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Sea Level Rise: Implications for Management and Restoration of Coastal Wetlands in Southern California

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SEA LEVEL RISE: IMPLICATIONS FOR MANAGEMENT AND RESTORATION OF COASTAL WETLANDS IN SOUTHERN CALIFORNIA

By

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PREFACE

This document was prepared in partial fulfillment of the requirements for completion of a Master's Degree in Marine Biodiversity and Conservation at the University of California San Diego, Scripps Institution of Oceanography, under the guidance of advisor Lisa Levin, PhD.

This document looks at the implications of climate change, in particular impacts associated with sea level rise, for management and restoration of coastal wetlands in southern California. To achieve this task, the latest information available in the 2007 Fourth Assessment Report from the Intergovernmental Panel on Climate Change provides the foundation for the discussion. The global context of sea level rise is then scaled down regionally and locally to focus purely on coastal wetlands.

As an abundance of climate change information continues to become available, it is difficult to determine which is the most current. As a result, this paper strives to provide an up-to-date and comprehensive synthesis for consideration of sea level rise as we understand it today and in consideration of future projections. In comparison, the research available for the impacts of sea level rise on tidal wetlands, especially in southern California, is limited. Therefore, a more theoretical analysis is included in this paper with recognition of the need to incorporate the unique challenges and qualities of these coastal wetlands when considering climate change impacts in southern California. In some cases, the referenced authors used very succinct and specific wording. To ensure accuracy, extensive efforts were put forth to preserve the original intent of the wording.

While not meant to be inclusive of all factors related to climate change, particularly sea level rise, and coastal wetlands, this paper highlights not only the need for additional research for application to southern California, but also inclusion of coastal wetland management and restoration in general with regard to climate change. For example, incorporation of research and sea level rise into existing policy for wetland protection and practice as well as shared importance with other habitats like forests when developing adaptative strategies in the State of California.

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EXECUTIVE SUMMARY

This paper focuses on sea level rise associated with climate change and implications for restoration and management of coastal wetlands in southern California. The paper begins with a look at climate in general and how to assess climate change. The next section looks at the process of decision-making to utilize global information in a regional and local context. Included in this section is a look at federal, state, and local efforts to address climate change. The section ends with a look at adaptation in regards to climate change impacts that are occurring today and projected for the future. Section 3 delves into the fine points of how to determine global sea level and the considerations for regional spatial variation, and the vulnerability of California in regard to sea level rise. Section 4 looks at sea level rise in the context of coastal ecosystems, particularly coastal wetlands. After a broad perspective, the section ends with a theoretical look at the previous information in the context of a case study. The last section gives a list of recommendations for adaptive strategies to complement emission reductions in sufficient detail to provide information on the next steps to incorporate climate change impacts such as sea level rise into existing policy, research, and communication. Overall, this paper is a mere overview of the breadth of knowledge available for one aspect of climate change. It is important to note climate change impacts such as sea level rise do not occur in isolation and as such research and analysis require an interdisciplinary approach as well as the measures for addressing it.

Glossary of Abbreviations

ACOE	- U.S. Army Corps of Engineers
AR4	– IPCC Fourth Assessment Report
CalEPA	- California Environmental Protection Agency
CAP	- California Applications Program
CAT	- Climate Action Team
CCC	- California Coastal Commission
CCCC	- California Climate Change Center
CCRI	- Climate Change Research Initiative
CCSP	- U.S. Climate Change Science Program
CDFG	- California Department of Fish and Game
CO_2	– carbon dioxide
CCSP	- U.S. Climate Change Science Program
EO	- Executive Order
EPA	– U.S. Environmental Protection Agency
KFR	- Mission Bay Kendall-Frost Reserve
GHG	- greenhouse gases
GCRP	- U.S. Global Change Research Program
IPCC	- Intergovernmental Panel on Climate Change
NOAA	- National Oceanic and Atmospheric Administration
NRC	- National Research Council
RISA	- Regional Integrated Sciences and Assessments
SRES	- Special Report on Emissions Scenarios
SPM	- Summary for Policymakers
TAR	- IPCC Third Assessment Report
TS	- Technical Summary
UN	- United Nations
USFWS	- U.S. Fish and Wildlife Service
USGS	- U.S. Geologic Service

Key Concepts and Definitions

Adaptation refers to ranges of adjustments of the environment or the actions taken by individuals, organizations, communities, or other entities to deal with potential or experienced impacts of climate change in the near term.

Climate refers to the average of weather conditions and varies on timescales ranging from seasonal to centennial. *Climate change* is a shift in the average weather

Use of the phrase "*climate change*" is preferred to use of the phrase "*global warming*" to convey there are changes in addition to rising temperatures. However, these phrases are used interchangeably in this paper in reflection of sea level rise impacts associated with global warming.

The meaning of *mitigation* in reference to climate change refers to reduction of GHG emissions into the atmosphere. Mitigation in reference to wetland loss refers to replacement of wetlands in one area to compensate for wetland impacts in another area.

Resilience is the ability of a system to absorb and rebound from the impacts of weather extremes, climate variability, or change and to continue functioning.

Use of the term *restoration* in this paper includes creation of wetlands in areas that were not previously wetlands and reestablishment or rehabilitation of former or degraded wetlands.

Vulnerability is the extent to which a natural system is susceptible to sustained damage from weather extremes, climate variability, and change as well as other interactive stressors.

SECTION 1: Climate and Assessing Change

"The Earth's well-being is also an issue important to America. And it's an issue that should be important to every nation in every part of our world. The issue of climate change respects no border. Its effects cannot be reined in by an army nor advanced by any ideology. Climate change, with its potential to impact every corner of the world, is an issue that must be addressed by the world." President Bush, June 11, 2001 (Office 2001)

1.1 Introduction

Human activities, particularly the burning of fossil fuels, are profoundly altering the world's climate by saturating the atmosphere with carbon dioxide (CO_2), methane, and other greenhouse gases (GHGs). As a result, the atmosphere is trapping more of the sun's energy, causing the temperature of the planet to rise, and impacts associated with this anthropogenic change to directly affect water availability and quality, agriculture, forestry, power production, and entire ecosystems.

Climate refers to the average of weather conditions and varies on timescales ranging from seasonal to centennial. *Climate change* is a shift in the average weather that a given region experiences such as temperature, wind patterns, precipitation, and storms. Natural fluctuations result from interactions between the ocean, the atmosphere, the land, cryosphere (frozen portion of the Earth's surface), and changes in the Earth's energy balance resulting from volcanic eruptions and variations in the sun's intensity. Broadly defined to include both natural and anthropogenic causes, variation in the average weather of the Earth as a whole over timescales from decades to millions of years is termed global climate change – an important concern for the future of humankind and the environment with which we depend (CalEPA 2006).

Climate science concerns the study of Earth's climate system with emphasis on the physical, dynamical, and chemical interactions of the atmosphere, ocean, land, ice, and the terrestrial and marine biospheres. One of the central challenges is developing the ability to predict future climate changes, whether they are the consequences of human activities, or the result of natural climatic cycles. A related challenge is understanding how and why the climate of the earth has changed in the past.

To understand Earth's climate system requires understanding the mechanistic links between physical and chemical changes in the atmosphere (e.g. changes in winds, clouds, rainfall, sunlight, greenhouse gas abundances, or stratospheric ozone) and changes in the oceans (e.g. shifts in the current systems, temperature structure, or ocean biota), in the ice sheets (e.g. advances and retreats), and in land biota (e.g. changes in length of growing seasons or habitat range).

The climate system includes powerful feedback mechanisms. The amount of moisture in the atmosphere, for example, increases with global temperature, but the moisture also contributes to additional warming through the greenhouse effect (IPCC 2007a). Scientists studying the climate system need experience in many disciplines including meteorology, oceanography, geography, ecology, geology, and paleontology.

Continuing such activities under "business as usual" scenarios will lead to serious, potentially catastrophic consequences. Significant sea level rise from water expansion and the melting of ice caps and glaciers will result in increased flooding and inundation of low-lying coastal areas compounded by more severe storms and surges. Another serious consequence is degradation of coastal wetland habitats, and the extinction of plant and animal species that are unable to evolve or adapt to a change in temperature.

These are concerns not expressed by a few alarmists, but respected governmental and scientific entities such as the U.S. Environmental Protection Agency (EPA), the National Academies, and a worldwide panel of experts commissioned by the United Nations (UN) known as the Intergovernmental Panel on Climate Change (IPCC). While the IPCC recognizes there exists a degree of uncertainty regarding the exact causes and effects of global warming synonymous with climate change, all agree the symptoms of such warming from rising sea levels and decreased snow cover to shifting patterns of rainfall have become increasingly apparent (IPCC 2007a).

1.2 Climate

1.2.1 Climate Change

Anthropogenic warming and sea level rise will continue for centuries due to the time scales associated with climate processes and feedbacks, even if GHG concentrations were stabilized. Long-lived GHGs, like $CO_{2,}$ are chemically stable and persist in the atmosphere over time scales of a decade to centuries or longer, so their emission has a long-term influence on climate. CO_2 does not have a specific lifetime because it is continuously cycled between the atmosphere, oceans and land biosphere involving a range of processes with different timescales (IPCC 2007b). These changes, as well as the options for adapting to or slowing changes, may have substantial environmental consequences. Thereby, decision makers, resource managers, and other interested stakeholders need reliable science-based information to make informed judgments regarding policy and actions. Figure 1 illustrates some of the range and complexity of the climate system elements that must be considered in addressing short- and long-term climate change issues (CCSP 2003).

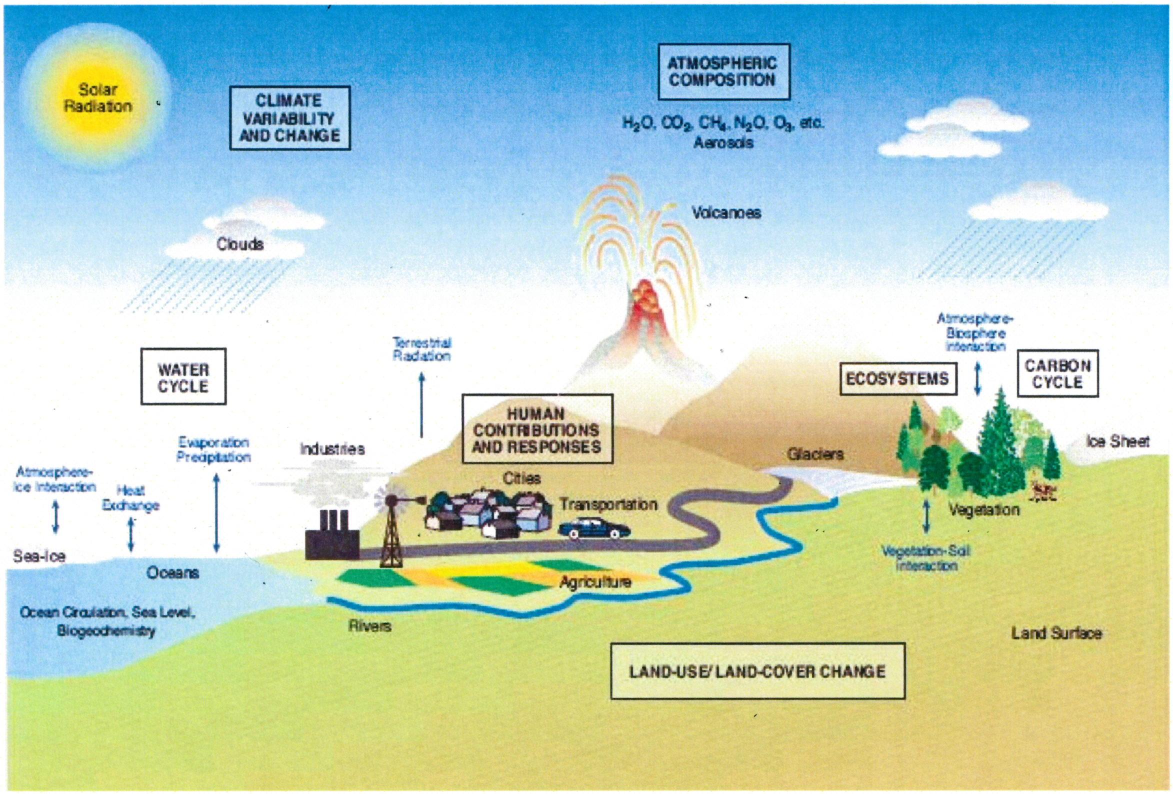


Figure 1: Major components needed to understand the climate system and climate change. Source: 2003 Climate Change Strategic Plan.

1.2.2 Climate Models and Future Projections

Climate models are the only means to estimate the effects of increasing GHGs on future global climate. These models are based on well-established physical principles to simulate the interactions of the atmosphere, oceans, land surface, and ice; and have been demonstrated to reproduce observed features of recent climate and past climate changes (IPCC 2007b). Advances in climate change modeling enable best estimates and likely assessed uncertainty ranges to be given for projected warming for different emission scenarios. A broader range of models along with information from observations provides a quantitative basis for estimating likelihoods for many aspects of future climate change.

1.2.2.1 Global

The Fourth IPCC Assessment Report (AR4) relies on a larger number of climate models of increasing complexity and realism and new information regarding the nature of feedbacks from the carbon cycle and constraints on climate response from observations (IPCC 2007a). The IPCC *Special Report on Emissions Scenarios* (SRES) developed a set of possible future emissions scenarios based on different assumptions about global development paths (IPCC 2000). Model experiments show that even if all emissions were held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.1ºC per decade. About twice as much warming (0.2ºC per decade) would be expected if emissions are within the range of the emission scenarios. Best estimate projections from models indicate that decadal average warming over each inhabited continent by 2030 is insensitive to the choice among emission scenarios. Model-based projections of global average sea level rise at the end of the 21st century range from 0.18 to 0.38 m for the lowest emission scenario to 0.26 to 0.59 m for the highest emission scenario. Notably, sea ice is projected to shrink in both the Arctic and Antarctic under all emission scenarios (IPCC 2007a).

However, the models used to date do not include uncertainties in the climate-carbon cycle feedback nor do they include the full effects of rapid dynamical changes in ice sheet flow due to lack of a basis in published literature. However, the projections do include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for the period 1993-2003, but these flow rates could increase or decrease in the future. Larger values cannot be excluded, but the understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise (IPCC 2007a).

1.2.2.2 California

Climate change and temperature projections can be developed on a regional basis using techniques to downscale from the results of global SRES models, although the level of uncertainty related to regional climate change and temperature projections is higher than global projections since downscaling adds more uncertainty (CDWR 2006). California used results from three SRES emission scenarios – higher emissions, medium-high emissions, and lower emission scenarios (IPCC 2000).

Both California's coastal observations and global model projections indicate that California's open coast and estuaries will experience increasing sea levels during the next century about 2mm/yr similar to trends estimated for global sea level. By 2070-2099, projected sea level rise ranges from 13 to 76 cm, depending on the magnitude of climate warming. The middle to higher end of this range would exceed the historical rate of sea level rise, approximately 20 cm per century observed at San Diego during the past 100 years (Cayan et al. 2006b). Also, climate projections show little difference between the emissions scenarios prior to 2035 due to the inertia of the climate system, indicating that even under the lower emissions path some further impacts from climate change are inevitable. Another factor to consider beyond long-term trends is that sea levels along the California coast undergo shorter period variability above or below predicted tide levels. Highest sea levels usually occur when winter storms and Pacific climate disturbances such as El Nino have coincided with high astronomical tides (CalEPA 2006).

Overall, all climate models show temperature increases in California and these increases alone would impact the California hydrological cycle with consequences for the state's ecosystems. Magnitudes in the warming vary because of uncertainties in the climate sensitivity. However, all the GHG scenario simulation exhibit higher warming in summer than in winter. Furthermore, climate change could produce compounding impacts such as heightened sea levels and high river inflows in the San Francisco Bay Delta. More analysis and information is needed to better understand the vulnerability of California's environment to climate change (Cayan et al. 2006a).

1.2.3 Climate Model Uncertainties

The accuracy of climate models is limited by the spatial resolution possible with present computer resources and our ability to describe the complicated atmospheric, oceanic, and chemical processes mathematically (IPCC 2007b).

1.3 Intergovernmental Panel on Climate Change

1.3.1 Background

The IPCC was established in 1988 by two UN organizations, the World Meteorological Organization and the UN Environment Program, as both an intergovernmental body and a network of the world's leading climate change scientists and experts to assess the risk of human-induced climate change. As such, the IPCC does not carry out new research, nor does it monitor climate related data. It bases its consensus-based assessments on existing peer reviewed and published scientific literature. Thereby, the reports are by their nature conservative, while intending to provide information for international policy and negotiations on climate issues. Another important note is that the IPCC assessments do not constitute policy nor are they written by policymakers. The IPCC assessment is a science document (Sommerville 2007).

1.3.2 Assessment Reports

Since 1990, the IPCC has produced three assessment reports (1990, 1995, and 2001). The Fourth Assessment Report (AR4) is nearing completion. Each subsequent report notes areas where the science has improved since the previous report and also notes gaps in information and understanding where further research is required. Thus, each report provides a comprehensive and up-to-date scientific assessment of past, present and future climate change. Each report consists of three working groups – each focused on a different aspect of global warming – plus a final synthesis report. The following is the status of AR4 (**http://www.ipcc.ch/**):

- Working Group I: The Scientific Basis released in February 2007
- Working Group II: Impacts, Adaptation, and Vulnerability released in April 2007
- Working Group III: Mitigation released in May 2007
- Final Synthesis Report expected to be released in the last quarter of 2007

It is important to note, AR4 incorporates scientific knowledge on climate science available in peer-reviewed literature by mid-2006 (IPCC 2007b).

Since the Third Assessment Report (TAR), a gain in the understanding of how climate is changing in space and time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. For example, increasingly comprehensive observations are available for sea level and ice sheets since about the past decade (IPCC 2007a). The complexity of the climate system and the multiple interactions that determine its behavior impose limitations on our ability to fully understand future global climate. There remain uncertainties that include the role of clouds, the oceans, land use and couplings between climate and biogeochemical cycles.

The reports also include a Summary for Policymakers (SPM) and a Technical Summary (TS), in addition to the main chapters in the reports. These supplemental documents follow the same structure to simplify cross-reference between them and incorporate associated reference to the main report for further detail. The SPM is also approved line by line to ensure consistency with the factual material contained in the full report.

SECTION 2: Informed Decisions, Efforts, and Adaptation

2.1 Introduction

One of the most important problems today is determining the physical response of the coastline to sea level rise. Prediction of shoreline retreat and land loss rates is critical to planning future coastal management strategies and assessing biological impacts due to habitat change or destruction. Presently, long term planning has been piecemeal, if at all. Consequently, development continues without adequate consideration of the potential costs of protection or relocation from sea level rise related erosion, flooding, and storm damage. Furthermore, the federal government is not consistent in terms of the amount of activity devoted to the issue of sea level rise within its agencies. The reasoning may possibly be a result of agency mission. However, the federal government should devote more energy than has been in light of the importance of sea level rise. Agencies such as the U.S. Army Corps of Engineers (ACOE), U.S. Fish and Wildlife Service (USFWS), U.S. Environmental Protection Agency and National Oceanic and Atmospheric Administration (NOAA) all have varying degrees of activity in regards to sea level rise issues. The question is whether they adequately address the problem.

2.2 Decisions

Numerous decisions may be sensitive to sea level rise. To inform those decisions, better information about the implications of sea level rise is needed at various scales. For analyzing national decisions (e.g., incorporating shoreline retreat into flood insurance or wetland protection programs), nationwide estimates are important, perhaps with a state-by-state breakdown. Shore-protection and land-use decisions, by contrast, are primarily made at the local level or on a parcel-specific basis and those decisions require maps that show site-specific implications. However, natural and political systems operate at different scales.

Unlike many other sciences where measurements can be carefully controlled, climate change research relies on many datasets from satellites to ocean buoys operated by various government agencies and countries in addition to indicators of past climate from ice cores, tree rings, corals, and sediments (NRC 2006). Often the data was originally collected for other purposes and higher accuracy is needed to detect gradual climate trends, the observing programs must be sustained over long time periods and accommodate changes in technology, and observations are needed at both global and local scales for a range of climate information users (NRC 2006).

2.3 Federal, State and Local Efforts

Federal

In an effort to provide insight into climate change more than a dozen federal agencies are involved in producing and using climate change data and research. For example, the ACOE in collaboration with the Federal Emergency Management Agency, and several states are developing elevation data for floodplain mapping. NOAA and the U.S. Geological Survey (USGS) are developing Digital Elevation Models that use a common vertical reference for both topographic and bathymetric maps (NOAA 2004). The USFWS develops wetland data. NOAA's coastal change analysis program periodically provides a comprehensive assessment of land cover changes in the coastal zone of the U.S. USGS collects high resolution airborne Light Detection and Ranging (LIDAR) elevation data for coastal areas for use in producing assessments of shoreline erosion and other coastal processes through its National Assessment of Coastal Change Hazards (Morton et al. 2004; Morton and Mill 2005). The USGS also evaluates the ability of wetlands to keep pace with rising relative sea level (e.g., Mississippi River Delta) (Rybczyk and Cahoon 2002). With so many efforts, the question becomes how to bring all the resources together.

The U.S. Climate Change Science Program (CCSP) was established in 2002 to coordinate climate and global change research conducted as part of the U.S. Global Change Research Program (GCRP) created in 1989 and the Climate Change Research Initiative (CCRI) created in 2002. The interagency CCSP is responsible for compliance with the Global Change Research Act of 1990, including its provisions for annual reporting of findings and short-term plans, scientific reviews by the National Academies, periodic publication of a 10-year strategic plan for the program, and assessments of climate change impacts such as the IPCC. The CCSP is also developing a series of studies that summarize the current state of scientific understanding related to climate change, variability, ecosystems and human society. In regions sensitive to climate change and variability (e.g., Louisiana, Florida, and the Mid-Atlantic), these studies will communicate what is known including degrees of uncertainty, about climate and its interactions with natural systems (CCSP 2003).

CCSP studies such as the one titled "*Coastal Elevations and Sensitivity to Sea Level Rise*" are important for federal agencies to put the research into practice like the ACOE (CCSP 2006). The ACOE is responsible for maintenance of coastal and inland waterborne navigation, harbors, and ports along with prevention of coastal damage produced by storms, erosion control, emergency response, and restoration of natural environments along coasts and rivers. A less recognized ACOE responsibility involves wetland protection and compensatory mitigation for unavoidable impacts under Section 404 of the Clean Water Act, although the Act does not authorize measures to ensure survival of wetland ecosystems as sea level rises. Notably, knowledge about climate change and sea level rise is a key factor for all of these responsibilities.

Other federal efforts include NOAA's Regional Integrated Sciences and Assessments (RISA) program, which supports climate research of concern to decision-makers and policy planners at a regional level. The RISA research team members are primarily based at universities though some of the team members are based at government research facilities, non-profit organizations or private sector entities. RISA researchers also work directly with regional and/or local stakeholders to address climate issues in their area that may be vulnerable to climate change. This not only aids the decision makers, it improves scientific understanding of stakeholder needs. For California, the RISA program includes the Climate Action Program (CAP), which works in collaboration with the California Climate Change Center (CCCC) to provide climate information for decision makers in California. Both the CAP and CCCC are led by researchers at Scripps Institution of Oceanography who work directly with users and downscale climate forecasts and simulations from global to regional to local scales (www.climate.noaa.gov). Many opportunities exist to enhance California's adaptive capacity and resilience in the face of change, even in the absence of perfect foresight about climatic changes.

State

"As of today California is going to be the leader in the fight against global warming. ...I say the debate is over. We know the science. We see the threat. And we know the time for action is now." Governor Arnold Schwarzenegger June 2005 (CDWR 2006)

In response to global climate change, Executive Order (EO) S-3-05 signed in June 2005 established GHG emission targets for California. Included in this EO, among other key issues such as water resources, was recognition that rising sea levels threaten natural habitat and the requirement for biennial reports on climate change impacts. In response to the EO, the California Environmental Protection Agency (CalEPA) created the Climate Action Team (CAT) to coordinate the state's climate change programs. The CAT is comprised of representatives from various state agencies and commissions including the Resources Agency. The Resources Agency is in charge of the California Department of Fish and Game (CDFG) and the California Coastal Commission (CCC) both of which oversee natural resources management along the coast. A subgroup of the CAT is the Scenario Analysis Subgroup, which evaluates the impacts of climate change on the state and adaptation measures that can be taken to prepare for the impacts of climate change (CalEPA 2006). In addition to overview reports being produced under the guidance of the CAT, the California Department of Water Resources (CDWR) also established a complimentary program to incorporate climate change in to management of California's water resources (CDWR 2006).

Local

Local governments play a key role because they directly influence and control many of the activities that produce GHG emissions. Decisions about land use and development, investments in public transit, energy-efficient building codes, waste reduction and recycling programs all affect local air quality and living standards as well as the global climate. However, there is a gap between science and practice. Local political officials need to often balance more immediate concerns such as infrastructure improvements and economic development. Hence, these interests may preclude them from gaining the knowledge to factor another consideration into their decisions – one laden with discussion of uncertainty, numerous ranges of numbers, and technical dialogue.

Scientists and government are still trying to understand all the intricacies while trying to relay a call for action at the same time, but is the message lost in the confusion. As sea level rises, coastal flooding may become more frequent. In some low-lying coastal areas, high tides during new and full moons flood streets that were above the tides when originally constructed; however, the question is whether the local community makes the connection to sea level rise beyond an interest to repair the damage.

Moreover, if the local communities want to address sea level rise, the scale of the available information is largely global with little downscaled into a context both useful and accessible to local officials. Currently, local officials act purely on a voluntary basis because federal agencies do not have tools to force coastal communities to make good land use decisions. However, federal agencies like the ACOE have an opportunity to consider sea level during environmental review of projects such as shoreline protection (e.g., bulkheads that eliminate intertidal wetlands or prevent landward migration of habitat) and the associated compensatory mitigation.

2.4 Adaptation

Clearly, there is a need for current policy throughout government to address the likely impacts of climate change projected to occur in the foreseeable future regardless of any simultaneous emissions reductions. Furthermore, the government has a crucial supportive role to provide an appropriate enabling environment, such as institutional, policy, legal, and regulatory frameworks. Adaptation is necessary for near term unavoidable climate change impacts while mitigation is needed to prevent further, more severe impacts in the future. Like mitigation efforts to reduce CO_2 emissions, adaptive strategies to address climate change impacts should be proactive to be more cost effective and efficient rather than reactive or maintenance of the status quo. Understandingly financial resources at the federal, state, and local levels are already strained with competing demands and priorities, and unfunded mandates are some of the reasons why many managers and policy makers resist taking on other issues. Yet, it is precisely for this reason climate change should be integrated into existing policy wherever possible (Luers and Moser 2006).

Policies should include actions already justified by current climatic conditions and actions that can be justified as protection against future climate change impacts. For example, in the course of regular infrastructure upgrades and maintenance such as replacement of sewage pipes or long-term development planning and siting, incorporate safety buffers to account for potentially more extreme runoff or higher sea levels without incurring huge additional costs at the time of the upgrade. In cases where present-day weather extremes and climate variability cause damages, additional opportunities exist during the recovery period to rebuild in ways that are informed by the possibility of future climate change (Luers and Moser 2006).

Adaptation whether planned or unplanned, or undertaken by the public or private sector is imperfect. Measures are not always perfectly timed, efficiently implemented, or wholly adopted because of a variety of constraints and barriers. It takes time and committed resources to initiate and implement new programs (or revise existing ones), develop new technologies, evaluate effectiveness of these measures, and address related barriers such as finances, institutional framework, and information. Integration of climate change policy into broader development policies will make implementation and overcoming barriers easier. Moreover, what may appear as the most reasonable pathway for adaptation may sometimes be completely avoided or can generate negative ecological ancillary effects. In addition, there are limits to adaptation, especially in addressing threats of abrupt climate change (Luers and Moser 2006).

SECTION 3: Climate Change and Sea Level

3.1 Introduction

The introduction to this section begins with a passage from an older book about sea level change that included work by two notable authors from the University of California San Diego at Scripps Institution of Oceanography – Walter Munk and Roger Revelle. These words are as relevant today as they were then.

Sea level change, seemingly so simple and straightforward, is in fact the product of many interrelated processes. Insight into these processes can be gained by intensive study of sea level change in the context of related environmental phenomena, remembering that changes in sea level are an integrated measure of environmental change, in terms of both causes and consequences. Changes occur on all space and time scales, from local to global and from a few seconds to geologic ages.

Climate, plate tectonics, the cryosphere, and ocean circulation all contribute to changing sea level. The relative importance of the forcing functions varies with the time scales of interest. The effects of changing sea level are also broad with on the one hand direct feedbacks to the causative forcing functions and on the other hand with effects on other processes such as sedimentation and coastal ecology (NRC 1990).

Many processes can change sea level at any given location. These processes include:

- uplift (e.g., plate tectonics), accretion (from sediment accumulation) and subsidence (owing to sediment load or withdrawal of groundwater) of the land;
- changes in atmospheric pressure, winds, or ocean currents;
- eustic changes in the mass of ocean water (e.g., melting of ice sheets and mountain glaciers);
- steric changes in ocean volume without changes in mass in response to temperature or salinity changes; and
- changes in the volume of the ocean basins (e.g., changes in the elevation of the seafloor from mid-ocean volcanism).

The latter three processes affect global mean sea level or eustatic sea level; however, all these processes need to be considered, even though depending on the desired time scale or magnitude of change, some may be insignificant. The effects of ocean water mass on sea level change are based on how water is partitioned between the major hydrologic reservoirs. In order of abundance, the four major reservoirs are the oceans, ice, ground and surface waters, and atmospheric moisture (IPCC 2007c).

3.2 Global Mean Sea Level

Processes in several nonlinearly coupled components of the Earth system contribute to sea level change and understanding these processes is therefore interdisciplinary. On decadal and longer time scales, global mean sea level variations are driven by two major processes, mostly related to recent climate change, that alter the volume of water in the global ocean (thermal expansion) and the exchange of water between oceans and other reservoirs (glaciers and ice caps, ice sheets, other land water reservoirs including through anthropogenic change in land hydrology, and the atmosphere). From 1993-2003, thermal expansion and melting of land ice each account for about half of the observed sea level rise (IPCC 2007b and 2007c).

3.3 Geographical Variation

Spatial variation of the rates of sea level rise is primarily due to non-uniform changes in temperature and salinity and related changes in ocean circulation and atmospheric pressure while contributing negligibly to changes in the global mean. Vertical land movements from glacial isostatic adjustment, tectonics, subsidence and sedimentation influence local sea level measurements but do not alter ocean water volume (IPCC 2007c). In some regions, rates of rise from 1993 to 2003 are up to several times the global mean, while in other regions sea level is falling. Regional sea level is also affected by climate variability on shorter timescales such as El Niño leading to regional interannual variations which can be greater or weaker than the global trend (IPCC 2007b).

3.4 Global Sea Level Rise

3.4.1 Recent Past

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature since 1850. The total temperature increase form 1850-1899 to 2001-2005 is 0.76ºC (0.57ºC to 0.95ºC). For the 20th century, the average rate of global MSL was 1.7 ± 0.5 mm per year consistent with the previous TAR estimate of 1 to 2 mm per year (IPCC 2007c). Global average sea level rose at an average rate of 1.8 ± 0.5 mm/yr (1.3 to 2.3) from 1961 to 2003 estimated from tide gauge data. The average rate increased to 3.1 ± 0.7 mm/yr (2.4 to 3.8) between 1993 and 2003 as measured by TOPEX/Poseidon satellite altimetry (Figure 2). Whether this latter rate reflects decadal variability or an increase in the longer term trend is unclear. The total 20th-century rise is estimated to be 0.17 (0.12 to 0.22) m. Overall, the sum of the climate contributions from thermal expansion, glaciers and ice caps, and the Greenland and Antarctica Ice Sheets is consistent within uncertainties with the total sea level rise that is directly observed (IPCC 2007a and 2007b).

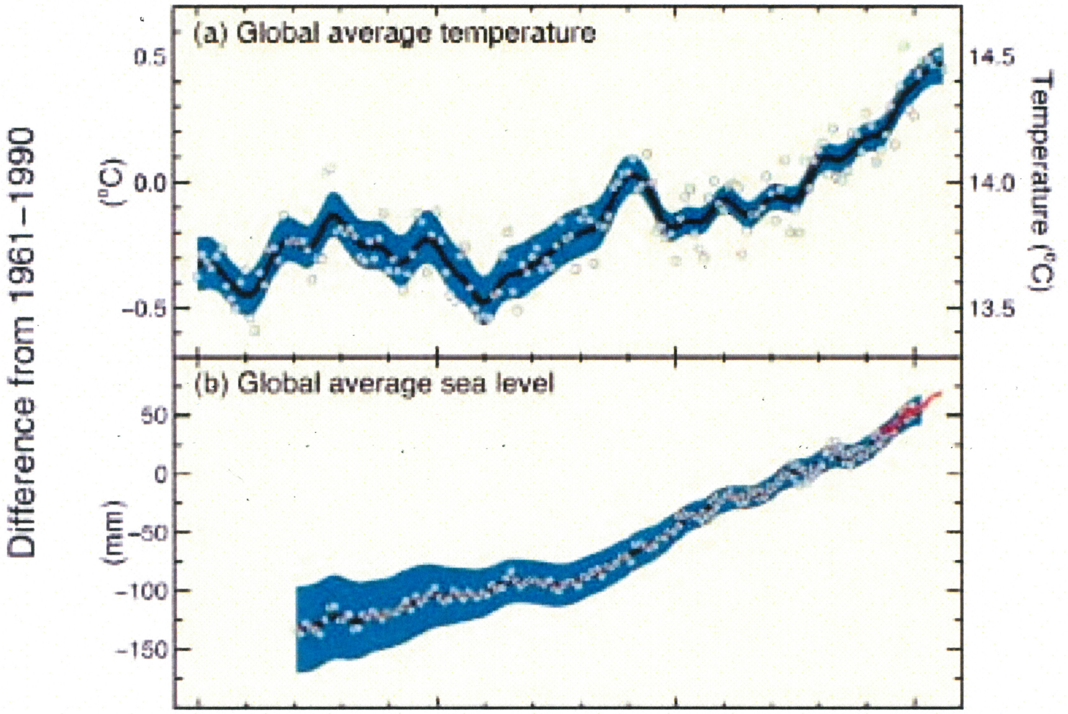


Figure 2: Observed Changes in (a) global average surface temperature and (b) global average sea level from tide gauge (blue) and satellite (red) data. All changes are relative to corresponding averages for the period 1961-1990. Smooth curves represent decadal average values while circles show yearly values. The shaded areas are the estimated uncertainty intervals (IPCC 2007a).

3.4.2 Future

Sea level is expected to continue to rise and changes in the cryosphere will continue to affect sea level rise during the 21st century. Glaciers, ice caps and the Greenland Ice Sheet are projected to lose mass because increased melting with exceed increased snowfall. Current models suggest that the Antarctic Ice Sheet will remain too cold for widespread melting and may gain mass in the future through increased snowfall, acting to reduce sea level rise. However, changes in ice dynamics could increase the contributions of both Greenland and Antarctica to 21st century sea level rise. If recently observed increases in ice discharge rates from the Greenland and Antarctic Ice Sheets were to increase linearly with global average temperature change that would add 0.1 to 0.2 m to the upper bound of sea level rise. Models indicate that sea level rise during the 21st century will also not be uniform (IPCC 2007b).

3.4.3 Cryosphere

Currently, ice permanently covers 10% of the land surface, with only a tiny fraction occurring outside Antarctica and Greenland. Since TAR, observations and analyses of changes in this ice have expanded and improved, including shrinkage of mountain glacier volume, decreases in snow cover, changes in permafrost and frozen ground, reductions in arctic sea ice extent, coastal thinning of the Greenland Ice Sheet exceeding inland thickening from increased snowfall, and reductions in seasonally frozen ground and river and lake ice cover. These allow an improved understanding of how the cryosphere is changing, including its contributions to recent changes in sea level (IPCC 2007b).

Mass loss of glaciers and ice caps (excluding those around the ice sheets of Greenland and Antarctica) is estimated to be 0.50 ± 0.18 mm per year in sea level equivalent (SLE) between 1961 and 2003, and 0.77 ± 0.22 mm per year SLE between 1991 and 2003. Additionally, recent observations show evidence for rapid changes in ice flow in some regions, contributing to sea level rise and suggesting that the dynamics of ice motion may be a key factor in future responses of ice shelves, coastal glaciers and ice sheets to climate change (IPCC 2007b).

3.4.3.1 Antarctica and Greenland

New data since the TAR show that losses from the Greenland and Antarctica Ice Sheets have very likely contributed to sea level rise from 1993-2003 (IPCC 2007a and 2007b). It is very likely the Greenland Ice Sheet shrunk because increased melting in the coastal regions more than offset thickening in the central regions. Melting of the Greenland Ice Sheet may have raised global sea level by 0.14 to 0.28 mm per year during 1993 to 2003 with even larger losses in 2005 and an the melting is expected to increase further. There are greater uncertainties for earlier time periods and for Antarctica (IPCC 2007b). Contraction of the Greenland Ice Sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest that loss of ice mass increases with temperature and complete elimination of the Greenland Ice Sheet would contribute to a 7m sea level rise (IPCC 2007a).

3.4.4 Catastrophic Events

Global climate models predict that anthropogenic climate change will be continuous and somewhat gradual process. However, sudden climate change could occur if progressive changes in the Earth's climate cause a physical threshold to be reached where one of the Earth's major atmospheric or oceanic systems changes significantly, or ceases to function (CDWR 2006).

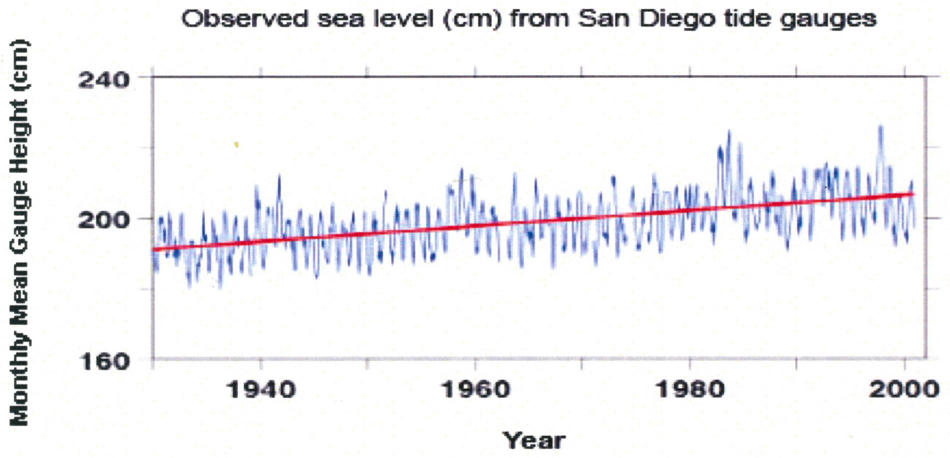
The frequency and intensity of extreme events are expected to change as Earth's climate changes, and these changes could occur even with relatively small mean climate changes. The greatest climate and weather related impacts of sea level are due to extremes on time scales of days and hours, generated by tropical cyclones and mid-latitude storms. Low atmospheric pressure and high winds produce large local sea level excursions called storm surges, which are more serious when they coincide with high tides. Changes in the frequency of occurrence of these extreme sea levels are affected by both changes in mean sea level and in the meteorological phenomena causing the extremes (IPCC 2007b). There is evidence for an increase in the occurrence of high water worldwide related to storm surges, and variations in extremes during this period are related to the rise in mean sea level and variations in regional climate (IPCC 2007c).

A growing problem facing California coastal regions is the incidence of episodes with high sea level, which occurs during high astronomical tides and is exacerbated by weather and climate effects such as El Niño. If warming is near the low end of the temperature range of projections so that sea level rise trends are also near the low end, the occurrence of extremely high sea level events will increase, but not greatly (Cayan et al. 2006a). On the other hand, if warming is large so sea level rise values are at the higher end of each emissions scenario, the incidence of extreme events would increase markedly. The frequency of high sea level extremes may increase if storms become more frequent or severe as a result of climate change. Increases in the duration of high storm-forced sea levels increases the likelihood that they will occur during high tides (Cayan et al. 2006b).

Additionally, the Earth's climate system is capable of sudden violent shifts. Climate change will not necessarily be gradual. For example, increasing emissions may push the oceans past a critical threshold and into a different future. More study is needed on this subject in addition to the gradual possibly accelerated climate changes projected by current climate models (CalEPA 2006).

3.4.5 Determining Sea Level

Measurements of sea level change for recent time scales (past 50-100 yr) rely on two different techniques: tide gauges and satellite altimetry. Tide gauges provide sea level variations with respect to a fixed point on land and are restricted to a small number of locations (Figure 3). These instruments, usually placed on piers, measure the height of the sea relative to a nearby geodetic benchmark. Relative sea-level change is derived from the increase (or decrease) in annual mean water elevation over time as measured at tide gauge stations along the coast such as La Jolla and San Diego (Figures 4 and 5) .



Source: Cayan, D., P. Bromirski, K. Hayhoe, M. Tyree,M. Dettinger and R. Flick. (2006). Projecting Future Sea Level. Pub. # CEC-500-2005-202-SF.

Figure 3: Observed sea level (cm) from the San Diego tide gauge.

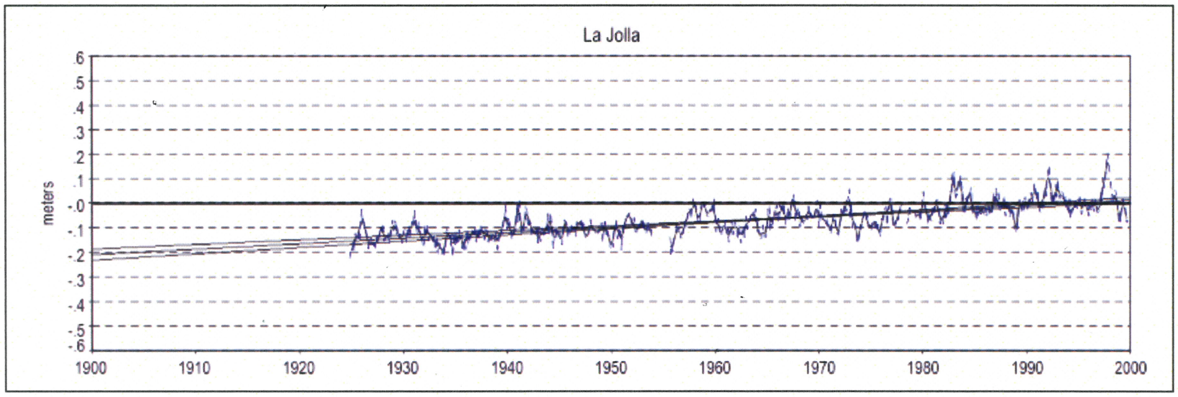


Figure 4: The mean sea level trend for La Jolla is 2.22 mm/yr (0.73 feet/century) with a standard error of 0.17 mm/yr based on monthly mean sea level data from 1924 to 1999. Source: **http://tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ca**

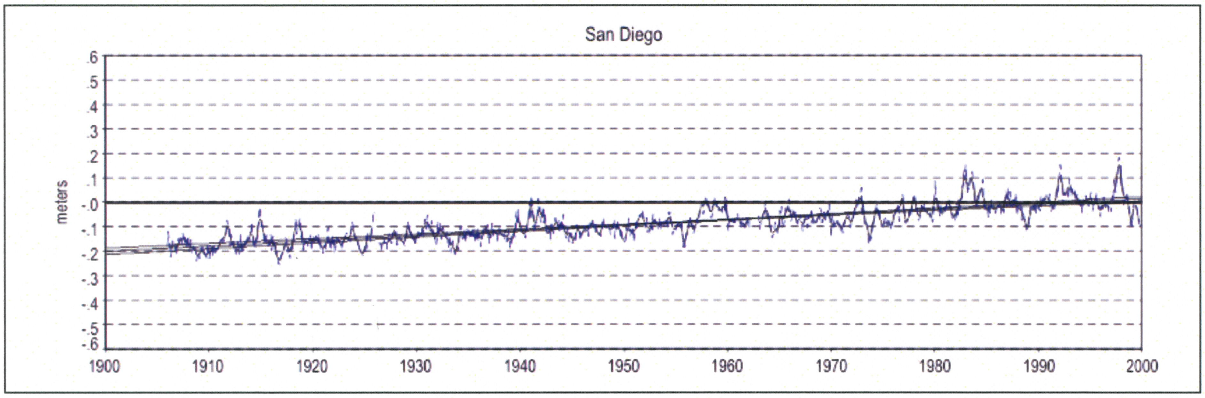


Figure 5: The mean sea level trend for San Diego is 2.15 mm/yr (0.71 feet/century) with a standard error of 0.12 mm/yr based on monthly mean sea level data from 1906 to 1999. Source: **http://tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ca**

This variable inherently includes global (eustatic) sea-level rise. Eustatic change (as opposed to local change) results in an alteration to the global sea levels, such as changes in the volume of water in the world oceans or changes in the volume of an ocean basin. Relative sea level change also includes local isostatic or tectonic land motion and a resurvey, commonly done annually, is made to determine if settling of the pier has occurred. Some coastal areas experience subsidence whereas others experience uplift, which can result in a decrease in relative sea level rise.

Sea level change based on satellite altimetry is more accurate with nearly global coverage and is measured with respect to the Earth's center of mass, so it is not distorted by land motion (IPCC 2007c). In addition, detection of change in the rate of rise using tide gauges takes longer (decades) time compared to satellite altimetry. Airborne laser monitoring also has great promise, particularly in providing high resolution (e.g. 1-foot contour) elevation maps needed to evaluate the local impact of increased sea levels.

3.5 Coastal Vulnerability

Note: The source of information for this section is the 2001 *National Assessment of Coastal Vulnerability to Sea-Level Rise* (Thieler and Hammar-Klose).

The historical record of sea-level change can be combined with other variables (e.g., elevation, geomorphology, and wave characteristics) to assess the relative coastal vulnerability and/or impacts from future sea-level change. However, predicting this coastal change is difficult because many factors are involved such as the following:

- tidal range, which contributes to inundation patterns;
- wave height, which is also linked to inundation;
- coastal slope (steepness or flatness of the region), which is linked to the susceptibility of a coast to inundation by flooding and to the rapidity of shoreline retreat;
- shoreline erosion and accretion rates, which indicate how fast or slow a section of shoreline has been eroding;
- geomorphology, which indicates the erodibility of different landform types for a section of shoreline; and historical rates of relative sea level rise, which correspond to how the global (eustatic) sea level rise and local tectonic processes (land motion such as uplift or subsidence) have affected a section of shoreline.

These factors also need to be integrated with climatic sea level change predictions (including episodic events such as El Niño-related climate data that contribute to short-term sea-level rise), and human influences (e.g., coastal engineering such as beach nourishment) to assess the potential impacts on the shoreline due to these changes. Sea level rise is an underlying driver, but most damage is episodic due to wave action during storms, especially those that occur at high tides. El Niño events and decadal-scale phenomena also provide higher sea levels on which storm-driven waves can do more damage.

Tide range, obtained from tide stations, is linked to both permanent and episodic inundation hazards and the values are contoured for the coastline. For application to interior bays and lagoons, the values would need to be adjusted, especially if the water levels are controlled by weirs such as Buena Vista Lagoon and/or areas that are routinely dredged to control tidal exchange such Batiquitos, San Elijo, and San Dieguito Lagoons in San Diego County.

Wave height can be used as an indicator of wave energy, which drives the coastal sediment budget. Wave energy increases as the square of the wave height; thus the ability to mobilize and transport beach/coastal material is a function of wave height.

Shoreline erosion and accretion rates for the U.S. can be drawn from a variety of sources, including published reports, historical shoreline change maps, field surveys and aerial photo analyses if an area has been studied. However, the lack of a standard method among coastal scientists for analyzing shoreline changes means the data utilized a variety of reference features, measurement techniques, and rate-of-change calculations. Thus, while some data is available for the U.S., much work is needed to accurately document regional and local erosion rates. Further, shoreline erosion and accretion rates are the variable in the data set that is the least well-documented and it is this variable that adds the greatest variation to the assessment values.

Geomorphology expresses the relative erodibility of different landform types. If this data were derived from state geologic maps and USGS 1:250,000 scale topographic maps, the broad scale of this information would likely not be at a scale detailed enough for local area planning. Likewise, to calculate slope of the coastal zone for a local area, site-specific topographic and bathymetric elevations extending landward and seaward of the shoreline is needed.

Note, the data variables underlying the vulnerability show variability at several spatial scales. The rate of sea-level rise and tide range vary over a spatial scale of ~100 km and for geomorphology and wave height, the variance on a ~10 km spatial scale reflects the alongshore changes in environments and distribution of energy in the coastal system.

3.5.1 United States

Sea level along most of the U.S. coast has been rising 2.0-3.0 mm per year. The rate of sea level rise varies from about 0.36 inches per year (10 mm per year) along the Louisiana Coast (due to land sinking), to a drop of a few inches per decade in parts of Alaska (because land is rising) (www.epa.gov/climatechange/science/recentslc.html). Louisiana's vulnerability is very different from other parts of the U.S. coast because of management of the flow of the Mississippi River. The most vulnerable regions in the United States appear to be Louisiana, Florida, and the Mid-Atlantic. Florida's vulnerability results largely from hurricane flooding. Coastal flooding is also important in the mid-Atlantic (CCSP 2006). Low-lying (below sea level) populated areas, such as islands of California’s Sacramento-San Joaquin Delta, are also more vulnerable to rising sea level (Mount and Twiss 2005). Figure 6 shows rates of relative sea level rise along the coast of the U.S.

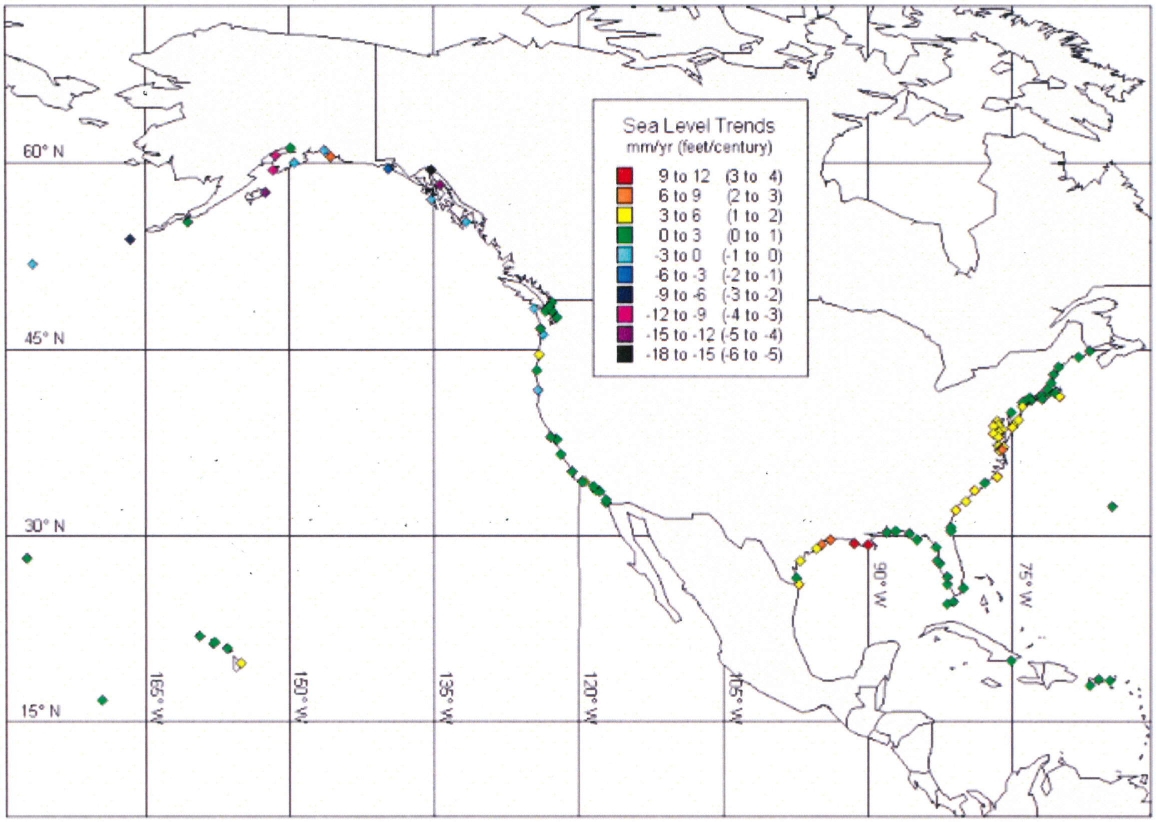


Figure 6: Rates of relative sea level rise measured by tide gauges along the coast of the U.S. over the 20th century. Source: http://co-ops.nos.noaa.gov/sltrends/slrmap.html.

3.5.2 California

3.5.2.1 Tides

California's coastline is about 1100 miles (1770 km) in length without inclusion of inland bays, estuaries and offshore islands (CDWR 2006). California's tidal regime is different from the semi-diurnal conditions that dominate the east coast of the U.S. On the California coast, tides are mixed, periodically having nearly equal semi-daily and daily components (Zetler and Flick 1985). The monthly tidal changes are dominated by the spring-neap cycle, with two periods with large tidal ranges (springs) near the times of full and new moon, and two periods with lower ranges (neaps) near times of the quarter moons. One spring tide range per month is usually higher than the other because of the moon's distance and declination. Due to lunar and solar declination effects, highest monthly tides in the winter and summer months are higher than those in the spring and fall with differences ranging up to 0.5 m (Cayan et al. 2006b). Extreme monthly higher-high tides also tend to occur in the morning (Flick 2000).

3.5.2.2 Sea Level

Along the coast, sea levels rose about 15-20 cm (6-8 in) over the last century (Cayan et al. 2006a). Future sea levels, while projected to rise gradually, present an alarming prospect for California, especially extreme projections. The effects of sea level rise will include: increased erosion of beaches, bluffs, and other coastal features; inundation of coastal land and marshes; local flooding near the mouths of rivers and streams due to backwater effects; increased potential for sea water intrusion into coastal aquifers; increased sea water intrusion into estuaries; increased potential for levee failure in the Sacramento-San Joaquin River Delta; potential adverse impacts on flow control and diversion facilities; and inundation and alteration of aquatic ecosystem habitat. Figure 5 shows the topography of the California coastline (CDWR 2006).

3.5.2.3 Northern and Southern California

Based on a 2001 *National Assessment of Coastal Vulnerability to Sea-Level Rise* for the U.S. Pacific Coast, areas of very high vulnerability include the San Francisco - Monterey Bay area and in southern California from San Luis Obispo to San Diego, where the coast is most highly populated. The highest vulnerability areas were considered lower-lying beach areas based on geomorphology and coastal slope. On the northern coast, high wave energy is a dominant variable (adds weight to the index), whereas to the south, low wave energy tides and relative sea-level dominate the index (Thieler and Hammar-Klose 2001). In addition, extreme sea level height fluctuations are larger to the north as a result of increasing storm intensities at more northerly coastal locations (Cayan et al. 2006b) and areas around the San Francisco Bay are also well below sea level.

Figure 7: California's topography and coastline (CDWR 2006).

In general, the vulnerability values for northern California are defined by variable geomorphology over small spatial scales of about 10 km (Thieler and Hammar-Klose 2001). Extensive stretches of mountainous and rugged coastline (e.g., rocky headlands and cliffs) with limited coastal plains characterize northern California. In contrast, the southern coast of California has broad coastal plains and wide beaches (CDWR 2006), where geomorphology typically varies at a longer length scale from 50 to 100 km (Thieler and Hammar-Klose 2001). Of importance is that about half of California's population resides in Southern California where annual precipitation and runoff is much less than in Northern California (CDWR 2006).

SECTION 4: Climate and Ecosystems

4.1 Introduction

Climate influences the distribution, structure, function, and services of ecosystems and ongoing climate changes are interacting with other environmental changes to affect biodiversity and the future condition of ecosystems (e.g., IPCC 2001b; McCarty 2001; Parmesan and Yohe 2003). Significant climate change will affect many U.S. ecosystems, including wetlands, forests, grasslands, rivers, and lakes (NRC 2001). The extent to which ecosystem conditions will be affected will depend on the magnitude of climate change, the degree of sensitivity of the ecosystem and non-climate related pressures on biodiversity to that change, the availability of adaptation options for effective ecosystem management, and the willingness to deploy those options.

Factors that contribute to the sensitivity of coastal lands to rising sea level include low elevations, coastal erosion, wetland accretion, and human modifications of the coastal zone. Direct land loss of low lying areas can rapidly (decadal to centennial periods) damage or destroy coastal ecosystems such as those in Chesapeake Bay. The average rate of relative sea level rise in this area has been approximately 3.5 mm per year during the twentieth century due to regional subsidence. This is about twice the global value of sea level rise. Downs et al. (1994) describe the widespread loss of the Bay's wetlands due to this increase of sea level. Land loss due to relative sea level rise in coastal areas is also aggravated by high levels of local subsidence. For example, the Mississippi River Delta is experiencing rapid sinking from surface loading and sediment compaction due to sediment deposition by the Mississippi River and subsidence related to oil and gas extraction in some areas (CDWR 2006).

Human modifications to address impacts such as erosion of ocean beaches, lead states to initiate sand replenishment projects where dredges or dump trucks replace the sand lost to erosion. Shoreline erosion along estuaries has led many property owners to defend their back yards by erecting shore protection structures such as bulkheads, which eliminate the intertidal wetlands and beaches that would otherwise be found between the water and the dry land. In the past, as sea level rose wetlands could retreat naturally inland but roads and coastal structures prevent this natural process along much of the U.S. coastline. The result is that the total area of wetlands may diminish even farther in the U.S. over this century.

In addition, management of coastal wetlands face a multitude of pressures independent of climate change such as increased land-use intensity and associated destruction of natural or semi-natural habitats. These pressures limit geographic extent (e.g., shift animal and plant distribution to higher elevations); increase habitat loss and fragmentation; introduce exotic species (invasives); and affect reproduction (e.g., start and end of breeding season and shifts in migration patterns), dominance, and survival (e.g., population growth) of both plants and animals. Therefore, the question is how much will climate change add to and exacerbate these multiple interacting stresses and existing ecosystem and resource management concerns. Regardless of the answer, reducing the loss of natural habitat, particularly coastal wetlands, can affect biodiversity, pollution removal, habitat available for endangered species, and protection from floods, storms, and high tides among other ecosystem services.

Climate change is clearly just one of many challenges that communities, industry, resource managers, and regional planners must address. Whether natural and managed ecosystems can adapt as global warming accelerates or indefinitely provide a wealth of ecosystem services that support life and human well-being as stresses on ecosystems continue to increase is questionable.

4.2 Future Projections

Due to the complexities involved with these multiple stressors between human and nature and the interactions within each of them, future projections of the impacts of climate change are difficult. Nevertheless, rising temperatures affect the natural world and raise questions of how vulnerable wetland ecosystems will adapt to further increases in temperatures and other climatic changes such as sea level rise. Plant growth is limited by temperature, effective moisture (i.e., the balance between the supply of moisture in the soil and the demand for moisture by plants and evaporation), and nutrient availability (Lenihan et al. 2006). For example, the risk of extinction could increase for many species, especially those that are already endangered or at risk due to isolation by geography or human development, low population numbers, or a narrow temperature tolerance range. Of course, there are also other serious impacts of climate change such as ocean acidification and loss of soil moisture that will also need further attention in the near future. According to Cayan et al. there is no evidence from the projections indicating that the Mediterranean seasonal precipitation regime in California will change (2006a), although more analysis is needed (CDWR 2006).

4.3 Coastal Salt Marsh

Sea level rise will cause increased sea water intrusion into California's coastal marshes and likely disrupt the marsh ecosystems, especially at the higher projections of sea level rise. Ecological collapse of tidal wetlands occurs when marsh vegetation cannot accrete fast enough to keep abreast of rising level in locations where inorganic sediment inputs are low. Eventually plant productivity decreases because excessive submergence effectively drains carbon reserves thereby reducing peat formation and marshes are converted to unvegetated mudflats until eventually they become open water bodies. Temperature also influences photosynthesis and respiration, and controls developmental processes such as flowering and reproduction that may then introduce asynchrony between the life cycles of the plants and important insect pollinators. Photosynthesis increases when a plant is exposed to increased atmospheric CO_2 concentrations, although elevated CO_2 levels are associated with decreased concentrations of mineral nutrients in plant tissues, especially a decrease in plant nitrogen, which plays a central role in plant metabolism (Cayan et al. 2006a).

Salt marshes are transitional areas between land and water, existing in areas where the land is low enough to receive tidal flow, but not so low as to flood the plants continually, and where wave action is minimal (Chapman 1960). Because of their existence at the land-sea interface, salt marshes have frequently been damaged or destroyed by human activity. More than 90% of coastal salt marshes in California have been destroyed since historical times, leading to several salt marsh-specific animal and plant species becoming listed as endangered, especially in southern California (Zedler 2001). Because they exist in areas which humans have steadily developed or altered over many years, they are also among the most threatened habitats.

Salt marshes are considered one of the most biologically productive habitats on the planet, although species diversity is low. This is partly due to the daily tidal surges that bring in dissolved nutrients, the natural chemical activity of salty (or brackish) water, the tendency of nutrients to settle in the plant roots, and the tendency of algae to bloom in the shallow unshaded water. They provide numerous ecosystem services such as habitat provisioning, water filtration, nursery habitat, and provide storm and flood protection.

4.4 Salt Marsh Vegetation

Salinity, frequency and extent of flooding of the marsh determine the types of plants and animals found there. In salt marshes, salinity ranges from near ocean strength to near freshwater in upriver marshes and thus, these areas are dominated by halophytic (salt tolerant) herbaceous plants. Stout stems, small leaves, and physiological adaptations for salt excretion and gas exchange characterize the inhabitants of the salt marsh, which are mostly grasses and low perennial herbs. Plant species diversity is relatively low, since the flora must be tolerant of salt, complete or partial submersion, and anoxic mud substrate. The most common salt marsh plants are glassworts (*Salicornia* spp.) and the cordgrasses (*Spartina* spp.), which have worldwide distribution.

In general, the California tidal marsh has a fringe of *Spartina foliosa* at the bayward margin, a broad marsh plain, and a high marsh transition to upland. Tides inundate *S. foliosa* twice daily and the tidal creek riddled marsh plain at least once daily, with water depth varying by season. The regular influence of tides is punctuated by creek flooding and sea storms over the long term. Annual rainfall in San Diego averages 25 cm and creek flows are correspondingly low, although nuisance runoff and irrigation often contribute to an increased flow regime. Loss of area and habitat quality has caused many wetland-dependent species to become threatened with extinction. For example, the endangered Belding's savannah sparrow (*Passerculus sandwichensis beldingi*) and the light-footed clapper rail (*Rallus longirostris levipes*), nest in pickleweed (*Salicornia*) and cordgrass (*Spartina*) respectively (Zedler et al. 2001).

Eelgrass (*Zostera marina)* for example, occupies the lowest or most marine zone. It cannot tolerate a freshwater environment or intertidal conditions that would expose its roots to air. Cordgrass (*Spartina foliosa)* occurs in the marine-to-terrestrial transition zone, characterized by lower salinity and periodic exposure to the air. Shoreward, where conditions are even drier, pickleweed species belonging to the genus *Salicornia* are common. On higher ground, where tidal intrusions are rare, the wiry, prickly-leaved succulent jaumea (*Jaumea carnosa)* is common, as are the bushy shoregrass (*Monanthochloe littoralis)*; tall and slender sea arrowgrass (*riglochin maritime);* and endangered salt marsh bird's beak (*Cordylanthus maritimus)*. The green, wiry-leaved saltgrass (*Distichlis spicata)* is widespread, occurring from the middle to high marsh, as well as in dunes and on salt flats. This species usually grows in colonies, and forms thick mats of roots and underground stems called rhizomes..

4.5 Salt Marsh Sediment Elevation

As addressed in Zedler 2001, intertidal wetlands are a function of tidal hydrology, fresh water inflows, sediment inputs, sea level rise, subsidence, storm inputs, and other extreme events. As such, organic sediments are a basic feature of natural wetlands. For most wetlands, the development of organic sediments occurs over periods that are closer to centuries or millennia than to years or decades (Zedler 1996). This lengthy timeframe translates into serious implications for sea level rise, if the pace of the rise exceeds development of wetland soils appropriate for landward migration of coastal wetlands. Small elevation differences of just centimeters control many marsh functions from flooding and nutrient cycling to draining of the marsh interior.

High marsh in southern California is a narrow wetland margin with *Salicornia subterminalis* as an indicator species. The upper and lower boundaries of this habitat are fuzzy because the vegetation changes along a continuum. The marsh plain is a relatively flat 30 cm elevation band, except where dissected by tidal channels and creeks with *Salicornia virginica* the most widespread species. The bayward portion of the marsh plain and lower elevations is referred to as cordgrass habitat for the areas dominated by (*Spartina foliosa*) (Zedler et al 1999).

The mean elevation of salt marsh surfaces must increase to keep pace with the rise in sea level and subsidence of marsh organic substrates. If sedimentation rates in a salt marsh do not equal or exceed the net loss in elevation due to the steady increase in sea level and salt marsh subsidence, the marsh will 'drown.' When a salt marsh drowns, the surface of the marsh becomes subtidal. This change in inundation can cause drastic changes such as the conversion of vegetated salt marsh to unvegetated mudflats.

Understanding changes in relative salt marsh elevation is important for interpreting changes in salt marsh vegetation communities and other estuarine ecosystem components. Salt marsh erosion and accretion are also important parameters for measuring the response of restored tidal influence, and are critical if the rate of sea level rise accelerates as predicted.

As the sea rises, the outer boundary of these wetlands will erode, and new wetlands will form inland as previously dry areas are flooded by the higher water levels. The amount of newly created wetlands, however, could be much smaller than the lost area of wetlands - especially in developed areas protected with bulkheads, dikes, and other structures that keep new wetlands from forming inland.

4.6 Upland Transition

The upper transition zone is the interface between land and salt marsh – a barrier zone where the wetland meets the urban environment. The zone can be subdivided into upland, a narrow transitional band or ecotone, and a high-marsh habitat each with their own suite of associated plant species that are described in more detail below. This is a result of differences in physical conditions such as tidal flux, elevation, soil characteristics, and nitrogen supply all of which influence what species will be present. For example, canopy surface heterogeneity and the presence of woody plants tend to increase in this zone as salinity decreases and elevation increases. The transition zone is rarely flooded and is defined to be an elevation up to 30 cm higher than predicted tide levels (Zedler 2001).

The transition zone is also important because it supports native species such as boxthorn (*Lycium californicum*) that can only grow in this ecotone (James and Zedler 2000). Since *Lycium* grows in such a narrow elevation band, it can be a good indicator of climate or other disturbances if the zone shifts over time. Finally, the transition zone is an area that actively transforms nitrogen as evidenced by total soil nitrogen content that is higher in the transition zone than in the upland, but not significantly different from the marsh plain. This has wetland ecosystem-wide effects through the uptake of these nutrients and subsequent connections through the food chain (Zedler 2001).

4.7 Salinity

Moderate hypersalinity of 40-45 parts per thousand (ppt) is typical for marsh plain soils. Extreme hypersalinity is more characteristic of higher elevations with less frequent tidal inundation (Noe and Zedler 2001).

4.8 Restoring Coastal Wetlands

California has less than ten percent of its original wetland acreage and even with a federal policy of "no net loss", degradation and loss of the remaining wetlands continues. Many of the required compensatory wetland mitigation sites have limited success with attempts to recreate natural processes. Restoring ecosystems to functional equivalency, to reference systems and/or the originally impacted natural wetlands, requires that the site support essential functions, attract the desired species, and resist invasion by nonnative species. Both physical and biological variables affect the ability of a restoration site to achieve these goals. For most ecosystems, we know far too little about what constrains restoration. Hence, the opportunities for research are numerous, and the demand for information is great. There is a need to focus on the development of methods to improve the design, implementation, and assessment of habitat restoration projects. Even the wetlands protected as mitigation areas and reserves are threatened by highway and utility expansion projects. Climate change impacts such as sea level rise may also contribute to additional wetland loss. Natural resource management that historically has been based on a view that the future will echo the past must adjust to one of husbanding complex systems through rapid climate change, while minimizing catastrophic disturbance and preserving the sustainable functioning of ecosystems and their services (Lenihan et al. 2006).

4.9 Case Study

Mission Bay Park is located within the City and County of San Diego, approximately 5 miles north of downtown San Diego, adjoining the Pacific Ocean. Interstate 5 borders the Park to the east and Interstate 8 is just south of the Park. The Park encompasses seven square miles of relatively flat coastal area, of what was once a vast tidal marsh. Twenty-five million cubic yards of sand and silt were dredged and used as fill by the early 1960s to create the land forms evident in the Bay today. Current water depths range from 7 to 20 feet and the existing wetlands are subject to tidal circulation (City of San Diego 1994). Figure 8 shows the topography of Mission Bay and the surrounding area.

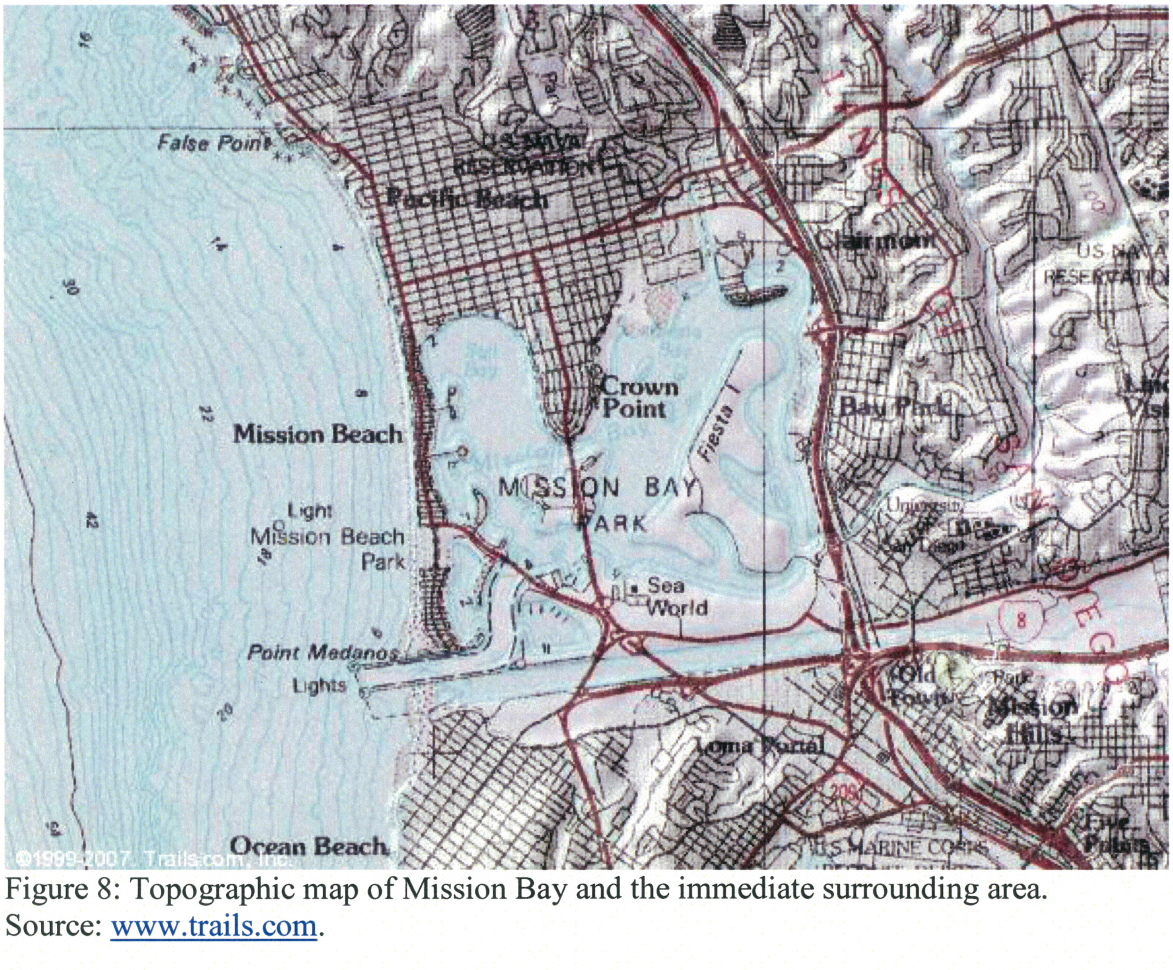


Figure 8: Topographic map of Mission Bay and the immediate surrounding area. Source: www.trails.com.

Similar to many coastal wetlands constrained by development, this area is subject to habitat change from sea level rise. Although subsidence is typical in wetlands where erosion and decay exceeds sedimentation and accretion, it has not been listed as a major issue for wetlands in Mission Bay. The area receives sediment from Mission Bay and the surrounding watershed as well as the existing marsh plants slow water flow over the marsh thereby increasing sedimentation. Storm inputs are primarily restricted to sediment from the watershed brought to the marsh from rains because the reduced fetch and extensive mudflats minimize sedimentary impacts from wave action. Figure 9 shows an aerial view of these wetlands in Mission Bay.

Figure 9: Aerial view of wetlands in Mission Bay including the Northern Wildlife Preserve and the University of California San Diego Kendall-Frost Reserve.
Source: http://maps.google.com/.

Existing salt marsh habitat is located in the northern portion of the Bay adjacent to urban development known as the Northern Wildlife Preserve and the Kendall-Frost Marsh Reserve (KFR). Management considerations include invasive, nonnative plant and animal species such as mangroves and feral cats. *Spartina alterniflora* is currently not known to be in the area, but its geographic range may expand under the right conditions such as climate change. Another concern is protection of listed species. Shorebirds, including the endangered Belding's savannah sparrow (*Passerculus sandwichensis beldingi*) and the light-footed clapper rail (*Rallus longirostris levipes*), nest in the pickleweed and cordgrass respectively.

4.9.1 Vegetation and Climate Change

The upland areas currently not subject to tidal influence are dominated by non-native species such as highway ice plant (*Carpobrotus edulis*), crystalline iceplant *Mesembrythanthemum chrystallinum,* and *Mesembrythanthemum nodiflorum* commonly used for erosion control and groundcover. Other nonnative plant species include Brazilian pepper (*Schinus terebinthifolius*) and Eurasian grasses (possibly including *Lolium perenne*, *Avena fatua*, and *Cromus diandrus*). Given these nonnative species have been able to adapt to southern California and outcompete native species in a range of conditions, the impacts of climate change may be more favorable for these species than less tolerant native plants. Nonetheless, the upland species may also respond differently than the wetland species accustomed to higher salinity for which many nonnative species cannot tolerate. Figure 10 shows a view looking across the wetlands in KFR.

Figure 10: View across Kendall-Frost Marsh Reserve in Mission Bay, California.

The high marsh plain is dominated by *Salicornia subterminalis*, with a lower marsh area dominated by *Salicornia biglovii* and *Salicornia virginica*. Cordgrass (*Spartina foliosa*) dominates low marsh elevations. *S. foliosa* has a high nitrogen demand and grows poorly in substrates that are coarse in texture and/or low in organic matter (Zedler 1998). Competition with *S. virginica*, high salinity and low nutrients make colonization by *S. foliosa* difficult. Cordgrass has difficulty surviving in new locations unaided because *Salicornia* has been shown to outcompete it for nitrogen (McCray 2001). Zedler (1999) has documented *S. virginica* as the most widespread species of the marsh plain. It dominates low elevations of marshes where *S. foliosa* is absent, but is generally restricted to mid elevations of salt marshes where *S. foliosa* is present (Zedler 1996) and is generally found at higher elevations than *S. bigelovii.* While research on these respective plant species mentioned here is by no means complete, the information illustrates the compounding considerations for microtopographical spatial and temporal heterogeneity – different from the traditional nomenclature of the elevation-based zonation (Zedler et al 1999).

Given only recent understanding of some of these interspecific interactions and feedback mechanisms, conditions that historically have been difficult to reproduce for wetland restoration, attempting to interpret how this plant community may change as a result of sea level rise commands attention to the problem and need for additional research. In general, rising sea level will likely have an adverse effect on salt marsh vegetation. Hydrologic modifications that alter inundation and salinity regimes are likely to cause shifts in the distribution of characteristic salt marsh species because these factors are known to influence species occurrence and plant growth. Another adverse generalization can be made for limited habitat migration inland due to the adjacent urban environment regardless of other limiting factors such as development of appropriate soil conditions. Simply, a factor like elevation can not be looked at in isolation to determine the impacts of sea level rise on coastal wetlands.

For example, nonnative plants that can establish faster and tolerant a broader range of conditions in tidally influenced areas may out compete native salt marsh species as sea level rises, especially at a faster pace of increase and more frequent catastrophic events, but life history (e.g. annual, perennial, short-lived, or long-lived) and growth form (succulent, broad-leafed, upright, or trailing) likely contribute to distribution or decline. Species diversity may also not be easily restored because of changes in the environment or disruption of critical species interactions (Zedler et al. 2001). Hence, this exercise demonstrates the opportunities to combine science, research, and monitoring information from compensatory wetland mitigation for southern California salt marshes to determine impacts associated with climate change such as sea level rise and possible adaptive strategies to address these impacts.

4.9.2 Future Plans

The most recent Mission Bay Park Master Plan Update, approved by the City of San Diego and the California Coastal Commission in 1994, includes wetland creation at the mouth of Rose Creek in addition to future development plans for the park. The area known as Campland located between the KFR and Rose Creek is designated for future use as wetlands and would be dredged for the creation of salt marsh west and south of Rose Creek. The Plan also specifies associated development criteria including implementation of hydrologic improvements aimed at safeguarding the viability of these marsh areas. Given this criteria, future development planning for Mission Bay should incorporate climate change impacts such as sea level rise, in particular landward migration of wetlands unable to adapt to the pace of increasing sea level rise as well as appropriate elevations and space for wetland creation. The Plan also proposes to treat the creek shoreline with bulkhead/riprap, which may affect the impacts of sea level rise on both the existing and created wetlands in the future.

Another important note is the consideration of additional hydrologic studies and sediment transport analyses, which would benefit research on the implications of sea level rise and management as well as potential future restoration of coastal wetlands in Mission Bay. Hence, this site would be ideal for continued research into the impacts of sea level rise on both a natural and restored southern California wetland.

Section 5: Recommendations

5.1 Introduction

Since anthropogenic changes to the climate system are likely to persist into the future regardless of emissions mitigation, adaptation is an essential complementary response for future protection of coastal ecosystems and a necessity. Climate change is demonstrably underway, impacts are already being observed, and further impacts over the next 30 years are unavoidable due to the long residence time of GHGs already released into the atmosphere and the time lag in the climate system. At the same time, society needs to increase focus on enhancing its capacity to cope with the already-occurring and unavoidable impacts that we will experience over the next few decades, no matter what water emission-reducing steps will be taken.

Some climate changes may also compound other climate changes through feedback mechanisms in addition to multiple pressures that affect management of coastal wetlands independent of climate change. The implication is that many of these impacts will be detrimental given they will occur as both population and infrastructure in coastal regions increase, though not all coastal areas are equally vulnerable. Because of the diversity of coastal environments; regional and local differences in projected relative sea level and climate changes; and differences in the resilience and adaptive capacity of ecosystems and society, the impacts will be highly variable in time and space. For instance, societal impacts of sea level change primarily occur due to extreme levels rather than as a direct consequence of mean sea level changes, although even relatively weak storms will be able to do a great deal of damage as more people move to the coast and sea level rises. Also, measures taken to protect private property from rising sea level as well as coastal development itself, may dictate federal, state and local priorities for coastal management without proper regard for geologic or biologic processes. Thus, these protective measures may be the primary determining factor in how the coast evolves and subsequently, the spatial and temporal effects related to climate change.

Policy responses to climate change impacts such as sea level rise include: maintain the status quo; pursue hard engineering (e.g., dikes, revetments, sea walls, bulkheads, etc.); pursue soft engineering (e.g., aim is to replicate natural processes, encourage retreat from the beach, and use limited beach nourishment); and strategic relocation (impose setback lines and use economic inducements such as buyouts, development bans, etc.). It is likely a portfolio of adaptive responses will be needed, including more conservation, local focused research, expanded wetland monitoring, and continued communication of all relevant information.

Clearly, the additional complication of sea level rise and other climate change impacts mean hard decisions lie ahead for management of wetlands in southern California. While weighing numerous multiple stressors, these future decisions will become one of priority for either natural or urban landscapes. New policy may be necessary to provide additional agency activity, resources and funding; however regulations and guidance currently in place can be interpreted to encompass the implications of projected sea level rise on restoration and management of coastal wetlands. Utilizing existing mechanisms would minimize the time delay associated with formulation of new policy and provide opportunities for immediate action.

II. List of Recommendations

A number of promising approaches are suggested, but it is important to note that any adaptive mitigation strategy for climate change would need to overcome political and social barriers as well as be in a context and format useful and accessible for policymakers, resource managers, scientists and other stakeholders. The order of the recommendations below is not indicative of importance nor should they be used in isolation. While not exhaustive, they demonstrate prompt action can be taken to incorporate the latest science, improve communication, expand research, and plan for a future that predictably may endure serious threats from climate change.

Informed Decisions

Make the wealth of climate data and information already collected more accessible to a range of users who can apply it to make informed decisions. This is analogous to efforts by the National Weather Service to provide useful weather information (NRC 2006). Climate data should be user-friendly and the government agencies, universities, and other stakeholders involved in climate change data collection and research today should establish active and well-defined connections to continue to generate public discussion and build awareness of the need to manage coastal wetlands for climate change.

Modeling

Modeling is a useful tool to provide a comprehensive picture of future climate change impacts. For example, the San Francisco Bay Conservation and Development Commission Climate Change Planning Project recently produced maps to identify areas in San Francisco Bay likely to be most impacted by a one meter rise in sea level.

Although limitations in the geospatial data may affect their accuracy, the findings are generally consistent with the projections in the 2006 California Climate Action Team Report (BCDC 2007). Similar modeling efforts would be beneficial for a large coastal area such as San Diego Region if only to begin discussion of how to plan for potential impacts of future climate change.

Vulnerability Assessment

Extend analysis prospective for long-term resources planning from assessing impacts to assessing risk. Impact assessment identifies possible outcomes resulting from a given change. Risk assessment takes the impacts assessment and investigates the likelihood or probability of occurrence that a particular outcome may occur (CDWR 2006). The national coastal vulnerability assessment previously discussed provides insight into the relative potential of coastal change due to future sea-level rise. It also is a base for developing a more complete inventory of variables influencing coastal vulnerability to climate change to which other elements can be added as they become available. Since the rates of shoreline change are complex and poorly documented, to best understand where physical changes may occur large-scale variables of low resolution must be clearly and accurately mapped and small-scale variables understood on a scale that takes into account their geologic and environmental influences.

Impact assessments are good for managers of potential future issues that may require management action. However for managers to make decisions related to potential climate change impacts, they need information on both the ranges of impacts of climate change and their associated likelihood. Perceived risk allows planners to make statements about the probability of impacts exceeding certain established thresholds and can be weighed against reliability levels for establishing planning direction (CDWR 2006). Periodic regional assessments also allow resource managers to assess the consequences of their decisions in a broader and more ecologically meaningful context.

Enhance Institutional Flexibility

Strategies enacted at different levels of government can facilitate preparedness for and adaptation to unavoidable impacts from climate change. As climate changes, patterns of extreme events are shifting in yet-difficult-to-predict ways. This uncertainty is also aggravated by the incomplete understanding of how ecological systems such as coastal salt marshes will respond to rising sea level and other climate change impacts. Furthermore, even when individuals have the knowledge and inclination to change, institutional barriers can prevent implementation of needed changes. As a result, a critical component of climate change adaptation must be increasing institutional flexibility to enhance the capacity for planners and managers to address uncertainty and respond more readily as well as to assess and learn from adaptive management.

Multidirectional Strategies

Improvements in incorporating climate change science into management of coastal wetlands can be achieved if approached from multiple directions in the decision-making process since a portfolio of adaptation responses will likely be needed. Currently, many resource planners do not use climactic information for their day-to-day responsibilities. Others use information about current weather and climate, but do not consider the implications of future climate projections such as sea level rise for decisions that will have long-term impacts. In some cases institutional constraints may present barriers to regularly integrating climate information into long-term planning because different people within an organization have responsibility for short-term planning versus long-term planning. Their professional responsibilities may not formally require the use of climate information or long-term planning such as wetland protection and mitigation, although these guidelines can easily be interpreted to include climate information. In addition, regardless of knowledge or awareness of climate change, these professionals likely do not have the time, staff, or financial resources to examine climate change impacts within the context of their management responsibilities. Thus, science can play a critical role to raise awareness and understanding while filling information gaps about climate change risks.

Integrated Resource Management

Programs that enhance society's capacity to cope with climate variability and change provide a framework to build capacity to cope with current climate variability and to adapt to climate change within the context of multiple stresses. Improved communication among stakeholders, increased observations (especially at regional and local scales), improved model and information systems, and increased infrastructure to provide better environmental monitoring, vulnerability assessment, and response analysis are all important parts of moving toward better understanding of and response to multiple stresses. Suggestions include integration of existing observations into a coherent framework, an integrated and comprehensive information system (e.g., database) accessible to researchers and all stakeholders, and development of a comprehensive regional and local framework for environmental studies. Increasing stakeholder involvement to help identify problems and solutions as well as provide ideas on the information needed (and in what format).

For example, the federal wetland compensatory mitigation and monitoring guidelines, although not specific to climate change, promote consistency and compatibility with local, state and other federal resource management systems and to take into account zoning regulations, regional council and metropolitan planning organization initiatives, and other factors of local public interest. This provides yet another avenue for localized climate change impacts to be a larger consideration for wetland restoration and management under review by the federal government.

Broader Focus

Currently, the focus of federal compensatory wetland mitigation is a watershed-based approach such as special area management planning for aquatic resource protection and problems associated with sufficient freshwater hydrology. Applying similar efforts to tidal wetlands would utilize information available beyond that of a single site to incorporate current climate science, research, other wetland mitigation efforts underway, and integrate related adaptive strategies. This would prioritize efforts for restoration and management of coastal wetlands on a regional scale.

Expand Monitoring
California and in particular southern California would benefit from expanded monitoring of tidal wetlands (e.g., plant communities, and disturbance processes) to gain knowledge about impacts of sea level rise on these ecosystems. In addition to research opportunities available to academia, the ACOE compensatory wetland mitigation and monitoring guidelines could easily be interpreted to include monitoring of impacts associated with sea level rise throughout a large area. Of course, standard measurements and data collection would need to be established, but the regulations allow for regional protocols to be easily implemented. Furthermore, better monitoring will be crucial to detecting and understanding a complex chain of impacts (CalEPA 2006).

Vegetation Monitoring
Monitoring vegetation is an effective way to assess salt marsh development and respective changes after establishment to both understand the impacts of climate change and provide compensatory mitigation. Remote sensing, aerial photography and field surveys are some of the available tools to document the baseline plant community as well as continued monitoring for comparison to past and future conditions. Besides temporal and spatial plant community composition, factors such as canopy architecture, species diversity and abundance, above and below ground biomass, nitrogen pools, salinity, soil moisture, and percent organic matter can also be monitored to both indicate ecosystem functioning (Zedler 2001) and provide opportunities for climate change related research. Note monitoring methods like aerial photography and LIDAR can be used in combination to be more cost effective while providing an abundance of valuable data.

Enlarge Buffers
Buffers areas are upland areas typically composed of native plant communities reflective of the local landscape and ecology that separate wetlands from developed areas. Traditionally, they have been used to protect aquatic resource functions at mitigation sites located more inland of the coast from disturbances or adjacent land uses. However, buffers are not always incorporated into compensatory wetland mitigation and/or an arbitrary measurement of length (e.g., 50 ft) with no or a limited ecological basis is put forth. Requiring the largest extent of buffer length and width feasible, disregarding a set distance and instead looking at the natural geography of the land, would allow for the landward migration of coastal wetlands as sea level rises. Meanwhile, the buffers would protect adjacent real estate and provide ecosystem functions. Buffers enhance or provide habitat for wildlife and other organisms, sediment removal, erosion control, excess nutrient and metal removal, runoff filtration, moderation of water temperature changes, detritus for aquatic food webs, and reduction of human impact on the natural environment. Since the Corps has the statutory authority to require vegetated buffers next to coastal waters pursuant to the goal of the CWA to restore and maintain the chemical, physical and biological integrity of Nation's waters, additional policy would be unnecessary. The buffers also would protect the ecological integrity of the mitigation site.

Extend Long Term Maintenance
Currently, long term maintenance of the mitigation site is considered as part of the compensatory mitigation. Some form of funding such as a letter of credit or performance

bond is only required to ensure available funds for five years of mitigation implementation and monitoring. Often a twenty-percent contingency is added to the estimate of the total mitigation cost to ensure sufficient funding for completion of the required mitigation. However, most mitigation sites are subject to no more than five years of oversight, but some wetlands take decades to adequately replace the wetland habitat lost to development and the Corps does not require additional funding to maintain the mitigation site beyond these five years. The only consideration that extends beyond five years is for protection of the mitigation site in perpetuity with the appropriate real estate instrument (e.g., conservation easements, deed restrictions, and title transfers to federal or state resource agencies or non-profit conservation organizations).

Establish Long Term Monitoring

Establishment of a long term ecosystem monitoring program beyond the traditional five-years of monitoring for each mitigation site stipulated in the federal mitigation and monitoring program would capture the natural timescales and regional complexity of the environment. Climate change impacts, not to mention many ecosystem processes, occur over a longer timescale and cannot be adequately monitored in such a short time. Current sea level rise predictions are forecast for the next 100 years and prior measurements demonstrate sea level has been rising for the last century. Furthermore, future climate change impacts are currently not included during the initial monitoring of the mitigation site or after the site has achieved predetermined success criteria and monitoring is no longer required.

Greater Use of Preservation

The Corps defines preservation in reference to compensatory mitigation in terms of removal of a threat to, or preventing the decline of, wetland conditions by an action in or near a wetland such as the purchase of land or easements, deed restrictions, and repair of water control structures. However, the use of this form of compensatory mitigation has traditionally been given limited consideration in deference to a more direct replacement of actual wetland acreage. Given the current knowledge of the continued rise of sea level, preservation should be viewed as a more significant form of compensatory mitigation to address the potential loss or degradation of restored and/or existing coastal wetlands as well as protection of coastal development. Although the federal guidance and regulations concerning preservation do not specify wetland impacts related to sea level rise, they can easily be interpreted to address such impacts under the categories of demonstratable threat of degradation or loss and/or regionally important physical, biological or chemical functions.

Include More Upland Areas

Federal guidance and regulations allow for inclusion of existing upland areas as part of compensatory mitigation for wetland impacts if the protection and management of such areas in an enhancement of aquatic functions and increases the overall functioning of the mitigation site. With consideration of sea level rise, available land for habitat migration becomes vitally important, although the timing of wetland mitigation implementation would need to be coupled with research, current knowledge, and weighed against uncertainty to ensure both replacement of lost or impacted wetlands in the short-term and the long-term sustainability of these wetlands as climate changes.

Managed Retreat

In the context of coastal erosion or inundation, managed retreat allows a low-lying area that was not exposed to flooding by the sea to become flooded. Approaches to maintain wetlands in the face of rising sea level include: no further development in low-lying coastal areas, no action now but a gradual abandonment of lowlands as sea level rises, and allowing future development only with a binding agreement to allow the development to revert to nature if it is threatened by inundation. The first option would encounter legal and financial hurdles. The extent to which the Constitution would allow governments to prevent development in anticipation of sea level rise has not been addressed by the courts, and the cost of buying the majority of lowlands would be prohibitive. Addressing sea level rise as it happens would avoid the costs of planning for the wrong amount of sea level rise, but would probably result in less wetland protection. Further the cost to buy developed areas would be greater than the cost of buying undeveloped land.

From the perspective of wetland protection, the loss of wetlands would be greatest if all developed areas are protected, less if only densely developed areas are protected, and least if shorelines retreat naturally. (Note: Section 404 of the Clean Water Act discourages development of existing wetlands, but it does not address development of areas that might one day be necessary for wetland migration).

Designate Difficult to Replace Aquatic Resources

Even before we gain a full understanding of how coastal wetlands function in an altered or somewhat natural state and how to restore them, particularly along the southwestern coast of the U.S., coastal wetlands that historically have undergone significant decline continue to be lost or degraded at an alarming rate. With additional impacts associated with sea level rise likely to cause further loss of these wetlands, there should be special emphasis given to protection of them in situ. Some coastal wetlands may undoubtedly become submerged regardless of protection and therefore, the remaining wetlands may become even more ecologically important. Currently, environmental review of potential wetland impacts emphasize more the likelihood of suitable mitigation sites available than ecological importance and coastal protection. Further, special aquatic sites already subject to more stringent protection include mudflats, which salt marshes may become. If sea level rise exceeds the pace of sedimentation and accretion of soil substrate, increased frequency and duration of inundation may result such that the associated plant and animal communities are unable to adapt given the pace of change.

Again federal regulations and guidance do not specify the impacts of sea level rise; however, they can be interpreted to allow designation of coastal wetlands as a difficult to replace or special aquatic resource.

Additional Research

A considerable amount of research has been developed across the country and elsewhere for climate change impacts such as sea level rise. The State of California could build on this existing research, support research that applies the insights from elsewhere to the state, and fill gaps in understanding. Historically, environmental problems have been studied one at a time and sector by sector. Although researchers have made progress, this approach does not consider the composite effects of simultaneous environmental changes. Research that is collaborative, multidisciplinary and participatory; identifies critical thresholds such as species-specific thresholds of landscape connectivity to help in the design of protected areas as environmental conditions change; looks at the feasibility of adaptation options against factors such as climate change, technological, institutional, and ecological constraints and stressors as well as how to overcome these obstacles or minimize these constraints; and responds to identified informational needs of different decision makers by providing relevant and easily accessible information to different stakeholders is of the utmost importance to respond to climate change.

Clearly, research is vitally important for both the public and private sectors to adapt to climate change. For example, the ACOE recognize compensatory wetland mitigation is not a precise, exact science and predictable results are not always obtainable. Thus, the ACOE utilizes adaptive management and incorporates experimentation into mitigation even if not specified as such in their guidance.

Central database

Creation of a central database for current climate change related research, understanding, localized predictions, and data collected from monitoring and management of coastal wetlands would provide a wealth of information valuable for everyone involved with addressing the impacts of climate change. Such a database would expedite interpretation and understanding of comprehensive regional changes and identify status and trends in ecosystems, although careful, organized, and professional management of the database is essential.

Greater Awareness

To enhance preparedness for climate variability and change, decision makers in the private and public sectors require greater awareness of the risks. Many opportunities exist to enhance adaptive capacity and resilience in the face of change, even in the absence of perfect foresight about future climatic changes. Implementing adaptive capacity into real adaptive actions on the ground is difficult. It requires attention and long-term commitment at all levels of government, across climate-sensitive industries and society. Decision makers in the private and public sectors require greater awareness of the risks they face, increased capacity to analyze such information and use it in decision-making, and the ability to remove any institutional, financial, political and other barriers in the way of turning good intentions into actions. A decision-maker with the motivation and political will to act on climate variability and change may be able to translate such intent directly into a decision and action, or he or she may be in a position to design policy or guidance which then is implemented by others such as the wetland protection and compensatory wetland mitigation where federal policy level is implemented at the local level (Luers and Moser 2006).

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