the coming century. There are various adaptation strategies that can assist in minimizing flood and upland erosion damage, including armoring the shoreline and nourishing the beach. We estimate that the shoreline at Torrey Pines State Beach could be armored at a capital cost of $68.5 million (2010 dollars) and annual maintenance infusions of $2.1 million (2010 dollars). The capital costs could change substantially depending on the year of placement and maintenance costs would significantly increase as the beach and its ability to dissipate wave energy is lost.

Our analysis indicates that in the coming decades, armoring the shoreline in its entirety is not an economically feasible solution to address flood and backbeach erosion risks. Further, if one fixes the shoreline, a 1.4 m sea-level rise will passively reduce a quarter of the existing beach by 2050, which could result in losses to recreational and habitat value reaching $8.3 million (NPV), lost state and local spending totaling $36.3 million (NPV) and lost state and local sales tax totaling $1.4 million (NPV). Using nourishment projects to maintain the existing beach width would require $6 million (NPV). While nourishment could help to minimize losses related to recreational value, spending, and taxes, nourishment could also result in reductions to habitat value not modeled in this report. Allowing the beach to retreat landward unimpeded can help support the existing beach width without the added costs of nourishment, safeguarding the recreational and habitat services that are threatened when the backbeach is armored.

Upland erosion damages increase from $4 million at mid-century to $353 million at the end of the century. Ninety-five percent of this exponential increase in damages is directly tied to structural adjustment costs to ensure the continued operation of the LOSSAN railway north of the Los Peñasquitos Lagoon. If armoring is introduced along the entire stretch of shoreline, over 75 percent of the beach could erode following a 1.4 m sea-level rise, resulting in significant losses to recreational and habitat services. Promoting natural beach processes where the beach is allowed to migrate landward unimpeded could result in significant economic benefits up to mid-century. In the decades following the mid-century, a managed retreat strategy could support an adaptive planning framework that incrementally evaluates responses as the hazard zone approaches critical infrastructure like the adjacent railway corridor.

6.0 Limitations

Ecosystem Services

Economists and ecologists have yet to develop a standard methodology for the measurement of ecosystem services that can be used with great confidence in environmental and welfare accounting. Indeed, our knowledge of the ecosystem services provided by beaches and other coastal ecosystems is very limited. The lack of consensus for valuing existing ecosystem services led us to be conservative when estimating direct ecosystem benefits. We encourage future analyses to introduce sensitivity analyses and site-specific accounting mechanisms for valuing these services.

Further, our methodology did not account for changes in ecosystem services that could be caused by nourishment or coastal armoring (see 4.3).

Direct, Indirect and Social Damages

Flooding and erosion can result in significant damages—direct, indirect and social— that are not evaluated in this study. An overview of these additional damages follows:

- Infrastructure damages: roads, water, sewage, electricity, natural gas, etc.
- Indirect damages: substitution effects of accommodations, economic disruption, business profit losses, time losses, etc.
- Social/intangible damages: stress and anxiety, injuries, hospitalization, deaths, etc.

Collectively, these losses can compound the total expected damages following coastal hazard events. We encourage further evaluation of these damages, as they provide a more comprehensive picture of the extent of potential future economic impacts.

Data

The quality of available data affects the accuracy of the damage assessment methods used in this study. The following is a summary the primary data inputs that influence the precision of our results:

- Base flood elevation data used to model storm scenarios do not fully account for existing flood protection structures. While existing flood barriers may provide sufficient protection for people living within the current 100-year coastal flood hazard zone, such defenses are likely to become less suitable as sea levels rise in the coming century. Further, measuring damages with depth-of-flooding characteristics can overstate damages to land depressions, specifically low-lying objects to which there is no path for seawater to flow. To partially address this limitation, we made an effort in our geospatial analysis to isolate and remove small 'ponds' that did not represent realistic dynamics of flooding connectivity. Additionally, because coastal BFEs represent water elevation at the coast, energy dissipation will likely reduce the extent and amplitude of flooding inland, and lessen overall damages.

- Complex feedback effects exist between flooding and erosion processes. Severe storm and flood events often cause significant short-term erosion. Conversely, erosion can weaken the vital storm-buffering effect that beaches provide, thereby possibly exacerbating flooding. We modeled each phenomenon separately, as modeling feedback effects is beyond the scope of this economic study.

- To date, there is no consistent statewide dataset evaluating the expected acceleration in coastal erosion from a rise in sea level. Data limitations required us to use two distinct approaches in mapping future erosion hazard zones. For our study sites in northern California, we evaluate damages with a combined dune and bluff erosion hazard zone developed by geomorphologists and coastal engineers from PWA. In southern California, we developed a framework to interpolate the acceleration of long-term shoreline change rates outlined in the 2009 California Climate Adaptation Strategy. Our southern California modeling efforts are less robust than those developed by PWA for northern California. Future studies would benefit from a dataset that models upland erosion damages with identical parameters.

- To value losses to structures and their contents, we made use of the best available data accessible to the public. The quality of data varied both by site and by property. Holes in data necessitated the use of cluster analyses and assumptions to assign values to each parcel uniformly.

- Estimating the costs of coastal protective structures and transportation infrastructure is a highly site-specific activity. We made use of the best available default values, adjusting values to capture region-specific costs and inflation.

- When estimating shoreline erosion impacts on spending and taxes, we primarily made use of attendance data collected by local, state and county agencies. A study by King and McGregor (2010) demonstrates that many public agencies in California report inaccurate attendance estimates as a consequence of outdated and/or flawed collection methodologies that fail to capture beach participation across time and activity.

- We did not quantify potential sea-level rise impacts to wetlands due to data limitations on the profile of wetlands at risk.

Given the obvious limitations of coastal geophysical and geomorphological data, one might easily conclude that an economic analysis is unwarranted due to these huge uncertainties. However, we believe such a conclusion is mistaken for a number of reasons:

- Just as it will take time to develop the tools and expertise necessary to evaluate the geophysical/geomorphological impacts of sea-level rise, it will take time to develop the economic models and develop an academic and professional consensus regarding the best practices to apply in an economic analysis.

- Although one will never have perfect foresight about future events, decision makers must plan for this uncertain future based on the best information available today. Indeed, the State of California and the USACE have developed guidelines for sea-level rise precisely for that reason and have encouraged communities to plan for sea level rise.

- Planning for sea-level rise inevitably involves costs and tradeoffs. Economic analyses are essential in order to make the decisions based on the best available data and analyses. If we fail to provide an economic analysis, decisions about resource allocation will be uninformed.

Any economic analysis should be flexible and decision makers should be well aware of the limitations of any study. A sensitivity analysis is also an important element of a good economic analysis. In this study we have provided estimates of the impacts arising from different sea-level rise scenarios, which also serves in part as a sensitivity analysis. Ultimately, however, planners will need specific tools that allow them to estimate the economic impacts of specific scenarios under specific assumptions about sea level rise and the geomorphological responses engendered by sea level rise.

The complexity of these various systems—geophysical, geomorphological, ecological, and socioeconomic—can be overwhelming. However, it would be a mistake to conclude that one should therefore wait until we have better data. Policy makers need to start to address these issues now, and they can only do so when adequate economic models have been created to complement other models developed by physical scientists, engineers and ecologists.

Although this study has limitations, we believe we have made a significant contribution by integrating a wide variety of publicly data together. Perhaps even more importantly, a crucial element of this study has been to develop techniques that are scalable and can be applied in a cost effective manner throughout the State and in other coastal areas.

7.0 CONCLUSION AND RECOMMENDATIONS

This study provides a quantitative analysis of a number of economic risks facing California's coast. Those charged with coastal management decisions will need to weigh the costs and benefits of various responses in order to adapt to new and existing threats to their communities, many of which rely on a healthy coast. The risks that sea-level rise presents to coastal California communities are real and significant, extending beyond physical threats to beaches and coasts, and reverberating throughout local and State economies. This study provides what we believe is a cost-effective way for local communities to begin an analysis of sea-level rise impacts.

In this report, we do not implicitly or explicitly recommend implementation of particular coastal adaptation response strategies. The site-specific consequences, positive and negative, of implementing these strategies vary too greatly on a case-by-case basis for a study of this scope to sufficiently address. Rather, these results indicate the scale and nature of the economic risks that coastal California communities will face in the coming century and beyond.

Our results illustrate the highly site-specific impacts of coastal hazards in the coming century following a rise in sea level. The sandy beaches at Ocean Beach, San Francisco and Torrey Pines State Beach, San Diego are highly susceptible to sea-level rise. If these shorelines are fixed to protect upland infrastructure, sea-level rise will passively swallow a large percentage of these sandy reaches, which provide extensive recreational and habitat services, which under varying scenarios, provide economic benefits of a larger magnitude that the adjacent infrastructure that armoring is designed to protect. Other sites like Venice Beach and Carpinteria City Beach maintain relatively wide beach profiles yet are susceptible to extensive flooding damages. In the near term, soft solutions such as the placement of winter berms and periodic nourishment could assist in minimizing flood risks to valuable structures in the hazard zone (see 5.0 for detailed results).

Any future analysis should seriously evaluate incremental planning approaches, like managed retreat that promotes both the wellbeing of the natural coast and the long-term sustainability of coastal economies. A recently completed sediment master plan follow-up in southern Monterey Bay (PWA-ESA 2011) provides an empirical framework for evaluating the physical, ecological and economic outcomes for a suite of shoreline mitigation strategies. Studies like this are needed along the California coast, building on the southern Monterey Bay report to include the impacts of sea-level rise to coastal hazards for producing recommendations that are adaptable to climate change and compatible across planning regions.

Our study sites encompass only about 15 of the more than 2,000 miles of open coast and bays of the California coastline. Sea-level rise poses unique threats to every coastal community in California. We recommend more studies of this type to identify and assess distinct, site-specific economic risks for the consideration of local policymakers.

This study, though conducted at a finer scale than previous economic studies, is limited by geomorphological modeling weaknesses and data availability as well as the very limited understanding of coastal ecosystems that we currently have. We urge further collaboration between scientists and economists to better model coastal processes and more accurately assess economic risks. Further, we recommend city, county, and state data pertaining to infrastructure and property be made more accessible for research of this type. The data collection process used significant portions of the limited time and resources allotted for this study; better data availability for future studies can free time and resources for further refinement of research.

Although there still exists a great deal of uncertainty regarding the geomorphological and ecological changes that will occur as sea level rises, that should not lead to complacency. The well-established consensus in the scientific community is that sea-level rise is occurring and will accelerate in the coming years. Communities will be forced to respond in one way or another to the increased erosion and coastal storm damage that accompanies accelerating sea level rise. If State and local governments fail to plan for sea level rise, they will be forced to deal with the consequences on an *ad hoc* basis, which is likely to lead to less than optimal solutions. In many cases on California's coast a failure to plan has meant that armoring, which is permitted under the Coastal Act if property is in "imminent" danger, has become the *de facto* solution.

As the analysis in this paper indicates, coastal armoring is often more expensive and generates fewer recreational and ecological benefits, compared to other alternatives. However, when property owners are faced with an imminent threat, which must be responded to on short notice, armoring may be, or may be seen to be, the only option. Nourishment strategies and managed retreat options such as rolling easements or conservation credits take time to develop and often must overcome legal hurdles. These options, to be effective, involve long-range planning and the requisite political consensus that such planning entails.

Economic analysis is a critical part of this planning. Although not all political and ecological decisions can necessarily be reduced to dollar signs, failure to consider the economic value of recreation, property loss and to the extent possible, ecological damages, will almost certainly lead to poor policy outcomes and misinformation.

The techniques developed and applied in this study further the application of economic analysis to sea-level rise by allowing a more granular level of analysis than most previous economic studies of sea level rise. Such an analysis allows coastal planners to examine different options for different sub-regions and areas, as small as a few hundred feet. Since it is virtually certain that California will not proceed with a one-size-fits all coastal management policy, but rather a mixture of different strategies, any planning approach, to be feasible and effective, must be able to account for differences in economic and ecological benefits and costs at the level of local communities, parks and even buildings.

The techniques developed here are also far less expensive than the types of analysis used for specific project studies (e.g., a Corps of Engineers feasibility study. Given the budget constraints that virtually all city governments face in California, the cost effective techniques outlined in this paper allow one to evaluate the costs and benefits of various management strategies at an appropriately small scale, providing a framework for dedicating available resources to more fine tuned feasibility studies. Also, if local managers begin with the type of analysis developed in this report, it is likely that they can identify critical data needed to comprehensively evaluate the pros and cons of various adaptation strategies. Organizing baseline data and identifying data gaps can greatly reduce the time and resources needed for future analyses.

We also believe that it is essential to continue developing techniques that can be applied to cost/benefit analysis used for coastal planning. We frequently hear critics state that since there is so much uncertainty surrounding the physical and biological science associated with sea level rise, that trying to quantify economic benefits and costs is meaningless. However, despite these uncertainties, decisions will be made about how to deal with sea level rise. A complete failure to account for economic costs and benefits only serves to increase this uncertainty.

We recommend further research on the valuation of the natural habitat and ecosystem services of California's numerous types of coastal ecosystems. Disparity between the fields of economics and biology have led to disputing ideas of how to value natural assets in terms of dollars. Traditional economic cost-benefit analyses can dangerously undervalue assets that hold significant value to society, intrinsic or otherwise. Research on this subject is in its nascency in both economics and biology, and we urge collaboration toward its progress.

Our analysis indicates the importance of considering sea-level rise impacts in the coastal management and policymaking processes. Continued collaboration between economists, scientists, and policymakers will allow for informed decisions regarding the management, health, and sustainability of both our natural coast and our coastal economies.

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8.0 Acronyms

BEACON	Beach Erosion Authority for Clean Oceans and Nourishment
BFE	Base flood elevations
BT	Benefits Transfer
CCC	California Coastal Commission
CSBAT	Coastal Sediment Benefits Analysis Tool
CV	Contingent valuation
DBW	California Department of Boating and Waterways
DEM	Digital elevation models
ENSO	El Niño-Southern Oscillation
FEMA	Federal Emergency Management Authority
GHG	Greenhouse gases
GIS	Geographic Information Systems
HAZUS	Hazards U.S. Multi-Hazards
IFSAR	Interferometric Synthetic Aperture Radar
IPCC	Intergovernmental Panel on Climate Change
LIDAR	Light Detection and Ranging
NAS	National Academy of Sciences
NIBS	National Institute of Building Sciences
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
PI	Pacific Institute
PV	Present Value
PWA	Philip Williams and Associates
RUM	Random Utility Model
SANDAG	Sand Diego Association of Governments
SCRRA	Southern California Regional Rail Authority
TWL	Total water level
USACE	United States Army Corps of Engineers
WTP	Willingness to pay