ESTIMATING THE POTENTIAL ECONOMIC IMPACTS OF CLIMATE CHANGE ON SOUTHERN CALIFORNIA BEACHES

A Paper From:
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DRAFT PAPER

DISCLAIMER

Arnold Schwarzenegger, *Governor*

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California's electricity and natural gas ratepayers. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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In 2003, the California Energy Commission's PIER Program established the **California Climate Change Center** to document climate change research relevant to the states. This center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts and the efforts designed to reduce emissions.

The California Climate Change Center Report Series details ongoing center-sponsored research. As interim project results, the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the center seeks to inform the public and expand dissemination of climate change information, thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

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Abstract

Climate change could substantially alter the width of beaches in Southern California. Climate-driven sea level rise will have at least two important impacts on beaches: (1) higher sea level will cause all beaches to become more narrow, all things being held constant, and (2) sea level rise may affect patterns of beach erosion and accretion when severe storms combine with higher high tides. To understand the potential economic impacts of these two outcomes, this study examined the physical and economic effects of permanent beach loss caused by inundation due to sea level rise of one meter and of erosion and accretion caused by a single, extremely stormy year (using a model of beach change based on the wave climate conditions of the El Niño year of 1982/1983.) Researchers used a novel model of beach attendance in Southern California that examines the impacts of changes on beach width for different types of beach user visiting public beaches in Los Angeles and Orange Counties. The model allows beachgoers to have different preferences for beach width change depending on beach size. The study team found that the effect of climate-driven beach change is different for users that participate in bike path activities, sand-based activities, and water-based activities. Using the model, researchers simulated the effects of climate-related beach loss on attendance patterns at 51 public beaches, beach-related expenditures at those beaches, and the non-market (consumer surplus) value of beach going to those beaches. The study found that increasing sea level causes an overall reduction of economic value in beach going, but with some beaches experiencing increasing attendance and beach-related earnings while others lose attendance and earnings. It also found that the potential annual economic impacts from a single stormy year may be as large as those caused by permanent inundation that would result from a rise in sea level of one meter. The economic impacts of both permanent inundation and storm-related erosion are distributed unevenly across the region. To put the economic impacts of these changes in beach width in perspective, the paper provides simple estimates of the cost of mitigating beach loss by nourishing beaches with sand.

Keywords: Beach, sea level rise, erosion, valuation, Southern California

1.0 Introduction

Always dynamic, California's coasts will certainly be altered by natural forces over the next 100 years. Increases in sea level will likely affect beaches through permanent inundation (the loss of beach due simply to flooding when beaches cannot migrate shoreward) and increasingly intense erosion and accretion when higher high tides interact with severe storms (Cayan et al. 2008). Composed of highly transportable materials, California's beaches are extremely vulnerable to such forces, but that vulnerability is not well understood. These beaches are important to home owners who depend on beaches to protect their homes from storm surge, for public infrastructure (especially roads), and to the millions of Californians who use beaches as an important destination for outdoor recreation (Neumann and Hudgens 2006).

Of the many potential economic impacts that may result from the impacts of climate change on beaches, we focus on the effects of sea level rise on the beach going economy of Southern California. We use a recently developed model of beach choice by day users in Southern California to demonstrate how predictions about future impacts of climate change on beaches can be linked to detailed economic models of beach going behavior. Our analysis is not intended to provide precise estimates of the impact of climate change on Southern California beach going. Our goal, rather, is to develop a framework with examples of how to link estimates of beach change (changes in width and volume of sand) caused by sea level rise to economic models of beach attendance, expenditures, and consumer surplus. This is a first step toward evaluating the effects of climate-related beach change on the net economic value of beaches in Southern California.

To illustrate our framework and the potential magnitude of the economic impacts of sea level rise, we use an economic analysis based on projections of beach width change from permanent inundation due to 1 meter (m) of sea level rise and beach width and volume change due to a an extremely stormy year. We recognize that sea level, and thus beach width, change constantly over the course of a day, a lunar cycle, a year, and over decades. We explore "permanent" inundation as a means of thinking about average loss in beach width that could occur due to a rise in average sea level. Projections about permanent beach inundation and beach erosion are provided by Peter Adams of the University of Florida; beach width change due to permanent inundation is estimated based on beach slope data (Hapke et al. 2006) and beach width and volume change due to large storms are based on a new model of beach sediment budgets being developed by Adams and Inman (2008). The model of Adams and Inman is in its early stages of development. Indeed, we view their results as indicators of the order of magnitude of the potential impacts on beaches that could be associated with extremely stormy years. Our methods can easily be applied to a variety of models that project future beach width.

Beach width has been shown to be an important determinant of where day use visitors go to the beach in Southern California (Hanemann et al. 2005) and is one of the primary explanatory variables in a model of beach choice for Southern California public beaches (originally developed by Hanemann et al. 2005 and recently updated by Pendleton et al. 2008). While tourism to beaches may also be affected by beach width, the models of Hanemann et al. and Pendleton et al. examine beach going only for Southern California residents. Hanemann et al.

showed that more than 50% of all households in Los Angeles, Orange, Riverside, and San Bernardino counties had at least one member who went to the beach over the course of a year. This large population of users may account for more than 100 million visits to local beaches annually (Pendleton and Kildow 2006.)

We use Adams and Inman's estimates of potential changes in beach width, and the beach choice model of Pendleton et al., to model the effects of a 1 m rise in sea level on beach attendance, beach expenditures, and the non-market value of beach going—the economic value of beaches to local beachgoers, beyond what they have to pay to use the beach. To provide perspective for our estimates of the impacts of steady rise in sea level, 1 m over 100 years, we also model the potential impacts on beach width due to a year of unusually intense storm events. In our case, we use the storm events of the El Niño events of 1982 and 1983. Because coastal managers may choose to counter permanent inundation and extreme erosion events, we also provide simple, but illustrative, estimates of the costs of physically renourishing beaches, by placing new sand on beaches, following such events.

1.1. Economic Value of Southern California Beaches

Beaches are an important recreational resource enjoyed by residents of California and many visitors to the state. According to The National Survey of Recreation and the Environment (NSRE) in 2000, nearly fifteen million people participated in beach activities in California. This dominates all other forms of marine recreation in the state but is still an underestimate because foreign tourists were not included in the survey. Most of these beach visitors spend money at the beach. It has been estimated that out-of-state beach-oriented tourism brings annual revenues of $61 billion to California (California Department of Boating and Waterways 2002). An additional $4 billion is spent annually on beach recreation by California residents (Pendleton and Kildow 2006). Many local visitors are able to enjoy the beach at little or no cost, but they enjoy considerable economic benefit from their presence. This benefit, beyond what people do pay, is called the *consumer surplus* or *non-market value* of beaches and represents the willingness to pay to visit beaches, beyond what people actually do pay. These non-market values are real and are most often realized when beaches are damaged (either through beach loss or deterioration of water quality) or removed from use (e.g., due to an oil spill). The non-market value of beaches has been evaluated numerous times in the literature and has been estimated to contribute more than $2 billion to the economic well-being of Californians (Pendleton and Kildow 2006).

The billions of dollars spent by beachgoers contribute to a number of local economic activities. Day visitors to beaches spend money locally on food, beverages, parking, and beach-related activities and rentals (e.g., body boards, umbrellas). Such purchases partially represent a transfer of expenditures that may have been made elsewhere in the state (e.g., gas and auto), but are largely expenditures that would not have been made in the absence of the beach trip.

King (1999) estimated the fiscal impact of beaches in California and reported that in 1998, California's beaches generated $14 billion dollars in direct revenue (King 1999).[1] In two other studies, the average expenditures per person per day trip ($/trip/person) were estimated for visits to California beaches at between $23 and $29 per day. Such numbers may appear small when compared to alternative activities, such as amusement parks, but with annual daily visits in the millions, it all adds up to a multi-billion dollar, renewable resource.

1.2. Impact of Climate Change on Beach Economies in Southern California

The market and non-market (consumer surplus) values that are generated by beach recreation can be affected by the quality of the coastal environment. Obvious problems such as trash on the beach clearly deter visitors, but beach width is an important factor as well (Lew 2005; Lew and Larson 2006; Bin et al. 2007). Pendleton et al. (2008) show that different users prefer different beach widths, depending on the type of recreation they plan to undertake (e.g., sand-based versus water-based versus pavement-based activities; see Appendix A for the model's econometric results). Changes in the width of beaches due to permanent inundation or storms can change beach attendance substantially. As demand for beach activities changes, so do local expenditures and non-market value.

For Southern California, climate change may physically affect beaches through at least two mechanisms: (1) permanent beach loss due to inundation caused by sea-level rise, and (2) increased intensity of storms caused by higher high tides (California Coastal Commission 2001; Cayan et al. 2005 and 2006). Inherently dynamic, beaches can be eroded very quickly if the rate of sand removal through erosion surpasses the rate of replenishment through accretion. In fact, several studies have indicated a net global loss in beach area over the last 100 years (Bird 1985; NRC 1990; Leatherman 2001; Eurosion 2004) and beaches are expected to shrink more rapidly because of sea-level rise (Brown and McLachlan 2002).

In Southern California, storm events and wave action also contribute substantially to coastal erosion (Flick 1998; Seymour et al. 2005). Storm surges, or waves of extraordinary height that occur during storms (especially storms that coincide with high tides), can be amplified by sea level rise, increasing their destructive power (Cayan et al. 2008). It also is possible that changes in wave climate (e.g., wave direction, height, and period) could have erosional effects on beaches, but evidence suggests that this factor will be much more important at higher latitudes (Allan and Komar 2006; Flick and Bromirski 2008), except when exacerbated by the El Niño Southern Oscillation (ENSO) cycle (e.g., Seymour 1984; Inman and Jenkins 1998).

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[1] *Direct revenue* is the direct expenditure from people making beach trips for items such as gas and parking, food and drinks from stores, restaurants, equipment rentals, beach sporting goods, beach-related lodging, and incidentals.

While efforts have been made to estimate the overall coastal impacts of climate change in California (see for instance Neumann and Hudgens 2006), no attempt has been made to examine carefully the impacts of sea level rise due to climate change on the beach going economy of the state. In a report to the California Department of Boating and Waterways, King and Symes (2003) determined that failure to protect Southern California beaches would reduce the California gross state product by over $5.5 billion annually. However, their data reflects changes in use based on the complete absence of beaches in the area, rather than losses specifically due to sea level rise. Cost estimates for previous extremely stormy years, such as the 1997–1998 El Niño, have been estimated at about $1.1 billion for California as a whole (Andrews cited as personal communication in Changnon 2000). In addition to changes in the amount beachgoers spend, climate change-induced alterations of beaches in Southern California could also reduce the consumer surplus that local beachgoers enjoy from having easy access to hundreds of miles of beaches. As noted above, the non-market value of beach going can be quite large.

1.3. Objectives and Organization

We link estimates of two basic scenarios of potential climate-induced beach change (Adams and Inman 2008) with socioeconomic models of beach choice and attendance (Pendleton et al. 2008) to demonstrate how integrated economic and geomorphological models and data can be used to show the potential impact of climate change on public beaches. Because our economic model is for beach going to beaches in Los Angeles and Orange counties, we limited our initial investigation to this part of the coast. Like other studies that have attempted to link climate change with beach recreation, we focus specifically on the effect on day use beach visitors (see for instance Bin et al. 2007; Deke et al. 2001; Darwin and Tol 2001; Bosello, Roson, and Tol 2007; Loomis and Crespi 1999). We focus on two potential scenarios of beach change. First we focus on a 1 m rise in sea level that we model as a smooth increase from present to the year 2100. We then estimate attendance and expenditures by beachgoers, for our 51 public beaches in Los Angeles and Orange counties (including one beach on the Ventura/Los Angeles County border and two beaches on the Orange/San Diego County border), with and without permanent beach loss that would result from inundation caused by sea level rise.

Sea level rise is unlikely to occur slowly and evenly, nor is simple flooding the only way in which sea level rise will affect beaches. To put the impacts of permanent inundation from sea level rise in perspective, we also estimate the potential erosion and accretion that could take place in an unusually stormy year. Specifically, we use predictions about beach erosion and accretion from the Adams and Inman model for the wave climate conditions of the El Niño year 1982/1983. For both of these scenarios, we simulate changes in beach attendance, spending (expenditures), and non-market (consumer surplus) value at public beaches in Los Angeles and Orange counties. This beach choice model is based on an updated version of the Southern California Beach Valuation Model (Hanemann et al. 2004 and 2005), which was funded by the California Department of Boating and Waterways (Pendleton et al. 2008). It incorporates attributes of beaches, including beach width, as well as demographic information about beachgoers and cost of travel. Accordingly, we also explore the effects of future changes in demographics and changing costs of travel on the predicted economic impacts of sea level rise.

To put the economic impacts on beach going into perspective, we also provide very basic estimates of the potential economic costs that would be incurred if coastal managers were to attempt to fight beach loss due to inundation and extreme erosion events at public beaches by nourishing these beaches with sand. Nourishment can be used to replace lost sand, to build up beaches that have grown smaller due to sea level rise, and to protect coastal homes and infrastructure. We simply estimate the costs of replacing lost sand due to erosion or the equivalent amount of sand that would need to offset inundation. The model of Adams and Inman provides simulations of beach width change and the volume of sand that would be deposited or eroded from public beaches in Los Angeles and Orange counties under wave conditions monitored for the 1982–1983 El Niño year. We use the ratio of volume loss to width loss for each beach to determine the approximate volume of sand that would need to be added to counteract beach area loss caused by inundation from sea level rise.

Historically, beach nourishment has been used to counter the effects of erosion, especially extreme erosional events in our study area (Los Angeles County and Orange County Beaches). Even at $11.5 million (in 2005 dollars) in annual expenditures in California (based on data from 2000), current levels of beach nourishment are largely considered inadequate to stem the erosion associated with current storm events (California Department of Boating and Waterways 2002). The Department of Boating and Waterways estimated that the minimum level of nourishment to preserve beaches in their current state would require $120 million ($138 million in 2005 dollars) in initial project costs and total annual costs of $26.8 million ($30.8 million in 2005 dollars). Escalated erosion, especially due to climate change, is likely to put additional stress on managerial resources, so the trade-offs between nourishment costs and width-based beach value will be an important determinant of future policy and future beach use.

Section 2 describes the methods we use to generate and analyze the expected economic costs of climate-induced beach change. First, we describe our socioeconomic model of beach attendance (Section 2.1). The data that feed into these analyses are then covered in the next subsections, including demographic scenarios, travel cost scenarios, and the beach change scenarios of Adams and Inman (Section 2.2).

We provide analysis for our results in Section 3. These results include expected differences in attendance, consumer surplus, and expenditures on beach-related activities that result from a loss of beach width due to the flooding that would accompany a 1 m rise in sea level over 100 years (with no wave-related erosion; Section 3.1). We follow a similar approach for changes in beach width caused by an extremely stormy year (Section 3.4), where beach loss, economic impacts, and nourishment costs are estimated for a single year. Because the beach attendance model includes population size; the age, income, and gender of potential beachgoers; and the cost of travel, we estimate the effects of changes in beach width under a variety of demographic, population, and travel cost scenarios, including one in which all current conditions remain constant for one hundred years. Results and implications for coastal management in Southern California are presented in Section 4.

2.0 Methods

Our work links three different types of analysis: a beach attendance model that models how beachgoers in Southern California choose among 51 public beaches, a beach sediment model (Adams and Inman 2008) that models erosion and accretion patterns for beaches, and an analysis of beach nourishment costs (Figure 1). The beach model predicts beach attendance patterns based on certain demographic features of potential beachgoers, the cost of travel, and the attributes of beaches, including beach width. Future projections of changes in beach width due to permanent inundation are calculated by averaging beach slopes to find the average slope for each of our 51 beaches. We then combine slopes and sea level rise (1 m) to estimate lost beach width. Since sea level rise could increase the erosion and accretion potential of winter storms when storms coincide with higher high tides, we also estimate the impacts of a highly stormy year. To estimate the changes in beach width due to erosion and accretion caused by an extremely stormy year, we use preliminary results from the beach sediment model of Adams and Inman to estimate the effects of the wave climate from El Niño (1982–1983). Finally, we estimate the costs of replacing sand volume lost to permanent inundation or storm-related erosion. In both cases, beach width data and sand volume loss or gain data are provided by estimates from the beach sediment model. We briefly describe each of the three analyses below.

2.1. Beach Choice and Attendance Model

A number of factors influence where and when residents of Southern California decide to go to the beach. These include personal factors (e.g., income, race, age, gender, and presence of children in the household), the cost of travel from home to all potential beaches, and the different attributes of beaches (e.g., water quality, availability of parking, presence of lifeguards). Beach width is one of many attributes that determine how a potential beachgoer will choose among 51 public beaches in Los Angeles and Orange counties (and one beach on the Ventura/Los Angeles County border and two beaches on the Orange/San Diego County border, see Figure 2). Our beach attendance model predicts the number of visitors, coming from each census block in four counties in Southern California (Los Angeles, Orange, Riverside, and San Bernardino), that would visit each of the 51 public beaches in Los Angeles and Orange counties, plus two proxy beaches that reflect all beaches north and south of our study area. By applying estimates of average beachgoer spending patterns to these beach attendance patterns, we can estimate how beachgoer spending might change as a result of changes in beach width induced by climate change. Changes in attributes can also directly affect the economic well-being (i.e., the non-market value) of beachgoers by making beaches more enjoyable if desired attributes are more available or by making a preferred beach less desirable if a preferred attribute is degraded.

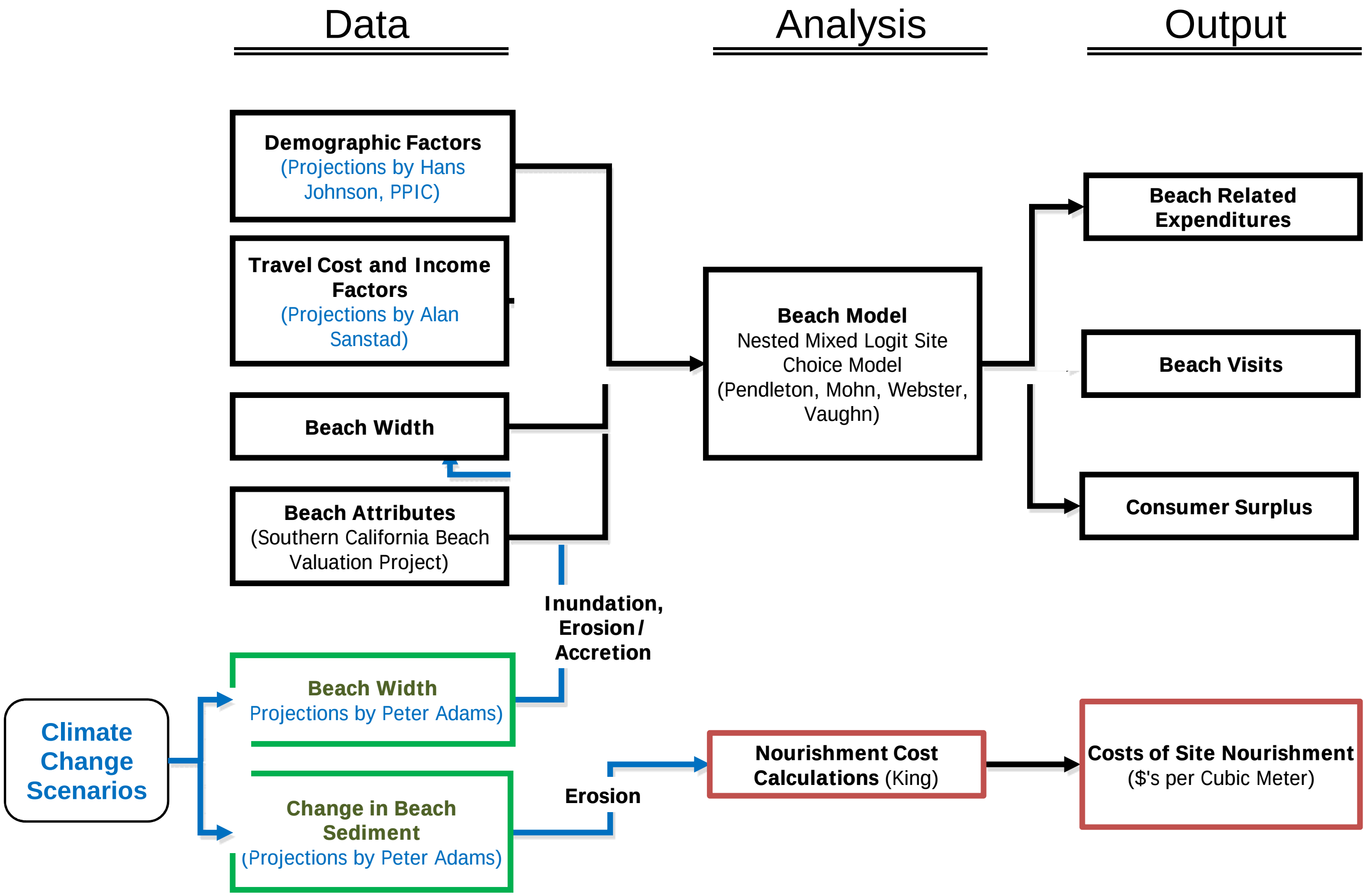

Figure 1. Dataflow for economic impacts of climate change on Southern California beaches

2.1.1. Data Used in Model Estimation

To simulate the impact of changes in beach width on beach-going activity, we modified the original Southern California Beach valuation model of Hanemann et al. 2005—a model that estimates attendance and associated consumer surplus, for the public beaches of Los Angeles and Orange counties. We use beach width measurement data (derived from estimates made from photographs or site visits from 1999, 2000, and 2008) to reestimate a Revealed Preference Random Utility Model (Hanemann, Pendleton, Mohn et al. 2004) of beach choice originally estimated using survey data on beach use from the year 2000. These data were collected in a one-year, multi-wave survey of 1161 individual beachgoers, who reported 7676 total trips to the beach.[2] The pool of respondents was drawn from a random telephone survey of more than 2000 households in Los Angeles, Orange, Riverside, and San Bernardino.

Every two months over the course of a year spanning 2000 and 2001, survey respondents were asked to report the beaches they visited and the activities that they engaged in during those visits (see Appendix B for a list of beaches covered and Appendix C for a list of beach-related activities). Respondents also supplied personal data such as their age group, income range, ethnicity, and the presence of children in the home, as well as data on expenditures related to their beach activities. We estimated the cost of travel to selected beaches from each respondent's home using PC miler software and the average cost per mile ($0.145 in year 2000 dollars) along with a time cost of one-half the hourly income.

Data on beach attributes were obtained by site visits to every beach. The research team collected data on 46 physical, visual, and management attributes of the beaches and a variety of water quality measures (for more detailed discussions of the data see Hanemann et al. 2005 or Pendleton et al. 2008). Many beach attribute variables were simple presence/absence measures (1/0), such as the availability of restrooms, camping facilities, campfire/grilling, and similar factors. Water quality data, given as beach water quality grades, were calculated by the not-for-profit Heal the Bay (HTB) and based on fecal indicator bacteria measures made by local health authorities. For this analysis, we transform their letter-grade format into a numerical scale, and then take the average of all HTB grades for a given beach for all dates, even if those measurements were in years other than the survey. This is an attempt to capture a general measure of quality that a user might expect.

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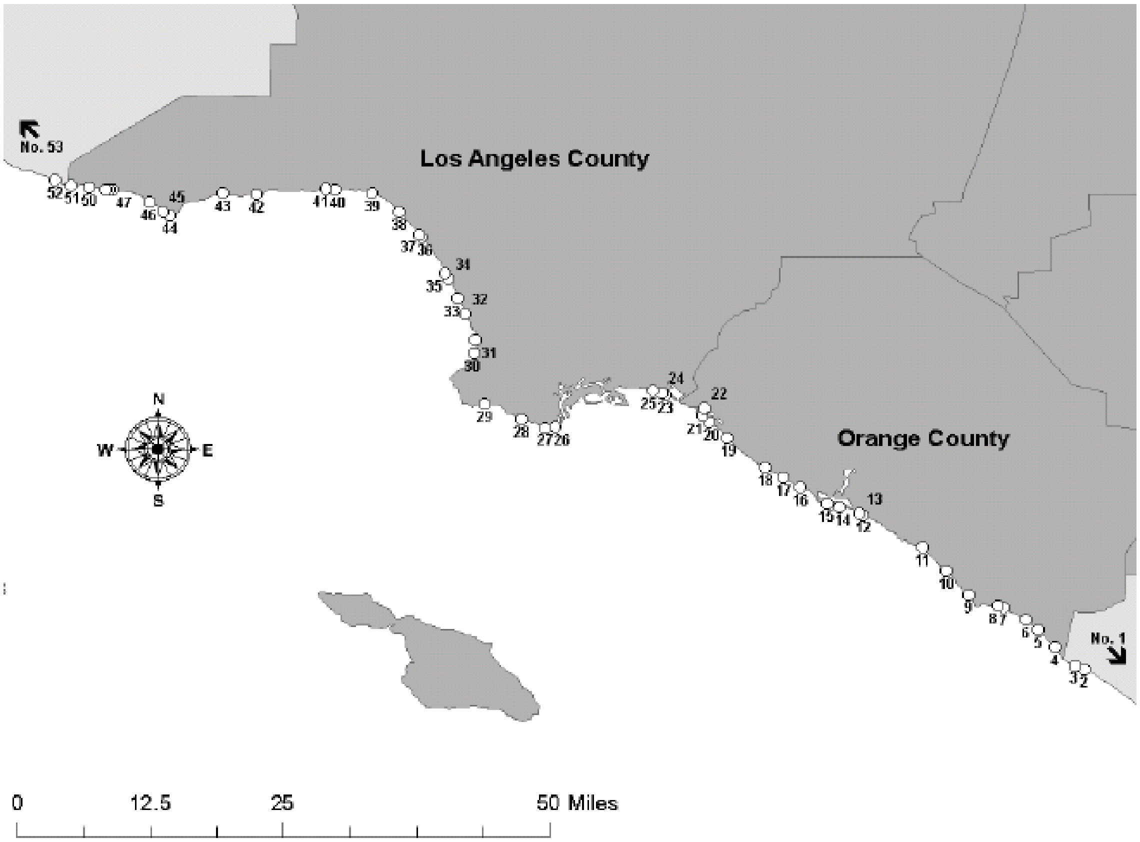
[2] Beachgoers were identified in a random phone survey of southern California residents. Participation in both surveys was voluntary (Pendleton, Martin, and Webster 2001).



1	Southern Proxy
2	San Onofre South
3	San Onofre North
4	San Clemente State
5	San Clemente City
6	Poche
7	Capistrano
8	Doheny
9	Salt Creek
10	Aliso Creek
11	Main Beach Laguna
12	Crystal Cove
13	Corona Del Mar
14	Balboa
15	Newport
16	Santa Ana River
17	Huntington State
18	Huntington City
19	Bolsa Chica
20	Sunset
21	Surfside
22	Seal
23	Alamitos Bay
24	Belmont Shores
25	Long Beach
26	Cabrillo
27	Point Fermin
28	Royal Palms
29	Abalone Cove
30	Torrance
31	Redondo
32	Hermosa
33	Manhattan
34	El Segundo
35	Dockweiler
36	Mother's
37	Venice
38	Santa Monica
39	Will Rogers
40	Topanga
41	Las Tunas
42	Malibu (Surfrider)
43	Dan Blocker (Corral)
44	Point Dume
45	Free Zuma
46	Zuma
47	El Matador
48	La Piedra
49	El Pescador
50	Nicholas Canyon
51	Leo Carrillo
52	County Line
53	Northern Proxy

Figure 2. Location of Southern California beaches covered in this study[3]

Finally, the research team collected data to estimate the width of each beach site from the wet sand to the back of the beach; for example a road, cliff, or other obvious boundary. The data come primarily from the work of a team of geomorphologists led by Anthony Orme from the

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[3] See Appendix A for a list of corresponding beaches.

University of California, Los Angeles (UCLA) (including James Zoulas, Carla Chenualt Grady, and Hongkyo Koo; Zoulas and Orme 2007). Using aerial photographs and digital orthophotography quadrangle images from the United States Geological Survey (USGS), the researchers estimated measurements of width (in meters) at 20 m transects along the entire length of each site identified in our study. Some variation, and thus measurement error, was introduced into these measures because measures for all of the beaches were derived from photographs taken on different dates and different years (see Appendix B). As a result, we round all beach width measures to the nearest meter. The measurements of the UCLA research team included measures for 48 of the 51 beach sites in our study. The remaining three sites were Mother's Beach, San Onofre North, and San Onofre South. Sufficiently recent aerial images of these beaches were unavailable. We measured these three sites by hand, at 20 m transects, using a Bushnell Golf Range Finder.

2.1.2. Formulation of Beach Model

As noted above, a user's response to a change in beach width will depend greatly on his or her choice of beach activities. We incorporate this activity-specific heterogeneity of preferences for beach attributes by allowing participants in different activities to have different preferences for beach attributes. We divide the trip data into three categories based on the activities that the panelists reported for that trip. We consider activities where the individual's primary activity involves: (1) getting in the water (e.g., swimming and wading), (2) actively using the sand or the ground at the beach (e.g., volleyball and kite flying), and (3) activities where the individual uses paved trails, sidewalks, or beachfront restaurants. A panelist may engage in different activities on different trips, so we use demographic variables and the expected utilities from the beach choice to model the choice of activity.

We jointly model three choices (or nests of choices) for the beachgoers' decision: (1) whether or not to make a trip to the beach, (2) the activity to undertake at the beach, and (3) the beach to visit based on the option which offers the highest utility (see Figure 3). Note that our joint estimation of the three nests does not mean that the beachgoer makes these choices simultaneously. The model is made to fit the data by assuming the beachgoer chooses the beach which maximizes his or her utility. The unobservable utility for each option is assumed to consist of a systematic part that is a function of observable attributes and an estimated parameter vector (indicating preferences for these attributes) and a stochastic term drawn from a generalized extreme value distribution. We use a nested multinomial logit model to analyze the tradeoffs that drive the consumption decision. We will not repeat the familiar mathematics of the model here, but the basic structure of the model is given in Figure 3 and Hanemann et al. (2004).

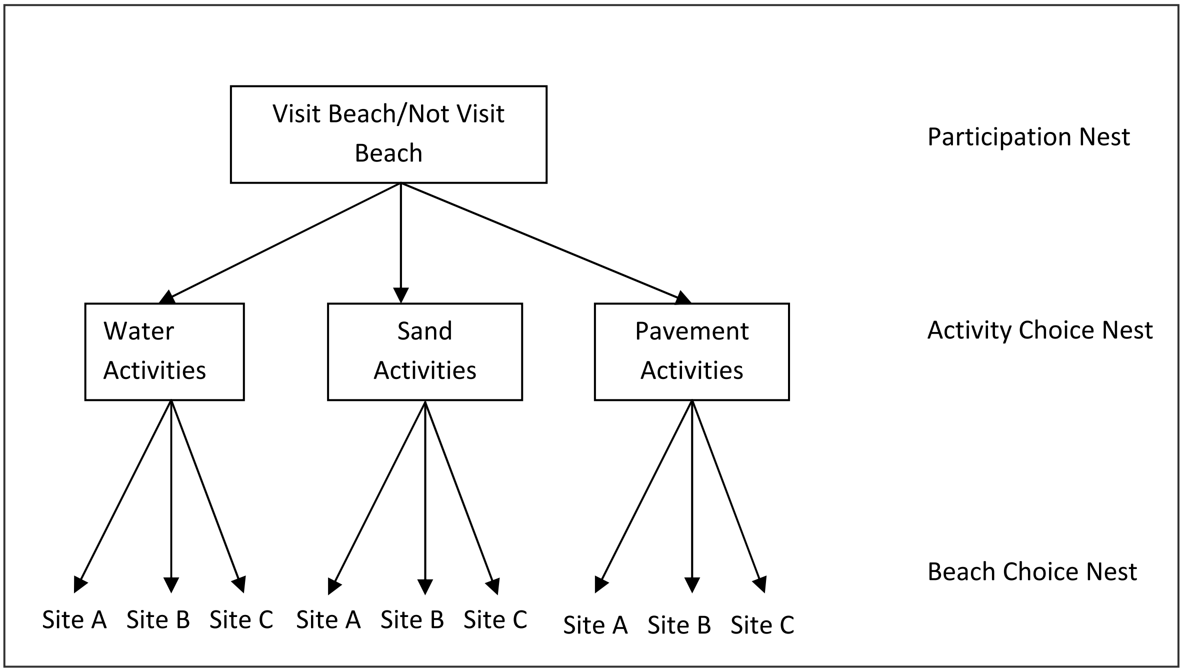


Figure 3. Beach choice model structure

The Participation Nest models the decision to take a trip to the beach each day. The Activity Choice Nest models the choice of activity, and the Beach Choice Nest models which beach the beachgoers chooses, conditioned on the activity choice. The levels of the model are linked by the expected utility derived from the choice below. As such, travel cost (including the cost of travel time) enters the beach choice decision for each of the three types of activity. To ensure that the marginal utility of money is constant for all options, we restrict the coefficient on travel cost to be the same for all three beach choice sub-models.

Train (1998) recommends the use of a logarithmically transformed size factor in the application of random utility models to recreational site choice. Since we have both length and width data for beaches, we use beach size as the logarithmically transformed size factor when we are considering water- and sand-based activities. This is the equivalent of treating all beach sub-sites equally in the user's decision function. We retain the use of beach length, though, as the logarithmically transformed factor for pavement and water activities, since the number of spots to recreate at a given beach is more likely to be proportional to length than area. Since the model includes the natural logarithm of beach width, the difference in this specification is primarily done to aid interpretation of the coefficients. Because log(area) = log(length) + log(width), the difference in specification merely shifts the value of the parameter capturing the utility of beach width.

We use a simple nested logit structure rather than a mixed-logit (random parameter) model because it gives us more control over the choice structure of the model and allows us to use data for which trip detail may be incomplete (see Appendix A for detailed estimation results). Because the trip count data do not perfectly map to the trip detail data, a mixed-logit model cannot estimate all three aspects of the choice decision. With three activity types, 51 beaches options for each, plus the option of no beach trip, there are 160 alternatives in each of 365 days. Considering the large number of alternatives and the large number of beach attributes, the mixed logit model becomes computationally very difficult to estimate.

2.2. Width Projections

As noted previously, climate change can affect beach width in at least two ways: (1) through permanent beach width loss caused by inundation, and (2) through a change in sediment budgets caused by a combination of higher high tides and storms. As described below, these projections were provided by Adams and Inman (2008) and cover scenarios of (1) a 1 m rise in sea level, and (2) the erosion and accretion patterns associated with an extremely stormy year (the El Niño year of 1982/1983.)

Dr. Peter Adams of the University of Florida used data on beach slopes estimated using Light Detection and Ranging (LIDAR) by Hapke et al. 2006 to estimate the potential loss of beach width due to sea level rise for beaches in our study area. For purposes of analysis, we assume permanent inundation occurs gradually across the study period (until 2100). Drs. Peter Adams and Doug Inman also use computer models to estimate sediment budgets (measured as volume of sand deposited or removed) in cells that are 100 meters wide for the length of coast extending from County Line Beach in Ventura County to San Onofre State Park in San Diego County. For our analysis, Adams and Inman estimate sediment budgets under current sea level and a wave climate equivalent to an extreme weather event (1982–1983 El Niño).

One limitation of the Adams and Inman model is that the system is transport limited, which means that the model only accounts for the loss or gain of sediment due to oceanographic conditions, ignoring shore-based sources of sediment change. We use the predictions of Adams and Inman, based on wave climate data for an extremely stormy year (the 1982/1983 El Niño year) as a starting point to explore the potential impacts that might result from years characterized by extreme erosional events, especially compared to the effects of a slow rise in sea level.

2.3. Demographic and Economic Projections

Changes in population size, demographics, and the cost of travel could seriously affect beach attendance in the coming century. We also explore how several demographic and economic factors may interact with sea level rise to alter beach going over time. The most important of these are average household income, gender, race, employment, and projections of estimated travel costs per mile. Hans Johnson (estimates provided by the California Energy Commission) and Alan Sanstad (memo, July 2, 2008) developed scenarios for use in the beach choice model. Table 1 summarizes these contributions and the six scenarios generated for beach attendance and expenditure.

Table 1. Beach choice model width and socioeconomic scenarios

Sea Level Rise (Adams and Inman)	Demographic changes (Hans Johnson)	Income and Travel Costs (Alan Sanstad)	
Current sea level (baseline)	Current	Current	**Scenario 1**
	Midrange predictions	Maximum expected	**Scenario 2**
		Minimum expected	**Scenario 3**
Plus 1 meter sea level rise (expected with climate change)	Current	Current	**Scenario 4**
	Midrange predictions	Maximum expected	**Scenario 5**
		Minimum expected	**Scenario 6**

Demographic inputs to the beach model were provided by Hans Johnson of the Public Policy Institute of California. Population projections for Los Angeles and Orange counties were provided in five-year increments from 2005 through 2100. The projections are based on low, moderate, and high assumptions regarding population growth factors. We use the middle-range results here, which are based on the assumptions listed in Table 2. These projections are broken down by age, sex, race, and place of birth (e.g., foreign born). These projections capture expected changes in the overall population of Southern California and demographic shifts that could affect the choice of beach activities and sites. For instance, black respondents to our beach visitation survey were less likely overall to choose a water-based activity, while Hispanics were not significantly different from others (e.g., whites, Asians, and Native Americans) in their choice of water-based activities. Alternately, males were more likely to get in the water than females.

Table 2. Population change assumptions for middle series of estimates

Years	Net international migration (thousands/year)	Net interstate migration (thousands/year)	Total fertility rate	Mortality rate
2005–2010	190	-90	2.15	0.98
2020–2025	225	-30	2.09	0.95
2045–2050	225	-30	2.09	0.9
2095–2100	50	-25	2.09	0.85

Alan Sanstad, from the Lawrence Berkeley National Laboratory, provided projections of two important economic indicators: household income and travel costs. He used the Intergovernmental Panel on Climate Change's *Special Report on Emissions Scenarios* (SRES, Nakicenovic and Stewart 2000) A2 and B1 global scenarios to derive "lower" and "higher" expected values for household income and the cost of driving over 10-year intervals from 2010 to 2100. Both economic indicators affect beach choice. As in most models of recreational site choice, household income enters our model through its effect on the cost of travel time. Income may also be related to other demographic factors, including level of employment and the number of children in a household. Like other models of recreational site choice, we find that increasing income results in fewer visits overall. A full exploration of the effects of income, keeping the cost of travel time fixed, has not been published in the literature. Out-of-pocket costs of travel also are important. As travel costs rise, we would expect individuals to select beaches that are closer to their homes, or even stay at home rather than traveling to a beach.

3.0 Results

3.1. Socioeconomic Projection Data

Before presenting the results of our economic analysis, we summarize the various projections that were used as inputs into our model. As described in Section 2.3, these include estimates of changes in beach width, demographic characteristics, and economic factors in Southern California. Table 3 reports the economic projections that were provided by Alan Sanstad (memo, July 2, 2008). Estimates of the "low growth" household income growth and lower growth travel costs were used for our low growth set of scenarios; "high growth" estimates were used for our higher growth scenarios. Travel costs do not vary by more than $1.00, but these small amounts add up quickly over the many miles traveled by Southern California beachgoers. Divergence between the higher and lower household income growth rates may seem small, with little variation over time, but the effects on beach choice are substantial given the distance traveled and time needed to reach all 51 beaches in the sample.

Table 3. Projected economic data

	Average annual household income growth rate in percent		Cost per mile in 2000 dollars		
Decade	**Low growth scenario**	**High growth scenario**	**Year**	**Low growth scenario ($)**	**High growth scenario ($)**
2000–2010	1.1	1.1			
2010–2020	1.1	1.1	2020	0.18	0.22
2020–2030	0.88	1.38	2030	0.2	0.26
2030–2040	1.04	1.54	2040	0.22	0.32
2040–2050	1.09	1.59	2050	0.24	0.39
2050–2060	1.03	1.23	2060	0.26	0.48
2060–2070	1.06	1.26	2070	0.29	0.58
2070–2080	1.06	1.26	2080	0.32	0.71
2080–2090	1.08	1.28	2090	0.36	0.86
2090–2100	1.09	1.29	2100	0.39	1.05

Source: Sanstad. Lawrence Berkeley National Laboratory.

The population for Los Angeles, Riverside, San Bernardino, and Orange counties is predicted to change dramatically over the course of the next century. Even moderate assumptions regarding fertility and immigration result in a doubling of the population from approximately 17 million in 2005 to 32 million in 2100. However, we only estimate the welfare effects on adults (> 18 years old), so the population for our study increases from about 10 million to 22 million over the period. The percentage of females is expected to increase from 50% to 52% of the total population. Los Angeles County will still be the major population center for the region, with more than 16 million inhabitants, but the populations of Riverside and San Bernardino counties are expected to increase from just below 2 million to over 7 million, and almost 5 million respectively by 2100. Orange County will be home to just over 4 million individuals by that time, an increase of about a million from 2005. Demographic change across the region also is expected to be significant. Most of the population growth across all counties is expected in the "Latino" racial category. In fact, the Latino population in Southern California is expected to triple from 7 to 22 million over the next one hundred years. The Asian population is also expected to double from 2 to 4 million, while White, Black, and American Indian groups decline by about 25%–30%. Finally, the projections predict a slight increase in the proportion of the population that is under 10 years of age, but the biggest shift will be an increase in the percent of individuals who are over 60 (Hans Johnson, personal communication).

Table 4. Parameters for the socioeconomic scenarios in the beach choice model

Year	2000	2020	2040	2060	2080	2100
Low Growth						
Population (18 years or older)	10,654,480	14,520,893	17,431,890	19,196,786	20,813,800	22,453,654
Mean Income in US$(2000)	69,507	83,451	98,359	118,563	143,637	174,932
Males	5,146,550	7,059,491	8,380,891	9,107,996	9,754,047	10,432,255
Black	693,280	854,020	869,722	797,612	734,899	695,186
Hispanic	3,864,630	6,563,182	9,111,722	11,265,883	13,232,582	15,243,547
Percent of Households with Children	0.50	0.53	0.56	0.58	0.60	0.61
Simple Mean Travel Costs in US$(2000)	56.19	70.82	86.86	105.66	129.81	159.87
Out-of-Pocket Cost per Mile in US$(2000)/mile	0.15	0.18	0.22	0.26	0.32	0.39
Mean Minimum Travel Cost/Trip in US$(2000)	26.86	35.78	45.61	56.74	70.82	88.62
High Growth						
Population (18 years or older)	10,654,480	14,520,893	17,431,890	19,196,786	20,813,800	22,453,654
Mean Income in US$(2000)	69,507	83,451	108,541	140,236	176,779	223,974
Males	5,146,550	7,059,491	8,380,891	9,107,996	9,754,047	10,432,255
Black	693,280	854,020	869,722	797,612	734,899	695,186
Hispanic	3,864,630	6,563,182	9,111,722	11,265,883	13,232,582	15,243,547
% Households with Children	0.50	0.53	0.56	0.58	0.60	0.61
Simple Mean Travel Costs in US$(2000)	56.19	75.42	105.04	145.85	198.44	272.83
Out-of-Pocket Cost per Mile in US$(2000)/mile	0.15	0.22	0.32	0.48	0.71	1.05
Mean Minimum Travel Cost/Trip in US$(2000)	26.86	38.21	55.38	78.85	109.19	152.83

Source: Sanstad and Johnson

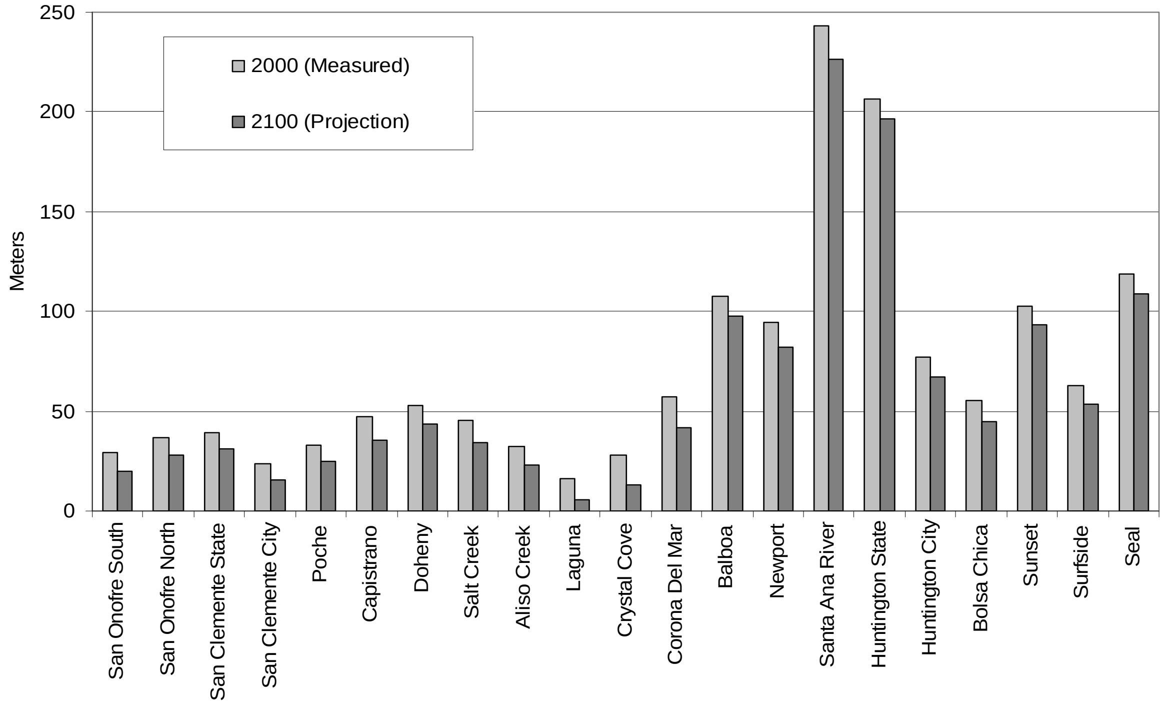
Table 4 summarizes the specific values that were derived from Sanstad and Johnson's projections and used in our "Low Growth" and "High Growth" scenarios. Note that demographic assumptions (population, males, black, Hispanic, and percent of households with children) are the same in both scenarios. Only economic factors (mean income, simple mean travel costs, out-of-pocket cost per mile, and average minimum travel costs) differ.

3.2. Width Projection Data

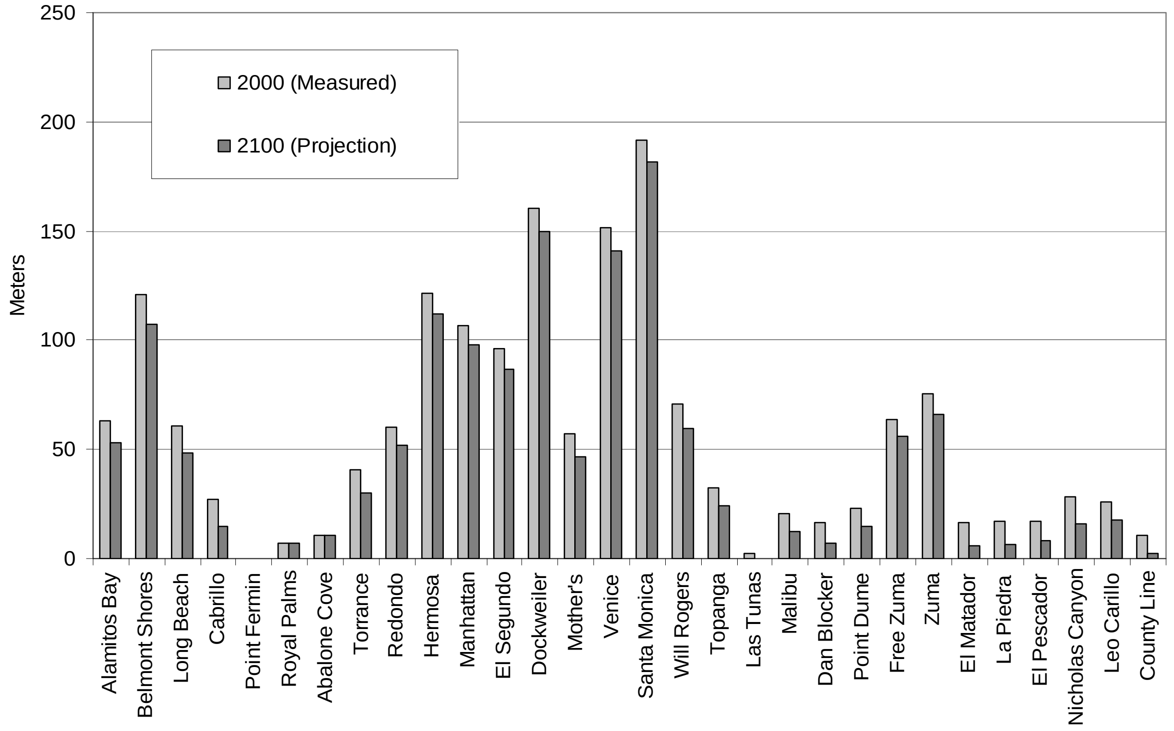
The third set of inputs for our analyses are estimates of future beach width changes due to permanent inundation with 1 m of sea level rise by the year 2100. These were provided by Adams and Inman (2008). Figure 4 provides measures of beach width for year 2000 and predicted widths under 1 m of sea level rise (estimated to occur in 2100). By 2100, a minimum of 1 m of sea level rise is expected to reduce the average widths of all beaches in Southern California, though some will be affected more than others. Average loss of width for all beaches is estimated to be approximately 9 m, which represents a range from -6 meters (County Line) to -16 meters (Santa Ana River). Note that slope data were not available for all beaches. Therefore, proxies were used for beaches with missing data. Cabrillo was assumed to have the same slope (and thus width change) as neighboring Long Beach. Point Fermin, Royal Palms, and Abalone Cove (already very narrow) were conservatively assumed to have no change. We used the average slope (and thus width change) for the two surrounding beaches to proxy the expected change in beach width at Mother's Beach in Marina Del Rey.

Sea level rise also will make the erosion and accretion effects of winter storms more severe. To investigate the potential size of the economic effects of extremely stormy years, we use estimates from Adams and Inman of changes in beach sediment budgets due to the wave climate that would be equivalent to a year with extreme weather (we use the wave climate of the 1982–1983 El Niño as an example). Figure 5 illustrates the potential transformative effects of such events, which can cause as much beach change in one year as is generated by the loss of beach width caused by permanent inundation caused by 1 m of sea level rise. In fact, another massive El Niño at current sea levels could temporarily reduce some beaches like Zuma Beach below the base projected width for under a scenario of 1 m of sea level rise.

The average impact on beach width of an extremely stormy year is projected to be a 10 m reduction in beach width at current sea level, but unlike beach width change due to inundation, some beaches could grow during an extremely stormy year, due to accretion (Figure 5). Many beaches are predicted to lose more than 20 meters during a single, extremely stormy year. In the short time frame given, the model of Adams and Inman was unable to provide estimates of erosional loss for 16 of 52 beaches in the study. For the most part, this lack of erosional estimates for some beaches was due to time constraints, but the model failed to converge for a few beaches due to anomalies created by manmade structures off these coastal areas. Where possible we used proxies with similar exposure to storm events to estimate these missing projections conservatively. Specifically, changes in beach width at Balboa and Newport were estimated using the width change for the Santa Ana River Mouth; Long Beach and Cabrillo were approximated by Belmont shores. Changes for Point Fermin, Royal Palms, and Abalone Cove were taken from Point Dume. Unfortunately such proxies were unavailable for northern Los Angeles beaches, so we used the average width change of all beaches as the proxy for Free Zuma, Zuma, El Matador, La Piedra, El Pescador, Nicholas Canyon, Leo Carrillo, County Line, and Mugu.

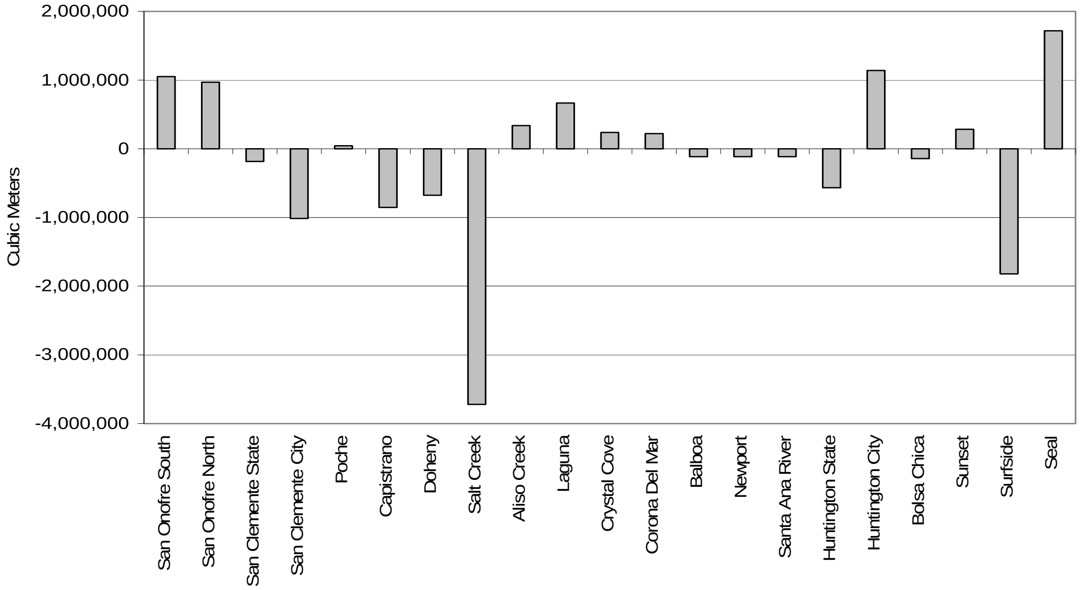


a. Orange County Beaches (South to North)

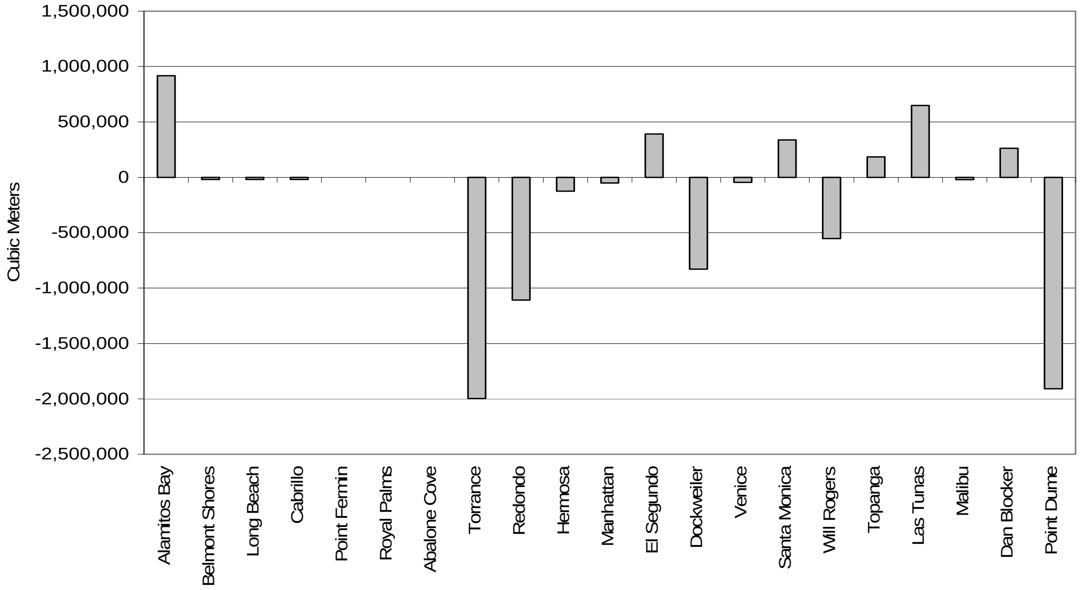


b. Los Angeles County Beaches (South to North)

Figure 4. Southern California beach widths in 2000 (measured) and 2100 (projected with 1 meter sea level rise)



a. Orange County Beaches (South to North)



b. Los Angeles County Beaches (South to North)

Figure 5. Change in beach volume due to an extremely stormy year

3.3. Estimated Annual Economic Impact Caused by Permanent Beach Loss from Inundation Due to Sea Level Rise

The economic impacts of permanent beach width loss due to inundation from sea level rise and even a single stormy year are large and unevenly distributed across the region. (Our analysis focuses only on the impacts on beach visits by residents of four counties of Southern California: Los Angeles, Orange, Riverside, and San Bernardino counties.) Inundation due to sea level rise has only a modest impact on total beach attendance to the region (see Figure 6). For illustration, we first examine the effects of sea level rise assuming no change in population or demographic factors. Holding population and demographic conditions fixed at year 2000 levels, a 1 m rise in sea level changes the total annual attendance at the public beaches in Los Angeles and Orange counties by a mere 589,000 visits. While the relative change in annual visits may be small, the overall change in consumer surplus is substantial (Figure 7). If we break down the results by beach, we can see that annual attendance increases at some beaches but declines at others (see Section 3.3.1). This effect is masked at the regional level—demonstrating the importance of scale when considering the impacts of sea level rise on beaches.

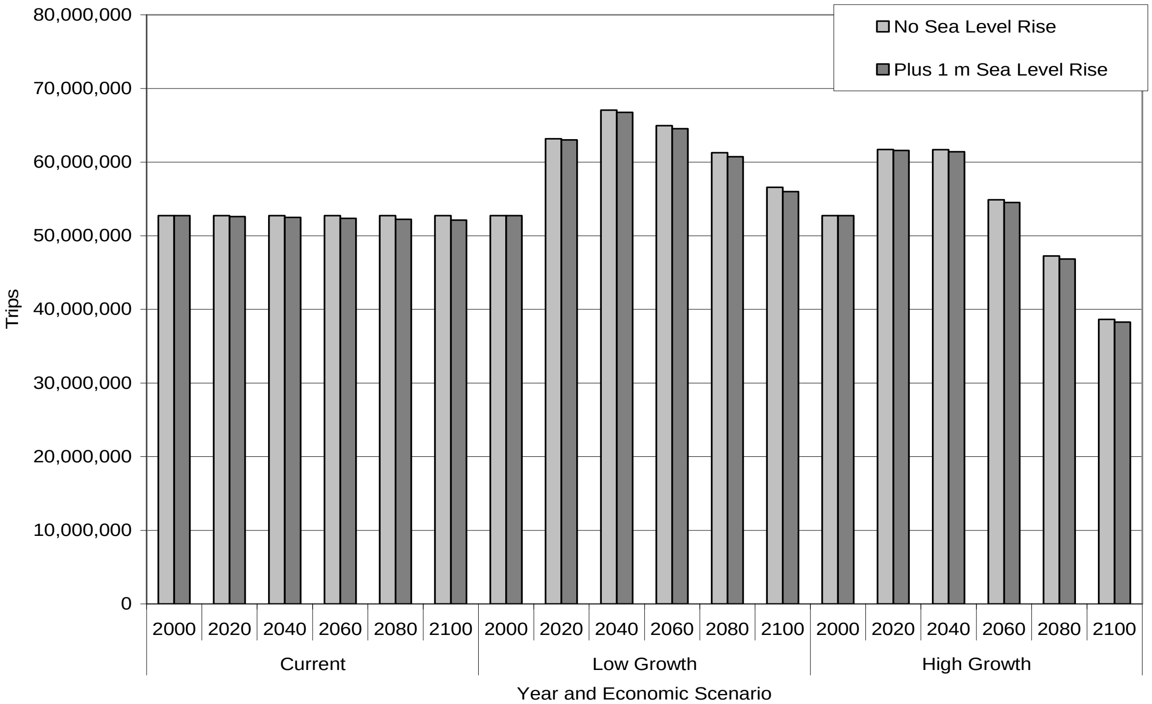


Figure 6. Projected annual beach attendance at Southern California beaches for inundation scenarios

Figure 6 also illustrates the role of change in population, household income, and travel costs in determining annual attendance over time. In the "Current" demographic scenarios, sea level rise is the only factor that is allowed to vary, which results in a constant baseline level of visits and gradually decreasing visits as sea level rises, reducing beach width. When population, income, and travel costs grow in real terms, the baseline of attendance increases and then declines as increases in income and travel cost offset increasing populations. Population growth means more potential beachgoers, but increasing income leads to increased costs of travel and recreation time (see previous discussion in Section 2.3 for other possible ways changes in income could affect visitation and site choice); increased travel costs also reduce the total number of trips per local resident annually. It is against this changing baseline of annual attendance that the impacts of climate change must be considered. For all three scenarios, it is clear that a simple loss of beach width (even across all beaches) has only a modest impact on overall beach going. The relatively small proportional change in annual beach attendance is due to the abundance of beach choices and the fact that many wide beaches will continue to be wide under the simple assumption of permanent beach inundation.

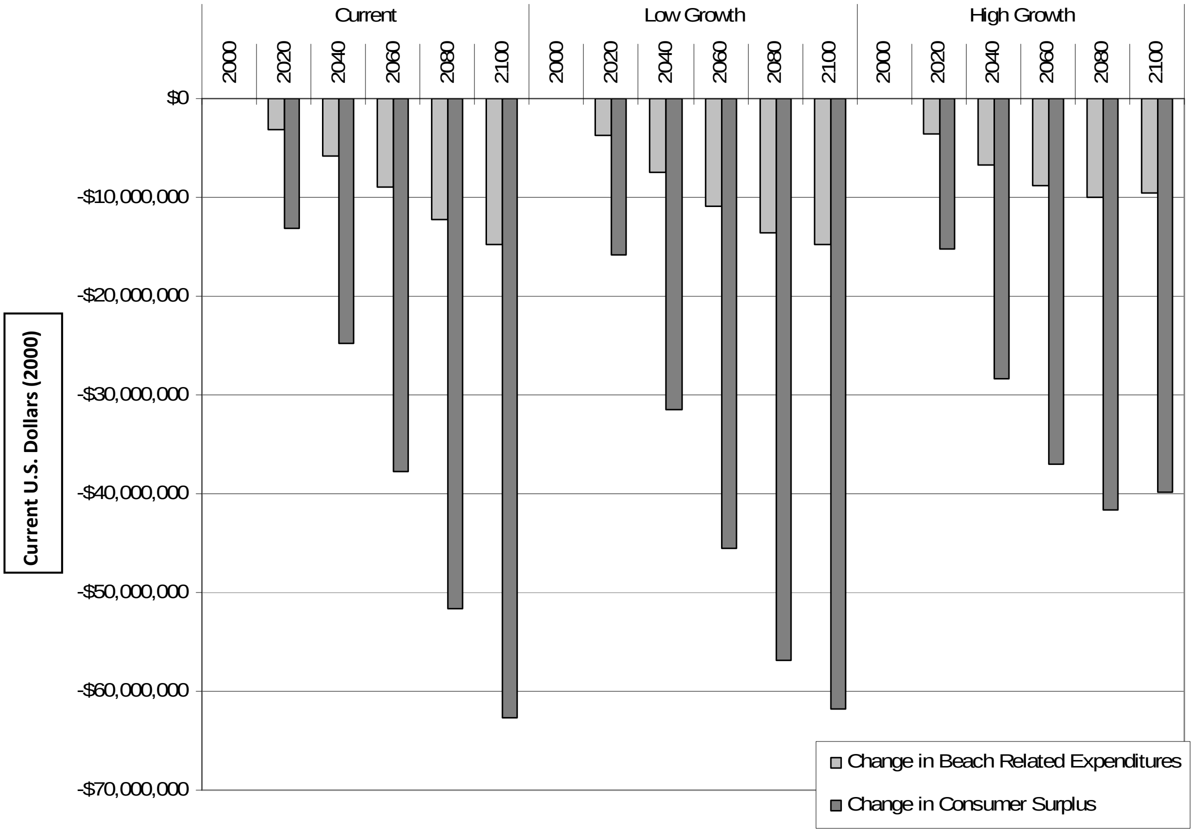


Figure 7. Change in annual expenditures and annual consumer surplus with +1 m sea level rise

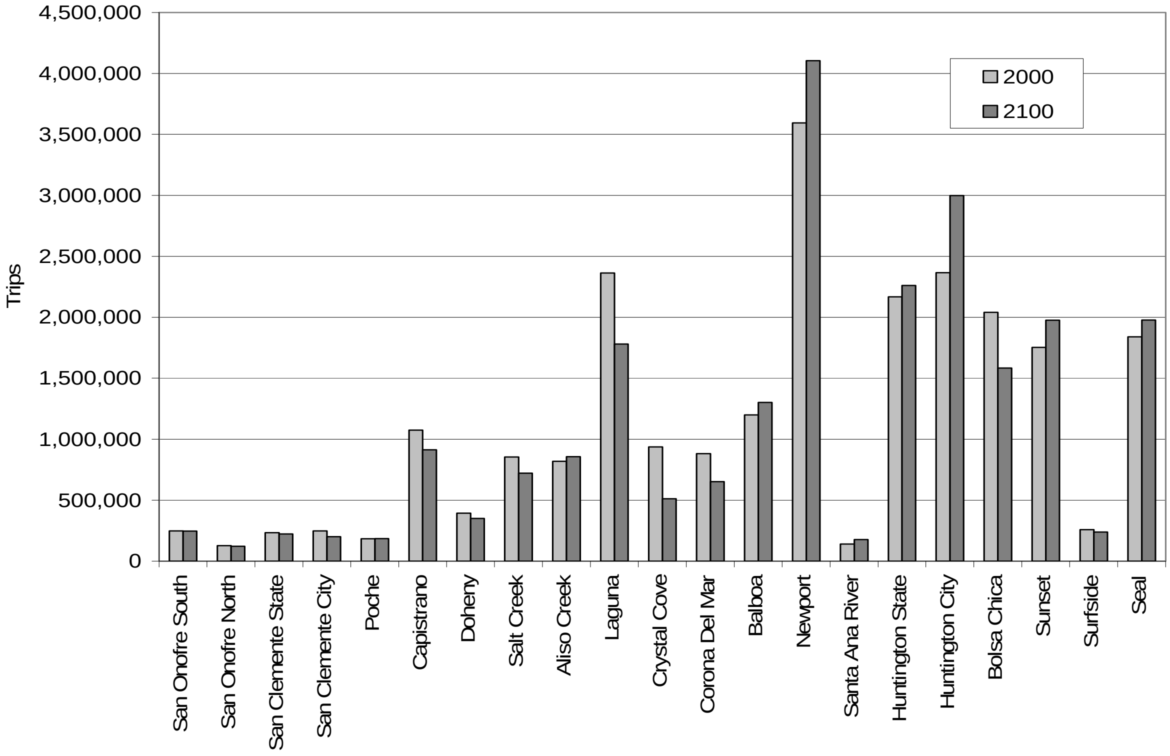
Changes in the number of beach visits made annually will also affect the amount of money beachgoers spend on beach-related activities and the amount of consumer surplus that they enjoy. Even relatively small overall expected differences in attendance due to sea level rise can have a large economic impact. As shown in Figure 7, compared to scenarios of no sea level rise, direct expenditures on beach-related activities can be expected to be lower by almost

$10 million annually under the high growth scenario, and by almost $15 million annually under the low growth and no change scenarios. Consumer surplus will be even more affected. Permanent beach loss, caused by sea level rise, may cause consumer surplus to be as much as $40 million lower annually under the high growth scenario or more than $60 million lower annually under the low growth and no growth scenarios. This result may seem counterintuitive at first. Figure 6 shows the difference between sea level rise and no sea level rise, not the overall change in benefits due to socioeconomic factors. Under projections of higher income and travel cost, the overall impact of permanent inundation due to sea level rise has a smaller impact on attendance, expenditure, and consumer surplus (compared to the baseline).

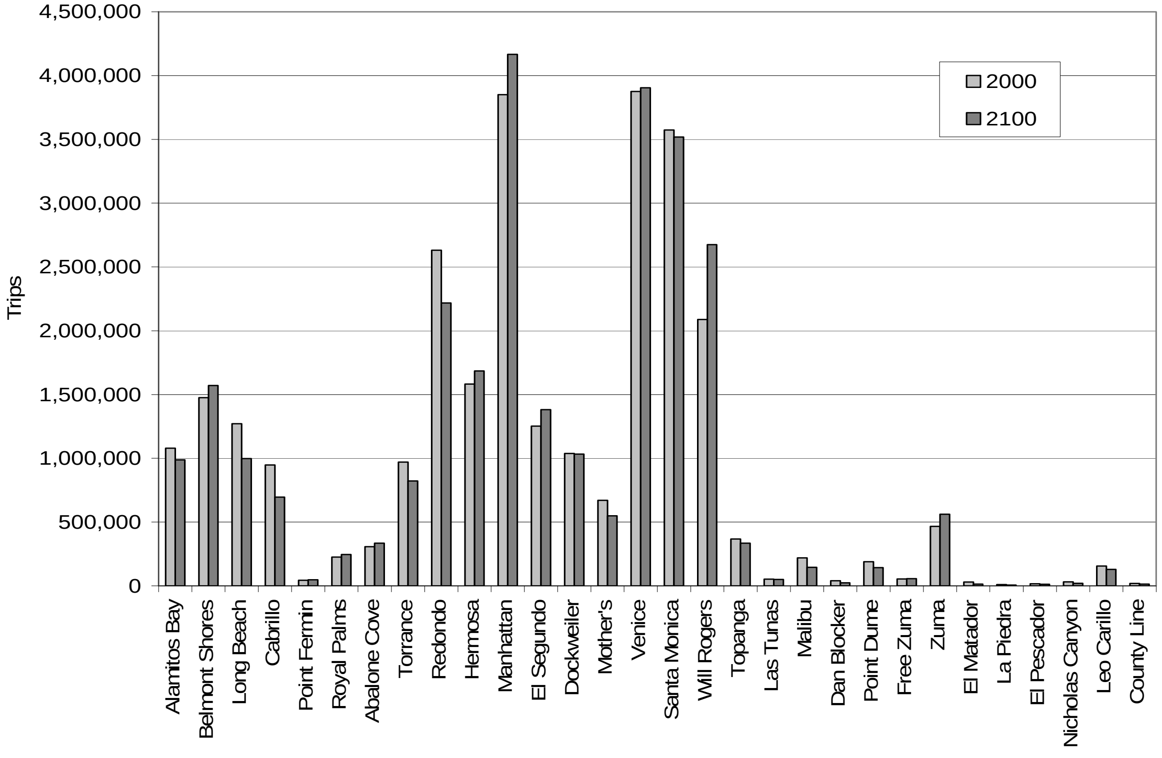
3.3.1. The Uneven Impact of Permanent Beach Loss, Due to Inundation, on Beaches

Beach width and attendance at Southern California beaches has never been uniform; beaches that are more accessible, wider, and provide more amenities tend to draw larger numbers of visitors. As shown in Figure 8, this reality is reflected in our projection results. It depicts the expected total number of beach visits over time with a gradual +1 m sea level rise under the "Current" economic scenario. In this case, all variation results from changes in width due to sea level rise. Even when the absolute loss of beach width is substantial (e.g., > 10 meters), very large beaches tend to remain large, even with permanent inundation due to sea level rise. As a result, visitors tend to substitute away from increasingly smaller beaches to those beaches that remain large. Large beaches with high attendance in 2000, like Newport, Huntington City, and Manhattan, will enjoy higher levels of attendance with sea level rise, while visits to other popular beaches like Huntington State, Venice, and Santa Monica are not expected to differ substantially. Still other beaches show lower levels of attendance with sea level rise, including Laguna, Bolsa Chica, Torrance, and Redondo. Visits to beaches with relatively low attendance in 2000 are not expected to differ much with sea level rise by 2100.

The differences in beach attendance due to permanent beach loss alone are much more pronounced when we examine the effects at individual beaches. Figure 9 shows the difference between beach attendance at current sea level and with +1 m sea level rise. (Note, if we assume that beach width change over time is linear, we see non-linear changes in beach attendance and associated expenditures and consumer surplus. See Appendix D.) "Winners," or beaches that receive increasing numbers of visitors as sea levels rise, can also expect higher local beach-related expenditures, since people spend about US$(2000)25.18 per trip to the beach (Pendleton and Kildow 2006). On the other hand, "Losers," or those beaches where visits are predicted to be fewer, can expect lower expenditures. The magnitude of such differences is indicated in Table 5, which lists the top five winners and losers when sea level rise is the only factor that is allowed to vary in the model. As a result of complex interactions between beach attributes and sea level rise, beaches like Huntington City and Will Rogers can expect big gains but others such as Laguna and Bolsa Chica can expect big losses with sea level rise.

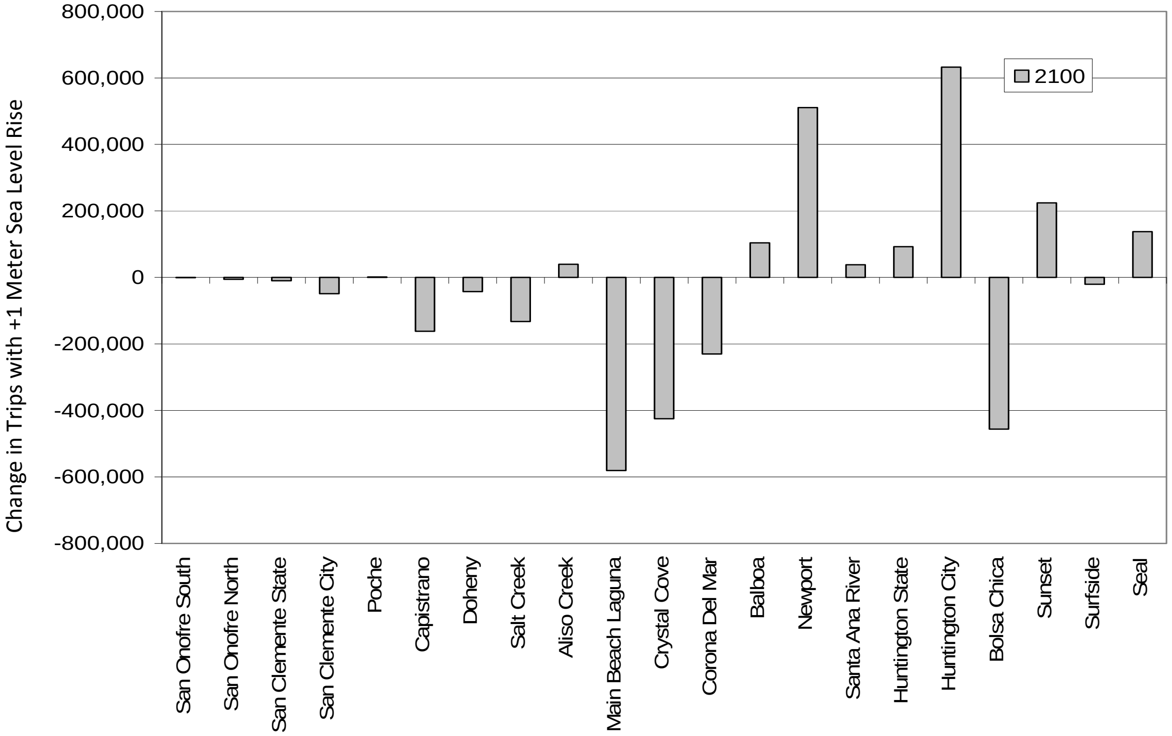


a. Orange County Beaches (South to North)

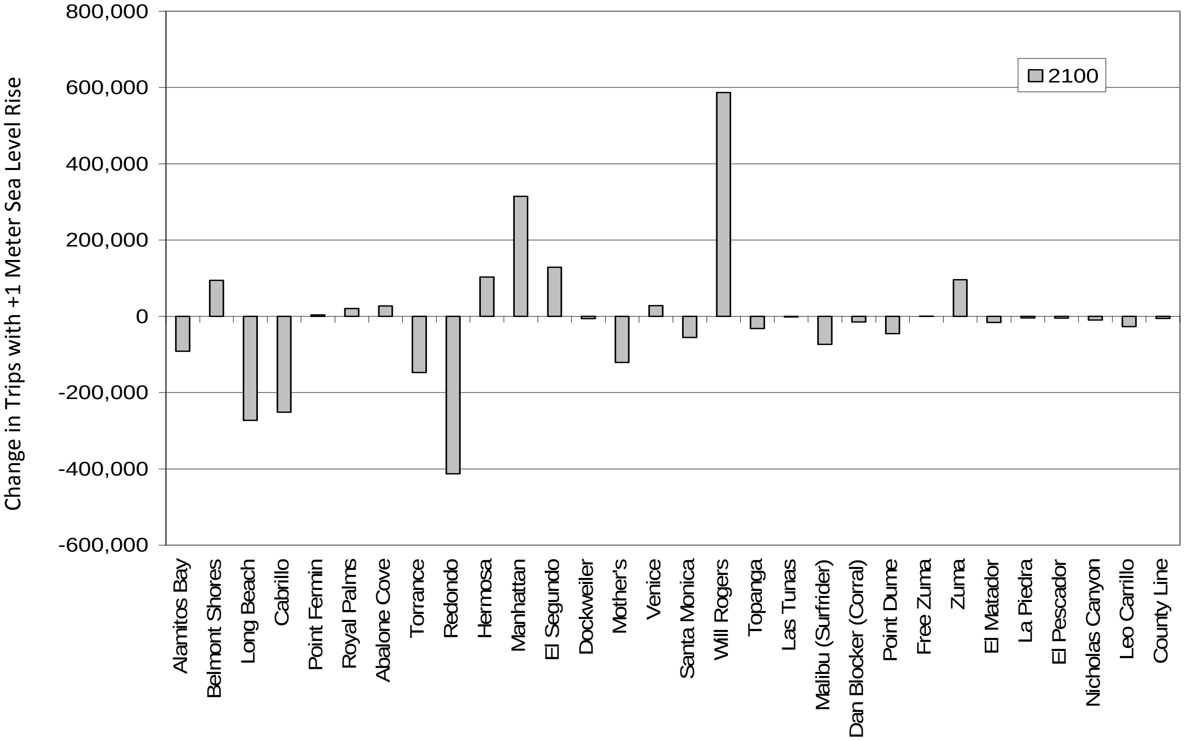


b. Los Angeles County Beaches (South to North)

Figure 8. Attendance by beach with +1 m sea level rise (current scenario)



a. Orange County Beaches (South to North)



b. Los Angeles County Beaches (South to North)

Figure 9. Difference in attendance by beach due to +1 m sea level rise (current scenario)

Table 5. Top 5 winners and losers with sea level rise (current demographic, population, and costs)

Winners	Difference in Annual Expenditures US$(2000), rounded to nearest million)	Losers	Difference in Annual Expenditures US$(2000), rounded to nearest million)
Huntington City	16 million	Main Beach Laguna	-14 million
Will Rogers	15 million	Bolsa Chica	-12 million
Newport	13 million	Crystal Cove	-11 million
Manhattan	8 million	Redondo	-10 million
Sunset	6 million	Long Beach	-7 million

Losses in the welfare of beachgoers will be felt differentially across the region too. Table 6 lists changes in consumer surplus for residents by their county of origin.

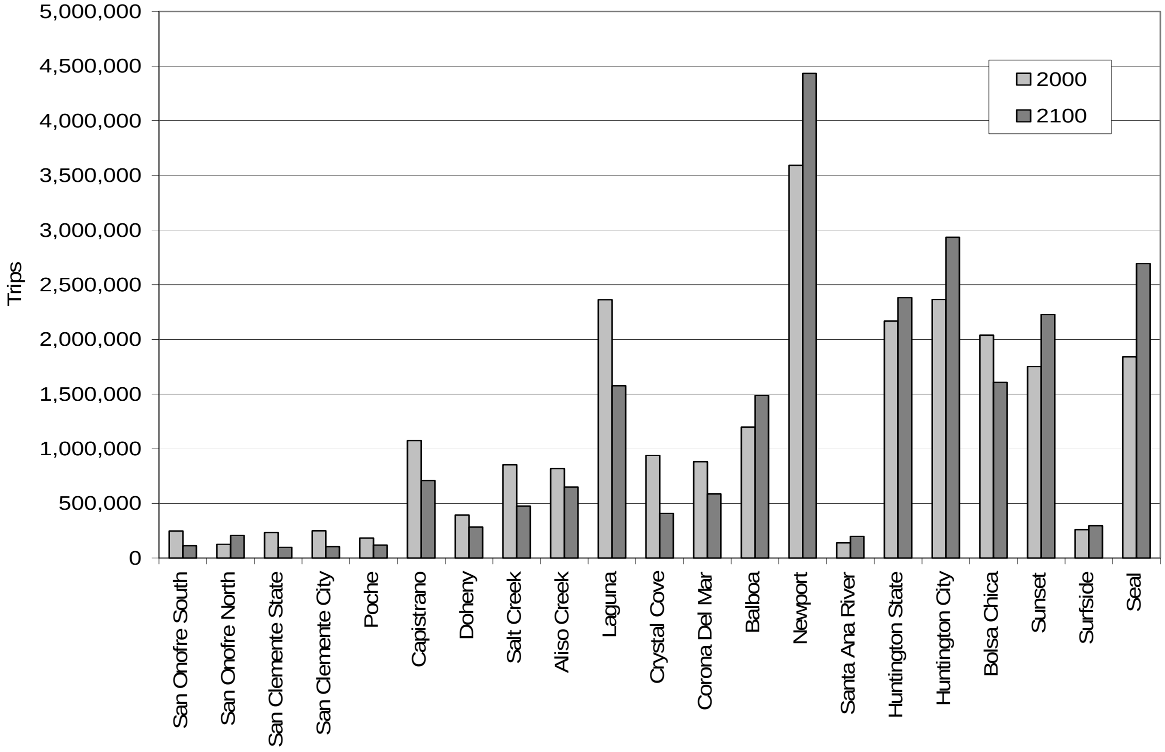
Table 6. Difference in annual consumer surplus caused by permanent beach loss, due to inundation, from +1 m sea level rise (US$[2000], rounded to nearest million)

	Los Angeles	Orange	Riverside	San Bernardino
	Consumer Surplus (estimated for county of beachgoer residence)			
2020	-7 million	-4 million	-1 million	-1 million
2040	-12 million	-7 million	-3 million	-2 million
2060	-19 million	-11 million	-4 million	-4 million
2080	-26 million	-15 million	-6 million	-5 million
2100	-31 million	-19 million	-7 million	-6 million

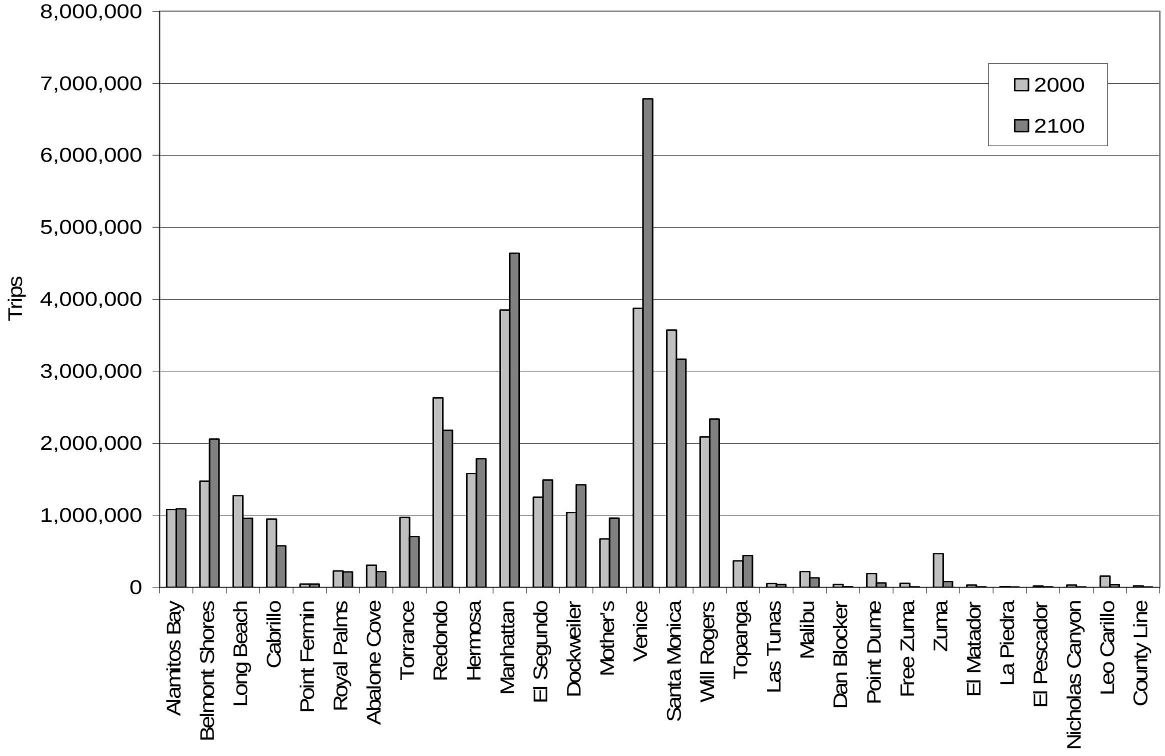
3.3.2. High Growth vs. Low Growth with Inundation

As noted above, we do not expect that all other factors will remain constant over the 100 years of our simulation run. Therefore we also analyze the impact of sea level rise under two additional socioeconomic scenarios: one in which there is “Low Growth” in income and travel costs and middle projections of growth in population and demographics and another in which there is “Higher Growth.” The relative change in attendance, expenditures, and consumer surplus at beaches caused by permanent beach loss follows a similar pattern for all scenarios of economic change, only the magnitude of impacts differs. Figure 10 shows the projected beach visits under sea level rise in the Low Growth scenario. The winners and losers are the same as in the current scenario, but the rate of change in visits decreases over time. Gains or losses in 2100 tend to be smaller in the Low Growth scenario than they are in the Current scenario. High economic growth has a greater impact, resulting in even lower final annual attendance estimates, as shown in Figure 11.

As before, even under these different scenarios of population and economic change, some beaches have fewer visitors with 1 m of sea level rise while others have more visitors when beaches are permanently inundated due to sea level rise. Figures 12 and 13 provide changes in beach attendance caused by permanent beach loss, by beach, for the low and high growth scenarios. In fact, most of the winners in all three socioeconomic scenarios are beaches that were initially large and that have a mix of accessibility and a high level of amenities. Nevertheless, further analysis will be necessary before we can truly understand the redistributive effects of sea level rise. For now, it is important to note that winners and losers with sea level rise do not change much between the two socioeconomic scenarios, but the magnitude of gains and losses does (see Table 7). Losses due to sea level rise are less severe when economic growth is factored into the model. Furthermore, this effect is much more pronounced under the high growth scenario. Compared to either no growth or low growth, change in expenditures by beach due to sea level rise is reduced by half when high growth is assumed.

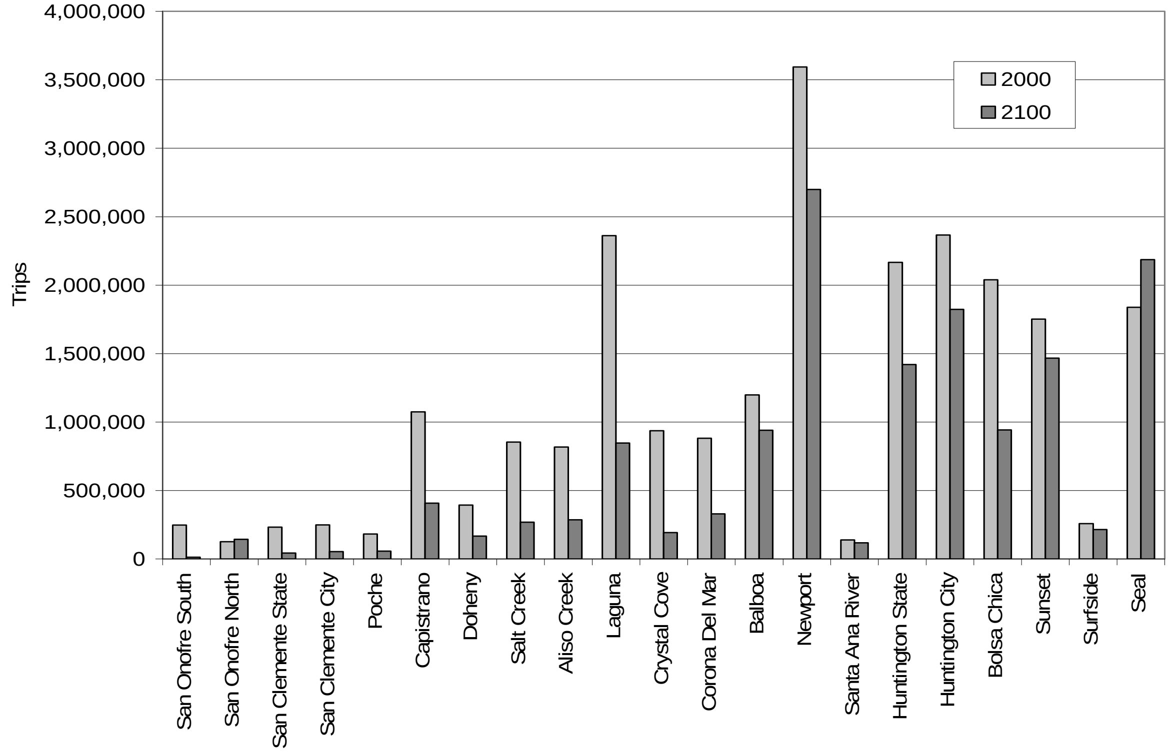


a. Orange County Beaches (South to North)

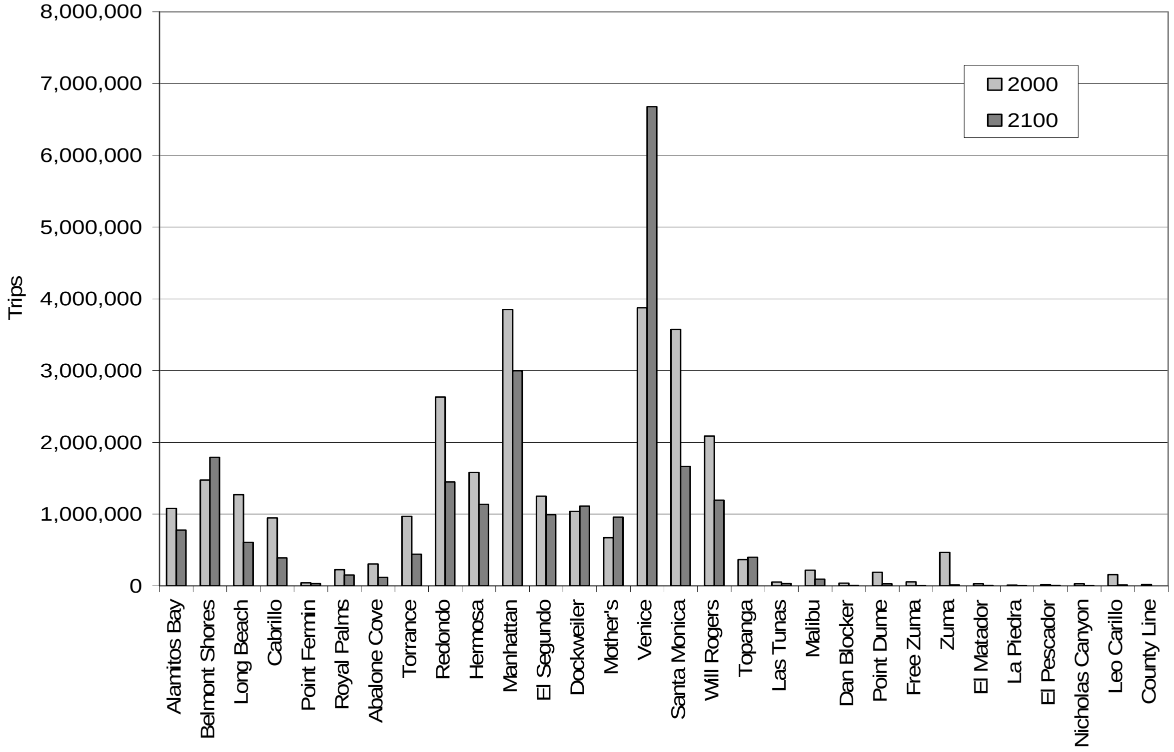


b. Los Angeles County Beaches (South to North)

Figure 10. Attendance by beach with +1 m sea level rise (low growth)



a. Orange County Beaches (South to North)



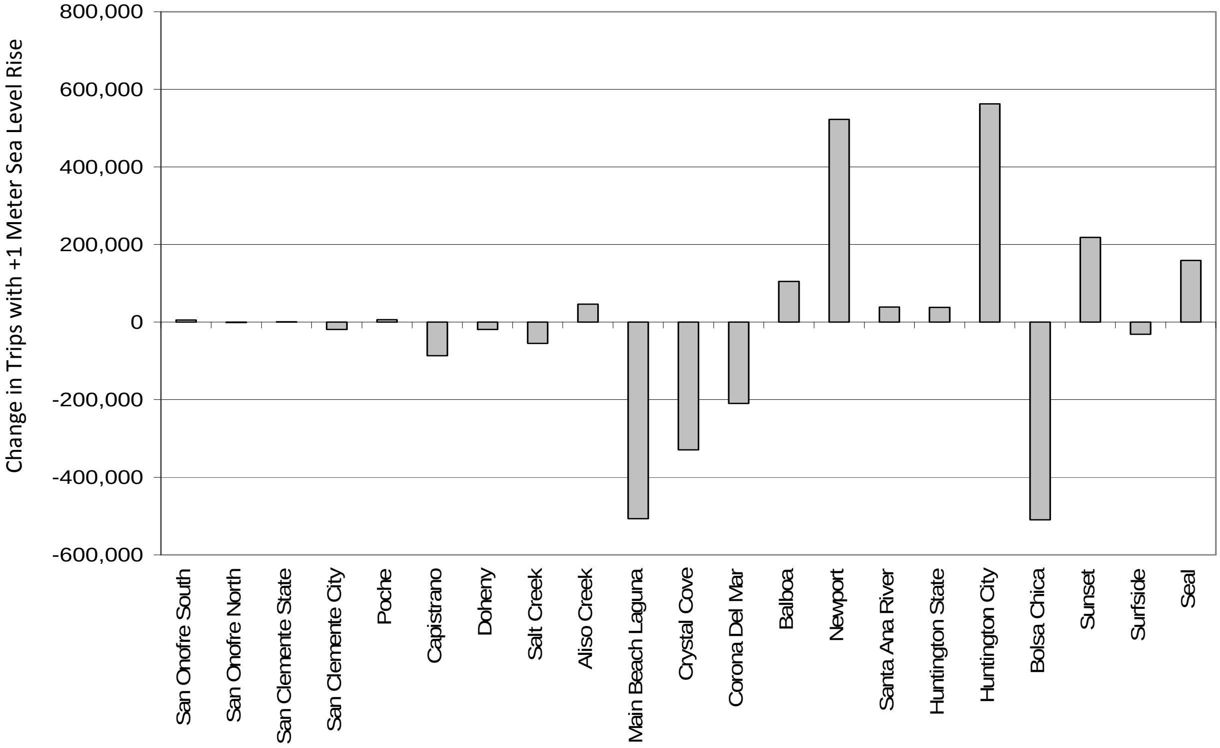
b. Los Angeles County Beaches (South to North)

Figure 11. Attendance by beach with +1 m sea level rise (high growth)

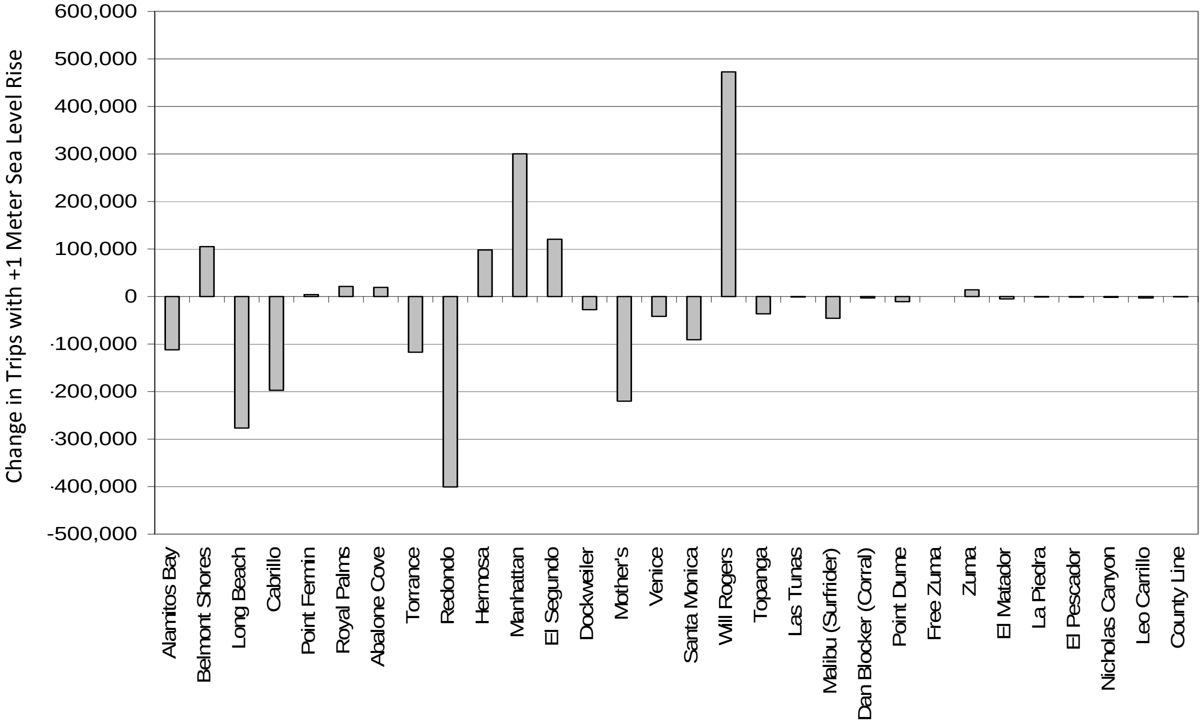
Table 7. Top five winners and losers for permanent beach loss due to inundation, two socioeconomic scenarios

Winners	Difference in Annual Expenditures US$[2000], rounded to nearest million)	Losers	Difference in Annual Expenditures US$[2000], rounded to nearest million)
Low Growth			
Huntington City	14 million	Bolsa Chica	-13 million
Newport	13 million	Laguna	-13 million
Will Rogers	12 million	Redondo	-10 million
Manhattan	8 million	Crystal Cove	-8 million
Sunset	5 million	Long Beach	-7 million
High Growth			
Huntington City	7 million	Bolsa Chica	-8 million
Newport	7 million	Laguna	-6 million
Will Rogers	6 million	Redondo	-6 million
Manhattan	5 million	Mother's	-5 million
Sunset	3 million	Long Beach	-5 million

Changes in expenditures follow similar patterns under the low and high scenarios. Figure 14 compares change in beach-related expenditures due to permanent beach loss caused by sea level rise in the three socioeconomic scenarios. The differences in economic impacts, by county in which the beach is located, are largest with current population, income, and travel costs. Losses, compared to the scenario with no sea level rise but the same population, demographic, and economic conditions, are twice as great for Orange County beaches compared to Los Angeles County beaches. However, when economic and demographic projections are factored into the model, the difference between expected expenditures with climate change compared to the baseline is smaller for Orange County. In fact, under either high or low growth, the difference between projected expenditures and the baseline are smaller in the future for Orange County beaches. This is likely due to the difference in population and growth projections for these and neighboring counties.

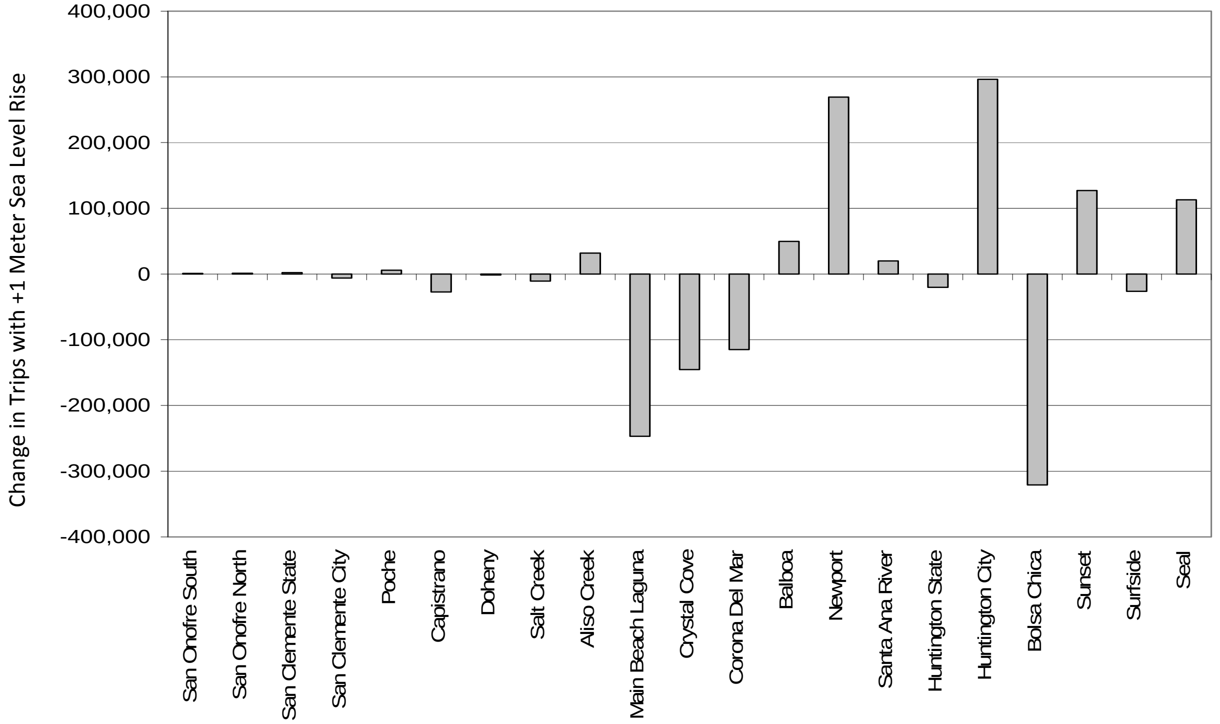


a. Orange County Beaches (South to North)

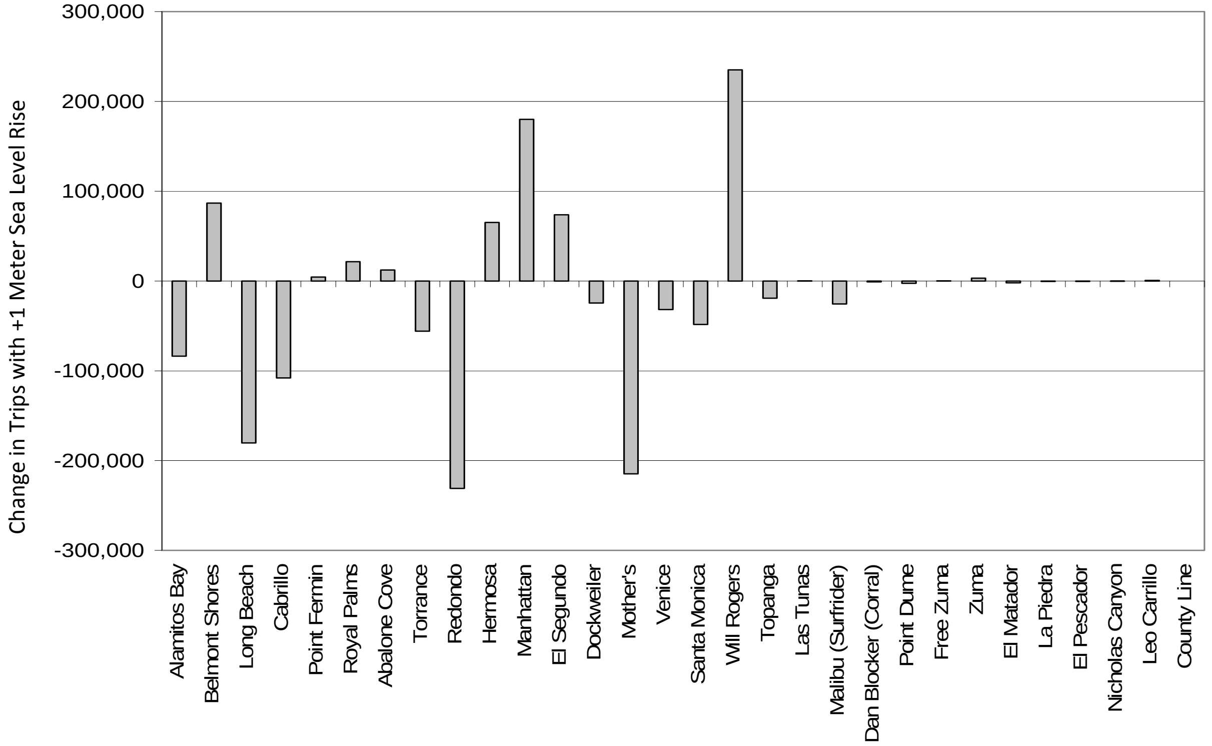


b. Los Angeles County Beaches (South to North)

Figure 12. Difference in attendance by beach due to +1 m sea level rise (low growth)



a. Orange CountyBeaches (South to North)



b. Los Angeles County Beaches (South to North)

Figure 13. Difference in attendance by beach due to +1 m sea level rise (high growth)

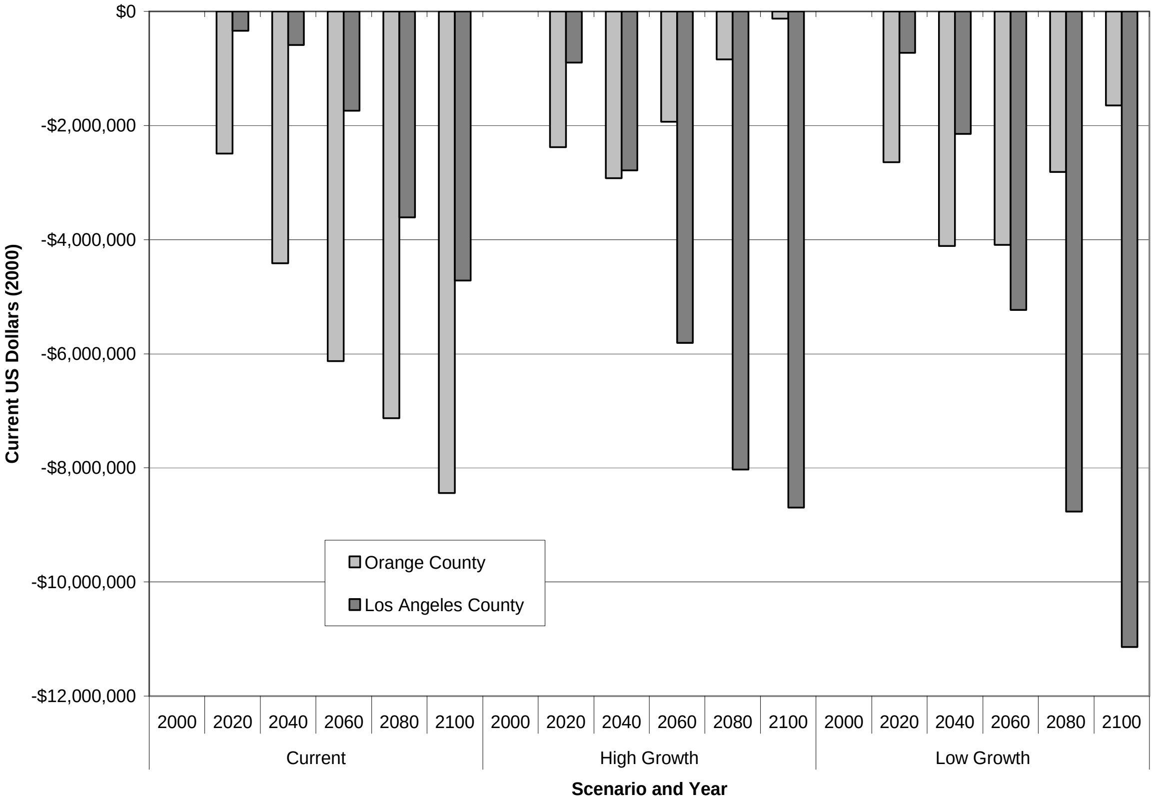


Figure 14. Difference in expenditure with +1 m sea level rise by county under three scenarios

Consumer surplus loss due to permanent beach loss caused by sea level also differs by county (Figure 15). Residents from Los Angeles County bear the greatest burden in lost consumer surplus, which is over $30 million lower with a 1 m rise in sea level under the current and low growth scenarios and by almost $25 million in the high growth scenario. Orange County experiences smaller differences in consumer surplus in the two growth scenarios, but Riverside County would experience its highest losses under the low growth scenario. San Bernadino suffers least in all three scenarios.

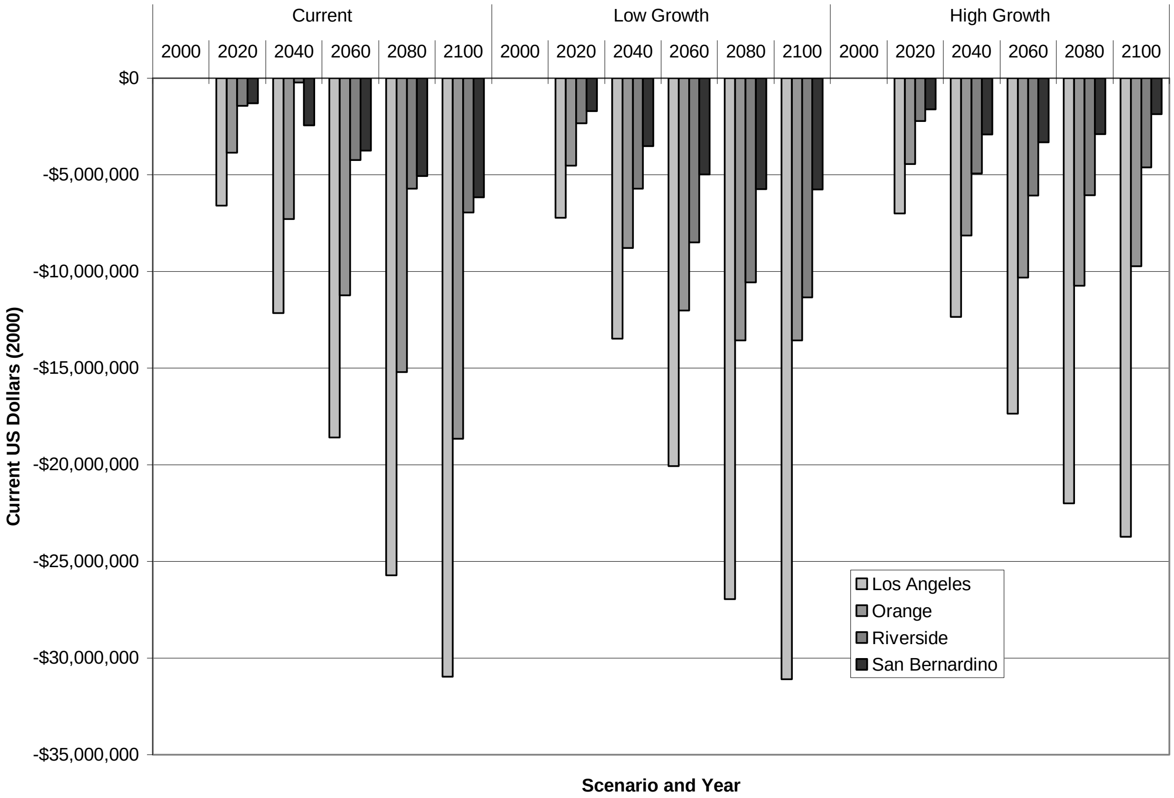


Figure 15. Difference in consumer surplus due to +1 m rise in sea level under three scenarios

3.4. The Economic Impact of Extremely Stormy Years

Of course, the effects of sea level rise on beach width are unlikely to occur slowly and evenly across the region. While wave climate may not change substantially due to climate change, sea level rise will increase maximum high tides and these high tides are likely to exacerbate the effects of wintertime storms on beach erosion and accretion (Cayan et al. 2008). To explore the potential economic impacts of erosion and accretion caused by extremely stormy years, we investigate the economic impacts of beach change simulated for a year similar to the 1982–1983 El Niño. These estimates are intended only to show how these extreme years compare to the assumption of simple inundation. We do not have good estimates, at this time, of how sea level rise and winter storms will affect beach change over the long run.

Unlike permanent beach loss caused by inundation due to sea level rise, which may occur over 100 years, an extremely stormy period has a large impact in a single year. We assume the effects of a major storm season linger for one year. The lasting effects of a storm depend on a number of factors including sediment availability and natural recovery. Back-to-back stormy years could also affect beach sand recovery. Thus, our estimates are intended to give an order of magnitude context for the severity of impacts that could result from increased storm intensity. We find that the effects on beach width and beach use of a single extremely stormy year are on the same order as the effects of one hundred years of sea level rise.

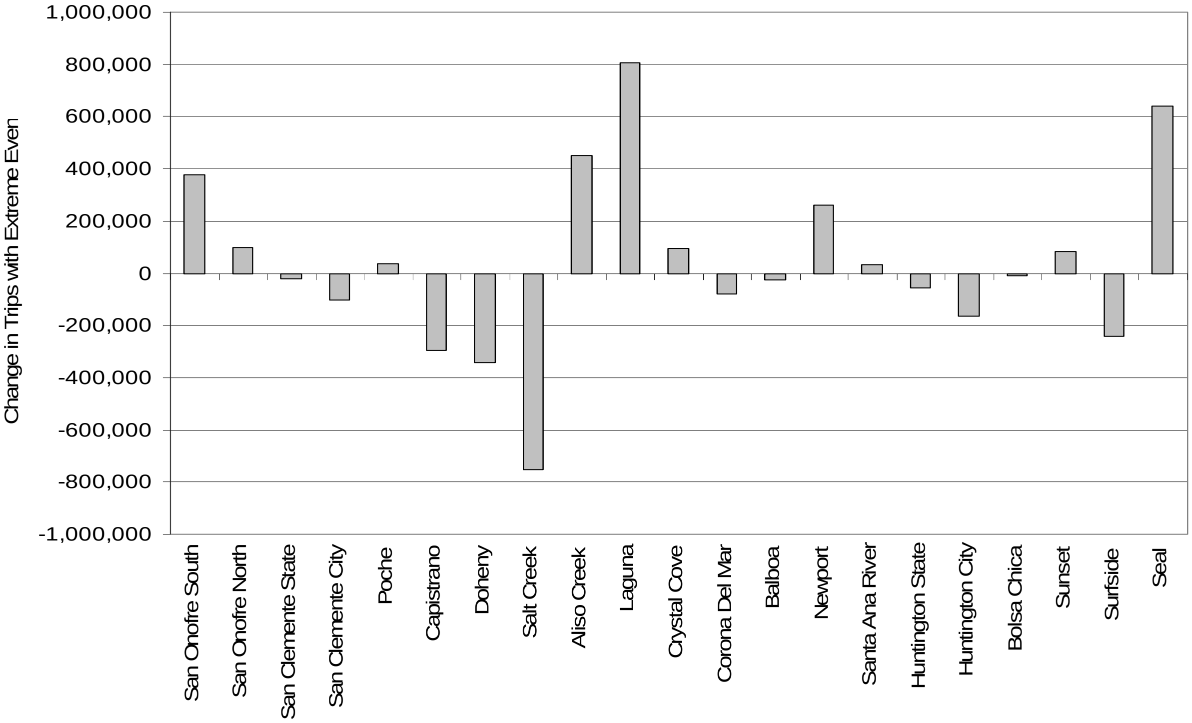
The effects of waves, especially from storms, on sediment budgets of beaches includes both increasing volumes of sand and width at some beaches and the loss of sand and beach width at other beaches (see Figure 6). The most extreme changes in beach width exceed those of permanent inundation due to a full meter of sea level rise. Like the effects of permanent beach loss caused by sea level rise, the net economic effect of beach change due to an extremely stormy year is detrimental with a predicted initial, temporary change of annual visits due to an extremely stormy year like that of El Niño equal to -343,446 and an associated change in total expenditures of -$8.6 million and a change in consumer surplus equal to $36.7 million (current US$[2000]). Also, like the effects of permanent beach inundation, the effects of erosional events are uneven across beaches. Figure 16 shows that the effect on beach attendance varies widely across beaches.

Also, as in the case of permanent beach loss, there are winners and losers in terms of expenditures. Table 8 demonstrates the range of change in expenditures that could be experienced by the winners and losers in a year with extreme erosional/accretion events. Interestingly, Laguna and Seal beaches, which lose considerable attendance and expenditure with inundation, are expected to be winners due to beach change caused by extremely stormy years. This is probably because Adams and Inman project a net loss in width for these beaches due to inundation but a net gain due to an extremely stormy year. On the other hand, beaches like Torrance and Redondo, which were expected to lose some visits and expenditure under inundation are worse off after an extremely stormy year because they lose even more width under conditions of extremely stormy wave conditions.

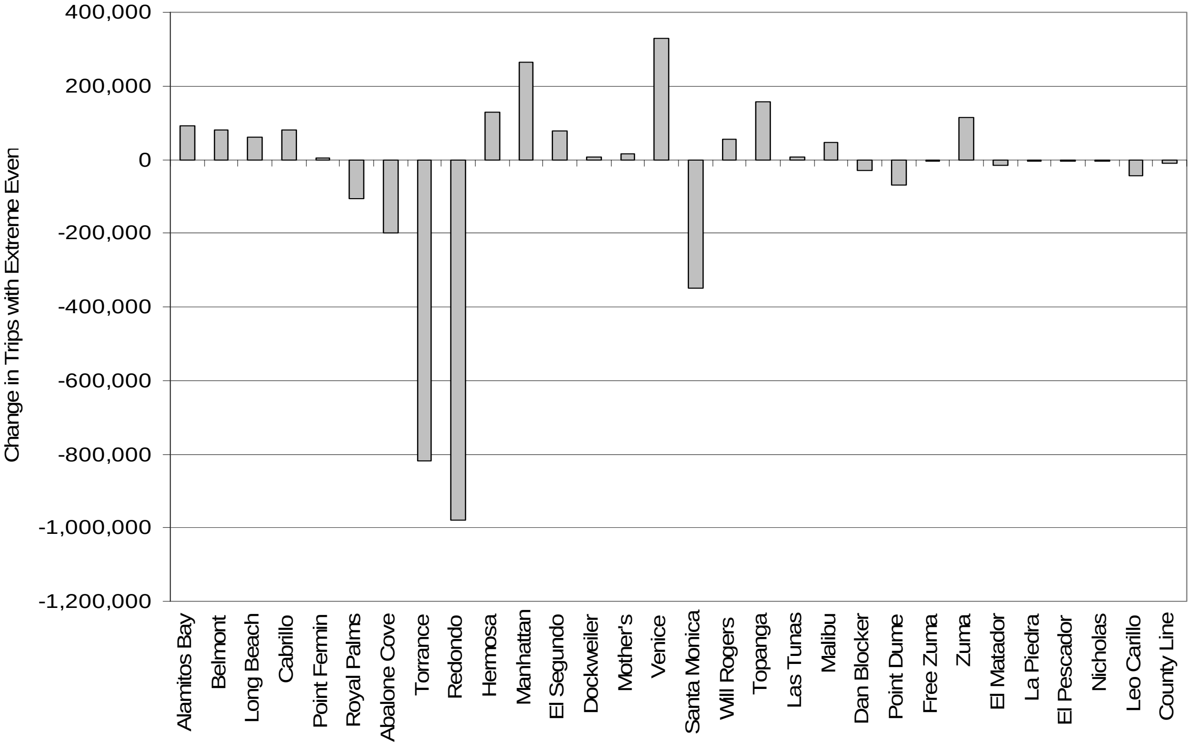
Table 8. Top five winners and losers with sea level rise, an extreme storm year

Winners	Difference in Annual Expenditures (US$[2000], rounded to nearest million)	Losers	Change in Expenditure (Current US$[2000])
Main Beach Laguna	20 million	Redondo	-25 million
Seal	16 million	Torrance	-21 million
Aliso Creek	1 million	Salt Creek	-19 million
San Onofre South	9 million	Santa Monica	-9 million
Venice	8 million	Doheny	-9 million

Finally, a breakdown of the change in consumer surplus due to a year-long change in beach width caused by extreme erosional and accretion events reveals variation in impact among the counties in Southern California. Three of the four counties are net losers under beach change scenarios that result from extremely stormy years (even under current sea level). Residents of Los Angeles County experience a large negative impact after an extreme event, losing over $30 million in consumer surplus annually. Orange County is a distant second, with almost $3 million in losses, followed by San Bernardino at about $2 million. However, Riverside County is a net winner, though only by about $350,000. Los Angeles suffers from having many beachgoers that live near beaches that are likely to be badly damaged during an extremely stormy year.



a. Orange County Beaches (South to North)



b. Los Angeles County Beaches (South to North)

Figure 16. Difference in attendance by beach due to an extremely stormy year at current sea level

3.5. The Costs of Mitigating Beach Loss through Nourishment

3.5.1. Estimates of the Cost of Nourishment

One of the most common ways to combat loss of beach width due to sea level rise is to nourish eroded beaches by replenishing them with sand from either inland or offshore sources.[4] In fact, many such beach nourishment projects have already been undertaken in Southern California, particularly to maintain wide, sandy beaches like Venice Beach and Dockweiler State Beach (State of California 2007; see Appendix E for a list of these projects). There are two major methods used in beach nourishment: trucking and dredging. Bringing in sand on trucks and then redistributing it around a beach using bulldozers is most cost-effective for small nourishment projects because the fixed costs are relatively low. Dredging, which requires scarce and expensive equipment that dredges sand from offshore and then deposits it near the beach site has high fixed costs but also significant economies of scale. Therefore, dredging tends to be more cost effective for very large projects.

Because of this divergence, our estimates of the costs of nourishment depends heavily on the amount of erosion expected in a given period and the frequency of nourishment projects. Nourished beaches require periodic maintenance, since waves and currents constantly move sand in the alongshore and cross-shore directions. Sand may also be removed due to persistent background erosion or a storm. Typical re-nourishment intervals under past sea-level conditions range from two to five years, though when financing is a problem the length of time between cycles may be much longer. Between increasing average erosion rates due to sea level rise and the potential that winter times storms will have greater impacts due to increased high tides (Cayan et al. 2008) and longer storm seasons (Peter Bromirski, personal communication), nourishment may need to be undertaken more often in the future to maintain the current quality of Southern California beaches.

Our model captures this effect by providing simple cost estimates for the placement of sand on beaches to counter simple flooding (permanent inundation) due to one meter rise in sea level and the erosional losses that could occur during an extremely stormy year.

Recent cost estimates for beach nourishment were calculated for the Los Angeles County Department of Beaches and Harbors (2007). A recently completed study analyzed the need for nourishment at Los Angeles County beaches and estimated the costs of these projects (Los Angeles County Department of Beaches and Harbors 2007). The study developed a general cost structure for nourishment projects in Los Angeles County.

Table 9 indicates that the variable costs of beach nourishment are $26 per cubic meter, including placing sand on the beach and bulldozing. Mobilization/demobilization costs were estimated at $585,000 for one project. For additional projects, the mobilization/demobilization costs are much

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[4] Sand may also be transferred from other beaches, but this is infrequent.

lower, approximately $60,000. Thus, if one is able to schedule a number of projects together, the fixed costs of mobilization and demobilization, as a percentage of the total costs, may be quite low.

Table 9. Estimated costs for hopper dredge nourishment[5]

Mobilization or Demobilization	$585,000
Mobilization or Demobilization for Additional Sites	$60,000
Additional Cost per Cubic Meter	$26

Using these cost parameters, the total cost of a nourishment project per beach was estimated for two different scenarios: (1) replacing beach lost due to inundation, and (2) replacing sand lost due to change in beach volume caused by an extremely stormy year at current sea level

The numerical results of our estimates are presented in Appendix D and summarized in Figures 17 and 18.

Since sea level rise implies accretion at some spots, some beaches will not need nourishment and, in fact, will be wider.

The total costs of nourishing all sites to mitigate against conditions in these two scenarios is quite high. To mitigate for permanent inundation caused by a rise in sea level of one meter, the total costs of nourishment are estimated to be $436 million, or just over $4 million per year. The cost of mitigating for beach loss from a single stormy year is estimated to be $382 million. Of course, complete renourishment may not take place for all beaches.

While these cost estimates are rudimentary, there is one clear story that emerges from the analysis. The cost of adding sand to beaches to counteract the effects of sea level rise is of a similar magnitude to the costs of renourishing after an extremely stormy year. There is one important difference, however. Inundation takes place over 100 years in our analysis. That means the undiscounted average annual cost of nourishment would be approximately $4 million if sea level rise resulted only in a slow flooding of beaches. This cost is just under one third the estimated loss in consumer surplus due to sea level rise and roughly equal to the average lost expenditures. This suggests that if permanent inundation were the only effect of sea level rise on beaches, then the recreational benefits from nourishment would outweigh the costs. The costs of nourishing for extremely stormy years, however, are many times the annual recreational benefit of nourishment. Recreational benefits alone are unlikely to justify the large expenditures that would be required to repeatedly replace sand lost by increasingly severe winter storms.

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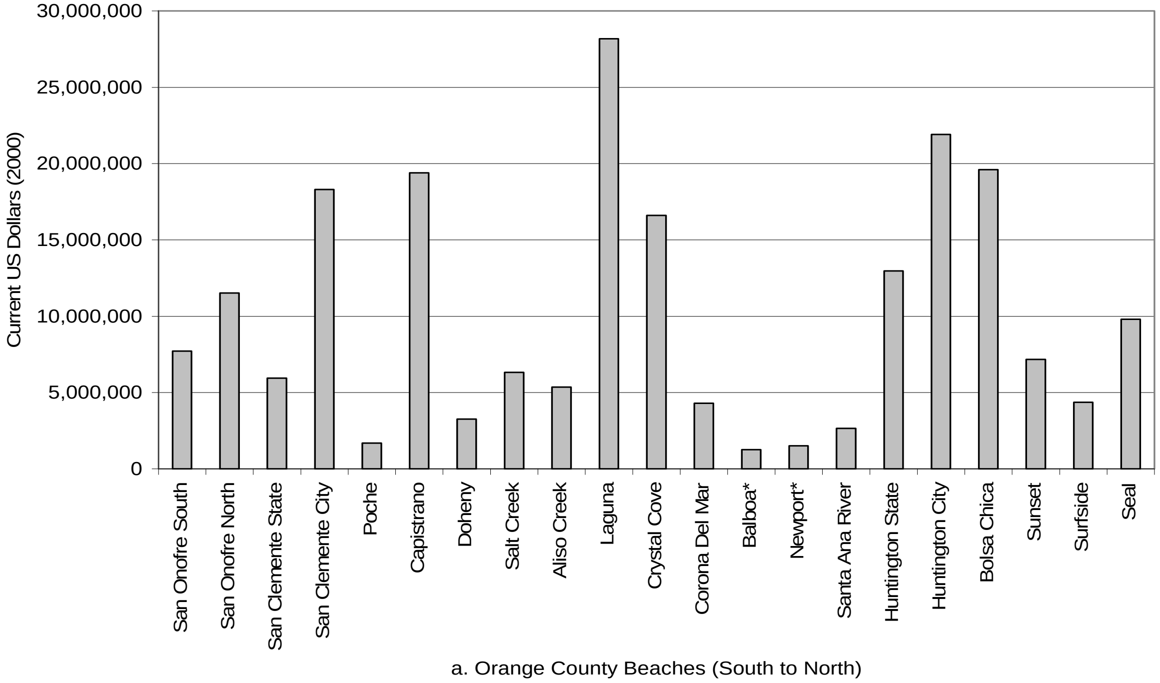
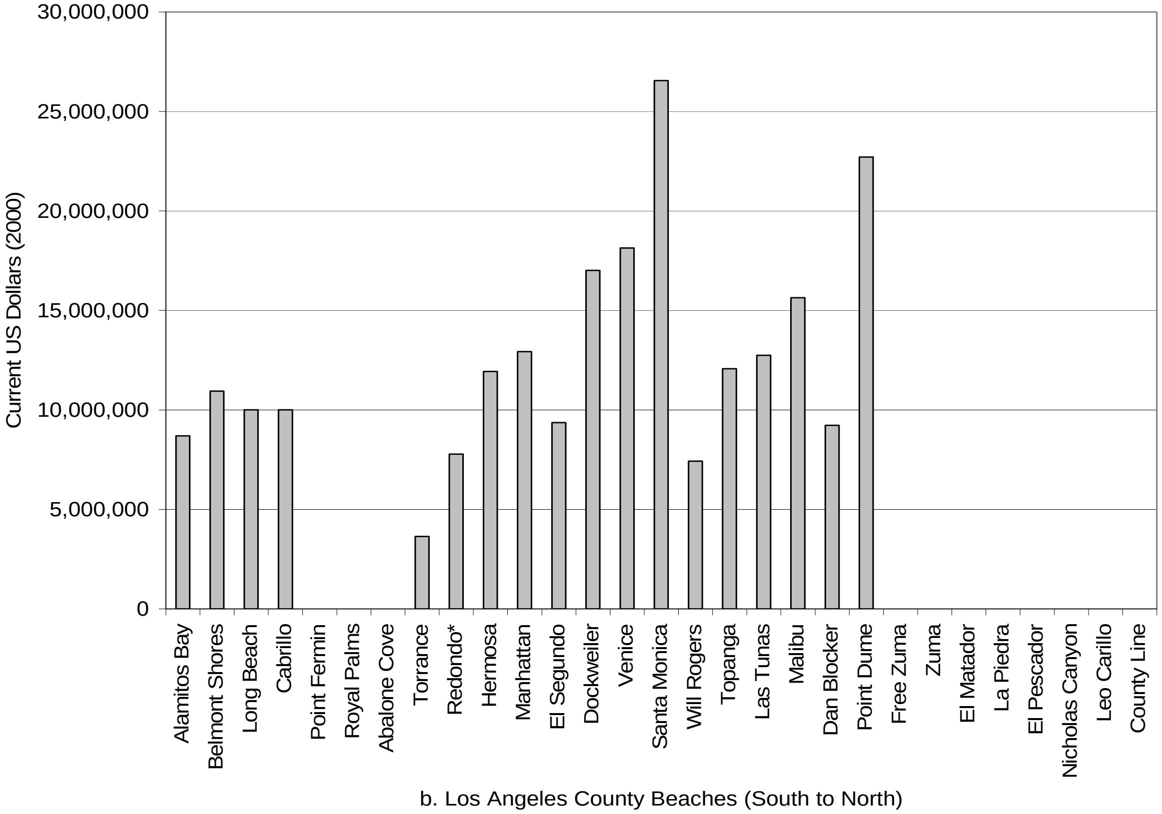
[5] Ibid.

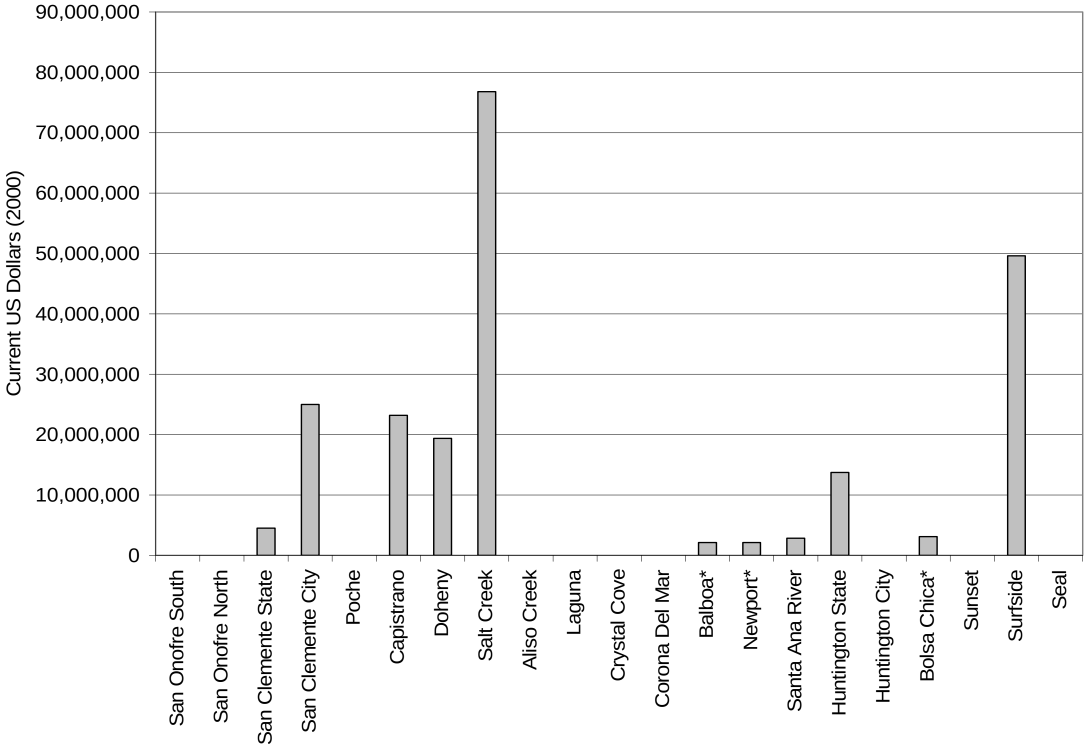


a. Orange County Beaches (South to North)

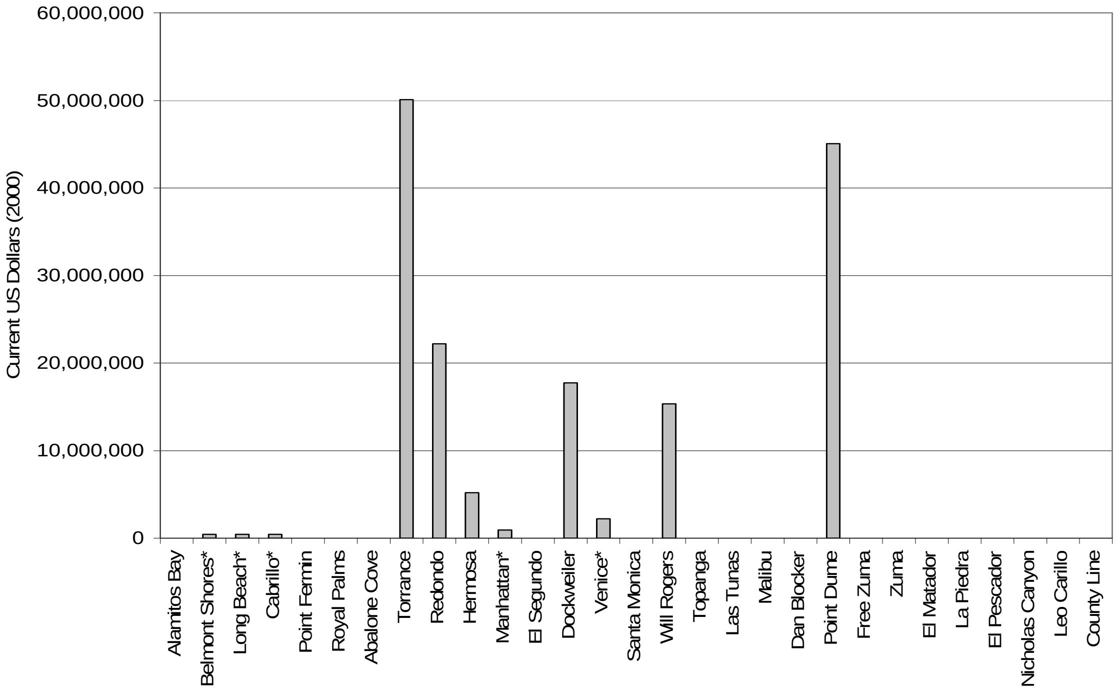


b. Los Angeles County Beaches (South to North)

Figure 17. Estimated costs of beach nourishment to mitigate for permanent inundation (1 meter sea level rise)



a. Orange County Beaches (South to North)



b. Los Angeles County Beaches (South to North)

Figure 18. Estimated costs of beach nourishment to mitigate for extremely stormy year

Note: * Indicates trucking is least cost method, otherwise dredging is least cost.

3.6. Limitations of the Models and Future Research

The analysis and estimates above should be considered a preliminary exploration of how to better understand the potential changes in beach attendance, beach-related spending, and consumer surplus that could result from climate change and also the potential costs of the beach nourishment that would be needed to mitigate these changes. These are not intended as a precise forecast. Indeed, we do not currently have accurate forecasts of beach loss due to sea level rise or climate change for both Los Angeles and Orange Counties. Given the limitations of the current geophysical models, we explored two aspects of beach change that could be affected by climate change and sea level rise: (1) permanent beach loss due to beach inundation caused by sea level rise, and (2) the effects of extremely stormy years on beach width.

Our study demonstrates the economic consequences that could arise if beaches are flooded by sea level rise or if sea level rise leads to substantial changes in the severity of erosion and accretion caused by waves and storms. Our current analysis of the impacts of increasingly severe storms is based on the predicted impacts of one extremely stormy season. Much more needs to be done to consider the impact of changes in the severity of winter storms that could result from the combination of winter storms and elevated high tides as well as the potential impact of lengthening winter of storm seasons that could increase erosion and reduce the time available for beach nourishment. Future research focused on understanding the probabilistic nature of large storm events could generate results that would be useful for decision makers (Sanstad 2008).

Future research also will be important to understand the true cost of beach nourishment and whether beach nourishment is a cost-effective response to beach changed caused by climate change. We have made simplifying assumptions about the pace of beach change, sources of sediments, and the costs of transporting sediment. Each specific beach varies in terms of how fast natural recovery will take place, how far away a sand source (offshore or onshore) lies, and whether or not this distance is a critical factor in determining costs. Market conditions also dictate costs. Furthermore, we have ignored the costs of environmental compliance and other permitting restrictions and also other positive and negative externalities which can be significant. All of these factors need to be considered to make our predictions about potential nourishment costs more accurate.

A more complete understanding of the economics of climate change on beach recreation and management should also factor in the political and economic feasibility of nourishment at various sites. In some areas, beach nourishment could also provide important protective benefits to homes and infrastructure. In other areas, beach nourishment could lead to the destruction of fragile surfing resources and sanding habitats. As noted above, nourishment costs at many sites run well into the millions of dollars, and the total estimated costs of all dredging runs into the hundreds of millions of dollars. These costs may be prohibitive for many state and local governments. There may also be opposition to nourishment, since there is public sentiment in California in favor of allowing beaches to retreat or erode "naturally," though if erosion is due to sea level rise caused by humans, one could debate what the natural state is.

4.0 Conclusion

Because there are so many beaches to choose from in Southern California, many of them quite large, beach going is likely to remain an important recreational asset to the area, even in the face of sea level rise. Nevertheless, changes in sea level could reduce the number of beach visits taken in Los Angeles and Orange counties by more than half a million visits annually by 2100. In this analysis, we focus only on day-use beach visits by local residents from Los Angeles, Orange, Riverside, and San Bernardino counties. The effect on tourist visits, which could represent as much as 100 million more visitor days for the region (Pendleton and Kildow 2006), is unknown but likely to follow a similar pattern. More dramatic, however, are the uneven local effects of climate change.

Our analysis shows that even the effects of permanent beach loss due to slow and steady sea level rise would create a substantial loss in economic welfare for the region (between $40 million and almost $63 million annually), with smaller impacts on beach-related expenditures (see Table 10). Perhaps more importantly, though, the effects of the impacts of permanent beach loss due to inundation from sea level rise would be spread unevenly across the region with some beaches gaining attendance and expenditures while other beaches lose visitors and their spending.

Table 10. Annual impacts caused by permanent inundation due to sea level rise of 1 m, US$(2000)

	Total Change by Residents			Maximum for One Beach	
Socio-economic Scenario	Annual Attendance	Annual Expenditures	Annual Consumer Surplus	Gain in Annual Expenditures	Loss in Annual Expenditures
No Change	-588,765	-$15 million	-$63 million	$16 million	-$15 million
Low Growth	-586,923	-$15 million	-$62 million	$14 million	-$13 million
High Growth	-380,223	-$10 million	-$40 million	$7 million	-$8 million

If sea level rise proceeds at the slow pace considered in this analysis, then an opportunity to offset the losses in beach width through selective beach nourishment could exist. The costs of nourishment appear to be outweighed by the avoided potential losses in consumer surplus, a measure of beachgoer economic welfare, and avoided lost expenditures. The effects of beach change on tourist visitors are likely to show that the value of mitigating the effects of inundation are even larger than predicted here. Of course, sea level rise is unlikely to proceed slowly and gradually.

The real challenge for understanding and adapting to the effects of sea level rise on beach management could come if winter storms, combined with higher tides, lead to even more erosion than beaches experience currently (Cayan et al. 2008). A single extremely stormy year can have a temporary, but substantial impact on annual beach attendance, spending, and consumer surplus that is similar to the average annual impacts that would result from a full meter of sea level rise. We estimate the impacts that might occur during an extremely stormy year like that of the El Niño year of 1982/1983. The impacts of beach loss from these extremely stormy years are of a similar magnitude to those caused by permanent inundation (Table 11), and are likely to be highly uneven across the region. Some beaches may benefit from losses of beach size at nearby beaches and some beaches may actually grow because of future sediment accretion caused by storms. Many other beaches, however, are likely to see sharply lower attendance levels if climate change and sea level rise result in more years with high erosional impacts. As a result, local businesses at highly eroded beaches will feel the loss of beach-related expenditures.

Table 11. Summary of annual impacts caused by an extremely stormy year

	Total Change by Residents			Maximum for One Beach	
Socio-economic Scenario	Annual Attendance	Annual Expenditures	Annual Consumer Surplus	Gain in Annual Expenditures	Loss in Annual Expenditures
No Change	-343,447	-$9 million	-$37 million	$20 million	-$25 million

Moving forward, our results make it clear that the real concern for beach going and the beach-related economy have to do with the impacts of wave-driven erosion and accretion. Future research needs to use the framework we provide here to take a more probabilistic approach to understanding the potential impacts that increasing sea levels may have on the erosional impacts of winter storms. Finally, this work shows that whether inundation or wave-driven erosion is the cause of beach change, the effects of climate-driven beach change are extremely uneven in their distribution throughout the region. Estimates of the impact of climate change on beaches must be conducted at a sub-regional level, preferably at the level of individual beaches.

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Appendix A

Estimation Results

Appendix A. Estimation Results

Coefficient Estimates

The coefficient estimates for the three-level nested model are given below. All levels and the expected utilities connecting them were estimated sequentially. Table A1 below presents the parameter estimates from the Beach Site Choice nest of the model.

Table A1.a

Site Choice Terms Common to all 3 Activity Types

	Coef.	Std. Err.
Travel Cost	-0.090	0.002
Mogu Dummy	1.977	0.730
Activity Choice Log Likelihood	-12526.746	

Table A1.b

Site Choice Terms For Water Based Activity Choice

	Coef.	Std. Err.
Average Water Quality Grade (HTB)	0.306	0.061
Ln(Length)	0.711	0.064
Width	0.076	0.020
Width > = 60m	-0.065	0.013
$(\text{Width})^2$	0.000	0.000
$(\text{Width})^3$	0.000	0.000
Ugly	-0.286	0.062
Much Development	-0.186	0.071
Wild	0.246	0.127
Surfing	0.786	0.135
Diving	0.628	0.105
Harbor/Marina	-1.341	0.109
Density of LifeGuard Stations	0.330	0.036
Average Water Quality Grade (February-March)	-0.201	0.137
Oceanside Dummy	3.311	0.378

Table A1.c

Site Choice Terms For Sandy Based Activity Choice

	Coef.	Std. Err.
Ln(Area)	0.373	0.056
Width	0.035	0.020
Width > = 20	-0.067	0.025
Width > = 60	-0.068	0.014
Sandy*(Width)	0.003	0.001
Kids*(Width > = 20)	0.002	0.001
$(\text{Width})^2$	0.001	0.000
$(\text{Width})^3$	0.000	0.000
Some Development	0.955	0.092
Wild	1.286	0.143
Harbor/Marina	-0.876	0.087
Restrooms	1.775	0.216
Oceanside Dummy	2.789	0.493

Table A1.d

Site Choice Terms For Pavement Based Activity Choice	Coef.	Std. Err.
Ln(Length)	0.627	0.074
Width	0.026	0.006
Width >= 60m	-0.019	0.006
Much Development	-0.841	0.085
Wild	0.823	0.171
Parking	-1.772	0.239
Public Facilities Available	-0.563	0.114
Sandy	0.561	0.411
Showers	2.469	0.211
Adjacent On Street Parking	1.549	0.213
Harbor/Marina	0.197	0.081
Nature	0.626	0.214
River at Beach	1.470	0.241
Bikepath	0.434	0.189
Camping	-3.038	0.217
Restrooms	0.968	0.332
Sidewalk	0.647	0.156
Rentals Available	0.039	0.095
Oceanside Dummy	4.674	0.571

The variables affecting beach choice are:

Table A1.e

Site Choice Term Definitions

Variable	Definition
Travel Cost	Travel Cost in 2000 US$
Mug Dummy	Alternative Specific Constant for Mug
Oceanside Dummy	Alternative Specific Constant for Oceanside
Average Water Quality Grade (HTB)	the average dry grade as reported by Heal the Bay
Ln(Area)	log of the beach area
Ln(Length)	log of the beach length
Width	Beach width
Width >= 20	Indicator of beach width being greater than 20m
Width >= 60	Indicator of beach width being greater than 60m
$(\text{Width})^2$	Beach width squared
$(\text{Width})^3$	Beach width cubed
Sandy*Width	Beach width for sandy beaches
Kids*(Width>=20m)	Indicator of beach width being greater than 20m for households with kids.
Ugly	oil rigs, power plants, etc visible from beach
Wild	beach is wild or remote
Some Development	beach has some development (condos, clubs, vendors, etc)
Much Development	beach has much development
Surfing	beach is good for surfing
Diving	beach is good for diving
Harbor/Marina	beach has a marina or is in a harbor
Restrooms	beach has public restrooms
Density of Firepots	density of firepots
Public Facilities Available	beach has facilities
Sandy	beach is sandy
Parking	beach has parking
Adjacent On Street Parking	beach has adjacent on street parking
Nature	beach adjacent to a natural area
River at Beach	river flows through beach
Bikepath	beach has bikepath
Sidewalk	beach has sidewalks
Camping	beach open for camping
Rentals	beach has equipment rentals
Density of LifeGuard Stations	density of lifeguard stations if trip in June or July
Average Water Quality Grade (February-March)	average dry grade if trip in February or march

For water-based activities, the coefficients on Width are positive, while Width>=60 is negative. Coefficients on $Width^2$ and $Width^3$ are not significantly different from zero. This means that wider beaches are better for water recreators, but there are diminishing returns to width, and further increasing a beaches width beyond 60 m reduces the economic wellbeing of beachgoers. This is intuitive, since while sand has some redeeming value to water recreators, most people would prefer to haul their boats, surfboards or scuba gear across the shortest distance of sand possible. Sand recreators only prefer width in excess of 20 m on sandy beaches, and those who have children have a stronger preference for wide beaches. Again this makes sense, since wider beaches provide a bigger buffer between the recreation site and surf which may be dangerous for young children. Pavement recreators also prefer wider beaches. These results suggest that where there is sand, there is always some public benefit obtained from beach nourishment.

The parameter estimates for the activity-choice nest are given below in table A2:

Table A2.a

Activity Choice Nest

	Coef.	Std. Err.
Inclusive Vale from Site Choice		
Rho	0.211	0.122
Water Based Activity Choice		
Male	0.562	0.069
Black	-0.892	0.235
Hispanic	-0.137	0.087
(Wave 4)*Kids	0.506	0.141
Wave 2	0.147	0.172
Wave 3	1.560	0.129
Wave 4	1.829	0.224
Wave 5	1.495	0.119
Wave 6	0.921	0.139
Constant	-1.508	0.211
Sand Based Activity Choice		
Wave 2	0.955	0.108
Wave 3	0.535	0.132
Wave 4	1.639	0.121
Wave 5	0.360	0.122
Wave 6	0.370	0.136
Constant	-0.948	0.140

The variables affecting activity choice are:

Table A2.b

Activity Choice Term Definitions

Variable	Definition
Male	The panelist is male
Black	The panelist is black
Hispanic	The panelist is Hispanic
(Wave 4)*Kids	The panelist has kids and the choice was made in June or July
Wave 2	Choice was made is February or March
Wave 3	Choice was made in April or May
Wave 4	Choice was made in June or July
Wave 5	Choice was made in August or September
Wave 6	Choice made in October or November
Rho	Expected Utility from Site Choice

The parameter estimate in the Inclusive Value section is the coefficient on expected utility from the beach choice level of the model for each activity type. The parameters in the Water Based Activity section capture the contribution of the variables to the utility of water-based activities; the parameters in the Sand Based Activity section capture the contribution of the variables to the utility of sand-based activities. The utility of pavement-based activities, being the baseline category, are determined from the expected utility alone. For instance, beachgoers are more likely to choose water-based activities from April through September (wave 3, 4, and 5) and Blacks and Hispanics are less likely than others to choose water-based activities.

The parameter estimates for the participation nest are given below in table A3.a:

Table A3.a

Participation Nest		
	Coef.	**Std. Err.**
Inclusive Value from Activity Choice		
Rho2	0.510	0.026
Participation Terms		
Summer	0.019	0.035
Male	0.331	0.026
Black	-0.642	0.067
Hispanic	-0.543	0.033
Kids	-0.359	0.037
Student	-0.178	0.033
Work Part-time	0.176	0.038
Summer*Kids	0.365	0.056
Constant	-4.635	0.059

The variables affecting participation are:

Table A3.b

Participation Nest Term Definitions

Variable	Definition
Male	The panelist is male
Black	The panelist is black
Hispanic	The panelist is Hispanic
Kids	The panelist has kids in their household
Student	The panelist is a student
Work partime	The panelist works part time
Summer*Kids	summer and has kids in household
Rho2	Expected Utility from Activity Choice

The parameter estimate in the Inclusive Value section is the coefficient on the inclusive value from the activity choice level of the model, reflecting the expected utility of choosing a given activity for any beach trip. The fact that it is larger than the coefficient on the beach choice submodel is consistent with a correctly-specified nested logit model capturing utility maximizing behavior. These coefficients combined with the variables give the utility of taking a beach trip relative to not taking a trip (which has utility normalized to zero).

Appendix B

Beaches Covered in the Study

Code	Beach	Year Beach Width Measured
1	Oceanside	n/a
2	San Onofre South	2007
3	San Onofre North	2007
4	San Clemente State Beach	2001
5	San Clemente City	2001
6	Poche	2001
7	Capistrano Beach	2001
8	Doheny	2001
9	Salt Creek	2001
10	Aliso Creek	2001
11	Laguna	2001
12	Crystal Cove	2001
13	Corona Del Mar	2001
14	Balboa	2001
15	Newport	2001
16	Santa Ana River	2001
17	Huntington State	2001
18	Huntington City	2001
19	Bolsa Chica	2001
20	Sunset Beach	2001
21	Surfside	2001
22	Seal Beach	2001
23	Alamitos Bay	2001
24	Belmont Shores	2001
25	Long Beach	2001
26	Cabrillo	2001
27	Point Fermin	2001
28	Royal Palms	2001

Code	Beach	Year Beach Width Measured
29	Abalone Cove	2001
30	Torrance	2002
31	Redondo	2002
32	Hermosa	2002
33	Manhattan	2002
34	El Segundo	2002
35	Dockweiler	2002
36	Mother’s	2008
37	Venice	2002
38	Santa Monica	2002
39	Will Rogers	2002
40	Topanga	2002
41	Las Tunas	2002
42	Malibu	2002
43	Dan Blocker	2002
44	Point Dume	2001
45	Free Zuma	2001
46	Zuma	2001
47	El Matador	2001
48	La Piedra	2001
49	El Pescador	2001
50	Nicholas Canyon	2001
51	Leo Carillo	2001
52	County Line	2001
53	Point Mugu	n/a

Appendix C

Beach-Related Activities

	Categories	Count	Count	Count	Count
		Activity 1	Activity 2	Activity 3	Activity 4
Boating	Water	27	2	0	0
Body boarding/body surfing/skimboarding	Water	249	69	21	9
Canoeing	Water	12	1	0	0
Jet boating/jet skiing/personal water craft	Water	0	37	9	6
Kayaking	Water	20	4	4	0
Sailing	Water	5	0	0	0
Scuba diving	Water	0	1	0	0
Snorkeling	Water	2	14	0	0
Splashing in water	Water	75	59	2	4
Surfing	Water	418	64	2	0
Swimming	Water	291	170	54	4
Wading	Water	64	98	11	2
Water skiing	Water	2	1	0	0
Windsurfing / boardsailing	Water	1	1	0	0
Activities with children	Sand	111	114	40	21
Bar-b-q	Sand	19	21	20	6
Beachcombing	Sand	9	28	26	0
Enjoying the view	Sand	135	138	51	18
Fishing (shore or pier)	Sand	69	20	1	0
Frisbee	Sand	29	39	28	2
Kite flying	Sand	10	10	1	0
People watching	Sand	93	100	63	29

	Categories	Count	Count	Count	Count
		Activity 1	**Activity 2**	**Activity 3**	**Activity 4**
Picnicking	Sand	137	120	38	14
Played in the sand	Sand	14	26	9	6
Reading	Sand	28	45	32	0
Relaxing	Sand	1	1	2	0
Sand football/soccer	Sand	15	25	2	15
Sleeping	Sand	1	1	0	0
Sunbathing	Sand	305	156	88	12
Volleyball	Sand	91	160	31	1
Walking the dog	Sand	65	15	5	0
Watched fireworks	Sand	21	19	1	0
Bicycling	Pavement	444	64	3	10
Hiking	Pavement	7	0	9	5
Jogging	Pavement	343	50	13	19
Rollerblading/roller skates	Pavement	165	18	52	2
Walking	Pavement	1478	450	155	12
Amusement park/ arcade	Pavement	7	5	1	0
Eating/ drinking	Pavement	31	53	11	4
Shopping/dining	Pavement	207	278	109	17
Other	Other	414	299	194	107
Total		5415	2776	1088	325

Appendix D

Attendance Projections over 20-Year Intervals

Appendix D. Attendance Projections over 20-Year Intervals

Beach attendance projections were calculated for each of the beaches in our study area over 20-year intervals from 2000 to 2100. These tables provide the annual number of trips per beach for each period and the change in number of trips per beach for all three growth scenarios.

Beach Attendance Projections: Current Scenario

	2000	2020	2040	2060	2080	2100
Oceanside	436,364	425,995	405,835	397,648	382,273	375,489
San Onofre South	247,545	245,359	243,222	242,141	247,072	246,403
San Onofre North	127,048	124,940	123,167	124,208	123,328	121,717
San Clemente State	233,162	234,228	228,489	224,309	227,027	223,205
San Clemente City	248,406	248,828	252,070	237,105	209,848	199,522
Poche	183,155	181,600	183,133	182,244	182,205	184,311
Capistrano	1,074,954	1,048,248	1,020,893	973,682	955,190	913,054
Doheny	393,428	381,496	369,426	359,655	350,795	350,976
Salt Creek	854,117	807,163	784,341	766,707	753,535	721,170
Aliso Creek	818,042	821,723	825,531	834,422	846,450	857,458
Laguna	2,362,280	2,225,827	2,097,798	1,987,621	1,882,413	1,781,569
Crystal Cove	936,783	902,823	871,790	793,454	636,970	511,536
Corona Del Mar	881,505	823,228	770,021	725,434	687,469	651,654
Balboa	1,198,846	1,218,354	1,236,824	1,260,244	1,283,446	1,302,599
Newport	3,593,347	3,680,353	3,764,885	3,872,774	3,984,561	4,104,358
Santa Ana River	139,090	146,318	154,784	162,177	169,948	176,949
Huntington State	2,167,366	2,189,819	2,207,679	2,218,840	2,243,096	2,259,595
Huntington City	2,366,058	2,473,088	2,583,115	2,710,459	2,855,958	2,998,661
Bolsa Chica	2,039,629	1,931,951	1,828,307	1,739,115	1,663,273	1,583,603
Sunset	1,752,183	1,789,697	1,828,704	1,875,660	1,928,748	1,976,035
Surfside	258,652	276,844	277,893	263,274	250,912	237,980

	2000	2020	2040	2060	2080	2100
Seal	1,839,327	1,864,164	1,887,551	1,917,997	1,949,620	1,977,397
Alamitos Bay	1,079,022	1,103,445	1,094,752	1,058,162	1,022,609	987,225
Belmont Shores	1,475,430	1,488,206	1,505,309	1,524,350	1,547,979	1,570,152
Long Beach	1,270,375	1,227,860	1,178,542	1,103,348	1,064,809	997,879
Cabrillo	947,906	930,108	895,563	881,408	762,655	696,735
Point Fermin	45,021	45,801	46,405	47,183	48,150	48,769
Royal Palms	225,808	229,930	233,427	237,573	242,710	246,190
Abalone Cove	306,814	312,381	316,950	322,428	329,441	333,940
Torrance	970,147	935,975	901,790	872,870	849,291	822,652
Redondo	2,630,397	2,505,633	2,462,594	2,351,500	2,252,587	2,217,429
Hermosa	1,581,371	1,601,151	1,617,433	1,638,912	1,665,335	1,684,581
Manhattan	3,850,527	3,909,636	3,962,662	4,029,146	4,103,652	4,165,045
El Segundo	1,252,498	1,276,713	1,297,499	1,324,419	1,354,442	1,381,397
Dockweiler	1,038,478	1,037,868	1,034,634	1,033,700	1,035,940	1,032,774
Mother's	671,390	646,571	622,621	601,275	582,742	550,314
Venice	3,876,121	3,887,705	3,868,791	3,880,274	3,899,324	3,904,172
Santa Monica	3,573,830	3,571,907	3,562,088	3,557,332	3,530,609	3,518,284
Will Rogers	2,088,077	2,178,343	2,307,823	2,418,504	2,546,859	2,675,292
Topanga	366,750	363,948	353,128	350,486	342,956	334,515
Las Tunas	53,065	50,485	48,519	49,335	50,226	51,013
Malibu	219,192	209,139	187,417	179,096	161,871	146,064
Dan Blocker	40,114	36,213	32,801	29,898	27,535	25,369
Point Dume	189,552	185,785	185,105	166,173	159,437	144,142
Free Zuma	55,113	57,956	59,752	59,661	56,696	55,572
Zuma	466,055	477,876	495,173	515,224	538,553	561,863
El Matador	29,552	25,822	20,882	18,242	15,970	13,825

	2000	2020	2040	2060	2080	2100
La Piedra	10,957	9,916	9,003	8,226	7,597	7,023
El Pescador	17,069	15,816	14,698	14,343	13,476	12,680
Nicholas Canyon	30,762	30,105	28,947	28,470	26,372	21,080
Leo Carillo	155,940	153,093	152,448	150,045	138,549	129,267
County Line	19,206	17,673	16,310	15,851	14,810	13,854
Mugu	22,142	21,100	19,498	18,673	17,527	16,866

Beach Attendance Projections: Low Growth Scenario

	2000	2020	2040	2060	2080	2100
Oceanside	436,364	669,040	845,672	915,021	932,143	940,815
San Onofre South	247,545	276,420	266,962	216,300	162,555	112,427
San Onofre North	127,048	183,112	225,350	232,192	224,951	207,697
San Clemente State	233,162	258,944	240,612	190,090	141,598	99,124
San Clemente City	248,406	280,716	276,889	215,507	145,612	103,136
Poche	183,155	211,834	215,927	186,164	149,977	119,181
Capistrano	1,074,954	1,250,905	1,264,474	1,081,123	894,190	708,941
Doheny	393,428	458,332	463,699	407,620	338,084	283,521
Salt Creek	854,117	939,532	923,589	784,194	626,173	474,890
Aliso Creek	818,042	986,176	1,032,196	933,344	790,470	648,869
Laguna	2,362,280	2,731,579	2,747,531	2,397,006	1,968,211	1,576,679
Crystal Cove	936,783	1,090,569	1,103,240	909,445	620,004	408,341
Corona Del Mar	881,505	1,009,822	1,008,002	880,410	728,851	586,845
Balboa	1,198,846	1,543,396	1,734,660	1,718,124	1,617,645	1,485,904
Newport	3,593,347	4,627,976	5,196,860	5,138,995	4,824,319	4,433,036
Santa Ana River	139,090	185,853	217,404	221,124	212,956	197,742

	2000	2020	2040	2060	2080	2100
Huntington State	2,167,366	2,746,144	3,027,095	2,924,407	2,687,484	2,381,720
Huntington City	2,366,058	3,049,280	3,427,960	3,412,528	3,227,886	2,935,105
Bolsa Chica	2,039,629	2,367,219	2,399,928	2,188,313	1,914,430	1,607,872
Sunset	1,752,183	2,212,187	2,451,372	2,458,466	2,379,604	2,229,084
Surfside	258,652	345,310	380,008	358,435	330,242	296,029
Seal	1,839,327	2,343,016	2,631,212	2,708,543	2,727,768	2,693,554
Alamitos Bay	1,079,022	1,335,680	1,415,960	1,333,038	1,221,458	1,089,856
Belmont Shores	1,475,430	1,837,535	2,028,625	2,063,795	2,074,804	2,058,201
Long Beach	1,270,375	1,461,283	1,469,556	1,305,041	1,153,774	957,647
Cabrillo	947,906	1,031,046	978,707	886,961	699,067	576,476
Point Fermin	45,021	51,249	51,698	49,084	46,548	43,681
Royal Palms	225,808	255,553	256,674	242,298	228,380	213,072
Abalone Cove	306,814	334,140	322,325	290,017	256,186	218,665
Torrance	970,147	1,052,094	1,012,638	915,318	816,144	702,901
Redondo	2,630,397	2,874,645	2,885,809	2,646,521	2,400,772	2,181,384
Hermosa	1,581,371	1,876,513	1,972,013	1,949,478	1,898,182	1,785,999
Manhattan	3,850,527	4,607,337	4,891,852	4,903,006	4,844,069	4,639,050
El Segundo	1,252,498	1,494,975	1,582,115	1,579,711	1,556,104	1,487,711
Dockweiler	1,038,478	1,263,830	1,367,189	1,403,161	1,433,637	1,423,484
Mother's	671,390	808,020	873,910	909,031	955,283	960,154
Venice	3,876,121	4,869,690	5,445,873	5,881,301	6,392,882	6,783,988
Santa Monica	3,573,830	4,056,170	4,103,935	3,903,006	3,595,261	3,167,612
Will Rogers	2,088,077	2,464,751	2,637,739	2,618,033	2,539,192	2,336,161
Topanga	366,750	428,030	441,164	446,133	447,249	438,114
Las Tunas	53,065	53,390	49,762	46,683	43,590	39,140
Malibu	219,192	220,289	193,888	176,214	153,627	129,778

	2000	2020	2040	2060	2080	2100
Dan Blocker	40,114	32,365	24,206	17,228	12,368	8,808
Point Dume	189,552	173,489	147,992	108,992	83,938	59,686
Free Zuma	55,113	47,839	36,586	24,532	14,457	8,043
Zuma	466,055	393,938	301,732	209,878	135,065	79,445
El Matador	29,552	23,914	16,617	12,100	8,963	6,642
La Piedra	10,957	9,175	7,149	5,432	4,217	3,289
El Pescador	17,069	15,088	12,524	10,687	8,961	7,497
Nicholas Canyon	30,762	25,924	19,466	13,858	8,855	4,644
Leo Carillo	155,940	134,145	106,968	79,877	54,702	37,165
County Line	19,206	14,736	10,324	7,065	4,393	2,567
Mugu	22,142	15,059	8,800	4,709	2,150	888

Beach Attendance Projections: High Growth Scenario

	2000	2020	2040	2060	2080	2100
Oceanside	436,364	664,179	838,413	847,900	728,650	525,504
San Onofre South	247,545	248,207	191,140	105,527	46,179	13,108
San Onofre North	127,048	186,762	229,013	230,081	200,158	143,700
San Clemente State	233,162	236,252	180,026	109,505	67,419	44,484
San Clemente City	248,406	258,296	214,040	133,230	77,637	53,964
Poche	183,155	197,490	175,184	125,363	85,280	57,609
Capistrano	1,074,954	1,177,385	1,066,050	792,572	580,574	408,880
Doheny	393,428	432,155	393,073	301,885	222,773	167,117
Salt Creek	854,117	887,137	773,008	566,339	399,664	269,739
Aliso Creek	818,042	934,792	868,371	658,564	456,702	286,388
Laguna	2,362,280	2,615,788	2,395,219	1,825,164	1,290,709	847,875

	2000	2020	2040	2060	2080	2100
Crystal Cove	936,783	1,046,231	957,463	673,864	380,686	192,110
Corona Del Mar	881,505	973,517	892,363	685,353	491,903	329,519
Balboa	1,198,846	1,503,526	1,594,665	1,437,039	1,204,627	940,364
Newport	3,593,347	4,499,930	4,732,470	4,219,827	3,497,432	2,698,865
Santa Ana River	139,090	181,363	199,768	183,101	154,308	118,720
Huntington State	2,167,366	2,676,627	2,768,240	2,400,793	1,927,579	1,421,105
Huntington City	2,366,058	2,979,382	3,138,256	2,813,156	2,348,817	1,823,560
Bolsa Chica	2,039,629	2,318,439	2,207,404	1,809,291	1,378,081	942,157
Sunset	1,752,183	2,174,259	2,288,713	2,109,220	1,834,741	1,467,468
Surfside	258,652	341,554	361,949	320,733	272,777	216,344
Seal	1,839,327	2,323,285	2,535,051	2,499,091	2,391,141	2,186,208
Alamitos Bay	1,079,022	1,316,461	1,321,855	1,154,585	976,021	777,717
Belmont Shores	1,475,430	1,821,653	1,941,733	1,895,728	1,851,223	1,793,539
Long Beach	1,270,375	1,435,406	1,344,258	1,079,784	854,051	605,655
Cabrillo	947,906	989,718	844,138	674,129	491,558	390,127
Point Fermin	45,021	49,400	45,306	38,812	35,228	33,210
Royal Palms	225,808	244,890	221,864	186,349	166,024	154,120
Abalone Cove	306,814	316,397	266,912	203,278	157,430	117,907
Torrance	970,147	1,022,857	899,826	721,212	576,032	441,711
Redondo	2,630,397	2,802,160	2,611,410	2,162,973	1,780,078	1,448,392
Hermosa	1,581,371	1,841,889	1,814,188	1,622,586	1,408,985	1,138,932
Manhattan	3,850,527	4,527,315	4,533,176	4,130,984	3,642,847	2,997,212
El Segundo	1,252,498	1,473,345	1,469,158	1,340,409	1,189,945	992,458
Dockweiler	1,038,478	1,260,795	1,330,644	1,302,804	1,244,132	1,111,305
Mother’s	671,390	816,597	896,720	942,821	985,216	958,487
Venice	3,876,121	4,919,825	5,580,978	6,075,330	6,540,393	6,678,584

	2000	2020	2040	2060	2080	2100
Santa Monica	3,573,830	3,981,525	3,746,620	3,155,455	2,463,092	1,665,785
Will Rogers	2,088,077	2,418,858	2,401,866	2,100,542	1,713,198	1,196,281
Topanga	366,750	425,098	430,703	428,499	424,327	399,993
Las Tunas	53,065	51,989	45,514	40,517	36,830	31,666
Malibu	219,192	213,820	179,836	156,720	129,711	95,999
Dan Blocker	40,114	30,355	19,139	11,712	7,839	5,402
Point Dume	189,552	161,128	117,496	73,479	49,724	31,051
Free Zuma	55,113	42,813	24,344	11,079	4,423	1,443
Zuma	466,055	351,921	199,259	93,355	40,368	13,812
El Matador	29,552	21,763	12,875	8,074	5,607	3,939
La Piedra	10,957	8,345	5,535	3,616	2,613	1,907
El Pescador	17,069	13,881	10,196	7,827	6,215	4,807
Nicholas Canyon	30,762	23,288	13,637	7,173	3,575	1,451
Leo Carillo	155,940	119,258	75,525	43,297	24,510	13,683
County Line	19,206	12,972	6,895	3,329	1,502	581
Mugu	22,142	12,511	4,577	1,231	256	34

Change in Attendance: Current Scenario

	2000	2020	2040	2060	2080	2100
Oceanside	0	-10,369	-30,529	-38,716	-54,091	-60,875
San Onofre South	0	-2,185	-4,323	-5,404	-473	-1,142
San Onofre North	0	-2,108	-3,880	-2,840	-3,720	-5,330
San Clemente State	0	1,066	-4,673	-8,853	-6,135	-9,957
San Clemente City	0	422	3,664	-11,301	-38,558	-48,884
Poche	0	-1,556	-22	-911	-950	1,156

	2000	2020	2040	2060	2080	2100
Capistrano	0	-26,706	-54,061	-101,272	-119,764	-161,900
Doheny	0	-11,932	-24,001	-33,773	-42,632	-42,452
Salt Creek	0	-46,954	-69,776	-87,410	-100,582	-132,947
Aliso Creek	0	3,681	7,488	16,380	28,408	39,416
Laguna	0	-136,454	-264,482	-374,660	-479,867	-580,711
Crystal Cove	0	-33,959	-64,992	-143,329	-299,813	-425,246
Corona Del Mar	0	-58,277	-111,485	-156,072	-194,036	-229,851
Balboa	0	19,509	37,978	61,399	84,600	103,754
Newport	0	87,006	171,538	279,427	391,214	511,011
Santa Ana River	0	7,227	15,693	23,087	30,857	37,859
Huntington State	0	22,453	40,313	51,474	75,730	92,229
Huntington City	0	107,030	217,057	344,401	489,900	632,603
Bolsa Chica	0	-107,678	-211,323	-300,514	-376,357	-456,026
Sunset	0	37,514	76,521	123,477	176,565	223,852
Surfside	0	18,191	19,241	4,622	-7,741	-20,673
Seal	0	24,837	48,223	78,670	110,292	138,070
Alamitos Bay	0	24,423	15,729	-20,860	-56,413	-91,798
Belmont Shores	0	12,776	29,879	48,920	72,548	94,722
Long Beach	0	-42,515	-91,833	-167,027	-205,566	-272,496
Cabrillo	0	-17,798	-52,343	-66,498	-185,251	-251,171
Point Fermin	0	780	1,384	2,162	3,129	3,749
Royal Palms	0	4,121	7,619	11,765	16,901	20,382
Abalone Cove	0	5,566	10,136	15,613	22,627	27,126
Torrance	0	-34,172	-68,357	-97,277	-120,856	-147,495
Redondo	0	-124,764	-167,803	-278,897	-377,810	-412,968
Hermosa	0	19,781	36,062	57,541	83,964	103,210

	2000	2020	2040	2060	2080	2100
Manhattan	0	59,109	112,135	178,619	253,125	314,517
El Segundo	0	24,215	45,001	71,921	101,944	128,899
Dockweiler	0	-610	-3,844	-4,778	-2,538	-5,704
Mother's	0	-24,818	-48,769	-70,115	-88,647	-121,076
Venice	0	11,584	-7,330	4,153	23,203	28,050
Santa Monica	0	-1,922	-11,742	-16,498	-43,221	-55,545
Will Rogers	0	90,266	219,746	330,427	458,782	587,214
Topanga	0	-2,801	-13,622	-16,264	-23,794	-32,235
Las Tunas	0	-2,580	-4,546	-3,730	-2,839	-2,052
Malibu	0	-10,053	-31,775	-40,096	-57,321	-73,129
Dan Blocker	0	-3,901	-7,312	-10,215	-12,579	-14,745
Point Dume	0	-3,767	-4,448	-23,380	-30,115	-45,410
Free Zuma	0	2,843	4,639	4,548	1,583	459
Zuma	0	11,822	29,118	49,169	72,498	95,808
El Matador	0	-3,730	-8,670	-11,310	-13,582	-15,727
La Piedra	0	-1,040	-1,953	-2,731	-3,359	-3,933
El Pescador	0	-1,253	-2,371	-2,726	-3,593	-4,389
Nicholas Canyon	0	-656	-1,815	-2,292	-4,390	-9,682
Leo Carillo	0	-2,847	-3,493	-5,896	-17,392	-26,673
County Line	0	-1,533	-2,896	-3,355	-4,396	-5,351
Mugu	0	-1,042	-2,644	-3,469	-4,616	-5,276

Change in Attendance: Low Growth Scenario

	2000	2020	2040	2060	2080	2100
Oceanside	0	-13,865	-47,577	-59,768	-78,137	-78,893
San Onofre South	0	-1,675	-1,253	205	5,735	5,255
San Onofre North	0	-2,579	-4,267	-997	-321	-1,308
San Clemente State	0	1,742	-2,866	-4,039	623	523
San Clemente City	0	1,022	5,997	-6,667	-21,702	-19,005
Poche	0	-1,376	1,622	2,250	3,709	6,437
Capistrano	0	-29,462	-57,564	-93,230	-83,240	-86,284
Doheny	0	-13,431	-26,584	-30,977	-30,014	-18,845
Salt Creek	0	-52,215	-73,126	-72,004	-58,223	-54,787
Aliso Creek	0	5,755	14,578	28,009	39,709	46,271
Laguna	0	-166,033	-341,265	-444,055	-493,479	-506,795
Crystal Cove	0	-40,288	-79,391	-159,587	-283,716	-329,384
Corona Del Mar	0	-71,429	-145,678	-189,964	-207,231	-209,632
Balboa	0	24,626	52,673	80,629	98,471	104,615
Newport	0	110,087	237,987	367,619	459,010	522,541
Santa Ana River	0	9,141	21,829	30,617	36,686	38,860
Huntington State	0	26,530	48,216	48,543	52,478	38,062
Huntington City	0	130,671	282,862	418,033	518,865	562,247
Bolsa Chica	0	-133,814	-283,890	-394,064	-465,098	-509,557
Sunset	0	45,036	97,884	150,513	194,712	218,287
Surfside	0	22,495	25,665	4,612	-13,983	-31,614
Seal	0	30,167	63,309	101,963	135,217	158,709
Alamitos Bay	0	29,292	19,047	-29,941	-74,865	-112,255
Belmont Shores	0	14,797	36,863	58,944	83,401	104,684

	2000	2020	2040	2060	2080	2100
Long Beach	0	-51,314	-117,416	-204,053	-234,150	-276,865
Cabrillo	0	-20,076	-58,127	-68,294	-166,922	-197,135
Point Fermin	0	848	1,473	2,135	3,091	3,820
Royal Palms	0	4,504	8,208	11,803	17,113	21,190
Abalone Cove	0	5,867	10,071	13,617	17,815	18,922
Torrance	0	-38,589	-77,142	-101,611	-112,533	-117,460
Redondo	0	-143,853	-199,047	-316,867	-402,563	-400,786
Hermosa	0	22,483	41,469	63,186	87,002	97,939
Manhattan	0	67,572	130,568	198,967	264,514	300,382
El Segundo	0	27,583	51,899	78,863	104,338	120,402
Dockweiler	0	-1,547	-7,911	-13,451	-17,390	-27,744
Mother's	0	-31,442	-69,749	-109,515	-152,415	-220,573
Venice	0	11,058	-22,337	-25,087	-25,477	-41,974
Santa Monica	0	-4,692	-21,639	-37,317	-77,319	-91,179
Will Rogers	0	99,947	243,246	339,606	425,490	472,292
Topanga	0	-3,565	-17,277	-21,105	-30,121	-36,530
Las Tunas	0	-2,701	-4,448	-3,263	-2,059	-955
Malibu	0	-10,262	-30,246	-33,987	-42,948	-46,065
Dan Blocker	0	-3,366	-4,912	-4,932	-4,129	-3,064
Point Dume	0	-3,447	-3,086	-12,647	-11,115	-10,866
Free Zuma	0	2,308	2,782	1,807	410	157
Zuma	0	9,460	17,191	19,379	17,941	14,004
El Matador	0	-3,401	-6,580	-6,769	-6,145	-5,134
La Piedra	0	-943	-1,445	-1,566	-1,397	-1,095
El Pescador	0	-1,148	-1,793	-1,566	-1,497	-1,207
Nicholas Canyon	0	-565	-1,174	-993	-1,177	-1,630

	2000	2020	2040	2060	2080	2100
Leo Carillo	0	-2,436	-1,905	-1,801	-3,932	-2,898
County Line	0	-1,262	-1,751	-1,352	-1,074	-707
Mugu	0	-761	-1,229	-919	-601	-294

Change in Attendance: High Growth Scenario

	2000	2020	2040	2060	2080	2100
Oceanside	0	-13,023	-40,552	-43,777	-43,894	-29,851
San Onofre South	0	-1,211	494	1,654	2,653	983
San Onofre North	0	-2,453	-3,107	671	1,891	1,039
San Clemente State	0	1,837	-1,102	-466	2,315	2,001
San Clemente City	0	1,183	5,747	-1,867	-8,453	-6,272
Poche	0	-1,097	2,295	3,644	4,735	5,733
Capistrano	0	-26,708	-42,531	-53,875	-34,474	-27,406
Doheny	0	-12,273	-20,183	-17,157	-11,711	-1,575
Salt Creek	0	-48,262	-55,231	-38,558	-19,197	-10,808
Aliso Creek	0	5,988	15,459	26,732	32,445	31,768
Laguna	0	-158,415	-293,630	-329,000	-308,324	-247,128
Crystal Cove	0	-38,483	-67,875	-115,910	-168,753	-145,583
Corona Del Mar	0	-68,909	-129,257	-148,804	-140,002	-114,891
Balboa	0	23,811	46,830	62,059	62,498	49,562
Newport	0	106,804	213,097	288,225	303,192	269,209
Santa Ana River	0	8,880	19,700	24,188	24,315	19,853
Huntington State	0	25,013	37,942	22,417	6,445	-20,196
Huntington City	0	126,841	252,841	326,491	341,889	296,193
Bolsa Chica	0	-132,050	-266,416	-337,502	-353,730	-320,811

	2000	2020	2040	2060	2080	2100
Sunset	0	43,550	87,463	120,626	136,368	126,907
Surfside	0	22,132	23,831	2,771	-14,021	-26,482
Seal	0	29,328	57,572	86,794	106,498	112,830
Alamitos Bay	0	28,659	16,541	-28,332	-63,062	-83,656
Belmont Shores	0	14,173	32,779	50,065	69,712	86,872
Long Beach	0	-50,794	-109,497	-172,695	-178,346	-180,366
Cabrillo	0	-19,450	-50,288	-50,321	-105,766	-107,936
Point Fermin	0	804	1,274	1,784	3,024	4,478
Royal Palms	0	4,269	7,077	9,542	15,524	21,566
Abalone Cove	0	5,496	8,260	9,693	12,260	12,165
Torrance	0	-37,664	-68,221	-76,463	-68,992	-55,884
Redondo	0	-140,719	-180,554	-253,566	-279,200	-231,037
Hermosa	0	21,658	36,858	51,936	66,220	65,280
Manhattan	0	65,234	116,253	160,003	189,411	180,222
El Segundo	0	26,739	46,293	63,418	74,916	73,820
Dockweiler	0	-1,915	-9,217	-15,323	-18,843	-24,434
Mother's	0	-31,968	-72,173	-114,453	-157,087	-214,611
Venice	0	9,596	-29,505	-39,291	-40,219	-31,717
Santa Monica	0	-5,752	-23,706	-37,093	-59,138	-48,363
Will Rogers	0	96,944	216,532	263,176	276,515	235,269
Topanga	0	-3,685	-16,595	-18,122	-21,331	-19,146
Las Tunas	0	-2,624	-3,858	-2,362	-973	208
Malibu	0	-9,867	-26,386	-26,419	-29,624	-25,550
Dan Blocker	0	-3,129	-3,611	-2,751	-1,768	-949
Point Dume	0	-3,188	-2,061	-6,640	-3,963	-2,575
Free Zuma	0	2,044	1,849	868	232	121

	2000	2020	2040	2060	2080	2100
Zuma	0	8,299	11,336	9,062	6,239	3,231
El Matador	0	-3,080	-4,887	-3,994	-3,008	-2,104
La Piedra	0	-852	-1,050	-877	-606	-351
El Pescador	0	-1,042	-1,325	-858	-618	-339
Nicholas Canyon	0	-510	-766	-361	-226	-251
Leo Carillo	0	-2,155	-884	197	96	827
County Line	0	-1,104	-1,109	-535	-254	-80
Mugu	0	-641	-645	-237	-64	-8

Appendix E

Nourishment Projects in Los Angeles and Orange Counties

Appendix E. Nourishment Projects in Los Angeles and Orange Counties

Site	City/County	Date of project	Dredge/Fill Volume (yd3)
Santa Monica Bay Beaches	Santa Monica, Los Angeles Co.	1947-1948	14,000,000
Venice City Beach/Dockweiler	Playa Del Rey, Los Angeles County	1948	13,984,900
Santa Monica Bay Beaches	Santa Monica, Los Angeles Co.	1960-1963	10,063,900
Long Beach	Long Beach, Los Angeles Co.	1946 to 1989	9,000,000
Dockweiler Beach	Playa Del Rey, Los Angeles Co	1963	7,022,667
Long Beach	Long Beach, Los Angeles Co.	1942-43	6,000,000
Newport Beach	Newport Beach, Orange Co.	1934-35	5,706,667
Newport Beach	Newport Beach, Orange Co.	1934-1936	5,593,960
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1964	4,000,000
Newport Beach	Newport Beach, Orange Co.	1935	3,700,000
Dockweiler Beach	Playa Del Rey, Los Angeles County	1962	3,202,150
Dockweiler Beach	Playa Del Rey, Los Angeles Co	1960-62	3,200,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1990	3,000,000
Dockweiler Beach	Playa Del Rey, Los Angeles Co	1962	3,000,000
Cabrillo Beach	San Pedro, Los Angeles Co.	1948	2,900,000
Cabrillo Beach	Los Angeles, Los Angeles County	1948	2,866,251
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1985	2,700,000
Cabrillo Beach	San Pedro, Los Angeles Co.	1948	2,536,500
Dockweiler Beach	Playa Del Rey, Los Angeles Co	1956	2,400,000
Dockweiler Beach	Playa Del Rey, Los Angeles Co	1956	2,400,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1971	2,364,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1985	2,293,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1971	2,260,000
Long Beach	Long Beach, Los Angeles Co.	1975-85	2,026,670
Newport Beach	Newport Beach, Orange Co.	1933-35	1,933,333
Newport Beach	Newport Beach, Orange Co.	1933-1935	1,895,150
Dockweiler Beach	Playa Del Rey, Los Angeles Co	1938	1,840,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1990	1,826,000
Dockweiler Beach	Playa Del Rey, Los Angeles County	1938	1,803,660
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1990	1,800,000
El Segundo	El Segundo, Los Angeles Co.	1936	1,800,000
Dockweiler Beach	Playa Del Rey, Los Angeles Co	1938	1,800,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1979	1,664,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1979	1,664,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1997	1,600,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1997	1,600,000
Newport Beach	Newport Beach, Orange Co.	1919-1930	1,594,540
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1979	1,544,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1982	1,500,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1984	1,500,000
Surfside-Sunset Beach	Huntington Beach, Orange Co.	1978	1,489,980
Redondo Beach	Redondo Beach, Los Angeles Co	1968	1,405,961
Redondo Beach	Redondo Beach, Los Angeles Co	1968	1,400,000
Redondo Beach	Redondo Beach, Los Angeles Co	1968	1,400,000
Redondo Beach	Redondo Beach, Los Angeles County	1968	1,398,490
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1964	1,315,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1990	1,300,000
Newport Beach	Newport Beach, Orange Co.	1992	1,300,000
Cabrillo Beach	San Pedro, Los Angeles Co.	1964	1,300,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1947	1,245,333
Newport Beach	Newport Beach, Orange Co.	1992	1,227,000
Cabrillo Beach	San Pedro, Los Angeles Co.	1964	1,226,667
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1947	1,220,000
Surfside/Sunset Beach	Huntington Beach, Orange Co.	1947	1,220,000
Cabrillo Beach	Los Angeles, Los Angeles County	1963	1,202,440
Dockweiler Beach	Playa Del Rey, Los Angeles Co	1989	1,100,000
Redondo Beach	Redondo Beach, Los Angeles Co	1971	1,020,000
Santa Monica State Beach	Santa Monica, Los Angeles Co.	1950	1,000,000
Project)	Huntington Beach, Orange Co.	1988	1,000,000

One of the most common ways to combat loss of beach width due to sea level rise is to nourish eroded beaches by replenishing them with sand from either inland or offshore sources.[6] In fact, many such beach nourishment projects have already been undertaken in Southern California, particularly to maintain wide, sandy beaches like Venice Beach and Dockweiler State Beach (State of California 2007; see Appendix D for a list of these projects). There are two major methods used in beach nourishment: trucking and dredging. Bringing in sand on trucks and then redistributing it around a beach using bulldozers is most cost-effective for small nourishment projects because the fixed costs are relatively low. Dredging, which requires scarce and expensive equipment that dredges sand from offshore and then deposits it near the beach site has high fixed costs but also significant economies of scale. Therefore, dredging tends to be more cost effective for very large projects.

Because of this divergence, our model of the costs of nourishment depends heavily on the amount of erosion expected in a given period and the frequency of nourishment projects. Nourished beaches require periodic maintenance since waves and currents constantly move sand in the alongshore and cross-shore directions. Sand may also be removed due to persistent background erosion or a storm. Typical re-nourishment intervals under past sea-level conditions range from two to five years, though when financing is a problem the length of time between cycles may be much longer. Between increasing average erosion rates due to sea level rise and the potential that winter times storms will have greater impacts due to increased high tides (Cayan et al. 2008) and longer storm seasons (Peter Bromirski, personal communication), nourishment may need to be undertaken more often in the future to maintain the current quality of Southern California beaches.

Our model captures this effect by comparing the cost of nourishment for average and extreme erosional events across our two base scenarios of +1 meter sea level rise and no sea level rise. We also look at delayed response to average erosion by calculating the costs if nourishment is undertaken over 2-, 5-, or 10-year time periods. Estimates of the volume of sand required to nourish selected Southern California beaches will be provided by Peter Adams as described in Section 2.3 and will be the major driver of change in the volume of both average and extreme erosional events.

The costs of a nourishment project can also be broken down into components parts. For the purposes of this study, which is focused on sea level rise due to global warming, costs will be decomposed into capital costs, which include the rental costs of the dredge or truck, as well as the costs of pipes, diesel generators, bulldozers, sifters (if the sand is mixed with other material), barges, and other materials and equipment. Labor costs include the costs of personnel to manage and run this machinery. If one includes the cost of project design and environmental compliance, labor costs will be substantially higher, since these operations primarily involve the use of (highly skilled) labor.

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[6] Sand may also be transferred from other beaches, but this is infrequent.

Since beach nourishment involves moving heavy sediment, often mixed as slurry with sea water, over considerable distances, energy is an inherent component in the process. The main energy input for all of these operations is diesel fuel, since virtually all of the components, such as ship engines, pumps, and bulldozers use diesel engines. Mobilization and demobilization of dredges and other components also involves transporting heavy equipment over significant distances. Thus the exact amount of energy used depends critically on the distance that the sediment must be transported from source to receiver site and, to a lesser extent, the distance that the dredge and other equipment must be moved during mobilization/demobilization for the project. Since these factors vary considerably by project, estimating precise energy inputs require that one make assumptions about these parameters.

There are a few opportunities for substitution across inputs or methods. The transportation of sediment by boat or barge (e.g., when a hopper dredge moves from the source site closer to shore or when a barge transports the sediment) will use less energy per cubic yard than pumping, especially since pumping typically involves seawater. Likewise, placement of sediment near shore, which eliminates the need to pump sand on the beach or bulldoze it, can also lower energy requirements.

A final factor that should be accounted for, if possible, is that dredges and trucks are generally leased by competitive bid at whatever the market rate. During periods of high demand, trucks and dredges, as well as other ancillary equipment that must be leased, will command a higher price than in low-demand periods. After a major storm event, one should expect that truck and dredge rental rates will be significantly higher than otherwise. Indeed, it may make more economic sense to postpone nourishment for a few months after an erosion event, which is reasonable because storms tend to occur in winter, well before the peak period of recreational demand.

Although diesel engines have been the primary sources of mechanical energy for most construction projects in the twentieth century, it is unlikely that this will remain so until 2100. Other engines with other energy sources will likely be developed including diesel-electric hybrids and biodiesel engines. However, these engines will still require substantial energy to operate.

While moving sediment around requires a great deal of energy, capital is typically the largest expense since dredges and related equipment are expensive and scarce. It is also reasonable to assume that for a particular project, which typically involves many constraints involving site sources, when dredging can occur, funding, etc., the options for substituting to a less energy-intensive process are very limited. A more reasonable approach would be to assume that capital, labor, and energy are inelastic substitutes, and such an approach involves using inputs in fixed proportions. We take that approach here; however, we acknowledge that the exact proportion of energy will vary with the distance between receiver and sources and other variables mentioned above (King 2006).

For smaller nourishment projects (typically less than 100,000 cubic meters) it is generally cheaper to use trucks to carry sand from inland sources to the beach. This sand may be opportunistic—from a building site or the result of accumulated sand and silt from a flood control project such as a debris basin or dam. As with a dredge, the cost of trucking varies with market conditions. After an extreme event, like a winter storm, the cost of trucking may rise due to either an increased demand for trucking or increased difficulty in transportation over flooded or flood damaged roads. However, it may be possible to delay moving sand to a time when costs are lower and conditions are better, especially since the peak beach season is several months after the winter storm season.

The most significant cost involved in trucking is the distance between the sand site and the receiver site, and this is reflected in our cost function. These distances would also affect the percentage of total costs dedicated to energy consumption since the typical pattern would be: (a) load sand, (b) drive from source to receiver site, (c) unload sand. Loading and unloading use relatively little energy. The estimates below are based on a 15 mile distance between the source and receiver site. Longer distances would entail a higher percentage of energy costs; a shorter distance would mean a lower percentage.

The two counties in this study contain dozens of beaches, many of which are potential sites for erosion and thus potential sites for future beach nourishment. In practice, though, not all eroding beaches have received nourishment. Likewise, not all eroding beaches are likely to be nourished in the future. We estimate the costs of nourishment by examining opportunities and needs for nourishment on a beach-by-beach basis.

Tables E-1 and E-2 provide estimates of the cost of nourishment. Column 3 of these tables indicates whether the least cost feasible alternative is trucking or dredging. As a practical matter, most sites required more sand than is feasible (due to environmental and other constraints) for trucking.

Column 4 estimates the total costs of dredging at each site and column 5 estimates the average costs. For most sites, the quantities of sand required are large enough so that the fixed costs of mobilization and demobilization will be quite small as a total percentage of the cost of the project. Thus, for most dredge projects, the average total cost is $26 per cubic meter, reflecting the average variable costs of moving sand plus the (very small) fixed costs per cubic meter of sand. For trucking, the average cost is closer to $20 per cubic meter.

References

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Table E-1: Least cost alternatives at beaches in need of nourishment: Scenario A

Beach Name	Estimated Beach Volume Change (cubic meters) Scenario A	Least Cost Alternative	Cost of Alternative ($)	Avg. Cost per Cubic Meter ($)
SanOnofreSouth	(291,964)	Dredge	7,713,754	26
SanOnofreNorth	(437,473)	Dredge	11,520,119	26
SanClementeState	(224,517)	Dredge	5,949,412	26
SanClementeCity	(697,096)	Dredge	18,311,610	26
Poche	(61,457)	Dredge	1,683,906	27
Capistrano	(738,393)	Dredge	19,391,896	26
Doheny	(121,676)	Dredge	3,259,169	27
SaltCreek	(238,621)	Dredge	6,318,350	26
AlisoCreek	(201,980)	Dredge	5,359,864	27
Laguna	(1,074,488)	Dredge	28,183,834	26
CrystalCove	(631,900)	Dredge	16,606,148	26
CoronaDelMar	(160,236)	Dredge	4,294,870	27
Balboa	(61,895)	Truck	1,255,447	20
Newport	(75,047)	Truck	1,519,254	20
SantaAnaRiver	(98,422)	Dredge	2,650,888	27
Huntington State	(493,014)	Dredge	12,973,031	26
HuntingtonCity	(834,404)	Dredge	21,903,448	26
BolsaChica	(746,535)	Dredge	19,604,903	26
Sunset	(130,233)	Dredge	7,176,745	26
Surfside	(163,684)	Dredge	4,358,058	27
Seal	(371,618)	Dredge	9,797,410	26
AlamitosBay	(329,516)	Dredge	8,696,075	26
BelmontShores	(415,502)	Dredge	10,945,382	26
Long	(379,594)	Dredge	10,006,075	26
Cabrillo	(379,594)	Dredge	10,006,075	26
Point Fermin	-			

Table E-1 (continued)

Beach Name	Estimated Beach Volume Change (cubic meters) Scenario A	Least Cost Alternative	Cost of Alternative ($)	Avg. Cost per Cubic Meter ($)
Royal Palms	-			
Abalone Cove	-			
Torrance	(136,337)	Dredge	3,642,707	27
Redondo	(386,991)	Truck	7,776,057	20
Hermosa	(453,469)	Dredge	11,938,557	26
Manhattan	(491,250)	Dredge	12,926,879	26
ElSegundo	(335,546)	Dredge	9,363,856	26
Dockweiler	(647,351)	Dredge	17,010,337	26
Venice	(690,268)	Dredge	18,133,006	26
SantaMonica	(1,012,179)	Dredge	26,553,880	26
WillRogers	(280,941)	Dredge	7,425,394	26
Topanga	(458,484)	Dredge	12,069,764	26
LasTunas	(484,308)	Dredge	12,745,286	26
Malibu	(595,158)	Dredge	15,645,004	26
DanBlocker	(349,748)	Dredge	9,225,326	26
PointDume	(865,199)	Dredge	22,709,036	26
FreeZuma	-			
Zuma	-			
ElMatador	-			
LaPiedra	-			
ElPescador	-			
NicholasCanyon	-			
LeoCarillo	-			
CountyLine	-			
Mugu	-			
Total	(16,546,090)	-	436,650,813	

Table E-2. Least cost alternatives at beaches in need of nourishment: Scenario B

Beach Name	Estimated Beach Volume Change (cubic meters) Scenario B	Least Cost Alternative	Cost of Alternative	Avg. Cost per Cubic Meter
SanOnofreSouth	1,062,633		$ -	$ -
SanOnofreNorth	949,141		$ -	$ -
SanClementeState	(168,433)	Dredge	$ 4,507,832	$ 27
SanClementeCity	(951,745)	Dredge	$ 24,998,523	$ 26
Poche	40,156		$ -	$ -
Capistrano	(882,527)	Dredge	$ 23,187,846	$ 26
Doheny	(710,493)	Dredge	$ 19,356,855	$ 26
SaltCreek	(956,867)	Dredge	$ 76,784,741	$ 26
AlisoCreek	436,924		$ -	$ -
Laguna	734,950		$ -	$ -
CrystalCove	107,423		$ -	$ -
CoronaDelMar	224,324		$ -	$ -
Balboa	(105,066)	Truck	$ 2,121,356	$ 20
Newport	(105,066)	Truck	$ 2,121,356	$ 20
SantaAnaRiver	(105,066)	Dredge	$ 2,850,212	$ 27
Huntington State	(521,264)	Dredge	$ 13,737,552	$ 26
HuntingtonCity	1,217,812		$ -	$ -
BolsaChica	(153,637)	Truck	$ 3,095,566	$ 20
Sunset	231,996		$ -	$ -
Surfside	(1,125,737)	Dredge	$ 49,603,770	$ 26
Seal	1,677,742		$ -	$ -
AlamitosBay	840,266		$ -	$ -
BelmontShores	(21,523)	Truck	$ 445,696	$ 21
Long	(21,523)	Truck	$ 445,696	$ 21
Cabrillo	(21,523)	Truck	$ 445,696	$ 21

Table E-2 (continued)

Beach Name	Estimated Beach Volume Change (cubic meters) Scenario B	Least Cost Alternative	Cost of Alternative	Avg. Cost per Cubic Meter
Point Fermin	-		$ -	$ -
Royal Palms	-		$ -	$ -
Abalone Cove	-		$ -	$ -
Torrance	(545,904)	Dredge	$ 50,097,810	$ 26
Redondo	(845,189)	Dredge	$ 22,211,120	$ 26
Hermosa	(194,266)	Dredge	$ 5,183,598	$ 27
Manhattan	(45,195)	Truck	$ 920,496	$ 20
ElSegundo	279,597		$ -	$ -
Dockweiler	(674,281)	Dredge	$ 17,740,331	$ 26
Venice	(109,715)	Truck	$ 2,214,603	$ 20
SantaMonica	256,891		$ -	$ -
WillRogers	(582,559)	Dredge	$ 15,340,971	$ 26
Topanga	175,462		$ -	$ -
LasTunas	664,277		$ -	$ -
Malibu	26,425		$ -	$ -
DanBlocker	236,080		$ -	$ -
PointDume	(1,507,270)	Dredge	$ 45,059,552	$ 26
FreeZuma	-		$ -	$ -
Zuma	-		$ -	$ -
ElMatador	-		$ -	$ -
LaPiedra	-		$ -	$ -
ElPescador	-		$ -	$ -
NicholasCanyon	-		$ -	$ -
LeoCarillo	-		$ -	$ -
CountyLine	-		$ -	$ -
Mugu	-		$ -	$ -
Total	(1,192,751)		$ 382,471,176	